ANNALS OF THE NEW YORK ACADEMY OF SCIENCES VOLUME 775

# THE FLIGHT FROM SCIENCE AND REASON



EDITORS
PAUL R. GROSS
NORMAN LEVITT
MARTIN W. LEWIS

# *ANNALS OF THE NEW YORK ACADEMY OF SCIENCES*

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ANNALS OF THE NEW YORK ACADEMY OF SCIENCES
*Volume 775*

# THE FLIGHT FROM SCIENCE AND REASON

*Edited by Paul R. Gross, Norman Levitt, and Martin W. Lewis*

*The New York Academy of Sciences*
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# THE FLIGHT FROM SCIENCE AND REASON[a]

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## CONTENTS

Introductory Remarks: Medicine Took an Earlier Flight.
*By* HENRY GREENBERG . . . . . ix

Introduction. *By* P. R. GROSS . . . . . 1

**The Public Image of Science** . . . . . 9

Imaginary Gardens with Real Toads. *By* DUDLEY R. HERSCHBACH . . . . . 11

Conduct and Misconduct in Science. *By* DAVID GOODSTEIN . . . . . 31

Mathematics as the Stepchild of Contemporary Culture.
*By* NORMAN LEVITT . . . . . 39

**Reasonable Foundations** . . . . . 55

Concern for Truth: What It Means, Why It Matters. *By* SUSAN HAACK . . . 57

The Propensity to Believe. *By* JAMES E. ALCOCK . . . . . 64

Flights of Fancy: Science, Reason, and Common Sense.
*By* BARRY R. GROSS . . . . . 79

Feelings and Beliefs. *By* LOREN FISHMAN . . . . . 87

In Praise of Intolerance to Charlatanism in Academia. *By* MARIO BUNGE . . 96

**The Foundations of Physics** . . . . . 117

Quantum Philosophy: The Flight from Reason in Science.
*By* SHELDON GOLDSTEIN . . . . . 119

[a] This volume represents the proceedings of a conference entitled **The Flight from Science and Reason**, which was sponsored by the New York Academy of Sciences and held in New York, New York on May 31–June 2, 1995.

Physics and Common Nonsense. *By* DANIEL KLEPPNER . . . . . 126
Science of Chaos or Chaos in Science? *By* J. BRICMONT . . . . . 131

**Health** . . . . . 177

"Sucking with Vampires": The Medicine of Unreason.
*By* GERALD WEISSMANN . . . . . 179

Antiscience Trends in the Rise of the "Alternative Medicine" Movement.
*By* WALLACE SAMPSON . . . . . 188

Constructivism in Psychotherapy: Truth And Consequences.
*By* BARBARA S. HELD . . . . . 198

**Environment** . . . . . 207

Radical Environmental Philosophy and the Assault on Reason.
*By* MARTIN W. LEWIS . . . . . 209

Is Environmental Cancer a Political Disease? *By* STANLEY ROTHMAN and
S. ROBERT LICHTER . . . . . 231

Old Messages: Ecofeminism and the Alienation of Young People from
Environmental Activism. *By* RENE DENFELD . . . . . 246

**Social Theories of Science** . . . . . 257

Towards a Sober Sociology of Science. *By* SUSAN HAACK . . . . . 259

Wrestling with the Social Constructor. *By* NORETTA KOERTGE . . . . . 266

Voodoo Sociology: Recent Developments in the Sociology of Science.
*By* STEPHEN COLE . . . . . 274

The Allure of the Hybrid: Bruno Latour and the Search for
a New Grand Theory. *By* OSCAR KENSHUR . . . . . 288

**History, Society, Politics** . . . . . 299

Whatever Happened to Historical Evidence? *By* MARY LEFKOWITZ . . . . . 301

Building Bridges to Afrocentrism: A Letter to My Egyptological
Colleagues. *By* ANN MACY ROTH . . . . . 313

State of the Art/Science in Anthropology. *By* ROBIN FOX . . . . . 327

Liberalism, Public Opinion, and Their Critics: Some Lessons for
Defending Science. *By* SIMON JACKMAN . . . . . 346

Pathological Social Science: Carol Gilligan and the Incredible Shrinking
Girl. *By* CHRISTINA HOFF SOMMERS . . . . . 369

**Feminisms** . . . . . 383

Why Feminist Epistemology Isn't. *By* JANET RADCLIFFE RICHARDS . . . . . 385

Feminist Epistemology: Stalking an Un-Dead Horse.
*By* NORETTA KOERTGE . . . . . 413

The Science Question in Postcolonial Feminism. *By* MEERA NANDA . . . . 420

Are "Feminist Perspectives" in Mathematics and Science Feminist?
*By* MARY BETH RUSKAI . . . . . 437

**Humanities** . . . . . 443

On Sitting Down to Read *King Learns* Once Again: The Textual Deconstruction of Shakespeare. *By* PAUL A. CANTOR . . . . . 445

Constructing Literature: Empiricism, Romanticism, and Textual Theory.
*By* GEORGE BORNSTEIN . . . . . 459

Freudian Suspicion versus Suspicion of Freud. *By* FREDERICK CREWS . . . 470

Ecosentimentalism: The Summer Dream beneath the Tamarind Tree.
*By* GERALD WEISSMANN . . . . . 483

**Religion** . . . . . 491

Two Sources of Unreason in Democratic Society: The Paranormal and Religion. *By* PAUL KURTZ . . . . . 493

Creationism, Ideology, and Science. *By* EUGENIE C. SCOTT . . . . . 505

The Flight from Reason: The Religious Right. *By* LANGDON GILKEY . . . . 523

Doubt, Certainty, Faith, and Ideology. *By* OSCAR KENSHUR . . . . . 526

**Education** . . . . . 537

Science, Reason, and Education. *By* HENRY ROSOVSKY . . . . . 539

Scientific Literacy. *By* JAMES TREFIL . . . . . 543

Science Education and the Sense of Self. *By* GERALD HOLTON . . . . . 551

Afrocentric Pseudoscience: The Miseducation of African Americans.
*By* BERNARD R. ORTIZ DE MONTELLANO . . . . . 561

Notes on Contributors . . . . . 573

Index of Contributors . . . . . 577

Subject Index . . . . . 579

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# INTRODUCTORY REMARKS
## Medicine Took an Earlier Flight

HENRY GREENBERG
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THIS VOLUME EMERGED out of the primary concerns of the hard physical and biological sciences. The proponents and organizing committee of the conference on which this volume is based reflect this. And the individual chapters concentrate on the threats to these disciplines. Although a majority of the authors come from a background in the social sciences, the issues under scrutiny relate to scientific reasoning, logical deduction, and professional expertise.

Let me take a brief look at a soft science that engages all levels of society—namely, medicine. Last year I organized a conference, sponsored by this Academy, that sought to enlarge the view of health care reform so that potential long-term results could be included in the debate. Its title was *Beyond the Crisis: Preserving the Capacity for Excellence in Health Care and Medical Science.*[1] In my talk I focused on threats to excellence in medicine.[2] Toward that end, I explored the genesis of the term *health care provider*, a description with which we are all familiar and one which infuriates physicians. I tried to show that the apparent democratizing of the team, the cultural leveling of the peak usually inhabited by the physician, was a genuine threat to the professional uniqueness of the physician. The social construction of reality has come to medicine. Borrowing from Larry Churchill,[3] I showed that without his or her own professional ethic, a physician who is dependent only upon the usual guiding ethics—law, custom, and common sense—would not be able to defend the best interests of his patient when law, common practice, and conventional wisdom defined a patient's interests in terms that best serve society and not the individual. The loss of the professional ethic will curtail the physician's ability to defend his patient's best interests.

Since then—and those of us in the east are behind—a new threat has emerged. The for-profit health maintenance organization (HMO) has arrived in Gotham. Everyone—hospitals, doctors, medical schools—is fighting to join. Packaging themselves in new organizations, bundling their services in financially pleasing ways, and then devaluing these services so as to be the lowest bidder, they are part of the great game to survive; at least we all think so. And the HMOs, with their ten-million-dollar CEOs, paying out sixty-eight

cents on the dollar for care, understand and like what they see. With little extra effort they will reduce the physician to an employee. Again, the unique professional ethic will be stripped away, and the doctor will measure his life in degrees of compliance with cost-driven algorithms and will hone his skills to reduce an office visit to seven minutes.

One HMO circulated a memorandum stating that it wanted all its specialists to have at least twenty office hours a week. Since a physician could arrange to see a patient within a day should the need arise, why are his ten hours a week inadequate? I think I know the answer. He must have a financial base outside the office. If he does, he may not be as subservient to the HMO requirements as he should be. But if he is dependent upon his office practice, the HMO will gain the control it wants. The physician can be kept in place.

Medicine, then, is being put at grave risk by many strong forces. The social construction of its reality is only one of these forces. This on-going assault has, however, weakened medicine. The profession's inability or unwillingness to confront, let alone recognize, this attack has sapped it of much of its vigor. The other criticisms have a core validity. Because of accentuated attention to these—arrogance, greed, and excessive paternalism—medicine feels constrained to defend itself and is paralyzed when it comes to speaking clearly about its strengths. The rare but highlighted focus on fraud and the less rare examples of marginally scrupulous physicians feeding at the "pass through" trough of Medicare and other insurance plans are commonplace headlines. However, the near-comprehensive inability to distinguish the profession from the practitioner has inhibited the defense of professionalism. And yet when the profession is dead, it will be missed, warts and all.

There is a parallel development in the research science environment. If the incursion of attempted invalidation of scientific reasoning gains a foothold and then saps significant energy for its refutation, the body politic of science will be weakened. If the defense is incomplete or intellectually ineffective, the situation will be frighteningly similar to medicine's. Such a failure to defend science from its irrational critics can set the stage for a lethal blow when the real budgetary attacks arrive, and they are nearly upon us. Some would say they are here, but I am not so optimistic. If science cannot claim a preeminence for its intellectual virtues or an excellence for its methodologies and sense of design, then it will have great difficulty laying claim to a rational share of the nation's resources for its perpetuation. This volume has an important role to play.

## NOTES

1 H. M. Greenberg & S. U. Raymond, eds., *Beyond the Crisis: Preserving the Capacity for Excellence in Health Care and Medical Science.*
2 H. M. Greenberg, "Three Threats to the Capacity for Excellence in Medicine."
3 L. R. Churchill, "Reviving a Distinct Medical Ethic."

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GREENBERG, H. M. & S. U. RAYMOND, eds. *Beyond the Crisis: Preserving the Capacity for Excellence in Health Care and Medical Science. Annals of the New York Academy of Sciences* 729 (1994).

GREENBERG, H. M. "Three Threats to the Capacity for Excellence in Medicine." In *Beyond the Crisis: Preserving the Capacity for Excellence in Health Care and Medical Science*, edited by H. M. Greenberg & S. U. Raymond. *Annals of the New York Academy of Sciences* 729 (1994): 8–18.

# INTRODUCTION

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*Mephistopheles* (disguised, in Faust's academic gown, ready to receive a fawning student whom the sage refuses to see; sotto voce, after the withdrawing protagonist):

> *Scoff at all knowledge and despise*
> *reason and science, those flowers of mankind.*
> *Let the father of all lies*
> *with dazzling necromancy make you blind,*
> *then I'll have you unconditionally—*
>
> —GOETHE, *Faust*[1]

EVIDENCE OF A FLIGHT from reason is as old as human record-keeping; the *fact* of it certainly goes back an even longer way. Flight from science specifically, among the forms of rational inquiry, goes back as far as science itself. Whenever and wherever what we generally mean by "science" *really* began, it is true that rejection of it began in earnest with the Enlightenment itself. Nor has it been a rejection solely by the ignorant, by professional irrationalists, or by minor figures. William Blake rejected all the forms of inquiry upon which modern science was built; Goethe, himself a keen scientific investigator, author of the diabolical whisper used here as an epigraph, nevertheless opposed, finally, the very reasoning that allowed science to escape the straitjacket of *naturphilosophie.* Examples like these could be multiplied. So flight from reason, and from science, is nothing new. We owe the reader some explanation for a new volume on the subject.

There are common, and obvious, forms of antireason and antiscience. Religious obscurantism has always been with us. The mountebank healer and dispenser of potions is an archaic figure of fun on the stage and in print; and there are plenty of them on the bench today, and the sales of snake oil will expand, for reasons given in this book. The cults of UFO-watchers, victims of abduction by extraterrestrials, spoon benders, adjusters of human energy fields, reincarnates recovering their past lives, have had equivalents and defenders in every period since empirical science arose and posed them a terrible threat. At no time since the late nineteenth century, when the concordances of evi-

dence for an evolutionary history of Earth and its biosphere became evident, has wrathful opposition been lacking, opposition not on the basis of evidence but by denial of the efficacy of rational inquiry—or insistence upon the equal epistemic merit of alternatives.[2]

Humbug and credulousness, however, are one thing. Their widespread promotion by intellectuals and in the respected media of communications is another. We believe that there is today in the West, among professors and others who are paid, in principle, to think and teach, a new and more systemic flight from science and reason.[3] It is given endless and contradictory justifications; but its imperialism—for example under the banner of "science studies"[4]—and the high esteem in which it holds the trendiest irrationalisms, are undeniable. This has brought with it, from that unexpected academic quarter, a truculent defense in the name of "democracy" of New Age and traditional forms of sophistry and charlatanism.[5] Younger programs of antilogic and antiscience are both diffuse (oppositionist movements being by their nature fractious) and angrier than the siege, already a few decades old, of "objectivity" in the social sciences and humanities.

But rejection of reason is now a pattern to be found in most branches of scholarship and in all the learned professions. Antirealism has taken hold even in such surprising venues as psychotherapy.[6] For readers of this volume I need not, presumably, argue that such a movement, if it is as pervasive as we think, has consequences, short- and long-term, for the culture as a whole. Those go far beyond the nonfiction book business, the haruspicies of media pundits, the sedations of the seminar room. On the record of history, they are evil consequences,[7] and they affect, more and more as students become alumni, hierarchs, and opinion makers, the way everybody thinks and lives.

If, then, there *is* a new onslaught against science and reason, sufficiently pervasive and well enough supported to deserve examination, and—if appropriate—rebuttal of its ritual pejoratives, then scholars of competence and integrity, representing a broad range of disciplines, need a forum in which to measure the phenomenon. Such was the purpose of the conference of which this volume is the product; and it is the purpose of the volume itself. Not only are all the contributors to this volume such scholars and writers, but included among them are honored figures in disciplines matching the range of a modern university: philosophy, history, religion, literature, economics, sociology, political science, psychology, biology, geography, chemistry, physics, mathematics, medicine. It is not their honors, however, that we hope will be convincing; it is what they said at the conference and have now written here, in their unique ways and from unique points of view. Those points of view reflect not only a broad range of disciplines, but a similar range of political interests and affiliations. At the conference, liberals and conservatives, socialism and capitalism, shared the panel table; feminism, multiculturalism, anticolonialism, and environmental activism were as central to the positions of some contributors as they were remote from the interests of others. *The issues are of reason and one of its applications—science—and their status in our time; not of politics.*

## THEORY

That acidulous balloon pricker, the Underground Grammarian, inveighed, some time ago, against the following product of educational Theory: the confident assertion that young children can and must be equipped with correct views on complex questions (the cold war was his case in point), despite absent knowledge (often matching that of the teacher) of the facts of the case. Thus:

> This is the fact that lies at the heart of all our troubles in "education," the fact that must ultimately defeat all attempts at reform. The children in the schools are just children, who might someday, if left unmolested, put away childish things. But the *other* people in the schools, the teachers and teacher-trainers, the educrats and theory-mongers, are confirmed children. They are, indeed and alas, exactly what they claim to be—"role models." And they represent the end of that process to which schooling is the means: the subversion of knowledge and reason . . .[8]

Not much has happened, in the twelve years since these words were published in book form, to reduce their acid *or* their sting, but a great deal has happened to extend their applicability. It would then have been blatant exaggeration to substitute "universities" for "schools," "professors" for "teachers." It would be, while still an exaggeration, rather less blatant today. Not only have the definition of, and the need for "role models" been inflated, but—and this is much more important—the conviction is stronger than ever that inculcating correct *attitudes* toward big questions is far more important than conveying actual knowledge of their substance. Indeed, admired Theory has it that there is no such thing as actual knowledge, all "knowledge" (the scare quotes are obligatory; the well-spoken postmodernist refers to *knowledges*) being social, a social construction, whose content flows from, and is designed to support, the elites of power. Thus all teaching must be indoctrination.

I do *not*, in this, refer to "political correctness." That term refers to certain unpleasant institutional styles, activities, and policies. To be sure, derogation of science and reason, the oxymoronic multiplication of "knowledges," are among its characteristics. But the flight from—the "demythologizing" of—science and reason is not so limited: those flying from reason are far more numerous. There are well-known instances of it at both ends of the political spectrum. It just happens that derogation of science and reason is an old story on the far reaches of the right. It is something relatively new coming from the left, where until a decade or two ago naming oneself a "progressive" meant aligning oneself with logic, science, and the truth; associating oneself, as it were, with the future.

Over a wide area of academic life today, these self-characterizations have been reversed. One need not, as a "progressive," align oneself with science; one "critiques" it from a suitable "standpoint." To show respect for science, or for universalism, to allude to any sort of "foundations" of knowledge in a truly with-it college (or in some parts of the media world) today, is to show oneself incapable of "the vision-thing," a stick-in-the-mud, a dinosaur—or worse, insensitive. Among philosophers, beleaguered realists and other nonrelativists are well aware of all this; but academic courage being what it is, they do not say much about it directly (although there are some splendid excep-

tions,[9] including contributors to this volume). Among scientists, whose work is the most recent target of pop epistemology and "standpoint" (that is, *political*) criticism from commentators who may know little or nothing about the work itself, awareness of what is going on is spotty at best.

To explore the reasons would require an essay much too long for this collection. Suffice it to say that awareness among scientists has begun lately to increase a bit, not least because of such discreditable, high-profile performances of the critics as the Smithsonian exhibit "Science in American Life" and the earliest versions of the National Science Education Standards.[10] It is a sad comment on our era of expertise that such performances leave most scientists *surprised,* and hurt—but unsure of why they are hurt and whether an effort to respond would be in good taste. So urgent is the demand for Theory, and so suspicious the idea that a case can have *facts*, that it is now acceptable to assert, and to get away with, not only the claim that authors of literary works do not really know or mean what they say, but the same for the recorders of laws, of all manner of social and political facts, and of scientific observations.

There is Theory and there are theories; some are serious and some are not. Judgments of seriousness, furthermore, will differ among honest commentators on theory that *is* theory. Thus it is consistent with the catholicity of tastes, backgrounds, political views, and technical commitments among our contributors that the responses of some to particular theories differ from those of others to the same, even when both recognize and hope to eliminate an irrational element upon whose existence they agree. Cases in point are the views of Bornstein and Cantor on the new Oxford Shakespeare, of Lefkowitz and Roth on Afrocentric history, and of Kurtz and Scott (and to some extent Gilkey) on the proper response of reason and science to certain forms of religion. Conversely, speakers approaching a vexed issue of theory from quite different but equally expert points of view offer conclusions that converge in a satisfactory way, as for example in the judgments offered by Goldstein and Kleppner on the quantum formalisms, their meaning, and their utility.

But a collection of impressions and assertions about impressions is in any case not a theory, by any reasonable definition, let alone a tenable one. The flight from reason of which our contributors write is in large measure, among contemporary scholars (as opposed to innocent believers in the unbelievable), based upon a body of modish Theory that is not theory and upon theories that are untenable. A number of these essays concern themselves, therefore, quite directly with theory, grand and otherwise.

## CREDITS

The New York Academy of Sciences provided appropriate and effective sponsorship, for which we are grateful. One or another of the humanities or social sciences has lately been defended against standpoint attacks by official or unofficial voices, however thinly and sporadically; but science has not done so to even that level of seriousness. In fact, the politics of organized science, and of many distinguished scientists, seem to be limited to avoiding offense to all critics whatsoever, perhaps so as to ward off empty accusations

of biases, crimes, and *systematic* misconduct.[11] The burgeoning interest of the New York Academy of Sciences in the social and broader intellectual implications of natural science is thus a welcome development; it will, we hope, extend a regular, civilized welcome to honest social analysis and provide a platform for cogent response from scientists willing to take the time to study and respond thereto; and vice versa! Perhaps such a movement will receive some stimulus from the conference and this volume.

Norman Levitt (who contributes an essay of his own to the collection) and I first spoke of this effort in 1994, and were encouraged in it by many proposals from colleagues; but it was early evident to us that our competences fell far short of those needed to plan the kind of conference and volume we believed to be needed. Accordingly, we took our courage (and all the spare time left from teaching, research, and family) in hand and inveigled into joining us as an organizing committee the following equally busy scholars: Gerald Holton (Physics, History of Science), Susan Haack (Philosophy), Martin Lewis (Geography, Environmental Science), and Loren Fishman (Medicine). That group designed the conference. Included here are the written versions of conference presentations (but not *ad hoc* remarks by the session chairs and others), with a few late additions from contributors who could not be present. In aid of continuity of argument, the grouping of essays here is somewhat altered from that followed in the sessions.

Professor Levitt and I agreed to edit the published proceedings; but of course much of the real editorial labor was accomplished by the staff of the Academy's *Annals*, especially Mr. Richard Stiefel. Among the external sponsors whose contributions supported conference operations and participant travel were the Lucille P. Markey Charitable Trust, the John M. Olin Foundation, the Lynde and Harry Bradley Foundation, the Russell Sage Foundation, and the Center for Advanced Studies, University of Virginia. We are deeply indebted to them all for their confidence in the timeliness and value of this undertaking. As appropriate to its purpose as general sponsorship by the New York Academy of Sciences was conduct of the sessions in the historic home of the New York Academy of Medicine. This is so, not only because a disproportionate volume of trendy science and cultural criticism is directed at medicine and the biomedical sciences, but also because "alternativism,"—in philosophy, history, and literature as well as in natural science—whose benign exterior can cover dangerous and exploitative interior machinery, is at the moment a more serious problem for the sciences of health than for any others. Because of the Human Genome Project, because of AIDS, because of the eagerness of the media, some of the new biotechnology companies, and some investigators to report (often inaccurately and prematurely) and to solemnize heavily on every new finding in medical or behavioral genetics, biomedicine has joined high-energy physics under the pejorative rubric, "Big Science"—the instrument of oligarchs. By contrast, "alternative," or "nontraditional," or "natural" healing is portrayed, even in the nominally most serious outlets,[12] as small, beleaguered, innocent, and above all, *democratic,* the consolation of the people. Some of our contributors offer here the fruits of long and practical experience with these forms of consolation.

The essays to follow are grouped by broad categories of concern: Literary Studies, Education, Reason and the Social Sciences, Medical Science, Sociology of Science, Religion, Feminisms, Physical Science, Inquiry, Belief and Credulity, Environmentalism. Inevitably, there is considerable overlap of categories, and the categories do not correspond to any university's—or political party's—catalog of departments and offerings. They are, explicitly, *categories of concern;* there is no reasonable way to eliminate the core epistemic issues, to which a separate group of papers is devoted, from, say, an examination of current styles and practices in sociology of science, or in literary studies. Nevertheless these groups, and the essays they contain, cover a large part of the academic acreage and a good deal of the terrain over which there is, or should be, dispute among intellectuals. We hope that readers of these proceedings will find, whether or not they agree with particular arguments, that the contributions are in general not only competent but convincing.

## NOTES

1 The stage-direction is mine; from Part One, II, 1851–1855, Goethe's lines are:

> Verachte nur Vernunft und Wissenschaft,
> Des Menschen allerhöchste Kraft,
> Lass nur in Blend- und Zauberwerken
> Dich von dem Lügengeist bestärken,
> So hab' ich dich schon unbedingt—

here given in the translation of Carlyle F. MacIntyre. I am grateful to my Virginia colleague, Professor Paul A. Cantor, for reminding me of this episode.

2 A recent and very influential example of the promotion of "alternative" modes of inquiry, even about the physical world, has been the antievolutionist tract by Phillip E. Johnson. *Darwin on Trial.* For a sober review of this book, see David L. Hull, "The God of the Galápagos."

3 A bestiary, reasonably current, is given in Paul R. Gross and Norman Levitt, *Higher Superstition.* Its fourteen-page, small-type bibliography can hardly scratch the surface, however. To see what goes on in particular disciplines, *à la mode*, one needs concentration, as in the study, by a committed and serious environmentalist thinker, of ecoradical mythology: Martin W. Lewis, *Green Delusions.*

4 The celibate (as regards "STS"—Sci-Tech-Studies) reader can get a sense of its agreements, which are few but unquestioned (science is a social process, not a mode of inquiry, it has no special claim to efficiency in getting at "truth"), and its internecine wars, which are deadly and amusing, from Andrew Pickering, *Science as Practice and Culture.* Its imperialistic hopes, however, the size of its literature, and its wildly variable standards are even more evident in a massive document that recently surfaced on the World Wide Web. This is, apparently, a manifesto from a Summer Institute sponsored by the National Endowment for the Humanities in the Summer of 1991: "Science as Cultural Practice," edited by Steve Fuller and Sujatha Raman. It would overburden this note to list even its many authors; but here is a characteristic passage:

> . . . So far, the public has been able to view the divergence of expert opinion in public commissions and courts, and still retain confidence in the institution of science. This confidence seems to hinge on the notion that what is being debated is the "truth of the matter" which can be determined by the scientific method. Discoveries of flaws are treated as human error.
>
> Given that this image does not stand up to scrutiny, and this becomes public knowledge, the system could be in a state of uncertainty. In this context, STS is a two-edged sword capable of precipitating a backlash triggered by the already existing disillusionment over the consequences of science. Alternatively, STS can steer the response to an examination of why and how is science successful, followed by a discussion of what we can expect from science if it is to be worthy of public support. Science can still be worthy of respect, although not for the reasons that are

commonly projected. Hence the significance of having people trained in STS move into policy negotiation roles and science teaching is that they are part of the vanguard that has already faced up to the new conception of science and begun rethinking the role of science in society.

5 Nearby on a bookshelf, as I write this, is an example whose title is enough, given as a gift (that is, approved and strongly recommended) to a member of my family by someone who should know better: Deepak Chopra, M.D., *Ageless Body, Timeless Mind: The Quantum Alternative to Growing Old.*

6 For which see the recent book by a psychologist who is also a contributor to this volume: Barbara S. Held, *Back to Reality: A Critique of Postmodern Theory in Psychotherapy.*

7 See, for example, Gerald Holton, *Science and Anti-Science.*

8 Richard Mitchell, *The Leaning Tower of Babel,* p. 266.

9 Examples: John R. Searle, *The Construction of Social Reality;* David Stove, *The Plato Cult and Other Philosophical Follies.*

10 A response to the complaint that the scientific oligarchy has overreacted to the Smithsonian exhibit can be found in Paul R. Gross, "Response to Tom Gieryn."

11 An encouraging and very recent sign of change, on the eve of putting this book to bed, is the devastating review written by Nobel Laureate biophysicist M. F. Perutz, of a recent, debunking biography of Pasteur (by Gerald L. Geison). Perutz's essay, "The Pioneer Defended," is explicitly an effort "to deconstruct his [Geison's] deconstruction."

12 Try PBS or the *New York Times,* or any day on one of the numerous internet discussion lists devoted to science studies.

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# THE PUBLIC IMAGE OF SCIENCE

THIS OPENING SECTION addresses the public perception of science. How well does the general population comprehend what science is, how scientists do it, what tools, intellectual and moral, are necessary? How well do nonscientists understand, and how far do they misperceive? What can be done to remedy misperception?

Nobel Laureate Herschbach ponders the misunderstanding—indeed, the hostility—towards science and scientists that is frequently found within the community of humanist intellectuals. Much of this derives from the sense that doing science is an inflexible, mechanistic procedure, the prime example of "linear thinking," to use a pejorative now much in vogue. By analysis and example, Herschbach shows that on the contrary, science is better compared to a tapestry of variable design, constantly under construction, with seemingly unrelated threads combining in unexpected and beautiful ways. This makes clear that imagination, insight, and even poetry are requisite for scientific success. In short, science is as "holistic" as any critic of linearity could wish.

David Goodstein, administrator, physicist, and gifted scientific pedagogue, examines a question that has greatly agitated the public in recent years: how pervasive is fraud in science, and how far does it bring into question the reliability of scientific knowledge? He shows that actual fraud in the scientific world is quite rare and its effect in misdirecting scientific work minimal. But he also acknowledges that there are other kinds of misconduct, sometimes confused with fraud, that cause public unease. In Goodstein's view, the public must acquire more sophistication in sorting out such matters. For their part, scientists should be more candid in admitting to the human elements in scientific work. The image of scientists as a neutral and aloof priesthood, whatever its origins, invites disenchantment that, in today's climate, is damaging to science.

Norman Levitt, a Rutgers mathematician, finds that the public's estrangement from science is in large measure traceable to a distaste for the mathematical language in which so much of science is embodied. He notes that the exile of mathematics from the humanistic worldview is a relatively new phenomenon, reversing a long tradition that incorporated mathematics into the background of most serious thinkers. He analyzes the effects of this blind spot on the worldviews of prominent intellectuals, and speculates on how a reunion of mathematics with contemporary humanism might improve discourse among the disciplines.

# IMAGINARY GARDENS WITH REAL TOADS

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MARIANNE MOORE SAID: "Poetry is about imaginary gardens with real toads in them." That applies just as well to many aspects of human cultures and especially to science. Scholars and scientists of all kinds are gardeners of ideas, trying to cultivate lovely flowers and fruits of understanding. Such intellectual gardeners usually pay little attention to toads or other uninvited creatures residing among the flowers—unless those creatures begin to munch or trample the plants. Visitors who seem greatly concerned about the toads but unappreciative of the fruits and flowers naturally dismay the gardeners, especially if such visitors even mistake the gardeners for toads.

This horticultural whimsy explains my title and offers rustic metaphors for some of the phenomena addressed in this volume. In my view, the blossoming of "science studies" by historians, sociologists, and philosophers is to be welcomed. It is seeding fallow fields that have long separated scientific and humanistic gardens. In the process, some dust and mud is being stirred up, coating alike flowers and toads. That is inevitable. Science has always drawn lively critics, often motivated by ideology or mysticism. However, I am startled to find a philosopher suggesting that Newton's *Principia* could be regarded as a "rape manual," or radical postmodernist scholars asserting that scientific discoveries are "socially constructed fictions." Such claims, and the disregard for rational analysis that often indulges them, deprecate not only science but all objective scholarship and public discourse. As in horticulture, blights readily spread to neighboring gardens.

In this paper, my chief aim is to welcome any visitors or critics, friendly or not, to tour three patches of my personal scientific garden. The first deals with what for me was a rehearsal for this conference. It was a public television program, titled "The Nobel Legacy" and aired last May, in which I had to counter doleful complaints about science delivered by Anne Carson, a poet and professor of classics at McGill University. The second part comments on aspects of scientific work that are often misunderstood. These pertain to science education as well as to the pursuit of new knowledge. The third part sketches a saga of scientific discovery, submitted to exemplify favorite themes

and to confound postmodern nihilists. I conclude by emphasizing the kinship of natural science with other liberal arts.

A few caveats. For brevity, I say just "science" when usually I mean to include all or most of natural science, mathematics, and some engineering and technology. I do not mean to include social science; that would stretch too far my unruly metaphors and commentary.

## SCENES FROM *THE NOBEL LEGACY*

The television program was part of a trilogy comprising Medicine, hosted by J. Michael Bishop; Physics, hosted by Leon Lederman; and Chemistry, hosted by me. The series was directed by Adrian Malone, known for his many previous science productions, including "The Ascent of Man" with Jacob Bronowski and "Cosmos" with Carl Sagan. As described in a synopsis, *The Nobel Legacy* "seeks to reveal the beauty and humanity of science to audiences not generally drawn to science programming . . . and [to] encourage viewers to become more aware of the scientific strides transforming their lives." Each segment featured one or two scientists whose work ushered in major revolutions: Jim Watson and Francis Crick, Werner Heisenberg, Antoine Lavoisier, and Robert Woodward, my late colleague at Harvard who transformed synthetic organic chemistry. The filming was done at sites of great historical or esthetic interest, ranging from Venice, Florence, and Paris to Hawaii and Carlsbad Caverns.

Anne Carson appears in two or three scenes in each of the segments. Her role was "to provide a provocative philosophical counterpoint . . . the spark of dissenting opinion." Typical of the sparks she struck were her scenes in the Chemistry program. It opens with Carson in Paris, on a bridge over the Seine, and she says:

> The Nobel Prize idealizes the notion of progress. My problem is that I don't believe in progress, and I am skeptical of how chemistry is contributing to my humanity. . . . Now that we've filled the world with Styrofoam cups, carbon monoxide and holes in the ozone, maybe it's time . . . to stand still and pay attention to the real relation between our humanity and our progress.

From this beautiful scene, there's a quick flash, without explanation, to the guillotine (in anticipation of Carson's later description of Lavoisier's execution). Next Carson appears at the Institute de France, the famous "home of the immortals." She explains that it was previously a school attended by Lavoisier, and continues:

> Before the Revolution this place had a reputation for reason . . . Lavoisier's teachers believed that using the light of reason, old ideas and superstitions could be burned away . . . [and] a truly rational society lay around the corner.

As she stands by the bust of Lavoisier, with ominous flashbacks to the guillotine punctuating her sentences, she delivers a scornful verdict:

> What an irrational idea. . . . This happy delusion that there are such things as facts, and they do not deceive us, underlies the whole progress of science and chemistry down to the present day.

A later scene, my favorite among hers, has Carson in the lovely garden within the inner courtyard of the Gardner Museum in Boston, where she says:

> Like every science, chemistry promises to use technology to bring us to paradise. . . . This garden is a little like paradise. It's a small enclosed area of symbolic perfection, an illusion created by the idea that you can have perfect control of nature and all external conditions. It would be a mistake to confuse that illusion with reality, or to think that tinkering with the chemistry of the human condition can ever bring us to paradise. I don't want scientists messing around in the garden of my soul.

Some of my scientific colleagues were quite annoyed with Anne Carson; they regarded her remarks as nonsensical, a silly distraction.[1] Others were annoyed with me, because in interviews I defended her role in the program.[2] I regarded it as a forthright way to acknowledge grim concerns that many people have, misplaced as some of them are. At the outset of the filming, I thought it odd that Adrian Malone did not allow the scientists serving as hosts to reply directly to Carson's criticisms. He wanted to maintain dramatic tension. Later, I came to appreciate that, at least for TV, his indirect approach was more effective. It left the hosts free to extol the wonder and beauty of science and to give our own perspective on toadish issues like pollution. Likewise, it invited the viewers to think for themselves about the issues rather than passively watching a battle of sound bites.

## NOTES FOR A CONVERSATION

Someday I would like to meet Carson and discuss her concerns, with the hope of understanding them better. As Malone liked to emphasize, TV is an emotional medium, not suited to comprehensive explanations. Having experienced that, I do not suppose Carson is so dogmatic as some of the caustic lines she delivered on the program. In any case, again I do not feel obliged to refute her comments directly. Instead, I offer here notes on six points I would want to bring up if I ever do have the opportunity for a conversation with Anne Carson.

1. However questionable the moral or spiritual progress of humanity may be, science has vastly enhanced our capacities and perspectives. As just one example, plucked from a cornucopia, consider the germ theory of disease.[3] For millennia, humankind was almost helpless to combat frequent epidemics of infectious diseases. Two of Pasteur's five children died of typhoid fever, not an uncommon toll in his time. His work establishing the germ theory transformed medicine. Beyond the enormous practical impact of the vaccines thereby developed, the conceptual advance opened the way to the incredible modern era of biomolecular science. Ultimately, this will profoundly impact cultural perspectives too. Just as the Copernican revolution drastically recast mankind's place in the outer world, the "DNA revolution" has transformed our conception of life's inner cosmos.

Exhilarating as they are, the achievements of science cannot create an earthly paradise or even a humane civilization. Much beyond science is required for that. Today, about two million children die each year of diseases for which vaccines are already available.

2. Most scientists would agree with Carson's concerns about toads nurtured in the gardens of science. Our modern technological society has fostered reckless proliferation of people, weapons, pollution, and environmental damage. These are not inevitable consequences, but cannot be overcome without unprecedented economic and political initiatives. Such problems have often plagued preindustrial societies too.

The specialization and sophistication of modern technology have induced another pervasive anxiety. People understand less and less about the many machines, techniques, and underlying concepts on which they depend. This has increasingly serious political consequences; it prevents objective assessment of important questions of public policy involving science, and fosters both distrust and credulity. Here science education, which I discuss later, has a crucial task.

3. There is another kind of pollution, not spawned by science, and far more terrible and intractable than any chemical garbage. It is a pollution by words, toads in humanistic gardens. Perceptions shaped by the power of words have given rise to countless wars and all sorts of political and social folly. Most often that power is illegitimate, not drawn from objective referents. Science can seldom solve sociopolitical problems. Yet sometimes it can change conditions enough to enable resolution, or provide evidence and analysis to help contend with wordly pollution.

4. The notion, advocated by Francis Bacon, that the aim of science is to attain "power over nature" has long drawn attacks as a foolish and arrogant quest. In my view, the aim is not control but comprehension. When science enables us to cope better with microbes and lightning bolts, we should be grateful. When it lets us glimpse more deeply into mysteries of Nature, we should be awed.

At a time when lightning was considered a divine punishment, Ben Franklin gave a sparkling response to a critic of his lightning rod:

> He speaks as if he thought it Presumption in man, to propose guarding himself against the Thunders of Heaven! Surely the Thunder of Heaven is no more supernatural than the Rain, Hail or Sunshine of Heaven, against the inconveniences of which we guard by Roofs & Shades without Scruple.[4]

The alleged arrogance of science also does not accord with what I regard as the most important aspect of the modern scientific "world view." As stated by Richard Feynman: "Science is not about what we know; it's about what we don't know." Science lives at its frontiers, looking to the future, aware of the enormous scope of our ignorance.

This is painfully evident in medicine; Judah Folkman, a distinguished physician, points out that the medical encyclopedias describe some fifteen to twenty thousand recognized human diseases, but fewer than a thousand can be "cured" or completely reversed.[5] Many more cannot be affected at all by modern medicine, even to relieve symptoms. That is what allows "alternative medicines" to flourish, some of it outright fraudulent.

5. Before our conversation, I would recommend to Anne Carson, as I do to my science students, a wise and delightfully engaging book: *The Limits of*

*Science* by Peter Medawar. In particular, Medawar points out that, while Bacon is identified with seeking power over Nature, his writings have "many more typical passages in which he advocated a much more humbly meliorist position," and quotes from his preface to *The Great Instauration*:

> I would advise all in general that they take into serious consideration the true and genuine ends of knowledge; that they seek it neither for pleasure, or contention, or contempt of others or for profit or fame, or for honor and promotion; or suchlike adulterate or inferior ends: but for the merit and emolument of life, and that they regulate and perfect the same in charity: for the desire of power was the fall of angels.[6]

Like most philosophers and all politicians, Bacon said different things at different places. But I do believe that this statement, rather than any urge to control nature, and despite familiar human frailties, represents the chief motivation of most scientists. Recently, Henry Rosovsky proposed, in discussing university governance and contentions, that there should be a creed that professors subscribe to just as do physicians.[7] Perhaps Bacon's preface might serve for any field of scholarship (although I could not forswear seeking knowledge for pleasure!). It would be interesting to find out how Carson and other critics of science might respond.

6. Another book I especially recommend, both to scientists and critics, is *Science and Human Values* by Jacob Bronowski. It comprises three eloquent essays, devoted to showing that science imposes "inescapable conditions for its practice" which compel an ethic. Far from being neutral with respect to human values, science like art requires freedom, honesty, and tolerance in order to foster originality and creativity. Bronowski was both a scientist and author of a major study of William Blake, a Romantic poet vehemently hostile to science. In the revised edition of *Science and Human Values*, Bronowski added a dramatic dialogue, "The Abacus and the Rose." This presents a vigorous debate between a literary scholar, "bitter because he feels helpless in a changing time," and a molecular biologist, "slow to see that there really are other points of view." In his preface, Bronowski says he tried "to put the arguments on each side fairly . . . in words which do not caricature its case." As the conversation spirals between the two cultures, their perspectives gradually intertwine and become complementary. Bronowski concludes with a sonnet; his first lines are:

> I, having built a house, reject
> The feud of eye and intellect,
> And find in my experience proof
> One pleasure runs from root to roof

This humane unity in spirit, more often praised by scientists[8] than others, should be more widely acknowledged.

## SOME METAPHORS FOR SCIENCE

At its frontiers, science-in-the-making is inevitably a messy and uncertain business, easily misunderstood by policy makers, funding agencies, reporters, students, and sometimes even the researchers. Those who decry science often

confuse its rude frontiers with its civilized domains or foundations. Many examples of such confusion, inadvertent or deliberate, are noted and analyzed in *Higher Superstition* by Paul Gross and Norman Levitt and in *Science and Antiscience* by Gerald Holton. Here I simply outline aspects of frontier science that I think should be considered by anyone approaching it, pro or con. My sermonette begins with three favorite metaphors: language, pathfinding, and puzzle solving.

1. Nature speaks to us in many tongues. They are all alien. In frontier research, the scientist is trying to discover something of the grammar and vocabulary of at least one of these dialects. To the extent the scientist succeeds, we gain the ability to decipher many messages that Nature has left for us, blithely or coyly. No matter how much human effort and money we might devote to solve a practical problem in science or technology, failure is inevitable unless we can read the answers that Nature is willing to give us. That is why basic research is an essential and practical investment, and why its most important yield is ideas and understanding.

The language metaphor occurred to me when I received a letter in Braille. We are all born blind to Nature's language, and it takes much persistent groping and guessing to learn something of it. Ironically, our academic science courses inhibit the willingness of students to guess. In my teaching, I try to counteract that with questions that cannot be approached otherwise. Also, I tell my students:

> Not so many years from now, most of you will be considered expert in something. Then you will find that clients often come to ask your opinion, not because of what you know, but because they think as an expert you can guess better than they can.

Of course, the expert must also devise means to test the guesses. That is a crucial part of science; like children playing with new words, we want to try to converse with Nature. In some fields, few of Nature's words are yet known; in others, many volumes.

2. Science is often described as finding a way up an unexplored mountain. This emphasizes a tremendous advantage enjoyed by science: the goal, call it truth or understanding, waits patiently to be discovered at the top of the mountain. Thus marvelous advances can be achieved by ordinary human talent, given sustained effort and freedom in the pursuit. Far more formidable are enterprises such as business or politics; there the objectives may shift kaleidoscopically, so a brilliant move often proves a fiasco rather than a triumph because it comes a little too soon or too late.

The patience of scientific truth has another important consequence, often puzzling to the public. Frequently, what might appear as the most promising path up the mountain does not pan out; there are unanticipated roadblocks. Then it is vital to have some scientists willing to explore unorthodox paths, perhaps straying far from the route favored by consensus. By going off in what is deemed the wrong way, such a maverick may discern the right path. Hence in science, it is not even desirable, much less necessary or possible, to be right at each step. Since the truth waits patiently, and we must grope for it, wrong steps are intrinsic to the search. Adventurous scientists are heading in wrong

directions much of the time, optimistically looking for new perspectives that may show the way up the mountain.

Again, this pathfinding contrasts markedly with introductory science courses. Many students have told me about a disheartening syndrome: the questions and problems seem to have only one right answer, to be found by some canonical procedure. The student who does not quickly grasp the "right" way, or finds it uncongenial, is soon likely to become alienated from science. There seems to be very little scope for a personal, innovative experience. Nothing could be further from what actual frontier science is like. At the outset, nobody knows the "right" answer, so the focus is on asking an interesting question or casting the familiar in a new light. In my freshman chemistry course, I explain this to the students and ask them to write poems about major concepts, because that is much more like doing real science than the usual textbook exercises. I also show them quite a few poems that pertain to science, often without intending to. For instance, here is a quatrain by Jan Skacel, a Czech poet:

> Poets don't invent poems
> The poem is somewhere behind
> It's been there a long long time.
> The poet merely discovers it.[9]

This is the crux of our pathfinding metaphor. I hope the poems help students realize that there is much in science that transcends its particulars.

3. Science is also often likened to assembling a giant jigsaw puzzle. This metaphor was invoked by Michael Polanyi in his classic essay on the organization of scientific research, "The Republic of Science." He envisions competing teams with exactly the same talent, some structured in the hierarchical ways customary in practical affairs but one enjoying the chaotic freedom of science. In the hierarchical organizations, the team would be divided into units directed by a chain of officers; one unit might focus on yellow pieces of the puzzle, another on blue pieces, etc. Each unit would report up the chain of officers to a central authority that assigns tasks. Science proceeds very differently and much more efficiently. Each unit is on its own, free to look at whatever parts of the puzzle interest it. Nonetheless, the independent units are coordinated by "an invisible hand," because each has the opportunity to observe and apply the results found by the others. This creates a community of scientists that fosters and amplifies individual initiatives. Such a community, as Polanyi says, is "a society of explorers, poised to examine any new understanding of Nature."

Again, there is an ironic contrast between such intrinsic cooperation and the artificial competition among students that is imposed in typical courses. In my general chemistry course, we use an absolute grading scale, so students compete against my standard, not each other. Also, some work is designed to be done by teaming up with other students. Of course, in research there is some competition, but it is superficial in the context of the essential collaboration with predecessors and colleagues. Since results are reported openly, the work of a competitor often proves especially helpful, as it is likely to provide a complementary perspective.

## IMAGINARY TOADS IN REAL GARDENS

As suggested by these metaphors, creativity in science has much in common with the arts. New insights often seem strange and idiosyncratic; blunders and breakthroughs at first look very much alike. The typically fitful evolution of germinal work into a widely accepted paradigm or movement is also in some respects similar for science and the arts. These aspects were brought out clearly by Thomas Kuhn[10] as well as Michael Polanyi.[11] Both wanted to counter simplistic depictions of the scientific method as a rather mechanical collecting of facts and calmly logical testing of hypotheses. In my laboratory, visitors are reminded of this theme by an epigram of Vladimir Nabokov: "There's no science without fancy, and no art without facts."

Such cheerful bows to the artistic qualities of science may be considered damning by critics like radical cultural constructionists and postmodernists. Among them some think that the political, class, and gender bias of scientists renders them incapable of finding objective knowledge about Nature. Those critics cannot imagine that toadish scientists could discover real gardens.

When asked to refute Bishop Berkeley, Ben Johnson simply kicked a rock. To a cultural constructionist, we might likewise point out an airplane, say. Rather than being limited to "socially constructed fictions," the natural sciences attain objective truths by functioning as a constructive society. A major part of Michael Polanyi's *Personal Knowledge* is devoted to showing in detail just how this works, despite human frailties and cultural contingencies.

For brevity, again I invoke my horticultural whimsy. In essence, the validity and range of applicability of new knowledge is established by examining many generations of its progeny, when it is mated with other plants already well established in the garden. In this propagation, errors are revealed as unviable mutations and die out. The stock that emerges is hardy, but not an eternal, universal tree of knowledge. Eventually, it will be hybridized anew to produce further progeny. Any part of the garden (as well as the toads) can be transplanted to another culture, so long as it gets suitable care, sun and soil there.

Now I turn from genial horticulture to consider the rape motif favored by Sandra Harding.[12] Like many scientists, male and female, I am sympathetic to feminist issues. But not to Harding's notion that Newton's *Principia* could be regarded as a "rape manual," later generalized by comparing science to "marital rape, the husband as scientist forcing nature to his wishes." As noted already, like Medawar and Bacon in his meliorist mood, I do not regard "forcing nature" as an aim of science. Certainly, it is absurd to tar Newton with that; he was an extremely pious fellow who regarded his work as revealing a divine order. For me, the chief lesson of all natural science, typified by Newton's mechanics, exalts Nature: she is the boss; we try to discover her rules; she lets us know the extent to which we have done so. Harding should consider Richard Feynman's remark:

> For a successful technology, reality must take precedence over public relations, for Nature cannot be fooled.[13]

This was the last sentence of his report on the tragic explosion of the Challenger space shuttle.

Science, like so much else, has often been marred and misled by sexual bias.[14] It is thus gratifying that embryology now indicates the Garden of Eden story needs to be recast, as Eve came before Adam.[15] For its first thirty-five days in the womb, every human fetus is female, whether or not it has XX or XY chromosomes. On about the thirty-sixth day, a genetically programmed switch kicks in. For a normal XY fetus, some already developing female structures then fade away and male structures begin to form. In rare cases, however, the switch is defective; the XY fetus then continues on to become a woman, with external anatomy correct in all respects, although infertile. (Olympic athletes have since 1968 been subjected to a chromosome test, and allegedly a number of XY women athletes have been barred from competing.)[16] The most common defect in the genetic switch has recently been shown to occur on a single amino acid residue, at a critical location on the Y chromosome.[17] In fact, that defect is a missing methyl group, just a carbon atom with three attached hydrogen atoms. Thus, a single methyl group can determine the sex of an XY fetus. If it were missing much more often, human males might be as outnumbered as male bees or ants.

This evidence, indicating Eve's primacy and shrinking Adam's rib to a methyl group, was found by male scientists. Ultimately, Nature forces scientists, willing or not, to her truths.

## AN EXEMPLARY SAGA OF SCIENCE

Several garden paths crisscross my field of research; here I retrace one such path.[18] It begins in Frankfurt with the work of Otto Stern, seventy-five years ago. The invention of the high speed vacuum pump had made it possible for him to undertake experiments using "molecular rays," now called "beams." These are tenuous, ribbonlike streams of molecules traveling in a vacuum at sufficiently low pressures to prevent disruption of the beams by collisions with background gas. The most celebrated of Stern's experiments using these beams was devised to test a curious prediction of the early form of quantum mechanics proposed by Niels Bohr. His atomic model postulated that an electron circulated around the nucleus only in certain definite orbits, whereas the classical mechanics of Newton imposed no such restriction. Stern's experiment focused on that key difference.

His simple apparatus was set up inside an evacuated glass tube, about the size of a quart jar. Silver atoms evaporated from a heated wire passed through a slit which collimated them into a narrow beam (only 0.1 mm wide, about the breadth of a human hair). The beam then passed between the poles of a small magnet and deposited its silver atoms on a glass plate. Stern's magnet was special: one pole came to a sharp edge, like the roof of a house; the opposite pole had a wide groove, like a trench. The magnetic field therefore was much stronger near the sharp pole, weaker near the grooved pole.

According to the Bohr model, the orbital motion of its outer electron makes a silver atom act like a tiny bar magnet. Furthermore, the model predicted that the atomic magnets could point only in either of two directions, "up or down," say, when the atoms interact with an external field, like that of Stern's magnet. Consequently, as indicated in FIGURE 1, atoms with one of these two allowed orientations would move towards the strong field of the

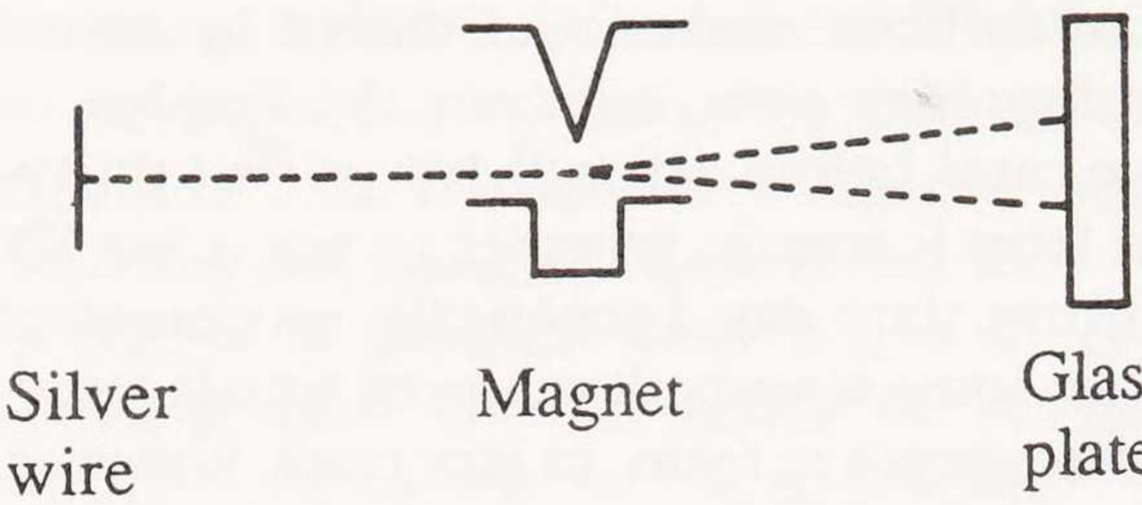


FIGURE 1 Stern's experiment: a beam of silver atoms splits into two on traversing a magnetic field, revealing "space quantization."

sharp pole, the other towards the weak field of the grooved pole: the beam would split into two components. In contrast, if Newton's mechanics were applicable to atoms as it is to planets, the atomic magnets could have any orientation in space: in passing through Stern's magnet, the beam would not split but merely broaden.

The experiment showed unequivocally that the beam split in two. This discovery, revealing the existence of what is now called "space quantization," was shocking to physicists of the day. It provided one of the most compelling items of evidence that a new mechanics was required to describe the atomic world. Two aspects are especially pertinent here. First, Stern himself did not want to accept the quantum picture; he hoped and expected that his experiment would support a Newtonian description of atoms. Second, the atomic magnetism demonstrated by Stern's experiment actually does not come from orbital electronic motion but from a different intrinsic property, called "spin," not discovered until a few years later. The Bohr model was soon discarded; it was seen to have merely simulated, in a limited way, some features of a far more comprehensive quantum theory. I note these aspects because they so clearly show how myopic is the view of cultural constructivists. In its historical context, Stern's experiment gave an "antisocial" result. Other experiments revealed the Bohr model was not correct; yet it was not "fiction" but rather scaffolding for the emergent quantum theory.

Descendants of Stern's beam technique and his concept of sorting quantum states are legion. The prototypes for nuclear magnetic resonance (NMR), radioastronomy, and the laser all derived from space quantization. NMR spectroscopy, first developed at Columbia University by Isidor Rabi in the late 1930s, deals with the orientation of nuclear magnets or spins in an external field. FIGURE 2 indicates the key aspects. For the different orientations, the energy of interaction of the nuclear spin with the field differs slightly. The higher energy state corresponds to an unfavorable orientation, the lower energy to favorable orientation. By means of radio waves of an appropriate "resonant" frequency, the nuclear spin can be induced to change its orientation, or "flip." However, it was not obvious that the minute nucleus, with dimensions about 100,000-fold smaller than the atomic electron distribution, would interact appreciably with the electrons. If not, the different nuclear spin orientations (favorable: "up" or unfavorable: "down") would remain equally probable even when subjected to an external magnetic field. There would then be no net absorption of resonant radio waves, since spin flips induced by the radiation are equally likely up or down. Net absorption can only occur if interactions permit the populations of the spin orientation states to be unequal.

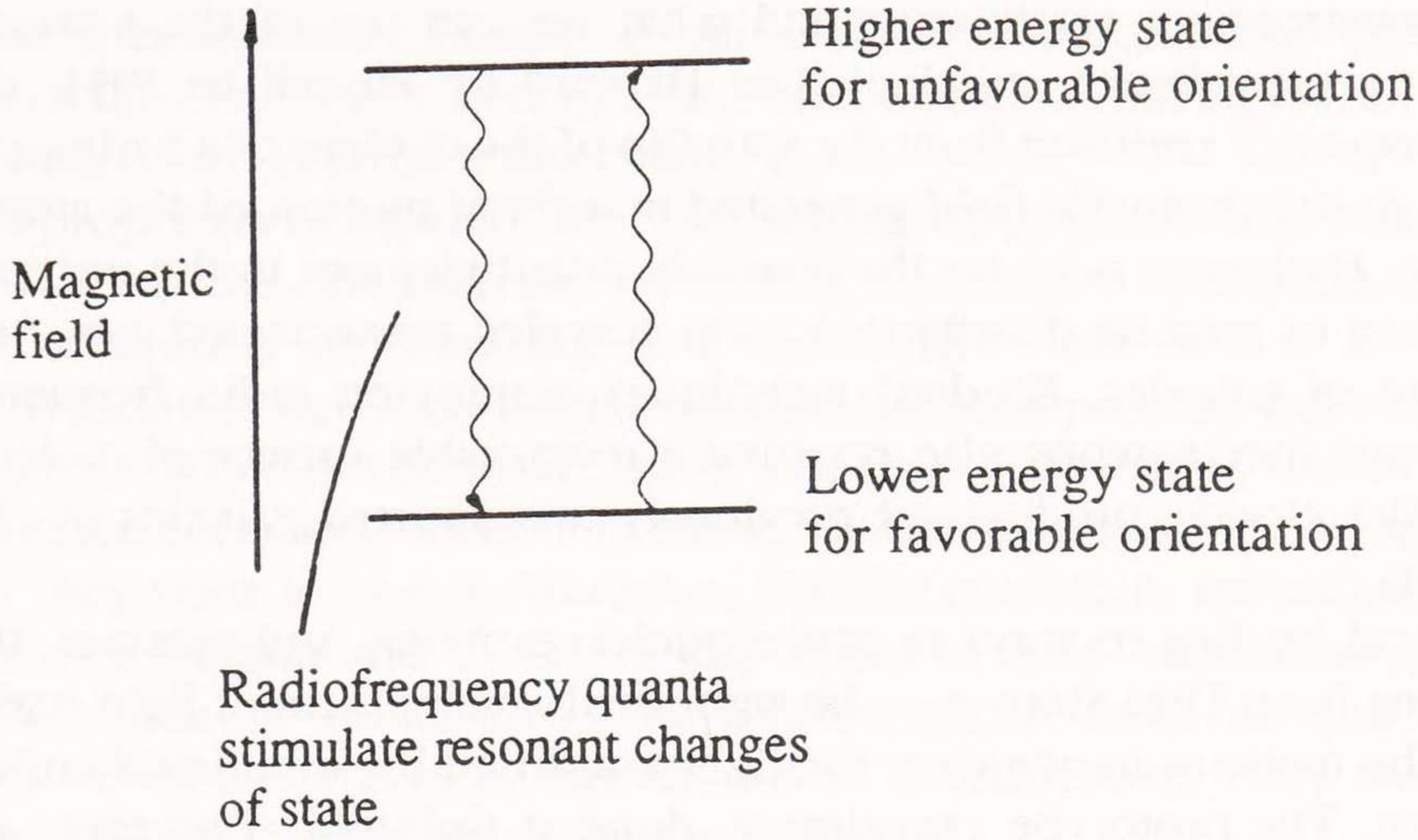


FIGURE 2 Rabi's experiment: transitions between energy levels, corresponding to different spin orientations, are induced by absorption or emission of quanta.

Rabi devised an elegant way to use atomic beams to escape this constraint. In an evacuated chamber, he introduced two magnets like Stern's, but with their fields in opposite directions. A beam of atoms traversing the first field (denoted A) is split into its nuclear spin components, but on passing through the second field (denoted B) these are recombined. Between these magnets, which act like diverging and converging lenses, Rabi introduced a third magnet (the C-field). This had flat pole pieces, so had no lens action, but served to define the "up" and "down" directions. Since atoms in the beam experience virtually no collisions, the populations of the component spin orientation states remain equal. Also, radio waves in the C-field region will at resonance flip equal numbers of spins up or down. But now any spin changing its orientation after the A-field will not be refocused in the B-field. That enabled Rabi to detect which radio frequencies produced resonances. He thus created a versatile new spectroscopic method with extremely high resolving power. His work provided a wealth of information about nuclear structure and led to many other fruitful developments.

The scope of NMR has expanded vastly since 1945, when resonances were first detected in liquids and solids, at Harvard by Edward Purcell and at Stanford by Felix Bloch and their coworkers. In these prototype experiments, the key discovery was that the populations of the "up" and "down" nuclear spin orientations in a magnetic field (C-field) become unequal by virtue of intra- and intermolecular interactions (so Rabi's A- and B-fields are not needed). Over the intervening decades, many sophisticated variants have been devised, with myriad applications. Now NMR spectra are routinely used to determine detailed structural features of proteins containing thousands of atoms. For instance, that was how the missing methyl group in the defective switch on the Y chromosome was detected.[19] Another marvelous offspring is magnetic resonance imaging, which provides far higher resolution than x-rays. It is applicable also to soft tissues such as the brain; we can now literally catch sight of glimmering thoughts.

Radioastronomy vastly extended what we can see of the heavens. The prototype experiment, conducted at Harvard by Purcell in 1951, detected radio frequency emission from the spin flip of the nucleus of a hydrogen atom, subject to the magnetic field generated by orbital motion of the atom's lone electron. Hydrogen is by far the most abundant element in the universe, and the ability to map its distribution soon revealed unsuspected aspects of the structure of galaxies. Kindred techniques employing radio frequency and microwave spectroscopy also revealed a remarkable variety of molecules in interstellar clouds, products of previously unsuspected galaxies of chemical reactions.

Beyond leading to ways to probe nuclei, proteins, and galaxies, the path stemming from Otto Stern even brought forth a new form of light itself: laser light. The name is an acronym for **l**ight **a**mplified by **s**timulated **e**mission of **r**adiation. The prototype experiment, done at Columbia University in 1955 by Charles Townes and his students, employed a beam of ammonia molecules subjected to an electric field which acted as a state-selection device quite analogous to Stern's magnet. The device selected an energetically unfavorable molecular state. When illuminated with microwaves, the molecule reverted to the energetically favorable state, emitting the excess energy as radiation. Unlike ordinary light, this emission has a special property, called "coherence"; the difference is analogous to that between a meandering crowd of people and a marching band. Thus was born molecular amplifiers and oscillators and other wonders of quantum electronics.[20] Laser light now performs eye surgery, reads music or data from compact disks, and scans bar codes on grocery packages or DNA base pairs in the human genome.

As Stern was a physical chemist, he would be pleased that his beam techniques, augmented both by magnetic and electric resonance spectroscopy and by lasers, have also evolved powerful tools for study of molecular structure and reactivity. In my own work, the basic method simply involves crossing two molecular beams in a vacuum and detecting the products in free flight, before subsequent collisions degrade the information they carry about the intimate dynamics of the reactive encounter. This method, applied and refined in many laboratories over more than thirty years, has enabled the forces involved in making and breaking chemical bonds to be resolved and related to the electronic structure of the reactant molecules.

From this point, I want to trace a trail that backtracks from Stern's path. Usually, an atomic or molecular beam comes from a small source chamber mounted within a vacuum apparatus. Stern had stressed that the pressure in the source chamber should be kept low enough so that the atoms or molecules, as they emerge from the exit orifice, do not collide with each other. The emergent beam then provides a true random sample of the gas within the source, undistorted by collisions in the exit orifice. Of course, this canonical ideal was blatantly violated by chemists who wanted to study reactions in crossed beams. Such experiments desperately needed intensity, so much higher source pressures were used. Collisions within the exit orifice then produce supersonic flow. This has advantageous properties. In addition to high intensity, supersonic beams have narrow distributions in both direction and

molecular speeds. Under suitable conditions, the rotational and vibrational motions of the beam molecules can also be markedly reduced, in effect producing a very low internal temperature.

These properties of supersonic beams, all resulting from collisions as molecules crowd out the exit aperture, are readily understood by anyone who has attended a Saturday morning sale at a department store such as Filene's in Boston. Typically, a dense crowd gathers (like the high-pressure gas within the beam source). When the doors are thrown open and the crowd rushes in, collisions induce everybody to flow in the same direction with the same speed, whether they want to or not. Moreover, if some customers are excited at the prospect of a bargain and therefore leap about or turn handstands (like vibrating or rotating molecules), they suffer more frequent and harder collisions—even black eyes or bloody noses. Thereby such lively customers are calmed down (to low effective temperatures).

The drastic cooling that occurs in supersonic beams has proved extremely useful. In particular, it led to the discovery a few years ago of a new form of elemental carbon.[21] The molecules have sixty carbon atoms, arrayed in linked hexagons and pentagons in the same highly symmetrical pattern as a soccer ball, and whimsically named "Buckyball" to celebrate the architectural resemblance to Buckminster Fuller's geodesic domes. It is striking that the study that led to Buckyball was motivated by interstellar spectra. The question had been raised whether a series of absorption lines, long unidentified, might arise from clusters of carbon atoms. That seems not to be the case. Ironically, however, it was eventually shown that Buckyball and kindred molecules can be extracted in quantity from soot. For synthetic chemists, this has opened up a huge realm of potential molecular structures, built with a form of carbon that has sixty valences rather than just four. By looking at the heavens, scientists came to find, in ashes that had lain under the feet of ancestral cavemen, a Cinderella-like molecule.

Our path next pauses at a computer screen.[22] Three years ago a graduate student at the University of California at San Francisco was trying to see if he could find or design a molecule that would inactivate an enzyme that is crucial for replication of the AIDS virus. The inactivating molecule needs to have the right size and shape to fit into a cleft in the enzyme. The molecule also needs to present a water-repellent torso, since the cleft is hydrophobic. A friend of the student, listening to him lament about what he tried that did not fit, jokingly suggested he try Buckyball. He went back to the computer and found it was just right. Soon a chemist at the University of California at Santa Barbara synthesized a derivative of carbon-sixty which has a pair of wings that make the molecule water soluble despite its hydrophobic torso. Physiologists at Emory University in Georgia then found that, at least in a test tube, this Buckyball derivative does indeed totally inactivate the enzyme that governs replication of the AIDS virus.

This is still a long way from having an actual AIDS drug that can function in living cells. However, the path from Stern's atomic magnets to the AIDS virus, like many others, serves to emphasize that research on fundamental questions inevitably creates a host of unforeseeable opportunities. No funding

agency would find plausible a research proposal requesting support of work on supersonic beams or interstellar spectra as an approach to AIDS. But many such historical paths can be traced that celebrate hybridizing discoveries from seemingly unrelated patches of scientific gardens.

## SCIENCE AMONG THE LIBERAL ARTS

In *As You Like It*, set in an imaginary garden, Shakespeare said: "Sweet are the uses of adversity, which, like the toad, ugly and venomous, wears yet a precious jewel in his head." The fruits and flowers of science and rationalism are, I believe, hardy enough to withstand even venomous critiques. Provided we gardeners respond well, the critiques can help us learn how to nurture better our precious flora. Like our gardens, the newly luxuriant growth of "science criticism" in academic fields will be subject to the scrutiny of a coming generation of scholars. With that in mind, I conclude with three comments emphasizing why and how we need to cultivate common ground, shared by science and the liberal arts.

1. The masterworks of natural science and human arts alike testify to the marvelous creative capacities of mankind. Wherever in the world these emerged, they now are a rich legacy cherished by all cultures. This should be a powerful force for amity. Forty years ago, as a beginning graduate student, I heard this theme sounded by Rabi in a fervent lecture to the Harvard physics department:

> How can we hope to obtain wisdom, the wisdom which is meaningful in our own time? [The wisdom of] balanced judgment based on . . . a well-stored mind and feeling heart as expressed in word and action. . . . We certainly cannot attain it as long as the two great branches of human knowledge, the sciences and the humanities, remain separate and even warring disciplines. . . .
>
> To my mind, the value of science or [the humanities] lies not in the subject matter alone, or even in greater part. It lies chiefly in the spirit and living tradition in which these [different] disciplines are pursued. . . . Our problem is to blend these two traditions. . . . The greatest difficulty which stands in the way . . . [is] communication. The nonscientist cannot listen to the scientist with pleasure and understanding.
>
> Only by the fusion of science and the humanities can we hope to reach the wisdom appropriate to our day and generation. The scientists must learn to teach science in the spirit of wisdom, and in the light of the history of human thought and human effort, rather than as the geography of a universe uninhabited by mankind. Our colleagues in the nonscientific faculties must understand that if their teachings ignore the great scientific tradition and its accomplishments, however eloquent and elegant in their words, they will lose meaning for this generation and be barren of fruit. Only with a unified effort . . . can we hope to succeed in discovering a community of thought, which can lead us out of the darkness, and the confusion, which oppress all mankind.[23]

Rabi later discussed these concerns with C. P. Snow, who developed them further in his famous *Two Cultures.*

Today, the cultural gulf seems wider and more ominous. The recently proposed new national standards for teaching American history are blatant evidence.[24] From a process extending over three years and involving many his-

torians, there emerged a 250-page document describing the new curriculum for grades 5–12. It makes no mention of any scientific discovery or any scientist, not even Benjamin Franklin.

2. Yet there is also much to hearten both scientists and humanists responsive to Rabi's appeal. Many efforts are now under way to foster major reforms in science education at all levels. The past forty years have in fact produced an outpouring of articles, books, films, and TV programs that make science accessible to a wide public. Most large cities now have thriving science museums; for instance, last year the Boston Museum of Science drew nearly 1.7 million visitors (compared with 2.2 million for a typical Red Sox season). The Internet soon will greatly enhance such resources.

Excellent science writing in a humanistic mode is now abundant. Much of this stems from the history of science, approaching full bloom as an academic discipline (even if often ignored by other historians). Much also comes directly from scientists writing of "human thoughts and effort," exemplified by Lewis Thomas, Victor Weisskopf, Philip and Phylis Morrison, Gerald Holton, Freeman Dyson, Jeremy Bernstein, Carl Sagan, Jared Diamond, James Trefil, Roald Hoffmann, and many others.[25] Another genre effective in conveying both specific and cultural aspects is fiction incorporating genuine science (in contrast to science fiction);[26] a fine example is Carl Djerrasi's recent novel, *The Bourbaki Gambit*.

A liberal arts education worthy of the tradition surely must aim to integrate science into our general culture. But we cannot expect to accomplish much if we continue to confine science to separate courses. Even a "physics for poets" course reinforces the prevalent view that science belongs solely to its professionals. There are abundant opportunities to include some science in many other subjects—and vice versa! Often such items, used to broaden perspectives, take the form of parables. Here are a few examples, appropriate for various courses.

*Economics*

In 1880, aluminum metal was more precious than gold. Although aluminum ores are plentiful, the metal is tightly bound to oxygen, and no cheap means had yet been found to free it. Consequently, the Washington Monument is capped with a small pyramid of aluminum; The Danish King Christian X wore a crown of aluminum; and at dinner parties of Napoleon III, plates of gold were placed before ordinary guests, an aluminum plate before the guest of honor. In a chemistry class at Oberlin College, Charles Hall heard his professor assert that "whoever frees aluminum from its oxide, will make his fortune." Hall undertook a long series of experiments, working in a woodshed with a frying pan and jars borrowed from his mother's kitchen. By 1886, he found he could dissolve aluminum oxide in a molten mineral, install electrodes, and run electricity to free the metal.[27] (This is still the way the metal is obtained.) Within a few years a new industry had emerged and the price of aluminum metal had dropped to about fifty cents a pound. The price has remained fairly constant for the past century, but economists seem not to have proposed using aluminum as a monetary standard.

*History*

Polymer synthesis had a crucial role in enabling the United States to enter World War II.[28] The Japanese attack on Pearl Harbor on December 7, 1941, was much less disastrous than the fall of Singapore three months later. That deprived the United States and Britain of virtually their sole supply of rubber. As stated in a report by Bernard Baruch:

> Of all the critical and strategic materials, rubber presents the greatest threat to the success of the Allied cause. . . . If we fail to secure quickly a large new rubber supply, our war effort and our domestic economy both will collapse.[29]

This report launched a crash program to produce synthetic rubber, using a method developed and implemented in Germany. In effect, our enemy had provided the saving key. Some 50 plants were quickly built, enabling military action to start in late 1942. The Allied victory could not have been achieved without this enormous rubber project. However, for it to succeed on such an urgent time scale, we had to have a sufficient corps of polymer chemists and engineers. It was actually the pursuit of artificial silk started 15 years before and culminating in nylon that largely created those vital human resources.

*Political Science*

The eminent historian of science, I. Bernard Cohen, has just published a remarkable book, *Science and the Founding Fathers.* This traces the role of science in the political thought of Franklin, Jefferson, Adams, and Madison, an aspect "conspicuously absent from the usual textbooks." Here I will mention just a bit about Franklin. As an American icon, he is aptly portrayed as wise, witty, and pragmatic in business and politics, but his scientific work is greatly undervalued. He is represented as a chubby, comic fellow flying a kite or a clever tinkerer coming up with useful devices, such as the lightning rod, bifocals, and an efficient stove. As Cohen emphasizes, in the early eighteenth century, electricity was a greater mystery than gravity had been a century earlier. Franklin, almost entirely self-educated and far from any center of learning, solved that mystery. His book, *Experiments and Observations on Electricity*, was a sensation in Europe: it went through five editions in English and was translated into French, German, and Italian. It was read not only by scholars but by the literate public, including the clergy and aristocracy. Many high honors were bestowed on Franklin, including election as a foreign associate of the French Academy; he was the first American elected and the only one for another century.

His scientific stature, comparable to Newton in his day or Einstein in ours, had a significant role in the success of the American Revolution. Franklin's arrival in Paris in 1776 coincided with the signing of a nonaggression pact, which specified that France not aid any rebellion in the British Colonies. His fame as the tamer of lightning helped him gain influence with the French court and immense popularity with the public. That accelerated and enlarged the vital flow of arms and funds supplied by the French to the American rebels. Indeed, Franklin's celebrity was like that of a rock star today; although T-shirts were not yet fashionable, his image appeared everywhere in Paris

on medallions and banners, often with the motto *Eripuit celeo fulmen sceptrumque tyrannis* ("he snatched lightning from the sky and the scepter from tyrants"). Louis XVI became so annoyed by this veneration that he gave his favorite mistress a chamber pot with a Franklin medallion at the bottom of the bowl.

*Mathematics*

The account of Thomas Jefferson's science in Cohen's book offers several items that could provide an appealing and instructive context for standard topics. My favorite concerns Jefferson's mathematical skill. Among the extraordinary range of his intellectual interests, Jefferson ranked science as his "supreme delight." He especially esteemed Isaac Newton, studied avidly the *Principia*, and mastered geometry and calculus. When Jefferson undertook to design an improved plow, a key question was the optimum shape of the moldboard, the part that peels back and turns over the sod as the blade cuts through the soil. At first, he pursued this by trial and error, using only simple geometrical calculations. On consulting some mathematical friends, however, he realized that finding the optimum shape required a solution of a calculus problem. He was thus able to treat the plowing of earthly furrows by means of a mathematical tool that Newton had developed to analyze the orbits of heavenly bodies. Jefferson's moldboard design remained the standard for a century; it might open vistas for calculus students today.

3. A liberal arts education aims above all to instill the habit of self-generated questioning and adventurous thinking. In pursuit of that aim, as urged by Bronowski and Rabi, the humanities and sciences should be complementary. Each academic subculture deals with entirely different kinds of questions, develops very different criteria for evaluating answers, and evolves its own language. That handicaps interdisciplinary communication, but need not be allowed to engender disrespect. Science or any subculture can only treat questions amenable to its methods. We should strive for an inclusive intellectual society in which the whole can greatly exceed the sum of its parts.

In conclusion, I return to Peter Medawar, because he stated so well what I believe:

> I am a rationalist, but I'm usually reluctant to declare myself to be so because of the widespread misunderstanding or neglect of the distinction there must always be drawn in philosophic discussion between the sufficient and the necessary. I do not believe, indeed I deem it a comic blunder to believe, that the exercise of reason is *sufficient* to explain our condition and where necessary to remedy it. But I do believe that the exercise of reason is at all times unconditionally *necessary* and that we disregard it at our peril. I and my kind believe that the world can be made a better place to live in . . . believe, indeed, that it has already been made so by an endeavor in which, in spite of shortcomings which I do not conceal, natural science has played an important part. . . . To people of sanguine temperament, the thought that this is so is a source of strength and the energizing force of a just and honorable ambition. . . . The dismay that may be aroused by the inability of science to answer the ultimate first and last questions is really something for which ordinary people have long since worked out for themselves Voltaire's remedy: "We must cultivate our garden."[30]

## NOTES

1 R. Seltzer, "New Television Series May Draw both Kudos and Arrows."
2 M. C. Seidel, "The Forgotten Science"; D. R. Herschbach, "On the Nobel Legacy."
3 F. Ashall, *Remarkable Discoveries*, pp. 137–151, 160–170.
4 Quoted in R. W. Clark, *Benjamin Franklin*, p. 89.
5 Personal communication from J. Folkman, derived from *The International Classification of Diseases*, 9th Revision, 1996.
6 Quoted in P. Medawar, *The Limits of Science*, p. 40.
7 H. Rosovsky, "Appearing for the Defense Once Again."
8 See, for example, D. W. Curtin, ed., *The Aesthetic Dimension of Science*; S. Chandrasekhar, *Truth and Beauty*; R. Hoffmann, *The Same and Not the Same.*
9 Quoted in M. Kundera, *The Art of the Novel*, p. 99.
10 T. S. Kuhn, *The Structure of Scientific Revolutions.*
11 M. Polanyi, *Personal Knowledge*; *The Tacit Dimension.*
12 S. Harding, *The Science Question in Feminism*; "Value-Free Research Is a Delusion."
13 Quoted in J. Mehra, *The Beat of a Different Drum: The Life and Science of Richard Feynman*, p. 599.
14 E. F. Keller, *Reflections on Gender and Science*; E. Martin, "The Egg and the Sperm: How Science Has Constructed a Romance Based on Stereotypical Male-Female Roles."
15 T. W. Sadler, *Langman's Medical Embryology.*
16 J. D. Wilson, "Sex Testing in International Athletics."
17 C. M. Haqq, C.-Y. King, E. Ukiyama, S. Falsafi, T. N. Haqq, P. K. Donahoe & M. A. Weiss, "Molecular Basis of Mammalian Sexual Determination."
18 D. R. Herschbach, "Molecular Dynamics of Elementary Chemical Reactions."
19 Haqq *et al.*, "Molecular Basis."
20 C. H. Townes, "Quantum Electronics, and Surprise in the Development of Technology."
21 R. F. Curl & R. E. Smalley, "Fullerenes"; H. W. Kroto, "$C_{60}$: The Celestial Sphere That Fell to Earth."
22 R. Baum, "Fullerene Bioactivity."
23 Quoted in J. S. Rigden, *Rabi, Scientist and Citizen*, pp. 256–257.
24 R. L. Park, "The Danger of Voodoo Science."
25 A sampling of recent vintage: Gerald Holton, *The Advancement of Science and Its Burdens*; Philip Morrison & Phylis Morrison, *The Ring of Truth*; James S. Trefil, *Meditations at Sunset*; C. Tanfold, *Ben Franklin Stilled the Waves*; R. Levi-Montalcini, *In Praise of Imperfection*; Victor Weisskopf, *The Joy of Insight*; S. J. Gould, *Wonderful Life*; B. Hölldobler and E. O. Wilson, *Journey to the Ants*; P. Ball, *Designing the Molecular World.*
26 L. Herschbach, " 'True Clinical Fictions': Medical and Literary Narratives from the Civil War Hospital."
27 N. C. Craig, "Charles Martin Hall—The Young Man, His Mentor, and His Metal."
28 H. F. Mark, *Giant Molecules.*
29 Quoted in H.F. Mark, *Giant Molecules*, p. 130.
30 Peter Medawar, *The Limits of Science.*, pp. 98–99.

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# CONDUCT AND MISCONDUCT IN SCIENCE

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MY CAREER IN SCIENTIFIC FRAUD began some years ago when, as Caltech's vice provost, I became aware that federal regulations would soon make it necessary for us, for the first time ever, to have in place formal rules about what to do if the unthinkable were to happen on our own campus, the very inner sanctum of pure science. Since then it has virtually become an academic subspecialty for me. I have given lectures, written articles,[1] and taught courses about it. I have written the regulations, seen them adopted by Caltech (and copied by other universities), and, much to my dismay, seen them put into action in a high-profile case at Caltech. During that case I had the remarkable experience of seeing a skilled lawyer, with a copy of my regulations highlighted and underlined in four colors, guide us in following every word I had written, whether I meant it or not. Through all of that, I have learned a few things about conduct and misconduct in science that I would like to share with you.

Let me begin by stating right up front a few of the things I have come to believe. Outright fraud in science is a special kind of transgression, different from civil fraud. When it does occur, it is almost always found in the biomedical sciences, never in fields like physics or astronomy or geology, although other kinds of misconduct do occur in these other fields. Science is self-correcting, in the sense that a falsehood injected into the body of scientific knowledge will eventually be discovered and rejected; but that does not protect us against fraud, because injecting falsehoods into the body of science is never the purpose of those who perpetrate fraud. That is why science needs active measures to protect itself. Unfortunately, the government has so far made a mess of trying to do that job. Part of the reason government agencies have performed so poorly in this arena is that they have mistakenly tried to obscure the important distinction between real fraud and lesser forms of scientific misconduct. I also believe that fraud and other forms of serious misconduct have been and still are quite rare in science, but there are reasons to fear that they may become less rare in the future. Finally, I believe we scientists are responsible for complicity in presenting to the public a false image of how

science works—one that can sometimes make normal behavior by scientists appear to be guilty. Let me try to explain what I mean by all of this.

Fraud means serious misconduct with intent to deceive. Intent to deceive is the very antithesis of ethical behavior in science. When you read a scientific paper, you are free to agree or disagree with its conclusions, but you must always be confident that you can trust its account of the procedures that were used and the results produced by those procedures. There are, to be sure, minor deceptions in virtually all scientific papers, as there are in all other aspects of human life. For example, scientific papers typically describe investigations as they logically should have been done rather than as they actually were done. False steps, blind alleys, and outright mistakes are usually omitted once the results are in and the whole experiment can be seen in proper perspective. Also, the list of authors may not reveal who deserves most of the credit (or blame) for the work. Behavior of these kinds may or may not be correct or laudable, but they do not amount to fraud. Real fraud occurs only if the procedures needed to replicate the results of the work or the results themselves are in some way knowingly misrepresented.

This view of scientific fraud differs from civil fraud as described in tort law in that in civil fraud there must be a plaintiff, who brings the case to court and who must be able to prove that the misrepresentation was believed and led to actual damages. By contrast, if a scientist makes a serious misrepresentation in a scientific presentation, knowing that it is false or recklessly disregarding whether it is false, then, virtually all scientists would agree, scientific fraud has been committed. It is unnecessary to prove that anyone in particular believed the statement or was damaged by believing it. In fact, it makes no difference at all whether the conclusions reached by the scientist are correct or not. In this stern view of scientific fraud, all that matters is whether procedures and results are reported honestly or not.

This kind of misbehavior seems to be restricted largely to the biomedical and closely related sciences. A study by sociologist Pat Woolf[2] of some twenty-six cases that surfaced one way or another between 1980 and 1986 revealed that twenty-one came from biomedical science, two from chemistry and biochemistry, one from physiology, and the other two from psychology. I do not know of any more recent studies of this kind, but one cannot help noticing that the Office of Research Integrity of the Public Health Service, which investigates misconduct in research supported by the National Institutes of Health—in other words, biomedical research—seems constantly to be embroiled in controversy; while the Inspector General of the National Science Foundation, which supports all of the sciences, including biology, conducts its business in relative anonymity, unmolested by serious attention from the press.[3]

There are undoubtably many reasons for this curious state of affairs. For example, many of these cases involve M.D.'s, rather than Ph.D.'s, who are trained to do research. To an M.D. the welfare of the patient may be more important than scientific truth. In a recent case, a physician in Montreal was found to have falsified the records of participants in a large-scale breast cancer study. Asked why he did it, he said it was in order to get better medical care

for his patients.[4] However, the larger number of cases arise from more self-interested motives.

In the cases of scientific fraud that I have looked at, three motives, or risk factors, have always been present. In all cases, the perpetrators

1. were under career pressure;
2. knew, or thought they knew, what the answer would turn out to be if they went to all the trouble of doing the work properly; and
3. were working in a field where individual experiments are not expected to be precisely reproducible.

It is by no means true that fraud always occurs when these three factors are present; quite the opposite; they are often present, and fraud is quite rare. But they do seem to be present whenever fraud occurs. Let us consider them one at a time.

*Career Pressure.* This is included because it is clearly a motivating factor, but it does not provide any distinctions. All scientists, at all levels from fame to obscurity, are pretty much always under career pressure. On the other hand, simple monetary gain is seldom, if ever, a factor in scientific fraud.

*Knowing the Answer.* If we defined scientific fraud to mean knowingly inserting an untruth into the body of scientific knowledge, it would be essentially nonexistent, and of little concern in any case because science is self-correcting. Scientific fraud is always a transgression against the *methods* of science, never purposely against the body of knowledge. Perpetrators always think they know how the experiment would come out if it were done properly, and decide it is not necessary to go to all the trouble of doing it properly. The most obvious seeming counterexample to this assertion is Piltdown Man, a human skull and ape jaw planted in a gravel pit in England around 1908. If ever a fraudulent physical artifact was planted in the scientific record, this was it. Yet it is quite possible that the perpetrator was only trying to help along what was known or thought to be the truth. Prehistoric remains had been discovered in France and Germany, and there were even rumors of findings in Africa. Surely human life could not have started in those uncivilized places. And, as it turned out, the artifact was rejected by the body of scientific knowledge. Long before modern dating methods showed it to be a hoax in 1954, growing evidence that our ancestors had ape skulls and human jaws made Piltdown Man an embarrassment at the fringes of anthropology.

*Reproducibility.* In reality, scientific experiments are seldom repeated by others. When a wrong result is found out, it is almost always because new work based on the wrong result does not proceed as expected. Nevertheless, the belief that someone else can repeat an experiment and get the same result can be a powerful deterrent to cheating. This appears to be the chief difference between biology and the other sciences. Biological variability—the fact that the same procedure performed on two organisms as nearly identical as possible is not expected to give exactly the same result—may provide some apparent cover for a biologist who is tempted to cheat. This last point, I think, explains why scientific fraud is found mainly in the biomedical area.

Federal agencies, particularly the Public Health Service (PHS, parent of the National Institutes of Health, NIH) and the National Science Foundation (NSF), take quite a different view from that outlined above of what constitutes serious misconduct in science. The word *fraud* is never used at all, because fraud means intent to deceive, and the agencies do not want investigations hung up on issues of motive. Instead they (both PHS and NSF) define serious misconduct to be

> . . . fabrication, falsification, plagiarism, or *other practices that seriously deviate from those that are commonly accepted within the scientific community* for proposing, conducting and reporting research.[5]

Controversy has swirled around this statement ever since it was first proposed in 1988 and issued as a "final rule" in 1990. No one takes issue with "fabrication, falsification (and) plagiarism," (ffp, mnemonic, "frequent flier plan" for the cognoscenti). The controversial part is the catch-all phrase "practices that seriously deviate from those commonly accepted. . . ." To the agencies, that phrase is a mandate needed to enable them to carry out their mission as stewards of public funds. To many scientists and other observers it raises the horrifying specter of the government forcing scientists into some preconceived mold of orthodox thought. To me it seems poor public policy to create a government bureaucracy mandated to root out transgressions that are not specified in advance. The NSF Inspector General's Office has argued, for example, that the catch-all phrase was needed for it to be able to deal with a principal investigator (government phrase for one of their grantees) who committed sexual harassment against female students during an NSF-sponsored archeological dig.[6] Surely that was serious misconduct, it deviated seriously from practices commonly accepted within the scientific community, and the NSF had a duty to do something about it. Nevertheless, there are other laws governing that kind of misbehavior. It was not scientific misconduct.

Even the uncontroversial "ffp" part of the final rule is different from the view of scientific fraud outlined above, and also different from the definition of research fraud given in the Caltech rules. The federal rule includes plagiarism, and the Caltech rules, not content with plagiarism alone, specifies ". . . faking data, plagiarism and misappropriation of ideas." The idea here is that "faking data" includes both "fabrication and falsification," and that one can misappropriate ideas in science without committing plagiarism, a rather technical term that means copying a certain number of consecutive words or consecutive musical notes or the like without proper attribution.

Early on, when I had just begun to think and write about this subject, one of my very distinguished Caltech colleagues came to see me, and said, in effect, "Look, son, let me explain to you how all this works. Scientific truth is the coin of the realm. Faking data means counterfeiting the coin. That's a serious crime. All this other stuff you talk about, plagiarism, authorship problems, and so on, that's just a matter of who's been handling the coins. That's much less important." In light of this "coin of the realm" view, one can easily summarize everything that has been said above. Science is a special currency

that needs to be protected. I have outlined a strict view, in which only counterfeiting the coin is real scientific fraud. The federal agencies see themselves instead as central banks, charged with overseeing all transactions and catching all wrongdoers, not merely counterfeiters. Thus, they wish to protect not only the integrity of the "monetary" system, but all other forms of behavior by scientists as well. Plagiarism and misappropriation of ideas are intermediate cases because, although they do not threaten the integrity of the coin itself, they do deal with the orderly assigning of credit for scientific discovery, an important motivating factor in scientific progress. One would think that actual plagiarism would be rare in science, where the precise words used are less important than the substantive content; but it turns out that outright plagiarism does show up, especially in the frantic cut-and-paste procedures that are used in preparing grant proposals for federal funds (for currency of the real kind, not the metaphorical kind).

Federal regulations (both PHS and NSF) call for each university to investigate any case that turns up before turning it over to the sponsoring agencies (that is why universities are required to have regulations of their own). The Caltech regulations call for a scientific investigation rather than a judicial proceeding. There is no confrontation of the accuser, cross-examination of witnesses, and so on. In fact, private attorneys are strongly discouraged. Nevertheless, sufficient safeguards are built in to protect both accused and accuser so that the courts have many times ruled that this sort of proceeding does have the requisite degree of fairness or, to use the inappropriate constitutional term, of "due process." In limited experience up to now, these proceedings have been more successful than those of the federal agencies, where the Office of Research Integrity of PHS has seen virtually all of its major decisions overturned on appeal, and where the Inspector General of NSF has had little to do in this area.

Although I have said I believe fraud in science to be quite rare, the popular press, certain congressmen, and some others inside and outside science sometimes seem to believe otherwise. These suspicions were given a boost recently by an article published in the Sigma Xi journal *American Scientist*[7] and widely noted in the press. Based on questionnaires sent to 2000 graduate students and 2000 faculty in chemistry, civil engineering, microbiology, and sociology, it concluded that ". . . such problems are more pervasive than many insiders believe." A more thoughtful analysis, however, might lead to a different conclusion. To indicate what I mean, let us leave aside for the moment the perceived behavior of students (who, after all, may not yet have completed their ethical as well as their scientific educations) and lesser misdeeds ("keeping poor research records," "violation of government regulations") and get to the core of the matter: how often were faculty members perceived by fellow faculty members or by students to have committed "coin of the realm"–type misbehavior (defined in the article as "falsifying or 'cooking' research data")? The answer is that six percent of the faculty and eight percent of the students responding to the survey reported having seen direct evidence of such misbehavior once or twice (none more than once or twice, and ninety-four percent and ninety-one percent, respectively, none at all). What are we to make of such figures?

Needless to say, the response to the questionnaire was less than universal, and those who responded may be imperfectly representative of the whole group. Furthermore, of the six to eight percent who think they saw instances of real scientific fraud, only a fraction will be sufficiently confident or sufficiently disturbed to bring charges before an appropriate authority. As I can attest on the basis of first-hand experience at Caltech, of the charges that do come forth to an appropriate authority only a fraction (one-third or one-fourth) survive the initial discreet inquiry phase and proceed to full investigation (the inquiry usually finds that the perceived misconduct was a misunderstanding that can be resolved to everyone's satisfaction, including the "whistleblower's"). Finally, of those that go to investigation, not all are found guilty. Thus, the correct conclusion to be drawn from the "data" (if that is what they are) is that real fraud in science is exceedingly rare. However, I think a more sensible conclusion is that this kind of study is not very valuable, and that we do not know much about the incidence of fraud in science.

Whatever the situation is now and has been in the past, it seems likely to change for the worse in the future. Throughout most of its recent history, science was constrained only by the limits of imagination and creativity of its participants. In the past couple of decades that state of affairs has changed dramatically. Science is now constrained primarily by the number of research posts, and the amount of research funds available. What had previously always been a purely intellectual competition has now become an intense competition for scarce resources. This change, which is permanent and irreversible, is likely to have an undesirable effect in the long run on ethical behavior among scientists. Instances of scientific fraud are almost sure to become more common, but so are other forms of scientific misbehavior. For example, the institution of peer review is now in critical danger.

Peer review is used by scientific journals to decide what to publish and by granting agencies to decide what research to support. Obviously, sound decisions on what to publish and what research to support are crucially important to the proper functioning of science. Journal editors usually send manuscripts submitted to them to referees, who remain anonymous to the authors of the manuscript. Funding agencies sometimes do the same, especially for small projects, and sometimes instead assemble panels of referees to judge proposals for large projects.

Peer review is quite a good way to identify valid science. It was wonderfully well suited to an earlier era, when progress in science was limited only by the number of good ideas available. Peer review is not at all well suited, however, to adjudicate an intense competition for scarce resources such as research funds or pages in prestigious journals. The reason is obvious enough. The referee, who is always among the few genuine experts in the field, has an obvious conflict of interest. It would take impossibly high ethical standards for referees to fail to use their privileged anonymity to their own advantage, but as time goes on more and more referees have their ethical standards eroded by receiving unfair reviews when they are authors. Thus the whole system of peer review is in peril.

Editors of scientific journals and program officers at the funding agencies

have the most to gain from peer review, and they steadfastly refuse to believe that anything might be wrong with the system. Their jobs are made easier because they have never had to take responsibility for decisions. They are also never called to account for their choice of referees, who in any case always have the proper credentials. Since the referees perform a professional service, almost always without pay, the primary responsibility of the editor or program officer is to protect the referee. Thus, referees are never called to account for what they write in their reviews. As a result, referees are able, with relative impunity, to delay or deny funding or publication to their rivals. When misconduct of this kind occurs, it is the referee who is guilty; but it is the editors and program officers who are responsible for perpetuating a corrupt system that makes misconduct almost inevitable.

This is the kind of misconduct that is, I fear, rampant in all fields of science, not only biomedical science. Recently, as part of a talk to a large audience of mostly young researchers at an extremely prestigious university, I outlined this analysis of the crisis of peer review. The moderator, a famous senior scientist, was incredulous. He asked the audience how many disagreed with my heresy. No one responded. Then he asked how many agreed. Every hand in the house went up. Many of us in my generation wish to believe that nothing important has changed in the way we conduct the business of doing science. We are wrong. Business as usual is no longer a real option for how we conduct the enterprise of science.

Finally, I think we scientists are guilty of promoting, or at least tolerating, a false popular image of ourselves that may be flattering but that, in the long run, leads to real difficulties when the public finds out that our behavior does not match that image. I like to call it the Myth of the Noble Scientist. It arises, I think out of the long-discredited Baconian view of the scientist as disinterested seeker of the truth, gathering facts with a mind cleansed of prejudices and preconceptions. Thus, the ideal scientist would be more honest than ordinary mortals, certainly immune to such common human failings as pride or personal ambition. When it turns out, as invariably it does, that scientists are not at all like that, the public that we have misled may react with understandable anger or disappointment.

The fact is that scientists are usually rigorously honest about the things that really matter to them, such as accurate reporting of procedures and data. In other arenas, such as disputes over priority or credit, they tend to behave like the ordinary mortals they are. Furthermore, scientists are not disinterested truth seekers; they are more like players in an intense, winner-take-all competition for scientific prestige, or perhaps merchants in a no-holds-barred marketplace of ideas. The sooner we learn to admit to those facts, and to distinguish carefully between serious scientific misconduct and common human conduct by scientists, the better off we all will be.

## NOTES

1 David L. Goodstein, "Scientific Fraud"; "Science Fraud."
2 Patricia K. Woolf, *Project on Science Fraud and Misconduct, Report on Workshop Number One*, p. 37.
3 The Office of the Inspector General of the National Science Foundation recounts its activities twice each year in its Semiannual Report to the Congress.

4 Reported, e.g., *New York Times*, April 4 and 12, 1994; *Time*, March 28, 1994.
5 See, for example, the Office of Inspector General of the National Science Foundation, Semiannual Report to the Congress, number 9, April 1, 1993–September 30, 1993, p. 22, for a discussion of this definition.
6 D. E. Buzzelli, "The Definition of Misconduct in Science: A View from the NSF."
7 J. P. Swazey, M. S. Anderson & K. S. Lewis, "Ethical Problems in Academic Research."

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# MATHEMATICS AS THE STEPCHILD OF CONTEMPORARY CULTURE

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MY TITLE WILL DOUBTLESS strike some as impertinent, others as paranoid. Mathematicians in particular will hardly be likely to view themselves as pariahs skulking at the margins of academic and intellectual life. Mathematical research, partly because it is incredibly cheap by the standards of experimental physics, chemistry, or biology, tends to be resistant to the ups and downs of funding policy. It flourishes with exponential vigor. Every year, hundreds of thousands of papers appear in thousands of journals, and journals themselves proliferate at the rate of dozens per year. Math libraries groan with the burden of incoming publications. Math department bulletin boards are scarcely able to hold all the conference announcements that arrive with "please post" requests. In that sense, mathematics and related fields can hardly be thought of as the starveling outcasts of intellectual life.

And yet, I will argue, mathematics itself occupies an ambiguous place in the larger world of ideas. It is as much resented as admired. Even worse, there is a widespread strategy, among humanist intellectuals, of cheerfully conceding that one is mystified and paralyzed by mathematics, with the clear corollary that this defect, like lack of perfect pitch, is to be regretted mildly or not at all. Implicitly, one categorizes mathematics, and those deeply involved with its ideas and methods, as an arcane cult, mostly harmless, sometimes useful, but, all in all, inexplicable and extraneous to one's deepest interests, whatever those might be. Occasionally, the affectation of disinterest falls away, and comments on mathematics and mathematicians become positively envenomed. Yet even discounting this occasional spitefulness, and concentrating solely on the rather more widespread combination of ignorance and indifference, we find a deep fault line in the culture of those who take ideas seriously, or pretend to.

This is the theme I want to explore. At the same time, I propose to understand the gulf between *mathematics*—and, as will be seen, I am content to use that term rather broadly—and *humanistic culture* as something rather novel in Western intellectual life, if one takes the long view. This exclusion of mathematics from the general traffic in ideas is not only recent, but goes

against the grain of our deepest traditions. A recent piece by the cosmologist David N. Shramm[2] puts it well:

> The beauty of the mathematics and physics that describe nature is repeatedly noted by scientists and mathematicians. One's impression is that in the past it was not uncommon for intellectual leaders in the humanities to appreciate it as well. Mr. Osserman quotes Voltaire as saying a great mathematician has at least as much imagination as a great poet. He could find similar testimony from any number of other generally cultured people in the 18th and 19th centuries.

Indeed, he could. "Euclid alone has looked on beauty bare," says Edna St. Vincent Millay, a sentiment hardly less enthusiastic than Bertrand Russell's own dictum:[3]

> Mathematics possesses not only truth, but supreme beauty—a beauty cold and austere, like that of sculpture, without appeal to any part of our weaker nature, sublimely pure and capable of a stern perfection such as only the greatest art can show.

Yet, much nearer to our own day, we find the distinguished humanist Jacques Barzun dismissing Russell's very words as "sheer affectation" and "nonsense."[4] Millay may be seen as speaking for a tradition nearing its end, that end having been heralded by William Blake:

> May God keep us
> From single vision and Newton's sleep.

Here, I cannot help pointing out that it is Blake who seems to be retreating into "single vision." Nonetheless, it is Blake to whom Barzun recurs, citing the quoted line with evident enthusiasm.[5]

The historical links, within the Western tradition, between mathematical competence and the general ability to think deeply and effectively go back at least as far as the ancient Athenians, for whom mathematical training, specifically in the rigorous technique of axiomatic geometry, was the necessary precursor to any significant philosophical speculation. Nearly two millennia on, the "liberal arts" of the Schoolmen were: grammar, rhetoric, logic, geometry, arithmetic, music, and astronomy. (Notwithstanding, my everyday dictionary has it that "liberal arts" are to be defined as "the course of study, including literature, philosophy, history, etc., distinguished from professional and technical subjects." In other words, to be a liberal arts major nowadays is to declare oneself hell-bent on avoiding anything mathematical in the curriculum.) The great English composer of the 15th century, John Dunstable, was famed throughout Europe as a mathematician simply because, in the high culture of his day, musical composition, *ars combinatoria*, *was* a branch of mathematics. A modern student of his music reminds us that "The composer's task could therefore be described as reflecting the ordered perfection of the universe in musical structures that obeyed the same numerical principles."[6] From Walter of Chatillion, the 12th-century poet and scholar, we have:[7]

> Creatori serviunt omnia subjecta,
> sub mensure, numero, pondere perfecta.
> Ad invisibilia, per haec intellecta
> sursum trahit hominem ratio directa
>
> (The Creator orders all matters
> by measure, number, just weight
> Through this intellect, under right reason
> He raises Man to the Invisible Realm)

We might reflect as well that the finest of Middle English poets, Chaucer, was an astronomer of some skill (as was Omar Khayyam, at the other end of the great arc of Euro-Islamic civilization). As for medieval architecture, "With few exceptions the Gothic builders have been tight-lipped about the symbolic significance of their projects, but they are unanimous in paying tribute to *geometry* as the basis of their art.[8] (Contrast Barzun:[9]

> A general recognition that science is at the other extreme from art and cosmology [sic![10]]; that at least a double view of nature is possible; that much of life is to be dealt with anthropomorphically, because *anthropos* is the customer to be served—this might begin to clear the ground of errors and stumbling blocks.)

It might be noted that, much as the medieval scholar doted on mathematics, he viewed it as rather a static and settled matter, a body of law that had been set down by the ancient pagan philosophers, much as Scripture had been set down, by divinely inspired prophets, Evangelists, and Apostles. In that sense, mathematics was something to be displayed or exhibited, rather than put to use in the modern fashion. Inevitably, though, an architect—a composer as well—would have found himself reckoning and computing by means of arithmetic and geometry, in addition to contemplating their perfection. Nonetheless, the view of "mathematics" as an open-ended, creative process, capable of indefinite expansion and of being applied to detailed explication of a vast range of natural phenomena, was not that of the European Middle Ages.

The mathematics of the 17th century is, to indulge in gross understatement, something else again. Partly through the inspiration of Arab and Persian mathematicians and astronomers, partly through what must be called (though to say so is highly unfashionable these days) the singular genius of the culture of Western Europe in that age, mathematics burgeoned with a vigor that is, even today, astounding to contemplate. What the cultural roots of this phenomenon were, how it might have been generated by the *Zeitgeist* or the deep structure of socioeconomic imperatives, I shall not presume to say, for the simple reason that the whole matter seems deeply obscure to me. Such analyses along these lines as I have seen strike me as shallow and unconvincing, at best *post-hoc* fables to be admired, if at all, more for ingenuity than persuasiveness. We do not, however, need any solid theory of origins, we don't even need to believe such a theory is accessible, to note just how deeply and firmly the ideal of mathematical virtuosity was embedded in the tissue of 17th-century intellectual life. It was an era in which there was a near-universal sup-

position that serious thinking of any kind, participation in the debates and contentions that roiled the landscape, necessitated a panoply of mental equipment within which mathematical ability took a prominent place, possibly the leading role. Of course, there were other requirements as well. One had to be a decent Latinist, at the least, and to be well acquainted with a range of thinkers both ancient and contemporary. But beyond these, there was the further assumption that one was as much at home in Euclid as in the Latin poets and the Gospel. Even more, since mathematics was now a feverishly active science, and not just a received text, there was a presumption that one could follow arcane disputes in geometry, algebra, and physics.

We find ample documentary confirmation of this widespread mathematical competence. Pepys's diary reveals a man who read Boyle's physics simply for his pleasure. The lively, wildly disjointed memoranda of John Aubrey comprise another highly amusing source. Though of modest mathematical ability in his own right, Aubrey took the subject seriously and was personally acquainted with most of the major English mathematical thinkers of his time, Hooke, Wallis, and Newton among them. In the anthology of his *Brief Lives*[11] that I consulted, I found about twenty entries devoted to eminent mathematicians, with about as many references to others scattered through the text. On the basis of his antiquarian interests, Aubrey was a founding member of the Royal Society, as were his fellow-antiquarian Ashmole and the poet John Dryden. It was expected of all these gentlemen that they could follow with unfeigned interest discussions and disputes in which intense mathematical reasoning played a central role. There were, it is true, some wryly comical counterpoints to this phenomenon. The political philosopher Thomas Hobbes suffered greatly from "delusions of adequacy" in the mathematical realm, and his attempts at circle squaring (quite accurately denounced by Huygens as "absurd, childish nonsense") led to a long series of fractious disputes wherein Hobbes, thoroughly outclassed in matters mathematical by opponents and onlookers alike, made a rather pathetic spectacle of himself.[12]

Equally interesting testimony comes from the journal *Acta Eruditorum*, published in Leipzig, which first appeared in 1683. The closest contemporary analog (in English) to this serial is the *New York Review of Books*, or possibly, the *Times Literary Supplement*. *Acta Eruditorum*, a sort of pan-European intellectual-journal-of-record, was principally composed of careful, lengthy accounts of significant new books—accounts that were extensive summaries rather than mere reviews. Occasional original publications were included as well. Topics ranged from theology to jurisprudence to botany to narratives of exploration. But mathematics and mathematical physics were also well represented. We find tables of new astronomical observations, Hooke's analysis of a proposed perpetual motion machine, and papers by Leibniz in pure and applied mathematics. There is also a long, detailed summary of Newton's *Principia*. It's possible to wonder how many subscribers (aside from Leibniz) read the *Acta* from cover to cover, but the presumption that there were such readers hardly requires an extraordinary leap of faith.

Mathematical ability was a vital component of the typical scholar's intellectual arsenal well into the 18th century. The celebrated naturalist Buffon,

for instance, made the first translation of Newton's *Method of Fluxions* (i.e., calculus) into French. Voltaire was conversant with geometry and physics, as was Diderot. Another Encyclopedist, d'Alembert, was a mathematician of the first rank. Hume and Kant were at home in mathematical discourse, and in some respects initiated the inquiry into the nature of mathematical knowledge that was to engage so many 19th- and 20th-century mathematicians.

Notwithstanding this long history, the 19th century witnessed a growing disjunction between what was regarded as general scholarly competence and the particular talent for doing and understanding mathematics. This development was, perhaps, foreshadowed by certain strains within 18th-century thought itself. Even Diderot anticipated a "physics" of the future wherein mathematical thinking would become marginal or irrelevant. And Berkeley challenged the growing influence of a mechanistic, essentially atheistic worldview on the basis of a conceptually shrewd but ideologically biased examination of the foundations of the new mathematics, as they were then widely understood.[13] But, whatever the underlying causal pattern, the arrival of the Romantic style in art and thought seems to coincide with the point at which humanistic and scientific thought began seriously to split apart in Western culture. It almost goes without saying that one must use a diffuse term like *Romantic* only with the greatest caution and with full knowledge of its fragility as an analytic category. Nonetheless, it almost takes willful blindness not to see in some primal Romantic figures the very personification of the reaction against rational, analytically reductive thought, against science, certainly, but particularly against the formalization of science that mathematics embodies. Both Blake and Goethe, polar opposites in so many respects, loudly despised a cosmology the deepest insights of which were embedded in what to them was an alien, disagreeable tissue of computation and mathematical abstraction. Both men constructed private demonologies centered on the figure of Newton; and, it is interesting to note, in both cases Sir Isaac was assigned his ungrateful role after the poet had made an intense but unsuccessful attempt to master Newtonian physics and the mathematical methods—those of Newton's calculus—central to it.

Whatever one thinks of Romantic poets, it is undeniable that the 19th century witnessed the growth of increasingly impermeable barriers between humanistic culture and the world of scientific ideas, especially highly mathematical ones. I do not believe that there is any easy, reductive explanation for this alienation of philosophers, historians, and men of letters from mathematical thought. It strikes me, however, that there are certain obvious factors that no thorough account can omit. First of all, the growing difficulty, both technical and conceptual, of mathematics itself played an important role. Calculus and mathematical physics, at any reasonable level of sophistication, are harder than basic geometry and elementary algebra.[14] The savant of the 17th century needed to know his Euclid and might perhaps be expected to follow with a modicum of understanding some of the newer ideas in algebra and the evaluation of infinite series. By the early 18th century, however, a sophisticated student of mathematics and physics had to know not only Newton, but the further elaborations that had emerged with bewildering swiftness in

Newton's wake from the fertile minds of the Bernoullis, Hamilton, Taylor, Euler, Lagrange, Laplace, and, of course, Gauss. Those readers who know mathematics will appreciate the vast intensification and deepening of mathematical thought that this involved. The chief consequence was that whereas until Newton's era the intelligent and well-educated layman could follow the progress of mathematical work and even comment upon it astutely, a hundred years later such capabilities were reserved to those with substantial mathematical talent and extensive mathematical training.

Another factor lay in the emergence of a professional class of technocrats, and an educational system designed to nurture it. Engineering became a learned profession with its own schools and institutes, usually distinct from those of traditional humanistic learning. Mathematics was increasingly adjoined to these studies, where its methods were indispensable. There are, it is true, some curious exceptions to this. In England, at Oxford and Cambridge, mathematics remained the special province of aspiring clergy of the Church of England (C. L. Dodgson—Lewis Carrol—being the best-known example). But, generally speaking, mathematics increasingly came to be thought of as the special province of engineers and builders. To a corresponding extent, it lost its longstanding associations with the worlds of classical learning and systematic philosophy. Naturally, the associated exact sciences—physics, astronomy, and, eventually, chemistry—came to have these new affiliations as well. Correspondingly, humane studies generally lost touch with the great corpus of mathematical ideas, even those ancient ones that had once constituted part of humanism's root system.

Matthew Arnold's essay *Literature and Science*[15] provides clear evidence of this. Indignantly refuting Huxley's insistence that science ought to be central to education, Arnold allows that an educated man should have some knowledge of the most significant scientific facts and theories. But he is clearly uneasy about the demand that *details* of science should be mastered. He seems to dismiss the possibility that education might be designed to provide the nonspecialist with some insight into the method and internal structure of the scientific disciplines. On mathematics itself, he has this to say:

> My friend, Professor Sylvester, who is one of the first mathematicians in the world, holds transcendental doctrines as to the virtue of mathematics, but those doctrines are not for common men. In the very Senate House and heart of our English Cambridge I once ventured, though not without an apology for my profaneness, to hazard the opinion that for the majority of mankind, a little mathematics, even, goes a long way. Of course, this is quite consistent with their being of immense importance as an instrument to something else; but it is the few who have the aptitude for thus using them, not the bulk of mankind.

Now Arnold, as we know, famously and admirably insists that esthetics and ethics are "for the bulk of mankind," and that the finest discernment in these matters is the goal of education, not just for the elite but for the mass of humanity, in whom the highest ideals are to be evoked. But it is pretty clear that in regard to mathematics, he much prefers to be classed with those "common men" who are free to live in blessed ignorance of deep mathematical notions. I venture to say that Barzun's book, cited above, is very much in the Arnoldian

tradition, although possibly with an added element of resentment at the central, ineluctable role of science in 20th-century thought and society. With variations in emphasis and tone, this has been pretty much the standard line of humanistic scholars for decades. Occasionally, it is inflected with outright venom, as displayed by the jeremiad of the fictitious but representative Professor Nightingale in Tom Stoppard's recent play *Arcadia*.[16]

What, however, ought we to make of this great divide in intellectual life? Even if we accept the proposition, declared a generation ago by C. P. Snow, that humanists ought to shape up and learn at least the rudiments of contemporary science, does it then follow that in the process they must acclimate themselves to the intricacies of technical mathematics? Does their failure to do so have any grave consequences, or is it merely the corollary of a diverse, complicated, rather messy world of ideas where division of labor is inevitable and attempts to remove the supposed blinders from specialists' eyes will do more harm than good, provoking intense resentment in the process? In other words should we mathematicians simply leave well enough alone?

My position is that the situation is not benign, although its ill effects are long-term and subtle, rarely manifesting themselves acutely. Just as ideas have consequences, so does a hole in the realm of ideas. The consequences may build slowly and circuitously, and by the time they are discernible, their tracks may be difficult to read; but I think they are nonetheless real and unwelcome.

I am not trying to mandate the intense study of modern mathematics by present and future humanities scholars. There might be some mathematicians whose enthusiasm would be ignited by such a project, but I am not among them; and, frankly, I have never met anyone who is. I do not believe in Leibniz's dream of a universal discursive calculus that could resolve all questions in every subject of interest to humanity. It makes an amusing metaphor in the form, say, of Hesse's *Glass-Bead Game*; and it survives in attenuated form as the thesis, appealing to most computer scientists, that intelligence itself is computational in the technical sense. But even within mathematics, the death of the Hilbert program at the hands of Gödel's incompleteness theorem annihilated the Leibnizian conceit that knowledge could be at once exhaustive and reducible to an algorithmic procedure.

At a more quotidian level, it is clear that, while there may be some clever specialists in history or archaeology or even literary study who will be able to exploit mathematical technique of some sort, they will be rare exceptions. Most humanists will never need to know very much about 18th-century, let alone 20th-century, mathematics in order to get on with their work. Nor will mathematicians have any particular head start should they wish to do some serious study of the humanities.

I want to argue, therefore, on a more general level than that of academic specialization and its singular product, the publishable paper. In that regard, let me say that I want to use the term "intellectual" in a more general sense than "professional academic." I want to define it, risking vagueness, to mean, simply, someone who takes abstract ideas seriously and is willing to put in hard (and, to some degree, disinterested) work in order to clarify and evaluate them. By the same token, and in the face of four decades of my own rather

snobbish habits, I want to use the term "mathematician" in a somewhat wider sense than the current academic taxonomy allows. Hereafter, "mathematician" is understood to mean anyone who is familiar with a body of nontrivial mathematics and who uses it in his work in a way that demands genuine understanding of what is involved. Thus, in my usage, "mathematician" naturally embraces physicists and computer scientists but also most other physical scientists and engineers, many biologists, psychologists, and linguists, and, to the bargain, a host of economists, sociologists, demographers, and professional gamblers. My question, then, in bluntest form, is: What does an intellectual lose by not being a mathematician?

Frankly, I do not think the loss is all that trivial. Let me start with a well-known example that is as vulgar as it is obvious. The central point in the O. J. Simpson trial, which, as of this writing, colonizes an absurd amount of television airtime, is a probabilistic one. The notion that the chances are "one in six billion" (or whatever) that a drop of blood came from anyone but the defendant sounds almost mystical in its astronomical resonance. In fact, it is the result of a straightforward computation that crucially depends for its relevance on the notion of "independence" of random variables. I doubt this is at all well understood even by most of the well (outside of mathematics) educated who follow the trial.[17] I would go so far as to say that most of the lawyers don't understand it. I think most educated people believe the experts, on the whole.[18] Yet they do so somewhat grudgingly, with that faint animus reserved for oracles who are known to be trustworthy but whose methods are maddeningly inscrutable. They are probably made somewhat uneasy by questions like: "If you've taken samples from only a few thousand people, how can you talk about odds like several billion to one?" Of course, a little knowledge of elementary statistics and probability would dispel that uneasiness. But such a background is precisely what most of the well educated, most "intellectuals," lack.

This is just one instance of a broad phenomenon. Uninstructed human intuition is simply not very good at estimating probabilities, judging the significance of apparent coincidences, discerning actual randomness in patterns. Evolution seems not to have done a particularly good job in that respect. By way of experiment, I have tried simple probability questions—simpler, even, than those that come up in the Simpson trial—on very bright people whose familiarity with the relevant mathematics has lapsed, if it ever existed. A surprising number not only guess wrong, but stick adamantly to their guns for hours, despite hearing what I judge to be clear, cogent explanations of the correct answer. Systematic analysis and a certain amount of work are needed to rectify the defects of most people's instinctive habits of thought in this area. In a word, one must study some mathematics. Not to do so excludes one from a decent comprehension of vast realms of experience.

But again, this is not the whole story. The stunting of one's mathematical intelligence simply leaves one at a loss to understand what goes on in the world. It cuts one off from any sense of how our most accurate analyses of physical and natural reality are structured. It reduces them to disjointed collections of odd, unaccountable "facts," naked propositions without context,

logic, or elegance. This is precisely what happened to poor Matthew Arnold, thus rendering his view of science so "philistine." The thinker whose mathematics lags behind his general intelligence finds that, for him, our deepest, best-founded theories about how the world is put together and how phenomena are linked are severely occluded. Their skeletons, muscles, and sinews are forever invisible. One need not take mathematical theory building in the exact sciences as the prototype for all meaningful knowledge to consider that a deficient understanding of how this kind of theory-building proceeds—which may, to be old-fashioned about it, constitute a failure to understand how reality itself is structured—leaves one, at the very least, with a deficient appreciation of human capability and human aspiration. It represents a vast hole in one's grasp of psychology and a lack of suppleness in one's capacity to accommodate the insights and to appreciate the striving of one's fellows.

I assert as well that the smug homilies of generations of high school geometry teachers were, in fact, correct; that is to say, the wisdom of the Hellenic philosophers, from Pythagoras to Aristotle, was, in fact, wisdom. Training in systematic, rigorously deductive thought, experience of the process and results of that kind of thinking, is an aspect of intellectual development whose neglect invites, if it does not quite insure, a measure of intellectual slovenliness. Only a woefully small number of intellectuals have actually engaged in the kind of mental calisthenics where principles of logical inference are rigidly applied, ambiguities of language sifted out, unstated assumptions kept from the premises, words prohibited from sliding unannounced from one meaning to another, and appeals to emotion or cultural prejudice or moral indignation despised. This is an exercise well worth going through, just to see that it can, in fact, be done. Furthermore, there are extra rewards to doing the kind of mathematical thinking that genuinely stretches one's intuition. At the very least, it greatly enriches one's library of phenomenological models.

It would be wonderful (mathematical snobbery alert!), even for a Milton scholar, to learn the machinery of algebraic topology or differential geometry! Granted, that may be a bit utopian. Yet is it too much to ask that the well-rounded scholar know what the fundamental theorem of algebra is or even, if that is too demanding, why two angle bisectors of an isosceles triangle are equal?[19] Just this last modest project is incontestably worthwhile, if done honestly and thoroughly.

The real value, as I see it, of even a modest mathematical education is that it breeds a certain salutary impatience, a distaste for intellectual flatulence, for otiose pseudotheorizing, for argument by browbeating. It breeds a certain shrewdness, as well, in all sorts of odd corners of modern life. It helps purge the staleness, the laziness, the careless propensity to accept unexamined clichés, from ones thinking, simply because it provides a rich array of mental patterns and the habit of looking for instances where they are applicable. The recent book by John Alan Paulos[20] provides numerous examples of this. Many of his illustrations are homely, and some are whimsical; but modest as they are, they throw into relief the limitations with which even the well ed-

ucated are afflicted for want of cultivating mathematical habits of mind. At one point, Paulos throws out the following catechism:

> What's the difference between an empirical statement and an a priori one, between scientific induction and deduction? What about the difference between scientific induction and mathematical induction? Does some implication go both ways or is its converse false? Is such and such a claim falsifiable?

I am willing to bet that most intellectuals will someday come to grief somewhere in this thicket. Paulos is on the mark in claiming that the proper inoculation against such gaffes lies in getting on reasonably friendly terms with some serious, formal mathematics. The great mathematician Poincaré once remarked that mathematics may be defined as "the exact part of our thinking." He was making a point in connection with the debates about the epistemological status of mathematics that were beginning to quicken in his day, but I think his assertion can be glossed in another sense. Not to know mathematics at a mature level is to open oneself, however unwittingly, to the definite possibility of inexactitude in one's thinking.

Let us consider whether the institutionalization of mathematical illiteracy—for that is what we are talking about, after all—has any dire consequences for culture and politics on a global, transpersonal level. It is one thing to talk about the debilities, even the follies, of one's fellow intellectuals as individual quirks, and, simply because to do so as a mathematician constitutes, *ipso facto*, a kind of sneering, a trace of nastiness is inevitably involved. But do these individual shortcomings have, cumulatively, any larger impact upon the quality and content of discourse? Do they steer us, in the collective sense, into blind alleys or weigh us down with nonsense or place us in danger of ignoring things, as a culture, that we cannot afford to ignore? In keeping with the theme of this volume, I think that the answer is "yes." This, it must be said, is tricky ground. I don't want to hedge; my convictions on this question are not at all tentative. I think that over the years, the world of ideas has come to pursue its concerns with an increasingly impaired organ. Yet, as I have indicated above, the particulars can be devilishly hard to trace, and it would be futile to try to describe a simple mechanism by which all the putative damage is being done. Yet something has gone wrong with the machinery of our higher-order cogitation, outside the realm of the sciences themselves and more broadly, those areas where the "mathematicians" function. In the latter precincts, things are going along nicely, as I see it, at least on the purely intellectual front. But much of humanistic thought and much of what purports to be political thought is in rather poor shape. Windbags, bluffers, and moral one-uppers are having a field day. The daft and the silly are raised on high. A palpable impatience reigns—not the healthy impatience of the logician, the impatience that cauterizes sloppy thinking, but rather an impatience with the attitude that thinks it at all important to challenge sloppy thinking. It no longer comes as news, for instance, that logical thought itself is in bad odor in certain scholarly circles; indeed, that realization is what occasions this volume in the first place. The denial that rational, systematic, largely disinterested inquiry is even possible is a virtual rite-of-passage in some corners of

the academic world, most notably postmodern literary criticism, post-Geertzian anthropology, and, tragically, women's studies.[21] The social sciences are importuned, with increasing success, to regard the exact sciences as delusory.[22] The most prominent spokesmen for this odd view are gleefully touted as the elect of contemporary scholarship.[23]

The one comforting fact in all of this is that those most eager to challenge the efficacy and reliability of rational thought have not, as a general rule, shown themselves to be particularly good at it. There are some exceptions, but these seem to be cases of conversion through embitterment. The giddy enthusiasms that have roiled the academy, reduced hundreds of administrators to speaking in psychobabble, commandeered the coffers of dozens of foundations, and bored the living hell out of most sensible undergraduates reflect precisely those deficiencies of thought against which the study of mathematics is supposed to be an effective prophylactic. And, indeed, these fads hardly provide a counterexample to this supposition. Mathematical literacy is only rarely to be found among the cheerleaders of the current academic foofaraw. This is particularly noteworthy in "science studies," a new hybrid ostensibly comprising sociological, historical, political and cultural analysis of science, with some philosophical aspects thrown in as well. To date, this has been a rather uneven enterprise, but I think it is safe to say that flashy and politically emphatic work has tended to overshadow sober competence. A recurrent theme among the Young Turks of the field is that a close familiarity with the methodology and conceptual content of science is not only unnecessary but positively detrimental. Science, in this view, is an anthropological phenomenon; it may be studied in ignorance of the truths it discovers, or even with disdain for the notion that it discovers truth. Mathematics is especially suspect. It is perceived as an arcane, exclusionary code. One even hears mutterings to the effect that the mathematization of science is "historically contingent" and that equally valid "alternative science"—including physics—might well have come into being without drawing upon the machinery of abstract mathematics.[24] Naturally, the people who make these claims seem unimpaired by any deep understanding of what mathematics is. More tellingly, they are locked into the delusion, which arises repeatedly in the scholarly world of the postmodernists, that mere assertion is equivalent to argument. This quirky logic underlies the high reputation of many of the most admired books in the field. Quite clearly, if any fantasy is likely to be cured by a comfortable familiarity with mathematics, it is this one.

"Science Studies," in this vein, clearly seems to be an enterprise driven by resentment. Since most of its practitioners and fans clearly identify themselves, in some fashion, with the political left, it is exquisitely ironic that they seem to have found the politicians of their dreams in the new Republican Congress. The scientific philistinism of the ax-wielding freshmen legislators seems to echo perfectly, in the realm of practical politics, that of the science studies academics. This is not so much an instance of "strange bedfellows" as of the metaphorical truth (for which I am indebted to the superb mathematician V. Arnold) that the best geometrical model for politics is projective space![25]

All this having been said, one may take quizzical note of the fact that re-

sentment of mathematics has an envious aspect to it, and that such envy, as it exists among faddish humanists, emerges in a minor fad for studying mathematics under the rubric of cultural studies, poststructuralist discourse theory, and the like. There are entire tomes in this mode, and celebrities like Lyotard, Baudrillard, Irigaray, Lacan, and Derrida have frequently been known to dress up their pages with mathematical, or quasimathematical, or pseudomathematical phraseology. On the cultural studies end of things, the received doctrine is that the methodology of this brand-new field is such a powerful intellectual solvent that anything may be brought under its purview. The dictum that everything that people do is "cultural" in its essence licenses the idea that the cultural critic can meaningfully analyze even the most intricate accomplishments of art and science—and of mathematics, when it comes to that—solely by recourse to the tool-kit of "cultural theory." This need not—in plain fact, it does not—involve analyzing, nor even comprehending, the particular details of what one is supposedly studying. All the methodological problems are dispelled at a stroke by invoking the doctrine of "interdisciplinarity," which means simply (to the eyes of this cynical observer) that if one has bluffed one's way to success in the fields of postmodern literary analysis and "critical theory," it is open season on everything else. For a mathematician, encountering this stuff can produce some dizzying effects. It is distinctly weird to listen to pronouncements on the nature of mathematics from the lips of someone who cannot tell you what a complex number is! Much as one might wish to see the people who propound this sort of cant get their comeuppance, it is probably an idle fantasy. Folks like this have had the intellectual shame wrung out of them by a perverse educational system, and it will take considerable ingenuity, perhaps on the part of a practical joker of genius, to shake them out of their complacency.

It is worth noting that much of the recent fad for cultural criticism of what the critics take to be mathematics centers on the relatively new discipline of "chaos theory." I conjecture that the name itself has something to do with this. So, too, the opportunity to see it as the embodiment of a seismic "paradigm shift," à la Thomas Kuhn. Chaos theory has produced important new insights, as well as a host of delightful multicolored pictures; at its best, it is fascinating and highly useful mathematics. But the mathematical issues it raises are subtle and delicate. One has to have swum fairly far upstream, mathematically speaking, to be able to talk about it sensibly and coherently. The chief virtue, then, of its popularity among cultural theorists is that it gives those prone to doing so every opportunity to make asses of themselves. For that, at least, we should be grateful.[26]

In the exclusion of the habits of mind associated with careful mathematical thinking from so much of contemporary intellectual work, we find both symptom and cause of the weakness, the outright frivolity, of much academic discourse. Mathematics, one surmises, has always made a lot of people nervous. It is hard! It is exacting and unforgiving. It does not let you squirm out of things. The "coldness" of it, which Bertrand Russell spoke of as "without appeal to any part of our weaker nature," is understandably off-putting to many. We are not a species that has evolved to be able to separate thought and

feeling with good grace, but mathematics demands this of us. Confronted with an obligation to deal seriously with mathematics, individuals often look for a way out. So, apparently, do cultures.

This, I submit, has cost us something over the long haul. It has deadened the ears of the culture to exactitude in argument and discourse. It has disarmed suspicions that ought to have remained acute, while nurturing suspicions that are poorly founded, when they are not outright silly. It has allowed the general culture's ties with reality to fray, simply because science, I insist, conveys many important things about reality to those equipped to listen, and because a minimum of mathematical skill is a vital component of the listening equipment.

I am not trying to claim that, on the individual level, mathematics is the guarantor of either wisdom or virtue. There are plenty of skillful mathematicians who are bullies, bigots, selfish neurotics, fanatics, and damned fools. At best, the cultivation of mathematical skill provides but a fraction of what one needs to deal successfully with the endless complexities of life and thought, of morality and politics. It only marginally improves the capacity of the scholar or thinker who works at some remove from the mathematical sciences. For someone in that situation, it is just one auxiliary device among many others; it may do little more than hone certain intellectual edges and provide a testing ground for certain capacities.

Yet on the collective level the effects of being at home in mathematics would be stronger and deeper. Let us suppose, contrary to current fact, a broad intellectual community in which a repertoire of nontrivial mathematical skills and insights is accessible to pretty much anyone. There, I think, we would find some pleasant contrast to our present situation. The cement of common rationality and mutual intelligibility among thinkers of all kinds would be appreciably stronger. The edginess one now meets when forcing people to deal with scientific matters—or economic or demographic matters—would be substantially softened. Bluffs would be called when they ought to be. Analysis and exposition would reacquire a sureness of touch that has, I submit, decayed as general familiarity with mathematics has leached out of the culture. Above all, effective canons of rationality, of coherence, of consistency would be restored to their appropriate place.

What can we do to realize this pipe dream? Nothing about it seems particularly easy to me. It will not be a matter of simply making some adjustments, even far-reaching ones, in the system of formal education. This is not a task for educational bureaucrats, even competent, high-minded, and well-intentioned ones. It is not a matter of suddenly forcing a horde of humanities and social science majors to enroll in the math courses that heretofore have been forced upon only economics, biology, and engineering majors. What is involved is, in the deepest and most mystifying sense, cultural or even moral. What puts a culture at ease with mathematics, and with the world of golden ideas and quicksilver intellectual deftness that it opens up, is very difficult to specify. But we know that such a cultural possibility exists because history shows us cultures where it has been realized. There have been times and places where mathematics was a vital element in the play of ideas that edified

and enriched the entire society, where it lent a quality of easefulness and repose to thought, where it obliged thinkers of all kinds to be more elegant and accurate. There is no royal road that will swiftly transport our contemporary culture to a similar state of grace. But we ought now to be scrutinizing our cultural road maps for whatever guidance they can offer, in hopes of finding an accessible pathway.

## NOTES

1 I wish to thank the following for helpful and instructive comments and conversations: Renate Blumenfeld-Kosinski, Felix Browder, Jeff Cheeger, Robin Fox, Sheldon Goldstein, Paul R. Gross, Antoni Kosinski, and Hector Sussmann.

2 David N. Schramm, "Nature Throws a Curve."

3 Bertrand Russell, "The Study of Mathematics."

4 Jacques Barzun, *Science: The Glorious Entertainment*, p. 115.

5 Ibid., p. 295.

6 Paul Hillier, Notes to *Dunstable: Motets.*

7 Quoted in Otto von Simson, *The Gothic Cathedral*, p. 13.

8 Otto von Simson, *The Gothic Cathedral*, p. 13.

9 Barzun, *Science: The Glorious Entertainment*, p. 116.

10 There is an unintended irony in Barzun's complaint that physics has abandoned cosmological questions. His book appeared just as the discovery of the cosmological "background radiation" put cosmological questions at the center of the physics agenda, while making the "Big Bang" theory the central theme in cosmological thinking.

11 *Aubrey's Brief Lives.*

12 This point is thoroughly ignored, or perhaps misunderstood, in Shapin and Schaffer's well-known *Leviathan and the Air-Pump.* Paul R. Gross and I have analyzed this misreading at length in *Higher Superstition: The Academic Left and Its Quarrels with Science.*

13 Berkeley's challenge was to the ontological reality of the "infinitesimal quantities" favored by Leibniz and his followers. This, as the astute freshman calculus student knows, is something of a red herring. Newton certainly understood the essential role of the notion of limit (although his published work on "fluxions" avoids a detailed discussion), and D'Alembert proffered definitions that were essentially equivalent to the modern ones.

14 Take this with a grain of salt; it is very much an "other things being equal" kind of statement. A rigorous and exacting course in Euclidean geometry will be very much *harder* than a conceptually vacuous powder-puff calculus course such as is usually offered by high schools (and colleges).

15 Matthew Arnold, *Literature and Science.*

16 One of the ironies of *Arcadia*—fully intended by Stoppard, of course—is that it is nearly impossible for a playgoer to follow the piece fully without a pretty thorough grounding in contemporary mathematics, or at least a companion who is well equipped in this respect.

17 Let us be honest; damn few of us are so abstemious as not to follow it at all!

18 My apologies to Judge Ito for commenting on a case that is still *sub judice* at this writing, but I doubt this essay will reach the snugly sequestered jurors in time to pervert the course of justice.

19 If you are ambitious, you might try the converse: show that a triangle with two equal angle bisectors must be isosceles. It is trickier than you might think.

20 John Alan Paulos, *A Mathematician Reads the Newspaper.*

21 See, *inter alia*, Christina Hoff Sommers, *Who Stole Feminism* and Daphne Patai and Noretta Koertge, *Professing Feminism.* See as well the articles by Martha Nussbaum ("Feminists and Philosophy") and Susan Haack ("Knowledge and Propaganda: Reflections of an Old Feminist").

22 See Mario Bunge, "A Critical Examination of the New Sociology of Science" (Parts 1 and 2).
23 See David Berreby, "That Damn'd Elusive Bruno Latour."
24 See, in particular, the work of the up-and-coming Steve Fuller. Fuller seems to think that "set theory" alone might have been adequate to the formulation of physics, which is very odd because (a) set theory is quintessentially mathematical and (b) once set theory is in the door, the rest of mathematics tends to come tumbling in close behind it. Fuller ("Can Science Studies Be Spoken in a Civil Tongue?" p. 164, note 8) attributes to W. V. O. Quine the view that for physics, "set theory" is adequate and "number" a superfluous ontological luxury. The present author, who personally watched Quine construct the classical continuum from the elements of set theory in a couple of courses, has no choice but to regard this as bizarre.
25 "Projective space" is derived from the geometry of the sphere by thinking of antipodal points as identical. It is an important model for axiomatic non-Euclidean geometry.
26 Gross & Levitt, *Higher Superstition: The Academic Left and Its Quarrels with Science*, contains a brief analysis of the popularity of chaos theory among cultural critics.

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# REASONABLE FOUNDATIONS

IN RECENT YEARS, fashionable thinkers, particularly those associated with postmodernism and some brands of feminism, have challenged the traditional veneration of reason, claiming, variously, that reason is chimerical, impossible, or simply oppressive to groups outside the magic circle of white, male privilege. This section evaluates the standing of reason from a number of viewpoints.

Philosopher Susan Haack decries attempts by some contemporary philosophers to join the antireason bandwagon. She notes that the abandonment of a genuine commitment to truth as the purpose of inquiry leads inevitably to sophistry, frivolity, speciousness, or outright bad faith. For Haack, truth and reason (which is the chief instrument for the pursuit of truth) deserve their traditional place of honor.

Psychologist James Alcock has a different concern. He shows how the "reasonableness" of human intuition is unreliable. In particular, we are, as a species, rather poorly equipped to make good instinctive judgments of probability, randomness, coincidence, and so forth; and countless errors of judgment result. Exact thinking, indispensable as it is, thus goes in many respects against the evolutionary grain. Critical analytic thought, vital to an accurate picture of the world, faces a continuing struggle to maintain itself against a deeply embedded predisposition toward belief in magic.

Philosopher Barry Gross (who died, tragically, shortly after writing this piece) traces much of the confusion in contemporary academic and intellectual life to a reverence for inappropriate abstraction at the expense of common sense and practical wisdom. He finds that theory builders are often willfully blind to prosaic evidence that inconveniently contradicts them, and that their stubbornness, these days, is often reinforced by a persistent utopianism.

Physician Loren Fishman evaluates some recent cynicisms as to the efficacy of reason. The first derives from the argument that social convention is not only a factor in determining belief, but a force powerful enough to overwhelm mere logic even within the thinking that makes up scientific theory. The second challenges scientific modes of thought on the ground that, since scientists often do rely on intuition and flashes of insight, science cannot claim the rationality usually associated with it. Fishman finds deep flaws in both arguments.

Finally, the distinguished philosopher Mario Bunge, noting that disparagement and outright dismissal of reasoned inquiry have become commonplace in the academic world, delivers a stinging rebuke. He calls for a renewal of the academy's traditional devotion to canons of reason, to be enforced by an implicit code of intellectually responsible conduct that would turn its back on postmodern extravagances.

# CONCERN FOR TRUTH: WHAT IT MEANS, WHY IT MATTERS[a]

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A CENTURY OR SO AGO, C. S. Peirce wrote, "in order to reason well . . ., it is absolutely necessary to possess . . . such virtues as intellectual honesty and sincerity and a real love of truth,"[1] and that genuine reasoning consists "in actually drawing the bow upon truth with intentness in the eye, with energy in the arm."[2] Forty years or so ago, C. I. Lewis observed that "we presume, on the part of those who follow any scientific [he means, "intellectual"] vocation, . . . a sort of tacit oath never to subordinate the motive of objective truth-seeking to any subjective preference or inclination or any expediency or opportunistic consideration."[3] These philosophers had some insight into what the life of the mind demands.

Now, however, it is fashionable to suggest that such insights are really illusions. Stephen Stich professes a sophisticated disillusionment, writing that "once we have a clear view of the matter, most of us will not find any value . . . in having true beliefs."[4] Richard Rorty refers to those of us who are willing to describe ourselves as seeking the truth as "lovably old-fashioned prigs"[5] boasting that *he* "do[es]n't have much use for notions like 'objective truth' "[6] since, after all, to call a statement true "is just to give it a rhetorical pat on the back."[7] Jane Heal concludes with evident satisfaction that "there is no goddess, Truth, of whom academics and researchers can regard themselves as priests or devotees."[8] These philosophers reveal a startling failure, or perhaps a refusal, to grasp what intellectual integrity is, or why it is important.

Still, as the saying goes, those who know only their own side of a case know very little of that; so perhaps it is healthy to be obliged to articulate, as I shall try to do, what concern for truth means, why it matters, and what has gone wrong in the thinking of those who denigrate it.

[a] This paper was prepared for publication with the help of N.E.H. Grant #FT-40534-95. I wish to thank Paul Gross for helpful comments on a draft, and Mark Migotti for supplying the quotation from Nietzsche in Note 9. I draw in what follows on my *Evidence and Inquiry*, especially Chapter 9; "The First Rule of Reason"; "The Ethics of Belief"; and "Preposterism and Its Consequences."

The first step is to point out that the concept of truth is internally related to the concepts of belief, evidence, and inquiry. To believe that *p* is to accept *p* as true. Evidence that *p* is evidence that *p* is true, an indication of the truth of *p*. And to inquire into whether *p* is to inquire into whether *p* is true; if you aren't trying to get the truth, you aren't really inquiring.

Of course, both pseudobelief and pseudoinquiry are commonplace. Pseudobelief includes those familiar psychological states of obstinate loyalty to a proposition that one half suspects is false, and of sentimental attachment to a proposition to which one has given no thought at all. Samuel Butler puts it better that I could when, after describing Ernest Pontifex's sudden realization that "few care two straws about the truth, or have any confidence that it is righter or better to believe what is true than what is untrue," he muses, "yet it is only these few who can be said to believe anything at all; the rest are simply unbelievers in disguise."[9]

And pseudoinquiry is so far from unusual that, when the government or our university institutes an Official Inquiry into this or that, some of us reach for our scare quotes. Peirce identifies one kind of pseudoinquiry when he writes of "sham reasoning": attempts, not to get to the truth of some question, but to make a case for the truth of some proposition one's commitment to which is already evidence- and argument-proof. He has in mind theologians who devise elaborate metaphysical underpinnings for theological propositions that no evidence or argument would induce them to give up; but his concept applies equally to the advocacy "research" and the politically motivated "scholarship" of our times. And then there is what I have come to think of as fake reasoning: attempts not to get to the truth of some question, but to make a case for the truth of some proposition to which one's only commitment is a conviction that advocating it will advance oneself—also a familiar phenomenon when, as in some areas of contemporary academic life, a clever defense of a startlingly false or impressively obscure idea is a good route to reputation and money.

But we need to go beyond the tautology that sham inquirers and fake inquirers aren't really inquiring to see what, substantively, is wrong with sham and fake reasoning. Sham and fake inquiries aim, not to find the truth, but to make a case for some proposition identified in advance of inquiry. So they are motivated to avoid careful examination of any evidence that might impugn the proposition for which they are seeking to make a case, to play down or obfuscate the importance or relevance of such evidence, to contort themselves explaining it away. The genuine inquirer, by contrast, wants to get to the truth of the matter that concerns him, whether or not that truth comports with what he believed at the outset of the investigation, and whether or not his acknowledgment of that truth is likely to get him tenure, or make him rich, famous, or popular. He is motivated, therefore, to seek out and assess the worth of evidence and arguments thoroughly and impartially; to acknowledge, to himself as well as others, where his evidence and arguments seem shakiest and his articulation of problem or solution vaguest; to go with the evidence even to unpopular conclusions or conclusions that undermine his

formerly deeply held convictions; and to welcome someone else's having found the truth he was seeking.

This is not to deny that sham and fake reasoners may hit upon the truth, and, when they do, may come up with good evidence and arguments; nor that genuine inquirers may come to false conclusions or be led astray by misleading evidence. Commitment to a cause and desire for reputation can prompt energetic intellectual effort. But the intelligence that will help a genuine inquirer figure things out will help a sham or fake reasoner suppress unfavorable evidence more effectively, or devise more impressively obscure formulations. A genuine inquirer, by contrast, will not suppress unfavorable evidence, nor disguise his failure with affected obscurity; so, even when he fails, he will not impede others' efforts.

The genuine inquirer's love of truth, as this reveals, is not like the love of a collector for the antique furniture or exotic stamps he collects, nor is it like a religious person's love of God. He is not a collector of true propositions, nor is he a worshipper of an intellectual ideal. He is a person of intellectual integrity. He is not, like the fake reasoner, indifferent to the truth of the propositions for which he argues. He is not, like the sham reasoner, unbudgeably loyal to some proposition, committed however the evidence turns out. Whatever question he investigates, he tries to find the truth of that question, whatever the color of that truth may be.

The argument thus far has taken us beyond the tautology that genuine inquiry aims at the truth, to the substantive claim that lack of intellectual integrity is apt, in the long run and on the whole, to impede inquiry. But why, it will be asked, should we care about that? After all, in some circumstances one may be better off not inquiring, or better off having an unjustified belief than one well grounded by evidence, or better off having a false belief than a true one; and some truths are boring, trivial, unimportant, some questions not worth the effort of investigating.

Intellectual integrity is instrumentally valuable, because, in the long run and on the whole, it advances inquiry; and successful inquiry is instrumentally valuable. Compared with other animals, we are not especially fleet or strong; our forte is a capacity to figure things out, hence to anticipate and avoid danger. Granted, this is by no means an unmixed blessing; the capacity that, as Hobbes puts it, enables men, unlike brutes, to engage in ratiocination, also enables men, unlike brutes, "to multiply one untruth by another."[10] But who could doubt that our capacity to reason is of instrumental value to us humans?

And intellectual integrity is morally valuable. This is suggested already by the way our vocabulary for the epistemic appraisal of character overlaps with our vocabulary for the moral appraisal of character: e.g., "responsible," "negligent," "reckless," "courageous," and, of course, "honest." And "He is a good man but intellectually dishonest" has, to my ear, the authentic ring of oxymoron.

As courage is the soldier's virtue par excellence, one might say, oversimplifying a little, so intellectual integrity is the academic's. (The oversimplification is that intellectual integrity itself requires a kind of courage, the hardihood

needed to give up long-standing convictions in the face of contrary evidence, or to resist fashionable shibboleths.) I would say, more bluntly than Lewis, that it is downright indecent for one who denigrates the importance or denies the possibility of honest inquiry to make his living as an academic.

This explains why intellectual integrity is morally required of those of us who have a special obligation to undertake inquiry; but the explanation of why it is morally important for all of us has to be more oblique. Over-belief (believing beyond what one's evidence warrants) is not always consequential, nor is it always something for which the believer is responsible. But sometimes it is both; and then it is morally culpable. Think of W. K. Clifford's striking case of the ship owner who knows his ship is elderly and decaying, but doesn't check and, managing to deceive himself into believing that the vessel is seaworthy, allows it to depart; he is, as Clifford rightly says, "verily guilty" of the deaths of passengers and crew when the ship goes down.[11] The same argument applies, mutatis mutandis, for under-belief (not believing when one's evidence warrants belief). Intellectual dishonesty, a habit of reckless or feckless self-deceptive belief formation, puts one at chronic risk or morally culpable over- and underbelief.

So, what has gone wrong in the thinking of those who denigrate concern for truth? Unfortunately, even with just the three writers I quoted at the beginning of this paper, not quite the same thing in each case.

Stich begins by ignoring the internal connection of the concepts of belief and truth, and misconstruing belief as nothing more than "a brain-state mapped by an interpretation-function into a proposition," or, as he likes to say to make the idea vivid, a sentence inscribed in a box in one's head marked "Beliefs." This encourages him in the mistaken idea that truth would be a desirable property for a belief to have only if truth is either intrinsically or instrumentally valuable. He then compounds the confusion with two manifest non sequiturs: that since truth is only one of a whole range of semantic properties a sentence in one's head could have, truth is not intrinsically valuable; and that since one may sometimes be better off with a false belief than a true one, truth is not instrumentally valuable either.

With Heal one encounters a different kind of misdirection. She points out, correctly, that not every true proposition is worth knowing; again correctly, that, like courage, intellectual integrity can be useful in the service of morally bad projects as well as good ones; correctly once more, that what an inquirer wants to know is the answer to the question into which he inquires. Even her conclusion—that there is no goddess, Truth, of whom academics can regard themselves as devotees—is true enough. What is wrong with it is not that it is false, but that it suggests that if one takes concern for truth to matter, one must deny it. The instrumental value of intellectual integrity does not require that all truth be worth knowing; its moral value does not require that it be a character trait capable only of serving good uses; and valuing intellectual integrity is not, as Heal's conclusion hints, a kind of superstition.

And as Rorty more than hints when he tells us that he sees the intellectual history of the West as an attempt "to substitute a love of truth for a love of God,"[12] Rorty is of the party that urges that there is no one truth, but many

truths. If this means that different but compatible descriptions of the world may be both true, it is trivial; if it means that different and incompatible descriptions of the world may be both true, it is tautologically false. More likely, Rorty has confused it with the claim that there are many incompatible truth *claims.*

This reveals a connection with a ubiquitous fallacy. What passes for known truth is often no such thing, and incompatible truth claims are often pressed by competing interests. But it obviously doesn't follow, and it isn't true, that incompatible truth claims can be both true; or that to call a claim true is just to make a kind of rhetorical gesture or power grab on its behalf. This latter mistaken inference, like the inference from the true premise that what passes for objective evidence is often no such thing to the false conclusion that the idea of objective evidence is just ideological humbug, is an instance of what I have come to dub the "passes for" fallacy.[13] Rorty transmutes this fallacy into a shallow misconception that identifies "true" and " 'true'," the true with what passes for true. "True" is a word that *we apply* to statements about which we agree, simply because, if we agree that *p*, we agree that *p* is true. But we may agree that *p* when *p* is *not* true. So "true" is not a word that *truly applies* to all or only statements about which we agree; and neither, of course, does calling a statement "true" *mean that* it is a statement we agree about.

Here is Peirce again, describing what happens if pseudoinquiry becomes commonplace: "man loses his conceptions of truth and of reason . . . [and comes] to look upon reasoning as mainly decorative. The result . . . is, of course, a rapid deterioration of intellectual vigor."[14] This is the very debacle taking place before our eyes. Sham reasoning, in the form of "research" bought and paid for by bodies with an interest in its turning out this way rather than that, or motivated by political conviction, and fake reasoning, in the form of "scholarship" better characterized as a kind of self-promotion, are all too common. When people are aware of this, their confidence in what passes for true declines, and with it their willingness to use the words "truth," "evidence," "objectivity," "inquiry," without the precaution of scare quotes. And as those scare quotes become ubiquitous, people's confidence in the concepts of truth, evidence, inquiry, falters; and one begins to hear, from Rorty, Stich, Heal and company, that concern for truth is just a kind of superstition—which, I should add, in turn encourages the idea that there is, after all, nothing wrong with sham or fake reasoning . . . and so on.

One thinks of Primo Levi on the subject of Fascism and chemistry: "the chemistry and physics on which we fed, besides being nourishments vital in themselves, were the antidote to Fascism . . ., because they were clear and distinct and verifiable at every step, and not a tissue of lies and emptiness, like the radio and newspapers."[15] I would put it more prosaically, but perhaps a little more precisely: the antidote to pseudoinquiry, and to the loss of confidence in the importance of intellectual integrity it engenders, is real inquiry and the respect for the demands of evidence and argument it engenders. Real inquiry of any kind, I should say: scientific, historical, textual, forensic, . . ., even philosophical. But there is a reason for putting "scientific" first on this list, the same reason that led Lewis to write "scientific vocation," meaning "in-

tellectual vocation," and that led Peirce sometimes to describe the genuine inquirer's concern for truth as "the scientific attitude":[16] not that all or only scientists have the scientific attitude, but that this is the attitude that made science possible. It is not concern for truth, but the idea that such concern is superstition, that is superstitious.

## NOTES

1 C. S. Peirce, *Collected Papers*, 2.82.
2 Ibid., 1.235.
3 C. I. Lewis, *The Ground and Nature of the Right*, p. 34.
4 Stephen P. Stich, *The Fragmentation of Reason*, p. 101.
5 Richard Rorty, *Essays on Heidegger and Others*, p. 86.
6 Richard Rorty, "Trotsky and the Wild Orchids," p. 141.
7 Richard Rorty, *Consequences of Pragmatism*, p. xvii.
8 Jane Heal, "The Disinterested Search for Truth," p. 108.
9 Samuel Butler, *The Way of All Flesh*, p. 259. See also Friedrich Nietzsche, *The Gay Science*, p. 76; "*[t]he great majority of people* does not consider it contemptible to believe this or that and to live accordingly, without first having given themselves an account of the final and most certain reasons pro and con, and without even troubling about such reasons afterward."
10 Thomas Hobbes, *Human Nature*, p. 23.
11 W. K. Clifford, "The Ethics of Belief," p. 70.
12 Richard Rorty, *Contingency, Irony and Solidarity*, p. 22.
13 A term I introduced in "Knowledge and Propaganda: Reflections of an Old Feminist."
14 Peirce, *Collected Papers*, 1.57–59.
15 Primo Levi, *The Periodic Table*, p. 42. I owe this reference to Cora Diamond, "Truth: Defenders, Debunkers, Despisers," to which I refer readers for illuminating discussion of Rorty and Heal.
16 And another reason, too: that, in scientific inquiry the circumpressure of facts, of evidence, is relatively direct (though not, I think, as direct as the quotation from Levi suggests). It may be worth recalling in this context that Peirce, a working scientist as well as the greatest of American philosophers, was trained as a chemist.

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# THE PROPENSITY TO BELIEVE

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WE ARE MAGICAL BEINGS in a scientific age. Notwithstanding all the remarkable achievements of our species in terms of understanding and harnessing nature, we are born to magical thought and not to reason.

The nervous system of the newborn is primed to learn. Entering this world with little to guide it apart from some basic reflexes and some rudimentary perceptual ability, the infant immediately sets out on the long journey of trying to make sense of the vast swirl of sensory stimulation with which it is bombarded. Gradually, the child develops an internal representational model of the outside world, a model so powerful that the resultant perceptions of the world seem to occur outside the brain. We logically know that perception takes place in the brain, but when we look at objects or listen to sounds or sniff the air, it is as though our perceptions of reality actually *are* reality. We do not see an image of an apple; we see the apple.

It is very difficult for most people to accept that what they perceive is not always isomorphic with what is really "out there." Our perceptual apparatus constantly and automatically seeks meaningful patterns among the myriad stimuli that impinge upon our senses. Many of these patterns that we detect are truly meaningful, while some are not; and it is difficult, if not impossible, for us to tell the difference on the basis of perceptual processing alone. We do such pattern finding unconsciously and automatically, but we are limited in two ways. First, there are limits imposed by the incoming data: it may be distorted or fragmentary. For example, walking to our campsite late at night, we see a shadow in the woods, ill-defined, fleeting. What is it? Our mental set and anxiety level and past experience will influence what we perceive. Second, there are limits imposed by the perceptual process itself. Our attention is selective. We cannot focus on everything at once, and so we collect only some of the information, particularly in situations of emotional impact.

However, our perception goes beyond these limits; it goes beyond the available information. We fill in the gaps—again usually automatically and without awareness—and perceive and recognize whole objects or events. Much of the time this works well. Sometimes it leads to egregious errors. Our perception

of a bear in the darkness may be based on nothing more than a bush swaying in the breeze.

Under some conditions, perceptions have little or nothing at all to do with the outside world. The brain in some circumstances cannot tell the difference between external perceptual information and information originating within other parts of the brain itself. Dreams and nightmares are examples. However, we systematically teach children that dreams and nightmares are the product of fantasy, and we all learn to recognize them as such. Once we realize that we were asleep at the time of their occurrence, we categorize the experience as one of fantasy. Even then, the emotional impact may be so great that an individual is tempted to find some link—possibly precognitive—between the experience and external reality. There are other situations, which are not so common, where internally generated perceptions are taken to be actual perceptions of external reality. Hallucinations are, of course, one example. The so-called near-death experience—in which a person sees himself or herself as outside the body, being drawn away down a long tunnel, meeting deceased loved ones and so on—is almost certainly another. The experience is an emotionally powerful one, the perceptions are vivid and seem to be "real," and thus there is no reason for most people not to treat the experience as one of literal reality. If such experiences happened frequently in everyone, then no doubt we would be prepared for their occurrence and would come to see them as fantasy based.

## EXPERIENTIAL LEARNING

The brain and nervous system are "hardwired" to learn about the world, to learn about associations among objects and actions and events. This learning occurs on the basis of two major factors. The first of these is stimulus similarity, or *resemblance*: what we learn about one object or event will automatically be attributed to similar objects or events, unless we have enough experience to permit differentiation between them. If we taste guava for the first time and do not like it, we are unlikely to try other guavas in future. If we are thrown from a horse the first time we try to ride one, we will be cautious about all the horses, at least until we gain enough experience to see differences among them.

The second factor upon which learning is based is *temporal contiguity*: our nervous systems are set up so that salient events that occur closely together in time automatically come to be associated in the brain, as though they in some way "go together." Thus, Pavlov's dogs came to salivate at the sound of the bell that had been paired several times with the presentation of food. This is referred to as "classical conditioning"—a previously neutral stimulus becomes capable of eliciting a physiological response on the basis of being paired with another stimulus that naturally produces that response. There is another form of basic learning. Skinner's rat, having happened to press a bar that led to the presentation of a food pellet, quickly learned to press it over and over to get more food. This is referred to as "operant conditioning"—a behavior that is followed by some desirable consequence is likely to be repeated in order to gain the same consequence again. The desired consequence

or "reinforcer" might be food for a hungry organism, water for a thirsty one, or relief from anxiety for a frightened one.

This learning, or "conditioning," occurs in fish, fowl, animals and humans, infants and adults. It provides the basis for experiential learning. Humans of course "think," and such automatic learning will feed into our mentation. However, such conditioning generally occurs without awareness, or in some cases despite awareness, and thus it happens without benefit of logical scrutiny. This sometimes condemns us to learning things that we do not want to learn. If we are attacked by a vicious dog, we may well develop a phobic fear of all canines that has nothing to do with any theory or logic. Emotional reactions can be readily conditioned, and emotion is often involved in experiential learning.

Indeed, an emotional response may be elicited, on the basis of past learning, by stimuli from the outside world even before we are consciously aware of the stimuli. For example, if while one is walking through the woods at night, one's visual system picks up some vague movement of a shadowy form among the trees, this information, once it reaches the limbic system, may lead to autonomic arousal before the information has arrived at the cortex—before we have any conscious perception of it.[1] When the cortex becomes aware of this information, it is also aware of the concomitant autonomic arousal, the emotion of fear, that has developed; and this emotion may influence the cognitive appraisal to the extent that the cognitive representation develops in line with the fear—"it's a bear!"

## INTELLECTUAL LEARNING

Experiential learning, based on resemblance and temporal contiguity, continues to play a powerful role throughout an individual's life. However, as the child grows a second form of knowledge acquisition gradually develops. This form is based on the mental manipulations of ideas and concepts, rather than being tied directly to personal experience. It is usually deliberate instead of automatic, and it can be carried on quite independently of emotion. As the child grows, this form of information processing becomes more and more dominated by language. It is in this *intellectual* system that nonexperiential information is absorbed—through books, teachers, stories from other people. And gradually, even without any instruction, a native logic takes shape: "Let me see, I did not have my hat on when I went into the barn, so there is no point in looking for it there." Through all the years spent in school, the child is given the benefit of thousands of years of human experience and deliberation, rather than having to experience everything first hand.

## INTERPLAY OF EXPERIENTIAL AND INTELLECTUAL LEARNING

Thus, human beings relate to and learn about the world in two distinctly different ways.[2,3] One of these ways is tied very much to the automatic associations that the nervous system constructs on the basis of temporal contiguity and resemblance and is more likely to involve emotion, while the other is a logical, analytical, and largely verbal approach. Epstein has written at

length about the ways in which these two modes of information processing interact with each other.[2] He points out that people's thinking is transformed in the presence of emotional arousal; and the more aroused they become, the more their thinking is nonanalytical, concrete, and action oriented—all of which are attributes of the experiential system. Moreover, thinking that occurs in a highly emotional state often seems to be more obviously valid to the thinker, and thus high confidence in the products of one's thinking is not always reflective of accuracy or cogency of thought.

These two learning systems, being more or less independent, sometimes work in opposition. A person may have a dread for high places and yet "know" logically that a particular trip up an elevator in a high building presents no real danger. Yet an attempt to overcome the phobic learning can lead to such distress that the individual fails and actually strengthens the phobia, all the while recognizing logically that there is nothing to fear. We may disavow a belief in ghosts, and yet—having experienced chills while listening to ghost stories in our childhoods—may feel uncomfortable or even frightened while walking through a graveyard late at night, all the while telling ourselves that ghosts do not exist. Such anxieties are not easily staved off by reason. People who have given up a childhood belief in God may be surprised to find themselves silently praying for divine assistance in a moment of great fear where intellectual problem solving proves insufficient.

## SOCIAL TRANSMISSION OF BELIEF

While language provides a powerful means for the symbolic analysis of events, it also provides a basis for the transfer of massive amounts of information from others. In childhood, of course, such information is usually provided by older people, whose attractiveness or authority is such that the child rarely questions the accuracy of what he or she is taught. Whether instructed on the benefits of regular dental hygiene or on the spooky effects of the full moon on people's behavior, the child has no reason to reject what is being taught. A society may teach that all perception is illusion, or that the earth is flat, or that we are born and reborn millions of times, bound to the wheel of life. The child will have no reason and no means to reject such teaching.

We generally come to think that our beliefs are justified and sensible. In maintaining a healthy self-image, it is difficult to view our own beliefs as silly, irrational, chauvinistic, prejudiced, or unjustified; and we invest considerable effort in maintaining a belief system that is credible to ourselves. Rarely do we question most of our beliefs. We believe the earth to be a globe, but when asked to justify that belief, people cannot generally point to personal experience. They have always believed that "the world is round," since that is what they have been taught, even though the flat earth notion often fits better with everyday experience. And most people believe in God for similar reasons. While most North Americans may react with disbelief to Hindu pantheism, and they may find bizarre the Zoroastrian belief in the sanctity of earth, air, fire, and water that leads to the practice of disposing of dead bodies by leaving them atop tall towers to be consumed by birds, little such reaction attends thoughts of a Christian God who sent His son to earth to die for our sins against Him.

It is not only information that is transmitted from one generation to the next. Families and societies also strive to inculcate certain forms of thinking. While the individual may and does develop some form of logical analysis through simple personal experience, the larger society makes considerable efforts to teach logic of some sort. The logic may be basically hypothetico-deductive, or it may be based in magical thought. Usually, both logical and magical forms of analysis are taught, to be applied to different situations. In Western society, we systematically immerse children in two belief systems, which Frank has referred to as the *scientific-humanist* belief system and the *transcendental* belief system.[4] The former is allied with intellectual learning processes, while the second is more closely, although not exclusively, tied to automatic, experiential, intuitive learning. In the first belief system, children are taught to value logic and critical thinking to some degree. They are encouraged to question, to analyze. However, in the second belief system, they are taught to turn off analytical skills and to accept ideas on the basis of faith or experience. With regard to transcendental belief, religion generally teaches children to accept on faith phenomena that would make little sense if viewed from an analytical perspective. Often, guilt feelings are associated with any attempts to examine the religious belief from an intellectual point of view. Even children who have little exposure to organized religion are led by popular culture to believe in various aspects of reality—God and Heaven, for example—that are not easy to reconcile with the prevailing scientific viewpoint. Even in these days of declining religious participation in Western countries, religious and quasi-religious belief is abundant. United States currency affirms a belief in trust in God. The Canadian national anthem asks God to maintain freedom, while the British national anthem prays for the well-being of the monarch. Courts try to ensure a high standard of truth by means of an oath before God. Weddings and funerals usually involve prayers to God. It is interesting that during the recent Gulf War, the most highly technological war in history, major leaders including the president of the United States, the British prime minister, and the Iraqi president all publicly prayed to God for victory. Thus do modern technology and ancient theology work together towards a common purpose.[5]

Little wonder, then, that a Gallup poll in 1990 reported that 90% of Americans express a belief in God. Moreover, more than seventy percent indicated a belief in life after death. Most people reported belief in some sort of paranormal phenomenon: only seven percent indicated rejected all of a list of eighteen such beliefs presented in the poll.[6] Forty-nine percent reported a belief in extrasensory perception, and half of these claimed to have had experienced the phenomenon personally. One person in four reported a belief in the reality of ghosts, and one in ten claimed to have experienced the presence of a ghost. Thus, the large majority of individuals believe in some aspect of reality that supposedly lies beyond the realm of science, that lies beyond the application of quantum mechanics, and that has nothing to do with quarks or photons or blood corpuscles or neurons.

Virtually every society is a society of contradiction, valuing and promoting reason and logic to some degree, but at the same time valuing and promot-

ing deeply held transcendental beliefs that defy that logic. In consequence, individuals learn to question, to analyze, to apply logic in one belief system, but not to do so in the other. From then on, whether or not critical thinking is brought to bear will depend a great deal on what sort of phenomenon is involved. The child is taught, essentially, that certain classes of problems and events require logic and others do not. People will be doubtful about claims that a new car can run without fuel, but will be much less ready to analyze faith healing from a skeptical perspective.

## MAGICAL THINKING

As discussed above, automatic, experiential learning is tied to resemblance and temporal contiguity. *Magical thinking* is characterized by taking resemblance and/or co-occurrence as indicators of some sort of link or causal relationship between two objects or actions or events without any concern about the actual reality of, or the nature, of that link or relationship. Magical thinking was a topic of considerable interest to anthropologists earlier in this century, as they were confronted by the superstitious beliefs and practices that they found rampant in the so-called primitive societies that were being examined in various corners of the world. However, contemporary anthropologists recognize that the propensity for magical thinking does not distinguish "primitive" societies from technologically advanced ones. It is a feature of the intellectual activity observed in all societies.[7] Just as has been observed in pretechnical societies,[8] it has been observed in modern industrial societies that during stressful times superstitiousness, magical thinking, and belief in the paranormal increase.[9,10]

The automatic power of temporal contiguity to produce a perceived relationship between two events promotes survival, as well as understanding of the world around us. It also leaves us open to egregious error from time to time. Crossing one's fingers may *seem* to produce desired outcomes, just as taking large doses of Vitamin C may *seem* to protect against colds, or supplication to Jehovah or Krishna or Zeus may *seem* to ward off danger. And of course, *seeming* is reinforcing; one might even say that *seeming* is believing. Although the ritual appears to bring the desired outcomes only occasionally, that is all that is necessary to establish a powerful belief in it.

Causality is important to humans, and most make considerable effort to explain the reason behind events that affect them. As early as eight months of age, the infant begins to demonstrate some attention to cause and effect. The infant's first concept of causality develops through observation of co-occurring events (events occurring in temporal contiguity). The great Swiss psychologist Jean Piaget studied how infants come to see cause and effect in situations where two unrelated events occur one after the other.[11] A baby laughs, and by chance the mobile above her head is moved by a gust of air. The baby laughs again and again, while staring at the mobile, in the apparent belief that her laughing will produce more movement. He referred to this as *magico-phenomenalistic causality*, "magico" because there is no comprehension or concern about the link between the cause and the sought-after effect, and "phenomenalistic" because the personal perception of the coincidental occur-

rence of the two events, one shortly after the other, leads the infant to react as though they are causally related. Such magical thought reflects the fundamental nature of the nervous system, as discussed earlier, which links together two stimuli that occur closely together in time. Only with repeated experience and explicit teaching does the child gradually acquire a more accurate understanding of causal relationships in the physical world. Yet, the brain by its very nature remains forever vulnerable to magical thinking.

Magical learning in its simplest form is referred to *superstitious conditioning*, which occurs without any necessary cognitive component, and is observed in animals as well as humans. The pigeon that finds itself in a cage where grains of food fall from a chute on a random basis can be observed to develop superstitious behaviors based on what it was doing at the time of a food delivery. It if happened to have lifted one foot just as the food appeared, it is likely to continue in future to hop on one foot from time to time, as if it is trying to produce the food. Occasionally, the food will appear again while it is hopping on one foot, reinforcing the behavior that in reality has nothing to do with the appearance of food. It is operantly conditioned by the happenstance pairing of a particular behavior with a particular event. Human superstitious behaviors are little different, except that they often become part of the belief system of a society, so that individuals learn them without the need for direct original experience. If one has been told often enough that a black cat crossing one's path leads to bad luck, then when one sees a black cat cross one's path, one may become slightly anxious. Such superstitious beliefs are readily maintained by anxiety reduction—see a black cat ahead, avoid it, feel better—and by salient events that occur at random, producing partial reinforcement. And it is important to recognize that partial reinforcement—that is, reinforcement that occurs sporadically and not on every occasion—leads to patterns of behavior and belief that are very resistant to extinction. For example, after having had a black cat cross our path, we may interpret subsequent events as though they reflect the portended bad luck. Again, we may well experience conflict with our intellectual system—we *know* that the belief in the jinx brought by a black cat is not something we should take seriously, and yet, if we have been reared with that belief, it may be very hard to shake off.

Transcendental beliefs can provide a sense of understanding of the world and an avenue for controlling undesirable elements in the world, and this is especially so in areas where science can offer little comfort: Why was my friend killed in the accident while everyone else survived? I am getting old, life is almost over; is this all there is? Why does this drought go on so long; how will we survive it, and who can help us? Transcendental beliefs that provide explanation or offer hope or intervention result in a lessening of anxiety, which is itself a powerful reinforcement of the belief. If woodland sprites or omnipotent deities are the cause of our problems or control our fates, then if we can find out how to please them, we should be able to rest easier. If our God is a loving and omnipotent being, then He will save us if we pray. Such is the basis of what Kurtz has called the "transcendental temptation;"[12] it is tempting to believe in transcendental reality because such a belief offers us respite, comfort, and salvation.

It is also important to understand that such beliefs may help calm an individual who is in a crisis; and he or she may, in turn, react in a calmer, more intellectual manner, solving the problem and then attributing the solution to the magical belief. Thus, the frightened individual who believes that praying to Zeus or waving an amulet will aid escape from a rapidly pursuing wolf may be in a better position to take defensive action once he or she has prayed or rubbed the amulet. By calming down a little, and perhaps deciding to climb a tree to escape the wolf, the individual comes to believe even more powerfully in the efficacy of the prayer or charm.

While experiential learning is the wellspring of magical thinking, intellectual activity is often harnessed in service of magical/transcendental beliefs. If we believe that dowsers can locate water or gold by means of a forked stick, we may generate quasi-scientific explanations to make our belief more palatable to ourselves. Quantum mechanics has been bent and twisted in all sorts of ways by those anxious to accommodate belief in precognition or psychokinesis (the putative movement of physical objects directly by the power of the mind).

## PROBABILISTIC REASONING

We rely upon both logical thought and intuitive thought in our day-to-day lives. Intuitive thought—"experientially derived knowledge"—comes to us without effort and is often very compelling and may influence behavior to a greater extent than does abstract intellectual knowledge.[13] Reed suggested that intuitive thought may be so very compelling because its products spring full-blown into consciousness.[14] Unlike the products of our logic, we have no access to how the thought developed.

A well-known example of how intuitive thought can overwhelm logic is the Monte Carlo, or "gambler's," fallacy. Although we take for granted that playing cards and dice and roulette wheels have no memory and that each outcome is independent of the preceding outcomes, this is not the way our intuition works. If the person playing the roulette wheel has observed that the outcome has been black twenty times in a row, it may seem compellingly obvious that red is "overdue," and that one should bet on red. Even people who are aware of the illogic of this conclusion can be caught up in it. Again, we have the conflict between experiential and intellectual systems.

Indeed, intuition is often very wrong when we deal with subject matter removed from the realm of everyday life. While an apocryphal scientist may have declared that a honey bee cannot possibly fly because its wing span is not great enough, for some lay people it is in some sense hard to believe that a jumbo jet can ever get off the runway, even though they have in the past witnessed this happen. They *know* that the airplane can fly, and they may even understand Bernoulli's principle and know enough about the physics of flight not to be surprised that it can indeed get into the air. Yet, it does not really fit in with common sense. It is much easier at an intuitive level to accept that small model airplanes can fly. They are light, and we all "understand" intuitively how birds and newspapers and other light things can be lifted on currents of air. The further we are removed from everyday commonplace experience, the more likely our intuition is to be wrong.

Psychologist Ray Hyman provides an interesting example of how intuition fails when we stray from the realm of ordinary experience.[15] Imagine taking a sheet of paper and folding it exactly into two. Repeat this operation a total of fifty times, ignoring—since this is a thought experiment—the difficulty of making all those tiny folds. The question is this: how high from the floor would the folded paper extend? When I pose this question to my students, some venture that it would go from the floor to the top of the desk. None ever believe that it would reach the ceiling. The correct answer is that a piece of paper of ordinary thickness would extend out beyond the sun, over 93,000,000 miles, after fifty folds. This is very counterintuitive, and students are always quick to demand proof—which is, of course, readily given.

There are other areas where intuition fails us. Our brains are very poor at keeping track of relative frequencies and thinking in terms of correlations between co-occurring events.[2] It is interesting to observe that despite thousands of years of exploration and discovery in mathematics, the study of probability did not begin until the 17th century. The Babylonians were skilled in several areas of mathematics—for example, they developed enough sophistication to be able to solve for the positive roots of any quadratic equation and even some cubic equations, and they developed compound interest tables. The ancient Greeks are well-known for their prowess in geometry—Pythagoras, Euclid, Archimedes, for example. In the Middle Ages, Muslim scholars made significant discoveries relating to number theory and algebra. Yet, through all those years, and even though games of chance had been a part of every age, notions of probability were ignored. Only in the 17th century, when a gambling devotee who happened also to be an amateur mathematician approached Pascal seeking assistance in his efforts to understand the likelihood of winning or losing in a particular game of chance, did humanity for the first time bring intellect to bear on the subject of probability. The lack of interest in this domain across the centuries possibly mirrors the inherent inability we have with regard to processing relative frequencies and thinking in terms of correlations.

We are inherently poor at correlational thinking because of an asymmetry that exists in the nervous system that makes it difficult for us to intuit co-occurrence rates. If a child touches a hot stove and feels pain, and then later accidently touches it again but this time it is cool and there is no pain, the association between stove and pain is not simply nullified. Many pairings of stove/no pain would be needed to overcome the association that was made on the basis of one experience. The co-occurrence of two significant events, even if purely coincidental, can have an overwhelming effect on our judgement of co-occurrence likelihood and our interpretation of cause and effect. A motorcycle gang rides into town, and that night the town hall burns down under suspicious circumstances. Just get into the shower, and the telephone rings, as it so often seems to do on such occasions. Stare at someone's back and the person turns around, as if the stare had caused this. Dream about an accident, and the next day someone runs into your car. The brain does not automatically keep track of nonpairings of the two events that have on this particular occasion occurred closely together in time. If the motorcycle gang

rides into town and nothing bad happens, this does not get stored away to cancel out a subsequent pairing with some negative event. If one has a dream of death and the next day one learns that a friend has died, logically we would want to know how many times the individual has had dreams of death and nothing happened. In other words, was this simply a coincidence? However, situations where people dream of death and no one dies, or where people die and there was no prior dream, do not make an impact, again because of the architecture of the nervous system. Yet, logically we cannot evaluate the correlation between dreaming and subsequent events without a tally of those situations as well. Thus, we store relevant information not in terms of probabilities but rather in terms of frequencies of salient co-occurrences. Given that a predictor event has occurred, people have great difficulty in using nonconfirmatory information coming from a nonoccurrence of the second event.

Many research studies have shown that individuals have little ability to judge correlations between a series of events. For example, subjects in one study were shown a whole series of trials relating to cloud seeding. On each trial they were informed that cloud seeding had or had not been carried out, and that it had or had not rained. Although there was no actual statistical association between seeding and rain, the subjects judged that such an association indeed existed. This judgment was based on those times when seeding and rain were paired. In other words, the subjects were much more influenced by the pairing of seeding and rain than they were by other pairings—seeding, no rain; no seeding, rain; no seeding, no rain. They incorrectly intuited that seeding did indeed make rain more likely.[16]

People have considerable difficulty organizing information into a format that is amenable to correlational inference. We do not normally need to worry about our correlational deficiencies because in general in everyday life events that are highly correlated statistically also tend to follow each other closely in time.[16] Thus temporal contiguity is normally enough to inform us about which events are related to each other. Tversky and Kahneman have demonstrated that it is not only the general public that is poor at probabilistic reasoning; so are professionals, even professional statisticians in situations outside their work.[17]

Even if paranormal phenomena do not exist, the workings of the brain are such that it is likely that most people will sooner or later experience something that seems to be paranormal—be it in the form of telepathy, psychokinesis, precognition, or whatever. The experience of the paranormal most often involves an emotionally striking co-occurrence of two events. One is about to call Uncle Harry, to whom one has not spoken for months; as one reaches for the telephone, it rings, and it is Harry calling. A person has a dream about a fire, and the next day there is a major explosion in the city. In each of these and many other situations, the nervous system of the individual says to him or her that there is a significant correspondence between these events. If we are not careful to subject these events to a probabilistic analysis, if we do not keep records about how often we dream with no correspondence to events of the next day, then we are unable to evaluate properly the likelihood that the correspondence occurred by chance. And given the emotional zing

that such correspondence often produce, we are more likely to categorize the occurrence as something meaningful and be loath to think of it in terms of coincidence.

## SCIENCE AND CRITICAL THINKING

Science, religion, and even natural magic all attempt to make sense out of nature. Co-occurrences are important in all three. However, unlike magico-religious thought, a basic goal of science is to discriminate between patterns that are meaningful and those that are not. It is only science that attempts to evaluate whether or not coincidence accounts for observed co-occurrence. Scientists have to learn to bend their own thinking—which is subject to intuitive and magical influences just as is everyone else's—to the rules of science, through the use of socially developed and socially agreed-upon tools to help avoid error.[18] Science is in part a social enterprise, in which the observations and conclusions of a single individual are fully accepted only if they can be verified independently by other researchers. Hence, collective, rather than individual, validation of findings is paramount.

However, when science is taught, it is almost always taught without any reference to existential or transcendental questions, thus allowing students' transcendental beliefs to continue to escape logical analysis and reinforcing the notion that science need not concern itself with transcendent beliefs. This in turn helps nourish the notion that science is limited and that putatively transcendent phenomena lie in a realm of reality beyond science's ken. Great care is generally taken to avoid challenge to religious beliefs. Hence, why should we expect scientists to be any different from the general public when it comes to transcendental belief?

Many scientists are religious; many believe in psychic phenomena based on their own experiences and emotional needs. We are left, then, in a situation of conflict between experiential learning and logic, between faith and science. As William James, himself deeply interested both in science and the paranormal, wrote, "At one hour scientists, at another they are Christians or common men, with the will to live burning hot in their breasts; and holding thus the two ends of the chain, they are careless of the intermediate connection."[19]

## PARAPSYCHOLOGY: AT THE FRONTIER BETWEEN SCIENCE AND RELIGION

Science and organized religion have clashed mightily in the past, but today there is a generally peaceful coexistence between them. Parapsychology lies at the frontier between science and religion. It is the quest to find evidence that there is more to the human personality than materialistic science allows. Parapsychological phenomena are by definition those that involve human (or animal) agency, that are not explainable in terms of modern science, and that involve some radically different relationship between consciousness and the physical world than is held to be possible by contemporary science.[20]

When the Society for Psychical Research (SPR) was organized in England in 1882, with well-known Cambridge philosopher Henry Sidgwick as its president, a central part of its mission was to prove scientifically the existence of

the soul, or at the very least to demonstrate that there is a nonmaterial aspect to human existence.[21] Sidgwick and other leaders of the SPR had suffered tremendous personal conflicts between their religious beliefs and the implications of developing science, especially the implications of Darwinian theory.[22] They felt a strong need to reconcile science and religion. By giving up the apparent mythology of religion and focusing instead on survival of the human personality, Sidgwick was hopeful that the postmortem survival of the human personality could be put on a solid scientific footing.

Some years later in the United States a young botanist, Joseph Banks Rhine, who was to become the preeminent parapsychologist in the world and transform parapsychology into a laboratory discipline, was also caught in a struggle between religious beliefs and scientific materialism. He had planned to become a minister until science got in the way. He came to believe that parapsychology could serve as a bridge between science and religion and believed that in order to demonstrate the existence of a soul or of at least mind-body dualism, it was first necessary to demonstrate that extrasensory perception and psychokinesis were genuine phenomena.

Such conflict between science and religion was experienced by many of the most influential figures in parapsychology. Indeed, it has been observed that most parapsychologists, after a fall into agnosticism, have been motivated by a search for evidence that would show that life has meaning.[23]

There is an important difference between the role of religion in the lives of conventional scientists and the role it plays in the lives of many if not most parapsychologists. In the former science is pursued in spite of religious needs, whereas with parapsychologists it is typical that a dissatisfaction with or renunciation of traditional religious teaching has promoted a search for transcendent phenomena *because* of such needs.[22] This reflects a dissatisfaction both with traditional religious "mythology" and with the materialism inherent in modern science. The inherent difficulty, if not impossibility, of reconciling science and religion underlies the difficulties that separate parapsychology from conventional science.

It is noteworthy that there is nothing emerging from conventional scientific research that would suggest the existence of psychic (psi) phenomena. Physicists do not report that their experiments turn out differently depending on the wishes and motivations and thoughts of the researcher. Yet for more than a century various researchers trained in the ways of science, some of them preeminent scientists in their own right before they turned to parapsychology, have tried without success to produce empirical evidence of a quality that would convince mainstream science of the existence of psi phenomena. How is the belief in such phenomena sustained despite such a history? In my view, the belief comes first: the quest is to find data to substantiate the belief, rather than to find an explanation for an observable phenomenon.

Parapsychology attempts to be a science. Many of its practitioners are devoted to the application of scientific research methods. Yet it has not been able to gain real acceptance within the halls of science, and this for a number of reasons. First of all, its subject matter is defined in exclusively negative terms. One can demonstrate that a psychic phenomenon has occurred only if one

can rule out all normal explanations; and since one can never be certain that all such explanations can be ruled out, one can never be certain that a particular event lies outside the range of normal explanation. Second, even using this highly unsatisfactory negative definition, there has never been a demonstration of a psychic phenomenon that is, in the words of parapsychologist John Beloff "strongly replicable,"[24] meaning that any competent researcher can follow the specified methodology and produce the same effect. Unrepeatability is such a problem in parapsychology that some parapsychologists have argued that criterion should be abandoned, that psi is not only elusive but may also be inherently unlawful. The suggestion that the very criteria that scientists have developed to help protect them from error should be lowered in order to accommodate the elusiveness of psi is hardly likely to find attentive ears in the mainstream scientific community. Add to this the fact that parapsychological research continues to be plagued by methodological flaws (e.g., Refs. 25–27). Equally important, parapsychologists render their hypotheses virtually unfalsifiable by the employment of various "effects" to explain away failures in their data. One of the more notable of these is the "psi experimenter effect," an effect that is cited so often that it has been described by one parapsychologist as parapsychology's one and only finding.[28] It suggests that failures to replicate may be due to differences in the psychic abilities of the researchers. Of course, this would explain the inability of skeptical researches to obtain results. Indeed, if this hypothesis were correct, it would seem that science as a whole would be impossible, for the theoretical predilections of researchers would influence the results they obtain.

Finally, parapsychology cannot and will not specify when psi should *not* occur. It supposedly transcends space and time, and according to some studies works just as powerfully across the world as across the room, and forward and backward in time as well as contemporaneously. Humans, animals, insects, and even fertilized eggs have supposedly proved to be successful psi operators. Psi apparently knows no bounds.

Belief in parapsychological phenomena, including the belief that words or actions lead to physical effects not accountable for in terms of normal science, falls within the definition of magical thinking, since an effect is imputed to a cause without knowledge of, or particular concern about, the putative causal link.[29] Some parapsychologists admit this and view natural magic simply as a manifestation of psychic power; and, indeed, it has been stated in the parapsychological literature that if one takes away the rituals, natural magic is nothing more than psychokinesis.[30]

In conclusion, parapsychology reflects a duality in our thinking, a duality that can be traced back to the inherent conflict between the two ways in which we learn—between experiential, magical thought and logical, analytical thought. Reflecting these two different and often conflicting information processing systems, human beings have constructed two major belief systems, one scientific-humanist and the other transcendental. They are difficult to reconcile. Some people resolve the conflict by compartmentalization. Others reject science and logic and go with intuition; there is abundant worship at this temple these days. Others choose logic and science, and then overcome or sup-

press whatever existential anxieties may present themselves. Parapsychologists attempt to find a single system to accommodate the two.

In any case, it is an ongoing struggle. Every one of us is vulnerable to magical thinking whether we recognize it or not; and those who fail to recognize it are most likely to be vulnerable to a conversion experience. The critical thinking and data gathering methods that make up science have proved to be the most effective system we have for protecting ourselves from error and self-delusion. They are the product of centuries of intellectual activity, but they do not come naturally or easily to the human brain. We need to be as concerned for their survival as we are about the survival of rain forests and other endangered treasures.

## NOTES

1 J. E. LeDoux, "Emotion, Memory and the Brain."
2 S. Epstein, "Integration of the Cognitive and Psychodynamic Unconscious."
3 J. E. Alcock, *Parapsychology: Science or Magic?*
4 J. T. Frank, "Nature and Function of Belief Systems."
5 J. E. Alcock, "Religion and Rationality."
6 G. H. Gallup, Jr. & F. Newport, "Belief in Paranormal Phenomena among Adult Americans."
7 R. A. Shweder, "Likeness and Likelihood in Everyday Thought: Magical Thinking in Judgments about Personality."
8 B. Malinowski, *Magic, Science, Religion and Other Essays.*
9 V. R. Padgett & D. O. Jorgenson, "Superstition and Economic Threat: Germany, 1918–1940."
10 G. Keinan, "Effects of Stress and Tolerance of Ambiguity on Magical Thinking."
11 J. Piaget, *The Construction of Reality in the Child.*
12 P. Kurtz, *The Transcendental Temptation.*
13 R. M. Shiffrin & W. Schneider, "Controlled and Automatic Human Information Processing 2: Perceptual Learning, Automatic Attending and a General Theory."
14 G. Reed, "Superstitious Beliefs and Cognitive Processes."
15 R. Hyman, personal communication.
16 H. M. Jenkins & W. C. Ward, "Judgments of Contingency between Responses and Outcomes."
17 A. Tversky & D. Kahneman, "Judgment under Uncertainty: Heuristics and Biases."
18 D. W. Fiske, "Comments."
19 W. James, *The Will to Believe.*
20 J. E. Alcock, "Parapsychology: Science of the Anomalous or Search for the Soul?"
21 J. J. Cerullo, *The Secularization of the Soul.*
22 J. E. Alcock, "Parapsychology as a 'Spiritual Science.'"
23 R. L. Moore, *In Search of White Crows.*
24 J. Beloff, "Research Strategies for Dealing with Unstable Phenomena."
25 J. E. Alcock, *Science and Supernature.*
26 C. Akers, "Methodological Criticisms of Parapsychology."
27 R. Hyman, "The Ganzfeld/psi Experiment: A Critical Appraisal."
28 A. Parker, "A Holistic Methodology in psi Research."
29 L. Zusne & W. H. Jones, *Anomalistic Psychology.*
30 L. M. Beynam, "Quantum Physics and Paranormal Events."

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# FLIGHTS OF FANCY
## Science, Reason, and Common Sense

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A CONSIDERABLE PART though by no means the whole of philosophy is given to the task of constructing accounts of how one or another interesting aspect of human activity that works actually does work. To give such an account turns out to be much harder than one might have thought, and I know of no example of one that is agreed by all knowledgeable observers to be successful. For example, we know certain things. But how do we know that we know them? What is knowledge and how does it come about? In the *Theaetetus*, Plato attempts a definition of "knowledge" that, after a lengthy discussion he admits collapses into circularity.[1] And in his *Sophist* he attempts an account of how we can predicate, as he calls it, "nonbeing"—how we can say, for instance, "There are no unicorns" without finding ourselves speaking about nothing and, therefore, not having succeeded in speaking at all. Here he is less unsuccessful, if one may speak that way, but unsuccessful still.[2] More recent examples are Susan Haack's neat reconstruction of the theory of justification[3] and John Searle's attempt to show how and in what sense social reality, but only social reality, is constructed.[4]

Another part of philosophy is given over to the task of saying how arguments or ontological commitments that seem to go wrong do, in fact, go wrong. Here one thinks of Aristotle on sophistical refutation,[5] Aquinas on the ontological proof,[6] Russell on denoting,[7] Ryle on category mistakes,[8] Goodman on the logic of evidence,[9] and Wittgenstein on everything.[10]

I associate the quite modest remarks that follow with this second philosophical tradition. I hope to give an outline of what has gone wrong in the thinking of the critics of science in particular, and of many of the critics of the successes of the developed West in general. For we shall not be able to combat antiscientism and its epigones with any great hope of success unless we understand quite clearly just what the problem is. As I see it, the problem is intellectually not very deep. That is the good news. The bad news is that it appears to be psychologically quite deep in two ways. First, those attracted to such modes of thinking are tenacious, and no amount of argument or coun-

† Deceased (July 14, 1995).

terevidence is likely to move many of them. Second, the antiauthoritarianism and Utopian modes of thought are perennial in Western history.

The sole remedy at our disposal is to quarantine the antiscience brigades and inoculate the rest of the population against them. This requires that those who understand something about science—I mean scientists—and have some common sense, too, will have to devote some of their energy to systematic confrontation with the enemies of science and continually to make the case for science for those, including our political masters, who have not thought much about it. And that means that scientists will have to ally themselves with intelligent nonscientists and learn how to turn aside the rhetoric of the Luddites, uncongenial as that task may seem. To rework a phrase, eternal vigilance is the price of a reasonable society.

My late and sometime mother-in-law was no intellectual. She moved in romantic poetic circles in the Riga of the twenties, thirties, and forties. Not only did she not understand science, she was unreasonably, or perhaps reasonably, suspicious of it—of medicine in particular, whose principle and nefarious task she thought was the use of one's body for experimental purposes. Even so, she would avail herself of its services as old age crept up, provided always that she could summon a Latvian doctor in New York. However, she did know a thing or two and hewed to an old Baltic proverb as she watched human antics: smart people have smart problems—perhaps a colloquially expressed version of Hume's first inquiry.[11]

Peasants and other plain folk don't mess with epistemology. They are unlikely even to know the word. Only smart people do that. The organizers of this conference did not ask me to suggest a title for it. Had they sought my counsel, I should have suggested that it wasn't any flight from reason that fuels most of the problems that confront us. I should have suggested that, on the contrary, the difficulty we face stems from hewing to reason, but hewing to it unreasonably—to sophistic and sophomoric reason, in the manner of Buridan's ass,[12] but to reason nevertheless.

There is a flight, but it is a flight from common sense. What is common sense? I suppose a decent approximation is that it is reason robustly laced with experience, to which experience one pays serious attention. A rational man proportions his belief to the evidence, as Hume puts it.[13] *Reason* has many different meanings, one of which is, of course, just *common sense.* It will emerge shortly why I find it useful to set common sense off against the other meanings.

About reason it is probably helpful to keep in mind the distinctions among (1) the multiple and particular uses of reasoning that any of us is likely to employ in his daily and professional life, (2) the defenses we might mount if challenged on any one or few of these particular uses, and (3) a general defense of reason that philosophers (who else?) might make against a global attack not on this or that particular piece of reason but on reason *tout court.*

I would be very curious to read a global attack on reason itself. That term denotes so many different things that the attack would have to cover vast territory. And how could it be made without presupposing some canons of what was supposed to be under attack—reason? Of course, there always have been glancing attacks—some skeptical, like Epictetus; some religious, like

Tertullian, Paul, Luther, Calvin, or Kierkegaard; some literary, like Swift, Dostoevsky, or Sartre; and some conversational, like the late Feyerabend and the still quick Rorty. But to my knowledge no one has challenged, say, Aristotle's syllogistic, or the proofs of consistency and completeness for the propositional and first order predicate calculi. As Aristotle would no doubt point out were he still with us and a *Metaphysics*-ish (Book Gamma) mood, the Sandra Hardings and Latours of this world still do count their change at the checkout counter and negotiate their fringe benefits with care. Radical *aporia* raises its ugly head only in the lecture hall or the seminar room. Those who claim to deny reason's claims give pragmatic refutation of their denial.

But in the seminar room and in print there is a flight from science. Though I have not tried to apply my thesis to all the fauna catalogued in *Higher Superstition*,[14] I think it would be tedious but not difficult to show that the various attacks on science all accept implicitly what we loosely call reason. They employ reason to attack science, sometimes as merely misapplied—like radical environmentalists—sometimes as a complete enterprise—e.g., Harding-type feminists.[15] Harding herself is not good at making arguments. A shockingly high percentage of hers are either invalid or unsound. But even bad arguments are arguments. So she uses reason. Her problem is that she misconstrues her target. She focuses not on central issues but on ancillary ones, which she wrongly thinks are central. To put it neutrally in a formulation I borrow from Susan Haack,[16] Harding and her allies have different background beliefs from those of us who think current science is in general a salutary enterprise. Insofar as her background beliefs miss the central points, Harding lacks not reason but reasonableness or judgment or common sense.

Among the background beliefs shared by the antiscience brigades we may pick out one general belief and seven particular ones. The general belief is that what most of us take to be ancillary to the scientific enterprise is really central. The particular beliefs are (1) authority is always wrong and, consequently, (2) so is hierarchy; (3) populations should be represented in the various sciences proportionately by race, sex, and ethnicity; (4) one can give meaningful analyses and criticisms of a technical subject though completely ignorant of it; (5) abstract argument supersedes particular results; (6) there exist non-Western ways and feminine ways to do science that are, root and branch, different from the ways in which science is now done; and (7) Utopia cannot merely be agreed upon in principle but can actually be achieved.

Consider Harding's complaints,[17] among others, that (1) science is dominated largely by men, (2) it is hierarchical, and (3) it is authoritarian. Her strong point is that all three claims are true; her weakness is, of course, that they are all irrelevant, for they do not constitute an attack on anything central in what we value in science. What do we value in the various sciences? We value the production of knowledge and its practical application to ease our lives.

Now Harding says in several places that the fact that science works is not enough to justify it. *A fortiori*, she admits that it works. And if it works, then the facts that it is male dominated, hierarchical, and authoritarian are no reasons to change it unless one could be reasonably sure that it would work better were these things not the case. Let's leave male bashing aside for the

moment. Could science be egalitarian? Only if all scientists had equal and equally important levels of knowledge and ideas. To state this condition is to see its absurdity. While it is logically possible that we should all be mental clones of each other, nothing that we know about the world or about evolution suggests there is the remotest possibility of such a state. Indeed, if this state came about, the world would be a most uninteresting and unfruitful place. If we all had the same knowledge and ideas, then there would be far less new knowledge. Science would advance like a slowly moving wave front, and I suppose we could make do with only one scientist.

But the way the world actually is, we find in athletics, entertainment, science, and mathematics that some of us will be better than others, a few will be outstanding, and a very few, towering. So some of us will know a great deal more than others and have a great many more new and successful ideas. This hierarchy is as necessary a concomitant of science as it is of tennis or plumbing.

In fields of knowledge as in other fields authority goes roughly along with achievement. Those who know and have achieved more will have more authority. Of course personality traits enter the picture, but this complication does not alter the main principle that hierarchy and authority are systematically correlated with high levels of knowledge and achievement. So if you want knowledge, you must accept the correlatives. Now, attacks on hierarchy and authority are not attacks on reason. They are attacks aimed to buttress a set of background beliefs. Among them are the beliefs that hierarchy and authority are, in themselves, evil and that one can have science without them. Given what we know about science, these beliefs are false. They are poor judgments and unreasonable beliefs, but they are not flights from reason itself.

Turning to the question of male "domination" we see that the background beliefs are two: that proportionality by race or sex in every occupation is achievable and that absence of proportionality is morally wrong. Of course, this indicts virtually all activities, since such proportionality is never, as a matter of sociological fact, found. Baseball, football, Grand Prix racing, government, the arts—virtually all occupations (shall we indict childbearing here, too?) will, on this view, turn out to be morally culpable. For reasonable people this would constitute a kind of *reductio.* But, *credo, quia ineptum.*[18] Some people are not reasonable. Them we could never convince. And, of course, proof in the strict sense is out of the question, since there never could be strict proof of such things. In any case, those who hold such absurd background beliefs are rather like my logic students. They do not understand how a formal proof works and so never see that any particular proof proves any result. What would be morally culpable, of course, is not if the population of immunologists or particle physicists exhibited one or another racial, ethnic, or sexual pattern, but rather if talented particle physicists or immunologists were prevented from a career because of race or sex. Here as elsewhere the disparate impact argument has much to answer for.[19]

Another absurd background belief held by most, though not quite all, of the antiscience brigade—the late Paul Feyerabend[20] was an exception, the still quick Dick Rorty[21] is not—is that one can make useful, even profound, criticisms about a technical subject of which one is entirely ignorant. Now,

we might have to show some sympathy with this notion, for it is a very American one, seen especially in our penchant to moralize about politics and international relations in deep ignorance of history, diplomacy, and the current situation. The fact is, though, that people who have not been trained in one or another science and have not practiced at it are very unlikely to know how it works on the ground, or even in theory. They will not know how research is produced, how it is written up, how it is announced at meetings or in journals, or what counts as success. Lacking this technical knowledge they will tend to focus on those aspects of science they think they understand—the social aspects.

Consider the following example. The mythical, proverbial middle American who has never been abroad and is innocent of the rules of any card games of skill—suppose him transported, say, to a London bridge party about which he is to write a sociological analysis. Suppose, further, that the dominant player, the player who takes most hands and takes them brilliantly, and to whom the others defer, rejoices in a hereditary title with accent to match. What will our plain-speaking sociologist think? What will he write? Very likely that dominance at the bridge table is a function of ancient peerage, plumy voice, and arrogant behavior.

Now you may think this unkind. But I have a real-life example. Last fall one prominent proponent of this sort of nonsense submitted to the National Association of Scholars journal, *Academic Questions*, a paper that claimed—*en passant*, as so often—that the major reasons German physicists accepted Heisenberg's uncertainty principle were to be found in money and politics; that the reputation of physics in general had fallen in Weimar, Germany—why he did not say—and that control of funds fell largely into Heisenberg's hands—why he did not say. Wishing to get funds, physicists were obliged to climb aboard the Heisenberg express. We did not publish this article.

If you are ignorant of a subject, the best available way to talk about it is in the abstract. Newspaper and television editorials provide many amusing examples. So do the antiscience brigades. Strong social constructivism trades on this, and it would be tedious to enumerate every example. It is this reference to the abstract that allows such silly formulations as "reality is socially constructed." Is one meant to think that if "society" (another abstraction) changed its mind and came to a different consensus, then one might happily drink $H_2SO_4$ with the results one now expects from a glass of $H_2O$, or hurl himself from the top of the World Trade Center to float down like a feather?

Even in cases of those aspects of the world where it is not altogether wrong to say, very carefully, they are socially constructed—e.g., money and markets—there is a recalcitrant reality one does bump up against, as you easily may find out by attempting to evade payment for goods purchased. And as Aristotle pointed out some time ago, it is a non-socially constructed fact about the world that money and markets tend to make life much easier and more efficient than it would be in their absence.[22]

About the possibility of any science completely and utterly different from science as we know and practice it I have written at length elsewhere.[23] Here I merely point out that it is possible to think and utter such phrases only *in*

*abstracto*, only if one gives no thought to any content they may have. For to try to think of a possible content for them is to see them as entirely empty.

Not so for Utopias. Everyone can imagine his own. For example, the recent death of Burl Ives recalled to me his rendition of "Big Rock Candy Mountain" and the buzzing of the bees in the politically incorrect cigarette trees. And, of course, there is Verlaine's naughty vision of a ballroom constructed entirely of bits of female anatomy.[24] What are absurd are the notions (1) that we should all agree in theory on what Utopia is, and (2) that any Utopias at all are on offer. With thoughts of Utopias all common sense has vanished, and we see plainly that no amount of argument or reason or evidence will carry weight with the antiscience brigades.

There are two more sources of antiscientism that should be kept in mind. First is the general antiintellectualism that pervades American life.[25] One of innumerable examples that I could give is the article that appeared in *The New York Times* on the O. J. Simpson trial and supposed juror reaction to the DNA evidence.[26] I quote briefly:

> For the squirming jurors held captive in Judge Lance A. Ito's Los Angeles courtroom, the last couple of weeks of DNA testimony must seem like the worst possible visitation of a well-known recurrent nightmare: It's the last week of the semester and suddenly you remember the science class you forgot and signed up for and never thought to attend. Too late to drop it now. In a vast silent hall, you stare at the final exam with its sickening thicket of meaningless symbols and equations. Your head swimming with the nausea of incomprehension, you run for the exit. . . . You're being asked to comprehend the incomprehensible. . . .

Does one have to point out the sophomorically fictitious character of this passage and what it says about the mind-sets of the author who wrote it and the editor who permitted it to be printed?

The second sort of antiscientism is that of the political paranoia[27] that runs deep in some souls. One need merely notice those AIDS activists who blame science and government both for the origins of AIDS and for the lack of a vaccine and a cure, or that small spectrum of black nationalists who claim that AIDS is black genocide practiced by white doctors and whose rantings keep many an AIDS victim from seeking help.[28]

While writing out this paper I had the nagging feeling that I ought to apologize for outlining such obvious points to this distinguished audience. But it would be wrong of me to do so. It is a *déformation professionelle* of scholars and scientists to prize depth and originality in every context. In the battle for the hearts and minds of the public, the government, and the media it is far better to make a few obvious and important points as accurately and clearly as possible and to hold to them tenaciously. If you wish large numbers of people to accept what you say, then the very last thing you want to be is original. Moreover, what is obvious to you as scholars and scientists will be quite mysterious to those who have not spent years thinking about it.

We must make no mistake about what it will take to show up the antiscience Luddites for what they are and to defeat them. The two tasks are by no means the same. It will take organized, continuous, strong, and clear opposition.

## NOTES

1 Plato, *The Theaetetus*, pp. 209d, ff.
2 Plato, *The Sophist*, pp. 263b, ff.
3 Susan Haack, *Evidence and Inquiry: Towards Reconstruction in Epistemology.*
4 John Searle, *The Construction of Social Reality.*
5 Aristotle, *Sophistical Refutation.*
6 Saint Thomas Aquinas, "Question 2: The Existence of God: Article 1, Whether the Existence of God Is Self-Evident."
7 Bertrand Russell, "On Denoting." See also P. F. Strawson, "On Referring."
8 Gilbert Ryle, *The Concept of Mind*, pp. 15–24; and "Systematically Misleading Expressions."
9 Nelson Goodman, *Fact, Fiction, and Forecast.*
10 Ludwig Wittgenstein. See, e.g., *Philosophical Investigations.*
11 David Hume, *Enquiries Concerning Human Understanding and Concerning the Principles of Morals.*
12 John Buridan (1295?–1365?), philosopher and logician. This epithet refers to an ass who, finding himself equidistant from two equally succulent bales of hay, starves to death, there being no reason to incline him towards one or the other. It is absent from Buridan's extant works. Some speculate that it arose as a counterexample to Buridan's theory of the will: that one must will that which presents itself to reason as the greater good, though choice may be delayed until reason has examined the alternatives thoroughly. For the origins of the problem see Aristotle, *De Caelo*, 295B:32.
13 David Hume, *An Enquiry Concerning Human Understanding*, sec. x, pt. 1. para. 88.
14 Paul R. Gross & Norman Levitt, *Higher Superstition: The Academic Left and Its Quarrels with Science.*
15 Sandra Harding, *Whose Science? Whose Knowledge?*
16 Susan Haack, "Response to Thomas Nagel, 'Relativism and Reason.'"
17 Sandra Harding, *The Science Question in Feminism.* See almost any page.
18 "I believe because it is absurd." Tertullian, *On the Flesh of Christ*, ch. 5. Quoted in Etienne Gilson, *A History of Christian Philosophy in the Middle Ages*, p. 45.
19 For the theory that all conduct that adversely affects minority groups in employment should be legally defined as discriminatory, see Alfred Blumrosen, *Blacks, Employment, and the Law.* The first use of this analysis of which I am aware is in the landmark case *Griggs v. Duke Power Company*, 401 U.S. 424 (1971). The term "disparate impact" is first used in Barbara Lindemann Schlei and Paul Grossman, eds., *Employment Discrimination Law.*
20 Paul Feyerabend, *Against Method.*
21 Richard Rorty. See, e.g., *The Consequences of Pragmaticism.*
22 Aristotle, *The Nichomachean Ethics*, bk. V 1133a:7, *et seq.*
23 Barry R. Gross, "What Could a Feminist Science Be?"
24 Paul Verlaine, "At the Dance."
25 Richard Hofstadter, *Anti-Intellectualism in American Life.*
26 *The New York Times*, "News of the Week in Review," May 21, 1995, p. 1.
27 Richard Hofstadter, *The Paranoid Style in American Politics.*
28 See, e.g., Hanna Rosin, "The Homecoming"; Ann Louise Bardach, "The White Cloud"; and Dante Ramos, "A Second Wave."

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# FEELINGS AND BELIEFS

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IT IS A COMMONPLACE of psychology that beliefs may be engendered by feelings. Unfortunately, in putting things so bluntly we run the danger of conflating different categories, both of "feeling" and "belief." I want to explore two contexts in which there is, or at least there is asserted to be, a link between feeling and belief. One is the postmodern sociology of knowledge, and of science in particular. Here it is asserted that belief is always, or almost always, a social construction, and therefore to ask whether it is rational or irrational is beside the point and possibly meaningless. I contend that the mechanism invoked here, though rarely explicitly, is one that supposedly generates a "belief" from a "feeling." In this case, the belief might, for the sake of argument, be one concerning a scientific theory or the relevance of an observation to the truth of the theory. The general tenor of the constructivist view is that one believes because the psychic pressures of the social context in which one is embedded force one to believe: bluntly, "A believes X because A is afraid not to."

In contrast, there is another kind of situation in which feelings are said to generate beliefs, one that assuredly does occur in the practice of science and of scientific medicine. This is the realm of intuition, where hunches, surmises, "gut feelings" are brought into play in a manner that undergirds beliefs, at least conditional, provisional beliefs. In a practical science like medicine, however, these beliefs may be the only ones available as a guide to immediate action.

My aim is twofold. I want to assert that the first kind of mechanism, the one implicitly invoked by the constructivist, is highly problematical and certainly cannot be so commonplace or invariant in its effects as to account for the construction of something as self-consistent and reliable as a body of scientific theory. In other words, I assert that there are canons of rationality, that scientific theories adhere to these, and that the constructivist view of how scientific convictions are generated badly fails to account for this. On the other hand, I want to rescue science from the accusation that, since "intuition" or "hunch" or "educated guess" plays such an important role, science

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is ipso facto irrational in the pejorative sense implied by the constructivist literature.[1]

Let us explore the difference between feelings and beliefs. The vast majority of what we call beliefs, everyday beliefs if you will, are propositions that we are willing to defend if challenged. You have certain premises, which you can make explicit, and a high degree of confidence that others who agree with the premises and who have a chance to scrutinize your reasoning will agree with you on the point at issue. This doesn't end all arguments, of course. By invoking "premises," we open the door to indefinite regress, and even to questions of "foundational" beliefs. But in practice this is what rational discussion is about. One cannot believe (or, indeed, disbelieve) just because one wants to. On the contrary, belief must, by variable contributions of observation and persuasion, be earned.

Thus, as I propose to use the term, a belief is not just a proposition that is assented to in some haphazard fashion. Rather, it is a deep, intricate, and finely coordinated mental structure that bears the traces of complex inference. Characteristically, the scientific beliefs of scientists, pure and applied, have these qualities, and this is an important part of what makes them scientific.

Feelings, in practice, are different animals. Like beliefs, they cannot just be willed. One cannot be grateful or happy by dint of a willful act, any more than one can intentionally forget. Unlike beliefs, however, feelings cannot be justified from premises. Either a feeling exists, or it does not exist. You can persuade someone else to believe as you do through an examination of premises and reasoning, but you cannot persuade someone else to feel as you do, absent some predilection independent of the tools of persuasion. You can verbally induce somebody to feel something, at least with a high degree of reliability—"Your wife and baby just died in a traffic accident!"—but this is not persuasion, as it applies to supporting or changing belief.

Note that such common expressions as: "I guess," "I think," "I feel"—as was pointed out long ago by Gilbert Ryle[2]—can be understood *not* to represent an inner state of mind. Rather, they denote a certain hedge, a weakening of an assertion. "I feel that it will rain" is not a report of an internal mental event, but rather an overtly tentative step down from "It will rain" or "I am certain that it will rain." We must beware of figurative language as well; "I like Road Warrior in the third" is not a report of affection.

Also, we have to distinguish utterances from either beliefs or feelings. This is merely to say that people may make utterances that do not comport with their beliefs or their feelings. Lies are the most common instances, but the category also includes ironic comments, rote recitations, and playacting. Clearly, feelings may generate utterances that are not mere expressions of the feelings in question. If someone puts a gun to my head and demands that I recite the Ruritanian pledge of allegiance, I probably shall do so (if I know the words) because "I am afraid not to." Obviously, this will not correspond to a belief in me that Ruritania is supreme among the nations of the earth, nor to any feelings of deep nostalgia for the fields and woodlands of Ruritania. If the gunman then demands of me that I justify my stated loyalty to Ruritania, presumably I shall try to give utterance to such a justification; but this will be

spurious in the sense that the purported justification will either invoke reasoning that I consider unsound or recur to premises that I do not really believe (unless, of course, I really am a Ruritanian patriot).

Finally, we note that "intuitions," "hunches," and so forth deserve to be classed with feelings rather than beliefs for the primary reason that those who hold them cannot explicitly construct a justification for holding them from an adequate stock of premises and a compelling line of reasoning. This is precisely why there are special terms for them, distinguishing them from beliefs. You cannot persuade someone of a hunch, although you may possibly evoke a similar hunch in him. At the same time, hunches and the like are characterized by the same inscrutability usually acknowledged as such by the holder, that is associated with the realm of feeling. Note, however, that this is the way we treat such remarks. It is not, in itself, sufficient grounds for categorizing hunches, nor the use of hunches as "irrational" in any pejorative sense. How rational or irrational reliance upon hunches may be is a function of the origin of hunches and of the availability of sounder, timely guidance. About this we may make some reasonable guesses, as I hope to show.

## THE CONSTRUCTIVIST VIEW OF KNOWLEDGE

Let us consider a couple of points that come up in the work of Bruno Latour, since among postmodernist and "constructivist" theorizers about science he is as widely known and well regarded as any. In *Science in Action* he tells us "The fate of what we say and make is in later users' hands." Indeed, he states this as his "First Principle." This is a typical move—invoking an obvious tautology as though it were a profundity. But, to make a long story short, it comes as part of a strategy designed to make some highly contestable points. In Latour's view, as a general rule scientific statements:

1. Are often made from ulterior motives
2. Often have downright poor and incomplete justification
3. Are subject to inevitable vagaries of meaning and understanding because of changing historical and cultural contexts.

If this were so, we would have to concede that the Dark Ages continue and that we are fated to live narrow intellectual lives, necessarily confined to a body of observation and thought circumscribed by its time, locale, and language.

The contrasting and, I think, much stronger view is implicit in Galileo: "The secrets of nature are written in the language of mathematics."[3] He was referring to the symbolic representation of relationships expressed as mathematics usually expresses them, in the timeless present. Here we have no tenses; we are dealing, as in logic, with rules and their sequelae, which are timelessly true. Thus, whatever inheres in the logical structure of the representations and the deductions that result from them is transferable across periods and cultures, at least in principle. In practice, this is near enough to the truth. We have no more trouble in deciphering Galileo's mathematical arguments, or Archimedes's for that matter, than those of contemporary mathematical physics—rather less, in fact. This is despite the fact that, unless we are

specialist historians, we know very little about Galileo's ambient culture, and even less about Archimedes's. Moreover, the skill involved passes effortlessly to anyone trained in mathematical science, even if he (or she) is Peruvian or Papuan. There is no further need of acculturation to "Western" ways.

But the arguments of the constructivists fail in other ways than these. For they depend, essentially, on the view that feelings—in particular, feelings generated by social demands—can generate beliefs of the kind that scientists typically traffic in. Again, to telescope the argument, they assert, in effect, that a scientist believes a given belief "because he is afraid not to." Simply put, they assert that the feeling of fear constructs the psychic condition of belief. Let us see if this is at all plausible.

First of all, the historical example of Galileo gives us a prime instance of the kind of evidence that will *not* prop up the constructivist argument. Consider Galileo's famous recantation, an utterance made from fear if ever there was one. On the constructivist view, one ought to hold that, given the intense persuasive force directed at him by his society and its most powerful institutions, Galileo not only renounced his former heliocentric views verbally, but actually readopted the Ptolemaic system as a matter of *belief.* After all, the pressures upon him were far more severe than anything experienced by the average working scientist; so, too, the feelings they evoked. Thus, the "constructive" power of his experience must have been exceptionally mighty!

Of course, very few of us infer that Galileo, whatever his utterances before the Inquisition, actually changed his beliefs. History is against this. A belief is, as we have said, something more than the propositional content of an utterance. It is a whole system of justifications, prior beliefs, and potential arguments and lines of inference from those prior beliefs. "I used to think X; now I think Y" conveys much more than the assertion that X is false, while Y is true. In particular, if made in earnest, it means that the speaker is prepared to give a cogent account of the truth of Y and of the invalidity of the previously credited arguments for X.

Now let us look at constructivism carefully. One's beliefs, remember, are not simply what follows the words "I believe." Consider the following sentences, quite similar as to grammatical structure, each purporting to explain something.

1. He believed it turned red because of oxidation.

This is an *explanation.* If it turned red for another reason, his belief is false. If we change "he" to "I" and contemplate the speaker, we merely have an instance of someone applying a theory of causation (right or wrong) to an observed fact.

2. He believed it turned red because he suddenly saw a red reflection in the glass.

This reports a belief and a piece of evidence for that belief. It is, of course, reasonable to believe that the color of an object changes if its reflection changes color. But the sentence itself is true precisely when it correctly reports the subject's thinking. There is no particular problem involved in grasping its truth conditions. If it turned red, but that was totally independent

of any red reflection, the sentence is still true. Again, changing "he" to "I" merely produces a report by an observant individual.

Now consider another purported reason for believing:

3. He believed it turned red because he was afraid not to.

Surprisingly, many of M. Latour's comments about "explicit interests," etc., fit this model. It may superficially resemble sentence 2, but there is no empirical or logical connection with the world of color here. Instead, there is an imputation of motive. Sentence 3 is about *him*, the "he" referred to in it, and in no way explains or supports anything's redness, insofar as anyone else in the world is concerned. Whereas in the prior case we too could well infer "redness" if we believed the subject's report about reflected light, nothing about his "fear" persuades us of anything.

Again, change "he" to "I." Now the insincerity is out in the open: his tongue spoke but not his heart. The explanatory *form* of the words suggests a relationship between the beginnings and ends of all of these sentences, separated by the word *because.* But in this case the relationship is set up between his *saying* something and his fear. An individual emotion-and-action is described here, not a generalizable rule or an observation about why or when things turn red. Doing something—here the act of making a statement—has been connected to its reason. This is like a motive or feeling, a reason for *doing* something, not something others can *believe* for the same or different reasons, like a prediction, observation, or opinion. Yet this is exactly what authors confuse who cite "ulterior motives" as reasons for believing (as opposed to saying that one believes)!

Note that in 1 and 2 the belief (that something turned red) is connected with what follows (oxidation or red reflections). Yet in 3 the belief in redness is actually undermined if what follows is true—i.e., if it were "held because of fear."

This is a revered maneuver of sophists: attaching irrelevant truth conditions to a given statement, thereby making the latter appear spurious. But here, as often is the case, the meanings of the words resist the form into which they have been forced: being afraid is not a good, not a mediocre, not even a bad reason for believing something has turned red. It is an impossible reason. Recall that one cannot believe (or indeed disbelieve) just because one wants to, any more than one can forget, or be grateful or happy by willful act.

One notes an intentionality about what one feels and what one says, that does not apply to what one silently believes. Many sophistic arguments fasten what one says to what one believes, attempting to convert agreement based on different premises into the seeming disagreement seen in *oratio obliqua.* Yet: "Socrates believed in the Forms because he reasoned that they were necessary," and "Plato believed in the Forms because Socrates taught him" suggests that they agreed, not that they disagreed.

Thus, while the contention "A said that he believed X because he was afraid not to" is unproblematical—it is the story we tell schoolchildren about Galileo—the contention "A believed X because he was afraid not to" leaves

one with many problems indeed. What, precisely, is the mechanism for the construction of this belief, remembering now that a belief is not merely assent to an isolated proposition? How is "society" supposed to construct the apparatus, which, remember, includes ready recourse to a line of argument—often multiple lines of argument, in fact? If it is merely asserted that whoever adapted the belief absorbed, in some fashion, all the lines of argument that point to the belief, then it hardly makes any sense to say that "he believes because he is afraid not to." The notion that he believes because he has been persuaded by a certain line of argument makes infinitely better sense in this context. On the other hand, to assert that he believes something (in the sense that a scientist believes) without having at hand the rather elaborate justificatory mechanisms that warrant calling a belief "scientific" is fatuous. At best, he has acquired the habit of rote recitation of a proposition. This may constitute "credence" at some level, but certainly not "belief" in accordance with the everyday habits of scientists and other rational inquirers.

This being said, the constructivist is either left with no argument, or with an argument for something much weaker than what he really wants to assert. Of course, social factors limit the evidence available to an inquirer and direct his attention to one class of questions rather than another; this kind of "construction" is more or less universally conceded. But that beliefs, in and of themselves, with their necessary mechanisms of justification standing at the ready, are adopted in toto independently of internal logical coherence and with indifference to observable evidence, out of the need or desire to conform with some kind of shadowy social ethos, defies plausibility. It is doubtful that Latour or anyone else has ever seen this phantom "in action." The best evidence on offer, when examined, seems to stem from versions of the Galileo fallacy—that a compelled utterance is evidence of a compelled belief.

## INTUITION AND BELIEF

As I noted above, an intuitive feeling—a hunch—cannot be a belief in the sense that a scientific belief is. To say it again, the very condition of being "intuitive" means that sufficient grounds of explicit persuasion are absent. Yet hunches and the like are often the chief guides to scientific research. It is not too much to say that no science could proceed, in a practical sense, without them. Even more, hunches, often dignified as educated guesses or disparaged as "gut feelings," frequently underlie the decisions that are made in medical practice as the basis for diagnostic tests and, in dire emergency, for vital decisions or "judgment calls." Hunches are, in short, grounds for action. This is often adduced as evidence for the "irrationality" of science and of the scientific community, as though this reliance on hunches was tantamount to the reliance of other cultures on belief systems that Western rationality decries as superstition. Is this comparison at all apt? In what sense is a hunch an "alternative way of knowing" like those so dear to the devotees of the postmodern?

Consider something that happens in the everyday practice of medicine, which I will call the "difficult case" scenario. A physician is having difficulty with a case. After the results of indicated tests have been analyzed and evaluated in light of the signs, symptoms, and history, the physician cannot diag-

nose the patient or even determine a means of proceeding further with the diagnosis. Typically, a specialist is called, and, since medicine is highly pragmatically oriented, he knows which specialist to seek. He does not pause to savor the problem as a problem. In all probability the problem has, indeed, been solved before, but that is not of the essence here, nor is it particularly helpful; time, not the sorting out of scholarly priority, is what is of the essence.

Why a specialist? What does that specialist have that the physician calling him in lacks? Almost inevitably, the answer given is "more experience." But of what advantage is that greater experience? Certainly, a bigger database has something to do with it; but most physicians would say that a significant factor, if not the most significant one, is intuition. Practically, this means making a decision, proceeding along a path that in others would be called "guesswork," and doing so, moreover, without being able to bring forth an explicit set of reasons for making that decision.

I believe that what the specialist physician does to "solve" a problem by intuition is to recognize, by some mechanism, the pattern that most likely fits the case, and to extend that pattern in time from what is currently known to what can be expected.

Two elements come into play. There is rational deduction, with facts being adduced, accepted theories brought consciously into focus, and the like. But this works in conjunction with intuitions and hunches that are not readily put into this framework. Why, then, is the specialist who works in this hybrid fashion trusted? Presumably, where "beliefs" are involved, the specialist could assure his colleagues of the rational grounds of his judgment, citing facts, studies, methodologies, and so forth, that fall within his particular ambit. But why trust his intuitions? Does this not carry us out of the realm of rationality? Not really, because part of the database of the physician and of his trusted colleagues is that so-and-so is a reliable specialist whose intuitions, whose "feeling" for cases of a certain sort, has proved reliable in the past.

Inevitably, there is some tension in such cases between the physician's real need to rely on the intuitive gifts of the specialist and his desire to have a plain line of fact and inference that can justify the guesswork. Yet nothing like "black magic" is involved here. We must note that these hintings and promptings and intuitions are not feelings like pain or giddiness. They have a cognitive content, and their import is directed to solving concrete problems, as they frequently manage to do. There are cerebral phenomena here, at times nonlinguistic, at times not self-conscious; but not, on that ground, necessarily *irrational.*

Recent advances in computer science, based on observations of actual neuronal function, as well as discoveries in mathematics may help us to understand what is involved. We certainly need not invoke emotion or irrational bias to explain it. Recall that artificial neural networks (ANNs), now a popular tool among computer researchers, perform functions that seem closely analogous to the intuitive judgments of human experts, including medical specialists. (Needless to say, they may do so without any knowledge, or bias, of race, sex, age, employment status, feelings, politics, or even their own future.)

ANNs can pick up, analyze, and indeed begin to describe patterns far more elaborate and subtle than humans have been able to discern. In fact, by searching for so-called grandmother neurons one can actually identify correlations that were not suspected by the people who put the data into a computer file in the first place. Basically, these networks function by strengthening the predictive connections between depictions of (sets of) events that are observed to occur together. While humans are good at identifying one, two, or possibly even five causes and effects operating simultaneously, the ANNs can do so for fifty variables with no trouble at all. These are not to be confused with "rule-following" expert systems. In such systems, the programmer provides a decision algorithm based on his own understanding of the factors involved and their interrelationships. ANNs, on the other hand, develop their own "rules" autonomously, and it may well be that the human programmer who sets the system going in the first place will be unable to decode the "rule" that emerges in comprehensible terms.

The beauty of ANNs for our purpose is that they refine and clarify our notions of "intuitions." At root, it is simply a question of perceiving the relative strengths of repeating patterns and "going with them" as much as the facts warrant. I emphatically suggest that this may be one of the things that we commonly identify as "operating by intuition." If this is so, then intuition, as we may plausibly argue, loses its connotations of subjectivism and prejudice. There may well be a psychological mechanism (or mechanisms) that provide us with cognitive rules and generalizations from experience of which we are consciously unaware, and which we find impossible to articulate or formalize. Nonetheless, the knowledge or surmise that intuition generates may be defended, in principle, as perfectly rational—no less so, really, than the beliefs whose roots in conscious inference we can trace. Thus, the fact that scientists exploit intuition in a variety of ways is no argument for asserting that science depends either on irrationality or the clairvoyant. Nor does it give any real comfort to constructivists, who might wish to argue that the "intuitive" is intrinsically more subject to socially induced biases and prejudices than is self-conscious reasoning. For one thing, the charge that the "intuitive" is inevitably contaminated by whim, emotion, or prejudice is seen to be dubious, at the least; for the cognitive sciences as well as computer models offer us paradigms of "intuitive" process from which these elements are clearly absent. Intuitive rationality, though its mechanisms still remain mysterious, is not an oxymoron.

## CONCLUSION

The influence of cultural factors on thought and feeling is undeniable. The power of culture to dictate which facts we focus on, which conclusions we are most interested in, is all too apparent. Yet all facts are equally accessible to logic. The consistency of the principles of science is what holds science together. The characteristics of a society may hold its science together—for example, through practical respect for the scientific method, widely applied standards of measurement, a cultural commitment to free speech and telling

the truth, and so forth. But in general the idiosyncracies of factious, polymorphous society are not part of science.

Wittgenstein remarked that "Philosophy arises when language goes on holiday."[4] We might say that postmodernism, in its various extravagant formulations—deconstruction, relativism, extreme social determinism—would have us put language—and science—on indefinite furlough. Under the postmodernist regime, there can be no confidence in data-based conclusions, because, it is held, language is incapable of bearing facts or of being used logically. Still less are we to trust reports of investigators; when they come from even the not-too-distant past, they are held to be "incommensurable" with contemporary thought.

Postmodernist understanding of statements and their truth leaves us paralyzed as regards predictions, for prediction depends on the truth of premises and on the validity of inference. If, as postmodernists would have it, meaning and truth are inexorably bound to context and historical setting, then the whole point of scientific theorizing would vanish, and science itself would have to be abandoned.

As I hope I have shown, the situation is not all that dire. The main thrust of the postmodernist assault on science is that its rationality is illusory, because what purports to be scientific rigor is helpless against irrationality in various forms. I have argued above that two of the chief props of the postmodernist critique—that scientific beliefs are mysteriously constructed by (unspecifiable) social processes, and that the reliance of science, and of medicine, on intuitive judgments ipso facto introduces nonrational elements into scientific discourse—cannot stand close examination. The defenders of science have a robust and vigorous client. It is unlikely to melt away under any version of the postmodernist critique.

## NOTES

1 See, for instance, Bruno Latour, *Science in Action*, pp. 21–48, for one highly influential version of the constructivist position.
2 Gilbert Ryle, *The Concept of Mind.*
3 Galileo Galilei, *Discoveries and Opinions.*
4 Ludwig Wittgenstein, *Philosophical Investigations.*

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# IN PRAISE OF INTOLERANCE TO CHARLATANISM IN ACADEMIA[a]

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UP UNTIL THE MID-1960s whoever wished to engage in mysticism or freewheeling, intellectual deceit or antiintellectualism had to do so outside the hallowed groves of academe. For nearly two centuries before that time the university had been an institution of higher learning, where people cultivated the intellect, engaged in rational discussion, searched for the truth, applied it, or taught it to the best of their abilities. To be sure once in a while a traitor to one of these values was discovered, but he was promptly ostracized. And here and there a professor, once tenured, refused to learn anything new and thus became quickly obsolete. But he seldom lagged more than a couple of decades, was still able to engage in rational argument as well as to distinguish genuine knowledge from bunk, and did not proclaim the superiority of guts over brains or of instinct over reason—unless, of course, he happened to be an irrationalist philosopher.

This is no longer the case. Over the past three decades or so very many universities have been infiltrated, though not yet seized, by the enemies of learning, rigor, and empirical evidence: those who proclaim that there is no objective truth, whence "anything goes," those who pass off political opinion as science and engage in bogus scholarship. These are not unorthodox original thinkers; they ignore or even scorn rigorous thinking and experimenting altogether. Nor are they misunderstood Galileos punished by the powers that be for proposing daring new truths or methods. On the contrary, nowadays many intellectual slobs and frauds have been given tenured jobs, are allowed to teach garbage in the name of academic freedom, and see their obnoxious writings published by scholarly journals and university presses. Moreover, many of them have acquired enough power to censor genuine scholarship. They have mounted a Trojan horse inside the academic citadel with the intention of destroying higher culture from within.

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The academic enemies of the very raison d'être of the university can be grouped into two bands: the antiscientists, who often call themselves "postmodernists," and the pseudoscientists. The former teach that there are no objective and universal truths, whereas the academic pseudoscientists smuggle fuzzy concepts, wild conjectures, or even ideology as scientific findings. Both gangs operate under the protection of academic freedom, and often at the taxpayer's expense, too. Should they continue to use these privileges, misleading countless students and misusing public funds in defaming the search for truth, or should they be expelled from the temple of higher learning? This is the main problem to be tackled in the present paper. But first let us sample the production of the academic antiscientists and pseudoscientists, restricting ourselves to the humanities and social studies.

## ACADEMIC ANTISCIENCE

Academic antiscience is part of the counterculture movement. It can be found in nearly all departments of any contemporary faculty of arts, particularly in the advanced countries. Let us take a look at a small sample of the antiscientific reaction inside the gates of Academia: existentialism, phenomenology, phenomenological sociology, ethnomethodology, and radical feminist theory.

### *Example 1: Existentialism*

Existentialism is a jumble of nonsense, falsity, and platitude. Let the reader judge by himself from the following sample of Heidegger's celebrated *Sein und Zeit*, dedicated to Edmund Husserl, his teacher and the founder of phenomenology. On human existence or being-there (*Dasein*): "Das Sein des Daseins besagt: Sich-vorweg-schon-sein-in-(der Welt-) als Sein-bei (innerweltlich begegnendem Seienden)."[1] On time: "Zeit ist ursprünglich als Zeitigung der Zeitlichkeit, als welche sie die Konstitution der Sorgestruktur ermöglicht."[2] I dare anyone to make sense of these wordplays, or even to translate them into standard German. Other famous formulas of Heidegger's, such as *Die Welt weltet* ("The world worlds"), *Das Nichts nichtet* ("Nothingness nothings"), *Die Sprache spricht* ("Language speaks"), and *Die Werte gelten* ("Values are valuable"), have the virtue of brevity but are just as nonsensical as the former.

Not content with writing nonsense and torturing the German language, Heidegger heaped scorn on "mere science" for being allegedly incapable of "awakening the spirit."[3] He also denigrated logic, "an invention of schoolteachers, not of philosophers."[4] Last, but not least, Heidegger was a Nazi ideologist and militant, and remained unrepentant until the end.[5] (No mere coincidence here: the training of obedient soldiers ready to die for an insane criminal cause starts by discouraging clear critical thinking.) In short, existentialism is no ordinary garbage: it is unrecyclable rubbish. Its study in academic courses is justified only as an illustration of, and warning against, irrationalism, academic imposture, gobbledygook, and subservience to reactionary ideology.

*Example 2: Phenomenology*

This school, the parent of existentialism, is characterized by opaqueness. Let the reader judge from this sample of its founder's celebrated attack upon the exact and natural sciences: "I as primaeval I [*Ur-Ich*] construct [*konstituire*] my horizon of transcendental others as cosubjects of the transcendental intersubjectivity that constructs the world."[6] Phenomenology is also a modern paragon of subjectivism. In fact, according to its founder the gist of phenomenology is that it is a "pure egology," a "science of the concrete transcendental subjectivity."[7] As such, it is "in utmost opposition to the sciences as they have been conceived up until now, i.e., as *objective* sciences."[8] The very first move of the phenomenologist is the "phenomenological reduction" or "bracketing out" (*épochè*) of the external world. "One must lose the world through *épochè* in order to regain it through universal self-examination."[9] He must do this because his "universal task" is the discovery of himself as transcendental (i.e., nonempirical) ego.[10]

Having feigned that real things such as chairs and colleagues do not exist, the phenomenologist proceeds to uncover their essences. To this end he makes use of a special intuition called "vision of essences" (*Wesensschau*), the nature of which is not explained, and for which no evidence at all is offered. The result is an a priori and intuitive science.[11] This "science" proves to be nothing but transcendental idealism.[12] This subjectivism is not only epistemological but also ontological: "the world itself is an infinite idea."[13]

How could anyone think that this wild fantasy could shed any light on anything except the decadence of German philosophy? This extravagance can only have at least one of two negative effects on social studies. One is to focus on individual behavior and deny the real existence of social systems and macrosocial facts; these would be the products of such intellectual procedures as aggregation and "interpretation" (guessing). The other possible negative effect is to alienate students from empirical research, thus turning the clock back to the times of armchair ("humanistic") social studies. The effect of the former move is that *social* science is impossible; that of the second is that social *science* is impossible. Either or both of these effects are apparent in the two schools to be examined next.

*Example 3: Phenomenological Sociology*[14]

This school is characterized by spiritualism and subjectivism, as well as by individualism (both ontological and methodological) and conservatism—ethical and political. The first two features are obvious: according to phenomenology social reality is a construction of the knower, not a given; for all social facts would be "meaningful" (have a purpose) and the subject of "interpretation" (guessing), whence everything social would be spiritual and subjective, or at most intersubjective, rather than material and observer independent. The ontological individualism of phenomenology derives from its subjectivism. Because individuals are said to "interpret" themselves and others, without ever facing any brute social facts, the task of the sociologist is to grasp "subjective meaning structures" rather than to construct or test models of social systems or processes. In particular, he must study the *Lebenswelt* or everyday life of

individuals, skirting such macrosocial issues as gender and race discrimination, mass unemployment, social conflict, and war. The phenomenological sociologist claims to grasp directly the objects of his study, alleging that they are ordinary. Moreover, let us remember that he is graced with the "vision of essences," which gives him instant insight. Hence he can dispense with statistics, mathematical modeling, tedious argument, and empirical test. In short, phenomenological sociology is avowedly nonscientific and an invitation to sloth.

*Example 4: Ethnomethodology*[15]

This is the offspring of the union of phenomenology with symbolic interactionism. The members of this school practice what phenomenological sociologists preach: they observe at first hand and record trivial events in the *Lebenswelt* or everyday life, focus on symbols and communication, and skirt any important activities, processes, and issues, particularly large-scale social conflicts and changes. They engage in participant (short-range) observation but shun experimentation, which they disapprove of on philosophical grounds. Lacking theories of their own, the ethnomethodologists invoke the murky pronouncements of hermeneutics, phenomenology, and even existentialism—all of them declared enemies of science. Obviously an antiscientific philosophy that opposes the search for objective truth could hardly inspire scientific research. Mercifully the ethnomethodologists make no use of these doctrines in their empirical work. As a matter of fact, in field work they behave as positivists—even while vehemently denouncing positivism—inasmuch as they spend most of their time collecting data, which they are unable to interpret correctly for want of theory.

In fact, the ethnomethodologist audiotapes and videotapes "the detailed and observable practices which make the incarnate [?] production of ordinary social facts, for example, order of service in a queue, sequential order in a conversation, and the order of skillfully embodied [?] improvised conduct."[16] Possible English translation: "The ethnomethodologists record observable ordinary life events." The data thus collected are audible or visible traces left by people who presumably behave purposefully and intelligently. These traces are the only clues the ethnomethodologists can go by, for, lacking a theory, they cannot tell us what makes people tick—i.e., they cannot explain the behavior they observe and record. Their practice does not differ from that of the empiricist and, in particular, the behaviorist—as even Atkinson, a sympathizer of the school, has admitted.[17] In short, they behave like positivists even while engaging in positivism bashing—actually a devious way of attacking the scientific approach.

Only the ethnomethodologists' convoluted lingo suggests intimate contact with their philosophical mentors. For example, Garfinkel starts one of his books by stating that ethnomethodology "recommends" that "the activities whereby members [of a group?] produce and manage settings [?] of organized everyday affairs are identical with members' procedures for making those settings 'account-able'[?]. The 'reflexive'[?] or 'incarnate'[?] character of accounting [?] practices and accounts makes up the crux of that recommen-

dation."[18] Or consider the same author's definition of ethnomethodology as "the investigation of the rational [intelligible?] properties of indexical [context-dependent] expressions and other practical actions as contingent [?] ongoing accomplishments [outcomes?] of organized artful [purposive?] practices of everyday life."[19] Why use extraordinary prose to describe ordinary accounts of ordinary life?

This is not to deny the value of observing everyday life occurrences, such as casual encounters and conversations—the favorite material of ethnomethodologists. Such observation, a common practice of anthropologists, yields raw material for the scientist to process in the light of hypotheses and with a view to coming up with new hypotheses. But that empirical material is of limited use unless it is accompanied by reliable information concerning the role that the observed subject enacts, e.g., boss or employee. The reason is that such roles—in other words, the system in which the protagonists are embedded—largely determine the "meaning" (purpose) of everyday actions and the content of conversations.[20] But ethnomethodologists overlook the macrosocial context and are not interested in any large social issues. This fact, combined with the absence of tests of the proposed "interpretations" (hypotheses) and the lack of theory, explains the paucity of findings of ethnomethodology.

A characteristic product of this school is Lynch's study "Sacrifice and the Transformation of the Animal Body into a Scientific Object: Laboratory Culture and Ritual Practice in the Neurosciences." Taking his cue from Durkheim's studies in the sociology of religion, Lynch claims that the killing of laboratory animals at the end of a run of experiments is part of a ritual practice whereby the body of the animal is transformed into "a bearer of transcendental significances." Characteristically, he presents no evidence for the extraordinary claim that the laboratory bench is just a sacrifice altar.

### *Example 5: Radical Feminist Theory*

The word "feminism" nowadays denotes three very different objects: the movement for women's emancipation from male domination; the scientific study of the feminine biological, psychological, and social condition; and radical feminist "theory." While the first two are legitimate and laudable endeavors, the third is an academic industry that makes no use of science. It is, moreover, hostile to science and is characterized by pseudoproblems and wild speculation. Some radical feminist theorists have promised a "successor science" that would eventually replace or at least complement what they call "male-dominated science." Others, more consistent, are dead against all science, because they believe that reason and experiment are weapons of male domination. They hold that the scientific method is part of the "male-stream." They denounce precision—in particular, quantitation, rational argument, the search for empirical data, and the empirical testing of hypotheses as so many tools of male domination. They are constructivist-relativists: they denounce what they call "the myth of objectivity." (More on this below under ACADEMIC PSEUDOSCIENCE.)

For example, the feminist theorists Belenky, Clinchy, Goldberger, and Tarule hold that truth is context dependent and that "the knower is an inti-

mate part of the known"—just because some of the women they interviewed felt so.[21] Sandra Harding goes as far as to assert that it would be "illuminating and honest" to call Newton's laws of motion "Newton's rape manual."[22] (The rape victim would be Mother Nature, which of course is feminine.) Moreover, basic science would be indistinguishable from technology, and the search for scientific knowledge would be just a disguise for the struggle for power—as Herbert Marcuse[23] and Michel Foucault[24] had claimed earlier on the strength of the same empirical evidence, namely none. The radical feminist philosophers are interested in power, not in truth. They want to undermine science, not to advance it. In this way they do a double disservice to the cause of feminine emancipation: they discredit feminism by making it appear to be barbaric, and they deprive it of a strong lever—namely the scientific research of the spurious causes and the pernicious effects of gender discrimination. Moreover, their attack on science alienates women from scientific studies and thus reinforces their subordinate position in modern society.[25]

To sum up, our antiscience colleagues are characterized by their appalling ignorance of the very object of their attack, namely science.[26] Lacking intellectual discipline and rigor, they have been utterly barren. This has not prevented them from misleading countless students, encouraging them to choose the wide door, incapacitating them to think straight and get their facts right, and in many cases even write intelligibly.[27] Why should any serious and socially responsible scholar tolerate barbarians intent on discrediting genuine scholarly pursuits and even destroying modern culture?

## ACADEMIC PSEUDOSCIENCE

To paraphrase Groucho Marx: the trademark of modern culture is science; if you can fake this, you've got it made. Hence the drive to clothe groundless speculations, and even old superstitions, with the gown of science. The popular pseudosciences, such as astrology, pyramidology, graphology, UFOlogy, "scientific" creationism, parapsychology, and psychoanalysis, are easy to spot, for they are obviously at variance with what is being taught at the science faculties. (Psychoanalysis would seem to refute this assertion, but it does not. Indeed, nowadays psychoanalysis is taught in only some psychiatry departments, which are part of medical schools, not of science faculties.) On the other hand, the academic pseudosciences are harder to spot partly because they are taught at university departments the world over. A second reason is that these pseudosciences abide by reason, or at least seem at first sight to do so. Their main flaws are that their constructions are fuzzy and do not match reality. (Some of them, such as neo-Austrian economics, even claim that their theories are true a priori.) Let us take a small sample, restricting our discussion to two trends: the love of spurious precision (in particular, pseudoquantification) and the post-Mertonian sociology of science.

### *Example 1: Pseudomathematical Symbolism*

Vilfredo Pareto, an original, insightful, and erudite student of society who used mathematics in economics, passes for being one of the founders of mathematical sociology merely because in this field he used some symbols other

than words. Thus, in his massive and famous *Trattato di sociologia generale* Pareto listed a number of "residues" or "forces," among them sentiments, abilities, dispositions, and myths.[28] He assumed tacitly that the "residues" are numerical variables. But, since he failed to define them, the symbols he used are mere abbreviations for intuitive notions. Unaware of this confusion between arbitrary symbols and symbols designating mathematical concepts, he wrote about the composition of such "forces."[29] Further down he introduced the formula "$q = A/B$," where $A$ stands for "the force of class I residues," and $B$ for "the force of class II residues" in a given social group or nation.[30] Roughly, $q$ would be the ratio of progressivism to conservatism. Since Pareto made no attempt to define any of these "magnitudes," he had no right to divide them or to assert that they increased or decreased quantitatively over time in any group or nation. Ironically, earlier in the same work (p. 509) he had warned that "Residues correspond to certain instincts in human beings, and for that reason they are usually wanting in definiteness, in exact delimitation."[31] And even earlier in the same work he had devoted an entire chapter to characterizing and criticizing pseudoscientific theories.[32] Likewise Pitirim Sorokin, one of the founders of American sociology and an early critic of what he called "quantophrenia," sometimes indulged in the latter.[33] For example, he defined the freedom of an individual as the quotient of the sum of his wishes by the sum of his means for gratifying them.[34] But since he did not bother to define wishes and means in a mathematically correct way, he "divided" words. In sum, the symbols he used in this case were mere shorthand for intuitive notions.

Professor Samuel Huntington, the famous Harvard political scientist, was far sloppier. In fact he proposed the following "equations" concerning the impact of modernization in developing nations:

$$\begin{aligned} \text{Social mobilization}/\text{Economic development} &= \text{Social frustration}, \\ \text{Social frustration}/\text{Mobility opportunities} &= \text{Political participation}, \\ \text{Political participation}/\text{Political institutionalization} &= \text{Political instability}.[35] \end{aligned}$$

Huntington did not define any of these "variables," he did not explain how numerical values could be assigned to them, and he did not even bother to tell us their dimensions and units. Obviously, he was unaware that he had "divided" words, not numerical values of honest functions. This was pointed out by the mathematician Neal Koblitz in a paper titled "Mathematics as Propaganda," which led Yale mathematician Serge Lang to campaign successfully against the induction of Professor Huntington into the United States Academy of Sciences. Regrettably, many political scientists and sociologists defended Huntington, thereby exhibiting their mathematical and methodological naiveté.[36]

Professor Gary Becker, a Nobel laureate at the University of Chicago, is famous for his economic approach to the study of human behavior. Unfortunately he leans heavily on undefined utility functions and tends to pepper his writings with symbols that do not always represent concepts. For example, a key formula of his theory of social interactions reads thus: "$R = D_i + h$."[37] Here $i$ labels an arbitrary individual, and $R$ is supposed to stand for "the

opinion of $i$ held by other persons in the same occupation"; and "$h$ measures the effect of $i$'s efforts, and $D_i$ the level of $R$ when $i$ makes no effort; that is, $D_i$ measures $i$'s 'social environment.'" Becker christens these "functions" but does not specify them. Consequently he adds words, not functions. We are not even told what the dimensions and units of these pseudomagnitudes are. Therefore, we would not know how to measure the corresponding properties and so to test for the adequacy of the formula.

Of course, pseudoquantitation is sufficient but not necessary to engage in pseudoscience. An alternative is to relate precise magnitudes in imprecise ways, such as "$Y$ is some function of $X$," where $X$ and $Y$ are well defined but the function is left unspecified. Milton Friedman's "theoretical framework for monetary analysis" is a case in point.[38] Indeed, it revolves around three undefined function symbols ($f$, $g$, and $l$). Hence it may at most pass for a research proposal, an aim of which would be to find the precise form of the hopeful functions in question. But the project does not seem to have been carried out. And in any case, given the bankruptcy of monetarism, the project does not seem worthy of being carried out.

*Example 2: Subjective Probability*

When confronted with a random or seemingly random process, one attempts to build a probabilistic model that could be tested against empirical data; no randomness, no probability. Moreover, as Poincaré pointed out long ago, talk of probability involves some knowledge; it is no substitute for ignorance. This is not how the Bayesians or personalists view the matter: when confronted with ignorance or uncertainty, they use probability—or rather their own version of it. This allows them to assign prior probabilities to facts and propositions in an arbitrary manner—which is a way of passing off mere intuition, hunch, or guess for scientific hypothesis. In other words, in the Bayesian perspective there is no question of objective randomness, randomization, random sample, statistical test, or even testability; it is all a game of belief rather than knowledge.

This approach contrasts with science, where gut feelings and wild speculations may be confided over coffee breaks but are not included in scientific discourse, whereas (genuine) probabilities are measured (directly or indirectly), and probabilistic models are checked experimentally. (Think of models of radiative and radioactive decay, Brownian motion, gene mutation, or random mating.) This is not to write off the scientific study of belief. Such study is important; and, precisely for this reason, it belongs in experimental psychology and sociology, and it should be conducted scientifically. There is no reason to believe that probability theory, a chapter of pure mathematics, is the ready-made (a priori) empirical theory of belief. In fact, there is reason to believe that credences are not probabilities, if only because we seldom know all the branches of any given decision tree.[39]

In the field of jurisprudence the so-called new evidence scholarship, born in the mid-1960s, claims to use probability to measure credence and in particular the credibility of legal evidence. In this connection there is even talk of "trial by mathematics."[40] I submit that probability hardly belongs in legal

argument because probability measures only the likelihood of random events, not the plausibility of a piece of evidence, the veracity of a witness, or the likelihood that a court of law will produce the just verdict. Consequently, talk of probability in law is pseudoscientific. Worse, the American and other criminal codes require the death penalty when "there is a probability that the defendant would commit criminal acts of violence"—as if such a "probability" (actually a mere plausibility) could be either measured or calculated. Thus sometimes not only property and freedom but even life hang on epistemologies that would not stand a chance in science or engineering, and whose only function is to justify an academic industry.

*Example 3: Subjective Utility*

Most of the utility "functions" occurring in neoclassical microeconomics and its applications to other social studies are not well defined—as Henri Poincaré pointed out to Léon Walras.[41] In fact, the only conditions required of them is that they be twice differentiable, the first derivative being positive and the second negative. Obviously, infinitely many functions satisfy these mild requirements. This often suffices in some branches of pure mathematics. (Likewise the general theory of metric spaces does not require the specification of the distance function.) But the factual (or empirical) sciences are more demanding: here one uses only functions that are defined explicitly (e.g., by infinite series or products) or implicitly (e.g., by differential equations together with initial or boundary conditions). Such specification makes for definite meaning, more exacting testability, and more rigorous measurement. Finally, experimental studies have shown that preferences and subjective estimates of utility and risk do not satisfy the assumptions of expected utility theory.[42]

In short, the use of utility functions is often mathematically sloppy and empirically unwarranted. Now, rational choice models make heavy use of both subjective utilities and subjective probabilities, as well as of the simplistic hypothesis that selfishness is the only motivation of human behavior. Not surprisingly, none of these models fits the fact. Hence, although at first sight they look scientific, as a matter of fact they are pseudoscientific.[43]

*Example 4: Loose Talk of Chaos Theory*

James N. Rosenau, a well-known politologist, has claimed that political instability and turbulence are similar to the instabilities and vortices of fluids, and, moreover, that they satisfy chaos theory.[44] However, he did not write, let alone solve, any nonlinear differential or finite difference equation for political processes; all he did was some hand-waving. Another politologist, Courtney Brown, does write some equations, but they happen to concern two key variables—level of public concern and environmental damage—that he fails to define, so that the formulas are only ornamental.[45]

All of the above-mentioned examples are exercises in either shorthand or mathematical name-dropping, not in genuine mathematical social science. What we have here is some of the accoutrements of science without its substance; i.e., we are in the presence of pseudoscience.

### *Example 5: Post-Mertonian Sociology of Science*

The modern sociology of science is a scientific discipline born in the 1930s around Robert K. Merton.[46] It attempts to investigate in a scientific way scientific communities and the interactions between scientific research and social structure; and it holds the former to be realist, disinterested, critical, and subject to a moral code. In the mid-1960s an irrationalist and idealist reaction against the Merton school was born.[47]

The pseudoscientific sociology of science, usually described as constructivist-relativist, claims to paint a far more realistic image of scientific research through jettisoning what are called the "myths" of disinterested research and objective truth. However, most of the new-style sociologists of science mistrust or even attack science. They regard it as an ideology, a power tool, an inscription-making device with no legitimate claim to universal truth, one more social construction on a par with myths, dress codes, and a variety of politicking. They regard scientists as skilled craftsmen but somewhat unscrupulous wheelers-dealers and unprincipled politicians. In short, they laugh at Merton's classical characterization of the scientific ethos.

The members of this school regard all facts, or at least what they call scientific facts, as constructions, none as given. (Thus, the book that earned Latour and Woolgar instant fame is titled *Laboratory Life: The Social Construction of Scientific Facts.*) But actually in matters of knowledge the only genuine social constructions are the exceedingly uncommon scientific forgeries committed by a team. A famous forgery of this kind was the Piltdown fossil man, "discovered" by two pranksters in 1912, certified as authentic by a number of experts (among them Father Teilhard de Chardin), and unmasked as a fake only in 1950. According to the existence criterion of constructivism-relativism we should admit that the Piltdown man did exist—at least between 1912 and 1950—just because the scientific community believed in it. Are we prepared to believe this, or rather to suspect that the self-styled post-Mertonians are incapable or even unwilling to tell hot air from cold fact?

Because the constructivist-relativists deny that there is any conceptual difference between science and other human endeavors, they feel entitled to pass judgment on the content of science, not only on its social context. Thus, after reading one of Einstein's popularizations of special relativity, Latour concludes that the poor man was wrong in believing that it deals with "the electrodynamics of moving bodies," the title of the founding paper—one that Latour could not possibly understand for lack of mathematical and physical competence.[48] The theory, he reveals to us, is about long distance travelers. Not only this: it renders everything physical relative to the knower (not to the reference frame), thus confirming subjectivism—the misinterpretation popular among idealist philosophers at the beginning of this century. There is no telling what further wonders these modern day "Darwins of science"—as Latour calls himself and his friends[49]—may bring.

Because the constructivist-relativists ignore science, they are incapable of distinguishing it from pseudoscience. Thus Michael Mulkay, a pioneer of the movement, waxed indignant over the way the scientific community treated Immanuel Velikovsky's allegedly revolutionary *Worlds in Collision* of 1950.[50]

He scolded scientists for their "abusive and uncritical rejection" of Velikovsky's fantasies and for clinging to their "theoretical and methodological paradigms"—among them the equations of celestial mechanics. He claimed that the astronomers had the duty to put Velikovsky's fantasies to the test. Obviously Mulkay ignores that the burden of proof rests on the would-be innovator, that nearly all of Velikovsky's claims have been proved wrong, and that scientists have more important tasks than to test fantasies that collide head-on with the bulk of scientific knowledge. However, a number of scientists, headed by Carl Sagan, did take their time to criticize in detail Velikovsky's fantasies, and the American Association for the Advancement of Science devoted an entire symposium to them.[51]

Other vocal constructivist-relativists have mounted spirited defenses of astrology and parapsychology.[52] They attack the critics of these pseudosciences for espousing what they call "the standard model of science," which they dub "ideology." Regrettably they do not propose an alternative "model" of science. They only call for a "reappraisal of scientific method" to make room for astrology, parapsychology, psychoanalysis, and other "extraordinary sciences." It would go against the grain of their school to propose its own clear-cut criteria of scientificity, since it holds science to be an ordinary "social construction." But how is it possible to discuss rationally the scientific status of an idea or practice otherwise than in the light of *some* definition of scientificity? As for the truth values of the alleged findings of astrologers, parapsychologists, and the like, how can we discuss them in the constructivist-relativist framework, where truth is said to be a social convention on a par with table manners?[53]

*Example 6: "Scientific" Racism*

Racism is very old, but "scientific" racism is a 19th-century invention that culminated with the Nazi *Rassenkunde* and the accompanying extermination camps. The American version of this doctrine was introduced by some psychologists on the basis of flawed IQ measurements, and it was entrenched in the American legislation restricting immigration from Southern Europe and other regions.[54] It was muted for a while in the wake of the revelation of the Nazi horrors, but it was resuscitated in 1969 by the Harvard professor Arthur Jensen, who, on the basis of some IQ measurements, asserted the innate intellectual inferiority of Afroamericans. This "finding" was unanimously rejected by the scientific community. In particular the Genetics Society of America warned against "the pitfalls of naive hereditarian assumptions."[55]

Yaron Ezrahi, a member of the constructivist-relativist pseudosociology of science, claimed that this denial was due to ideological reasons.[56] He held that the geneticists were particularly vehement in their criticisms of Jensen's work for being concerned, at least in part, with their own "public image and support." Ezrahi did not bother to analyze the very IQ tests from which Jensen had derived his "conclusions." Had he done so he might have learned that (a) such tests were indeed culture bound and thus likely to favor whites over blacks, and (b) no IQ test will be fully reliable unless it is backed up by a well-confirmed theory of intelligence—a theory that is overdue.[57]

Undaunted by such methodological criticisms, Richard Herrnstein and Charles Murray repeated the racist claim in their best seller *The Bell Curve* without adding any new evidence.[58] Their book was promoted by the American Enterprise Institute and widely publicized by right-wing journalists, who saw in this book the "scientific" basis for their proposal to eliminate all the social programs aimed at giving a chance to Afroamerican children and youngsters. The idea is, of course, that no amount of money, particularly if public, can correct for an allegedly genetic deficiency. This time around geneticists and psychologists were slow to react: perhaps they took the book for what it is, namely a political tract. On the other hand some journalists and sociologists did point out the methodological flaws of the book, uncovered its ideological sources, and denounced its implications for public policy.[59]

*Example 7: Feminist Technology*

Since technology is the art and science of getting things done, maintained, and repaired, psychotherapy and jurisprudence should be regarded as technologies. Now, in recent years these technologies have acquired a sex: there is now talk of feminist psychotherapy and feminist jurisprudence. Let us take a quick look at the former. A forte of feminist psychotherapy is "recovered memory therapy," consisting in "enhancing" a woman's memory—if necessary, with the help of hypnosis and drugs—until she "remembers" having been sexually abused by her father during childhood. The patient is then encouraged to take her father to court, in order to punish him and extract from him the maximum possible monetary compensation—to be shared with the therapist. This racket flourished during the past decade in the United States until the American Medical Association and above all the False Memory Syndrome Foundation warned the courts of law that they were being taken in. Thanks to this reaction the number of lawsuits of that type has started to decline. This is not to deny that many children are sexually abused by their relatives. What is objectionable is planting by the therapist of false memories into her patient and the "theory" that underlies this practice: the former is unscrupulous, and the latter false. Indeed, the theory in question is psychoanalysis, a pseudoscience according to which we never forget anything unless it is repressed by the "superego." This hypothesis is false: psychologists know that memory is not photographic but selective, distorting, and constructive. They also know that many people are suggestible, so that unscrupulous psychotherapists can successfully plant false memories in their brains.

To sum up, academic pseudoscience is just as toxic as academic antiscience. Why should serious and socially responsible scholars tolerate it? Being a travesty of scientific research, it should be dissected and exposed, taught only to exemplify bogus science.[60]

## TWO KINDS OF IGNORANCE: NATURAL OR STRAIGHT, AND CONTRIVED OR WILLFUL

No chemistry department would hire an alchemist. A department of crystallography is no place for believers in the psychic power of crystals. No engineering school would keep someone intent on designing a perpetual motion

machine. An astronomical observatory is no place for people who believe that the planets are pushed by angels. A biology department would close its doors to anyone who rejects genetics. No one who denies the existence of Nazi concentration camps or Communist labor camps would be able to teach history at a decent university. No mathematics department would tolerate anyone holding that logic is a tool of male domination and quantity is masculine. No Jungian psychology is taught in any self-respecting department of psychology. Whoever believes in homeopathy cannot make it into an accredited medical school. To generalize: neither proven falsities nor lies are tolerated in any scientific or technological institution. And for a good reason, too: namely, because such institutions are set up with the specific purpose of finding, refining, applying, or teaching truths, not just any old opinions.

Walk a few steps away from the faculties of science, engineering, medicine, or law, towards the faculty of arts. Here you will meet another world, one where falsities and lies are tolerated, nay manufactured and taught, in industrial quantities. Here the unwary student may take courses in all manner of nonsense and falsity. Here some professors are hired, promoted, or given power for teaching that reason is worthless, empirical evidence unnecessary, objective truth nonexistent, basic science a tool of either capitalist or male domination, and the like. Here we find people who reject all the knowledge painstakingly acquired over the past half-millennium. This is the place where students can earn credits for learning old and new superstitions of nearly all kinds, and where they can unlearn to write, so as to sound like phenomenologists, existentialists, deconstructionists, ethnomethodologists, or psychoanalysts. This is where taxpayers' moneys are squandered in the maintenance of the huge industry of cultural involution centered around the deliberate rejection of rational discussion and empirical testing. This fraud has got to be stopped in the name of intellectual honesty and social responsibility.

Let there be no mistake: I am not proposing that we teach only what can be ascertained as true. On the contrary, we must doubt our learning, and we must continue teaching that we are all ignorant in most respects and to some degree or other. But we must also teach that ignorance can be gradually overcome by rigorous research, that falsity can be detected, that partial truth can be attained and perfected—the way Archimedes illustrated with his method for computing successive approximations to the exact value of the area of the circle.

We must also realize and teach that there are two kinds of ignorance: natural and willful, traditional and postmodern. The former is unavoidable and its admission mandatory; it is part of being a curious learner and an honest teacher. By contrast, willful or postmodern ignorance is the deliberate refusal to learn items relevant to one's interests. Examples: the refusal of the psychotherapist and the philosopher of mind to learn some experimental psychology and neuropsychology; the refusal of the literary critic with sociological interests to learn some sociology; and the refusal of the philosopher of science to learn a bit of the science he pontificates about. All these are instances of willful ignorance. This is the only intolerable kind of ignorance, for it is a form of dishonesty. And yet this kind of ignorance is being peddled nowadays in many faculties of arts.

Willful ignorance comes in two guises: naked or naive, and disguised or contrived. Naked or *indocta ignorantia* is the clear rejection of science, or—what amounts to the same—the denial of any differences between science and nonscience, in particular pseudoscience. This is what the irrationalists and the relativist-constructivists preach: it is part of the radical feminist and environmentalist "theories," as well as of existentialism, poststructuralism, general semiotics, philosophical hermeneutics, deconstructionism, and similar obscurantist fads.

The first to deny the difference between science and nonscience was Paul K. Feyerabend, the philosophical godfather of the "new" philosophy and sociology of science. He has been listened to because he was wrongly believed to know some physics. But in fact his ignorance of this, the one science he tried to learn, was abysmal. Thus he misunderstood the only two formulas that occur in his *Against Method*, the book that earned him instant celebrity.[61] The first formula, which he calls "the equipartition principle," is actually the Maxwell-Boltzmann distribution function for a system of particles in thermal equilibrium. (Incidentally, the constant occurring in the correct formula is not $R$, the universal gas constant, but Boltzmann's far more universal $k$. This is no small mistake, because it renders Feyerabend's formula dimensionally wrong.) The second formula, Lorentz's, does not give "the *energy* of an *electron* moving in a *constant magnetic* field" (my emphases), as Feyerabend claims. Instead, the formula gives the *force* that an *arbitrary electromagnetic* field $\langle E, B \rangle$ exerts on a particle with an *arbitrary* electric charge. (Incidentally, the constant $c$ is missing in Feyerabend's copy—which, again, makes his formula dimensionally incorrect.) To top it all, Feyerabend substitutes the second formula into the first; and, not surprisingly, he gets an odd result that, in a mysterious way, leads him to speculate on the (nonexistent) magnetic monopoles imagined by his teacher Felix Ehrenhaft. But the substitution cannot be made, because (a) the second formula does not give us an energy, which occurs in the first one; (b) the first formula refers to a system of particles, whereas the second concerns a single particle; and (c) unlike the energy, which is a scalar, the force is a vector, and therefore it cannot occur by itself in the argument of an exponential function, which is defined only for scalars.[62] None of Feyerabend's critics detected these elementary errors—a disturbing indicator of the present state of the philosophy of science. In sum, one of the gurus of the new philosophy of science was guilty of *indocta ignorantia*. He was also seen as a guru of the student leftist movement.

However, irrationalism, in particular the distrust of science, has no political color; it is found left, center, and right. Still, in most cases it is passive: Babbitt is not Torquemada but is just indifferent to and suspicious of intellectual pursuits. On the other hand militant philistinism is strong in the New Left, the Old Right, and the religious wing of the New Right. This is no coincidence: all of these groups are authoritarian. And, as Popper pointed out half a century ago, authoritarianism is incompatible with rationalism in the broad sense, i.e., "the readiness to listen to critical arguments and to learn from experience."[63] Indeed, the citizen of a democracy is supposed to form his own opinions on matters of public interest, to debate them in the agora, and to par-

ticipate to some extent in the management of the commonwealth. Rationality is thus a necessary component of democratic life, just as irrationality is a necessary ingredient of the *dressage* of a faithful loyal subject of a totalitarian regime. Remember Mussolini's commandment: "Believe, obey, fight." So much for academic antiscience.

Academic pseudoscience is a different ball game: it is far more subtle and therefore harder to diagnose and uproot. Indeed, it wears some of the accoutrements of genuine science, in particular an esoteric jargon that fools the unwary, or even a symbolic apparatus that intimidates the innumerate. It looks like science, but is not scientific because it does not enrich knowledge; and, far from having a self-correcting mechanism, it is dogmatic. Because it misleads the innocent, academic pseudoscience is at least as damaging as outright antiscience.

## CONCLUSION

I submit that the academic charlatans have not earned the academic freedom they enjoy nowadays. They have not earned it because they produce or circulate cultural garbage, which is not just a nonacademic activity but an antiacademic one. Let them do that anywhere else they please, but not in schools; for these are supposed to be places of learning. We should expel the charlatans from the university before they deform it out of recognition and crowd out the serious searchers for truth. They should be criticized, nay denounced, with the same rigor and vigor that Julien Benda attacked the intellectual mercenaries of his time (1927) in his memorable *La trahison des clercs*—which, incidentally, earned him the hatred of the so-called organic intellectuals of all political hues. Spare the rod and spoil the charlatan. Spoil the charlatan and put modern culture at risk. Jeopardize modern culture and undermine modern civilization. Debilitate modern civilization and prepare for a new Dark Age.

In former times higher learning was only a refined form of entertainment and a tool of social control. Today it is all that and more: scientific knowledge, science-based technology, and the rationalist humanities are not only intrinsically valuable public goods but also means of production and welfare, as well as conditions of democratic debate and rational conflict resolution. The search for authentic knowledge should therefore be protected from attack and counterfeit both inside and outside Academia. To this end I propose the adoption of the following Charter of Intellectual Academic Rights and Duties:

1. Every academic has the duty to search for the truth and the right to teach it.
2. Every academic has the right and the duty to question anything that interests him, provided he does it in a rational manner.
3. Every academic has the right to make mistakes and the duty to correct them upon detecting them.
4. Every academic has the duty to expose bunk, whether popular or academic.
5. Every academic has the duty to express himself in the clearest possible way.

6. Every academic has the right to discuss any unorthodox views that interest him, provided those views are clear enough to be discussed rationally.
7. No academic has the right to present as true ideas that he cannot justify in terms of either reason or experience.
8. Nobody has the right to engage knowingly in any academic industry.
9. Every academic body has the duty to adopt and enforce the most rigorous known standards of scholarship and learning.
10. Every academic body has the duty to be intolerant to both counterculture and counterfeit culture.

To conclude. Let us tolerate, nay encourage, all search for truth, however eccentric it may look, as long as it abides by reason or experience. But let us fight all attempts to suppress, discredit, or fake this search. Let all genuine intellectuals join the Truth Squad and help dismantle the "postmodern" Trojan horse stabled in Academia before it destroys them.

## NOTES

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23 Herbert Marcuse, *One-Dimensional Man: Studies in the Ideology of Industrial Society.*
24 Michel Foucault, *Discipline and Punish.*
25 D. Patai & N. Koertge, *Professing Feminism. Cautionary Tales from the Strange World of Women's Studies*, p. 157.
26 P. R. Gross & N. Levitt, *Higher Superstition: The Academic Left and Its Quarrels with Science.*
27 For more on antiscience, particularly in social studies, see M. Bunge, *Finding Philosophy in Social Science.*

28 Vilfredo Pareto, *A Treatise on General Sociology*, section 2087.
29 Ibid., e.g., section 2148.
30 Ibid., section 2466.
31 Ibid., p. 509.
32 Ibid., chapter 5.
33 Pitirim Sorokin, *Fads and Foibles in Modern Sociology and Related Sciences.*
34 Pitirim Sorokin, *Social and Cultural Dynamics*, vol. 3, p. 162.
35 Samuel Huntington, *Political Order in Changing Societies*, p. 55.
36 See S. Lang, *The File.*
37 Gary S. Becker, *The Economic Approach to Human Behavior*, p. 257.
38 Milton Friedman, "A Theoretical Framework for Monetary Analysis."
39 See, e.g., D. Kahnemann, P. Slovic & A. Tversky, eds., *Judgment under Uncertainty: Heuristics and Biases*; and M. Bunge, "Two Faces and Three Masks of Probability."
40 See P. Tillers, "Decision and Inference" and the subsequent papers.
41 H. Poincaré, *Correspondence of Léon Walras and Related Papers*, vol. 3, pp. 164–165.
42 M. Allais, "The Foundations of a Positive Theory of Choice Involving Risk and a Criticism of the Postulates and Axioms of the American School"; A. Tversky, "A Critique of Expected Utility Theory: Descriptive and Normative Considerations"; J. W. Hernstein, "Rational Choice Theory: Necessary but Not Sufficient."
43 M. Bunge, "Game Theory is Not a Useful Tool for the Political Scientist"; "The Poverty of Rational Choice Theory"; *Philosophy in Social Science*; D. P. Green & I. Shapiro, *Pathologies of Rational Choice Theory: A Critique of Applications in Political Science.*
44 J. N. Rosenau, *Turbulence in World Politics. A Theory of Change and Continuity.*
45 Courtney Brown, "Politics and the Environment: Nonlinear Instabilities Dominate."
46 See, e.g., R. K. Merton, *The Sociology of Science. Theoretical and Empirical Investigations.*
47 See, e.g., the journal *Social Studies of Science*; B. Barnes, ed., *Sociology of Science. Selected Readings*; D. Bloor, *Knowledge and Social Imagery*; K. D. Knorr-Cetina & M. Mulkay, eds., *Science Observed. Perspectives on the Social Study of Science*; and B. Latour & S. Woolgar, *Laboratory Life: The Social Construction of Scientific Facts.*
48 B. Latour, "A Relativistic Account of Einstein's Relativity."
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50 M. Mulkay, "Some Aspects of Cultural Growth in the Natural Sciences."
51 D. Goldsmith, ed., *Scientists Confront Velikovsky. Papers from an AAAS Symposium.*
52 See, e.g., T. J. Pinch & H. M. Collins, "Is Anti-science Not-science?" and "Private Science and Public Knowledge: The Committee for the Scientific Investigation of the Claims of the Paranormal and Its Use of the Literature."
53 More criticisms in M. Bunge, "A Critical Examination of the New Sociology of Science, Part 1"; "A Critical Examination of the New Sociology of Science, Part 2"; L. Wolpert, *The Unnatural Nature of Science*; R. Boudon & M. Clavelin, eds., *Le relativisme est-il irrésistible? Regards sur la sociologie des sciences*; and R. Boudon, *Le juste et le vrai.*
54 See, e.g., S. J. Gould, *The Mismeasure of Man.*
55 E. S. Russell, "Report of the Ad Hoc Committee."
56 Y. Ezrahi, "The Political Resources of American Science."
57 See, e.g., M. Bunge & R. Ardila, *Philosophy of Psychology.*
58 R. J. Herrnstein & C. Murray, *The Bell Curve. Intelligence and Class Structure in American Life.*
59 C. Lane, "The Tainted Sources of 'The Bell Curve' " and the March 1995 issue of *Contemporary Society.*
60 More on pseudoscience in social studies may be found in M. Bunge, *Finding Philosophy in Social Science* and *Social Science under Debate.*

61 P. K. Feyerabend, *Against Method. Outline of an Anarchistic Theory of Knowledge*, p. 62.
62 More on Feyerabend's scientific incompetence in M. Bunge, "What is Science? Does It Matter to Distinguish It from Pseudoscience? A Reply to My Commentators."
63 K. R. Popper, *The Open Society and Its Enemies*, chapter 24.

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# THE FOUNDATIONS OF PHYSICS

PHYSICS HAS OFTEN been regarded as the model of incontrovertible rigor in the empirical sciences, whence the prevalence of "physics envy" in other disciplines. Yet there is much about the foundations of the subject that is still incompletely understood; and when people outside the discipline (and some within) are brought face to face with this fact, the consequence can be an exaggerated despair over the possibility of reasoned inquiry, or, even worse, an outright celebration of unreason and incoherence.

This section deals with several aspects of the situation. It begins with an exchange between physicists Sheldon Goldstein of Rutgers and Daniel Kleppner of MIT. Goldstein points out that the undoubted perplexities of quantum mechanics, along with the philosophical predispositions of Niels Bohr and Werner Heisenberg, among the principal founders, led to the emergence of a mystifying "quantum philosophy" that not only left the apparent contradictions of quantum mechanics unresolved, but declared, in advance, that any attempt to resolve them is foredoomed to failure. Even more curiously, the preeminence of the "Copenhagen interpretation" masked the work of David Bohm and John Bell, which did, in fact, unravel many of the conundra. In Goldstein's view, physicists (if not physics itself) bear some responsibility for the current celebration of unreason.

Daniel Kleppner responds as an experimentalist. For him, the most striking thing about quantum mechanics is its uncanny accuracy in predicting phenomena that can be confirmed by observation and experiment. Such striking empirical success convinces Kleppner that even though foundational loose ends may remain to be tied up to the satisfaction of philosophers, quantum mechanics is simply additional evidence that physics embodies a true, or at least highly accurate, picture of physical reality.

In recent years, with the emergence of such notions as "chaos" and "self-organization," there has been renewed attention to the foundations of classical thermodynamics and statistical mechanics. Some thinkers, notably Ilya Prigogine, have offered a postmodern interpretation, in which indeterminacy and a kind of uncertainty principle make their appearance in what has traditionally been an offshoot of classical deterministic mechanics. These interpretations have been welcomed by literary theorists and poststructuralist social thinkers as validation of the postmodern viewpoint. In the current essay, however, Belgian physicist Jean Bricmont argues in detail that many of the claims of Prigogine, *et al.*, are misconceived, deriving from errors that are as much mathematical as philosophical. Bricmont vindicates the insights of Ludwig Boltzmann, the founder of statistical mechanics, and shows that contemporary challenges to his views are poorly supported.

# QUANTUM PHILOSOPHY
## The Flight from Reason in Science[a]

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I WANT TO DISCUSS a rather delicate matter concerning a notoriously difficult subject, the foundations of quantum mechanics, a subject that has inspired a great many peculiar proclamations. Some examples:

> The idea of an objective real world whose smallest parts exist objectively in the same sense as stones or trees exist, independently of whether or not we observe them . . . is impossible.[1]

and

> We can no longer speak of the behavior of the particle independently of the process of observation. As a final consequence, the natural laws formulated mathematically in quantum theory no longer deal with the elementary particles themselves but with our knowledge of them. Nor is it any longer possible to ask whether or not these particles exist in space and time objectively. . . .
>
> Science no longer confronts nature as an objective observer, but sees itself as an actor in this interplay between man and nature. The scientific method of analysing, explaining, and classifying has become conscious of its limitations . . . method and object can no longer be separated.[2]

and

> A complete elucidation of one and the same object may require diverse points of view which defy a unique description. Indeed, strictly speaking, the conscious analysis of any concept stands in a relation of exclusion to its immediate application.[3]

This last quotation is an expression of what has traditionally been called complementarity—but what might nowadays be called multiphysicalism.

For my purposes here, what is most relevant about these sentiments is that they were expressed, not by lay popularizers of modern science, or by its postmodern critics, but by Werner Heisenberg and Niels Bohr, the two physicists

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most responsible, with the possible exception of Erwin Schrödinger, for the creation of quantum theory. It does not require great imagination to suggest that there is little in these sentiments with which a postmodernist would be inclined to disagree and much that he or she would be happy to regard as compelling support for the postmodern enterprise (see, for example, Notes 4–6).

The "quantum philosophy" expressed by such statements is part of the Copenhagen interpretation of quantum theory, which, in addition to the vagueness and subjectivity suggested by the preceding quotes, also incorporated as a central ingredient the notion that in the microscopic quantum domain the laws of nature involve irreducible randomness. The Copenhagen interpretation was widely, I would say at one time almost universally, accepted within the physics community, though there were some notable exceptions, such as Einstein and Schrödinger. Here is Schrödinger in 1926:

> Bohr's . . . approach to atomic problems . . . is really remarkable. He is completely convinced that any understanding in the usual sense of the word is impossible. Therefore the conversation is almost immediately driven into philosophical questions, and soon you no longer know whether you really take the position he is attacking, or whether you really must attack the position he is defending.[7]

and Schrödinger in 1959:

> With very few exceptions (such as Einstein and Laue) all the rest of the theoretical physicists were unadulterated asses and I was the only sane person left. . . . The one great dilemma that ails us . . . day and night is the wave-particle dilemma. In the last decade I have written quite a lot about it and have almost tired of doing so: just in my case the effect is null . . . because most of my friendly (truly friendly) nearer colleagues (. . . theoretical physicists) . . . have formed the opinion that I am—naturally enough—in love with "my" great success in life (viz., wave mechanics) reaped at the time I still had all my wits at my command and therefore, so they say, I insist upon the view that "all is waves." Old-age dotage closes my eyes towards the marvelous discovery of "complementarity." So unable is the good average theoretical physicist to believe that any sound person could refuse to accept the Kopenhagen oracle. . . .[8]

Einstein in 1949 offered a somewhat more constructive response:

> I am, in fact, firmly convinced that the essentially statistical character of contemporary quantum theory is solely to be ascribed to the fact that this (theory) operates with an incomplete description of physical systems. . . .
>
> [In] a complete physical description, the statistical quantum theory would . . . take an approximately analogous position to the statistical mechanics within the framework of classical mechanics.[9]

Part of what Einstein is saying here is that (much of) the apparent peculiarity of quantum theory, and in particular its randomness, arises from mistaking an incomplete description for a complete one.

In view of the radical character of quantum philosophy, the arguments offered in support of it have been surprisingly weak. More remarkable still is the fact that it is not at all unusual, when it comes to quantum philosophy,

to find the very best physicists and mathematicians making sharp emphatic claims, almost of a mathematical character, that are trivially false and profoundly ignorant. For example, John von Neumann, one of the greatest mathematicians of this century, claimed in 1932 to have mathematically proved that Einstein's dream, of a deterministic completion or reinterpretation of quantum theory, was mathematically impossible. He concluded:

> It is therefore not, as is often assumed, a question of a re-interpretation of quantum mechanics—the present system of quantum mechanics would have to be objectively false, in order that another description of the elementary processes than the statistical one be possible.[10]

This claim of von Neumann was, of course, just about universally accepted. For example, Max Born, who formulated the statistical interpretation of the wave function, assures us:

> No concealed parameters can be introduced with the help of which the indeterministic description could be transformed into a deterministic one. Hence if a future theory should be deterministic, it cannot be a modification of the present one but must be essentially different.[11]

However, in 1952 David Bohm, through a refinement of de Broglie's pilot wave model of 1927, found just such a reformulation of quantum theory.[12] Bohm's theory, Bohmian mechanics, was precise, objective, and deterministic—not at all congenial to quantum philosophy and a counterexample to the claims of von Neumann. Nonetheless, we still find, more than a quarter of a century after the discovery of Bohmian mechanics, statements such as these:

> The proof he [von Neumann] published . . ., though it was made much more convincing later on by Kochen and Specker, still uses assumptions which, in my opinion, can quite reasonably be questioned. . . . In my opinion, the most convincing argument against the theory of hidden variables was presented by J. S. Bell (1964).[13]

and

> This [hidden variables] is an interesting idea and even though few of us were ready to accept it, it must be admitted that the truly telling argument against it was produced as late as 1965, by J. S. Bell. . . . This appears to give a convincing argument against the hidden variables theory.[14]

Now there are many more statements of a similar character that I could have cited; I chose these partly because Wigner was not only one of the leading physicists of his generation, but, unlike most of his contemporaries, he was also profoundly concerned with the conceptual foundations of quantum mechanics and wrote on the subject with great clarity and insight.

There was, however, one physicist who wrote on this subject with even greater clarity and insight than Wigner himself, namely, the very J. S. Bell whom Wigner praises for demonstrating the impossibility of a deterministic completion of quantum theory such as Bohmian mechanics. So let us see how Bell himself reacted to Bohm's discovery:

> But in 1952 I saw the impossible done. It was in papers by David Bohm. Bohm showed explicitly how parameters could indeed be introduced, into nonrelativistic wave mechanics, with the help of which the indeterministic description could be transformed into a deterministic one. More importantly, in my opinion, the subjectivity of the orthodox version, the necessary reference to the "observer," could be eliminated.[15]

and Bell again:

> Bohm's 1952 papers on quantum mechanics were for me a revelation. The elimination of indeterminism was very striking. But more important, it seemed to me, was the elimination of any need for a vague division of the world into "system" on the one hand, and "apparatus" or "observer" on the other. I have always felt since that people who have not grasped the ideas of those papers . . . and unfortunately they remain the majority . . . are handicapped in any discussion of the meaning of quantum mechanics.[16]

Wigner to the contrary notwithstanding, Bell did not establish the impossibility of a deterministic reformulation of quantum theory, nor did he ever claim to have done so. On the contrary, over the course of the past several decades, until his untimely death several years ago, Bell was the prime proponent, for a good part of this period almost the sole proponent, of the very theory, Bohmian mechanics, that he is supposed to have demolished. What Bell did demonstrate is the remarkable conclusion that nature, if governed by the predictions of quantum theory, must be nonlocal, exhibiting surprising connections between distant events. And unlike the claims of quantum philosophy, this nonlocality *is* well founded, and, with the experiments of Aspect,[17] rather firmly established. Nonetheless, *it* is far from universally accepted by the physics community. Here is Bell, expressing his frustration at the obtuseness of his critics, and insisting that his argument for nonlocality involves no unwarranted assumptions:

> Despite my insistence that the determinism was inferred rather than assumed, you might still suspect somehow that it is a preoccupation with determinism that creates the problem. Note well then that the following argument makes no mention whatever of determinism. . . . Finally you might suspect that the very notion of particle, and particle orbit . . . has somehow led us astray. . . . So the following argument will not mention particles . . . nor any other picture of what goes on at the microscopic level. Nor will it involve any use of the words "quantum mechanical system," which can have an unfortunate effect on the discussion. The difficulty is not created by any such picture or any such terminology. It is created by the predictions about the correlations in the visible outputs of certain conceivable experimental set-ups.[18]

So what is the relevance of what I have described to the theme of this volume? Well, there is some bad news and some good news. The bad news, nothing you did not already know anyway, is that objectivity is difficult to maintain and that physicists, even in their capacity as scientists, are only human. Nothing new. I must say, however, that the complacency of the physics establishment with regard to the foundations of quantum mechanics has been, it seems to me, somewhat astonishing, though I must admit to

lacking sufficient historical perspective to have genuine confidence that what has occurred is at all out of the ordinary. But let me once again quote Bell:

> But why then had Born not told me of this "pilot wave"? If only to point out what was wrong with it? Why did von Neumann not consider it? . . . Why is the pilot wave picture ignored in text books? Should it not be taught, not as the only way, but as an antidote to the prevailing complacency? To show us that vagueness, subjectivity, and indeterminism, are not forced on us by experimental facts, but by deliberate theoretical choice?[19]

The last quoted sentence refers, of course, to the good news: that when we consider, not the behavior of physicists, but the physics itself, we find, in the stark contrast between the claims of quantum philosophy and the actual facts of quantum physics, compelling support for the objectivity and rationality of nature herself.

Here is one more bit of information somewhat relevant in this regard. You may well be wondering how, in fact, Bohm managed to accomplish what was so widely regarded as impossible, and what his completion of quantum theory involves. But you probably imagine that what eluded so many great minds could not be conveyed in but a few minutes, even were this an audience of experts. However, the situation is quite otherwise. In order to arrive at Bohmian mechanics from standard quantum theory one need do almost nothing! One need only avoid quantum philosophy and complete the usual quantum description in what is really the most obvious way: by simply including the positions of the particles of a quantum system as part of the state description of that system, allowing these positions to evolve in the most natural way.[20] The entire quantum formalism, including the uncertainty principle and quantum randomness, emerges from an analysis of this evolution.[21] My long-time collaborator, Detlef Dürr, has expressed this succinctly—though in fact not succinctly enough—by declaring that the essential innovation of Bohmian mechanics is the insight that *particles move*![22] Bell, referring to the double-slit interference experiment, put the matter this way:

> Is it not clear from the smallness of the scintillation on the screen that we have to do with a particle? And is it not clear, from the diffraction and interference patterns, that the motion of the particle is directed by a wave? De Broglie showed in detail how the motion of a particle, passing through just one of two holes in screen, could be influenced by waves propagating through both holes. And so influenced that the particle does not go where the waves cancel out, but is attracted to where they cooperate. This idea seems to me so natural and simple, to resolve the wave-particle dilemma in such a clear and ordinary way, that it is a great mystery to me that it was so generally ignored.[23]

I think this should be a bit of a mystery for all of us!

## NOTES

1 W. Heisenberg, *Physics and Philosophy*, p. 129.
2 W. Heisenberg, *The Physicist's Conception of Nature*, pp. 15, 29.
3 N. Bohr (1934), quoted by M. Jammer, in *The Philosophy of Quantum Mechanics*, p. 102.

4 A. Plotnitsky, *Complementarity: Anti-Epistemology after Bohr and Derrida.*
5 S. Aronowitz, *Science as Power: Discourse and Ideology in Modern Society.*
6 E. Fox Keller, "Cognitive Repression in Contemporary Physics."
7 E. Schrödinger, Letter to Wien, quoted by W. Moore in *Schrödinger*, p. 228.
8 E. Schrödinger, Letter to Synge, ibid., p. 472.
9 P. A. Schilpp, ed., *Albert Einstein, Philosopher-Scientist*, pp. 666, 672.
10 J. von Neumann, *Mathematical Foundations of Quantum Mechanics*, p. 325.
11 *Natural Philosophy of Cause and Chance*, p. 109.
12 "A Suggested Interpretation of the Quantum Theory in Terms of "Hidden" Variables, Parts I and II.
13 E. P. Wigner, "Interpretation of Quantum Mechanics," p. 291.
14 E. P. Wigner, "Review of Quantum Mechanical Measurement Problem," p. 53.
15 J. S. Bell, *Speakable and Unspeakable in Quantum Mechanics*, p. 160.
16 Ibid., p. 173.
17 A. Aspect, J. Dalibard & G. Roger, "Experimental Test of Bell's Inequalities Using Time-Varying Analyzers."
18 Bell, p. 150.
19 Ibid., p. 160.
20 D. Dürr, S. Goldstein & N. Zanghì. "Quantum Equilibrium and the Origin of Absolute Uncertainty"; "Quantum Mechanics, Randomness, and Deterministic Reality."
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# PHYSICS AND COMMON NONSENSE

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SCIENTISTS are naturally dismayed when the concepts, goals, and achievements of science are misrepresented in newspapers and books, and particularly when they are misrepresented in the halls of Congress. The problem is more than a matter of professional pride. At a time when society is undergoing profound changes—sometimes for the better but often, it seems, for the worse—the rejection of scientific reasoning and science itself is potentially suicidal. Under such circumstances, scientists cannot afford to remain silent.

Reasoned criticism of science can be constructive, but unreasoned criticisms seem to attract the most popular attention. In particular, two cornerstones of physics, relativity and quantum mechanics, are irresistible to science bashers who happen to have a philosophical bent. I propose to comment on relativity and quantum mechanics from the point of view of a practicing physicist for whom these cornerstones are familiar everyday objects. The broader issues—the growing manifestations of antiscience and the historical and social forces that are contributing to a deteriorating climate for rational thought—are discussed elsewhere in these proceedings and have been documented in books by three of the conference organizers. *Higher Superstition* by Paul R. Gross and Norman Levitt provides a chart for voyagers who set out to navigate the shoals of antiscience. Gerald Holton's *Science and Anti-Science* and *Einstein, History and Other Passions* not only discuss these issues but reward the reader with fascinating essays on science and the history of science.

A recurrent complaint among science critics is that physics no longer makes sense, that it has parted ways with reality. An example is an op-ed essay in the *New York Times* by John Lukacs (June 17, 1993) which argued that the proposed superconducting supercollider, a major high-energy accelerator, was unwise. His objections, however, were not really to the accelerator, which in any case was subsequently canceled, but to science itself. He saw little difference between modern science and medieval attempts to weigh the soul. Because of Heisenberg's uncertainty principle, he argued, it is impossible to speak either of "nature" or of "matter." In essence, physics deserves no respect because it has parted company with reality.

Brian Appleyard, in "Understanding the Present," also bemoans the split between physics and reality. He views physics as an "affront to common sense."[1] Somehow Appleyard came to believe that knowledge fails at the quantum level. "If reality behaved differently in different circumstances, did this mean there was no reality?" The same confusion is echoed by Stanley Aronowitz in "Science as Power," as described in "Higher Superstition."[2] "The argument roughly but accurately paraphrased . . . is that since physics has discovered the uncertainty principle, it can no longer provide reliable information about the physical world, has lost its claim to objectivity."

Whether or not physics has parted ways with common sense can only be answered by turning to the physics itself. So, here are a few comments on the two theories invariably cited to illustrate the alleged breakdown of common sense: relativity and quantum mechanics.

Years ago, popular accounts of special relativity were filled with awe at its apparently radical view of space and time. However, the theory is intensely conservative as Einstein himself recognized. Without relativity, the great classical edifice of electromagnetic theory would crumble, the underlying unity of electricity and magnetism would vanish, and we would be left with innumerable paradoxes. With relativity, however, the structure of electromagnetic theory is united so transparently that it can be summarized in a single equation.

Happily, no sophisticated knowledge of physics or mathematics is needed to understand relativity—indeed, it is often taught in the freshman year. Furthermore, the experimental evidence for relativity is overwhelming. For particle physicists, relativistic mechanics is as immediate and intuitive as the law of the lever. And for all physicists, relativity's intimate linkage between space and time provides a harmonious picture of events, much as Newton's mechanics provides a harmonious picture of planetary motion. Like every fundamental theory of physics, relativity has been tested time and again. Some tests have been at a precision of a part per billion. So far, there have been no discrepancies. Far from being an esoteric theory that baffles common sense, relativity is a simple, reliable, and essential tool for physicists.

General relativity, Einstein's theory of gravity, is far more complicated than special relativity. The geometry of curved space with its bending light beams and distortion of time seems totally alien to our everyday experience. Such behavior, however, is not as remote as one might guess. According to general relativity, gravity effects time, though the effect at the earth is fantastically small. The flow of time at points that differ in height by one meter is about one second in three hundred million years. This is small but by no means negligible, for the effect of gravity on time must be taken into account in the recently developed global positioning system for navigation. This system allows observers to find their positions within a few hundred feet anywhere on earth. It works by comparing timing signals from various satellite-borne clocks. If general relativity were overlooked, a plane from San Francisco that was aiming for the middle of a runway at LaGuardia airport would find itself somewhere in New Jersey. That the flow of time depends on gravity may defy common sense, but rejecting that fact would be roughly tantamount to joining the Flat Earth Society.

One can gain a reasonable knowledge of relativity from any number of popular books, and it is often introduced in elementary physics courses. Quantum mechanics requires a little more work. A sophomore in physics can learn a good deal about it, and a junior can easily achieve a working mastery. To gain real intuition into the quantum world, however, requires some experience. For an experimenter, that could mean listening to the clicks or seeing the blips that indicate something has happened, or watching patiently as an interference pattern, resonance signal, or some other picture of quantum reality emerges from the data. It means designing an apparatus based on the laws of quantum mechanics and watching it come alive in harmony with those laws.

At a deeper level, understanding quantum mechanics means appreciating that it makes everything we measure measurable. At such a level of familiarity, there is nothing vague or tenuous about it. Quantum mechanics provides the language for describing what we see in the world of atoms and molecules. That world is no longer remote from our immediate experience. Today one can see with the naked eye the light radiated by a single atom, take photographs of atoms resting on a crystalline surface, and move them much as children move building blocks on a table. Quantum mechanics provides the language for describing this world. To those who understand it, the language is beautiful.

Unfortunately, quantum mechanics carries a mystique of mathematical complexity. C. P. Snow, in his autobiographical novel *The Search*, describes the enviable career of a young scientist at Cambridge University, a crystallographer who achieved eminence at a young age. The world was his oyster when he abruptly turned his back on science and started a new career in literature. The reason? The problem was not spiritual, religious, or romantic. It was mathematical. Quantum mechanics had just been invented, and though he was a brilliant scientist, he concluded that he lacked the mathematical talent needed to become one of the new scientists. I recall reading that story as I myself was struggling to learn quantum mechanics, and feeling rather annoyed that Snow had quit science so easily over material my teachers now expected me to take in stride. They were, of course, correct.

From time to time, Heisenberg's uncertainty principle, a central tenet of quantum mechanics, is cited by many critics, including Appleyard, as evidence that modern science has abandoned the search for objective knowledge. The impossibility of simultaneously measuring certain variables to arbitrary accuracy is unacceptable to these critics because it defies common sense. By the familiar rules of common sense, however, the very existence of matter is absurd. Here is the reason. There is abundant evidence that atoms are composed of negative electrons bound electrically to a positive nucleus. By the elementary law of electrical attraction, these particles should simply collapse into each other. If this happened, atoms and molecules—in fact, all of matter as we know it—could not exist. Fortunately, quantum mechanics provides not only a simple explanation for why this does not occur, why matter is actually stable, but also a marvelously detailed account of the structure of atoms.

Quantum mechanics also provides a natural explanation for a property of matter that is so deeply rooted in our consciousness that we merely take it for granted: the repetition of forms in nature. Why are identical atoms the same everywhere? On the human scale, identical objects are never exactly identical. On the atomic scale, they are. Without such exact identity, the atomic and molecular structures that underlie the physical and biological world around us could not exist. The concept of identity is inherent in the structure of quantum mechanics. Unless particles are exactly the same, they are totally different; there are no such things as "almost identical" particles. Once again, quantum mechanics defies naive common sense. To the generous eye, the world as we see it is a gift of quantum mechanics.

Another fallacious belief is that the uncertainty principle makes it impossible to know things accurately. The truth is otherwise. The precision of modern physics, in which some fundamental theories have been verified to a part in a trillion and most of the important physical constants have been measured to at least a part in a million, is in reality a gift from quantum mechanics. Although the uncertainty principle determines the scale for precision in individual measurements, it by no means limits the ultimate accuracy to which things can be measured. Rather than making things unknowable, the uncertainty principle provides the foundation for the incredible accuracy of measurements in modern physics.

The wave-particle duality is yet one more target for antiscientists. According to the principle of complementarity, physical entities can display properties that are fundamentally incompatible. To some people this is deeply disturbing because it defies—once again—common sense. The best known example is the wave-particle duality. It is a simple fact of observation that particles can exhibit wavelike properties, as in matter wave diffraction, and waves can exhibit particle-like properties, as in the photoelectric effect. There is, however, no inherent contradiction. Whether one wishes to observe particle properties or wave properties is a matter of choice, but the rule is that one cannot observe them simultaneously. This is the essence of the principle of complementarity. If one wishes, this can be viewed as a consequence of the uncertainty principle. Experimentally, there is no confusion. One can design an experiment to measure wave properties or particle properties, or, if one is more ambitious, even some combination of the two. In the latter case, however, the measurements of each property are invariably degraded.

In practice, quantum mechanics is a superb tool for studying and describing phenomena at the atomic level. Having given it this accolade, let me turn briefly to the debate on its conceptual foundations and the problems of measurement theory described elsewhere in these proceedings by Sheldon Goldstein.[3] That debate has been waged at various levels since quantum mechanics was first formulated, but the standard interpretation, the so-called Copenhagen interpretation, has stood the test of time and is widely accepted. Alternative formulations appear ultimately to yield the same description. The major advance in the past thirty years was the analysis by John Bell of possible incompleteness in the quantum description.[4] He proposed an experimental test that was carried out and which provided dramatic evidence for the stan-

dard formulation. So, unless the debate leads to new experimental tests, or provides a simpler description of known facts, it will continue to lie outside of the mainstream of physics. To me, if there is an underlying worry about the nature of quantum mechanics, it is that the theory works too well. Physical theories ultimately rest on observation, and just as observations are necessarily limited in scope, theories are necessarily limited in validity. So far, however, nobody seems to know the limitations of quantum mechanics.

To the critics who believe that physics affronts common sense and defies intuition, I pass on the advice sometimes given to students by a colleague at MIT, Arthur Mattuck, Professor of Mathematics: "*Don't use your intuition if you don't possess it!*" The tirades against relativity or quantum mechanics reflect little knowledge of the subject. Neither physicists nor philosophers need licenses to practice their professions, much less lay critics of science. These critics would command more respect, however, if they took the trouble to understand what they were criticizing. Physicists, for their part, have an obligation not to remain silent but to speak up when they encounter nonsense about physics.

## NOTES

1 Brian Appleyard, "Understanding the Present," p. 157.
2 Paul R. Gross & Norman Levitt, *Higher Superstition: The Academic Left and Its Quarrels With Science*, p. 51.
3 "Quantum Philosophy: The Flight from Reason in Science."
4 J. S. Bell, *Physics* 1 (1964): 195; and A. Aspect, "Atomic Physics 8," p. 103.

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# SCIENCE OF CHAOS OR CHAOS IN SCIENCE?

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IN THIS CHAPTER I try to clarify several confusions in the popular literature concerning chaos, determinism, the arrow of time, entropy and the role of probabilities in physics. Classical ideas going back to Laplace and Boltzmann are explained and defended, while some recent views on irreversibility, due to Prigogine, are criticized.

## 1 INTRODUCTION

> *We might characterize today's breakdown of industrial or "Second Wave" society as a civilizational "bifurcation," and the rise of a more differentiated, "Third Wave" society as a leap to new "dissipative structures" on a world scale. And, if we accept this analogy, might we not look upon the leap from Newtonianism to Prigoginianism in the same way? Mere analogy, no doubt. But illuminating, nevertheless.*
>
> —ALVIN TOFFLER

Popularization of science seems to be doing very well: the Big Bang, the theory of elementary particles or of black holes are explained in countless books for the general public. The same is true for chaos theory, irreversibility or self-organization. However, it seems also that a lot of confusion exists concerning these latter notions, and that at least some of the popular books are spreading misconceptions. The goal of this article is to examine some of them, and to try to clarify the situation.

In particular, I will make a critical evaluation of the various claims concerning chaos and irreversibility made by Prigogine and by Stengers, since "La Nouvelle Alliance." Several of those claims, especially the most recent ones, are rather radical: "the notion of chaos leads us to rethink the notion of 'law of nature.'"[1] For chaotic systems, "*trajectories are eliminated from the probabilistic description* . . . The statistical description is *irreducible.*"[2] The existence of chaotic dynamic systems supposedly marks a radical departure from a fundamentally deterministic worldview, makes the notion of trajectory obsolete, and offers a new understanding of irreversibility. Prigogine and Stengers claim that the classical conception was unable to incorporate time

in our view of the world[3] or to account for the irreversibility of macroscopic phenomena. Boltzmann's attempt to explain irreversibility on the basis of reversible laws failed.[4]

On the basis of these physical theories, a number of speculations are put forward on the notion of "event," on the place of human beings in Nature, or even on overcoming Cartesian dualism.[5] These writings have been indeed quite influential, mostly among nonexperts. They are frequently quoted in philosophical or cultural circles as an indication that chaos, nonlinear phenomena, and the "arrow of time" have led to a profound revolution in our way of thinking.

I want to develop quite different views on most of these issues. In my opinion, chaos does not invalidate in the least the classical deterministic worldview (the existence of chaotic dynamical systems actually strengthens that view). Besides, chaos is not related in a fundamental way to irreversibility. Finally, when they are correctly presented, the classical views of Boltzmann perfectly account for macroscopic irreversibility on the basis of deterministic, reversible, microscopic laws. Part of the difficulty in understanding those views comes from some confusions about the use of the words "objective" and "subjective," associated with probability or entropy. I will try to be careful with these notions. I will also argue that most of the speculation on the new alliance between Man and Nature is misguided.

On the other hand, I believe that the ideas of Laplace and of Boltzmann are worth defending against various misrepresentations and misunderstandings. Quite independently of the work of Prigogine, there are serious confusions that are found in the literature on irreversibility, chaos, or time (some of which go back to philosophers such as Popper, Feyerabend, or Bergson). Besides, many textbooks or popular books on statistical mechanics are rather obscure, at least in the part concerning the foundations of the field (e.g., on the role played by ergodic theorems). I will try to clarify these questions too.

I wrote this paper in nontechnical language, relegating formulas to footnotes and remarks. Nothing of what I say is new.[6] In fact, everything is quite standard and old, and it is a sad fact that those ideas that were so nicely explained by Boltzmann a century ago[7] have to be reexplained over and over again.

Finally, I have to emphasize that this is in no way a criticism of Prigogine's work in general, and even less of the Brussels school. I am concerned here only with the part dealing with chaos and irreversibility (which, however, occupies the largest fraction of the popular books). I believe that a lot of interesting scientific ideas have been developed around Prigogine and that he has had an exceptional taste for discovering new directions in physics, whether in irreversible thermodynamics or in chaotic phenomena. But this does not put his views on foundational questions beyond criticism.[8]

## 2 CHAOS AND DETERMINISM: DEFENDING LAPLACE

*The concept of dog does not bark.*

—SPINOZA

### 2.1 *Determinism and Predictability*

A major scientific development in recent decades has been popularized under the name of "chaos." It is widely believed that this development implies

a fundamental philosophical or conceptual revolution. In particular, it is thought that the classical worldview brilliantly expressed by Laplace in his "Philosophical Essay on Probabilities" has to be rejected.[9] Determinism is no longer defensible. I think this is based on a serious confusion between *determinism* and *predictability.* I will start by underlining the difference between the two concepts. Then it will be clear that what goes under the name of chaos is a major scientific progress but does not have the radical philosophical implications that are sometimes attributed to it.

In a nutshell, determinism has to do with how Nature behaves, and predictability is related to what we human beings are able to observe, analyze, and compute. It is easy to illustrate the necessity for such a distinction. Suppose we consider a perfectly regular, deterministic *and* predictable mechanism, like a clock, but put it on the top of a mountain, or in a locked drawer, so that its state (its initial conditions) becomes inaccessible to us. This renders the system trivially unpredictable, yet it seems difficult to claim that it becomes nondeterministic.[10] Or consider a pendulum: when there is no external force, it is deterministic and predictable. If one applies to it a periodic forcing, it may become unpredictable. Does it cease to be deterministic?

In other words, anybody who admits that *some* physical phenomena obey deterministic laws must also admit that some physical phenomena, although deterministic, are not predictable, possibly for "accidental" reasons. So a distinction must be made.[11] But once this is admitted, how does one show that *any* unpredictable system is *truly* nondeterministic, and that the lack of predictability is not merely due to some limitation of our abilities? We can never infer indeterminism from our ignorance alone.

Now, exactly what does one mean by determinism? Maybe the best way to explain it is to go back to Laplace: "Given for one instant an intelligence which could comprehend all the forces by which nature is animated and the respective situation of the beings who compose it—an intelligence sufficiently vast to submit these data to analysis—it would embrace in the same formula the movements of the greatest bodies of the universe and those of the lightest atom; for it, nothing would be uncertain and the future, as the past, would be present before its eyes."[12] The idea expressed by Laplace is that determinism depends on what the laws of nature are. Given the state of the system at some time, we have a formula (a differential equation, or a map) that gives in principle the state of the system at a later time. To obtain predictability, one has to be able to measure the present state of the system with enough precision, and to compute with the given formula (to solve the equations of motion). Note that there exist alternatives to determinism: there could be no law at all; or the laws could be stochastic: the state at a given time (even if it is known in every conceivable detail) would determine only a probability distribution for the state at a later time.

How do we know whether determinism is true—i.e., does nature obey deterministic laws? This is a rather complicated issue. Any serious discussion of it must be based on an analysis of the fundamental laws, hence of quantum mechanics, and I do not want to enter this debate here.[13] Let me just say that it is conceivable that we shall obtain, some day, a complete set of fundamental physical laws (like the law of universal gravitation in the time of Laplace), and

then we shall see whether these laws are deterministic or not.[14] Any discussion of determinism outside of the framework of the fundamental laws is useless.[15] All I want to stress here is that the existence of chaotic dynamic systems do not affect this discussion *in any way.* What are chaotic systems? The simplest way to define them is through sensitivity to initial conditions. This means that, for any initial condition of the system, there is some other initial condition, arbitrarily close to the first one so that, if we wait long enough, the two systems will be markedly different.[16] In other words, an arbitrarily small error on the initial conditions makes itself felt after a long enough time. Chaotic dynamic systems are, of course, unpredictable in practice, at least for long enough times,[17] since there will always be some error in our measurement of the initial conditions. But this does not have any impact on our discussion of determinism, since we are assuming from the beginning that the system obeys some deterministic law. It is only by analyzing this deterministic system that one shows that a small error in the initial conditions may lead to a large error after some time. If the system did not obey any law, or if it followed a stochastic law, then the situation would be very different. For a stochastic law, two systems with the *same* initial condition could be in two very different states after a short time.

It is interesting to note that the notion that small causes can have big effects (in a perfectly deterministic universe) is not new at all. Maxwell wrote: "There is a maxim which is often quoted, that 'The same causes will always produce the same effects.'" After discussing the meaning of this principle, he adds: "There is another maxim which must not be confounded with that quoted at the beginning of this article, which asserts 'That like cause produce like effects.' This is only true when small variations in the initial circumstances produce only small variations in the final state of the system."[18] One should not conclude from these quotations[19] that there is nothing new under the sun. A lot more is known about dynamic systems than was known in the time of Poincaré. But the general idea that not everything is predictable, even in a deterministic universe, has been known for centuries. Even Laplace emphasized this point: after formulating universal determinism, he stresses that we shall always remain "infinitely distant" from the intelligence that he just introduced. After all, why is this determinism stated in a book on *probabilities*? The reason is obvious: for Laplace, probabilities lead to rational inferences in situations of incomplete knowledge (I shall come back later to this view of probabilities). So he is assuming from the beginning that our knowledge is incomplete, and that we shall never be able to *predict* everything. It is a complete mistake to attribute to some "Laplacian dream" the idea of perfect predictability.[20] But Laplace does not commit what E. T. Jaynes calls the "Mind Projection Fallacy": "We are all under an ego-driven temptation to project our private thoughts out onto the real world, by supposing that the creations of one's own imagination are real properties of Nature, or that one's own ignorance signifies some kind of indecision on the part of Nature."[21] As we shall see, this is a most common error. But whether we like it or not, the concept of dog does not bark, and we have to carefully distinguish between our representation of the world and the world itself.

Let us now see why the existence of chaotic dynamic systems in fact supports universal determinism rather than contradicts it.[22] Suppose for a moment that the world would be such that no classical mechanical system can behave chaotically. That is, suppose we have a theorem saying that any such system must eventually behave in a periodic fashion.[23] It is not completely obvious what the conclusion would be, but certainly *that* would be an embarrassment for the classical worldview. Indeed, so many physical systems seem to behave in a nonperiodic fashion that one would be tempted to conclude that classical mechanics cannot adequately describe those systems. One might suggest that there must be an inherent indeterminism in the basic laws of nature. Of course, other replies would be possible: for example, the period of those classical motions might be enormously long. But it is useless to speculate on this fiction, since we know that chaotic behavior is compatible with a deterministic dynamics. The only point of this story is to stress that deterministic chaos increases the explanatory power of deterministic assumptions and therefore, according to normal scientific practice, *strengthens* those assumptions. And if we did not know about quantum mechanics, the recent discoveries about chaos would not force us to change a single word of what Laplace wrote.[24]

### 2.2 *Trajectories and Probabilities*

Now I will turn to the main thesis of Prigogine and Stengers on chaotic dynamic systems: the notion of trajectory should be abandoned, and replaced by probabilities. What does it mean? Let me quote Prigogine: "We must therefore eliminate the notion of trajectory from our microscopic description. This actually corresponds to a realistic description: no measurement, no computation leads strictly to a point, to the consideration of a *unique* trajectory. We shall always face a *set* of trajectories."[25]

Let us see how reasonable it is to "eliminate the notion of trajectory" for chaotic systems by considering a concrete example.[26] Take a billiard ball on a sufficiently smooth table, so that we can neglect friction (for some time), and assume that there are suitable obstacles and boundaries so that the system is chaotic. Now suppose that we use an "irreducible" probabilistic description—that is, instead of assigning a position to the ball, we assign to it a probability distribution.[27] Consider next the evolution of that probability distribution. Since we are dealing with a chaotic system, that distribution will spread out all over the billiard table. This means that after a rather short time, there will be an almost uniform probability of finding the ball in any given region of the table. Indeed, even if our initial probability distribution is well peaked around the initial position of the ball, there will be lots of nearby initial conditions that will give rise to very different trajectories (that is exactly what it means to say that the system is chaotic). But now we can hardly take the probability distribution after some time seriously as an "irreducible" *description* of the system. Indeed, whenever we look at the system, we find the ball somewhere, at a rather well-defined position on the table. It is certainly not completely described by its probability distribution. The latter describes adequately our knowledge (or rather our ignorance) of the system, obtained

on the basis of our initial information. But it would be difficult to commit the Mind Projection Fallacy more radically that to confuse the objective position of the ball and our best bet for it. In fact, chaotic systems illustrate this difference: if all nearby initial conditions followed nearby trajectories, the distinction between probabilities and trajectories would not matter too much. But chaotic systems show exactly how unreasonable is the assignment of "irreducible" probabilities, since the latter quickly spread out over the space in which the system evolves.

What the example of the billiard ball shows is that we must distinguish different levels of analysis: first of all, we may describe the system in a certain way: we may assign to the ball at least an approximate position at each time, hence an approximate trajectory.[28] Certainly the ball is not *everywhere*, as the "irreducible" probabilistic description would suggest. The next thing we can do is try to find exact or approximate laws of motion for the ball. The laws of elastic reflection against obstacles, for example. Finally, we may try to solve the equations of motion. We may not be able to do the last step. But this does not mean that one should give up the previous ones. We may even realize that our laws are only approximate (because of friction, of external perturbations, etc. . . .). But why give up the notion of (approximate) trajectories? Of course, since we are not able to predict the evolution of trajectories, one may *choose* to study instead the evolution of probability distributions. This is perfectly reasonable, as long as one does not forget that, in doing so, we are not only studying the physical system but also our ability or inability to analyze it in more detail. This will be very important in the next section.

At this point, I want to briefly discuss the classical status of probabilities in physics, i.e., of probabilities as "ignorance." This will also be very important in the next section. To quote Laplace again: "The curve described by a molecule of air or of vapour is following a rule as certainly as the orbits of the planets: the only difference between the two is due to our ignorance. Probability is related, in part to this ignorance, in part to our knowledge."[29] Let us consider the usual coin throwing experiment. We assign a probability 1/2 to heads and 1/2 to tails. What is the logic of the argument? We examine the coin, and we find out that it is fair. We also know the person who throws the coin, and we know that he does not cheat. But we are unable to control or to know exactly the initial conditions for each throw. We can, however, determine the average result of a large number of throws. This is simply because, if one throws the coin $N$ times, the overwhelming majority (for $N$ large) of the results will have an approximately equal number of heads and of tails. It is as simple as that, and there will be nothing conceptually more subtle in the way we shall use probabilities below. The part "due to our ignorance" is simply that we *use* probabilistic reasoning. If we were omniscient, it would not be needed (but the averages would remain what they are, of course). The part "due to our knowledge" is what makes the reasoning work. We could make a mistake: the coin could be biased, and we did not notice it. Or we could have a "record of bad luck" and have many more heads than tails. But that is the way things are: our knowledge *is* incomplete, and we have to live with that. Nevertheless, probabilistic reasoning is extraordinarily successful in practice, but, when it

works, this is due to our (partial) knowledge. It would be wrong to attribute any constructive role to our ignorance. And it is also erroneous to assume that the system must be somehow indeterminate when we apply probabilistic reasonings to it. Finally, one could rephrase Laplace's statement more carefully as follows: "Even if the curve described by a molecule of air follows a rule as certainly as the orbits of the planets, our ignorance would force us to use probabilistic reasonings."

## 3 IRREVERSIBILITY AND THE ARROW OF TIME

> *Since in the differential equations of mechanics themselves there is absolutely nothing analogous to the second law of thermodynamics, the latter can be mechanically represented only by means of assumptions regarding initial conditions.*
>
> —L. BOLTZMANN

### 3.1 *The Problem*

What is the problem of irreversibility? The basic physical laws are reversible, which simply means that, if we consider an isolated system of particles, let it evolve for a time $t$, then reverse exactly the velocities of all the particles, and let the system again evolve for a time $t$, we get the original system at the initial time with all velocities reversed.[30] Now there are many motions that we see without ever observing their associated "time-reversed" motion: we go from life to death but not vice versa, coffee does not jump out of the cup, mixtures of liquids do not spontaneously unmix themselves. Some of these examples taken from everyday life involve nonisolated systems, but that is not relevant.[31] I shall center the discussion below on the canonical physical example (and argue that the other situations can be treated similarly): consider a gas that is initially compressed by a piston in the left half of a box; it is then released and expands into the whole container. We do not expect the particles to go back to the left half of the box, although such a motion would be as compatible with the laws of physics as the motion that does take place. So the question, roughly speaking, is: if the basic laws are reversible, how is it that we see some motions but never their time-reversed ones?

The first point to clarify is that this irreversibility does not give rise to a *contradiction* with basic physical laws.[32] Indeed, the laws of physics are always of the form: given some initial conditions, here is the result after some time. But they never tell us how the world *is or evolves.* In order to account for that, one always needs to assume something about the initial conditions. The laws of physics are compatible with many possible worlds: there could be no earth, no life, no humans. Nothing of that would contradict the fundamental physical laws. Actually, one would have to give a rather strong argument to show that there is a conflict between the reversibility of the laws and the existence of irreversible phenomena. But no argument at all is given, beyond a vague appeal to intuition, as for example: "No speculation, no body of knowledge ever claimed the equivalence between doing and undoing, between a plant that grows, has flowers and dies, and a plant that resuscitates, becomes younger and goes back to its primitive seed, between a man who learns and becomes mature and a man who becomes progressively a child,

then an embryo, and finally a cell. Yet, since its origins, dynamics, the physical theory that identifies itself with the triumph of science, implied this radical negation of time."[33] But nobody says that there is an "equivalence" between the two motions, only that both are compatible with the laws of physics. Which one, if any, occurs depends on the initial conditions. And if the laws are deterministic, assumptions on initial conditions are ultimately assumptions on the initial state of the Universe.

Once one has remarked that there is no contradiction between irreversibility and the fundamental laws, one could stop the discussion. It all depends on the initial conditions, period. But much more can be said. It is perfectly possible to give a natural account of irreversible phenomena on the basis of reversible fundamental laws, and of suitable assumptions on initial conditions. This was essentially done a century ago by Boltzmann, and despite numerous misunderstandings and misguided objections (some of them coming from famous scientists, such as Zermelo or Poincaré), its explanation still holds today. Yet, Prigogine writes: "He (Boltzmann) was forced to conclude that the irreversibility postulated by thermodynamics was incompatible with the reversible laws of dynamics."[34] This is in rather sharp contrast with Boltzmann's own words: "From the fact that the differential equations of mechanics are left unchanged by reversing the sign of time without anything else, Herr Ostwald concludes that the mechanical view of the world cannot explain why natural processes run preferentially in a definite direction. But such a view appears to me to *overlook that mechanical events are determined not only by differential equations, but also by initial conditions.* In direct contrast to Herr Ostwald I have called it one of the most brilliant confirmations of the mechanical view of Nature that it provides and extraordinarily good picture of the dissipation of energy, as long as one assumes that the world began in an initial state satisfying certain initial conditions" (italics are mine).[35] I shall now explain this "brilliant confirmation of the mechanical view of Nature" and show that all the alleged contradictions are illusory.[36]

### 3.2 *The Classical Solution*[37]

First of all, let us see which systems do behave irreversibly. A good test is to record the behavior of the system on a movie, and then to run the movie backwards. If it looks funny (e.g., people jump out of their graves), then we are facing irreversible behavior. It is easy to convince oneself that all the examples of irreversible behavior involve systems with a large number of particles (or of degrees of freedom). If one were to make a movie of the motion of one molecule, the backward movie would look completely natural. The same is true for a billiard ball on a frictionless billiard table.[38] If, however, friction is present, then we are dealing with many degrees of freedom (the atoms in the billiard table, those in the surrounding air, etc.).

There are two fundamental ingredients in the explanation of irreversibility. The first one has already been introduced: initial conditions. The second one is suggested by the remark that we deal with systems with many degrees of freedom: we *have* to distinguish between microscopic and macroscopic variables. Let us consider the phase space $\Omega$ (see Note 30) of the system, so that

the system is represented by a point $\mathbf{x}$ in that space and its evolution is represented by a curve $\mathbf{x}(t) = T^t(\mathbf{x})$. Various quantities of physical interest—for example, the density or the average energy or the average velocity in a given cubic millimeter—can be expressed as functions on $\Omega$.[39] These functions (call them $F$) tend to be many-to-one, i.e., there is typically a huge number of configurations giving rise to a given value of $F$.[40] For example, if $F$ is the total energy, then it takes a constant value on a surface in phase space. But if $F$ is the number of particles in a cubic millimeter, there are also many microscopic configurations corresponding to a given value of $F$. Now let me make two statements, the first of which is trivial and the second not. Given a microscopic initial configuration $\mathbf{x}_0$, giving rise to a trajectory $\mathbf{x}(t)$, any function on phase space follows an induced evolution $F_0 \rightarrow F_t$, where $F_0 = F(\mathbf{x}_0)$, and $F_t = F[\mathbf{x}(t)]$. That is the trivial part. the nontrivial observation is that, in many situations, one can find a suitable family of functions (I shall still denote by $F$ such a family) so that this induced evolution is actually (approximately) *autonomous*. That is, one can determine $F_t$ given $F_0$ alone, and not knowing the microscopic configuration from which it comes.[41] This means that the different microscopic configurations on which $F$ takes the value $F_0$ will induce the same evolution on $F_t$. A very trivial example is given by the globally conserved quantities (like the total energy): for all microscopic configurations, $F_t = F_0$, for all times. But that is not interesting. It is more interesting to observe that all the familiar macroscopic equations (Navier-Stokes, Boltzmann, diffusion, . . .) are of that type. Actually, there are several provisos to be made here: first of all, it is not true that *all* microscopic configurations giving rise to $F_0$ lead to the same evolution for $F_t$. In general, there will only be a (vast) majority of microscopic configurations that will do that.[42] Moreover, if we want that evolution to hold strictly for all times, then this set of microscopic configurations may become empty.[43] Finally, the laws used in practice (Navier-Stokes, Boltzmann, diffusion, . . .) are usually approximations to the real laws satisfied by the corresponding $F_t$'s.

So the precise justification of a macroscopic law should be: given $F_0$, and given a (not too large) time $T$[44], there exists a large subset of the set of $\mathbf{x}$'s giving rise to $F_0$ (i.e., of the preimage in $\Omega$, under the map $F$, of $F_0$) such that the induced evolution of $F_t$ is approximately described by the relevant macroscopic equations up to time $T$. It should be obvious that it is not easy to prove such a statement mathematically. One has to deal with dynamic systems with a large number of degrees of freedom, about which very little is known, plus one has to identify limits in which one can make sense of the approximations mentioned above (a large subset, a not-too-large time $T$, . . .). Nevertheless, this can be done in some circumstances, the best known probably being the derivation of Boltzmann's equation by Lanford.[45] In the APPENDIX, I discuss a model due to Mark Kac that, while artificially simple, can be easily analyzed and shows exactly what one would like to do in more complicated situations.[46]

Let us come back to the problem of irreversibility: should we expect those macroscopic laws to be reversible? A priori, not at all. Indeed, I have emphasized in the abstract description above the role of initial conditions in their derivation.[47] The macroscopic equations may be reversible or not, de-

pending on the situation. But their derivation shows that there is no *logical* reason to expect them to be reversible. Note that I am not discussing irreversibility in terms of entropy, but rather in terms of the macroscopic laws. After all, when we observe the mixing of different fluids, we see a phenomenon described by the diffusion equation, but we do not see entropy flowing. The connection with entropy will be made in SECTION 5.

### 3.3 *The Reversibility Objection*

Let me illustrate this explanation of irreversibility in a concrete physical example (see also APPENDIX for a simple mathematical model). Consider the gas introduced in SECTION 3.1 that is initially compressed by a piston in the left half of a box, and that expands into the whole box. Let $F$ be the density of the gas. Initially, it is one (say) in one half of the box and zero in the other half. After some time $t$, it is (approximately) one half everywhere. The explanation of the irreversible evolution of $F$ is that the overwhelming majority of the microscopic configurations corresponding to the gas in the left half, will evolve deterministically so as to induce the observed evolution of $F$. There may, of course, be some exceptional configurations, for which all the particles stay in the left half. All one is saying is that those configurations are extraordinarily rare, and that we do not expect to see even one of them appearing when we repeat the experiment many times, not even once "in a million years," to put it mildly. [48]

This example also illustrates the answer to the reversibility objection. Call "good" the microscopic configurations that lead to the expected macroscopic behavior. Take all the good microscopic configurations in the left half of the box, and let them evolve until the density is approximately uniform. Now, reverse all the velocities. We get a set of configurations that still determines a density of one half in the box. However, they are not good. Indeed, from now on, if the system remains isolated, the density just remains uniform according to the macroscopic laws. But for the configurations just described, the gas will move back to the left half, leading to a gross violation of the macroscopic law. What is the solution? Simply that those "reversed-velocities" configurations form a very tiny subset of all the microscopic configurations giving rise to a uniform density. So that, if we prepare the system with a uniform density, we do not expect to "hit" even once one of those bad configurations.[49]

Now comes a real problem. We are explaining that we never expect to get a microscopic configuration that will lead all the gas to the left side of the box. *But we started from such a configuration.* How did we get there in the first place? Well, obviously the system was not isolated: an experimentalist pushed the piston. But why was there an experimentalist? Do we expect that to happen? In fact, this is even more unlikely than the gas going to the left half of the box. We can go back step by step, human beings depend on the food they eat (and on the history of natural selection), which itself ultimately depends on the sun (through the plants and their photosynthesis).

As discussed in Penrose,[50] for example, the earth does not gain energy from the sun (that energy is reradiated by the earth), but low entropy; the sun sends (relatively) few high-energy photons, and the earth reradiates more low-

energy photons (in such a way that the total energy is conserved). Expressed in terms of "phase space," the numerous low-energy photons occupy a much bigger volume than the incoming high-energy ones. So the solar system, as a whole, moves towards a larger part of its phase space while the sun burns its fuel. That evolution accounts, by far, for what we observe in living beings or in other "self-organized" structures.[51] I shall come back to this point in SECTION 6. Of course, for the sun to play this role, it has to be itself out of equilibrium, and to have been even more so in the past. We end up with an egg and hen problem and we have ultimately to assume that the universe started in a state far from equilibrium, an "improbable state" as Boltzmann called it. To make the analogy with the gas in the box, it is as if the universe had started in a very little corner of a huge box.[52]

To account in a natural way for such a state is, of course, a major open problem, on which I have nothing to say[53] (see Penrose, *The Emperor's New Mind*, for further discussion, and Figure 7.19 there for an illustration), except that one cannot avoid it by "alternative" explanations of irreversibility. Given the laws of physics, as they are formulated now, the world could have started in equilibrium, and then we would not be around to discuss the problem.[54] To summarize: the only real problem with irreversibility is not to explain irreversible behavior in the future, but to account for the "exceptional" initial conditions of the universe.

### 3.4 *Chaos and Irreversibility*

Now I come to my basic criticism of the views of Prigogine and Stengers, who argue that dynamic systems with very good chaotic properties, such as the baker's map, are "intrinsically irreversible." Let me quote from a letter of a collaborator of Prigogine, D. Driebe,[55] criticizing an article of J. L. Lebowitz[56] explaining Boltzmann's ideas. This letter is remarkably clear and summarizes well the main points of disagreement. "If the scale-separation argument were the whole story, then irreversibility would be due to our approximate observation or limited knowledge of the system. This is difficult to reconcile with the constructive role of irreversible processes. . . . Irreversibility is not to be found on the level of trajectories or wavefunctions but is instead manifest on the level of probability distributions. . . . Irreversible processes are well observed in systems with few degrees of freedom, such as the baker and the multibaker transformations. . . . The arrow of time is not due to some phenomenological approximations but is an intrinsic property of classes of unstable dynamical systems."[57]

Let us discuss these claims one by one. First of all, as I emphasized above, the scale-separation (i.e., the micro/macro distinction) is not "the whole story." Initial conditions have to enter into the explanation. Next, what does it mean that "irreversible processes are observed in systems such as the baker transformation"? This transformation describes a chaotic system with few degrees of freedom, somewhat like the billiard ball on a frictionless table.[58] For those systems, there is no sense of a micro/macro distinction: how could one define the macroscopic variables? To put it otherwise, if we make a movie of the motion of a point in the plane evolving under the baker's map, or of a

billiard ball, or of any isolated chaotic system with few degrees of freedom, and run it backwards, we shall not be able to tell the difference. There is nothing funny or implausible going on, unlike the backward movie of any real irreversible macroscopic phenomenon. So the first critique of this alleged connection between unstable dynamic systems (i.e., what I call here chaotic) and irreversibility is that one "explains" irreversibility in systems in which nothing irreversible happens, and where therefore nothing is to be explained.

It is true that probability distributions for those systems evolve "irreversibly," meaning that any (absolutely continuous, see Note 27) probability distribution will spread out all over the phase space and will quickly tend to a uniform distribution. This just reflects the fact that different points in the support of the initial distribution, even if they are close to each other initially, will be separated by the chaotic dynamics. So it is true, in a narrow sense, that "irreversibility is manifest on the level of probability distributions." But what is the physical meaning of this statement? A physical system, chaotic or not, is described by a trajectory in phase space, and is certainly not described adequately by the corresponding probability distributions. As I discussed in SECTION 2.2, the latter reflects, in part, our ignorance of that trajectory. Their "irreversible" behavior is therefore not a genuine physical property of the system. We can, if we want, focus our attention on probabilities rather than on trajectories, but that "choice" cannot have a basic role in our explanations.

One cannot stress strongly enough the difference between the role played by probabilities here and in the classical solution. In the latter, we use probabilities as in the coin-throwing experiment. We have some macroscopic constraint on a system (the coin is fair; the particles are in the left half of the box), corresponding to a variety of microscopic configurations. We predict that the behavior of certain macroscopic variables (the average number of heads; the average density) will be the one induced by the vast majority of microscopic configurations, compatible with the initial constraints. That is all. But it works only because a large number of variables are involved, *in each single physical system.* However, each such system is described by a point in phase space (likewise, the result of many coin throwings is a particular sequence of heads and tails). In the "intrinsic irreversibility" approach, a probability distribution is assigned to *each single physical system*, as an "irreducible" description. The only way I can make sense of that approach is to consider a *large number* of billiard balls or of copies of the baker's map, all of them starting with nearby initial conditions. Then it would be like the particles in the box, the average density would tend to become uniform, and we are back to the standard picture. But this does not force us to "rethink the notion of law of nature." And for that picture to hold, one does not even need the motion to have strong chaotic properties (as we shall see in SECTION 4.2).

### 3.5 *Is Irreversibility Subjective?*

I will now discuss the alleged "subjectivity" of this account of irreversibility (it is due to our approximate observation or limited knowledge of the system). I shall consider the "constructive role" of irreversible processes in SECTION 6. Branding Boltzmann's ideas as "subjective" is rather common. For

example, Prigogine writes: "In the classical picture, irreversibility was due to our approximations, to our ignorance."[59] But thanks to the existence of unstable dynamic systems, "the notion of probability that Boltzmann had introduced in order to express the arrow of time does not correspond to our ignorance and acquires an objective meaning."[60] To use Popper's image: "Hiroshima is not an illusion" (I shall come back to Popper's confusions in SECTION 4.4). This is only a dramatization of the fact that irreversible events are not subjective, or so it seems. The objection is that, if the microscopic variables behave reversibly and if irreversibility only follows when we "choose" to concentrate our attention on macroscopic variables, then our explanation of irreversibility is unavoidably tainted by subjectivism. I think that this charge is completely unfair, and reflects some misunderstanding of what irreversible phenomena really are. The point is that, upon reflection, one sees that all irreversible phenomena deal with these macroscopic variables. There is no subjectivism here: the evolution of the macroscopic variables is objectively determined by the microscopic ones, and they behave as they do whether we look at them or not. In that sense they are completely objective. But it is true that, if we look at a single molecule, or at a collection of molecules represented by a point in phase space, there is no sense in which they evolve "irreversibly," if we are not willing to consider some of the macroscopic variables that they determine.

However, it is true that the apparently "subjective" aspect of irreversibility has been sometimes overemphasized. Heisenberg wrote: "Gibbs was the first to introduce a physical concept which can only be applied to an object when our knowledge of the object is incomplete. If, for instance, the motion and the position of each molecule in a gas were known, then it would be pointless to continue speaking of the temperature of the gas."[61] And Max Born said: "Irreversibility is therefore a consequence of the explicit introduction of ignorance into the fundamental laws."[62] These formulations, although correct if they are properly interpreted, lead to unnecessary confusion. For example, Popper wrote: "It is clearly absurd to believe that pennies fall or molecules collide in a random fashion *because we do not know* the initial conditions, and that they would do otherwise if some demon were to give their secret away to us: it is not only impossible, it is absurd to explain objective statistical frequencies by subjective ignorance."[63] However, just after saying this, Popper gives what he calls "an objective probabilistic explanation of irreversible processes,"[64] attributed to Planck, which, as far as I can tell, is not very different from what I call the classical solution. The source of the confusion comes from two uses of the word "knowledge." Obviously, the world does what it does, whether we know about it or not. So, indeed, if "some demon" were to provide us with detailed knowledge of the microscopic state of the gas in the left half of the box, nothing would change to the future evolution of that gas. But we may imagine situations where one can *control* more variables, hence to "know" more about the system. When the piston forces the gas to be in the left half of the box, the set of available microscopic states is different from when the piston is not there, and obviously

we have to take that "knowledge" into account. But there is nothing mysterious here.

I believe that statistical mechanics would become easier to understand by students if it were presented without using an anthropomorphic language and avoiding subjective sounding notions such as information, observation, or knowledge. Or, at least, one should explain precisely why these notions are introduced and why they do not contradict an objectivist view of natural phenomena (see the writings of Jaynes on this point[65]). But I also believe that the charge of subjectivity should be completely reversed: to "explain" irreversibility through the behavior of probability distributions (which *are* describing our ignorance), as Prigogine does, is to do as if the limitations of human knowledge played a fundamental physical role.

## 4 SOME MISCONCEPTIONS ABOUT IRREVERSIBILITY

*The Second Law can never be proved mathematically by means of the equations of dynamics alone.*

—L. BOLTZMANN

### 4.1 *The Poincaré Recurrence Theorem*

According to Prigogine[66] Poincaré did not recommend reading Boltzmann, because his conclusions were in contradiction with his premises. Discussing our example of a gas expanding in a container, Prigogine observes that "if irreversibility was only that, it would indeed be an illusion, because, if we wait even longer, then it may happen that the particles go back to the same half of the container. In this view, irreversibility would simply be due to the limits of our patience."[67] This is basically the argument derived from the Poincaré recurrence theorem (and used by Zermelo against Boltzmann[68]), which says that, if the container remains isolated long enough, then indeed the particles will return to the half of the box from which they started. Replying to that argument, Boltzmann supposedly said "You should live that long." For any realistic macroscopic system, the Poincaré recurrence times (i.e., the time needed for the particles to return to the left half of the box) are much larger than the age of the universe. So that again no contradiction can be derived, from a physical point of view, between Boltzmann's explanations and Poincaré's theorem. However, there is still a mathematical problem (and this may be what Poincaré had in mind): if one tries to rigorously derive an irreversible macroscopic equation from the microscopic dynamics and suitable assumptions on initial conditions, the Poincaré recurrence time will put a limit on the length of the time interval over which these statements can be proved. That is one of the reasons why one discusses these derivations in suitable limits (e.g., when the number of particles goes to infinity) where the Poincaré recurrence time becomes infinite. But one should not confuse the fact that one takes a limit for mathematical convenience and the source of irreversibility. In the Kac model discussed in the APPENDIX, one sees clearly that there are very different time scales: one over which convergence to equilibrium occurs, and a much larger one, where the Poincaré recurrence takes place. But the first time scale is not an "illusion." In fact, it is on that time scale that all phenomena that we can possibly observe do take place.

## 4.2 *Ergodicity and Mixing*

One often hears that, for a system to reach "equilibrium," it must be ergodic, or mixing. The fact is that those properties, like the "intrinsic irreversibility" discussed above, *are neither necessary nor sufficient* for a system to approach equilibrium. Let me start with ergodicity. A dynamic system is *ergodic* if the average time spent by a trajectory in any region of the phase space is proportional to the volume of that region. There are several precisions to be made here: average means in the limit of infinite time, and this property has to hold for all trajectories, except (possibly) those lying in a subset of zero volume. One says that it holds for "almost all" trajectories. This property implies that, for any reasonable function on phase space, the average along almost all trajectories will equal the average over the phase space.[69] Then, the argument goes, the measure of any physical quantity will take some time. This time is long compared to the "relaxation time" of molecular processes. Hence, we can regard it as approximately infinite. Therefore, the measured time average will approximately equal the average over phase space of the physical quantity under consideration. But this latter average is exactly what one calls the equilibrium value of the physical quantity. So if a dynamic system is ergodic, it converges towards equilibrium. This appeal to ergodicity in order to justify statistical mechanics is rather widespread[70] even though it has been properly criticized a long time ago by, e.g., Tolman, Jaynes, and Schwartz.[71]

Let us see the problems with this argument: a well-known, but relatively minor problem, is that it is very hard to give a mathematical proof that a realistic mechanical system is ergodic. But let us take such a proof for granted, for the sake of the discussion. Here is a more serious problem. Assume that the argument given above is true: how would it then be possible to observe or measure *any nonequilibrium* phenomenon? In the experiment with the box divided into two halves, we should not be able to see any intermediate stage, when the empty half gets filled, since the time for our measurements is supposed to be approximately infinite. So where is the problem? We implicitly identified the "relaxation time" with what one might call the "ergodic time"—i.e., the time taken by the system to visit all regions of phase space sufficiently often so that the replacement of time averages by spatial averages is approximately true. But, whatever the exact meaning of the word "relaxation time" (for a few molecules) is, the ergodic time is certainly enormously longer. Just consider how large is the volume in phase space that has to be "sampled" by the trajectory. For example, all the particles could be in the right half of the box, and ergodicity says that they will spend some time there (note that this is not implied by Poincaré's theorem; the latter guarantees only that the particles will return to the part of the box from which they started—i.e., the left half here). To be more precise, let us partition the volume of phase space into a certain number of cells, of a given volume, and consider the time it takes for a given trajectory to visit each cell, even once, let us say.[72] That, obviously, will depend on the size (hence, on the number) of the cells. By taking finer and finer partitions, one can make that time as large as one wishes. So if one were to take the argument outlined above literally, the "ergodic time" is infinite, and speaking loosely about a relaxation time is simply misleading.

At this point of the discussion, one often says that we do not need the time and space average to be (almost) equal for all functions, but only for those of physical relevance (like the energy or particle densities). This is correct, but the criticism of the "ergodic" approach then changes: instead of not being *sufficient* to account for irreversibility, we observe that it is not *necessary.* To see this, consider another partition of phase space: fix a set of macroscopic variables, and partition the phase space according to the values taken by these variables[73] (see, e.g., Figures 7.3 and 7.5 in R. Penrose, *The Emperor's New Mind*, for an illustration, and the APPENDIX here for an example). Each element of the partition consists of a set of microscopic states that give the same value to the chosen macroscopic variables. Now these elements of the partition have very different volumes. That is just a restatement of the law of large numbers. There are (for $N$ large) vastly more results of $N$ throws of a coin where the number of heads is approximately one half than throws where it is approximately one quarter (the ratio of these two numbers varies exponentially with $N$). By far the largest volumes correspond to the *equilibrium values* of the macroscopic variables (and that is how "equilibrium" should be defined). So we need a much weaker notion than ergodicity. All we need is that the microscopic configuration evolves in phase space towards those regions where the relevant macroscopic variables take their equilibrium values. The Kac model (see APPENDIX) perfectly illustrates this point: it is not ergodic in any sense, yet, on proper time scales, the macroscopic variables evolve towards equilibrium.

There is a hierarchy of "ergodic" properties that are stronger than ergodicity: mixing, K-system, Bernoulli.[74] But none of these will help us to understand, in principle, irreversible behavior any more than ergodicity.

The problem with all those approaches is that they try to give a purely mechanical criterion for "irreversible behavior." Here is the basic dilemma: either we are willing to introduce a macro/micro distinction and to give a basic role to initial conditions in our explanation of irreversibility or we are not. If we make the first choice, then, as explained in SECTION 3, there is no deep problem with irreversibility, and subtle properties of the dynamics (like ergodic properties) play basically no role. On the other hand, nobody has ever given a consistent alternative, namely, an explanation of irreversibility that would hold for *all* initial conditions or apply to *all* functions on configuration space (therefore avoiding the micro/macro distinction). So we have to make the first choice. But then everything is clear, and nothing else is needed.

Another critique of the "ergodic" approach is that a system with one or few degrees of freedom may very well be ergodic, or mixing, or Bernoulli (like the baker's transformation). And, as we discussed in SECTION 3.4, it makes no sense to speak about irreversibility for those systems. So this is another sense in which the notion of ergodicity is not sufficient.[75]

To avoid any misunderstandings, I emphasize that the study of ergodic properties of dynamic systems gives us a lot of interesting information on those systems, especially for chaotic systems. Besides, ergodic properties, like other concrete dynamic properties of a system, may play a role in the form of the macroscopic equations obeyed by the system, in the value of some trans-

port coefficients, or in the speed of convergence to equilibrium. But, and this is the only point I want to make, ergodic properties are not very relevant conceptually for the problem of irreversibility or of approach to equilibrium.

### 4.3 *Real Systems Are Never Isolated*

Sometimes it is alleged that, for some reason (the Poincaré recurrences, for example) a truly isolated system will never reach equilibrium. But it does not matter, since true isolation never occurs and external ("random") disturbances will always drive the system towards equilibrium.[76] This is true but irrelevant.[77]

In order to understand this problem of nonisolation, we have to see how to deal with idealization in physics. Boltzmann compares this with Galilean invariance.[78] Because of nonisolation, Galilean (or Lorentz) invariance can never be applied strictly speaking (except to the entire universe, which is not very useful). Yet, there are many phenomena whose explanation involve Galilean (or Lorentz) invariance. We simply assume that the invariance is exact, and we argue that the fact that it is only approximate does not spoil the argument. It is the same thing in statistical mechanics. If we can explain what we want to explain (e.g., irreversibility) by making the assumption that the system is perfectly isolated, then we do not have to introduce the lack of isolation in our explanations. We have only to make sure that this lack of isolation does not conflict with our explanation. And how could it? The lack of isolation should, in general, speed up the convergence towards equilibrium.[79] Also, if we want to explain why a steamboat cannot use the kinetic energy of the water to move, we apply irreversibility arguments to the system boat + water, even though the whole system is not really isolated.

Another way to see that lack of isolation is true but irrelevant is to imagine a system being more and more isolated. Is irreversibility going to disappear at some point? That is, will different fluids not mix themselves, or will they spontaneously unmix? I cannot think of any example where this could be argued. And I cannot with a straight face tell a student that (part of) our explanation for irreversible phenomena on earth depends on the *existence* of Sirius.

### 4.4 *Bergson, Popper, Feyerabend (and Others)*

Here, I will discuss various confusions that have been spread by some philosophers. Bergson was a rather unscientific thinker, and many readers will wonder why he belongs here. I have myself been very surprised to see how much sympathy Prigogine and Stengers seem to have for Bergson.[80] But Bergson has been extremely influential, at least in French culture, and, I am afraid, he still is.[81] In particular, he is one source of the widespread confusion that there is a contradiction between life and the second principle of thermodynamics. Roughly speaking, Bergson saw a great opposition between "matter" and "life," and a related one between intellect and intuition. The intellect can understand matter, but intuition is needed to apprehend life.[82] Bergson was not a precursor of the discovery of the DNA, to put it mildly. The second principle of thermodynamics, which he called the "most metaphysical of the laws of physics," was very important for him.[83] It reinforced his "vision of the material world as that of a falling weight."[84] Hence, "all our analyses show indeed in life an effort to climb the slope that matter has de-

scended."[85] "The truth is that life is possible wherever energy goes down the slope of Carnot's law, and where a cause, acting in the opposite direction, can slow down the descent."[86] It is all metaphorical, of course, but Bergson's philosophy *is* entirely a "metaphorical dialectics devoid of logic, but not of poetry," as Monod calls it.[87] In any case, life is perfectly compatible with the Second Law (see SECTION 3.3).

Turning to Popper, we have already seen that he had many problems with statistical mechanics. Since Popper is generally considered positively by scientists,[88] it is worth looking more closely at his objections. He took too literally the claims of Heisenberg, Born, and Pauli on irreversibility as "subjective" (see SECTION 3.5), which he thought (maybe rightly so) were precursors of the subjectivism of the Copenhagen interpretation of quantum mechanics.[89] Besides, he was strongly opposed to determinism, and he was convinced that "the strangely law-like behaviour of the statistical sequences remain, for the determinist, *ultimately irreducible and inexplicable.*"[90] As I discussed in SECTION 2.2, there is no problem in using probabilities, even in a deterministic universe. He then invented a rather obscure "propensity" interpretation of probabilities. He also felt that one should define "objectively" what a random sequence is. A sequence (of zeros and ones) will be random if there are (almost) as many zeros and ones, as many pairs 00, 01, 10, 11, etc. . . .[91] He did not seem to realize that this is like saying that a "microscopic configuration" (a sequence) gives to certain "macroscopic variables" (the average number of occurrences of finite subsequences) the values that are given to them by the overwhelming majority of sequences. So the difference from what he calls the "subjective" viewpoint is not so great.

Finally, Popper was very critical of Boltzmann. Although he admires Boltzmann's realist philosophy, he calls Boltzmann's interpretation of time's arrow "idealist" and claims that it was a failure. As we saw, any explanation of irreversibility ultimately forces us to say that the universe started in an "improbable" state. Boltzmann tried to explain it as follows: in an eternal and infinite universe globally in equilibrium, all kinds of fluctuations will occur. What we call our universe is just the result of one such gigantic fluctuation, on its way back to equilibrium. But this explanation does not really work. Indeed, the most probable assumption, if a fluctuation theory is to hold, is simply that my brain is a fluctuation out of equilibrium, just at this moment and in this small region of space; while none of the familiar objects of the universe (stars, planets, other human beings) exist, and all my (illusory) perceptions and memories are simply encoded in the states of my neurons (a "scientific" version of solipsism). However improbable such a fluctuation is, it is still far more probable than a fluctuation giving rise to the observed universe, of which my brain is a part. Hence, according to the fluctuation theory, that "solipsist" fluctuation must actually have occurred many more times than the big fluctuation in which we live, and therefore no explanation is given for the fact that we happen to live in the latter.[92]

Boltzmann's cosmology does not work. So what? When Popper wrote (1974), no one took Boltzmann's cosmology seriously anyway: it had long since been superseded by cosmologies based on general relativity. Besides,

Popper does not raise the objection I just made. His criticism is, rather, that this view would render time's arrow "subjective" and make Hiroshima an "illusion." This is complete gibberish. Boltzmann gives a complete and straightforward explanation of irreversible processes in which Hiroshima is as objective as it unfortunately is (when it is described at the macroscopic level, which is what we mean by "Hiroshima"). Of course, questions remain concerning the initial state of the universe. In the days of Boltzmann, very little was known about cosmology. What the failure of Boltzmann's hypothesis on the origin of the initial state shows is that cosmology, like the rest of science, cannot be based on pure thought alone.[93]

Popper was also too much impressed with Zermelo's objections to Boltzmann, based on the Poincaré recurrence theorem, and discussed above.[94] But he has even stranger criticisms: in "Irreversibility; or, Entropy since 1905" he argues that Brownian motion (where fluctuations may pull the particle against gravity) is a serious problem for the Second Law. Maxwell had already observed that "The Second Law is constantly being violated . . . in any sufficiently small group of molecules. . . . As the number . . . is increased . . . the probability of a measurable variation . . . may be regarded as practically an impossibility."[95] Going from bad to worse, Feyerabend invents a "perpetuum mobile of the second kind" (i.e., one respecting the first law but not the second) using *a single molecule.*[96] He adds that he assumes "frictionless devices" (he had better do so!). Those claims are then repeated in his popular book *Against Method*, where it is explained that Brownian motion refutes the second law.[97] This is how the general educated public is misled into believing that there are deep, open problems that are deliberately ignored by the "official science"!

Unfortunately, this is not the end of it. Contemporary (or postmodern) French "philosophy" is an endless source of confusion on chaos and irreversibility. Here are just a few examples. The well-known philosopher Michel Serres says, in an interview with the sociologist of science Bruno Latour entitled paradoxically "Eclaircissements": "Le temps ne coule pas toujours selon une ligne (la première intuition se trouve dans un chapitre de mon livre sur Leibniz, pp. 284–286) ni selon un plan, mais selon une variété extraordinairement complexe, comme s'il montrait des points d'arrêt, des ruptures, des puits, des cheminées d'accélération foudroyante, des déchirures, des lacunes, le tout ensemencé aléatoirement, au moins dans un désordre visible. Ainsi le développement de l'histoire ressemble vraiment à ce que décrit la théorie du chaos. . . ."[98] Another philosopher, Jean-François Lyotard writes: "L'idée que l'on tire de ces recherches (et de bien d'autres) est que la prééminence de la fonction continue à derivée comme paradigme de la connaissance et de la prévision est en train de disparaître. En s'intéressant aux indécidables, aux limites de la précision du contrôle, aux quanta, aux conflits à l'information non complète, aux "*fracta*," aux catastrophes, aux paradoxes pragmatiques, la science postmoderne fait la théorie de sa propre évolution comme discontinue, catastrophique, non rectifiable, paradoxale. Elle change le sens du mot savoir, et elle dit comment ce changement peut avoir lieu. Elle produit non pas du connu, mais de l'inconnu. Et elle suggère un modèle de légitimation qui n'est nullement celui de la meilleure performance, mais celui de la différ-

ence comprise comme paralogie."[99] A sociologist, Jean Baudrillard, observes that "Il faut peut-être considérer l'histoire elle-même comme une formation chaotique où l'accélération met fin à la linéarité, et où les turbulences créées par l'accélération éloignent définitivement l'histoire de sa fin, comme elles éloignent les effets de leurs causes. La destination, même si c'est le Jugement dernier, nous ne l'atteindrons pas, nous en sommes désormais séparés par un hyperespace à réfraction variable. La rétroversion de l'histoire pourrait fort bien s'interpréter comme une turbulence de ce genre, due à la précipitation des événements qui en inverse le cours et en ravale la trajectoire."[100] Finally, Gilles Deleuze and Félix Guattari understood chaos as follows: "On définit le chaos moins par son désordre que par la vitesse infinie avec laquelle se dissipe toute forme qui s'y ébauche. C'est un vide qui n'est pas un néant, mais un *virtuel*, contenant toutes les particules possibles et tirant toutes les formes possibles qui surgissent pour disparaître aussitôt, sans consistance ni référence, sans conséquence (Ilya Prigogine et Isabelle Stengers, *Entre le temps et l'éternité*, pp. 162–163)."[101] Of course, Prigogine and Stengers are not responsible for *these* confusions (in that reference, they discuss the origin of the universe). But this illustrates the difficulties and the dangers of the popularization of science. Besides, Guattari wrote a whole book *Chaosmose*, which is full of references to nonexistent concepts such as "nonlinear irreversibility thresholds" and "fractal machines."[102]

## 5 ENTROPIES

*Holy Entropy! It's boiling!*

—G. GAMOW

There is some kind of mystique about entropy. According to K. Denbigh and M. Tribus,[103] von Neumann suggested that Shannon use the word "entropy," adding that "it will give you a great edge in debates because nobody really knows what entropy is anyway." Another author says that entropy "is nothing material but is, so to speak, purely spiritual and yet it rules the world."[104] But there is a very simple way to understand the notion of entropy. Just consider any set of macroscopic variables (at a given time) and consider the volume of the subset of phase space (of the microscopic variables) on which these macroscopic variables take a given value. The *Boltzmann entropy* (defined as a function of the macroscopic variables) equals the logarithm of that volume. Defined this way, it looks quite arbitrary. We may define as many entropies as we can find sets of macroscopic variables. Furthermore, since the micro/macro distinction is not sharp, we can always take finer-grained entropies, until we reach the microscopic variables (the positions and the momenta of the particles), at which point the entropy is constant and equals zero (giving a volume equal to one to a single microstate, which is rather a quantum-mechanical way of counting).

But one should make several remarks:

1. These entropies are not necessarily "subjective." They are as objective as the corresponding macroscopic variables. Jaynes, following Wigner, calls these entropies "anthropomorphic."[105] A better word might be "contextual"—i.e., they depend on the physical situation and on its level of description.

2. The "usual" entropy of Clausius corresponds to a particular choice of macroscopic variables (e.g., energy and number of particles per unit volume for a monoatomic gas without external forces). The derivative with respect to the energy of *that* entropy, restricted to equilibrium values, defines the inverse temperature. One should not confuse the "flexible" notion of entropy introduced above with the more specific one used in thermodynamics.[106]

3. The Second Law seems now a bit difficult to state precisely. "Entropy increases"; yes, but which one? One can take several attitudes. The most conservative is to restrict oneself to the evolution of a given isolated system between two equilibrium states; then the increasing entropy is that discussed in Point 2 above. The Second Law is then a rather immediate consequence of the irreversible evolution of the macroscopic variables: the microscopic motion will go from small regions of phase space to larger ones (in the sense of the partitions discussed in SECTION 4.2). The gas in the box goes from an equilibrium state in the left half of the box to another equilibrium state in the whole box. There are many more microscopic configurations corresponding to a uniform density than there are configurations corresponding to the gas being entirely in one half of the box. But this version of the Second Law is rather restrictive, since most natural phenomena to which we apply "Second Law" arguments are not in equilibrium. When used properly in nonequilibrium situations, reasonings based on the Second Law give an extremely reliable way to predict how a system will evolve. We simply assume that a system will never go spontaneously towards a very small subset of its phase space (as defined by the macroscopic variables). Hence, if we observe such an evolution, we expect that some hidden external influence is forcing the system to do so, and we try to discover it.[107]

4. In most nonequilibrium situations, most of these entropies are very hard to compute or even to estimate. However, Boltzmann was able to find an approximate expression of his entropy (minus his $H$ function), valid for dilute gases (e.g., for the gas in the box initially divided in two of SECTION 3) and to write down an equation for the evolution of that approximate entropy. A lot of confusion is due to the identification between the "general" Boltzmann entropy defined above, and the approximation to it given by (minus) the $H$-function.[108] Another frequent confusion about Boltzmann's equation is to mix two conceptually different ingredients entering in its derivation[109]: one is an assumption on *initial conditions*, and the other is to make a particular approximation (i.e., one takes the Boltzmann-Grad limit; see H. Spohn, *Large Scale Dynamics of Interacting Particles*, in which the approximation becomes exact; in the Kac model in the APPENDIX, this limit reduces simply to let $n$ go to infinity for fixed $t$). To account for irreversible behavior, one has always, as we saw, to assume something on initial conditions, and the justification of that assumption is statistical. But that part does not require, in principle, any approximation. To write down a concrete (and reasonably simple) equation, as Boltzmann did, one uses this approximation. Failure to distinguish these two steps leads one to believe that there is some deep problem with irreversibility outside the range of validity of that approximation.[110]

5. Liouville's theorem[111] is sometimes invoked against such ideas. For instance, we read in Prigogine and Stengers: "All attempts to construct an entropy function, describing the evolution of a set of trajectories in phase space, came up against Liouville's theorem, since the evolution of such a set cannot be described by a function that increases with time."[112] What is the difference with our entropies? Here I consider *a single system* evolving in time and associate with it a certain set of macroscopic variables, to which in turn an entropy is attached. But since the values of the macroscopic variables change with time, the corresponding set of microstates changes too. In other words, I "embed" my microscopic state into different sets of microscopic states as time changes, and the evolution of that set should not be confused with a set of *trajectories*, whose volume is indeed forced to remain constant (by Liouville's theorem).[113]

6. A related source of confusion comes from the fact that Gibbs' entropy, $-\int \rho \log \rho d\mathbf{x}$, which looks more natural and more "fundamental" (since it is expressed via a distribution function $\rho$ on phase space), is indeed constant in time (by Liouville's theorem again). But why should one use this Gibbs entropy out of equilibrium? In equilibrium, it agrees with Boltzmann and Clausius entropies (up to terms that are negligible when the number of particles is large), and everything is fine.[114] When we compare two different equilibrium states all these entropies change, and the direction of change agrees with the second law.[115] The reason is that the values taken by the macroscopic variables are different for different equilibrium states. Actually, trying to "force" the Gibbs entropy to increase by various coarse-graining techniques gives then the impression that irreversibility is due only to this coarse-graining and is therefore arbitrary or subjective.[116]

7. Finally, why should one worry so much about entropy for nonequilibrium states? A distinction has to be made between two aspects of irreversibility: one is that macroscopic variables tend to obey irreversible laws, and the other is that when an isolated system can go from one equilibrium state to another, the corresponding thermodynamic entropies are related by an inequality. Both aspects are connected, of course, and they can both be explained by similar ideas. But this does not mean that in order to account for the irreversible behavior of macroscopic variables, we have to introduce an entropy function that evolves monotonically in time. It may be useful or interesting to do so, but it is not required to account for irreversibility. All we really *need* is to define suitably the entropy for equilibrium states, and that has been done a long time ago.

8. Jaynes rightly says that he does not know what is the entropy of a cat.[117] The same thing could be said for a painting, an eye, or a brain. The problem is that there is no well-defined set of macroscopic variables that is specified by the expression "a cat."

## 6 ORDER OUT OF CHAOS?

> *In my view all salvation for philosophy may be expected to come from Darwin's theory. As long as people believe in a special spirit that can cognize objects without mechanical means, or in a special*

> *will that likewise is apt to will that which is beneficial to us, the simplest psychological phenomena defy explanation.*
>
> —L. BOLTZMANN

In this section, I will discuss the "constructive role" of irreversible processes.[118] But I also want to discuss the impact of scientific discoveries on the cultural environment. At least since the Enlightenment and the Encyclopaedia, scientists have communicated their discoveries to society, and, through popular books and the schools, have profoundly influenced the rest of the culture. But one has to be very careful. In his recent book on Darwin, the philosopher D. Dennett makes a list of popular misconceptions about the theory of evolution.[119] One of them is that one does not need the theory of natural selection any more, since we have chaos theory! He does not indicate the precise source of this strange idea, but it illustrates how easily people can be confused by loose talk, analogies, and metaphors.

I think that one should clearly reaffirm certain principles: first of all, no macroscopic system has ever jumped out of equilibrium spontaneously. Moreover, isolated macroscopic systems always evolve towards equilibrium. These are general qualitative statements that one can make about macroscopic mechanical systems. No violations of them have ever been found. Of course, nobody explicitly denies those principles, but if one puts too much emphasis on the constructive role of irreversible processes (or, worse, on our "dialogue" with Nature),[120] many people will be confused.[121] The fact is that the main principle that is clearly understood about irreversibility and is universally valid has nothing constructive in it: isolated systems go towards equilibrium.[122]

Of course, it has always been known that very complicated and interesting phenomena occur out of equilibrium, human beings for example. But this raises two completely different problems. One is to explain those phenomena on the basis of the microscopic laws and of suitable assumptions on initial conditions. Many progresses in this direction are made, but we are far from understanding everything; and, of course, to account for the existence of human beings, Darwin's theory *is* needed.

The other question, a much easier one, is to understand why there is no *contradiction* between the general tendency towards equilibrium and the appearance of self-organization, of complex structures or of living beings. *That* is not difficult to explain qualitatively; see SECTION 3.3 and Penrose's *The Emperor's New Mind*.

Going back to Popper (again), he wanted to solve the alleged contradiction between life and the second principle (see Note 51) by turning to Prigogine's *From Being to Becoming* and saying that "*open systems in a state far from equilibrium* show no tendency towards increasing disorder, even though they produce entropy. But they can export this entropy into their environment, and can increase rather than decrease their internal order. They can develop structural properties, and thereby do the very opposite of turning into an equilibrium state in which nothing exciting can happen any longer."[123] This is correct, provided the environment *is more ordered than the system*, where "order" is taken in a technical sense: the system plus its environment (considered as approximately isolated) is in a state of low entropy, or is in a small

subset of its *total* phase space and moves towards a larger subset of that space[124] (where the subsets are elements of a partition like the one discussed in SECTION 4.2). But it is misleading to suggest that order is created out of nothing, by rejecting "entropy" in an unspecified environment.[125] It is not enough to be an "open system"; the environment must be more ordered.

Here are some examples that *may* create this confusion[126]: Prigogine considers a system of particles (on a line), which start in a disordered configuration.[127] Then "the strong interactions between those particles" will push them to form an ordered crystal. It looks like a "passage from a disordered situation to an ordered one." But is this an isolated system? Probably not. If there are interactions between the particles favoring an ordered crystal, the disordered initial configuration must have been one of high potential energy; hence, the "ordered" configuration will have a high kinetic energy, and oscillations will occur. Of course, if dissipation takes place, the "passage from a disordered situation to an ordered one" is possible. But this means that some environment absorbs the energy of the system, in the form of heat; hence, it increases *its* disorder. And the environment must have been more ordered to start with.

To give another example, Prigogine and Stengers emphasize[128] that, for the Bénard instability[129] to occur *one must provide more heat to the system.* As noticed by Meessen, "It is remarkable that the structuration is initiated by a source of heat, which is usually a source of disorder."[130] This quotation shows clearly what is confusing: heating suggests an increase of disorder, while the result is the appearance of a self-organized structure. But what is needed, of course, is a temperature *difference* between the two plates. So if one heats up from below, one must have some cooling from above. The cooling acts like a refrigerator, so it requires some "ordered" source of energy. The more one heats, the more efficient must be the cooling.

These are fairly trivial remarks, but I believe they have to be made, at least for the general public, if one wants to avoid giving the impression that processes violating the second law can occur: all the emergence of complex structures, of whatever one sees, is perfectly compatible with the universal validity of the "convergence to equilibrium," provided one remembers that our universe started (and still is) in a low entropy state.[131]

Besides, one should be careful with the issue of determinism, at the level of macroscopic laws, for example, when bifurcations occur. In many places, Prigogine and Stengers put too much emphasis on the notion of *event*: "By definition, an event cannot be deduced from a deterministic law: it implies, one way or another, that what happened 'could' not have happened."[132] Let us consider Buridan's ass. One can describe it as being "in between" two packs of food. It could choose either. But that is a macroscopic description. Maybe one of the eyes of the ass is tilted in one direction, or some of its neurons are in a certain state favoring one direction. This is an example where the macroscopic description does not lead to an autonomous macroscopic law. At the macroscopic level, things are indeterminate, and the scheme of SECTION 3 does not apply: the microscopic configurations may fall into different classes, corresponding to different future evolutions for the macroscopic variables,

and no single class constitutes an overwhelming majority. Thus, when we repeat the experiment (meaning that we control the same *macroscopic* variables) different outcomes will occur, because different experiments will correspond to microscopic variables that belong to different classes.

The same thing may happen in a variety of phenomena—e.g., which way a roll in a Bénard cell will turn. But that (true) remark has nothing to do with the issue of determinism, which is meaningful only at the microscopic level: in a perfectly deterministic universe (at that level) there will always be many situations in which simple autonomous macroscopic laws can be found; hence, we shall have the illusion of "indeterminism" if we consider only the macroscopic level.[133]

One should avoid (once more) the Mind Projection Fallacy. The macroscopic description may be all that is accessible to us; hence, the future becomes unpredictable; but, again, it does not mean that Nature is indeterminate.[134]

I will conclude with some remarks on Boltzmann and Darwin, which may also clarify the relation between "subjective" evaluations of probabilities and what we call an "explanation." As we saw, Boltzmann had a great admiration for Darwin. While preparing this article, I read in "La Recherche" that "the couple random mutations-selection has some descriptive value, but not at all an explanatory one."[135] That attitude is rather common (outside of biology), but it goes a bit too far. Actually, there is an analogy between the kind of explanation given by Darwin and the one given by Boltzmann, and they are both sometimes similarly misunderstood[136] (of course, Darwin's discovery, although less quantitative than statistical mechanics, had a much deeper impact). What does it mean to explain some fact, like evolution or irreversibility? As we saw, we claim to understand some macroscopically observed behavior when, given some macroscopic constraint on a system, the overwhelming majority of the microscopic configurations compatible with those constraints (and evolving according to the microscopic laws) drive the macroscopic variables in agreement with that observed behavior.

Turning to Darwin, his problem was to explain the diversity of species and, more importantly, the *complexity* of living beings, "those organs of extreme perfection and complication," such as eyes or brains, as Darwin called them.[137] The fact is that we do not know, and we shall never know, every microscopic detail about the world, especially about the past (such as every single mutation, how every animal died, etc.). Besides, the initial conditions of the world could be just so that complex organs are put together in one stroke. To use a common image, it would be like "hurling scrap metal around at random and happening to assemble an airliner."[138] This does not violate any known law of physics. But it would be similar to various "exceptional" initial conditions that we encountered before (e.g., the particles going back to the left half of the box). And we would not consider an explanation valid if it appealed to such "improbable" initial conditions. But to say that such a scenario is "improbable" simply means that, given our (macroscopic) description of the world, there are very few microscopic configurations compatible with that description and giving rise to this scenario. And, indeed, if the

world were four thousand years old, the existence of those complex organs would amount to a miracle.

To understand the Darwinian explanation, one must take into account three elements, at the level of the macroscopic description: natural selection (very few animals have offspring), variation (small differences between parents and offspring occur, at least in the long run), and time (the earth is much older than one thought). Then, the claim is that the overwhelming majority of microscopic events (which mutations occur, which animals die without children) compatible with such a macroscopic description leads to the appearance of those "organs of extreme perfection and complication."[139] Note that we do not need to assume that mutations are genuinely "random." They may obey perfectly deterministic laws, and the randomness may reflect only our ignorance of the details. Note also that one can invent exceptional microscopic configurations: it is possible for the world to be just so that all the animals that, thanks to a mutation, have a slightly more sophisticated eye or brain are hit by lightning when they are young and do not have children. But they correspond now to extremely improbable initial conditions.[140]

A final point that is common to Boltzmann and Darwin (and his successors) is that they have provided "brilliant confirmations of the mechanical view of Nature."[141] Many people simply cannot swallow mechanical and reductionist explanations. They need some vital spirit, some teleological principle, or some other animist view. Their philosophies "thrive upon the errors and confusions of the intellect." And this is probably why the theories of Boltzmann and Darwin have been constantly attacked and misrepresented. Putting philosophical considerations aside, I believe that what we understand well, we understand in mechanical and reductionist terms. There is no such thing as a holistic explanation in science. And thanks to people like Boltzmann and Darwin the "mechanical view of Nature" is alive and well, and is here to stay.

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## APPENDIX
## THE KAC RING MODEL

Let me analyze a simple model, provided by Mark Kac,[142] which nicely illustrates Boltzmann's solution to the problem of irreversibility, and shows how to avoid various misunderstandings and paradoxes.

I shall describe a slightly modified version of the model and state the relevant results, referring to Kac's *Probability and Related Topics in the Physical Sciences* for the proofs (the quotations below also come from this book).

"On a circle we consider $n$ equidistant points"; $m$ of the intervals between

the points are marked and form a set called $S$. The complementary set (of $n - m$ intervals) will be called $\bar{S}$.

"Each of the $n$ points is a site of a ball which can be either white ($w$) or black ($b$). During an elementary time interval each ball moves counterclockwise to the nearest site with the following proviso."

If the ball crosses an interval in $S$, it changes color upon completing the move, but if it crosses an interval in $\bar{S}$, it performs the move without changing color.

"Suppose that we start with all white balls; the question is what happens after a large number of moves." Later, we shall also consider other initial conditions.

Let us emphasize the analogy with mechanical laws. The balls are described by their positions and their (discrete) "velocity," namely, their color. One of the simplifying features of the model is that the "velocity" does not affect the motion. However the "velocity" changes when the ball collides with a fixed "scatterer," i.e., an interval in $S$. Scattering with fixed objects tends to be easier to analyze than collisions between particles. The "equations of motion" are given by the counterclockwise motion, plus the changing of colors [see eqs. (5,6) below]. These equations are obviously deterministic and reversible: if after a time $t$, we change the orientation of the motion from counterclockwise to clockwise, we return after $t$ steps to the original state.[143] Moreover, the motion is strictly periodic: after $2n$ steps each interval has been crossed twice by each ball, hence they all come back to their original color. This is analogous to the Poincaré cycles, with the provision that, here, the length of the cycle is the same for all configurations (there is no reason for this feature to hold in general mechanical systems). Moreover, it is easy to find special configurations that obviously do not tend to equilibrium: start with all white balls, and let every other interval belong to $S$ (with $m = \frac{n}{2}$). Then, after two steps, all balls are black, after four steps they are all white again, etc. The motion is periodic with period 4. Turning to the solution, one can start by analyzing the approach to equilibrium in this model à la Boltzmann:

*Analog of the Classical Solution of Boltzmann*

Let $N_w(t)[N_b(t)]$ denote the total number of white (black) balls at time $t$ (i.e., after $t$ moves, $t$ being an integer) and $N_w(S;t)[N_b(S;t)]$ the number of white (black) balls that are going to cross an interval in $S$ at time $t$.

"We have the immediate conservation relations:

$$N_w(t + 1) = N_w(t) - N_w(S;t) + N_b(S;t)$$
$$N_b(t + 1) = N_b(t) - N_b(S;t) + N_w(S;t) \qquad (1)$$

Now to follow Boltzmann, we introduce the assumption ("Stosszahlansatz" or "hypothesis of molecular chaos"[144])

$$N_w(S;t) = mn^{-1}N_w(t)$$
$$N_b(S;t) = mn^{-1}N_b(t)" \qquad (2)$$

Of course, if we want to solve (1) in a simple way, we have to make some assumption on $N_w(S;t),N_b(S;t)$. Otherwise, one has to write equations for

$N_w(S;t),N_b(S;t)$ that will involve new variables and lead to a potentially infinite regress.

The intuitive justification for this assumption is that each ball is "uncorrelated" with the event "the interval ahead of the ball belongs to $S$," so we write $N_w(S;t)$ as equal to $N_w(t)$, the total number of white balls, times the density $\frac{n}{m}$ of intervals in $S$. This assumption looks completely reasonable. However, upon reflection, it may lead to some puzzlement (just as the hypothesis of "molecular chaos" does): exactly what does "uncorrelated" mean? Why do we introduce a statistical assumption in a mechanical model? Fortunately, here these questions can be answered precisely, and we shall answer them later by solving the model exactly. But let us return to the Boltzmannian story.

"One obtains

$$N_w(t + 1) - N_b(t + 1) = (1 - 2mn^{-1})[N_w(t) - N_b(t)]$$

Thus

$$n^{-1}[N_w(t) - N_b(t)] = (1 - 2mn^{-1})^t n^{-1}[N_w(0) - N_b(0)]$$
$$= (1 - 2mn^{-1})^t \tag{3}$$

and hence if

$$2m < n \tag{4}$$

(as we shall assume in the sequel) we obtain a *monotonic* approach to equipartition of white and black balls." Note that we get a monotonic approach for all initial conditions $[N_w(0) - N_b(0)]$ of the balls.

The variables $N_w(t),N_b(t)$ play the role of macroscopic variables. We can associate to them a Boltzmann entropy[145]

$$S_b = \ln \binom{n}{N_w(t)},$$

i.e., the logarithm of the number of (microscopic) configurations whose number of white balls is $N_w(t)$. Since

$$\binom{n}{N_w(t)} = \frac{n!}{N_w(t)![n - N_w(t)]!}$$

reaches its maximum value for $N_w = \frac{n}{2} = N_b$, we see that (3) predicts a monotone increase of $S$ with time. We can also introduce a partition of the "phase space" according to the different values $N_w$, $N_b$. And what the above formula shows is that different elements of the partition have very different numbers of elements, the vast majority corresponding to "equilibrium," i.e., to those near $N_w = \frac{n}{2} = N_b$.

We can see here in what sense Boltzmann's solution is an approximation. The assumption (2) cannot hold for all times and for all configurations, because it would contradict the reversibility and periodicity of the motion. However, we can also see why the fact that it is an approximation does not invalidate Boltzmann's ideas about irreversibility.

Let us reexamine the model at the microscopic level, first mechanically and then statistically. For each $i = 1, \cdots, n$, we introduce the variable

$$\varepsilon_i = \begin{cases} +1 \text{ if the interval in front of } i \in \bar{S} \\ -1 \text{ if the interval in front of } i \in S \end{cases}$$

and we let

$$\eta_i(t) = \begin{cases} +1 \text{ if the ball at site } i \text{ at time } t \text{ is white} \\ -1 \text{ if the ball at site } i \text{ at time } t \text{ is black} \end{cases}$$

Then, we get the "equations of motion"

$$\eta_i(t) = \eta_{i-1}(t-1)\varepsilon_{i-1} \tag{5}$$

whose solution is

$$\eta_i(t) = \eta_{i-t}(0)\varepsilon_{i-1}\varepsilon_{i-2}\cdots\varepsilon_{i-t} \tag{6}$$

(where the subtractions are done modulo $n$). So we have an explicit solution of the equations of motion at the microscopic level.

We can express the macroscopic variables in terms of that solution:

$$N_w(t) - N_b(t) = \sum_{i=1}^{n} \eta_i(t) = \sum_{i=1}^{n} \eta_{i-t}(0)\varepsilon_{i-1}\varepsilon_{i-2}\cdots\varepsilon_{i-t} \tag{7}$$

and we want to compute $n^{-1}[N_w(t) - N_b(t)]$ for large $n$, for various choices of initial conditions ($\{\eta_i(0)\}$) and various sets $S$ (determining the $\varepsilon_i$'s). It is here that "statistical" assumptions enter. Namely, we fix an arbitrary initial condition ($\{\eta_i(0)\}$) and consider all possible sets $S$ with $m = \mu n$ fixed (one can, of course, think of the choice of $S$ as being part of the choice of initial conditions). Then, for each set $S$, one computes the "curve" $n^{-1}[N_w(t) - N_b(t)]$ as a function of time. The result of the computation, done in *Probability and Related Topics in the Physical Sciences*, is that, for any given $t$ and for $n$ large, the overwhelming majority of these curves will approach $(1 - 2\frac{m}{n})^t = (1 - 2\mu)^t$, i.e., what is predicted by (3). (To fix ideas, Kac suggests that one think of $n$ as being of the order $10^{23}$ and $t$ of order $10^6$.) The fraction of all curves that will deviate significantly from $(1 - 2\mu)^t$, for fixed $t$, goes to zero as $n^{-1/2}$, when $n \to \infty$.

Of course, when I say "compute," I should rather say that one makes an estimate of the fraction of "exceptional" curves deviating from $(1 - 2\mu)^t$ at a fixed $t$. This estimate is similar to the law of large numbers, and (7) is, indeed, of the form of a sum of (almost independent) variables.

*Remarks*

1. The Poincaré recurrence and the reversibility "paradoxes" are easily solved: each curve studied is periodic of period $2n$. So that if we did not fix $t$ and let $n \to \infty$, we would not observe "irreversible" behavior. But this limit is physically correct. The recurrence time ($n$) is enormous compared to any physically accessible time. As for the reversibility objection, let us consider as initial condition a reversed configuration after time $t$. Then we know that for that configuration and *that set* $S$, $n^{-1}[N_w(t) - N_b(t)]$ will not be close to

$(1 - 2\mu)^t$ at time $t$ (since it will be back to its initial value 1). But all we are saying is that for the vast majority of $S$'s this limiting behavior will be seen. For the reversed configuration, the original set $S$ happens to be exceptional. The same remark holds for the configuration with period 4 mentioned in the beginning. Note also that if we consider the set of configurations for which $n^{-1}[N_w(t) - N_b(t)]$ is close to $(1 - 2\mu)^t$ for *all times*, then this set is empty, because of the periodicity.

2. We could consider other macroscopic variables, like the number of white and black balls in each half of the circle ($1 \leqslant i \leqslant \frac{n}{2}$ and $\frac{n}{2} + 1 \leqslant i \leqslant n$), and define the corresponding entropies. We could go on, with each quarter of the circle etc., until we reach a microscopic configuration (number of white or black balls at each site), in which case the entropy is trivially equal to zero (and therefore constant).

3. This model, although perfectly "irreversible," is not ergodic! Indeed, since it is periodic, no trajectory can "visit" more than $2n$ microscopic configurations. But the "phase space" contains $2^n$ configurations (two possibilities—black or white—at each site). So only a very small fraction of the phase space is visited by a trajectory. This nicely illustrates the fact that ergodicity is not necessary for irreversibility. What is used here is only the fact that the vast majority of configurations give to the macroscopic variables a value close to their equilibrium value.

*Conclusion*

I do not want to overemphasize the interest of this model. It has many simplifying features (for example, there is no conservation of momentum; the scatterers here are "fixed," as in the Lorentz gas). However, it has *all* the properties that have been invoked to show that mechanical systems cannot behave irreversibly, and therefore it is a perfect counterexample that allows one to refute all those arguments (and to understand exactly what is wrong with them): it is isolated (the balls plus the scatterers), deterministic, reversible, has Poincaré cycles, and is not ergodic.

The result obtained in the Kac model is exactly what one would like to show for general mechanical systems in order to prove irreversibility. It is obvious why this is very hard. In general, one does not have an explicit solution (for an $n$-body system!) like (5,6), in terms of which the macroscopic variables can be expressed; see (7). It is also clear in this example exactly what is the status of our "ignorance." If we prepare the system many times and if the only variables that we can control are $n$ and $m$, then we, indeed, expect to see the irreversible behavior obtained above. This is simply because it is what happens *deterministically* for the vast majority of microscopic initial conditions corresponding to the macroscopic variables that we are able to control. We may, if we wish, say that we "ignore" the initial conditions, but there is nothing "subjective" here. Finally, I shall refer to *Probability and Related Topics in the Physical Sciences* for a more detailed discussion, in this model, of the status of various approximations used in statistical mechanics (e.g., the Master equation).

## NOTES

1 I. Prigogine, *Les Lois du Chaos*, p. 15. Here and below I have translated texts that were available only in French.
2 Ibid., p. 59.
3 *Order out of Chaos*, chap. 1.
4 Prigogine, *Les Lois du Chaos*, p. 41.
5 See ibid., chap. 9 and Prigogine, "Why Irreversibility? The Formulation of Classical and Quantum Mechanics for Nonintegrable Systems," p. 106.
6 On the issue of irreversibility, see R. Feynman, *The Character of Physical Law*, and R. Feynman, R. B. Leighton & M. Sands, *The Feynman Lectures on Physics*; E. T. Jaynes, *Papers on Probability, Statistics and Statistical Physics*; J. L. Lebowitz, "Macroscopic Laws, Microscopic Dynamics, Times's Arrow and Boltzmann's Entropy" and *Physics Today*; and R. Penrose, *The Emperor's New Mind.*
7 L. Boltzmann, *Theoretical Physics and Philosophical Problems.*
8 I must add that I have defended, in the past, some of the ideas criticized below. Needless to say, I am interested in the critique of ideas and not of individuals.
9 For exaggeratedly negative comments on Laplace, see, e.g., I. Ekeland, *Le Calcul, L'Imprévu*, p. 31; and J. Gleick, *La Théorie du Chaos*, p. 21.
10 Likewise, only the most radical social constructivist might object to the idea that Neptune and Pluto were following their (deterministic) trajectories before they were discovered.
11 In an often-quoted lecture to the Royal Society on the three-hundredth anniversary of Newton's *Principia*, Sir James Lighthill gave an inadvertently perfect example of how to slip from unpredictability to indeterminism: "We are all deeply conscious today that the enthusiasm of our forebears for the marvelous achievements of Newtonian mechanics led them to make generalizations in this area of *predictability* which, indeed, we may have generally tended to believe before 1960, but which we now recognize were false. We collectively wish to apologize for having misled the general educated public by spreading ideas about *determinism* of systems satisfying Newton's laws of motion that, after 1960, were to be proved incorrect. . . ." (italics are mine; quoted, e.g., by L.E. Reichl, *The Transition to Chaos in Conservative Classical Systems: Quantum Manifestations*, p. 3; and by I. Prigogine & I. Stengers, *Entre le Temps et l'Éternité*, p. 93, and *Les Lois du Chaos*, p. 41). See also S. Vauclair, *Eléments de Physique Statistique*, p. 7, where, after describing a chaotic system, one concludes that "the deterministic approach fails."
12 P. S. Laplace, *A Philosophical Essay on Probabilities.*
13 I have expressed my point of view on the foundations of quantum mechanics in "Contre la philosophie de la mécanique quantique." For related views, see D. Albert, *Quantum Mechanics and Experience* and "Bohm's Alternative to Quantum Mechanics"; J.S. Bell, *Speakable and Unspeakable in Quantum Mechanics*; D. Dürr, S. Goldstein & N. Zanghi, "Quantum Equilibrium and the Origin of Absolute Uncertainty"; and T. Maudlin, *Quantum Non-Locality and Relativity.*
14 Most of the laws that are discussed in the literature on chaos (e.g., on the weather) are actually macroscopic laws, and not fundamental or microscopic ones. This distinction will be discussed in SECTION 3.
15 Opponents to determinism are quick to point out that determinism cannot be proved. Of course, no statement about the world can literally be *proved.* But they do not always see how vacuous are their own arguments in favor of indeterminism, arguments that rely ultimately on our ignorance. In *The Open Universe. An Argument for Indeterminism*, Popper gives a long series of such arguments. In a review of this book, the biologist Maynard Smith shows a rather typical misunderstanding of Laplace: first he agrees with Popper about Laplace, because the latter's computations are impossible, and then disagrees with Popper about free will and gives, as far as I can see, a perfectly causal and Laplacian account of human actions, which, of course, are not computable either (*Did Darwin Get It Right?*, p. 244). To avoid misunderstandings, I am not trying to say that determinism is or must be true. All I say is that various arguments against determinism miss the point.

16 Here is a simple example. Consider the "phase space" to be simply the interval $I = [0,1[$. And take as (discrete time) dynamics the map $f : x \rightarrow 10x \ mod \ 1$. This means, we take a number between 0 and 1, multiply it by 10, write the result as an integer plus a number between 0 and 1, and take the latter as the result [i.e., $f(x)$]. This gives again a number between 0 and 1, and we can repeat the operation. Upon iteration, we obtain the *orbit* of $x$; $x$ itself is the initial condition. To describe concretely the latter, one uses the decimal expansion. Any number in $I$ can be written as $x = 0.a_1a_2a_3 \ldots$, where $a_i$ equals $0,1,2, \ldots, 9$. It is easy to see that $f(x) = 0.a_2a_3 \ldots$. This is a perfect example of a *deterministic* but *unpredictable* system. Given the state $x$ at some initial time, one has a rule giving the state of the system for arbitrary times. Moreover, for any fixed time, one can, in principle, find the state after that time, with any desired accuracy, given a sufficiently precise characterization of the initial state. This expresses the deterministic aspect. Unpredictability comes from the fact that, if we take two initial conditions at a distance less than $10^{-n}$, then the corresponding orbits could differ by, say 1/2, after $n$ steps, because the difference will be determined by the $n$th decimal. One of the relatively recent discoveries in dynamical systems is that simple physical examples, like a forced pendulum, may behave more or less like this map.

17 How long a time this is depends on the details of the system.

18 J. C. Maxwell, *Matter and Motion*, p. 13. As for the applications to the weather, Poincaré (*Science et Méthode*, p. 69) already noticed that the rainfalls or the storm seem to occur at random, so that people are more likely to pray for rain than for an eclipse (for an exception to this rule, but based on prior knowledge, see Hergé, *Tintin et le Temple du Soleil*, p. 59). We are not able to predict the storms, because the atmosphere may be in a state of "unstable equilibrium." It may all depend on a tenth of a degree. And he adds, "If we had known this tenth of a degree, one could have made predictions," but since our observations are not sufficiently precise, it all looks as if it were due to randomness.

19 J. Hadamard ("Les Surfaces à Courbures Opposées et Leurs Lignes Géodésiques"), P. Duhem (*La Théorie Physique. Son Objet et Sa Structure*) and E. Borel ("La Mécanique Statistique et l'Irréversibilité") made similar observations. See D. Ruelle (*Chance and Chaos*) for a discussion of that history from a modern perspective, and a good popular exposition of chaos.

20 It is interesting to read the rest of the text of Laplace. First of all, he expresses the belief that there are, indeed, fundamental, universally valid laws of nature that can be discovered through scientific investigation (the only example that Laplace had of a fundamental law was that of universal gravitation). In that respect, nothing has changed today. One of the goals of physics is still to discover those fundamental laws. His basic idea could be called universal reductionism rather than universal determinism. Since reductionism is remarkably well defended in Weinberg's book *Dreams of a Final Theory*, I shall not pursue this point. Reading a little further, we see that Laplace's goal is to use science against superstition. He mentions the fears caused by Halley's comet in the Middle Ages (where it was taken as a sign of the divine wrath) and how our discovery of the laws of the "system of the world" "dissipated those childish fears due to our ignorance of the true relations between Man and the Universe." Laplace expresses also a deep optimism about the progress of science. Again, nothing of that has been refuted by the evolution of natural sciences over the last two centuries. But one will not find any claim about the computability, by us humans, of *all* the consequences of the laws of physics.

21 E. T. Jaynes, "Clearing up Mysteries—the Original Goal," p. 7. Jaynes's criticism were directed mostly at the way quantum theory is presented, but they also apply to some discussions of chaos theory or of statistical mechanics.

22 Of course, since classical mechanics is not really fundamental (quantum mechanics is), this issue is rather academic. We nevertheless want to discuss it, because there seems to be a lot of confusion in the literature.

23 Imagine that the Poincaré-Bendixson would hold in all dimensions.

24 And, concerning quantum mechanics, see the references in Note 13.

25 See also I. Prigogine & I. Stengers, *Entre le Temps et l'Éternité*, p. 28: "As we shall see, there exists, for sufficiently unstable systems, a 'temporal horizon' beyond which no determined trajectory can be attributed to them."

26 See R.W. Batterman, "Randomness and Probability in Dynamical Theories: On the Proposals of the Prigogine School," for a related, but different, critique. Batterman says that the replacement of trajectories by probabilities is "very much akin to the claim in quantum mechanics that the probabilistic state description given by the Ψ-function is complete, that is, that underlying exact states cannot exist" (p. 259). But he notes that here, unlike in quantum mechanics, no no-hidden-variable argument is given to support that claim (for the exact status of no-hidden-variable arguments in quantum mechanics, see J. S. Bell, *Speakable and Unspeakable in Quantum Mechanics*, and T. Maudlin, *Quantum Non-Locality and Relativity*).

27 An absolutely continuous one, i.e., given by a density. If one considers probabilities given by delta functions, it is equivalent to consider trajectories.

28 I say "approximate," because I describe the system as it is seen. I do not yet consider any theory (classical or quantum).

29 P. S. Laplace, *A Philosophical Essay on Probabilities.*

30 Mathematically, the microscopic state of the system is represented by a point in its "phase space" $\Omega$. Each point in that space represents the positions and the velocities of *all* the particles of the system under consideration. So, the phase space is $\mathbf{R}^{6.N}$ where $N$ is the number of particles (of the order of $10^{23}$ for a macroscopic system), since one needs three coordinates for each position and three coordinates for each velocity. Hamilton's equations of motion determine, for each time $t$, a map $T^t$ that associates to each initial condition $\mathbf{x} \in \Omega$, at time zero, the corresponding solution $T^t\mathbf{x}$ of the equations of motion at that time. Reversibility of the equations of motion means that there is a transformation (an involution) $I$ acting on $\Omega$ that satisfies the following relation:

$$T^t I T^t \mathbf{x} = I\mathbf{x}, \tag{8}$$

or $IT^t = T^{-t}I$. In classical mechanics, $I$ reverses velocities. (In quantum mechanics, $\Omega$ is replaced by a Hilbert space, and $I$ associates to a wave function its complex conjugate. For the role of weak interactions, see R. P. Feynman, *The Character of Physical Law.*)

31 We shall discuss in SECTION 4.3 a frequent confusion that assigns the source of irreversibility to the (true but irrelevant) fact that no system is ever perfectly isolated. But let us point out here that it is easy to produce nonisolated systems that behave approximately in "time-reversed" fashion: a refrigerator, for example. Living beings also seem to violate the second law of thermodynamics. But put a cat in a well-sealed box for a long enough time: it will evolve towards equilibrium.

32 Such a contradiction is suggested by the following statement of Prigogine and Stengers: " Irreversibility is either true on all levels or on none: it cannot emerge as if out of nothing, on going from one level to another" (*Order out of Chaos*, quoted by P. Coveney, "The Second Law of Thermodynamics: Entropy, Irreversibility and Dynamics," p. 412.

33 I. Prigogine & I. Stengers, *Entre le Temps et l'Éternité*, p. 25.

34 I. Prigogine, *Les Lois du Chaos*, p. 41. Stengers goes even further: "The reduction of the thermodynamic entropy to a dynamical interpretation can hardly be viewed otherwise than as an 'ideological claim' . . ." (*L'Invention des Sciences Modernes*, p. 192). We shall see below in what precise sense this "reduction" is actually a "scientific claim."

35 Quoted in J. L. Lebowitz, *Physics Today*, Sep. 1993, pp. 32–38.

36 This is, of course, not new at all. Good references, apart from Boltzmann himself (*Theoretical Physics and Philosophical Problems. Selected Writings*), include R. P. Feynman, *The Character of Physical Law*; E. T. Jaynes, *Papers on Probability, Statistics and Statistical Physics*; J. L. Lebowitz, "Macroscopic Laws, Microscopic Dynamics, Time's Arrow and Boltzmann's Entropy," and *Physics Today*, Sep. 1993, pp. 32–38; R. Penrose, *The Emperor's New Mind*; and E. Schrödinger, "Irreversibility."

37 By classical, I mean "standard." However, all the discussion will take place in the context of classical physics. But it could be extended to quantum mechanics (replacing phase points by state vectors).
38 Of course, the billiard ball itself contains many molecules. But the rigidity of the ball allows us to concentrate on the motion of its center of mass.
39 By "functions," I mean also families of functions indexed by space or time, i.e., fields, such as the local energy density or the velocity field.
40 I am a little vague on how to "count" configurations. If I consider discrete (finite) systems, then it is just counting. Otherwise, I use, of course, the Lebesgue measure on phase space. All statements about probabilities made later will be based on such "counting."
41 Although not trivial, this fact simply means that reproducible macroscopic experiments exist and that a macroscopic description of the world is possible.
42 To make the micro/macro distinction sharp, one has to consider some kind of limit (hydrodynamic, kinetic, etc.), where the number of particles (and other quantities) tend to infinity. That is a convenient mathematical setting to prove precise statements. But one should not confuse this limit, which is an approximation, with the physical basis of irreversibility. See J. L. Lebowitz, "Macroscopic Laws, Microscopic Dynamics, Time's Arrow and Boltzmann's Entropy" and H. Spohn, *Large Scale Dynamics of Interacting Particles*, for a discussion of those limits.
43 This is due to the Poincaré recurrences; see SECTION 4.1 and the APPENDIX.
44 I mean shorter than the Poincaré recurrence time.
45 O. E. Lanford, "Time Evolution of Large Classical Systems"; *Physica*; "On a Derivation of the Boltzmann Equation."
46 It is also important to clarify the role of "ensembles" here. What we have to explain is the fact that, when a system satisfies certain macroscopic initial conditions ($F_0$), it *always* (in practice) obeys certain macroscopic laws. The same macroscopic initial conditions will correspond to many different microscopic initial conditions. We may introduce, for mathematical convenience, a probability distribution (an "ensemble") on the microscopic initial conditions. But one should remember that we are physically interested in "probability one statements," namely, statements that are independent of the microscopic configuration, as opposed to statements about averages, for example. Otherwise, one would not explain why all individual macroscopic systems satisfy a given law. In practice, those "probability one statements" will hold only in some limit. Physically, they should be interpreted as "very close to one" for finite systems with a large number of particles. To see how close to one this is, consider all the bets and games of chance that have ever taken place in human history. One would certainly expect the laws of large numbers to apply to such a sample. But this number is minuscule compared to the typical number ($10^{23}$) of molecules in a cubic centimeter.
47 This remark is of some interest for the issue of *reductionism*: higher-level laws, such as the macroscopic laws, are reduced to the microscopic ones *plus* assumptions on the initial conditions. If this is the case in statistical mechanics, where it is usually granted that reductionism works, it should clarify the situation in other fields, like biology, where reductionism is sometimes questioned. In particular, the fact that some assumptions must be made on the initial conditions in going from the microscopic to the macroscopic should not be forgotten, nor should it be held as an argument against reductionism. Another frequent confusion about reductionism is to remark that the macroscopic laws do not uniquely determine the microscopic ones. For example, many of the macroscopic laws can be derived from stochastic microscopic laws or from deterministic ones. That is true, but it does not invalidate reductionism. What is true on the microscopic level has to be discovered independently of the reductionist program. Finally, what is considered microscopic or macroscopic is a question of scale. The classical description considered here at the "microscopic" level is an approximation to the quantum description and neglects the molecular and atomic structure. And the "macroscopic" level may in turn be considered microscopic if one studies large-scale motions of the atmosphere. But

despite frequent claims to the contrary, reductionists are quite happy not to explain carburetors directly in terms of quarks (see S. Weinberg, *Dreams of a Final Theory*, for a good discussion of reductionism).

48 R. P. Feynman, *The Character of Physical Law*. See the end of Note 46.

49 To put it in formulas, let $\overline{\Omega}_t$ be the configurations giving to $F$ its value at time $t$. If we denote by $F_t$ that value, $\overline{\Omega}_t$ is simply the preimage of $F_t$ under the map $F$. Let $\Omega_t$ be the set of good configurations, at time $t$, that lead to a behavior of $F$, for later times (again, not for *too* long, because of Poincaré recurrences), which is described by the macroscopic laws. In general, $\Omega_t$ is a very large subset of $\overline{\Omega}_t$, but is not identical to $\overline{\Omega}_t$. Thus, $\overline{\Omega}_0$ are all the configurations in the left half of the box at time zero, and $\Omega_0$ is the subset consisting of those configurations whose evolution leads to a uniform density. Microscopic reversibility says that $T^t\{I[T^t(\Omega_0)]\} = I(\Omega_0)$ (this is just (8) in Note 30 applied to $\Omega_0$). A reversibility paradox would follow from $T^t[I(\Omega_t)] = I(\Omega_0)$ (one takes all the good configurations at time $t$, reverses the velocities, lets them evolve for a time $t$, and one gets the original set of initial conditions, with velocities reversed). But $\Omega_t$ is *not equal*, in general, to $T^t(\Omega_0)$ (and this is the source of much confusion). In our example, $T^t(\Omega_0)$ is a tiny subset of $\Omega_t$, because most configurations in $\Omega_t$ we not in the left half of the box at time zero. Actually, $I[T^t(\Omega_0)]$ provides an example of configurations that belong to $\overline{\Omega}_t$ but not to $\Omega_t$. These configurations correspond to a uniform density at time $t$, but not at time $2t$.

50 R. Penrose, *The Emperor's New Mind* and "On the Second Law of Thermodynamics."

51 Failure to realize this leads to strange statements, as, for example, in J. Cohen & I. Stewart, *The Collapse of Chaos*: speaking of the evolution since the Big Bang, the authors write: "For systems such as these, the thermodynamic model of independent subsystems whose interactions switch on but not off is simply irrelevant. The features of thermodynamics either don't apply or are so long term that they don't model anything interesting. Take Cairns-Smith's scenario of clay as scaffolding of life. The system consisting of clay alone is *less* ordered than that of clay plus organic molecules: Order is increasing with time. Why?" (p. 259). The explanation given afterwards ignores both the action of the sun, and the original "improbable state" discussed here. As Ruelle wrote in a review of this book, "if life violates the second law, why can't one build a power plant (with some suitable life forms in it) producing ice cubes and water currents from the waters of Loch Ness?" ("Cracks in the Glass Menagerie of Science"). A similar confusion can be found in Popper: "This law of the increase of disorder, interpreted as a cosmic principle, made the evolution of life incomprehensible, apparently even paradoxical" (*The Open Universe. An Argument for Indeterminism*, p. 172).

52 I neglect here the effect of gravity, see R. Penrose, *The Emperor's New Mind*, for a discussion of the effect of gravity.

53 See R. Penrose, *The Emperor's New Mind*, for further discussion, and Figure 7.19 there for an illustration.

54 As Feynman says: "Therefore I think it necessary to add to the physical laws the hypothesis that in the past the universe was more ordered, in the technical sense, than it is today—I think this is the additional statement that is needed to make sense, and to make an understanding of the irreversibility" (*The Character of Physical Law*, p. 116).

55 D. Driebe, Letter in *Physics Today*, November 1994, p. 13.

56 J. L. Lebowitz, *Physics Today*, September 1993, pp. 34–38.

57 In a recent textbook one reads, after a discussion of the baker's map: "Irreversibility appears only because the instantaneous state of the system cannot be known with an infinite precision" (S. Vauclair, *Elément de Physique Statistique*, p. 198).

58 The baker map is quite similar to the map discussed in Note 16, and has the same chaotic properties as the latter, but is invertible.

59 I. Prigogine, *Les Lois du Chaos*, p. 37.

60 Ibid., p. 42. See, e.g., P. Coveney, "The Second Law of Thermodynamics: Entropy, Irreversibility and Dynamics": "Another quite popular approach has been to rele-

gate the whole question of irreversibility as illusory" (p. 412). See also R. Lestienne, *Les Fils du Temps. Causalité, Entropie, Devenir* (p. 176); and I. Prigogine & I. Stengers, *La Nouvelle Alliance. Métamorphoses de la Science*, p. 284, for similar remarks.

61 W. Heisenberg, *The Physicist's Conception of Nature*, p. 38. W. Pauli made a similar remark (see "Wahrscheinlichkeit und Physik"; quoted in K. R. Popper, *Quantum Theory and the Schism in Physics*, p. 109).

62 Max Born, *Natural Philosophy of Cause and Chance*, p. 72.

63 K. R. Popper, *Quantum Theory and the Schism in Physics*, p. 106. In his textbook *Statistical Mechanics*, S. K. Ma shows similar concerns. "In one point of view, probability expresses the knowledge of the observer. If he knows more about the system, the probability is more concentrated. This is obviously incorrect. The motion of the system is independent of the psychological condition of the observer" (p. 448). And H. Bondi wrote: "It is somewhat offensive to our thought to suggest that if we know a system in detail then we cannot tell which way time is going, but if we take a blurred view, a statistical view of it, that is to say throw away some information, then we can. . . ." ("Physics and Cosmology"; quoted in P. T. Landsberg, *The Enigma of Time*, p. 135. T. Gold expressed similar views; see P. T. Landsberg, *The Enigma of Time*).

64 K. R. Popper, *Quantum Theory and the Schism in Physics*, p. 107.

65 E. T. Jaynes, *Papers on Probability, Statistics and Statistical Physics*; "The Gibbs Paradox."

66 I. Prigogine, *Les Lois du Chaos*, p. 23.

67 Ibid., p. 24.

68 E. Zermelo, *Wiener Annalen* 57 (1896): 485.

69 In formulas, let $\Omega$ be the "phase space" on which the motion is ergodic (i.e., a constant energy surface, which is a subset of the space considered in Note 30, on which is defined the measure induced by the Lebesgue measure, normalized to one, and denoted $d\mathbf{x}$). Then, ergodicity means that

$$\lim_{T\to\infty} \frac{1}{T} \int_0^T F(T^t\mathbf{x})dt = \int_\Omega F(\mathbf{x})d\mathbf{x} \tag{9}$$

for $F$ integrable and for almost all initial conditions $\mathbf{x} \in \Omega$. The LHS is the time average and the RHS the space average. If we take for $F$ the characteristic function of a (measurable) set $A \subset \Omega$, the time average equals the fraction of time spent by the trajectory in $A$, and the space average is the volume of $A$.

70 For a history of the concept of ergodicity, and some very interesting modern developments, see G. Gallavotti, "Ergodicity, Ensembles, Irreversibility in Boltzmann and Beyond." It seems that the (misleading) emphasis on the modern notion of ergodicity goes back to the Ehrenfests's paper *The Conceptual Foundations of the Statistical Approach in Mechanics* more than to Boltzmann. A careful, but nevertheless exaggerated, interest in ergodicity and mixing is found in the work of A. I. Khinchin (*Mathematical Foundations of Statistical Mechanics*) and N. S. Krylov (*Works on the Foundations of Statistical Mechanics*). It is also found, e.g., in D. Chandler, *Introduction to Modern Statistical Mechanics*, p. 57; Y. G. Sinai, *Topics in Ergodic Theory*, p. 207; T. Hill, *Statistical Mechanics*, p. 16; S. K. Ma, *Statistical Mechanics*, chap. 26; C. J. Thompson, *Mathematical Statistical Mechanics*, app. B; and N. Dunford & J. T. Schwartz, *Linear Operators; Part 1: General Theory*, p. 657. But see J. T. Schwartz, "The Pernicious Influence of Mathematics on Science," for a self-criticism of *Linear Operators; Part 1: General Theory*; in the recent textbook of S. Vauclair, *Elément de Physique Statistique*, one reads: "One considers that during the time $\delta t$ of the measurement, the system has gone through all the possibly accessible states, and that it spent in each state a time proportional to its probability" (p. 11); and: "Only the systems having this property (mixing) tend to an equilibrium state, when they are initially in a state out of equilibrium" (p. 197).

71 R. C. Tolman, *The Principles of Statistical Mechanics*, p. 65; E. T. Jaynes, *Papers on Probability, Statistics and Statistical Physics*, p. 106; and J. T. Schwartz, "The Pernicious Influence of Mathematics on Science."

72 If there is some cell that has not been visited even once, there will be some function on phase space for which the space average and the time average, computed up to that time, differ a lot: just take the function that takes value one on that cell and zero elsewhere.

73 See, e.g., Figures 7.3 and 7.5 in R. Penrose, *The Emperor's New Mind*, for an illustration, and the APPENDIX here for an example.

74 See J. L. Lebowitz & O. Penrose, "Modern Ergodic Theory."

75 See, e.g., S. Vauclair, *Eléments de Physique Statistique*, p. 197, where the approach to equilibrium is illustrated by the baker's transformation.

76 One can even invoke a theorem to that effect: the ergodic theorem for Markov chains. But this is again highly misleading. This theorem says that probability distributions will converge to an "equilibrium" distribution (for suitable chains). This is similar, and related, to what happens with strongly chaotic systems. But it does not explain what happens to a single system, unless we are willing to distinguish between microscopic and macroscopic variables, in which case the ergodic theorem is not necessary.

77 E. Borel ("La Mécanique Statistique et l'Irréversibilité") tried to answer the reversibility objection, using the lack of isolation and the instability of the trajectories. As we saw in SECTION 3.3, this objection is not relevant, once one introduces the micro/macro distinction. And Fred Hoyle wrote: "The thermodynamic arrow of time does not come from the physical system itself . . . it comes from the connection of the system with the outside world" ("The Asymmetry of Time," quoted in P. T. Landsberg, *The Enigma of Time*). See also J. Cohen & I. Stewart, *The Collapse of Chaos* (p. 260) and (X. de Hemptinne, "La Source de l'Irréversibilité," for similar ideas.

78 See L. Boltzmann, *Theoretical Physics and Philosophical Problems. Selected Writings*, p. 170.

79 One has to be careful here. If we shake a mixture of fluids, it should become homogeneous faster. But, of course, there are external influences that prevent the system from going to equilibrium, like in a refrigerator. Also, the time scale on which the approach to equilibrium takes place may vary enormously, depending on the physical situation. This is what is overlooked in X. de Hemptinne, "La Source de l'Irréversibilité."

80 See the references to Bergson in I. Prigogine & I. Stengers, *La Nouvelle Alliance. Métamorphoses de la Science* and *Entre le Temps et l'Éternité.*

81 I remember that when I first heard, as a teenager, about the special theory of relativity, it was through Bergson's alleged refutation of that theory! He thought, probably rightly so, that there was a conflict between his intuitive views on duration and the absence of absolute simultaneity in relativity. So he simply decided that there was a "time of consciousness," as absolute as Newtonian time, and that the Lorentz transformations were merely some kind of coordinates "attributed" by one observer to the other. Running into trouble with the twin paradox, he decided that acceleration is relative, like uniform motion, and that, when both twins meet again, they have the same age! (See H. Bergson, *Durée et Simultanéité. A propos de la Théorie d'Einstein.*) At least Bergson had the good sense, after his lengthy polemic with Einstein, to stop the republication of his book. But, and this is a remarkable aspect of our "intellectual" culture, the *very same mistake* is repeated by some of his admirers: V. Jankelevitch, *Henri Bergson*, chap. 2; M. Merleau-Ponty, *Eloge de la Philosophie et Autres Essais*, p. 319; and G. Deleuze, *Le Bergsonisme*, p. 79; see also Deleuze's later writings. Of course, all this is explained by telling the physicists that they should stick to their "mathematical expressions and language" (M. Merleau-Ponty, *Eloge de la Philosophie et Autres Essais*, p. 320), while leaving the deep problems of the "time of consciousness" to philosophers. For a modern attempt to make some sense of Bergson's universal time, see the first appendix of I. Prigogine & I. Stengers, *Entre le Temps et l'Éternité.*

82 See J. Monod, *Chance and Necessity*, and B. Russell, *A History of Western Philosophy*, for critiques of his philosophy and G. Moreau, "Monsieur Ilya Prigogine 'Bouleverse' la Philosophie," for the relation between Bergson and Prigogine. The main problem with Bergson's lasting influence is well expressed by Bertrand Russell: "One of the bad effects of an antiintellectual philosophy such as that of Bergson, is that it thrives upon the errors and confusions of the intellect. Hence it is led to prefer bad thinking to good, to declare every momentary difficulty insoluble, and to regard every foolish mistake as revealing the bankruptcy of intellect and the triumph of intuition" (*A History of Western Philosophy*, p. 831).

83 H. Bergson, *L'Evolution Créatrice*, p. 264. As we shall see in SECTION 5, it is probably the least metaphysical of those laws (although I do not like this terminology), since it is not a purely dynamic law.

84 Ibid., p. 266.

85 Ibid., p. 267.

86 Ibid., p. 278.

87 J. Monod, *Chance and Necessity.*

88 See, e.g., the introduction by Monod to the French edition of *The Logic of Scientific Discovery*; also, e.g., I. Prigogine & I. Stengers, *Entre le Temps et l'Éternité*, p. 173. For philosophical critiques of Popper, see H. Putnam, "The 'Corroboration' of Theories"; and D. Stove, *Popper and After. Four Modern Irrationalists.* For a critique of his views on the arrow of time, see M. Ghins, "Popper versus Grünbaum and Boltzmann on the Arrow of Time."

89 See K. R. Popper, *Quantum Theory and the Schism in Physics.*

90 K. R. Popper, *The Open Universe. An Argument for Indeterminism*, p. 102.

91 See, e.g., K. R. Popper, *Quantum Theory and the Schism in Physics*, p. 112.

92 See R. P. Feynman, *The Character of Physical Law*, and J. L. Lebowitz, "Macroscopic Laws, Microscopic Dynamics, Time's Arrow and Boltzmann's Entropy," for a discussion of that fluctuation theory.

93 There are indications that Boltzmann did not take his fluctuation theory too seriously. For example, he wrote "that the world began from a very unlikely initial state, this much can be counted amongst the fundamental hypotheses of the whole theory and we can say that the reason for it is as little known as that for why the world is as it is and not otherwise" (*Theoretical Physics and Philosophical Problems. Selected Writings*, p. 172; compare with Note 53). In general, Boltzmann is quite opposed to unscientific speculations. In his criticism of Schopenhauer, he takes a very Darwinian (and surprisingly modern) view of mankind. He starts by observing that drinking fermented fruit juices can be very good for your health: "if I were an antialcoholic I might not have come back alive from America, so severe was the dysentry that I caught as a result of bad water . . . it was only through alcoholic beverages that I was saved" (Ibid., p. 194). But, with alcohol, one can easily overshoot the mark. It is the same thing with moral ideas. "We are in the habit of assessing everything as to its value; according to whether it helps or hinders the conditions of life, it is valuable or valueless. This becomes so habitual that we imagine we must ask ourselves whether life itself has a value. This is one of those questions utterly devoid of sense" (Ibid., p. 197). Finally, for theoretical ideas, he observes that our thoughts should correspond to experience and that overshooting the mark should be kept within proper bounds: "Even if this ideal will presumably never be completely realized, we can nevertheless come nearer to it, and this would ensure cessation of the disquiet and the embarrassing feeling that it is a riddle that we are here, that the world is at all and is as it is, that it is incomprehensible what is the cause of this regular connection between cause and effect, and so on. Men would be freed from the spiritual migraine that is called metaphysics" (Ibid., p. 198).

94 K. R. Popper, "Autobiography."

95 J. C. Maxwell, *Nature* 17 (1878): 257; quoted in J. L. Lebowitz, *Physics Today*, September 1993, pp. 32–38.

96 P. K. Feyerabend, "On the Possibility of a Perpetuum Mobile of the Second Kind."

97 This error is repeated, with many others, in A. Woods & T. Grant, *Reason in Revolt*, p. 177.

98 M. Serres, *Eclaircissements: Cinq Entretiens avec Bruno Latour.* I have left these texts in the original language, partly because they are difficult to translate, partly because the confusion might be blamed on the translator.

99 Jean-François Lyotard, *La Condition Postmoderne: Rapport sur le Savoir.*

100 Jean Baudrillard, *L'Illusion de la Fin.*

101 Gilles Deleuze & Félix Guattari, *Qu'est-ce que la Philosophie?*

102 I recommend to people interested in *tensors* (applied to psychology, sociology, etc.) Guattari's contribution to J. P. Brans, I. Stengers & P. Vincke, eds., *Temps et Devenir.*

103 K. Denbigh, "How Subjective is Entropy?"; M. Tribus, *Boelter Anniversary Volume.*

104 W. Thirring, "Boltzmann's Legacy in the Thinking of Modern Physics."

105 E. T. Jaynes, *Papers on Probability, Statistics and Statistical Physics*, p. 85.

106 This is again the source of much confusion, just like the "subjectivity of irreversibility" discussed in SECTION 3.5. See, for example, K. R. Popper, *Quantum Theory and the Schism in Physics*, p. 111; K. Denbigh, "How Subjective Is Entropy"; S. K. Ma, *Statistical Mechanics.* In M. Gell-Mann's popular book *The Quark and the Jaguar* we read: "Entropy and information are closely related. In fact, entropy can be regarded as a measure of ignorance" (p. 219). And further: "Indeed, it is mathematically correct that the entropy of a system described in perfect detail would not increase; it would remain constant" (p. 225). This is true, but it might be useful to emphasize that one does not refer to the "usual" thermodynamic entropy.

107 See also E. T. Jaynes, "The Gibbs Paradox," for a nice discussion on apparent violations to the Second Law. And see, e.g., the constraints on the plausible mechanisms for the origin of life, due to the Second Law, discussed by A. C. Elitzur, "Let There Be Life," sec. 11. There is some similarity between this use of the Second Law and the way biologists use the law of natural selection. The biologists do not believe that complex organs appear "spontaneously." Hence, when they occur, they look for an adaptive explanation (see R. Dawkins, *The Blind Watchmaker*, for an introduction to the theory of evolution). Both attitudes are, of course, similar to elementary probabilistic reasoning: if we throw a coin a million times and find a significant deviation from one-half heads one-half tails, we shall conclude that the coin is biased (rather than assuming that we have observed a miracle).

108 As emphasized by J. L. Lebowitz in "Macroscopic Laws, Microscopic Dynamics, Time's Arrow and Boltzmann's Entropy."

109 As, for example, in: "This so-called hypothesis of 'molecular chaos' admits the absence of correlations between the velocities of the molecules in the initial state of the gas, although, obviously, correlations exists between the molecules after the collisions. The hypothesis of molecular chaos amounts to introduce, in a subtle way, the irreversibility that one tries demonstrate" (R. Lestienne, *Le Fils du Temps. Causalité, Entropie, Devenir*, p. 172). Boltzmann never said that he would demonstrate irreversibility without assuming something on initial conditions. Another, more radical, confusion is due to Bergmann: "It is quite obvious that the Boltzmann equation, far from being a consequence of the laws of classical mechanics, is inconsistent with them" (in T. Gold, ed., *The Nature of Time*, p. 191).

110 To make a *vague* analogy, in equilibrium statistical mechanics, one has the concept of phase transition. Mean field theory (or the van der Waals theory, Curie-Weiss or molecular field approximation) gives an approximate description of the phase transition. But the concept of phase transition is much wider than the range of validity of that approximation.

111 This theorem says that, if $A$ is a subset of the phase space $\Omega$, then $Vol[T^t(A)] = Vol(A)$, where $Vol(A) = \int_A d\mathbf{x}$.

112 I. Prigogine & I. Stengers, *Entre le Temps et l'Éternité*, p. 104. See X. de Hemptinne, "La Source de l'Irréversibilité," p. 8, for a similar statement. See also I. Prigogine, "Un Siècle d'Espoir": "According to the mechanical view of the world,

the entropy of the universe is today identical to what it was at the origin of time" (p. 160). Or, as P. Coveney says: "As long as the dynamical evolution is unitary, irreversibility cannot arise. This is the fundamental problem of nonequilibrium statistical mechanics" ("The Second Law of Thermodynamics: Entropy, Irreversibility and Dynamics," p. 411).

113 Let me use the notations of Note 49. By Liouville's Theorem, indeed $Vol[T^t(\Omega_0)] = Vol(\Omega_0)$. But $T^t(\Omega_0)$ is a very small subset of $\Omega_t$. Confusing the two sets leads to the (wrong) idea that $Vol[T^t(\Omega_0)] = Vol(\Omega_t)$. The evolution of $\Omega_t$ does not coincide with a set of trajectories.

114 Note that these entropies agree with (minus) Boltzmann's *H* function only when the interparticle forces are negligible (as in a very dilute gas). This is rather obvious, since the *H* function is an approximation to the Boltzmann entropy. See E. T. Jaynes, *Papers on Probability, Statistics and Statistical Physics*, p. 81.

115 Amusingly enough, this conclusion can be reached using only Liouville's theorem (see E. T. Jaynes, *Papers on Probability, Statistics and Statistical Physics*, p. 83), which is blamed as the source of all the troubles!

116 See, e.g., P. Coveney, "The Second Law of Thermodynamics: Entropy, Irreversibility and Dynamics": Irreversibility is admitted into the description by asserting that we only observe a course-grained probability" (p. 412).

117 E. T. Jaynes, *Papers on Probability, Statistics and Statistical Physics*, p. 86.

118 Note that the word "chaos" in the title is used in a somewhat ambiguous way: sometimes it has the technical meaning of SECTION 2, sometimes it means "disordered" or "random."

119 D. C. Dennett, *Darwin's Dangerous Idea*, p. 392.

120 Concerning the rather poetic and enthusiastic style of Prigogine and Stengers (see, e.g., the title of Prigogine's conference at Cerisy: "A Century of Hope"), I can only agree with the comment of J. Maynard Smith: "I do not think we should embrace scientific theories because they are more hopeful, or more exhilarating. . . . I feel sensitive on this matter because, as an evolutionary biologist, I know that people who adopt theories because they are hopeful finish up embracing Lamarckism, which is false, although perhaps not obviously so, or Creationism, which explains nothing and suggests no questions at all. If nonequilibrium thermodynamics makes poets happier, so be it. But we must accept or reject it on other grounds" (Did Darwin Get It Right?, p. 257).

121 As, for example, in J. Cohen & I. Stewart: "The tendency for systems to segregate into subsystems is just as common as the tendency for different systems to get mixed together" (*The Collapse of Chaos*, p. 259). Or: "by watching some phenomena, one is led to say that time has an arrow pointing towards a greater disorder, but by considering other phenomena, it seems that time has an arrow pointing, on the contrary, towards a greater order. Then, what does this arrow mean? If we can orient it in opposite directions, it is better not to talk about it any more" (A. Meessen, "La Nature du Temps," p. 119).

122 I am not talking here about the "heat death" of the universe, but only about a "small" subsystem, like the solar system, over the "short" period during which the sun burns its fuel.

123 K. R. Popper, *The Open Universe. An Argument for Indeterminism*, p. 173.

124 One should always distinguish this precise but technical sense of order from vague, intuitive words, such as "complexity." If we speak of the "complexity of the brain," it has of course evolved from a less "complex" structure, but those words do not have a precise meaning. Note that precise definitions of complexity, such as algorithmic complexity, do not at all capture the intuitive meaning of the word, since "random" sequences are algorithmically complex, and, whatever "complexity of the brain" means, and whatever "random" means, they do not mean the same thing (a similar problem occurred with the word "information" in the past).

125 Besides, as we saw in SECTION 5, entropy is not really a "substance" to be "exported." This is a somewhat strange terminology for a philosopher like Popper, so critical of "essentialism."

126 To avoid any misunderstanding, I emphasize that I do not criticize any explicit statement made below, but I suggest that one may unwillingly mislead the general public by putting too much emphasis on certain aspects of irreversible processes.

127 I. Prigone, "Un Siècle d'Espoir," p. 157.

128 I. Prigone & I. Stengers, *La Nouvelle Alliance. Métamorphoses de la Science*, p. 427.

129 A fluid is maintained between two horizontal plates, the lower one being hotter than the higher one. If the temperature difference is large enough, rolls will appear. See, e.g., I. Prigone & I. Stengers, *La Nouvelle Alliance. Métamorphoses de la Science* and *Entre le Temps et l'Éternité* for a discussion of the Bénard instability.

130 A. Meessen, "La Nature du Temps," p. 118.

131 Somewhat to my surprise, I found the following *theological* commentary on the constructive role of irreversible phenomena: "Each time that a new order of things appear, it is marked by the dissipation of a chaotic behaviour, by a broken form of movement, that is, by a "fractal," by non-linearity, by variations or "fluctuations," by instability and randomness. In this way the dynamics of self-organization of matter, which reaches the great complexity of consciousness, manifests itself" (A. Ganoczy, *Dieu, l'Homme et la Nature*, p. 79). This is a bit of an extrapolation, starting from the Bénard cells. The quotation appears in a section of a chapter on "God in the language of the physicists," where the author refers mostly to Prigogine & Stengers, *La Nouvelle Alliance. Métamorphoses de la Science* and *From Being to Becoming*.

132 I. Prigogine & I. Stengers, *Entre le Temps et l'Éternité*, p. 46. And even more misleading: "In a deterministic world, irreversibility would be meaningless, since the world of tomorrow would already be contained in the world of today, there would be no need to speak of time's arrow" ("Un Siècle d'Espoir," p. 166).

133 It is also a bit too fast to say, as Prigogine & Stengers do, that this kind of mechanism allows us to go beyond the "very old conflict between reductionists and antireductionists" (*La Nouvelle Alliance. Métamorphoses de la Science*, p. 234; quoted in A. Boutot, *L'Invention des Formes*, p. 274). Any reductionist is perfectly happy to admit that some situations do not have simple, deterministic, macroscopic descriptions, while I doubt that antireductionists such as Popper and Bergson would be satisfied with such a simple fact.

134 Here is another theological commentary: "Irreversibility means that things happen in time *and thanks to time*, that it could be that they did not happen, or did happen otherwise and that an infinite number of possibilities are always open." " 'Inventive' disorder is part of the definition of things. . . . Impredictibility which is not due to our inability to control the nature of things, but to their nature itself, whose future simply does not yet exist, and could not yet be forecasted, even by 'Maxwell's demon' put on Sirius" (A. Gesché, *Dieu pour Penser. 4. Le Cosmos*, p. 121). The author claims to find his inspiration on the "new scientific understanding of the Cosmos" from, among others, *La Nouvelle Alliance* (Ibid., p. 120).

135 M.-P. Shützenberger, "Les Failles du Darwinisme."

136 In a critique of several "almost mystical views of life," which deny "an evolutionary role to Darwinian selection," the biologist A. C. Elitzur observes that "such a misleading discussion of evolution is based on a complete distortion of thermodynamics" ("Let There Be Life," p. 450). Besides, I disagree, needless to say, with the comment of Prigogine and Stengers that there is an "antithesis" between Boltzmann and Darwin and that the theories of Darwin were a success while those of Boltzmann failed (*Entre le Temps et l'Éternité*, pp. 23–24).

137 Here, I mean complexity in an intuitive sense. Of course, it is somewhat related to entropy, because, if we consider the set of molecules in an eye, say, there are very few ways to arrange them so as to produce an eye compared to the number of arrangements that cannot be used for vision. But as Jaynes says (see Remark 8 in SECTION 5), as long as we do not have a well-defined set of macroscopic variables that define precisely what an eye is, we cannot give a precise characterization

of this "complexity" in terms of entropy (and, probably, such an entropy would not be the right concept anyway).

138 R. Dawkins, *The Blind Watchmaker*, p. 8.

139 Not being a biologist, I do not want to enter into any debate about the origin of life, the speed of evolution, or how far the Darwinian explanation goes. I want only to underline the similarity with the type of (probabilistic) explanation used in statistical physics.

140 This remark also illustrates the well-known (but not universally accepted) fact that Darwin's theory is not a "tautology." Having a better eye helps to survive and to have children, hence to propagate the "good" genes. But "better" here is not *defined* solely in terms of the number of children.

141 Speaking about DNA as the solution to the enigma of "life," the biologist Dawkins writes: "Even those philosophers who had been predisposed to a mechanistic view of life would not have dared hope for such a total fulfillment of their wildest dreams" (*River out of Eden*, p. 17). Not surprisingly, Popper said that molecular biology became "almost an ideology" (*The Open Universe. An Argument for Indeterminism*, p. 172). As for Bergson, he must be turning over in his grave.

142 Mark Kac, *Probability and Related Topics in the Physical Sciences*, p. 99; see also C. J. Thompson, *Mathematical Statistical Mechanics*, p. 23.

143 There is a small abuse here, because I seem to change the laws of motion by changing the orientation. But I can attach another discrete "velocity" parameter to the particles, having the same value for all of them, and indicating the orientation, clockwise or counterclockwise, of their motion. Then, the motion is truly reversible, and the operation $I$ of Note 30 simply changes that velocity parameter.

144 The word "chaos" here has nothing to do with "chaos theory," and, of course, Boltzmann's hypothesis is much older than that theory.

145 The simplifying features of the model (the balls do not interact) have the unpleasant consequence that the "full" Boltzmann entropy introduced here and defined in SECTION 5 actually coincides with (minus) the Boltzmann $H$-function. But, in general, the latter should be only an approximation to the former.

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# HEALTH

NO BRANCH OF the natural sciences is so much upbraided in our time as biomedicine. Sharing this dubious honor with basic biomedical research is, of course, its application: the art of clinical medicine. In this regard, current science criticism commits its usual solecism of failing to distinguish research within strict scientific protocols from practical methods that necessarily include rules of thumb. Even worse, it now finds endemic sins and errors, including the demon Eurocentrism, in both medical practice and the rigorous science upon which it increasingly relies. Attacks now come not only from the traditional loci of obscurantism and quackery, but also from proliferating organs of New Age and postmodernist sentiment—which include, sadly, large segments of the mass media.

If ever there was a visible flight from science and reason, it is to be found in the rapid shift (now manifest, to some extent, even within the healing professions themselves) from rejection of quackery to acquiescence and accommodation. A few years ago, only Saturday Night Live comedians would have featured a shamaness gesturing above the head of a patient in open heart surgery. Today, such a spectacle is on view at Columbia's College of Physicians and Surgeons.

In his essay *Sucking with Vampires*, Gerald Weissmann recalls James Russell Lowell's loathing of superstition. Weissmann demonstrates that today's flight into medical unreason has a long, if not honorable, history within our national culture. The flirtation of NIH (and some medical schools) with the "alternative" (as seen on public television), with the babbling of "holistic" practitioners, is the echo of a long and dubious tradition; and the arguments set forth against it more than a century ago are just as valid today.

Wallace Sampson is a physician with long and intimate experience of "alternative medicine," its claims, its crooks, its depredations, and its methodological irresponsibility. He shows how the alternative, with the aid of wordsmiths, can be made to appear democratic, innocent, and hopeful, while scientific medicine is assigned the role of clown or villain, clueless, stodgy, and viciously protective of its turf. Traditional devices for peddling this point of view are now augmented by the trendy relativism, easily at hand thanks to the postmodern academy, that is examined elsewhere in this volume.

Barbara Held's findings are perhaps the most surprising. It was once the universal assumption that, whatever the idiosyncracies of training and doctrine, the psychotherapist maintained a strong sense of the gap between delusional systems and a healthy reality principle. Nowadays, many therapists, echoing the antirealism of academic theory, hold that all narratives are

equally valid, that the healer is under no obligation to correct delusions, but ought to make them more comprehensive and satisfying to the patient. It is evidence from the real world that may now be stigmatized. Held demonstrates how psychotherapy damages its patients and its own future by consenting to this.

# "SUCKING WITH VAMPIRES"
# The Medicine of Unreason

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*Credulity, as a mental and moral phenomenon, manifests itself in widely different ways, according as it chances to be the daughter of fancy or terror. The one lies warm about the heart as Folk-lore, fills moonlit dells with dancing fairies, sets out a meal for the Brownie . . . and makes friends with unseen powers as Good Folks; the other is a bird of night, whose shadow sends a chill among the roots of the hair: it sucks with the vampire, gorges with the ghoul and commits uncleanliness with the embodied Principle of Evil, giving up the fair realm of innocent belief to a murky throng from the slums and stews of the debauched brain.*

—JAMES RUSSELL LOWELL, *Witchcraft*

THREE YEARS AFTER he delivered his majestic *Commemoration Ode* at Harvard, in 1868, to mark the end of the Civil War, James Russell Lowell wrote a major analysis of the Salem witch trials. The Union had been preserved, Lincoln was enshrined, and abolition a fact. But progress and reason had enemies remaining. Lowell, the Edmund Wilson of his era, warned New England against the twin errors of sect and superstition. In 1692, thirty women of Salem had been convicted of witchcraft and twenty put to death in an episode connected in some fashion to intense village factionalism. Young Ann Putnam, the poor slave girl Tituba, and a score of other defendants in the witchcraft trials confessed to out-of-body experiences, the sightings of great balls of fire, to having visions of multitudes in white glittering robes, and the sensation of "flying out of body." Their reports mirrored those of the credulous in Lowell's postwar Boston, abuzz with "rappings, trance mediums, the visions of hands without bodies, the sounding of musical instruments without visible fingers, the miraculous inscriptions on the naked flesh, the enlivenment of furniture."[1]

Word for word, the out-of-body experiences described by "witches" in Salem and psychics in Boston overlap with those prescribed as cures for patients by the alternative healers of the 1990s. And thanks to the antinomian sentiments of modern universities, some of these healers are members of

medical school faculties in social medicine or psychiatry—as are their colleagues who accept the claims of abduction by aliens in spacecraft. One charismatic healer from the University of Massachusetts, son of a distinguished member of the National Academy of Sciences, describes wellness as the disembodied sensation of "riding the waves, much as if I were lying on a rubber raft on the ocean and the waves were picking me up and taking me down. Lifting and falling away. Lifting and falling away."[2] The patient would have been in the dock in Salem.

A century and a half ago, Lowell was encouraged that a stiff dose of *veritas* would overcome vulgar belief. The two aspects of credulity, fancy and terror, would, he believed, vanish among the educated classes as reason was joined to reform. He announced, prematurely it turns out, that "such superstition as comes to the surface nowadays is the harmless [enthusiasm] of sentiment, pleasing itself with a fiction all the more because there is no more exacting reality behind it to impose a duty or demand a sacrifice."[3] We might note that his critique of the sentimental was later endorsed by Lionel Trilling in *Sincerity and Authenticity.* Commenting on the curious notion of R. D. Laing, Michel Foucault, *et al.* "that madness is health, that madness is liberation and authenticity," he pointed out that those who believe in authenticity, the antinomians, "don't have it in mind to go mad, let alone insane—it is characteristic of the intellectual life of our culture that it fosters a form of assent which does not involve actual credence."[4]

In our New Age of Unreason, we seem to have gone one step further. There is, of course, precious little intellectual life left in our culture, and the credence we pay is to self. Conversations from Berkeley to the beltway, from the boutiques of Madison Avenue to the Bridges of Madison County, avoid the sincere to boast the authentic. We will brook every compromise of conscience, but not of coiffure. A recent item in the "Style" section of the *New York Times* described services offered by a fashionable hair salon—*Nymph*—in New York.

> In addition to cutting, coloring, perming and shampooing, *Nymph* offers some New Age extras. Clairvoyant counseling with Elaine Woodall ($75 for a one-hour session), astrological consultations with Shelly Ackerman ($65 an hour) and dream workshops with Ann Twitty (no charge) are available by appointment. The scalp massage, though, may be the most therapeutic of all the services.

The *elan vital* of *Nymph* and the rest of the narcissistic mind/body movement is clearly that of Mesmer's fluid energy, of animal magnetism. On this Mesmeric note, it may be useful to examine a prime document of the New Age movement. Bill Moyers' *Healing and the Mind*, book and TV series, are models of Mesmer redux—or Trilling's prediction gone mad. In fact, the Moyers tome is more a product than a book; in years past, one called these volumes "ooks." The Moyers ook nestled happily near the top of the *Times* best-seller list for some forty weeks, cheek to jowl with a Jungian analyst's *Women Who Run with Wolves* and Rush Limbaugh's *The Way Things Ought to Be.* Graven on that tablet of unreason were the left and right united, boys and girls together, tripping the light fantastic on the bookshelves of New York.

Moyers's volume consists of a series of interviews with fifteen well-respected doctors and scientists who are united in the belief that the conven-

tional medicine of penicillin and polio vaccines has for too long denied that the mind can heal the body. Those interviewed include proponents of traditional Chinese medicine, relaxation and meditation practitioners, imaging and stress-reduction specialists, group therapists, psychoimmunologists, general internists, behavioral pediatricians, and some laboratory scientists. Most direct, or work at, "centers" and "institutes"; some of these appear reputable. On the whole, the doctors are rational, devoted, and intelligent and Moyers elicits their views in the cozy, undemanding style of the Public Broadcasting System, a network that specializes in prime-time nature study. When the more self-referent of these healers become extravagant or grandiose in their claims, he makes sure that they err in the direction of Jeffrey Masson and not of David Koresh. The index has twelve references to "empowerment," and thirteen to "herbal medicine" but not one to "science," or "physiology," and the sampling offered of the fine arts is similarly weighted in favor of the occult. The text is of such minimal expectations that it refers to "a sociologist called Goffman" or an "Italian philosopher called Bruno." The book cannot be used as evidence that medicine is—or ever was—a learned profession. The healers seem to have suffered from ski injuries but not from all-nighters with dead white European males: they refer mainly to each other's work and their own exercise rituals. The few poems and literary quotes offered by these practitioners of New Age healing reveal most of them to be wildly uncultivated. Occasionally they bend the knee to elders such as Max Lerner or Norman Cousins. Mother Teresa comes up a lot. But, a tone of sweetness and light dominates the conversation. Amiably, these folks agree without dissent that the kind of scientific medicine we practice at American teaching hospitals like the Massachusetts General Hospital or Bellevue is suddenly inadequate to the needs of a New Age.

Are they right? Does the mind influence the body? Of course it does. This is not, however, great news to any of us. Doctors and patients alike have known since Hippocrates that we get ulcers when upset, break out in a sweat when afraid, suffer headaches when angry, and blush when embarrassed. Grief kills. The real question is whether these cause-and-effect relationships between mind and body require for their explanation the orphic insights of New Age meditation. One is forced to say—and to their credit many of Moyers' healers *do* say it—that the jury is still out. Were the Food and Drug Administration to have set hurdles for the approval of these unconventional medical practices as high as those now set for treatments of the conventional kind, the unconventional practices would fail to clear. All of these "treatments" are—at best—arrested at the level of what pharmacologists would call phase II trials, i.e., *before* they have been proved safe and effective by means of randomized, double-blind studies in humans.

The level of proof that is accepted by Moyers *et alii* can be judged from the following study in Los Angeles. Professional, "method" actors were asked to mimic acutely happy or sad experiences and the psychoimmunologists counted blood cells (N-K cells), which they believe to constitute the first line of defense against disease:

> DOCTOR: Then, when the actor got into that state, we looked for changes in the immune system. For example, we asked each actor to imagine that he had been rejected for a part. He began to feel very intense sad feelings. We found that

during the intense sad state there was an increase in the number of natural killer cells [N-K cells] in the actor's bloodstream, and that these killer cells were functioning more efficiently than they were when the actor was in a neutral state.

MOYERS: So when the actor became sad, *something healthy happened* [italics added] . . . [But, you also] studied each actor as he imagined he got the part and was a big success on opening night.

DOCTOR: We found that the effect of the happy state on the immune system was very similar to what we had seen as a result of the sad state.

MOYERS: What seems certain from your research is that short-term emotions do affect our immune system.[5]

What may seem certain to the uninitiated is that method acting affects the traffic of N-K cells. Besides, most card-carrying immunologists are by no means persuaded that N-K cells constitute the first line of defense against infection. That function is served by cells called neutrophils.

But, if emotions *do* influence body functions, how do the New Age healers restore what one of them calls "right inward measure"? Moyers describes a stress-reduction session at the University of Massachusetts in the course of which he underwent a "body scan," a procedure designed to promote self-awareness or -arousal:

MOYERS: What exactly is happening during the body scan?

THERAPIST: I don't know what's happening physiologically because we haven't wired up people and watched them go through this. But the chances are that they're learning how to relax and dwell in the present moment. In the body scan, you lie on the floor, and without moving begin by directing the focus of your attention to the toes of your left foot, then, gradually, up through your leg and over to the other toes, and the other leg, and eventually through the whole body.

MOYERS: That actually happened to me both times that I experienced the body scan with you. The first time I'd been up all the previous night, and this morning I had flown ten hours the day before to get here, so I came to both sessions really dragging my body like a sack of potatoes. But something happened during the body scan. I don't know what to call it, because physically, I haven't really had that kind of experience before. *Perversely, during the sitting meditation, I got agitated, and I had to get up and leave* [italics added]. That's happened to me in meditation before. The body scan worked for me, but the meditation didn't.[6]

"Healers" would call Moyers' agitation a crisis, and Moyers explains to the therapist the reasons for his agitation.

I thought the explanation for the difference I experienced was that you've got a good bedside manner, and during the body scan, your gentle soothing voice was a friendly ally in my descent into the body. But in the sitting meditation, you withdrew, and left me sitting there by myself.[7]

Well, one doesn't require training in dynamic psychiatry—or dialectical materialism—to figure out why a premature withdrawal by a "friendly ally" in a "descent into the body" might provoke a crisis in the best of us. Moyers describes the beginning of one of these sessions:

They are your everyday, garden-variety Americans, twenty-five of them, and they are sitting in a circle on the floor, their legs tucked beneath them, or on folding

> chairs. Their eyes are closed. They are eating raisins. Three raisins each, one at a time. "S-l-o-w-l-y," says the man in the center. "Lift one raisin slowly to your mouth. Chew it v-e-r-y s-l-o-w-l-y." He pauses and surveys the circle. "Observe your arm lifting the raisin." Pause. "Think about how your hand is holding it." Pause. "Savor it." Pause. "Notice any thoughts, either negative or positive, that you have about raisins." Pause. "Pay attention to your salivary glands." Pause. "Your jaws." Pause. "Your teeth." Pause. "Now notice your tongue as you slowly, s-l-o-w-l-y, swallow the raisin."[8]

Now, some doctors might regard unconventional medical practices of this sort as harmless shenanigans while others might recommend them to patients suffering from functional complaints of bowel or back. But unconventional medicine is on the rise, and clearly meets the needs of those who cannot gain comfort from pills or conventional medical advice alone. In a recent study, carried out by (among others) two of Moyers' interviewees, Drs. David Eisenberg and Thomas Delbanco,[9] one in three respondents in a nationwide telephone survey reported using at least one unconventional therapy in the last year (acupuncture, chiropractic, herbal medicine, spiritual healing, relaxation techniques, etc.). In fact, the estimated number of visits to unconventional medical providers (425 million/annum) exceeded those to all United States primary care physicians (388 million). The estimated cost, $10.3 billion/annum out of pocket compares to $12.8 billion spent out of pocket annually for all hospitalization in the United States!

Bill Moyers's experience with the raisin eaters may be slightly absurd, but it is possible to argue that the whole mind/body movement has a darker precedent: a recurrent *fin de siècle* preoccupation with the supernatural that culminated in seventeenth century witchcraft trials, eighteenth century Mesmerism, and nineteenth century "psychical" research. In our century, Moyers's interviewees also seem to believe that "energy" and its focus by "mind" are the keys to healing.

> DOCTOR 1: Health is a dynamic energy flow that changes over a lifetime.[10]
>
> SCIENTIST: The mind is some kind of enlivening energy in the information realm throughout the brain and body that enables the cells to talk to each other and the outside to talk to the whole organism.[11]
>
> DOCTOR 2: I think, ultimately, everything is a different form of energy. Even matter that seems solid as a rock is energy. We know from Einstein that energy and matter are interconvertible. Now, what I find interesting is that when you can focus energy, you gain more power, for better and for worse. . . . But we can use that same principle in a healing direction rather than in a harmful one by learning to concentrate mental energy.[12]

In that Einsteinian context, I note that our local, trendy workout club in New York features a logo composed in equal parts of a Bohr-model atom and a yin/yang circle. Beneath it, on the T-shirts of the fit airheads who worship there, is stenciled the equation $e = mc^2$. When asked what that means, the workout waifs avow that "energy equals motivated conditioning." In Moyers's book, there are seven references to yin/yang theory, twenty-two to "energy," six references to "motivation," and two whole chapters devoted to "conditioning!"

The *reductio ad absurdum* of such sentimental New Age fancies is the

celebrity of Marianne Williamson. This guru of spiritual healing has written an ook entitled *A Return to Love* (twenty-nine weeks as a best seller) and then hit the top of the "Advice, How-to and Miscellaneous" best seller list with another called *A Woman's Worth.* Williamson, in *Return to Love*, advised AIDS patients to write a letter to their disease as part of the "imaging" techniques so popular on the West Coast. She has counseled the deeply troubled spirits of Elizabeth Taylor, Oprah Winfrey, Judy Collins, and Mike Nichols. As reported in the *New York Observer*,[13] she disclosed in the course of a book tour a novel remedy of unconventional medicine. Speaking to an audience that crowded *Episode*, a chic Madison Avenue clothing boutique, she allowed that: "There's something interesting about speaking in a clothing store. I love clothes and I understand the healing power of shopping." Now, there's a form of alternative medicine that should drive the health care budget northward by a bundle!

Another guru to the stars has not hit the best seller lists yet, but Ms. J. Z. Knight of Yelm, Washington did grab the attention of the front page of the *New York Times* a few years ago. It seems that Ms. Knight—"the most popular of the New Age spirit channelers"—is being sued by her fifth (!) husband who argued that he was stiffed in an alimony settlement. It's a real Perry Mason case. Indeed, were he in the fragrance mood, Perry might call this "The Case of Channeler's No. 5." At any rate, Jeffrey Knight pleaded that he helped his wife transform herself from the middle-class wife of a Tacoma dentist into "a spiritual guru who lives in a two-million-dollar ranch house." Now he is dying of AIDS, she did not heal him or help him, and he's back to conventional treatment, AZT.

Ms. Knight, onetime advisor to the most spiritual of our film stars, Shirley MacLaine, gets $1,000 per trance, collected $100,000 from one troubled woman for "books, tapes, and survival gear," and had an annual income of up to $4 million. But Ms. Knight's power to heal remains unmanaged by the feds or the Pru while her diagnostic insight is guaranteed by a 35,000-year-old warrior named Ramtha. This spirit voice began speaking through her one day in 1977 after Ms. Knight had floundered through four earlier marriages and sporadic attendance at a beauty school.

Now all this would be simple fun and games, were it not for more discouraging implications of New Age healing. Spurred on by proponents of homeopathy, meditation and spiritualism in the Congress, the National Institutes of Health (NIH) has set up an Office of Unconventional Medical Practices (UMP) with funding recommended for 1995 at $6 million per annum. The NIH called a conference to clarify the goals of this office and convened many of the same experts (sic) in the fields of ayurvedic, naturopathic, chinese herbal, and homeopathic medicine who turned out to be the interviewees of Moyers' miniseries and tie-in book. This coven of experts went through the motions of proposing "multicentered, large-scale, definitive controlled trials of UMP's." They agreed that many of the unconventional methods have "associative belief systems" (twelve references in Moyers). Well, of course they do: one calls those belief systems "religions" and I am not sure that one wants NIH in the business of judging which religions work better than others in definitive, controlled trials.

As for those multicentered large-scale trials to be planned by the UMP office, one might direct the ayurvedic folk to the morbidity and mortality tables of rural India, Africa, and China today, the church records of Salem, Massachusetts of 1693, the life expectancy of Parisians in 1788, or the bills of mortality of Cambridge, Massachusetts, 1891. Before scientific medicine interfered with traditional practices, few folks lived to be as old as the youngest United States senator. Nor can the sorry public health statistics of our inner cities be attributed to inadequate access to folk remedies or group meditation. To paraphrase Lincoln Steffens: we have seen the future of unconventional medical practices and they do not work. Meanwhile, in the most important aspect of medical practice, the public health, young doctors are sweating over research grants that remain unfunded because an alliance of homeopaths and New Age toe ticklers seems to have gotten hold of a dotty Senator or two.

The Salem of Ann Putnam, the séance parlors of Beacon Hill, and today's yuppie ashrams share a common belief. Accused and accuser, seer and seen, healer and healed are convinced that magic rules the body. Generally there is money to be made from that conviction. Healing and the body, healing and the mind, healing and. . . . One of Moyers's healers reminds us that the word healing relates to making things whole. Yes, it does, but my OED informs me that its ultimate origin is Old Teutonic and in German the salutation is *Heil*, as in *Sieg Heil!* Another motto of national socialism was *Blut und Boden*, which referred to natural, folk-based German customs based on blood's affinity with the earth, an alliance that the Nazis believed had been broken by "Western cosmopolitanism." Natural medicine, based on principles of *Blut und Boden*, has had its own history of clinical trials. In their recent study, *Cleansing the Fatherland: Nazi Medicine and Racial Hygiene* (1994), Christian Pross and his colleagues present newer evidence of "the preference of early Nazi health policy for holistic medicine and natural healing over decadent, Jewish [read scientific] medicine" to the skeptical tradition of Western reason.[14] The Nazis based their movement on a popular resentment of established political parties, appeals to national honor and "family values" fueled by an open antipathy to "cultural elites."

We are told frequently, nowadays, that the expensive, autocratic, medical science of our day has substituted its own elite values for those that would better serve one or another of our subcultures. It seems to me that I have heard that song before. It is from an old familiar score. Dr. Karl Gebhard, Supreme Clinician (sic) to the SS, told the Nuremberg Tribunals that

> what the National Socialists wanted to do was to introduce a popular medicine, [they] had little regard for scientific medicine, and they were all attracted by natural medicine. All sorts of popular drugs which were not approved by the medical profession allegedly because we did not understand them or were too conceited or were financially interested in the suppression of them, were used experimentally in concentration camps. . . . The source of these experiments was Himmler's conception of medicine as pure mysticism.[15]

Of course the politics of the spiritualists and New Age healers are not those of the national socialists, but once the restraints of reason are cut, you leave

> with sympathy rather than correcting it with rebuke or lifting it away from its unmanly depression, as in the wholesomer fellow-feeling of Wordsworth. They seek in her an accessory, and not a reproof. It is less a sympathy with Nature than a sympathy with ourselves as we compel her to reflect us. It is solitude, Nature for her estrangement from man, not for her companionship with him; it is desolation and ruin, Nature as she has triumphed over man, with which this order of mind seeks communion and in which it finds solace. The sentimentalist does not think of what he does so much as of what the world will think of what he does. He translates should into would, looks upon the spheres of duty and beauty as alien to each other, and can never learn how life rounds itself to a noble completeness between these two opposite but mutually sustaining poles of what we long for and what we must.[7]

*The Waterworks* helps us to understand why the aging remnants of the New Left—as opposed to the Old Left of dialectical materialism—are now solidly arrayed in favor of the Noble Savage in a State of Nature as against the Pale Dead Male in an Age of Reason. Doctorow's *The Book of Daniel* was his attempt to justify the Old Left to the New, to tell the kids who burned their draft cards what Paul Robeson sang at Peekskill. In that novel's final lyrical outburst, Doctorow concludes that capitalism and science are enemies of the young and of the spirits of the Earth; only Arcadian Nature can be trusted. *Loon Lake* was another of Doctorow's sermons on that prelapsarian text. From *The Greening of America* to *Loon Lake*, the New Left has learned its lesson well: Mother Earth makes fewer demands than Mother Russia.

Perhaps Doctorow's most overt iteration of the Mother Earth theme in *The Waterworks* deals with our friend the Noble Savage:

> Ever since this day I have dreamt sometimes . . . I, a street rat in my soul, dream even now . . . that if it were possible to lift this littered, paved Manhattan from the earth . . . A season or two of this and the mute, protesting culture buried for so many industrial years under the tenements and factories . . . would rise again . . . of the lean, religious Indians of the bounteous earth, who lived without money or lasting architecture, flat and close to the ground—hunting, trapping, fishing, growing their corn and praying . . . always praying in solemn thanksgiving for their clear and short life in his quiet universe. Such love I have for those savage polytheists of my mind . . . those friends of light and leaf.[8]

This remarkable passage, set in the fictional New York of McIlvaine, is clearly a sentiment prompted by E. L. Doctorow's New York of 1995. It is difficult to square those notions with the facts either of the author's life or of his city. "Street rat in his soul"? Without money or lasting architecture"? According to my *Who's Who in America*, Doctorow is the Glucksman Professor of English and American Letters at New York University, a former editor-in-chief and vice-president of Dial Press, author of at least five best sellers, and recipient of the National Book Critics Circle Award (twice), the National Book Award, the PEN/Faulkner Award, the Edith Wharton Citation for Fiction, and the William Dean Howells medal of the American Academy of Arts and Letters (of which he is a member of the Institute). He has received several honorary degrees, is on the board of directors of the Author's Guild and a member of the Century Association. Nevertheless, in *The Waterworks*—a

book advertised as a "haunting tale" by The Book-of-the-Month Club—Doctorow proclaims the perfidy of institutions, claiming that "the institutional mind has only one mental operation: It abhors truth."

Professor Doctorow's ecological reflections on pre-Stuyvesant Indian life in Manhattan also seem disingenuous. "Thanksgiving for their clear and short life"? Who would presume to tell *anyone* that early and violent death from infective disease of one's wife and children is preferable to their survival? It has been estimated that the Native American population had a life expectancy of one generation. And as for those clear and short lives spent "so many industrial years under the tenements and factories," the actual numbers may be worth noting. The death rate in New York City in 1845, that pretenement and preindustrial era of Edgar Allan Poe, was 27.3 per thousand per year, and the average life expectancy was in the 40s. In our day, Doctorow's New York City, the death rate has dropped to 9.1 per thousand per year and life expectancy risen to almost 80. This was no achievement of street rats, but of those who became the sanitarians of New York, men who cleaned our water, built our sewers, and paved our streets, among them Frederick Law Olmsted and George Templeton Strong. Those men sought Nature as accessory, not a reproof—in Lowell's sense. Their monument is Central Park, not a wilderness. Theirs is the old legend of man conquering Nature and disease, to serve the uses of man rather than the fancies of poets.

Ecosentimentalists aside, the old legend may still have life in it. For generations Americans were taught that brave explorers found a New World peopled by savages, to which the white man brought the word of God and the ways of the West. When Columbus first met the Tainos, in 1492, he wrote:

> At daybreak there came to the beach many of these men as I have said, and all of good stature, very handsome people. Their hair is not kinky but loose and coarse like horsehair; and the whole forehead and head is very broad. . . . They bear no arms, nor know thereof; for I showed them swords and they grasped them by the blade and cut themselves through ignorance; they have no iron. . . . I saw some who had marks of wounds on their bodies, and made signs to them to ask what it was, and they showed me how people of other islands which are near came there and wished to capture them, and they defended themselves. And I believed and now believe that people do come here from the mainland to take them as slaves.[9]

Anthropologists are not certain that the gentle Tainos were actually enslaved by their mainland tormentors, the fierce Caribs. But life in pre-Columbian America was no New-Age paradise. The cannibalistic Caribs had moved into the lands of the Mayas and driven the Tainos (Arawaks) to refuge in the outer Caribbean islands. This followed a long and dreadful tradition of Native American imperialism that required no lessons from Europe. The Aztecs displaced the Toltecs, the Incas destroyed the Nascas and Chimus, Toltecs squabbled with Mayas, Seminoles with Choctaws, Algonquins with Iroquois, and so forth: homelands were looted, treasure stolen, tribes decimated. Plunder, pillage, and the plague were here before Columbus.

The specialty of pre-Columbian American religion was human sacrifice, in the course of which cardiectomy without anesthesia (extirpation of the beat-

ing heart) was perfected; the chosen few could nibble uncooked ventricles. At one great Aztec celebration 20,000 victims were dispatched to the service of their gods. Even the gentle Tainos indulged in practices that might make a revisionist wince. The male warriors, but not such nonpersons as females, owed their fine sloping foreheads to having these squeezed at infancy between two flat boards, a practice that extended to the Choctaws of our Mississippi. Slavery also anteceded the arrival of Europeans. When Cortez entered Tenochtitlan (Mexico City), he found slave auctions which reminded him of those conducted by the Portuguese who had captured Negroes on the African coast.

"Columbus has been portrayed as some great hero! Anyone with a bit of knowledge can read between the lines. He wasn't such a great guy," argued John Peters (alias Slow Turtle) Supreme Medicine Man of the Mashpee Wampanoag Indians in the Falmouth (MA) *Enterprise* of August 18, 1992. My colleague in the healing arts, who was at the time Commissioner of Indian Affairs for the State of Massachusetts, was pleading for adoption of his program "Relearning Columbus" as part of the cinquecentennial of the Admiral's discovery of America, an occasion that this country celebrated with as much enthusiasm as the Germans showed for V-E day. Said the good doctor about his revisionist program, "It's about nature; it's about reality: the waters and airs and all the things around us. It's about the animals and how we are all interlocked with one another." What a fine sentiment, elegantly put by Dr. Slow Turtle, whose salary derives in part from taxes paid by Raytheon and Genzyme, institutions that may also be said to be "about nature and reality."

Before Columbus, the tribes of both the Old World and New had for generation after generation been savagely interlocked with one another in rituals of attack and revenge. In the Old World, Christian and Moslem, Ethiop and Nubian killed each other on one or another tribal excuse; in the New World, Aztec and Toltec, Carib and Taino bashed skull against war club for one or another aboriginal cause. Those "waters and airs and all the things around us," beloved by medicine man and workout waif alike, brought yellow fever, plague, malaria, and cholera before Columbus set foot on these shores. And as for the interlocking of animals and the Mashpee Indians; the native Americans of Cape Cod had already eliminated most of the deer on the peninsula before the Puritans came. Not until the ecosentimentalists of our own day favored Bambi over venison, not until tick-bearing deer roamed every back yard from Falmouth to New Haven, did we have to undo the mischief of sentiment to battle the spirochete of Lyme disease. At the end of the twentieth century, rabies, tuberculosis, Lyme disease, and Hanta virus—not to speak of AIDS—are not due to industrial pollution but to a misguided choice of sentiment over reason. Nature is not always our friend, as those who dwell by the rivers Ganges and Ebola might tell us. Nature can, of course, serve human needs as—in Lowell's words—"a strengthener and consoler, a wholesome tonic for the mind ill at ease with itself."[10] It ought not remain the preserve of the ecosentimentalist, the new Rousseau who "translates should into would, looks upon the spheres of duty and beauty as alien to each other, and can never learn how life rounds itself to a noble completeness between these two opposite but mutually sustaining poles of what we long for and what we must."

## NOTES

1 Edgar Allan Poe, *The Complete Poems and Stories with Selected Critical Writings*, pp. 189–190.
2 James Russell Lowell, "Thoreau," p. 294.
3 Ibid., p. 298.
4 James Russell Lowell, "Fable for Critics," p. 72.
5 Oliver Wendell Holmes, *Professor at the Breakfast Table*, p. 281.
6 Poe, *Complete Poems and Stories*, p. 1090.
7 James Russell Lowell, "Rousseau," p. 266.
8 E. L., Doctorow, *The Waterworks*, p. 238.
9 S. E. Morison, *Admiral of the Ocean Sea: A Life of Columbus*, pp. 273 ff.
10 Lowell, "Rousseau," p. 266.

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# RELIGION

THE HEALTH of liberal democracy depends on the general use of reason. Reason must not be the cognitive tool of the few: if the integrity of science and reason are undermined among the majority, then democracy itself is in peril. The merits of this generalization are evident in the records of modern history. Also evident is the ambiguous role of religion, whose discomfort with reason, sometimes open and sometimes concealed, has nevertheless long been evident.

An exchange of views between Paul Kurtz and Eugenie C. Scott points up the difficulties of broadening rational inquiry in a world where religion and cult belief continue to be overwhelmingly popular. Kurtz sees linked threats to democracy in the widespread fascination with paranormal phenomena and the studied obsequiousness toward all religious truth claims, no matter how extreme. As Kurtz shows, this attitude reigns in the media and is unchallenged by those—including liberal religionists and intellectuals—who should know better. He calls for open confrontation and challenge, especially when the issues involve realities about which science has something to say.

Eugenie C. Scott, long a campaigner against educational nonsense in the form of creationism, presents a conflicting view. About the diagnosis of nonsense she has no doubt; she offers a catalog of creationism and the activities of its biblical-literalist troops, with analysis of the social anxieties that encourage it. But Scott believes that confrontation will lead only to political defeat. Instead, she argues, scientists should make common cause with religious moderates—and hence with the majority of the American population—by admitting the limits of science and by emphasizing the complementary, rather than the conflicting, functions of science and religion.

Langdon Gilkey, from the standpoint of a long career in religious studies, reaches yet another conclusion. This is that the diffuse dangers of antireason and antiscience are insignificant in comparison with the immediate danger of Christian fundamentalism in its politically aggressive forms. Theocracy is their goal, he insists, admitted or not; and where there is theocracy, there can be no democracy; neither reason nor science can survive. He too, therefore, urges resistance, but of a far more focused kind than does Kurtz.

Oscar Kenshur, finally, examines the complex relation between rational inquiry and religion in a historical context: the turn of the eighteenth century. He examines the work of the Huguenot philosopher Pierre Bayle, demonstrating the ingenious and convoluted way in which he interwove conflicting traditions: fideism—the rigid insistence on the primacy of faith, ignoring its improbabilities and the urgings of reason—alongside the scientifically informed rationalism that was coming to dominate European thought.

# TWO SOURCES OF UNREASON IN DEMOCRATIC SOCIETY: THE PARANORMAL AND RELIGION

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REPRESENTATIVE DEMOCRACY entrusts to the people the ultimate power to elect the chief officials and to determine the main directions of government. It requires widespread participation at all levels of civic life. Its key policies are based on the freely given consent of a majority of adults exercising the franchise. Democracy relies not upon aristocratic elites, oligarchs, or ruling classes but upon ordinary persons to exercise power. It assumes that the rulers can be turned out of office after a full discussion of the issues. It is receptive to the opinions of dissident minorities in debating alternative courses of action. It thus presupposes a free market of ideas and an open society, in which both orthodox and dissenting views are heard.

Democracy is rooted in a *method* of inquiry. It denies that any one sector of society has a monopoly of truth or virtue. It thus draws on the pooled intelligence of the broader public. Slow and laborious at times, it has nonetheless proven itself to be the most effective method of governing society—at least in comparison with alternative systems. If democracy is to function well, it must assume that there is some degree of competence and common sense and some level of education in the average person. In this view of democracy, the well-informed citizen is the best guarantee against the abuses of power from any sector of social life—political, economic, military, or ecclesiastic. Ideally, this means that we need to cultivate in the ordinary person the arts of intelligence, an appreciation for critical thinking, and some rationality. Where passion or caprice, power or violence predominate, the ability to make reflective judgments is curtailed. John Stuart Mill believed that democracy works best where a society has reached sufficient maturity in its judgment. Here Mill was critically evaluating the underdeveloped colonial areas of the world of the nineteenth century.[1] We reject Mill's limitations and believe that democracy should be permitted to develop in all societies. Nevertheless, this presupposes that great efforts will be made to raise the level of education of the citizens of a democracy. Ever since the Enlightenment, democrats have

believed that with an increase in education and literacy, and the application of reason and science, the progressive amelioration of the human condition would eventuate.

Unfortunately, America and other mature democratic societies have seen in recent decades an erosion of this reflective process. A number of technological and social developments have compromised our ability to make rational choices; and this may undermine the viability of democratic societies. Paradoxically, this is occurring at the same time that liberal democracy seems to be everywhere on the ascendent, having vindicated itself over totalitarian and authoritarian methods of rule. Fukuyama maintains that we are at "the end of history," for liberal democratic ideals have prevailed virtually everywhere. This view has been grossly overstated; for there are always new problems to be resolved if democracy is to prosper.[2]

There are many new challenges to reason and the democratic ethos today. Postmodernists reject the ideals of the Enlightenment, and they deny that any form of objective scientific knowledge is possible. Waves of multicultural critics and extreme feminists have sought to undermine the integrity of science and rationality. I wish to concentrate in this paper on two other challenges to rational democracy that are present in contemporary society and are all too rarely identified. The first area of concern is the steady growth of belief in a paranormal and occult universe, and the second concerns the unchallenged persistence of dogmatic religious beliefs and practices.

## THE PARANORMAL

The term "paranormal" refers to phenomena that allegedly cannot be accounted for or explained in terms of normal science and that thus transcend the limits of a naturalistic framework. A precursor of the currently popular paranormal paradigm was no doubt the spiritualist movement of the nineteenth century. The immediate founders of spiritualism were the Fox sisters, two young girls of eight and ten who in 1848 allegedly were able to communicate with discarnate spirits by receiving messages rapped from "the other side." The Fox sisters were heralded as mediums, and within a decade thousands of mediums appeared in America and Europe exhibiting similar "psychical powers." The Fox sisters were tested by scientific bodies, which pointed out that the so-called rappings could have been produced by crackings of the toe and knee bones against wooden floors, without the need for invoking a nonnaturalistic interpretation. The distinguished physicist Michael Faraday attempted to explain table levitation by involuntary psychological and muscular movements rather than occult forces.

The Society for Psychical Research was founded in 1882 in Cambridge, England by Henry Sidgwick and a group of eminent scientists and philosophers, and in the United States in 1885 by William James, founder of the first psychological laboratory at Harvard. Many of these researchers were disturbed by the growth of Darwinism and the challenge that evolution gave to the spiritualist picture of reality. They thought that if physical research were treated rigorously and experimentally, objective truth could be elicited. Thus they dealt with thought transference, apparitions, poltergeists, and other

"psychical phenomena." A number of mediums were tested by scientists—including Eusapia Palladino, Leonora Piper, D. D. Home, Margery Crandon; and many of these were caught in trickery, so much so that by the 1920s the entire field had been discredited.

A second wave of paranormalism was stimulated in 1927 by the founding of the first parapsychological laboratory at Duke University by J. B. Rhine. Rhine deferred the question of survival after death and attempted to establish the existence of ESP (clairvoyance, precognition, telepathy) and PK (psychokinesis) by using laboratory methods. The above- or below-chance calls on a run of Zener ESP cards could not be explained by reference to normal sensory perception, he maintained, and could be attributed only to some underlying extrasensory paranormal cause. Rhine explicitly stated that one of the primary motives for the rise of parapsychology was "to refute mechanistic philosophy."[3] He held a dualistic theory of reality in which mind was independent, in some sense, of its material basis. Rhine's interest in this regard was similar to the earlier founders of the Society for Psychical Research, who had hoped to provide a scientific basis for the "spiritual principle of man."

Scientific skepticism about the work of Rhine was widespread. He was criticized by psychologists because of loose protocol, questionable grading techniques, and sensory leakage. The apparent presence of trickery by several subjects and experimenters was also raised. For example, G. S. Soal claimed to demonstrate the presence or precognition and telepathy during the Second World War in London. Fraudulent manipulation of the data by Soal has been clearly demonstrated, so that all of his work has been held suspect. The history of psychical research and parapsychology continually provides similar tales of announced or impending breakthroughs demonstrating the existence of paranormal phenomena and their rejection after laborious examination by skeptics, who show the paucity of the evidential base and especially the inability to replicate the phenomena by other scientists. This has occurred in recent years with regard to dream research, remote viewing, and even the use of Ganzfield data.

Nonetheless, since World War II paranormal claims have proliferated. The mass media continually feeds a receptive public with modern tales of paranormal miracles, and science fiction has opened the imagination to new forms of fantasy and mystery. The term *paranormal* has been extended beyond parapsychology to include space-age claims, such as astrology, UFOlogy, and a wide range of pseudoscientific anomalous claims, including alternative medicines, faith healing, and a return of occult demons and monsters of the deep.

The mass media are in the business of packaging and selling the paranormal as a product. And this is true of book and magazine publishers as well as TV and film producers. If one visits any bookstore in America, one will find that the New Age, inspirational, spiritual, and paranormal shelves far outdistance the science books made available.

Virtually every major newspaper carries an astrology column, and there are dozens of mass-market astrology magazines and hundreds of astrology books that have been published in recent years. In the same period very few books have been published that are critical of astrological claims. Yet astrol-

ogy has no basis in empirical fact, and all efforts by objective scientists to confirm it have had negative results. Still, large sectors of the American public read their horoscopes daily, and many may not venture forth without doing so. Many Wall Street pundits claim to base their recommendations on astrology, and even AT&T has offered astrological readings to gullible telephone callers. A similar tale can be told for so-called psychic phenomena. There are tens of thousands of psychics offering readings and prognostications, and they are pandered to by the mass media. Literally thousands of books have been written about psychic healing, therapeutic touch, levitation, channeling, fire walking, poltergeists, etc. They claim wondrous powers, with very little scientific dissent. Books by serious publishers critical of this tidal wave are almost nonexistent.

Three recent illustrations of this phenomenon graphically demonstrate the problem. First is the widespread fascination with near-death experience (NDE). There are a great number of books portraying the experience.[4] Raymond A. Moody offers us a collage of various NDE accounts. He tells us that a dying person, overcome by fear and pain, perhaps lying on an operating table or hospital bed, begins to hear loud buzzing and ringing sounds. He feels himself falling rapidly through a tunnel. He finds himself outside of his physical body, which he is able to view as an onlooker. He may even hear the doctor pronounce him dead or attempt resuscitative efforts. As he enters the tunnel he has a panoramic review of his life. Eventually he encounters a bright light and meets the spirits of friends and relatives who welcome him, perhaps even Jesus or Krishna. There is a beam of light that he encounters, and he feels peace and joy. He discovers that he must return to his physical body on earth, though he is reluctant to do so. Suddenly he is back in his body, and his consciousness revives. The experience is so powerful that it may have a transforming effect on his life thereafter.[5]

Such accounts of near-death experience are highly reminiscent of the kinds of experience reported by classic mystics, who claim that they have encountered a being of light. These reports are introspective and subjective, so that most of the evidence is anecdotal. The spiritual significance attributed to the experience is unmistakable. Does this provide evidence that there is a paranormal realm? Is there scientific validity for the claim? Michael Sabom, Melvin Morse, and other researchers maintain that there is, and these views are widely broadcast.[6]

There have been very few skeptical studies published. Psychologist Susan Blackmore points out that there are alternative naturalistic explanations—physiological and psychological—that can be given without postulating the existence of an afterlife.[7] Not everyone who is dying and has been resuscitated has had the same experience. Moreover, elements of the collage can be experienced in other contexts of life. Out-of-body experiences are fairly common. We find them in hypnogogic and hypnopompic sleep. Alpinists who fall from mountains yet land safely, or people in car accidents who survive unscathed, sometimes experience an out-of-body experience and a panoramic review. Ronald K. Siegel reports that he chemically produced similar NDE-type phenomena by administering drugs.[8] Susan Blackmore has sum-

marized a plurality of possible causes: the experience of an hallucination triggered by the distress of the dying process, the deprivation of oxygen, increased levels of carbon dioxide in the blood, the release of endorphins and other natural opiates, seizures in the temporal lobe and lymbic systems, the dissolution of the sense of the self, etc. Skeptics point out that the spirits encountered on "the other side" are colored by the cultural experience of the person having and NDE. The proponents of the survival hypothesis deny this. They point out that even atheists, such as A. J. Ayer, have reported NDEs. They maintain that there is a remarkable consistency in all such reports. Skeptics maintain that if there is a consistency in reports, it is because we share a common physical and psychological structure. The person who has had an ND experience has not died (there is no clear case of brain death), but is undergoing a dying process. The transforming effect that the experience has can be simply explained by the fact that a harrowing brush with death can help us to alter our priorities in life. The dying brain hypothesis more parsimoniously accounts for the altered states of consciousness.

I cannot in this brief paper do justice to the scientific case pro and con. The point I wish to make is that this type of near-death experience illustrates the spiritualist-paranormalist outlook that pervades our culture and the paucity of skeptical critiques available to the public.

A second popular area that illustrates the same point is the reemergence of reincarnation. This classical doctrine presented in Hindu, Buddhist, and ancient Egyptian literature, and indeed even in Greek philosophy, held that the soul was separable from the body, preexisted birth, and will exist as separated from the body after death. Similarly, animals and plants were said to be possessed of souls. Upon death the soul could be transformed from one organism to another and could be released only after a period of time. This was dependent upon *karma*, the behavior of a person in his past lives.

Interestingly, these doctrines, held on a basis of faith, have now been given some kind of pseudoscientific credence by a number of parapsychologists and psychiatrists, and reincarnation is presented by the media as if it has been verified by science. For example, Ian Stevenson, American doctor and former president of the Parapsychological Society, maintains that there is evidence for this claim, especially in India, based upon the memories of young children of their previous lives.[9] I find the evidence he adduces highly questionable. Alternative naturalistic explanations fit the data more parsimoniously. Such memories have been suggested by those in the immediate circle of relatives, friends, and the cultural milieu; predisposed to believe in reincarnation, they interpret the experience of children in terms of it.

Another popular line of research often referred to today is the experience of "regression" that enables a person to recall his past lives. It is interesting to note that most of this evidence is based upon hypnosis. Indeed, there is a growing school of hypnotherapists who use regression as a therapeutic technique. Under an hypnotic state individuals allegedly recall their prior lives. There is an abundant literature of this kind of experience. For example, Dr. Brian Weiss, a Columbia- and Yale-trained psychiatrist practicing at the University of Miami, in his book *Many Lives, Many Masters*,[10] maintains that he

has regressed a great number of people and that by regressing them he is able to cure them of present neurotic or pathological conditions. His regressions take people back to the Civil War, the Middle Ages, or earlier. Without going into this alleged evidence in detail, it has been pointed out by skeptics that one does not have to postulate prior existence to account for the bizarre tales that are related. The subjects are rendering unconscious materials, hidden and repressed, and what they report is most likely a product of confabulation and cryptomnesia. Moreover, psychotherapists who believe in past lives tend to induce by suggestion similar beliefs in their subjects.

A third area in which hypnosis is used to support paranormal claimants is UFOlogy. A number of researchers have reported that in hypnotic sessions they are able to elicit tales of abductions of earthlings by extraterrestrials. These creatures from afar allegedly are performing sexual, reproductive, and genetic experiments on their helpless victims. There has been an extensive literature about this. Most noteworthy are the books by David Jacobs, associate professor of history at the University of Pennsylvania,[11] and John Mack, professor of psychiatry at Harvard.[12] Mack, in his book *Abductions*, claims to have investigated 76 abductees, though in the book he focuses on only 13. He calls them "experiencers," for they are undergoing anomalous experiences. His narratives of these experiences are based on hypnotic sessions with them. The phenomenological contours of such cases are that a person who is asleep is suddenly awakened by a bright light that infuses the bedroom, that he or she is paralyzed and unable to move. Visited by small creatures with huge heads and large eyes, he or she is levitated out of the bed, through the walls, and brought aboard a spacecraft, where sexual and genetic experiments are performed.

What are we to make of these reports? Perhaps we are being visited by extraterrestrials from other galaxies, and perhaps thousands or millions of people are being abducted daily, as proponents maintain. Skeptics seek alternative naturalistic explanations of the experiences: again, they point out that the hypnotic session is not a reliable basis for truth claims and that what is being reported is often suggested by a hypnotherapist who believes in the UFO ET hypothesis. Here both cryptomnesia and creative imagination seem to provide a more credible explanation.

Interestingly, John Mack believes that this phenomenon is quasireligious. He states that many abduction experiences are "unequivocably spiritual, which involves some sort of powerful encounter with or immersion in divine light. . . . The alien beings . . . may also be seen as intermediaries, closer than we are to God or to the source of Being."[13] The UFO abduction experience, says Mack, "while unique in many respects, bears many resemblances to the dramatic transformation experiences undergone by shamans, mystics, and ordinary citizens, who have had encounters with the paranormal."[14]

I have touched on only some of the more sensational aspects of the paranormal universe. Nonetheless, if one reads the popular literature, views film and TV productions, and reads popular magazine and newspaper accounts—and, indeed, listens to our students in the colleges and universities—one is impressed by the fact that, by and large, the proparanormal viewpoint is ac-

cepted with very little dissent. A serious problem that we face is the fact that the mass media do not give adequate attention to the skeptical and scientific critique. We surely cannot prejudge such paranormal questions—astrology may be true, ESP may exist, the Loch Ness Monster may be lurking underneath, near-death experiences may put us in touch with another reality, the reincarnation of souls may be true, and earthlings perhaps are being kidnapped by extraterrestrials. Surely scientists need an open mind and careful investigation. But some degree of skepticism is essential in the process of inquiry; and we must distinguish between a possible speculative conjecture and objective, reliable, confirmatory evidence. All too often eyewitness testimony is deceptive. Only by careful examination can one find a causal basis for an anomalous phenomenon. Moreover, there is a difference between an open mind and an open sink. The open mind allows for the critical examination of ideas, and it is receptive to new ones; the open sink is willing to accept anything and everything as worthy of examination without any responsible filtering process.

Regrettably, the public does not always appreciate the nature of science, particularly the open yet skeptical character of scientific inquiry. The scientific and academic community needs to convey to editors, publishers, and film and TV producers an appreciation for the methods of scientific inquiry. I am afraid that we have often failed in this regard; for the dispassionate scientific attitude is very rarely or adequately represented or understood. Bizarre claims are uncritically touted as true, often without the least scientific skepticism being heard. It seems to me that anyone concerned about public education should call for balance in the mass media. We believe that producers and publishers have an obligation to provide the public with some appreciation for critical thinking. If the democratic society is to function, it needs an educated public. But how is it possible to develop this when the public is fed mystery and purely speculative nonsense as true, without any inkling of there being scientific explanations for the so-called "unsolved mysteries" or the "X-files." What we are dealing with, I believe, is a religious or quasireligious spiritualist movement, which is constantly fed by a media industry and is growing in spite of evidence against its central beliefs.

## RELIGION

Why is this occurring? There are surely many complex explanations for this sociological phenomenon. One possible cause is the powerful new electronic, computer, and information technologies that we have developed. Many commentators have observed that we may be at a pivotal point in human history; perhaps we are at the beginning of the end of the age of books. The oral tradition gave way to the written word, and the invention of the printing press led to a vast expansion in the publication of books. We seem to be at another historic turning point in the mode of communication, one as dramatic as any of the above; and the effects of this upon the public mind and the education of citizens is incalculable. In my view it is a cause for some concern about the future of democracy. We may ask: Are the cognitive symbols of reading texts being replaced by the visual and auditory arts? Is reflective

thought being engulfed by fleeting images and sound bytes? And is this why the defenses against gullibility provided by critical thinking can so easily be broken down?

Another reason for the failure to convey an appreciation for scientific skepticism and critical thinking, I submit, is that there is a vast area of belief and practice that remains largely unexamined. I am here referring to religion. In present-day America it is usually considered to be in bad taste to question the claims of religion, even though many religionists present highly questionable theories about human behavior and reality and may even attempt to censor or suppress alternative naturalistic theories based on scientific inquiry. It is a paradox that America, the most advanced scientific technological society, is also the most religious and that numerous religious sects thrive and flourish—from the orthodox faiths to the bizarre cults of unreason. Interestingly, in countries such as Britain, the Netherlands, and France, church attendance has declined drastically, and the number of people who maintain membership in a church or temple or who profess belief in God is a minority of the population, whereas in America it is a predominant majority. A recent sociological study has shown a steady increase in this phenomenon since the eighteenth century—from Revolutionary days through the Civil War until the twentieth century.[15] Clearly, liberty of thought and conscience and the right to profess and to practice one's religion is not at issue; what is at issue is the reticence to criticize religion in the public square or to subject its basic premises to scrutiny. I am not talking about the criticism of the political role of religion or about attacks on clergy who engage in sexual or other improprieties. Rather, I am talking about the failure to examine critically the basic religious claims themselves: whether the Old Testament idea of the "chosen people" has any validity, whether the alleged revelations of the Ten Commandments by Moses can be sustained historically, whether New Testament claims of the divinity of Jesus hold up under critical examination, whether Mohammed's claims to divine revelation in the Koran are reliable, whether the evidence for the Book of Mormon adduced by Joseph Smith can be corroborated, etc. No doubt religious intolerance and warfare over the millennia by competing sects and doctrines have taught us all a lesson. The Spanish Inquisition, bitter conflicts between Catholics and Protestants, the suppression of the Mormons of the nineteenth century, the Holocaust, warfare between Muslims, Christians, Jews, Sikhs, and Hindus have bloodied human history. Thus the desire to seek a kind of accommodation by mutual tolerance is understandable, even commendable.

Nonetheless, speaking as a secularist and skeptic, I believe this should not preclude others within the community from questioning the claims of Biblical, Koranic, or other absolute faiths, particularly since massive efforts are constantly undertaken by missionaries to recruit members to the fold—whether Jehovah's Witness, Mormons, evangelical Protestant fundamentalists, conservative Roman Catholics, Orthodox Hassidim, or devout Muslims. Simply to accept their admonitions and recommendations without dissent is, in my judgment, irresponsible. This posture is especially questionable given the constant effort by militant religionists to apply their doctrines in the

political process, thus seeking to impose their views on others. For example, in the United States the Moral Majority and its successor, the Christian Coalition, are attempting to bridge the historic separation of church and state, and introduce prayer and other religious symbols into the public square; they wish to subvert secular neutrality. Their desire to mandate "creationism" in the public schools is especially threatening to the integrity of science education.

Since this volume is devoted to the "Flight from Science and Reason," I submit that one of the key offenders is the persistence of orthodox religiosity and fundamentalism. A graphic illustration of this is the recent campaign launched by a coalition of religious leaders that seeks to reverse the United States government's fifteen-year-old policy of granting patents for human and animal genes. The petition to the United States Patent and Trade Mark Office was signed by 180 leaders of mainstream Protestant, Roman Catholic, Evangelical Christian, Jewish, Muslim, Buddhist, and Hindu faiths. The proponents maintain the following: "We believe that humans and animals are creations of God, not humans, and as such should not be patented as inventions."[16] "One of the basic principles of our church is that life is a gift from God," said Methodist spokesperson Bishop Kenneth Carter. "The patenting of life forms reduces life to its marketability. Gone is the fundamental principle that life is a gift. . . ."[17] Those who support the patenting of life forms say that new medical technologies require considerable investment of venture capital and that without patents scientific research into new gene therapies (such as that for cystic fibrosis) may not develop. Until now the courts have permitted such patents. Perhaps the patents of the biogenetic industry need to be given public scrutiny and even challenged. This is not the issue. What I question are the reasons given for the opposition. These are all too reminiscent of historic efforts of religionists to suppress scientific research in the past—from Galileo and Darwin to the present—in the name of God.

This raises the broader issue that skeptical, agnostic, or atheist viewpoints in regard to religion really have no effective platform in America. There are literally hundreds and perhaps thousands of proreligious sermons delivered from television and radio pulpits every week. And there are hundreds of books and magazines promoting religious propaganda, with almost no response in kind to the claims made. All too many teachers in the universities and colleges of America, and surely in primary and secondary schools, are reticent about critically examining the existence of God, the doctrine of eternal salvation, the immortality of the soul, the efficacy of prayer. Consequently, large sectors of the American public have no knowledge at all of the skeptical scientific or naturalistic outlook, which is devoid of supernatural overtones.

How explain the fact that in America the majority of Americans still believe in the viability of miracles, the existence of angels, satanic forces, and other supernatural entities, etc? Most Americans are unaware of the fact that there is a rich literature of biblical and scientific criticism going back at least two centuries, in which the best scholarship drawing upon archaeology, linguistics, anthropology, etc., has questioned the very basis of the Bible. One reason for this, I submit, is that there is no existing free market of ideas in the area of religious belief; hence, a selective application of the methods of science to highly specialized and safe domains of inquiry is permitted, but little beyond that.

## EDUCATION

In conclusion, the premise with which I began this paper is that democratic society presupposes thoughtful, educated citizens who can deliberate reflectively and think critically. Yet the mass media continually bombard the public with paranormal pseudoscientific claims as if they were scientifically valid, and religious beliefs and practices are largely immune to sustained rationalist critiques.

Totalitarian societies in the twentieth century have used pseudoscientific ideologies destructively. Hitler's Third Reich was based on spurious theories of Aryan racial superiority and inferiority, and Stalin's Soviet Union drew upon Lysenkian environmentalism and dialectical materialism. The flight from reason can endanger democracy. The failure to distinguish between genuine science and pseudoscience could erode the decision-making process. Similarly, theological dogmas have been appealed to in the past to justify theocratic suppression. Today there are ominous challenges from religious militants who wish to remake America.

Do I have any recommendations to counter these threats? May I suggest two courses of action that I think scientists, scholars, academics, and all those concerned with rational democracy can undertake. These proposals, though modest, are vital.

First, we need to convey to the public an appreciation for the methods of science. This means that we need to encourage the teaching of critical thinking and the methods of scientific inquiry in the schools. Science education is essential if we are to counteract scientific illiteracy, but to be a specialist in a subject matter is not sufficient. One may know how to master his field of expertise—whether mathematics or physics, biology or economics, medical science or engineering—and yet not know how to apply the methods of scientific thinking outside of it. We need to extend the range of rational thought to as many areas of life as possible. The Japanese cult Aum Shinrikyo, which has been accused of gassing Japanese subways and which has several thousand disciples, is an interesting phenomenon. Many of the members of this cult were apparently trained in the sciences and are highly sophisticated in their fields of expertise, yet they were apparently unable to translate what they have learned in their field of competence to other areas and were swept up by the guru and followed him without dissent. The same is true of popular cults, such as Scientology, that are able to attract bright young people who do not apply critical thinking to challenge the cults' claims. The Creationist Institute, which rejects the theory of evolution, has many Ph.D.'s in engineering, chemistry, and other sciences affiliated with its efforts.

We need to convey the idea that the methods of scientific inquiry are not for the esoteric few, but are continuous with common sense. Ideas should be considered as hypotheses, supported by evidence, tested by experimental consequences, and validated by their consistency with other tested hypotheses. Beliefs should not be treated as absolutes, but rather should be open to modification in the light of evidence. It is the tentative, fallible character of science that needs to be appreciated along with an awareness that by using rigorous standards, objective and reliable knowledge can be achieved.

Second, we need to convey an appreciation for the scientific outlook itself and especially the implications of the sciences for our view of the human species and its place within nature. Thus we need some scientists who are generalists able to interpret the sciences and integrate what we know into a coherent framework. Philosophy and the liberal sciences can assist in this endeavor. This understanding can play an important role in evaluating paranormal, spiritualist, and metaphysical theories, especially those that have no basis in empirical fact. The evolutionary view of nature competes with the creationist doctrine today; yet how many scientists are willing to defend evolutionary theories and criticize fundamentalist biblical claims? There is insufficient evidence for the survival of the soul or for a teleological purpose in the universe. Yet many otherwise-thoughtful people still cling to these doctrines, perhaps because they have not read the critiques by scientific skeptics and biblical scholars.

This role of education should be twofold. We need to modify school curricula at all levels of education, from primary and secondary schools to universities and colleges, so that they include programs in critical thinking and an appreciation of the scientific outlook. All too many students today graduate with very little understanding of the sciences or their methods of inquiry. Liberal arts programs are not sufficiently rounded unless they also provide some rational comprehension of the scientific outlook.

But we also need to educate the leaders of the corporate and political world about the importance of this kind of general science education. We especially need to persuade those who control the media of communication of their obligation. This means that we need to impart to publishers, editors, producers, and writers some sense of their responsibility not to distort the truth and their obligation to raise the level of scientific comprehension and critical thinking. Not only is our postmodern industrial and information society dependent upon science and technology, but, even more, our democracy presupposes that our citizens will be well informed, and that they will be capable of exercising reflective judgment.

## NOTES

1 John Stuart Mill, *On Liberty.*
2 Francis Fukuyama, *The End of History and the Last Man.*
3 J. B. Rhine, "Comments on the Science of the Supernatural."
4 The most popular longest-running bestseller in America is Betty J. Eadie's *Embraced by the Light.* In it she reports on an experience she says she underwent twenty years ago when she nearly died and came back. Eadie claims she not only went to "the other side," but met Jesus. None of this is corroborated by independent observers.
5 Raymond A. Moody, *Life After Life* and *Reflections on Life After Life.*
6 M. B. Sabom, *Recollections of Death*; Melvin Morse, *Closer to the Light*; Melvin Morse and Paul Perry, *Parting Visions: Uses and Meanings of the Pre-Death, Psychic, and Spiritual Experiences.* See also Kenneth J. Ring, *Heading Toward Omega: In Search of the Meaning of the Near-Death Experience.*
7 Susan J. Blackmore, *Dying to Live.*
8 Ronald K. Siegel, "The Psychology of Life After Death"; Ronald K. Siegel & A. E. Hirschman, "Hashish Near-Death Experiences."
9 Ian Stevenson, *Twenty Cases Suggestive of Reincarnation.*

10 Brian Weiss, *Many Lives, Many Masters.*
11 David Jacobs, *Secret Life: First-Hand Accounts of UFO Abductions.*
12 John E. Mack, *Abductions: Human Encounters with Aliens.*
13 Ibid., p. 397.
14 Ibid., p. 8.
15 Roger Finke & Rodney Start, *The Churching of America, 1776–1990: Winners and Losers in Our Religious Economy.*
16 Barbara Rosewicz & Michael Waldholz, "Human, Animal Gene Patents Targeted by a Religious Coalition in a Petition."
17 Edmund L. Andrews, "Religious Leaders Prepare To Fight Patents on Genes."

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# CREATIONISM, IDEOLOGY, AND SCIENCE

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MANY CAUSES AND MOVEMENTS were discussed during the "Flight from Science and Reason" conference that occasioned this volume. Most reject science as a way of knowing, or denigrate logic or reason. Creationism differs in some important ways: supporters are science fans, not detractors, and they believe science is useful and important, something that students should be exposed to. But creation science illustrates extremely well one of the themes of the conference: the evasion or denial of empirically based knowledge when it conflicts with ideology. Opinions and values are more important than facts and reason for creationists, which is shown in their choice of which data to accept or reject. Whereas T. H. Huxley warned of the naturalistic fallacy—assuming that what *is* is what *ought* to be—creation scientists, like extreme Afrocentrists, radical feminists, and several others discussed at the conference, apparently see what *ought* to be as what *is*.

In this paper, I will first discuss who the creationists are, stressing the many varieties of creationism and how they differ in their approaches to both science and theology. I will outline a brief history of the movement, the emergence of creation "science," and also the current "neocreationism" period. I suggest that a characteristic of neocreationism is the rise of more moderate antievolutionists, some of whom are located on secular campuses. Some of these argue that a "Christian perspective" has equal status with a "feminist perspective," or a "Marxist perspective," or some similar approach extant on campuses today, and thus deserves a place in the curriculum.

The presence of so many "isms" on college campuses today invites the question, "What happens when ideologies become 'scholarly perspectives'?" Can there be a "Christian perspective" that is truly scholarly? I discuss reasons why I doubt that supernatural ideology, especially, can be consistently scholarly.

I then discuss the importance to public science literacy of teaching evolution and suggest some ways that university and professional scientists may assist in this important endeavor. To do so will require teachers to distinguish between where science leaves off and where philosophy begins.

## CREATIONISM, BIBLICAL LITERALISM, AND ANTIEVOLUTION

There is not one creationism, but many varieties, ranging from strict Biblical literalist young-earth creationism, through a variety of old-earth creationisms ("gap creation;" "day-age creationism"), to progressive creationism, to continuous creationism, to theistic evolutionism. Specific terms may have slightly different connotations depending on who is using them, but in general, young-earth creationism posits that the universe was created at one time, within the last 10,000 years. Noah's flood is an essential element to both young-earth theology and creation science. It was, supposedly, a historical occurrence, wherein water covered the whole globe. During the year the flood waters receded, all the geological features of the world (such as the Grand Canyon, the Himalayas, etc.) were established. By contrast, old-earth creationists accept modern geology and radiometric dating and their implication of an old planet. One version of "old earth" theory, "gap creationism," allows for a long period of time before the six days of creation described in Genesis,[1] or alternatively for the six days in Genesis to be separated by thousands or hundreds of thousands of years. Alternatively, "day-age creationism" accommodates some of modern geology by claiming that each of the six days in Genesis is actually an immensely long period of time.

In "progressive creationism," God is supposed to have created the original species, but subsequently they have "progressed" by diverging (i.e., evolving) into new forms. The flood is considered a local, not a universal, event. "Continuous creationism" and "theistic evolutionism" are further along the continuum, referring to a Christian perspective that accepts a considerable amount of evolution. In continuous creationism, God plays a very active role in directing evolution from the created kinds. Theistic evolution in the most general sense is the idea that God created, but through the process of evolution. By and large, theistic evolutionism accepts the evidence of science, and fine-tunes the theology if necessary. In this context, the flood of Noah is not a historical event, but a metaphor of the importance of obedience to God, and ultimately of God's love for humankind. Theology varies as to how involved God is in guiding the evolutionary process.

The above continuum is largely organized by the degree of biblical literalism, with theistic evolutionism (the perspective of most mainline Protestants and the Catholic Church) being the least literal. It can also be organized according to how much of modern science is accepted, with the young-earth creationists being the most out of touch. Some theistic evolutionists, especially those of a more deistic inclination (God created the universe and its laws, and left it to operate without further intervention), are scarcely distinguishable from nonreligious evolutionists, which is why the conservative Christian world, with its stress on a personal God, often speaks harshly of theistic evolutionism.

Whether God created is therefore in fact not the main issue in the creation/evolution controversy, since "God created" does not rule out the possibility that God created through the process of evolution. Catholics, mainline Protestant denominations, and Reformed, Conservative, Reconstructionist, and

most Orthodox Jews hold to some form of theistic evolution.[2] The term "special creation" has come to refer to the belief that God created according to a literal interpretation of Genesis: the universe was created all at one time, in essentially its present form.

Special creationists, especially at the more conservative end of this continuum, are fundamentally antievolutionist. They believe that evolution is an evil idea that children should be protected from. Their perspective is that if evolution occurred, then God did not create mankind specially, hence mankind is not particularly special to God, which would make the fall of Adam and Eve irrelevant. Without Adam and Eve's sin, the death of Christ is irrelevant—and the death of Christ is the foundational event of Christian theology. Everything in Christianity, in this view, relies on the literal truth of Genesis: six 24-hour days of creation, a flesh-and-blood Adam and Eve, a literal Noah's flood, and so on. If evolution is true, then, salvation itself is in jeopardy, for how can Revelations be true if the rest of the Bible is not? To protect children from the doctrine of evolution is to save their souls. Obviously, this motivates powerfully.

A further motive is to prevent society from going downhill, inasmuch as strict creationists believe that evolutionary theory (because it supposedly denies God) removes the source of morality. As Henry Morris, arguably the most influential creationist of the late twentieth century, puts it,

> Evolution is at the foundation of communism, fascism, Freudianism, social darwinism, behaviorism, Kinseyism, materialism, atheism, and in the religious world, modernism and neo-orthodoxy. Jesus said "A good tree cannot bring forth corrupt fruit." In view of the bitter fruit yielded by the evolutionary system over the past hundred years, a closer look at the nature of the tree itself is well warranted today.[3]

This is not evolution as seen by scientists: the idea that the universe today is different from what it has been in the past and that change through time has occurred. In regard to organic evolution, the evolution of plants and animals, this means that living things share common ancestors in the past from which they are different. Darwin called organic evolution "descent with modification," and it is still a useful phrase. The contrasting perceptions of evolution—those of Morris and of mainline science—illustrate again how ideology shapes interpretation of empirical data.

## CREATION "SCIENCE"

The antievolution movement has had a long history in the United States, dating from the first introduction of Darwin's ideas during the latter part of the nineteenth century. Creation "science" is only a recent manifestation of this antievolutionism. Creation "science" is a movement of largely biblical literalist Christians who seek to get evolution out of the public school curriculum. They differ from other antievolutionists in their attempt to demonstrate the truth of a literal biblical interpretation of Genesis using data and theory from science—not just through theology. The young-earth creationists are the most numerous, but many old-earth creationists use scientific arguments as

well. Although attempts to "prove" the literal truth of the Bible have been around for centuries, the most recent version of this approach hails from the mid-1960s, stimulated by the publication of John Whitcomb and Henry Morris's *The Genesis Flood* and the founding of both the Creation Research Society and the Institute for Creation Research. Why the 1960s? The answer is simple: the post-Sputnik science education panic of the late 1950s and 1960s resulted in improved textbooks that returned evolution to the curriculum at levels not seen since before the Scopes trial of 1925.[4] Giving an extra nudge to the process was the Supreme Court case of *Epperson v. Arkansas*, which overthrew antievolution laws such as Tennessee's under which John T. Scopes had been tried.

With evolution no longer liable to be banned, antievolutionists developed a strategy to ameliorate its "evil effects" by teaching biblical Christianity alongside it. Because the First Amendment of the Constitution clearly disallows advocating sectarian religious views in the classroom, "scientific" creationism was developed to be an "alternate scientific" view that could be taught as a secular subject. During the 1970s and early 1980s, creationists campaigned to pass "equal time" laws wherein creation science would be mandated whenever evolution was taught. This approach had to be abandoned in 1987 when the Supreme Court ruled in *Edwards v. Aguillard* that creationism was inherently a religious concept, and that to advocate it as correct, or accurate, would violate the Establishment Clause of the First Amendment. But Justice Brennan's decision left a couple of loopholes that antievolutionists have been exploiting ever since.[5] Subsequently, antievolutionism has evolved into new forms which are characterized by the avoidance of any variant of the "c word." Phrases like "intelligent design theory," and "abrupt appearance theory" are used instead of "creation science," "creationism," and related terms. I call this newest stage of antievolutionism "neocreationism."

## NEOCREATIONISM

The neocreationism tactic continues the "equal time" for creation and evolution of the creation science era, but with some new wrinkles. A popular neocreationist variant of creation science is "intelligent design theory" (IDT), a lineal descendant of William Paley's "argument from design." William Paley's 1802 *Dialogues Concerning Natural History* attempted to prove the existence of God by examining his works. Paley believed in the traditional God of the literal reading of Genesis: the creator who had produced a perfect world in which everything had its purpose. He used the metaphor of a watch to demonstrate how observing the perfection of nature "proved" there was a God, a "Divine Watchmaker." If you found an intricately contrived watch, he argued, it was obvious that such a thing could not have come together spontaneously; the existence of a watch implied a watchmaker who had designed the watch with a purpose in mind. Similarly, as there was order and purpose and design in the world, so naturally there must be an omniscient designer. The existence of God was proven by the presence of order and intricacy.[6]

The vertebrate eye was Paley's classic example of design in nature, and was well known to educated people of the nineteenth century. In response,

Darwin deliberately used the vertebrate eye in *The Origin of Species* to demonstrate how complexity and intricate design could come about by natural selection. Modern day IDT uses the vertebrate eye and similar structural wonders to demonstrate how evolution could not have possibly occurred, ostensibly because complexity of this sort could never have occurred "by chance." In fact, one will find not just the vertebrate eye, but the structure of DNA or cytochrome *c* held up as "too complex" to have evolved "by chance." Also, post-Paley information-theory is woven into the attempt to prove that evolution did not occur. (Or course, no evolutionist argues that complex structures evolve "by chance," but "chance" is synonymous with "evolution" in creationist literature.)

The best-known statement of IDT is a book by Percival Davis and Dean Kenyon, *Of Pandas and People*, written as a supplement for high school biology courses. Instead of advocating the more familiar creationist "teach evolution, but also teach creation science," *Pandas* offers the notion that teachers should "teach evolution, but also intelligent design theory." In content, there is nothing in IDT that has not already been expressed in earlier creation science literature. "Intelligent design theory" is merely a euphemism for creation science. A discussion of the promotion and use of *Pandas* is in Larson.[7]

## EVIDENCE AGAINST EVOLUTION

A second neocreationist approach not only avoids the use of the term "creation science," but eschews euphemism completely, coming right out with the essence of antievolutionism. The argument here is "teach evolution, but also teach the evidence against evolution." The "evidence against evolution" approach, of course, makes little scientific sense: it is rather like requesting that "evidence against heliocentrism" be presented when the solar system is taught. There is no scientific evidence against evolution. "Evidence against evolution" has always been synonymous with creation science, which specializes in finding anomalous tidbits in the scientific literature that appear to "prove" that evolution did not occur.[8]

In my job as director of a nonprofit clearinghouse for information on the creation/evolution controversy, I receive information on the full gamut of attacks on evolution. For example, during the last six months, I have received requests from New Hampshire for information to help keep old-fashioned scientific creationism out of a school district; requests from Louisiana and Texas for information on "intelligent design theory;" and requests from Ohio and California for assistance in combating "arguments against evolution," among other requests. The Epperson and Edwards Supreme Court decisions have only ended the attempts to outlaw the teaching of evolution, and to mandate the teaching of creation science alongside evolution. They have not ended attempts to prevent students from learning evolution, or even attempts (of individual teachers) to teach creation science.

Even though my office still handles numerous calls about creation science, given trends already apparent, I think that in the future the influence of creation science will wane in favor of more sophisticated neocreationist attacks

on evolution. Teachers and school boards will face more pressure to teach not creation science, but "intelligent design theory," or "evidence against evolution." I say this primarily because these approaches are less vulnerable to legal challenges. Intelligent design theory and evidence against evolution do not sound as blatantly sectarian as something with the word "creation" in it. They are merely bad science, and the First Amendment protects against the establishment of religion, not against bad science. If creation science is primarily the result of the efforts of young-earth special creationists such as those at the Institute for Creation Research (ICR) and the Bible Science Association, neocreationism is dominated by more moderate creationists, many of whom are conservative Christian antievolutionists operating at the university level. These are generally "old-earth" creationists, who do not quibble about the age of the earth (and who therefore appear more reasonable to the general public), but who nonetheless deny that evolution took place. I believe their influence will increase: although the ICR reaches thousands of individuals at their "back to Genesis" rallies and through their extensive publishing efforts, these neocreationist faculty members are influencing the attitudes of future college graduates. College graduates vote at higher levels than nongraduates, are the next journalists and politicians, and in general are more influential in shaping public opinion. These academically based "Christian scientists" are far less well known than their young-earth counterparts.

## "CHRISTIAN SCIENTISTS" AT THE UNIVERSITY

By "Christian scientists" I do not mean followers of Mary Baker Eddy, but Christians who are also practicing scientists. How many are there? In the general public, the percentage of self-identified Christians is eighty-six percent.[9] Is the percentage among scientists this high? I do not know of any reliable recent surveys on the religious inclinations of scientists, but even if only half the scientist corps identifies itself as Christian, the number of scientists who are believers would be substantial. As is the case with Christian theology, the degree of belief and specific doctrinal acceptance doubtless varies greatly among these academics. My comments will concern the fraction professing conservative Christianity, a term that overlaps with evangelistic Christianity and fundamentalist Christianity, in referring to belief in a personal God and a belief in the inerrancy (and/or literal truth) of the Bible. I also speak primarily of conservative Christians who teach at secular colleges and universities, not religious ones.

Many of these are associated with Christian Leadership Ministries, an affiliate of Campus Crusade for Christ, an organization that targets college and university faculty members. CLM claims to be active on more than 800 United States campuses. Its newsletter, *The Real Issue,* encourages faculty members to stand up for their academic freedom to express religious beliefs. But the expression of religious beliefs can take many forms, from benign to clearly illegal. In the mildest form of advocacy, religious belief might be expressed (as are many other opinions) in time-honored fashion by proclamations taped to a professor's office door. Conservative Christians can argue that if colleagues can put up gay-rights literature on their office doors, they should be

able to put up Christian literature without being harassed. On the other hand, in a far less acceptable effort, some professors try to convert students to Christianity in the classroom, in violation of the First Amendment's Establishment clause.

Two court cases concerning classroom proselytizing have arisen. Phillip A. Bishop, professor of exercise physiology at the University of Alabama, was accused of proselytizing students in class, and teaching "intelligent design theory" in an optional class held outside of regular class time. In this forum, he expressed his views on the "evidence of God in human physiology." Students did not have to attend, but as the special class was offered just before the final exam, at least some students felt coerced. The dean of the college instructed Bishop to quit witnessing in class and not to have extraclass meetings in which religious views of the subject matter were discussed.

Bishop sued his institution on free speech and academic freedom grounds, and won at the Federal District Court level.[10] The Appeals Court, however, reversed the decision, declaring that a classroom, during instructional time, was not an open forum, and that the University can reasonably restrict Bishop's speech during that time. The appeals court did not decide against Bishop on the grounds that he was violating the Establishment clause, but on the grounds, narrower in some ways, of the right of the University to set curricula.

In the second case, in 1991, Dilawar Edwards, an education professor at California University of Pennsylvania, used fundamentalist and religious-Right publications (including creation science books) to "balance" established, secular instructional materials in an educational methods course. Students claimed that he did not teach media resources, the topic of the course, but instead harangued them about how secular humanism in public schools violated Christian principles. The dean of the college told him to "cease and desist using doctrinate material of a religious sort" in the classroom. Edwards sued the college, claiming academic freedom to choose whatever materials he wants to use. The case is still pending.

These cases bring up important concerns regarding academic freedom for religiously-based views. It is clear that teachers at the K–12 level have strictly limited academic freedom regarding religion: they may not express religious views to students because of their special position as authority figures in relation to a "captive audience" of younger students. But faculty authority over adult college students is far weaker (though certainly not absent when grades are involved). Usually college students have options allowing them to avoid particular professors and classes. There are also no laws requiring college attendance such as there are at lower educational levels, and thus college students are not "captive" in the sense that kindergarten through twelfth grade students are. What, then, are the limits of academic freedom and religious speech at the university?

The Bishop case concluded that academic freedom is not absolute at the university level when it comes to religious speech: a professor does not have the right to proselytize students. But what about activities intermediate between posting Biblical literature on one's door, on the one hand, and emphatic "witnessing" in class on the other?

Some conservative Christians distinguish between proselytizing and presenting information "from a Christian perspective." As pointed out elsewhere in this volume, many academics openly teach "from the point of view of" some ideology. If it is considered legitimate for a professor to announce in, say, a history class, that he or she will be teaching the subject from a feminist, or Marxist perspective, should not a Christian professor be permitted to make a similar declaration? The point made by conservative Christians like George Marsden[11] is that sauce for the goose is sauce for the gander: if the university does not protest when Marxist, feminist, gay, or Afrocentric perspectives inform the presentation of scholarly material, it should not protest a Christian professor's analogous methods.

## CHRISTIAN SCHOLARSHIP, IDEOLOGY, AND SCIENCE

Christianity is clearly an ideology, but so arguably are Marxism and feminism, and perhaps some other "isms." The argument is made that Marxism and other "isms" are not only ideologies, but legitimate scholarly approaches to knowledge, as well. Can an ideology be scholarship? The question strikes at a fundamental tenet of scholarship and speaks directly to one of the themes of this volume. If knowledge is to be distinguished from opinion, there must be sources of information beyond the individual. Information comes in many guises, and some of it is contradictory. Scholarship requires the weighing and judging of information in order to come to reliable and valid conclusions. Ideology may or may not be based on scholarship, but what makes ideologies troubling is that they also include a component of belief that always has the potential to overshadow the scholarship. There is always the possibility that empirically based knowledge will be supplanted or denied because of ideology.

It is theoretically possible to have a scholarly feminist perspective, a scholarly Marxist perspective, a scholarly environmental science perspective. The sorts of radical feminism, radical multiculturalism, and radical environmentalism criticized in other essays in this volume are not truly scholarly precisely because they elevate ideology over empirical evidence and logic. In fact, some of them revel in their rejection of logic and reason. When the claim is made that black Egyptians sailed to Mesoamerica and taught the Olmec to build step pyramids, clearly the ideology of black superiority is being promoted at the expense of actual empirical evidence.

Now we come to another question. Ideology and scholarship are at best uncomfortable bedfellows. Can a supernatural ideology be scholarship? Can Christian scholarship meet the standards of scholarship in this sense? We are talking now not about posting religious items on one's office door, much less trying to convert students to Christianity, but something called "teaching from a Christian perspective" as a scholarly endeavor. Does a "Christian perspective" fall inherently into that class of views wherein ideology is the ultimate determinant of truth? Most conservative Christians who have complained that views important to them are given short shrift on campus have not been explicit about how their religious views might inform their scholarship, as opposed to their free speech outside of the classroom. George

Marsden suggests one way a Christian perspective might influence a teacher's presentation in social science:

> Such unproven assumptions [that there is no created order] have a greater effect in the humanities and social sciences than in the largely technical disciplines and natural sciences. Since most scholars today will tolerate only a naturalistic understanding of humans, they have no basis for interpreting moral standards except as survival mechanisms—that is, as social constructions suiting the needs of a particular community. The result of this view is, inevitably, moral relativism of one sort or another. Religiously informed scholars, on the other hand, while acknowledging the cultural forces that shape beliefs, are also open to the possibility of permanent, universal standards of right and wrong established by a creator.[12]

Marsden himself seems to imply that the "Christian perspective" may be more relevant in the more subjective sciences. But what of a "Christian" view of natural science? In truth, all true scholarship requires the collection of information and its logical evaluation against agreed-upon standards. Science may, however, be distinct from other scholarship because of the degree of emphasis it places on empirical information and on whether a given explanation "works." Obviously, there is subjectivity in science, and it is no great revelation to state that historical, political, and social factors influence the course of science, and even the conclusions reached. Science is a human endeavor, which means it is cumbersome, subject to human egos, messy, and slow. At any given time, much of it will be in error. But the saving grace of science is that it is open ended, and conclusions are tentative, subject to later revision. Explanations that do not hold up over time, or that are contradicted by other better data, are eventually rejected. (Sometimes we have to emphasize the "eventually!") Science's great power resides in its ability to reject explanations based on logic and empirical evidence, rather than by virtue of mere opinion, authority, or assertion. It is an untidy procedure, but it has given us enormously more knowledge of the natural world than obtained by any other society in the history of our species. Thus, even granting that "scholarship is scholarship," science is and must be held to different standards from other forms of knowledge. It is harder to argue the "strong constructivist"[13] perspective when discussing cell permeability than when discussing, say, the Civil War. One may correctly argue that the "truth" of Reconstruction varies considerably between southern blacks and southern whites, but there is no Afrocentric Krebs cycle that contrasts with a Eurocentric Krebs cycle. Except for those who deny objective reality, the logical-empirical methodology of science does allow the rejection of some ideas and the tentative acceptance of others.

Christianity is clearly an ideology, and it is apparent from many presentations in this volume that when ideology is given precedence over evidence, science suffers. The extensive literature of creation "science" demonstrates the futility of trying to do empirical science after conclusions based on "revealed truth" have already been posited in advance as unassailable. This fact was recognized by the Federal District Judge in the *McLean v. Arkansas* case.

Is there a "Christian perspective" that is not as extreme as the blatant dis-

tortions of science promulgated by the Institute for Creation Research? I have not found any examples that are free from the inclination to subvert science in order to defer to ideology. One largely old-earth creationist proposal, for instance, is that there are two different kinds of science: "operations science" and "origins science."[14] A distinction is made between phenomena that occur "with regularity" and those that occur "singularly." It is argued that regularly occurring phenomena can be studied in the fashion of normal science, or "operations science." But one-time phenomena, such as the Big Bang and other evolutionary events, come within what creationists call "origins science."

Of course, there are differences between the study of repeatable events and nonrepeatable ones, but mainstream philosophers of science agree that phenomena of historical sciences like geology, paleontology, and astronomy can be studied scientifically, and even experimentally. Mount St. Helens erupted as a singular event, but this does not exclude a science of volcanoes. Similarly, even if bears and dogs split from a common ancestor only once, we can still evaluate the hypothesis that bears and dogs are closely related against empirical evidence (from fossils, comparative anatomy, biochemistry, etc.). We can also learn about the processes that influence evolution by looking at the evidence for other such splits. There are many ways to study events of this type scientifically.

Creationists often add an additional factor to this bimodal division of the scientific world, one that I believe sheds light on why the division was invented in the first place. Specifically, they allow the explicit intrusion of the supernatural into scientific explanation. Geisler proposes that corresponding to the two kinds of science, there are two kinds of causation: primary causes and secondary causes. Operations science relies properly on secondary causes, but origins science is allowed to invoke primary causes. Thaxton *et al.* refer to "primary cause" more bluntly as the "God hypothesis," and agree that in operations science, "the appeal to God is quite illegitimate, since by definition God's supernatural action would be willed at His pleasure and not in a recurring manner."[15] But when dealing with "origins science," it is not only permissible, but essential to allow recourse to supernatural causation (i.e., miracles).

Few would argue with excluding miracles from "operations science," but proponents of this artificial division do not make a solid case for resorting to miracles in origins science. Arguably, nonrecurrent events may be more difficult and challenging to study than repeated events, but that in itself is insufficient to require resorting to the supernatural.

Science as it is practiced in the late twentieth century has, on the contrary, emphatically eschewed invoking miracles to explain natural phenomena. Creationists recognize that they are outside of the mainstream in their insistence on supernatural causation, but claim that the rejection of the supernatural in modern science is a function of "naturalism" (materialism), a philosophy that defines reality only in terms of material causes.[16] Because evolutionary scientists supposedly are caught up in a metaphysical viewpoint that rejects the possibility of a creator, creationists contend that evolutionists are unable to countenance evidence for supernatural intervention in the history of life.

Actually, modern science has omitted the supernatural for methodological, not philosophical, reasons. It is not that scientists have an axe to grind with respect to theism. Rather, we simply get better explanations by ignoring the possibility of supernatural intervention or causation. Much confusion exists between materialism as a *philosophy,* and the *methodological* materialism that informs all of modern science. It is logically possible to decouple philosophical and methodological materialism, and individual scientists who are believers do it all the time. Gregor Mendel was certainly not a metaphysical naturalist, but he developed his understanding of the rules of heredity using methodological materialism. Alternatively, I personally am a philosophical materialist, not a believer, but when I teach science to students, I leave my irrelevant philosophy out of my course. I stress methodological materialism as a tool to understand the natural world better, not as a foundation for a personal belief.

But creationists would say that Mendel's laws are examples of "operational" science, which elicits the question "what are the topics of origins science?" In my reading, I find that "origins science" is limited to subjects that have theological importance. Conservative Christian theology is concerned with the special creation of the earth, the special creation of life, the special creation of animals and plants, and the special creation of human beings, all by a personal God who had an ultimate purpose in mind. As a result, "origins science" focuses on the Big Bang (the origin of the universe), the origin of life, the origin of the "kinds" of plants and animals, and the origin of humans.

## THE BIG BANG

Creationists recently have split over the significance of the Big Bang, with "old earth" creationists like Hugh Ross of Reasons to Believe Ministries promoting the idea that the Big Bang is evidence for creation, and "young earth" creationists such as Henry Morris and others from the Institute for Creation Research arguing for a more Biblical, literal, special creation view that the entire physical universe came into being in only a few days. Some conservative Christian scientists thus accept modern physics, chemistry, and radiometric dating, but most have difficulty with modern biology, especially descent with modification. The other three "origins" topics all involve living things, which causes considerable discussion among these more moderate creationists.

Assuming that it is an open question whether life might have occurred through natural or supernatural causes, science, because it is limited to understanding the world only by natural processes, can only attempt to explain the origin of life through natural forces. By definition, special creationists do not accept the possibility of a naturalistic evolution of life from nonlife, though theistic evolutionists may. Theologically liberal creationists allow that God might have devised the first replicating molecule, and that descent with modification occurred thereafter.

## ORIGIN OF LIFE

Origin of life research has always been a mainstay of young-earth creationism, and is also of considerable concern to old-earthers. It seems to be the "soft underbelly" of evolutionary biology, as there is not yet a consensus

on precisely how life came about. It is a quite active area of research, however, and there are several vigorously competing explanations. Creationists, however, view the origin of life as an intractable mystery that will never be solved because it is "too complex" to explain through natural causes. They appear to assume that because it is not yet explained, it never will be.

The issue is theologically loaded: if life itself can be explained without recourse to supernatural intervention, to some (though not all) it will appear that the existence of God is thereby refuted. The idea that God could have willed life to have come about naturally (under the notion of God as ultimate force in the universe) is tainted with Deism so far as conservative Christians are concerned. It implies that God is a distant prime mover rather than the personal God of their theology. As a result, every possible breakthrough in the scientific analysis of the origins of organic life (the postulate of an RNA world, for example) is attacked as "too improbable." It is difficult to see how a "Christian perspective" on origin of life research could be scholarly, given this manifest unwillingness even to consider—much less evaluate objectively—opposing opinions.

## PLANT AND ANIMAL DIVERSITY

The explanation of the diversity of plants and animals also varies among conservative creationists. The Bible states that "kinds" (Heb.: *baramin*) were created, but "kinds" is a poorly defined term that may denote species, genus, or family. Much creationist literature concerns the definition of a "kind," and how much "variation within the kind" can take place. For the young-earth creationists, this becomes critical because of flood geology. Noah was instructed to take seven pairs of every clean kind of animal and five pairs of every unclean kind, so that even if the Ark was the size of the Queen Mary (as claimed), the number of "kinds" that could have been squeezed onto this ship is rather limited. Thus, if the "cat kind" is viewed as equivalent to the family Felidae, the "seven pairs taken" might have diverged, after the Ark landed, into lions, bobcats, lynxes, pumas, housecats, and other feline species: an example of "variation within a kind." Other conservative Christians might even more broadly allow a "kind" to encompass all carnivora, and for post-Noachian descent with modification to have taken place—in animals, anyway. Most, however—even the most flexible—draw the line at human evolution.

## HUMAN EVOLUTION

The notion of human evolution postulates that humans descended with modification from nonhuman ancestors. Humans and living apes shared a common ancestor. This view contrasts strongly with the idea that God specially created humans in his image. Even the most liberal of the conservative Christians have difficulty accepting human evolution, though many will accept that nonhuman animals evolved. Conservative Christianity is based on an individual, personal relationship with God. How, it asks, could humans have a special place with God if they result from the same processes that brought about the rest of nature? Humans—at the very minimum—have to have had a separate creation. And yet scientists infer from anatomy, biochem-

istry, behavior, the fossil record, and even embryology that we shared a common ancestor with modern chimps and gorillas.

It is perhaps most obvious in their insistence upon a separate creation for humankind that conservative Christians present a clear example of how Christian ideology affects the interpretation of scientific data. "Origins science" itself focuses on theologically important topics, allowing the intervention of the supernatural on theological, not scientific grounds.

This is illustrated by the fact that there is a direct correlation between the degree of theological conservatism and the amount of scientific evidence for evolution that is accepted. The most theologically conservative accept only physics and chemistry; the less conservative accept some of biology (for example, some evolution of nonhuman forms), and only the most theologically liberal accept human evolution. Ironically, the scientific evidence for the evolution of our species is far better than that for most other mammalian genera. I believe human evolution is not accepted predominantly because of ideological commitments.

There may indeed be a "Christian perspective" that is scholarly, but it will be difficult to apply it to evolutionary studies and still remain scientific. Whether there are other areas within science where a "Christian perspective" can be applied is an empirical question that has not yet been answered. But as with Marxism, feminism, Afrocentrism, environmentalism, or any other ideology, there is a great risk of subordinating evidence to belief. From the evidence so far, a supernatural ideology is even more fraught with this risk.

## TEACHING EVOLUTION: DEFUSING THE RELIGIOUS ISSUE

Currently, the most active and effective antievolutionists are the grassroots, young-earth proponents from the ICR, the Bible-Science Association, and affiliated groups. It is my contention that more moderate forms of antievolution, such as some of those discussed above, will be having a proportionately greater effect in the future partially because of their presence on secular campuses where they are able to influence the next generation of leaders.

A high percentage of citizens reject evolution (currently, polls consistently show forty-seven percent to forty-nine percent of Americans deny that humans evolved from earlier forms).[17] Evolution, however, is a basic component of science, and essential to the understanding of biology and geology. One is not scientifically literate if one does not understand evolution. I would hope that scientists would do what they can to encourage individuals to accept evolution as science.

Evolution—accurately presented—needs to be in precollege as well as college education. There are a number of things that scientists, especially those at colleges and universities, can do to teach it better. Most of these have little to do with the actual scientific content of the subject, but rather with improving the perception of evolution by the public.

I speak before many public audiences and do a fair number of radio call-in programs. The most common response I get when I ask people "what does evolution mean," is "man evolved from monkeys." The second most common

answer is, "evolution means that you can't believe in God." The perception that religious faith and acceptance of evolution are incompatible is, in my experience, widespread. One source of this confusion comes from antievolutionists. Leaders of the Institute for Creation Research proclaim that "one can be either an evolutionist or a Christian."

As mentioned before, reliable polls place the number of self-identified Christians in the United States at upwards of eighty-six percent,[18] the highest percentage of believers of any developed country. If scientists give Americans the same choice as the ICR proposes, there will be scant interest in teaching and learning evolution!! This, to say the least, would be highly detrimental to the science literacy of our nation. To encourage people to learn about evolution, it is necessary to allow them to retain their faith.

This follows from the logic of the limitations governing modern science. It is also good strategy, if our goal is to increase the amount of science literacy in our nation.

Not all creationists are extreme in their rejection of evolution. To many moderate creationists, evidence from science demonstrates that the universe is old, the earth is old, plants and animals evolved, and even human beings had earlier ancestors different from them. They merely want to draw the line at the assumption of evolutionary materialism, the philosophy that evolution (and its material causes) are not only sufficient for explaining the presence and form of the modern universe, but proof that there is no supernatural intervention. The fear that teachers are serving up not just science, but materialism in their lessons on evolution inspires much of the opposition to evolution that I have encountered—and not just from young-earthers who are at the fringes of modern science, but from more moderate conservative Christians who are within the modern scientific mainstream in many respects.

In dealing with hundreds of elementary and high-school teachers, I have found that the number of teachers that actually promote philosophical materialism along with evolution is vanishingly small. At the college level, it is more significant, but it is still not general. Vocal proponents of evolutionary materialism such as William Provine at Cornell, Paul Kurtz at the State University of New York, Buffalo, and Daniel Dennet at Tufts vigorously argue that Darwinism makes religion obsolete, and encourage their colleagues to argue likewise. Although I share a similar metaphysical position, I suggest that it is unwise for several reasons to promote this view as "the" scientific one.[19]

First, science is a limited way of knowing, in which practitioners attempt to explain the natural world using natural explanations. By definition, science cannot consider supernatural explanations: if there is an omnipotent deity, there is no way that a scientist can exclude or include it in a research design. This is especially clear in experimental research: an omnipotent deity cannot be "controlled" (as one wag commented, "you can't put God in a test tube, or keep him out of one."). So by definition, if an individual is attempting to explain some aspect of the natural world using science, he or she must act as if there were no supernatural forces operating on it. I think this methodological materialism is well understood by evolutionists. But by excluding the supernatural from our scientific turf, we also are eliminating the possibility

of proclaiming, via the epistemology of science, that there is no supernatural. One may come to a philosophical conclusion that there is no God, and even base this philosophical conclusion on one's understanding of science, but it is ultimately a philosophical conclusion, not a scientific one. If science is limited to explaining the natural world using natural causes, and thus cannot admit supernatural explanations, so also is science self-limited in another way: it is unable to reject the possibility of the supernatural.

Scientists, like other teachers, must be aware of the difference between philosophical materialism and methodological materialism and not treat them as conjoined twins. They are logically and practically decoupled. Furthermore, if it is important for Americans to learn about science and evolution, decoupling the two forms of materialism is essential strategy.

To further defuse the religious issue, scientists can be more careful about how they use terms. For example, evolutionists sometimes confuse the evidence we have for considerable contingency during the course of evolution with evidence for a lack of ultimate purpose in the universe. Futuyma writes,

> Perhaps most importantly, if the world and its creatures developed purely by material, physical forces, it could not have been designed and has no purpose or goal. . . . Some shrink from the conclusion that the human species was not designed, has no purpose, and is the product of more material mechanisms—but this seems to be the message of evolution.[20]

G. C. Simpson is regularly quoted with dismay by creationists as saying "Man is the result of a purposeless and natural process that did not have him in mind. He was not planned."[21] A theist might respond that we do not know what God's purpose is or what he planned. It is possible that if there is an omnipotent, omniscient deity, it was part of its plan to bring humans and every other species about precisely in what seems to us the rather zig-zag, contingency-prone fashion that the fossil evidence suggests. Of course, this would be a theological statement, but that, indeed, is the point. Saying that "there is no purpose to life" is not a scientific statement. We are able to explain the world and its creatures using materialist, physical processes, but to claim that this then requires us to conclude that there is no purpose in nature steps beyond science into philosophy. One's students may or may not come to this conclusion on their own; in my opinion, for a nonreligious professor to interject his own philosophy into the classroom in this manner is as offensive as it would be for a fundamentalist professor to pass off his philosophy as science.

Another way scientists can help defuse the religious issue is by being explicit about what we can and cannot say about design. As with "purpose" in nature, "design" is largely a theological position. But many evolutionists, ever mindful of William Paley's "argument from design," stress not the perfection of structure in nature, but the often erratic, cobbled-together-from-what-is-available nature of many structures, such as the panda's thumb or the anglerfish's lure. This is an important point to make, and helps students realize that natural selection does not result in "perfection" of structure. When we look at either the fossil record or the "design" of many structures, it is difficult

to see evidence of advance planning. In terms of proximate cause, then, design in nature is not apparent. But final cause is, as we discussed, outside the boundaries of science. Allowing a student of conservative religious views to continue to believe in final design or purpose need not detract from that student's understanding of the evidence for the contingency of proximate cause. Separating the two types of causation may, indeed, keep a student from being "turned off" by evolution, especially if he or she comes into the class with the idea that "evolution means you cannot believe in God."

## CONCLUSION

Creationism offers some interesting contrasts to other topics discussed in this volume. Creationists (antievolutionists) are not opponents of science, per se. They appreciate reason and believe they are being objective, but just like postmodernists, they reject the Enlightenment traditions that brought about modern scientific epistemology. The distinction is that they are premodernists, rather than postmodernists.[22] They illustrate extremely well one of the concerns that supporters of science and reason have in the face of so much antiscience: the replacement of empirical and logical evidence with ideology and dogmatic belief.

The antievolution movement has as its prime motive the fear that religion is under attack by the study of evolution. Great efforts have been made over the last seventy years to "shield" students from evolution's "evil effects." Like a neutral mutation that replaces the wild type if no selective forces are arrayed against it, antievolution will prevail if not opposed by academics at universities (and even more importantly, at the grass-roots level of the school board and the individual school). To oppose antievolution successfully, scientists need to understand what motivates the movement, and also to recognize that the movement is not monolithic. There is great variation among conservative Christians in the degree to which they reject evolution. Those who spurn evolution out of fear that a hegemonic materialist philosophy is being promoted at the expense of their religion are very different from and more "reachable" than those who reject evolution because of fancied scientific evidence against it.

I suggest that scientists can defuse some of the opposition to evolution by first recognizing that the vast majority of Americans are believers, and that most Americans want to retain their faith. It is demonstrable that individuals can retain religious beliefs and still accept evolution as science. Scientists should avoid confusing the methodological materialism of science with metaphysical materialism. Also, scientists should avoid making theological statements (such as those concerning ultimate purpose in life, or final cause) in the context of their scientific discussions.

Antievolutionism is perhaps the most successful form of irrationalism besetting the American public, though it currently is not represented at the university level to the same degree as some of the other "isms" discussed in this volume. It would be nice for American science literacy if its prevalence in the "real world" outside the university were to match its prevalence within. The efforts of university and professional scientists will be critical in this regard.

## NOTES

1 Ronald L. Numbers, *The Creationists.*
2 See Betty McCollister, *Voices for Evolution.*
3 Henry Morris, *The Twilight of Evolution,* p. 24.
4 Numbers, *The Creationists.*
5 Eugenie C. Scott, "The Evolution of Creationism: The Struggle for the Schools."
6 Richard Dawkins, *The Blind Watchmaker.*
7 Erik Larson, "Darwinian Struggle: Instead of Evolution, a Textbook Proposes 'Intelligent Design.'" See Padian, Ruse & Skoog in Liz Rank Hughes, ed., *Reviews of Creationist Books* for reviews.
8 Douglas Futuyma, *Science on Trial.*
9 Ari L. Goldman, "Portrait of Religion in U.S. Holds Dozens of Surprises."
10 *Bishop v. Aranov.*
11 George Marsden, *The Soul of the American University: From Protestant Establishment to Established Nonbelief.*
12 George Marsden, "Religious Professors Are the Last Taboo."
13 Paul Gross & Norman Levitt, *Higher Superstition: The Academic Left and Its Quarrel with Science.*
14 Charles B. Thaxton, Walter L. Bradley & Roger L. Olsen, *The Mystery of Life's Origin: Reassessing Current Theories*; Norman Geisler & Kerby Anderson, *Origin Science: A Proposal for the Creation-Evolution Controversy.*
15 Thaxton *et al.*, *The Mystery of Life's Origin,* p. 203.
16 Phillip E. Johnson, *Evolution as Dogma: The Establishment of Naturalism* (published under the auspices of the Foundation for Thought and Ethics).
17 American Museum of Natural History poll of 1,255 individuals conducted by Louis Harris and Associates, 1994; Eugenie C. Scott, "Anti-evolutionism, Scientific Creationism, and Physical Anthropology;" Christopher Toumey, *God's Own Scientists.*
18 Goldman, "Portrait of Religion."
19 Eugenie C. Scott, "Science and Christianity Are Compatible—with Some Compromises."
20 Douglas Futuyma, *Science on Trial.*
21 George Gaylord Simpson, *The Meaning of Evolution,* p. 345.
22 Raymond A. Eve & Francis B. Harrold, *The Creationist Movement in Modern America.*

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# THE FLIGHT FROM REASON: THE RELIGIOUS RIGHT

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FLIGHTS FROM REASON take off in our day as frequently as planes from O'Hare. The most serious and dangerous of these retreats is, however, the one represented by the current Religious Right and its drive—now fast, now slow—towards theocracy, the rule of civil society by one religion, by its creed, its code, its leaders. There are two interrelated levels of this present attack on reason. One is the denial of the authority of science on scientific subjects (or of history or social science) in the name of religious truth—for example, creation science. Here revelation replaces scientific inquiry, reshapes scientific conclusions, and overrules scientific education. In effect this is the elimination of science. The second is the denial of rational reflection in other social matters—in the areas of law, economics, politics, morals, and, of course, religion. The essence of religious fundamentalism is its claim to absolute truth. A politically aggressive fundamentalism in turn expands this claim outward from the areas of religion and personal morals (as in historic fundamentalism) to all matters in society generally—of law, economic policy, literature, art, and so on. If reason means and requires open criticism, debate, and reflection, reason here has effectively vanished. Note that the reason that is *here* threatened is more than science. Reason here is "culture creating" reason—legal, political, social, artistic, philosophical, and religious reason. And it is on *this* level of rational reflection that science as an enterprise is itself dependent. When this level is gone, science is gone.

This expansion is the essence of late twentieth-century fundamentalism—as it has been of modern political ideologies. Formerly in our century fundamentalism had been *a*political; it claimed absolute authority in religious and moral matters, but only for its own adherents. It thus has seemed in the American context to be "nice," if a bit out of date, because it was limited by the First Amendment. Now it has moved out; it sees itself as representing Middle America, "normal" America, and, as it now says, it intends to make this a "Christian nation"—in creation science, its social agenda, its identification of conservative politics and economics with real Christianity; its horrendous support of uncritical nationalism, military intransigence, unconditional private property rights; and its as-yet-implicit racism and sexism.

Without the limitation of the First Amendment, fundamentalism naturally drives towards theocracy—illustrated now, as noted, among *us*, but also evident in Islam, in radical groups in Israel and in Hindu India, and most recently in Japanese sects (note the bizarre marriage of science, advanced technology, and absolutist Buddhism in Aum). When politics becomes absolute, then its implicit religious dimension appears; when religion claims absolute validity and seeks control over all of life, there is political theocracy. In either case, reason at best serves a particular creed, code, and style of life; as a critical, constructive, and so creative factor in culture it has succumbed.

This is a much more serious matter than our many current, but merely irritating, forms of cultural antiscience. When the epistemological, metaphysical, and moral assumptions of a liberal culture are eradicated and a theocracy reigns in its place, there is no science. This has happened continually in the twentieth century, sometimes in secular ideological forms, sometimes in religious theocratic forms. The latter are now on the rise across the globe, not least here at home. In each case this union of secular or religious ideology with the political has gobbled up the rest of culture, as in Germany, Japan, Russia, and Iran, always including scientists and even conservative politicians! Modern American fundamentalism does not stand apart from American culture, as it is so apt to claim; on the contrary it has absorbed and united to itself important elements of contemporary culture—technology, nationalism, militarism, property rights, radical individual liberties. It has absolutized these conservative forms of our common life, and then added to them its own moral and religious agenda. The result, if they achieve their aim, will be a conservative Christian politics, a conservative Christian moral code, and in our schools creation science and a literal biblical history. As Duane Gish told me after a debate in 1985, "Now we have the White House, a decade from now the Republican Party."

This union of politics and religion should be no surprise. It has characterized most of human history; and we moderns are not as different from that history as we once supposed. All serious politics, including humanist democratic politics, presupposes particular views of human beings, of authentic community, and of the nature of history's course. On these assumptions depend directly the more immediate principles, policies, and actions of any political community. These grounding assumptions are articulated through the use of certain essential cultural symbols, symbols that skirt on the religious. Thus when politics becomes frantic, it makes these presuppositions absolute and so veers into absolutist religion, as fascism showed. Almost all religion in turn seeks to enact its convictions and norms in all of life, as the many creative Christian and Jewish movements of social reform have shown. If they represent a majority power, however, such unions of politics and religion become theocratic, unless they are carefully limited from within by self-criticism (the "Prophetic principle") and from without by civil patterns of tolerance and the recognition of diversity (e.g., the First Amendment). Most present forms of Judaism and Christianity—most mainline churches and synagogues—respect these limits and have fought more sturdily than many other institutions against such theocratic movements.

Apparently, modern culture—modern scientific, technological, and industrial culture—continuously produces deep anxieties: fears arising from technological developments, fears of economic insecurity, terror at a seeming abyss of relativism, despair at rootlessness and alienation, and, probably most fundamental of all, the common loss of a firm confidence in progress—progress of the individual, of family, of society generally. All this represents a deep threat, the terror—and it *is* a terror—of the loss of assured meaning, an emptiness occasionally felt even by academics. Such anxieties, if heavy enough, breed fanaticism. Our creative engines of modern progress—science, technology and industry—have also generated a host of deep dilemmas and apparently insoluble problems. And it is these dilemmas and problems that *that* side of reason—technical reason, the reason embodied in inquiry—cannot begin to answer or resolve; for it is just this progressive development of knowledge and technique that has created these dilemmas. If, therefore, a scientific culture limits reason to inquiry and technology, this whole essential, grounding basis of culture is left void—and is thus soon enough filled with horrendous demons. The irony is that a scientific culture seems to be breeding the very forms of religion that will, if they prevail, eliminate science—just as the rootless diversity of culture engenders a religion intent on eliminating diversity.

This drive towards theocracy—the growing power and authority of the Religious Right—must be resisted: by science, which slept during the creationist controversy and has ignored the larger problem of reason (and so in the end is in danger of succumbing to it); by mainline religious communities, which up to now have largely been silent, fearful of alienating conservative members. But especially it must be resisted by the managerial and propertied classes, by moderate Republicans and their political leaders—and not least by the Right's elite articulators, the conservative intellectuals. These latter have been happy to welcome this unexpected support from the Religious Right against the liberal forces both fear; and they continue to defend their absolutist colleagues as harmless and eccentric. They are apparently confident they can use rather than be used by these new allies. So were the faculties, entrepreneurs, and established politicians of the Weimar Republic! All we need now to repeat that tragedy is for the Religious Right to join forces with the National Rifle Association and the militias. A half-century ago in America, the liberal left was finally forced to admit that there was, even for them, an "enemy on the left"—namely, orthodox communism. So now the present moderate Right must recognize this danger on its own right flank, lest they too be gobbled up as quickly as will that other intellectual elite, the liberal religionists, humanists, artists, and scientists represented in this volume.

# DOUBT, CERTAINTY, FAITH, AND IDEOLOGY

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IN THE CURRENT STRUGGLE over the status of science and reason, even if one does not have a scorecard, one can tell which position a player plays merely by listening to what he or she says about the Enlightenment. The party that stands in defense of science and in opposition to irrational and antirational beliefs presents itself as being on the side of the Enlightenment. It tends to accept the Enlightenment's own characterization of itself as having achieved the benign separation between knowledge and superstition through the techniques of scientific rationalism. Unfounded traditional beliefs have been discarded in favor of the responsible investigation of things that can be observed, tested, and verified.

The party associated with fashionable relativizing theories challenges both the Enlightenment's claim to have found the way to objective knowledge and its claim to be progressive or benign. These theorists speak of the Enlightenment in terms of totalizing theories, foundationalism, and hierarchical or oppressive structures.

These two opposing groups, despite their differences, have certain things in common. In the first instance, both groups are, in varying degrees, heirs of the skeptical tradition. The emergence of scientific rationalism has been understood in terms of a kind of "mitigated skepticism," which employs techniques of skeptical doubt against certain kinds of knowledge claims and leaves the field to empiricist and experimental techniques.[1] The religious skepticism that we associate with the Enlightenment is often linked to skepticism regarding speculative philosophy—both being premised on the rejection of claims about transcendent or otherwise-unobservable reality—and this conjunction may be seen as a characteristic expression of mitigated skepticism. The anti-Enlightenment party, on the other hand, by dint of its refusal to allow Enlightenment science and reason to escape from the scourge of skeptical doubt, has been seen to hearken back to a more thoroughgoing skepticism that challenges all knowledge claims.

A second conspicuous similarity between the pro-Enlightenment and anti-Enlightenment parties is that they tend to characterize the specific epistemological stances that they favor as emancipatory. On the one side, Enlighten-

ment science and reason are seen as freeing us from religious superstition or despotism, and providing us with knowledge and autonomy. On the other side, science and reason are depicted as instruments of domination; and the skeptical undermining of Enlightenment epistemologies is associated, often only implicitly, with the potential emancipation from this domination.

Nor is this difference in the interpretation and valorization of Enlightenment epistemologies merely symptomatic of the competing theoretical positions. Rather, it might be seen as part of their etiologies. Defenders of science and reason today trace their ancestry back to the Enlightenment, while those who see our intellectual and political liberation in terms of the rejection of modernity often see the Enlightenment heritage as precisely that which must be overcome, and trace their own ancestry to the skeptical anti-Enlightenment gestures of Nietzsche, Heidegger, and their more recent acolytes.

Just as there are interesting similarities between the two opposing camps, there is, I think, at least one important respect in which both parties are wrong—namely, in the assumption that any given epistemology is either intrinsically oppressive or intrinsically liberating. I have argued elsewhere that early modern thought was permeated by "intellectual co-optation," a procedure that allowed thinkers to appropriate epistemological positions that at first glance seemed alien to their own, and also to alter the ideological valences of various epistemologies to suit their own purposes.[2] A particularly piquant example of the ideological mutability of epistemologies is that of skepticism itself. Skepticism, which today is often portrayed as an emancipatory antidote to oppressive rationalism, was often deployed as an argument for submission to secular or religious authority.[3] For example, the demonstration that fundamental tenets of Christianity cannot be philosophically defended against the powerful techniques of skepticism could be presented as a pious and humble activity. Fideists—those who held that faith, not reason or science, was the appropriate source of religious belief—could embrace skepticism by urging that the very incredibility of Christian doctrines, the ease with which they can be demolished by rational critiques, pointed up the need to abandon reason and submit ourselves to divine authority.

The very availability of a conservative justification for employing skeptical techniques against religious beliefs also meant, of course, that it would be possible to mock religious beliefs with the utmost sincerity and then insincerely appeal to fideism as a way of deflecting charges of impiety. This possibility, in turn, meant that pious appeals to fideism could arouse deep suspicion among the defenders of orthodoxy, and that one's skeptical critiques of Christian doctrines could be attacked as impious despite the fact that one looked heavenward and claimed that one's skepticism had been operating in the service of faith.

Once we recognize the difficulty of ascertaining whether skepticism was destructive or pious in a given case, we might be tempted to conclude that skepticism is unstable precisely to the extent that it can be tied both to positions that are intrinsically radical and iconoclastic and to positions, such as fideism, that are intrinsically conservative. But such a conclusion stops short of a full understanding of the ideological instability of competing justifica-

tions of belief. For fideism itself—despite the fact that it traditionally stipulates that reason and science should be ignored and that one should humbly submit to the authority of God—is also unstable, both epistemologically and ideologically, and no more inherently emancipatory or conservative than skepticism itself. Indeed, a case study that showed the actual complexity of the interplay between fideism and skepticism in the context of early modern epistemology might help to demonstrate the wrongheadedness of contemporary debates about the political implications of competing epistemologies. It is such a case study that I will be presenting here.

## II

In his *Dictionnaire historique et critique* (1697), Pierre Bayle masterfully applies skeptical techniques to various philosophical theories as well as to fundamental tenets of Christianity. His project, he assures his readers—in the best fideistic fashion—is not injurious to religion. He wishes merely to show the impotence of reason and to urge reliance on faith.

This fideistic justification did not succeed in disarming Bayle's critics; his powerful demonstration of the impotence of reason looked—both to orthodox Christian critics and to later mockers of Christianity such as Voltaire and Gibbon—for all the world like a demonstration of the impotence of Christianity when exposed to reason.

In response to his various critics, Bayle appended to the second edition of the *Dictionnaire* (1702) four "éclaircissements," or clarifications—the third of which specifically undertakes to answer charges that Bayle's apparent embrace of the rigorous skeptical position called Pyrrhonism had been injurious to religion.[4] Bayle here appeals to very orthodox Christian notions that faith is meritorious precisely to the degree to which it is different from and repugnant to reason. It is a certain and incontestable maxim Bayle tells us at the beginning of the third clarification,

> that Christianity is of a supernatural order, and that it [has to do with] God presenting us with mysteries not so that we will comprehend them, but so that we will believe them with all the humility that is owed to the Infinite Being . . .[5]

Stated thus, Bayle's maxim allows him to treat Christianity not simply as a set of beliefs that include certain mysteries, but as a separate discourse that is wholly beyond rational comprehension, and therefore wholly incommensurable with the language of philosophy. Accordingly, Bayle soon moves from this maxim to an invocation of the authority of St. Paul:

> [Christ] wanted his disciples and the wise men of this world to be so diametrically at odds that they should consider one another to be madmen; he wished that, just as his Gospel should seem madness to the philosophers, their knowledge, in turn, should seem madness to the Christians.[6]

What is most striking about Bayle's embrace of this Pauline conception of the incommensurability of faith and reason is that it valorizes faith on the ground that it requires adherence to beliefs that do not meet our ordinary criteria for knowledge and that therefore require us to abandon those criteria in favor of humble submission to divine authority:

> the moral worth of faith becomes greater to the degree that the revealed truth that is its object surpasses all the powers of our mind. . . . [W]e show ourselves to be more submissive to God and to give him stronger proof of our respect than we would if it were something only moderately difficult to believe.[7]

Faith is meritorious, in contrast to knowledge, because knowledge requires no effort, while faith is a heroic act of submission by virtue of which we believe what is otherwise unbelievable.

Bayle's invocation of St. Paul is only the beginning of a series of appeals to authority. Indeed, the third clarification is replete with citations and examples whose function is ostensibly to establish Bayle's orthodoxy. All this would appear to underscore the traditional and conservative nature of the discourse. But the examples do not always seem in tune with the principle that faith is utterly different from demonstrative knowledge.

Consider first Bayle's discussion of the English physician Sir Thomas Browne. In his *Religio Medici* (1643), Browne offers a vivid reformulation of the ancient fideistic position, complete with the invocation of Tertullian's celebrated paradox, "*Certum est quia impossibile est*" (It is certain because impossible).

In a passage that Bayle quotes immediately after quoting Browne's invocation of Tertullian, Browne congratulates himself for lacking certain knowledge of the articles of Christian belief, and for having to rely on faith:

> Some believe the better for seeing Christ's sepulchre; and when they have seen the Red Sea, doubt not of the miracle. Now contrarily, I bless myself, and am thankful that I lived not in the days of miracles . . . then had my faith been thrust upon me, nor should I enjoy that greater blessing pronounced to all that believe and saw not.[8]

Browne is alluding to Jesus' reproach to doubting Thomas in *John* (chapter 21, verse 29): "Have you believed because you have seen me? Blessed are those who have not seen and yet believe."

Thus framed between the authority of Tertullian and that of Jesus himself, Browne's fideism seems to fit nicely into the tradition that Bayle is setting forth in the third clarification.

But it needs to be observed that Browne's distinction is not between faith and reason, but between faith and direct sensory experience. His assumption seems to be that those who witnessed the historical miracles of the resurrection and the parting of the Red Sea deserve no credit for their beliefs because the beliefs require no effort of faith. Indeed, in the passage from Browne that Bayle goes on to quote (in Latin translation) Browne says, " 'Tis an easy and necessary belief, to credit what our eye and sense hath examined."[9] And in a passage that Bayle does not quote, Browne states, "to credit ordinary and visible objects is not faith but persuasion."[10] Browne thus treats beliefs that arise from normal sensory experience as outside the province of faith and as amounting to nothing more than mere "persuasion." What is even more interesting for our purposes is the possibility of reading Browne's position as implying something other than an unbridgeable gulf between faith and ordinary knowledge. For it might be possible to postulate an epistemological con-

tinuum along which the same beliefs may, by degrees, be more or less meritorious to the extent that they are farther from or closer to sensory knowledge.

Browne does not explicitly draw this implication, but it might be said that John Craige, whom Bayle had introduced in tandem with Browne and whom he discusses next, does precisely that. Craige's *Theologiae Christinae Principia Mathematica*, published in 1699, has generally been considered an almost comical oddity in the early history of probability theory.[11] But it begins with the notions about the credibility of marvelous historical events that we have encountered in our discussion of Browne. If we assume that extraordinary or miraculous events counted as knowledge to those who witnessed them, but lose their credibility progressively as time goes on, then it follows that we can say that the miraculous events associated with the origins of Christianity are less credible now than they were shortly after the events occurred, and will be even less credible in the future. What Craige did was try to express this notion in mathematical terms, by computing the degree of probability for each point in time. Once the probability of belief is quantified, then we can predict precisely when the credibility of Christianity will disappear altogether—namely, in the year 3150—and hence that the second coming of Christ will occur before that date.

At first glance, however, Bayle's inclusion of Craige in the third clarification seems to have nothing to do with the specifics of this bizarre mathematical exercise. Rather, it seems based on the fact that Craige had tried to ward off charges of impiety by appealing to the same fideistic conception of Christian belief that Bayle is invoking on his own behalf. Craige, in his preface, deems it necessary to deflect the objection that he is reducing Christian belief to mere probability. Indeed, it is only from this exculpatory preface that Bayle quotes, and at considerable length. Those who are prejudiced against his undertaking, Craige is quoted as saying,

> have not yet examined carefully enough the foundations of the religion they profess; and . . . they do not rightly understand the nature of faith, which is so much praised in Holy Scripture. For faith is nothing other than that persuasion of the mind, derived from an indeterminate probability, by which we believe certain propositions to be true. If the persuasion arises from certainty, then it is not faith that is being produced, but knowledge. Probability generates faith, but destroys knowledge; certainty, on the other hand, generates knowledge and destroys faith.[12]

In appealing to the foundations of Christianity and to Scripture, Craige, like Browne before him, is making a virtue of believing that of which he does not have certain knowledge. But the content of the dichotomy in which the meritoriousness of faith takes its place has been dramatically altered. Faith is no longer being characterized as the submission to beliefs in impossible events and concepts, in things that are repugnant to reason. Indeed, the dichotomy that previously separated absolutely incommensurable sorts of things is giving way to a kind of continuum, in which faith is understood in terms of shifting degrees of probability. In order to understand the significance of this change, we need to glance at aspects of the broader context of probabilistic thinking in the late seventeenth century.

III

We may profitably begin with John Locke, whose discussion of probability and assent in the *Essay Concerning Human Understanding* includes the following striking passage:

> any testimony, the further off it is from the original truth, the less force and proof it has. The being and existence of the thing itself is what I call the original truth. A credible man vouching his knowledge of it is a good proof; but if another, equally credible, do witness it from his report, the testimony is weaker; and a third, that attests the hearsay of a hearsay, is yet less considerable.[13]

Given Craige's general indebtedness to Locke,[14] and the specific similarity between this passage and the premise of Craige's probabilistic enterprise, one might well suppose that when Craige undertakes to compute the waning credibility of the foundational miracles of Christianity, he is giving mathematical expression to the Lockean observation just quoted. Locke, after all, unlike Browne, postulates a lengthy process whereby events lose their credibility step by step, through each new accretion of testimony. But Locke is in no way suggesting that it is meritorious to accept improbable beliefs *because* of their improbability. Far from giving us an opportunity to demonstrate our faith, the increasing weakness of second- and third- and fourth-hand testimony is adduced by Locke as a way of counteracting those who would valorize beliefs that are the products of a long tradition. Indeed the passage just quoted is followed immediately by this one:

> This I thought necessary to take notice of, because I find amongst some men the quite contrary commonly practiced, who look on opinions to gain force by growing older; and what a thousand years since would not, to a rational man contemporary with the first voucher, have appeared at all probable, is now urged as certain beyond all question, only because several have since, from him, said it one after another. Upon this ground propositions, evidently false or doubtful enough in their first beginning, come by an inverted rule of probability, to pass for authentic truths. . . .[15]

In deriding the "inverted rule of probability" that gives venerable status to beliefs whose truth, when viewed rationally, is very improbable, Locke is not addressing the subject of belief in miracles, but is evidently weighing in on the Protestant side in the long polemical battle against Catholic appeals to tradition as their special source of doctrinal and exegetical authority. Whereas Protestants could claim that the necessary truths of religion were directly available in the Bible, tradition was a pillar of Catholic epistemology. Thus Locke's cultural situation allows him to mount a rational attack on traditional beliefs based on a chain of testimony, while impelling him discreetly to ignore the fact that the same sort of critique of "the hearsay of a hearsay" could easily apply to Protestant doctrines regarding biblical miracles.[16]

Craige, on the other hand, it would seem, was willing to take the next logical step. Indeed, he was willing not only to apply to miracles the Lockean dictum about the increasing diminution of credibility as testimony becomes more and more mediated, but even to quantify the specific degrees of improb-

ability. Seen in this light, it might seem as if Craige's use of fideism is simply a way to protect himself against the consequences of his own daring.

But we need to recall that in the self-justification quoted above from Craige's preface, he not only departs from the ancient notion that the merit of faith comes from the utter incompatibility between Christian beliefs and reason, but he also departs from his own Lockean principle that faith in highly attenuated testimony has a very low probability. Faith is characterized as "that persuasion of the mind, derived from an indeterminate probability, by which we believe certain propositions to be true."[17] Both faith and knowledge are persuasions of the mind, but faith is based on probability rather than certainty. To help us see what is going on here, we might recall that Browne's fideism had included the statement that "to credit ordinary and visible objects is not faith but persuasion." For Browne, faith was something beyond persuasion and beyond probability. In his preface, by contrast, Craige seems to be invoking probability, not in order to separate the realm of faith from that of knowledge, but to place the two upon a single continuum.

This continuum links up with a significant seventeenth-century tendency to try to ground knowledge claims on probability, instead of having to aspire to the perhaps unattainable status of certainty. The extreme skeptics had used certainty as the criterion of knowledge, and had assumed that the failure to achieve certainty indicated the failure to achieve knowledge. Fideism, as we have seen, was one reaction to this skeptical tendency. The new interest in probability was another. While fideism is commonly viewed as an extreme reaction to skepticism, the early modern rise of probability is seen as an intermediate position between "fideist dogmatism on the one hand and the most corrosive skepticism on the other," an intermediate position that insisted that probable knowledge was attainable, and that "probable knowledge was indeed knowledge."[18] This intermediate position is associated with what I referred to above as "mitigated skepticism," and hence with scientific epistemology.

What we have found in our discussion of Browne, Craige, and Bayle, however, is nothing like a clear separation between skeptical and fideistic extremes, or between those extremes and an intermediate probabilism. Craige, after all, is appealing to fideistic tradition to justify his probabilism, and Bayle is appealing to Craige to justify his Pyrrhonian skepticism. In the process, the content of the ancient dichotomy in which the meritoriousness of faith was identified in opposition to worldly wisdom has been dramatically altered. Faith is no longer being characterized as the submission to beliefs in impossible events and concepts, in things that are repugnant to reason. Instead faith is characterized in terms of probability rather than impossibility, accepting the truth of testimony to remarkable events that one has not oneself witnessed. Indeed, the dichotomy that separated absolutely distinct sorts of things is giving way to a kind of continuum, in which faith is understood in terms of shifting degrees of probability.

When we think of probability as an "intermediate position" between skepticism and certainty, we tend to think of it simply as providing a pragmatic criterion of truth that allows us to get on with scientific work without being

plagued by epistemological doubts. But if we think of probability in the terms enunciated by Locke and Craige, having to do with degrees of credibility of testimonial evidence, then we can begin to see how the probability of scientific truths and the probability of miracles can fall along the same epistemological continuum. For although we are accustomed to thinking of the scientific revolution as rejecting blind faith in ancient beliefs, in favor of the fruits of our own experience and observation, we need to recall that many of the great discoveries of early modern science do not necessarily confirm what we think we have learned from ordinary experience. Rather, the results are often surprising and incredible, and the acceptance of experimental knowledge as true knowledge often depended upon the testimony of a few trustworthy witnesses to marvelous events that occurred in scientific laboratories. Hence the recent scholarly interest in the relationship between scientific marvels and miracles.[19]

According to Steven Shapin, one of the cultural factors that helped to give probable eyewitness testimony its proper epistemological weight were accounts of religious knowledge, since, according to Shapin, "much religious knowledge manifestly had a historical character." Indeed, as he goes on to observe:

> it was a central concern of Christian apologetics to warrant scriptural testimony as reliable and to show that people might as securely give their assent to it as to formally more certain types of knowledge. This meant that it had to be shown that the probable quality of properly testified matters substantially and practically overlapped with the quality of both demonstrable matters and the facts accessible to personal witness.[20]

Shapin seems to be suggesting that the new justificatory protocols of empirical science are borrowing from the older resources of religious epistemology. He presumably has in mind the sort of rationalist theology that is piously echoed by Locke, when he refers to miracles, "which, well attested, do not only find credit themselves, but give it also to other truths which need such confirmation."[21] However, in Craige's fideistic defense of probabilism and in Bayle's fideistic defense of skepticism, at least, I think we are seeing the reverse process: a fideism that is being altered through the appropriation of the role of probable testimony in the new scientific enterprise.

Bayle introduced Browne and Craige, respectively, as a physician and mathematician, and explicitly suggested that their status as men of science enhanced the force of their testimony. Their testimony, he writes, "will carry more weight because their profession does not pass for a school that teaches one to debase reason and to elevate faith."[22] This would seem to imply that the two men's status as scientists does not prevent them from being fideists. But there is a further sense in which Bayle wants to suggest that fideism is being enhanced by the scientific credentials of its adherents. In embracing their fideistic pronouncements without calling attention to the fact they mark a shift from the meritoriousness of believing the impossible to the alleged meritoriousness of believing the probable, Bayle is trying, I think, to quietly merge the new epistemological prestige of scientific probabilism with the moral prestige traditionally attributed to faith as an act of humble submission.

Bayle's conflation of the divergent poles of a fideistic tradition, in sum, allows him tacitly to uphold the moral approbation earned by opting for Christian beliefs in the face of uncertainty, while at the same time treating those beliefs as empirically justified. Thus, to accept the foundational events of Christianity is epistemologically valid because the beliefs, like the belief in scientific marvels, are, in some sense, probable; meanwhile, the acceptance of these very beliefs is morally meritorious because they are "merely" probable.

## IV

I suggested at the outset that my historical case study would have some bearing on contemporary debates regarding epistemology and ideology. Specifically, I indicated that current tendencies to link specific epistemological stances with specific political stances ran up against the historical fact that ideas can be coopted for various purposes. I further suggested that this difficulty was exacerbated by the fact that attempts to anchor one idea in the supposed ideological fixity of another ran up against the capacity of the supposedly stable idea itself to experience drift. I trust that this point has been demonstrated through our examination of fideism, a doctrine that—by dint of its appeal to the virtue of uncritical submission to authority—had at first glance appeared to be a limiting case of epistemological and ideological conservatism. If fideism can be transformed into probabilism and cloak itself in the language of scientific rationalism, then it is hard to imagine that any epistemological principle whatever can retain a fixed ideological valence.

Nor does this amenability to transformation result simply from the fact that the same theory can be put to different political uses. It also results from the fact that the "same theory" can take a different shape each time it is formulated. For theories are subject to interpretation not only by distant commentators, but also by the historical personages who embrace them.

The protean quality of fideism that we find exemplified in Bayle's deployment of it may be also found in his skepticism. I have argued elsewhere that Bayle interprets Pyrrhonism not as a denial of the possibility of certain knowledge, but as an open-ended search for truth—a search, moreover, that seems more hospitable to factual claims than to metaphysical systems.[23] The reason that someone can entertain such a distinction between metaphysical claims and claims about observable facts and nonetheless consider himself to be a rigorous skeptic is that while the evidence on either side of metaphysical questions can be shown to be equally balanced—and hence as requiring the skeptical *epochē*, or suspension of judgment—the evidence on either side of questions regarding the objects of sensory perception is not so balanced. That is to say, although the possibility that our sense perceptions may not be veridical prevents us from being certain about them, it does not follow that the reasons for doubting a given sense impression are as strong as the reasons for believing it to be probably correct.[24] This interpretation of the process of skeptical doubt, according to which skepticism takes a pragmatic and probabilistic turn, has been associated with the tradition of Academic Skepticism rather than that of Pyrrhonism. But it is entirely possible that Bayle combined the two skeptical traditions so as to empiricize and probabilize skepticism in a

manner that echoes the probabilistic treatment of fideism that I have examined above.

I am not concerned here with providing the correct interpretation of Bayle's skepticism or with assaying the relative cogency of competing versions of skepticism. I wish merely to show that the instability of epistemological theories—both with respect to their fundamental postulates and with respect to their ideological uses—makes a mockery of global generalizations to the effect that one general sort of theory is, by its very nature, an instrument of domination and that another sort is, by its very nature, a means of emancipation.

But as I have argued in my other essay in this volume and elsewhere,[25] none of this has the effect of undermining the legitimacy of ideological analysis. Indeed, the approach that I advocate gives ideological analysis a much greater scope and much more subtlety. Instead of forcing its practitioners to confirm ad infinitum an assumption about the oppressive or emancipatory tendency of theory A or theory B, ideological analysis should allow us to find surprising variations. Ideological analysis is a humanistic enterprise that, by requiring the investigations of each individual case, requires the practitioner to read texts carefully and to be attentive to nuances and idiosyncracies. Those interested in ideas and their ideological dimensions should not try to ape physics by discounting variations in order to establish general laws. For what we know in the humanities we have learned from a painstaking version of empiricism—one that focuses its energy and its care on the particular.

## NOTES

1 For the term *mitigated skepticism* and the early history of the interplay between skepticism and scientific rationalism, see Richard H. Popkin, *The History of Skepticism from Erasmus to Spinoza*.

2 Oscar Kenshur, *Dilemmas of Enlightenment: Studies in the Rhetoric and Logic of Ideology*.

3 Ibid., pp. 102–111.

4 Supposedly originated by Pyrrho of Elis (c. 360–c. 270 B.C.E.), but codified by Sextus Empiricus (in the second or third century C.E.), Pyrrhonism presented itself as a mode of inquiry that cultivated doubt by discovering equally powerful arguments on either side of every issue, but that avoided all dogmatism, including that which it attributed to the Academic Skeptics—whom it accused of dogmatically claiming that nothing could be known. See Sextus Empiricus, *Outlines of Pyrrhonism*.

5 Pierre Bayle, *Dictionnaire historique et critique*, 2nd edit., vol. 3, p. 3153. Translations from the French are my own.

6 Ibid., p. 3154.

7 Ibid., p. 3156.

8 I cite Brown's English original (p. 9). Bayle, not a reader of English, paraphrases Browne in French and quotes him in Latin translation (ibid., p. 3157).

9 Sir Thomas Browne, *Religio Medici and Other Works*, pp. 9–10.

10 Ibid., p. 9.

11 Ian Hacking, p. 72. Hacking discusses not only the aspect of Craige's probability theory that I describe here, but also an additional aspect that involves a mathematical version of Pascal's famous wager.

12 Bayle, *Dictionnaire historique et critique*, vol. 3, p. 3158. I give Nash's translation of Craige's Latin (pp. 53–54).

13 John Locke, *An Essay Concerning Human Understanding*, IV, xvi, 10.
14 For Locke's influence on Craige's *Theology*, see Richard Nash's commentary in his *John Craige's Mathematical Principles of Christian Theology*, pp. 33–45.
15 Locke, *An Essay Concerning Human Understanding*, IV, xvi, 10.
16 In his actual discussion of the topic a few paragraphs later, Locke evaluates the truth of miracles in terms of their consonance with our conception of the divine nature and purpose, and hence their capacity to "procure belief" in Christianity (IV, xvi, 13). The criterion, thus, is once again a rational one, but Locke does not concern himself with the reliability of testimony regarding the actual occurrence of miraculous events.
17 Nash, *John Craige's Mathematical Principles*, p. 54.
18 Gerd Gigerenzer *et al.*, *The Empire of Chance: How Probability Changed Science and Everyday Life*, p. 5.
19 Peter Dear, "Miracles, Experiments, and the Ordinary Course of Nature"; Lorraine Daston, "Marvelous Facts and Miraculous Evidence in Early Modern Europe"; Steven Shapin, *The Social History of Truth: Civility and Science in Seventeenth-Century England.*
20 Shapin, *The Social History of Truth: Civility and Science in Seventeenth-Century England*, p. 209.
21 Locke, *An Essay Concerning Human Understanding*, IV, xvi, 13.
22 Bayle, *Dictionnaire historique et critique*, vol. 3, p. 3157.
23 Oscar Kenshur, "Pierre Bayle and the Structures of Doubt."
24 Gisela Striker, "Sceptical Strategies."
25 Oscar Kenshur, *Dilemmas of Enlightenment: Studies in the Rhetoric and Logic of Ideology.*

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# EDUCATION

GIVEN THE OMNIPRESENCE of academic concerns in the previous sections, there might well have been a subsection entitled "Education" at the end of each. Here, however, are four contributions that deal directly with serious problems of education, to the extent that difficulties current in our schools and universities are in some measure consequent to a general decline of respect for reason and science, a decline within, as well as without, the halls of learning.

Henry Rosovsky, distinguished administrator and scholar, here subverts his own assertion that years of administrative chores have undermined his capacity to reason. Clearly, they have not, nor have they diminished his sense of humor (which is all the more remarkable). He deals briefly with a sampling of the more common reproaches to higher education: that its "science" is complicit in the devaluation of the humanities; that rationalist hubris deprives education of its spiritual content; that specialization makes a mockery of the ideal of liberal learning. He finds little merit in these claims, which come now from the left as well as the right.

For Gerald Holton there is a startling contradiction between the small part science plays in most curricula and the part it has played in the improvement of human life and hopes. This underemphasis in most programs of general education is matched, moreover, by the reticence of organized science itself in the face of its critics, a diffidence so conspicuous that the most strenuous attacks have until recently been met with equivocation or not met at all. Holton examines a number of cases where arrant antiscientism has imposed itself on what were supposed to have been science education projects. That a defense of any kind has been so slow in coming speaks volumes.

James Trefil sounds a more positive note. He has no illusions about the quality of science education today, or about the state of scientific literacy, in America. But as one of the early participants in the cultural literacy movement, he has argued effectively that the problem is not intractable. As with cultural literacy in general, standards of scientific literacy are definable, even amidst an explosion of information and disinformation. They point the way to new and more effective ways of teaching science to the great mass of non-scientists.

The final contribution is an epilogue of sorts to the prior exchange of views on Afrocentrism in the section entitled *History, Society, Politics.* Bernard Ortiz de Montellano, an anthropologist with a strong background in the physical sciences, examines one of the most widely implemented and most worrisome products of the contemporary romance with "multicultural" education. Far from *multi*cultural, however, the "science" presented in the Portland Base-

line Essays is unicultural Afrocentrist propaganda. Remarkably, it now serves as the science base for curriculum building in a number of public school systems, where its errors and distortions of fact are inevitably harmful to its supposed beneficiaries, and counterproductive for the recognition of important achievements of non-Western peoples in coming to grips with nature.

# SCIENCE, REASON, AND EDUCATION

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I ACCEPTED THE INVITATION to contribute to this conference and volume with great hesitation. My understanding of science is underdeveloped; years of administrative chores in universities have undoubtedly undermined my capacity to reason. This conference deserves philosophers, and I cannot claim membership in that exalted calling. Furthermore, I do not—in general—associate myself with the many critics of higher education who have captivated all the media as well as segments of the academy: Bloom, D'Souza, Anderson, etc. Much of what they have to say seems exaggerated and even untrue.

Nevertheless, I want to comment on certain criticisms of higher education—now quite common—that exhibit distrust and sometimes denigration of reason, objectivity, rationality, and science. These attitudes are not entirely identified with one end of the political spectrum. Right and Left as well as liberals and conservatives can be found in the group that shows some distrust of science and reason. That may make the problem more serious.

Let me begin with the common charge that higher education has devalued the humanities: this is what the critics say. In the "good old days," humanists were the most important voices in colleges and universities. They represented the eternal verities of our calling. Now, prestige and money go to science. Worse, prestige and money even go to pseudoscientists—i.e., social scientists who pretend to rigor and in reality are not much better than sellers of snake oil. (To put the matter in historical perspective, the debate of science vs. humanities raged at Cambridge University almost exactly one hundred years ago.)

In its least objectionable and mildest form, we can point to the recent writings of a most distinguished Yale scholar, Jaroslav Pelikan, who wrote:

> The university has not discharged its moral and intellectual responsibility if, in its heroic achievement of attaining the possibility of putting bread on every table, it ignores the fundamental axiom, which may be biblical in its formulation but is universal in its authority, that man does not live by bread alone. The religions of humanity all have their special versions of that axiom, and both in its teaching and research the modern secular university often ignores these at its peril.[1]

Few will wish to quarrel with these sentiments *unless* science and social science are seen primarily as "bread" and little else.

A much more problematic statement has been made by the philosopher Bruce Wilshire:

> The sciences are fractured from the humanities and exercise disproportionate influence in the university. Under the sway of thinking like Descartes's we tend to view ourselves as heads joined somehow with stomachs and groins—men without chests, calculating and inquisitive animals who no longer rejoice simply for being living parts of nature.[2]

Do these quotes illustrate a certain humanistic hubris? Does the study of science and yes, even social science, not impart values as much as the study of other subjects? "Calculating and inquisitive animals" without hearts is not a description that makes science feel appreciated or welcome.

The name of Descartes has already been mentioned, and that is not accidental. Our critics actively dislike the Enlightenment and its consequences. This philosophical movement—one thinks of Bacon, Montaigne, Descartes, Spinoza, and others—is related to the scientific revolution, skepticism (relativism?), and challenges to religious tenets (family values?). It emphasized breaking tradition and making everything subject to rationality. Figures as diverse as Foucault and Vaclav Havel, playwright and Czech President, have all—in one way or another—attacked the consequences of the Enlightenment. Havel sees industrialization and technology as the "soiling of heavens" and suggests that scientists are "playing God."[3] Concerning Foucault, Alexander Nehamas writes:

> For more than twenty years Foucault seemed dedicated to exposing the seamy underside of the Enlightenment, conceding to it no positive accomplishment and refusing any and all visions of a better future. He explicitly denied that reason can transcend time and accident and lead us out of the impasse, since reason itself was an instrument, a part of the program of the Enlightenment.[4]

There are also internal university voices echoing these sentiments. Once again, the thoughts of Bruce Wilshire are relevant.

> The last decades of the eighteenth century—the period of the enlightenment, *so called*, saw a momentous intersection of events: the founding documents of the United States were drafted, as science, secularism and individualism started to gain official status . . . when religion was separated from the official center of public life, it tends to take ethics with it.[5]

Alan Bloom is more ambivalent, though he does consider Russian communism to be a spiritual deformation caused by the Enlightenment. This is not a new attitude since Descartes has been called the father of the French Revolution and the grandfather of the Russian Revolution. Bloom says:

> Older, more traditional orders that do not encourage the free play of reason contain elements reminiscent of the nobler, philosophic interpretation of reason and helped to prevent its degradation. Those elements are connected with the piety that prevails in such orders. They convey a certain reverence for the higher, a respect for the contemplative life, understood as contemplation of God . . . and a cleaving to eternal beings that mitigates absorption in the merely pressing or current.[6]

The message that Bloom intends to convey needs no elaboration: it is clear. Is a monastery preferable to a modern university? He might have answered "yes," thereby questioning rationality as a basic premise of university life.

Are his words so different from the thoughts of the Bratslaver Rebbe (1770–1811):

> The science of Divine Knowledge is the only true science. The more one acquires of the secular sciences, the less room there is in his brain for holy studies. In the brain cells utilized by the secular sciences, gather and unite all passions and evil traits. Since understanding is the soul, he who devotes his understanding solely to holy subjects sanctifies his soul.[7]

Whatever happened to progress?

As we all know, many of our critics consider research universities as examples of most of what is wrong with higher education. Colleges, especially when they can be described as a few Mr. Chipses surrounded by adoring students in a rural setting, are normally treated more kindly. "Small is beautiful," country is better than city, technology equals pollution—is there a pattern?

There is one aspect of these attitudes that poses a particular danger to the flourishing of science—or so it seems to me. Research universities are the fountainhead of specialization and its natural consequence: academic departments. These are seen as evil influences.

What is bothering the opponents of specialization? Two things. First, their conviction that great truths are to be learned from interdisciplinary studies and that the structure of research universities is an obstacle to the discovery of these truths. Second, they fear the influence of "excessive fragmentation" on undergraduate education.

Is specialization not an inevitable aspect of progress and greater productivity? Adam Smith's lesson in *An Inquiry into the Nature and Causes of the Wealth of Nations* (1776) surely applies beyond pin factories. "Excessive fragmentation" is a pejorative term. Obviously excessive is bad. Anything excessive is bad. The challenge is not how to get rid of specialization but how to take advantage of it. *A specialized faculty is not the same thing as a specialized undergraduate curriculum.* It is even possible to use specialized knowledge to further the cause of general education.

Let us also keep in mind the key role of departments in setting professional standards within the university. This is where interdisciplinary units have the smallest comparative advantage. Who can best determine the quality of a physicist, an economist, or a professor of French literature? Members of other fields? Students? Presidents and deans? Of course, some of these individuals will have review responsibilities, and the opinion of outsiders is also important and desirable. However, I do not know of any group of individuals that is better qualified to make the initial selection than members of a disciplinary department. This applies even to scholars with interdisciplinary orientations because that description does not imply "without discipline"; instead it means the use of two or more disciplines. In other words, the judgment of disciplinary specialists remains necessary.

## NOTES

1 Jaroslav Pelikan, *The Idea of the University: A Reexamination*, p. 18.
2 Bruce Wilshire, *The Moral Collapse of the University: Professionalism, Purity, and Alienation*, p. 40.
3 On Havel, see Jan Vladislav, ed., *Vaclav Havel or Living in Truth*, ch. 4. In some ways, President Havel longs for the world before the Industrial Revolution.
4 Alexander Nehamas, "Subject and Abject: The Examined Life of Michel Foucault," p. 32.
5 Wilshire, *Moral Collapse of the University*, p. 47; italics added.
6 Alan Bloom, *The Closing of the American Mind*, p. 251.
7 See Louis I. Newman, *The Hassidic Anthology*, p. 316.

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# SCIENTIFIC LITERACY

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THIS PAPER is about the concept of scientific literacy, and there is one point I want to make right from the start. I am *not* talking about the education of scientists, or the idea that everyone ought to be, in some sense, a scientist. Too often, when scientists start to talk about scientific education, they skip the ninety-nine percent of the population that is not going to be trained in a technical career, and zero in on the one percent that are. The ability to calculate the trajectory of an artillery shell or to estimate the heat flow through a block of solid material are not things that I would include under the phrase "scientific literacy." They are skills that a certain group of working scientists will need to have at their disposal, but they are not part of the scientific knowledge that the average citizen needs to function in the world today.

I want to define scientific literacy, then, in a much more general sense. I will say that a person is scientifically literate if he or she has enough of a background in science to deal with the scientific component of issues that confront him or her daily. You have only to pick up a newspaper and look at the headlines to realize that there are very few aspects of the national debate that deal with science alone. Almost every issue that the citizen confronts deals with science in a much broader context. Thus, when we talk about global warming, we are talking about a scientific issue (has global warming begun? is it due to anthropogenic sources?), but it involves much more; it involves social issues (does the developed world have the right to tell developing countries not to cut down their forests?), economic issues (are we really ready to shut down our economy to save the Kirtland's warbler?). Thus, when the average person confronts social issues, he or she needs to know about a good number of subjects—economics, politics, social policy, . . . *and science.*

I will argue in this paper that what the average person needs to know about science is, in fact, very different from what is normally taught both at the high school and college level, and that, therefore, if we wish to have a scientifically literate population, we are not only going to have to teach more science, we are going to have to teach it differently than we do now. In fact, I would argue that we can probably get to the goal we want without increasing the actual

time that people spend learning about science, if we would only teach it in a different way.

I want to avoid preaching to the choir, so I will not spend a great deal of time trying to justify why we want a scientifically literate citizenry in this country. Instead, I will use this paper to discuss a series of increasingly focused topics. Scientific literacy is actually a subset of a much more general topic called "cultural literacy." Once I have established this broad framework, I will focus further and discuss a particular realization of a scheme for teaching scientific literacy.

## CULTURAL LITERACY

In any society, at any time, people make assumptions about what other people already know. No communication begins *ab initio*—every communication takes place in a social context. For example, if you pick up the newspaper on any given day, you may find a reference to something that happened at the United States Senate. The author of that article does not go on to explain what the United States Senate is: he does not say, for example, "the United States Senate is one arm of the legislative branch of the United States federal government. . . ." The author simply assumes that you know what the United States Senate is and then proceeds on that assumption.

This is an example of cultural literacy. Cultural literacy can be defined as that body of knowledge that educated people, in a given society, at a given time, assume that other educated possess. If I assume you know something, I am not going to tell you about it. If I do not tell you about it and you do not know, you are out of luck—you are just not going to understand what I am talking about. This is what cultural literacy is all about. In the United States, in 1995, it is possible to define what this body of knowledge we call cultural literacy is. Indeed, those who make a living by communicating with the public—magazine editors, for example—have a very clear idea in their mind of what kind of terms and concepts can and cannot be introduced to their readership without explanation.

Let me show you some examples of cultural literacy in action using cartoons from *The New Yorker* magazine. I will confess that when I get my copy of *The New Yorker*, the first thing I look at is the cartoons. I will also confess that if someone tells me that they look at something else first, I greet that statement with a certain level of skepticism.

One cartoon that I would like to refer to shows a woman and her husband standing in front of a closet. The wife is saying "I sent your favorite sweater out to be cleaned and carbon dated."

Now this is, on the one hand, a rather typical example of the gentle *New Yorker* humor. But think for a minute about what the author of that cartoon assumed that you knew. He assumed that you knew there was such a thing as carbon dating, and that it is used to date very old objects. He did not, however, assume that you knew the half life of carbon 14, or, indeed, that you knew there was such a thing as carbon 14 in the first place. In other words, the kind of knowledge that the cartoonist assumed was very general.

Here is another cartoon example. A young man is on his knees, obviously

proposing marriage. He says, "Marry me, Virginia. My genes are excellent and as yet unpatented."

This is what I call a double whammy. The author is assuming that you know there is something called a gene, that the gene has something to do with inheritance and children, and would therefore be something that might be appropriate to discuss in the context of a marriage proposal. The author also assumes that you are aware that there is a continuing set of skirmishes in the court over the legal status of genetic information. What both of these cartoons illustrate is that any kind of communication—even something as trivial as a cartoon—assumes a certain amount of background knowledge in the readership. Without that background, you just cannot understand what is being said.

In fact, there is a large body of psychological research that bolsters the notion that if you have a lot of information about a particular subject, it is easier for you to assimilate new information. I like to picture cultural literacy as a large matrix of knowledge. The idea is that if a particular area of the matrix is well filled in and richly articulated, it is much easier for you to add new things to that part of the matrix—having a lot there makes it easier to fit new things in.

Let me give you one example of some of the psychological research that bears this out. There was a study done a number of years ago at the University of Illinois in which a group of graduate students was selected. Half of these students were Americans, and half were Indian. Each of the students was given a written description of a wedding, and then tested for reading speed and comprehension.

Half the American students, for example, were given descriptions of American weddings, the other half descriptions of Indian weddings. The results of the tests should surprise no one. The American students read the texts on the American weddings quickly and understood them. They did not do so well with the description of the Indian wedding. The exact opposite, of course, happened with the Indian students.

Another story, concerning the genesis of the idea of cultural literacy, illustrates the role of preexisting knowledge. Don Hirsch was doing research based on a hypothesis he had about the importance of what is generally called "good English." His idea was that these rules make communication easier and more efficient. He tested this hypothesis by taking a particular text that was written in good English, giving it to students to read, and testing them on speed and comprehension. He would then compare those results to those of another group who had read texts that had the same information, but was written in bad English. The tests were going along pretty much as expected, with the students being able to read the well-written texts and comprehend them more easily than the poorly written texts. When he went to Sargent Community College in Richmond, Virginia, however, he was absolutely astonished to find that it made no difference to these students how the texts were written—they had trouble understanding both the well-written text and the poorly written one. Concerned with this anomalous data point, Don went back to Richmond and started interviewing the students. The texts the students had been given had something to do with Jefferson Davis, and what Don found was that these stu-

dents, growing up in the capital of the old Confederacy, had no idea who Jefferson Davis was. (I am sure you do not need to be reminded, but Jefferson Davis was president of the Confederate states.) In other words, what he found was that the students who did not have the background knowledge required to read the text were unable to do so very well. This was the genesis of the idea of cultural literacy.

So the picture that comes out of this theory is that everyone carries around in his or her mind a matrix of information and knowledge, and that matrix plays a very active part in communication. Whether or not you will understand something depends on whether or not you already know something about the subject.

In fact, as an old-line physics professor, I am incapable of giving a fifty minute lecture without doing a demonstration, so I am going to do a lecture-demonstration of cultural literacy. Consider the following text:

> The procedure is actually quite simple. First you arrange the items in different groups. Of course, one pile may be sufficient depending on how much there is to do. If you have to go somewhere else due to lack of facilities, that is the next step. Otherwise you are pretty well set. . . .

Now if you are like most people when you read this text, you get the sense of slipperiness, of sliding around. You have no idea as to what the writer is talking about.

Now let me give you the matrix of information you need to interpret the text. Imagine a title above that text that says "Doing the Laundry." Now, it all makes sense. That little moment of "a-ha!" that you just experienced is the best proof I could give you of the importance of cultural literacy.

I would argue that no one should be allowed to leave our educational system until their matrix of cultural literacy has been filled in. Of course, at the university level we expect people to do much more than possess a body of information. We expect them to be able to deal with abstractions, to communicate effectively, and so on. Nevertheless, cultural literacy represents the ground work, the basis, the floor beneath which no one should be allowed to fall. Now having made this statement, let me now go on to make several comments that I believe will anticipate some of the questions that normally are raised.

First of all, one of the criticisms that is often leveled at this particular approach is that in some way it represents the attempt by a high-class intellectual elite to impose its standards on the rest of society. In an academic climate in which a very high premium is placed on identifying new victims, this is an important point that has to be dealt with. I like to make my point by recalling an incident that was reported in the *Chicago Tribune* a number of years ago. It concerned one of the interminable battles going on in the city council. (I do not remember the details, and I am sure you have no desire to learn them.) At the end of the debate, the newspaper printed the following quotation: "'This was a gathering of Neanderthals, without any idea that Cro-Magnon may have existed.' said Alderman Timothy Evans, Fourth Ward Democrat."

The point of this quotation is that Alderman Evans not only thought that

the reporter to whom he was speaking would know what Neanderthals and Cro-Magnon were, but that the people who would be reading it—the people who voted for Alderman Evans—would understand these terms as well. It is a clear judgment on his part about the level of cultural literacy among his constituents.

Now let me be clear about this. I was born in Chicago, I grew up there, and I love the city. It is my favorite place in the world, and I go there as often as I can. But a Chicago Alderman is not a member of a high-class intellectual elite!

In fact, I would argue that in a culture as diverse as that of the United States, the fact that we need to communicate with each other drives us to the point of understanding cultural literacy. If it did not exist, we would have to invent it.

The second issue I would like to bring up is that the matrix of knowledge I have been talking about is not a collection of "just facts." In fact, when you look at realizations of the concept—the kind of thing I will talk about later with reference to scientific literacy—you will find that it is a mixture of terms, concepts, philosophy, history, literary allusions, and so on, and that all of these items are multiply connected by various threads. It is a very dynamic intellectual architecture, about as far from a list as you can possibly get.

Finally, we have to acknowledge that cultural literacy does change, both from one culture to another, and within one culture over time. In fact, we now have some base-line information on this. In the five years between the publication of the first two editions of *The Dictionary of Cultural Literacy*, the "to and fro" of terms in the dictionary changed at the rate of about one percent a year. This is the same rate of change as the words in a dictionary of standard English words itself. Consequently, although it is true that cultural literacy changes over time, it does not do so at a rate that is any less manageable than that of the language itself. We know how to deal with changes in the language, and I submit that we can use the same techniques to deal with the changes in cultural literacy.

## SCIENTIFIC LITERACY

There are three important questions one can ask about scientific literacy: (1) What is it? (2) What is it for? (3) How do we get it?

Scientific literacy consists of a potpourri of facts, concepts, history, philosophy, and ideas, all connected to each other by strands of logic. The scientifically literate person knows some of the basic facts about the way the universe operates, and has some sense as to how scientists came to that knowledge. The scientifically literate person can deal with those aspects of science and technology that come across his or her horizon as easily as he or she deals with aspects of economics, law, or government.

Notice that I have not included in this definition of scientific literacy the ability to *do* science. When I go to hear a concert, I do not expect to be stopped in the vestibule and asked to display virtuosity on the violin before being allowed into the auditorium. I would suggest that no one should be asked to demonstrate that they can do science as the price of entry into scientific literacy.

In fact, when students encounter science in their daily lives, it is never in

the context of "doing." For example, here are a series of headlines I took from a randomly chosen issue of the *Washington Post*.

NURTURING JOBS IN A LAND OF OLD GROWTH FORESTS

ASSESSING THE RISK IN CONTRACT'S "COST-BENEFIT" CURB ON (ENVIRONMENTAL) REGULATIONS

TOXIC SOUTH AFRICAN ARMS RAISE CONCERN

Each of these stories involves science and something else. For example, the story on old growth forests was primarily about the economic impact of environmental regulations on lumbering towns in the Pacific northwest, but required some understanding of notions of ecology and of the Endangered Species Act. Similar comments could be made for all the other headlines. In other words, science presents itself to the average person in the context of a problem or issue, and without the kind of academic boundaries that come as second nature to people in universities.

What that means is that when we talk about preparing people to meet the challenge of the future, we cannot talk in terms of university departments. Nature itself is seamless, and university organizations fail to reflect this fact only because they grew up before the underlying unity could be seen. So if science has come that way, why should science education not come that way as well? This, in a sense, is my approach to scientific literacy. It must deal with nature as it exists and must deal with nature as it is presented to the average citizen.

Let me give you an analogy. I think of the universe as being like a large spiderweb. Around the edge of the web are all physical phenomena—supernovae, beetles, radio transmissions, trees. If you look at any part of that web and start asking questions—"what is this?" "how does it work?" "why is it the way that it is?"—you begin to work your way toward the center. If you keep asking questions, eventually you come to the center of the web, where you find a small number of general overriding principles. These principles are either shared among all the sciences or serve as the guiding principles and provide coherence to the large subset of the physical world. The law of conservation of energy, for example, would be found at the center of the web; and all scientists, no matter what they are working on, are familiar with the concept of energy and use it to some degree in their work.

The important point about the ideas in the center is not so much to produce a list, but simply the fact that they exist. They tell us that science is organized in a hierarchical way, with phenomena leading back to what I would call great ideas. You may call them great ideas, laws of nature, or any other name you wish. The point is that there are a relatively small number of them.

And that, in turn, gives us a way of getting at education in scientific literacy. The internal structures of the sciences themselves give us an internal framework on which we can hang educational efforts in the discipline. Furthermore, someone who understands these ideas is very likely to be scientifically literate.

Here is my list of the central ideas of science in (more or less) rank order:

1. Causality/order
2. Energy/entropy
3. Electricity/magnetism
4. The atom
5. Chemical bonds/reactions
6. Natural selection/evolution
7. Cellular/biochemistry
8. Genetic code/molecular medicine
9. Plate tectonics
10. Big bang
11. Stars and galaxies
12. Mendelian genetics
13. Properties of materials
14. Earth cycles
15. Ecosystems
16. Relativity
17. Quantum mechanics

## CONCLUSION AND VIEW TOWARD THE FUTURE

In the end, then, what we want is a citizenry who has a sense of how the world works. I am not so interested in a student knowing the details of the structure of a particular set of minerals as I am in that student having a view of how the earth works. To be perfectly frank, this view could be represented by a little television snippet showing the mantel connection, the motion of plates, and the constant change of the earth's surface. In the same way, I am not so interested in the student being able to name various kinds of organic chemicals living in different cells as I am in the student having a picture of how a living cell works—of materials being brought in across cell boundaries, of information on DNA being transcribed and being turned into proteins, which in turn drive chemical reactions, and so on. What I am trying to avoid are situations like the one I encountered recently in which I was told by a student at the beginning of a class that she was against genetic engineering of foods because she did not want to eat genes. At the end of the course, that student may have decided she still did not like genetically engineered foods, but she would be aware that everything she ate had a lot of genes in it. This, to me, is the goal of education and scientific literacy—to give people enough information so that they can make their own, rational decisions about how they are going to run their lives.

I would like to conclude with what I see as the prospects for enhancing scientific literacy. My views on this issue arise largely from my experience in developing a course to teach scientific literacy and writing a textbook along with my colleague Bob Hazen. As part of this project, I have had the opportunity to visit many universities and address many professional meetings on the subject of scientific literacy.

I have found that there are few universities and colleges in the land that

are not thinking about changing the way they teach science to nonscientists. In fact, I know of well over a hundred institutions that have adopted our textbook since it came out a couple of months ago, and I take this as an index of the interest in this general area. Things seem to be moving, and this development should be encouraged.

Let me close by commenting on a somewhat unexpected pattern I see emerging at American universities. I see a tremendous amount of change in places that are not generally regarded as flagship institutions. I would not be surprised if in ten years' time, students coming out of places like East Texas State University and St. Petersburg Junior College are going to be much more scientifically literate than students coming out of Ivy League schools. As a guy who grew up on the wrong side of the tracks in Chicago, I must say that I find this to be a delightful prospect.

# SCIENCE EDUCATION AND THE SENSE OF SELF

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*Is it self-serving to advocate support for science? Perhaps. But if the "self" is the American people and the position of leadership of the U.S. in all fields of science and technology in the 21st century, then I wouldn't worry too much about appearing self-serving. [Yet] one thing that has been striking . . . is the perceived stony silence of the science and technology community.*

—NEAL F. LANE

IF HISTORIANS of the future will look back on the history of the United States, they will find two curious paradoxes.

On the one hand, many of the contributions to science and engineering in the United States in the twentieth century will be counted among the major intellectual achievements. In addition, this better understanding of how the world works has led to remarkable increases in industrial productivity in the human life span, in agricultural yields, and so forth. Science and engineering will also be seen as major factors in World War II in beating back enemies sworn to bring down Western civilization itself.

Of course, more needs to be done, and all too often the human race has either failed to avail itself of useful knowledge or, ever since the invention of fire, has found ways to abuse it. I know of no intellectual who would dispute this, or who adheres to the flagrant scientism that now exists mostly in fiction and in the rhetoric of critics. But precisely within the awareness of their limits, the sciences have achieved the moral authority to be considered among the central components of the twentieth-century world view, on a par with the other major motivating cultural forces, such as the arts, and what William Faulkner called the universal truths, those of "love and honor and pity and pride and compassion and sacrifice."

From this perspective, given the essential place of the scientific view, our hypothetical future scholars might reasonably expect that science education in the schools and colleges of our day will have been of the same high quality as the sciences themselves, and that the relation between science and society was rendered in a sound and balanced way by the usual purveyors of such information, our scholarly societies, academies, museums, and so forth.

But it is just at this point that those future historians will be startled to discover how wrong these reasonable expectations are. That is the first paradox. I need not spell out the details. We are all heartsick about the data, such as the fact that all but the most elementary rudiments of science, mathematics, and engineering have been squeezed out of the curriculum for the majority of college students. In some of our most prestigious colleges, a total of only two out of thirty-two one-semester courses are required in science and math—about six percent of the educational experience. And those courses usually have to build on the extremely tenuous foundation, if any, laid previously in high school. And into this void flow negative and bizarre views of science and technology, from courses these students take outside science and from the general culture.

This failure is traceable in large part to negligent acquiescence by scholars, intellectuals, teachers, administrators, and above all, by the scientists themselves. That in turn would not have even been thinkable if it were not for a profound displacement that has occurred in the position of science in our culture, at this so-called end of the modern era. On this point, I agree with the thoughtful analysis by Sir Isaiah Berlin, in his book entitled *The Crooked Timber of Humanity: Chapters in the History of Ideas.* He documents that many of the fundamental notions that the world view of the West developed since the Enlightenment are being challenged in our time, as in various periods in the past, by the rise of a worldwide movement that has the technical name "the Romantic Rebellion." As he says, no one predicted that the current form of this rebellion would be what dominates "the last third of the twentieth century."[1]

The timidity and ineffectiveness, at least until very recently, of most scientists and their scientific societies to counter what amounts to an attack on their very legitimacy are easy to document. I think it is wrong to decry the attacks themselves. They are part of an evolutionary mechanism by which cultures are formed. But the feebleness of the attempts to understand the attacks, and to oppose them—that constitutes the second paradox.

Here I want to illustrate the challenge to the legitimacy of science that has been appearing within the science education movement itself—that is, not in books by individual gurus or on the crazy corner of the Internet, but right in the publications and activities of teams of intelligent, well-educated and, on the whole, well-intentioned persons charged with the business of education. It is exactly such products that are most revealing of the role science is thought to play in American cultural life today.

The first document is a draft of the *National Science Education Standards* for grades K–12. This project started with excellent intentions and under the best possible patronage. The National Research Council of the National Academy of Sciences was commissioned to draft such standards in 1991 by a group including the United States Secretary of Education, the National Science Teachers Association, the National Science Foundation—all this in the wake of the 1989 declaration of the nation's fifty governors, who announced that internationally competitive national standards of excellence for the schools of America were important national goals. As is usual in such projects,

a complex set of advisory committees and other outreaches was arranged to assure that the standards will not only improve the study of science in schools, but also will represent the consensus of teachers and other science educators, scientists, and the general public. The list of members of advisory committees, national committees, working groups, and professional organizations involved during the first two years takes eight pages, as given in the first draft, released in November 1992. It includes the names of some of our best scientists.

But as these things are done, they did not write the report, and the result surprised some of them. For example, the version of the report released in November 1992 to selected commentators announced at the outset that the intellectual foundations of school science education and the national science education standards would not be merely the science disciplines, but also the philosophy, history, and sociology of science. In my own role as science educator, I have always tried to infuse science teaching with just such elements, so I was delighted to read this. But at that point in the document, there was a footnote directing the reader to an appendix that would set forth the "contemporary views of the philosophy of science." That appendix—written, according to one staff member, by two philosophers who had been hired for the purpose—is a confused farrago that includes the following flat statements: "Two competing paradigms of science have been the focus of disagreement among historians, philosophers, and sociologists. The older, referred to as logical positivism, is characterized by arguments for the objectivity of scientific observation and the truth of scientific knowledge." Parenthetically, I should insert that at that point I seemed to hear howls of laughter from the graves of the logical positivists about this confused summary of their intentions.

But to continue to the next sentence in the draft: "A more contemporary approach, often called postmodernism, questions the objectivity of observation and the truth of scientific knowledge." And after the admonition that science is "the mental representation constructed by the individual," this section on philosophy closed with the flat statement: "The National Science Education Standards are based on the postmodernist view of the nature of science."

The constructivist point of view had found its way into the educational standards being prepared under such high auspices. Of course, this 1992 draft caused some consternation among members of the national committee when they read it, at least two of whom, I am told, resigned. So the groups involved in the writing were sent back to the drawing board, and 18 months later, in May 1994, there was released for comment a second draft of the National Science Education Standards, from the same agency.

I received a copy and read it with care, because the adoption of national standards can have the biggest effect on the nation's precollege education since the founding of public schools. And in fact the May 1994 document had some promising features—for example, in the defense of evolution in biology, and in the pedagogic use of the history of science, where appropriate. But while the explicit section of 1992 on philosophy was now absent, its disappearance was merely strategic. The same social constructivist view, sometimes subtly and sometimes blatantly, shaped the document from one end to

the other. The pages were practically soaked in phrases centering on the word "constructing"—five times on some pages—from the introduction, which announced the "principle" that "in science, students ask questions [and] construct explanations," to the final pages where we find the admonition that "college science courses [too] should engage students in . . . constructing personal meaning."

Nowhere appeared a statement that scientists seek to find regularities in nature, or to discover and explain new phenomena or laws, or to reach shareable and testable insights about the lawfulness and order of the natural world. By these proposed standards, Marie Curie did not discover radium, she "constructed" it. Doing science is considered there on a par with constructing technical artifacts or social policies. From this extremist point of view, intended for the indoctrination of generations of students, the document elaborated some consequences. For example, nowhere is the student encouraged to consult as sources of information other, "external" resources such as books (not a single science book is named), atlases, science museums, planetaria, or science television programs. Nor is the teacher considered to be a resource person who already knows facts and who will provide them at the appropriate moment. The students supposedly must live in a closed, solipsistic universe. In companionship with one another, these youngsters will have to construct whatever knowledge about science they will get. As a result, one of the early examples given showed it might take days or weeks for a class to construct the concept of density.

One way of understanding what happened to the draft standards was that the "inquiry" method of learning and teaching—a current favorite among teachers, particularly in the lower grades—had been hijacked and carried to extremes. The inquiry style itself, while necessarily far from really "doing science," has much to recommend it for precollege schools (as did its now-defunct series of predecessors, such as case studies, "discovery," etc.). It also seems to make young students feel good about science learning. But that does not mean that inquiry must be limited to the mental "construction" by the learner, or that scientific research as such should be presented by that model. Also, the teacher should not fail to challenge students to perform at the highest level each can achieve. I believe the word "excellence" was mentioned only once in passing in the draft. Nowhere did I see an attempt to get teachers actively to discover and nurture any extra or exceptional ability, the kind that might make it more likely to produce a future scientist of special ability. Nor do the standards suggest that teachers should get more adequate training in science than most of them do now.

The philosophy underlying this version of course forbids using such phrases as the progress of science or the evolution of scientific ideas. The main engine of change in science presented there lay largely in changes in commitment. "Changes in commitments . . . forge change commonly referred to as advances in science." Thus scientific advances are only tautological concepts, because anything scientists make a commitment to is by definition an advance. What counts is not the discovery of some new aspect of nature, but the sociological and psychological interaction of the scientists. This view is

part of the famous, banalized picture of scientific work as the jump from one paradigm to another as a result of changes of commitment in the social group, rather than advance through the enlargement of the range of applicability of older conceptions, or the simplifications of theories, or the breakdown of old barriers between fields.

Happily, this is not the end of the road for these National Standards for Science Education. The final draft will be quite different, and acceptable to scientists and students, teachers and parents, as it surely must be, if the standards are to be effective. But it is important to see how long it took for scientists to wake up to what was happening, and to go into action. At a meeting that brought together some scientists to look over the 1994 draft I have just discussed, a few of them finally made clear how unacceptable this version was. *Science* magazine (December 9, 1994) went so far as to say that one of the physicists there confessed that he "went ballistic" after reading the version. Others there also objected strongly to the bizarre flaws. With Bruce Alberts, the new president of the National Academy of Sciences, taking particular interest in education and science, a much better outcome could be expected, and a much improved version was put into circulation for final comment and release in December 1995. If there is a flight from reason and science to extremism, of which the early stages of this episode were to a certain extent an illustration, what is required most of all is simply that some scientists and their organizations begin to pay attention to how the process of the delegitimation of science operates, and to defend themselves.

There is a faint analogy here with a lesson from the Gray board hearings in the matter of Robert Oppenheimer. In that case, it was Oppenheimer himself who was so strangely ineffective when his integrity was attacked. He seemed to acquiesce in his own destruction. But it is important to recall how Oppenheimer explained his inaction later. He said: During the hearings, "I had very little sense of self." His friend David Lilienthal, when also brow-beaten during his testimony on behalf of Oppenheimer, saw the rigged hearing procedure for what it was, and commented: "When I saw what they were doing to Oppenheimer, I was ready to throw chairs."[2] Oppenheimer himself, the architect of enormous weapons, was not a man to throw chairs.

I too do not advise throwing furniture. The point I am making by this useful analogy is that the scientific community, and its organizations, will have to learn quickly that one's moral authority depends on having a good "sense of self," and to act in its self-defense when attacked.

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I could illustrate in detail a similar distortion of the place given to science and education in the culture of the United States today in another quasiofficial document that is intended to have a profound effect on schooling. That document is the recently released *National Standards for United States History* for grades 5–12, subtitled *Exploring the American Experience.* It, too, has distinguished official patronage, in this case principally by the National Endowment for the Humanities and the Department of Education, and has benefited from the labors of "hundreds of classroom teachers of history [and] dozens

of talented and active academic historians in the nation," plus many professional and scholarly organizations. And this document, too, has been in the news, attacked and defended for various reasons. But little has been said about the role given to science and technology in the current draft, which is to guide how history is taught to each youngster during eight years of schooling. Again, the intentions were honorable, the labors onerous, but the results provide a window on the perplexed soul of our culture, and reveal the same animus of which I spoke earlier.

For you would expect to find that science, technology, and medicine would play a major role in the account these standards should urge for the study of our history, just as these fields have in fact played a major role in our history itself, especially so during the past one-and-a-half centuries. But the set of interlocking standards and examples in the published history standards refers to such topics only very infrequently, briefly, and anemically.

What is lacking, first of all, is any sense that science and technology in the United States, certainly since World War II, are in most fields culturally and intellectually strongest compared with the rest of the advanced nations. The *existence* in the United States of the development of this world-class science and technology, achieved in this century by the work of millions, is a historic fact of real importance—quite apart from and in addition to the *effects* on society. (A similar but less severe case can be made against the treatment of the arts, to which that document pays attention in a quite slanted and narrowly selective way.)

The most responsible attempt in the history standards document appears on the page before the very end: "Students should be able to demonstrate understanding of the modern American economy by . . . evaluating the importance of scientific and technological change on the workplace and productivity." A few examples of students' achievements intended to meet such standards are given on that page. But apart from appearing very late in the curriculum, the examples are entirely preoccupied with the "effects of" or "impacts of" technologies, rather than establishing first their existence and how they came into our history in the first place. As one observer noted: "Science is [here] implicitly viewed as something which has descended from elsewhere. . . . Technology, too, is treated as an external body which 'impacts' upon society. . . . An entire standard devoted to 'the second industrial revolution' is concerned solely with how it 'changed the nature and conditions of work,' for example in the employment of children." And he adds, "The proposed standards represent the current thought of a cross section of leaders in American primary and secondary education in academic history. Evidently if students are to learn what society has done in the past to nurture science, how science has affected the development of technology, and where scientific thought had stood within American culture, in the future as in the past, they should not look to the typical high school history course."[3]

A glance through the published volume shows how uncomfortably true this critique is. Thus an example of student activity is to "examine the influence of MTV on popular culture," with a special question posed: "How does Madonna symbolize the popular culture created by MTV?" Madonna and MTV

appear to be important; but how did TV itself come to be? And what about the telegraph, the telephone, radio, video, the laser, and the transistor, all surely known to students, and whose economic impacts have been vast? Would it not be well to put a little of the story of their American sources into the Standards for United States History, the more so as we are now in the Information Age?

The producers of these history standards have explained that they do not want to make lists of people, since this may be the job of the ultimate producers of curricula based on these standards. Yet one wonders whether it would have handicapped curriculum designers if Samuel Morse, Alexander Graham Bell, Thomas Edison, and others like them had at least been mentioned (not to speak of Benjamin Franklin, the Newton of electricity).

I inquired from some of my colleagues what they would like to see in such a set of national standards for United States history, and I was flooded by suggestions: electric lighting; a whole slew of chemical inventions—and particularly synthetic rubber, without which the United States, cut off from natural rubber in World War II, could hardly have entered the war successfully; something might be said about the finding and refining of petroleum, on which the development of the automobile depended; the invention and application of digital computers; the major immunizing interventions such as the Salk and Sabine contributions to the conquest of polio; before that, the discovery of penicillin by Fleming, and the age of antibiotic therapy that followed; the role of smallpox in history and the elimination of that scourge; similarly the conquest of diseases transmitted by contaminated drinking water. How about the Wright brothers' experiments and designs? Is it possible to have aircraft missing from the history of the United States?

Under these standards, students should be able to "demonstrate understanding of World War II and how the Allies prevailed."[4] Good. But radar is missing, which really helped win the war. And from grade 7 to grade 12, students are invited to examine the "decision to use atomic weapons during World War II." But there is again nothing here about why it was thought necessary to build such weapons in the first place. And that is more than ever an important part of the story, one that must not be neglected.

During this century, an increasing understanding of genetics has resulted in major advances in biology, medicine, and agriculture. One may leave to the *science* standards the description of the Watson-Crick model. But the fact of the *discovery* of the structure of DNA itself in 1953 was a world-historic event. Might it not merit one line of print in the history standards? Last but not least, students should know not only about the history of racism and Social Darwinism in the 19th century, to which a good deal of space is given in these standards, but also of its refutation by anthropological and related sciences in this century. This would be a good place to show that the efforts of scientists have helped to change and expand the concept of human rights in modern times.

All these examples of gaps indicate that they were not accidental. They stem from a particular contemporary vision of what counts in history, and that science and technology are low indeed on that agenda. The predictable

reply to such suggestions will be that the document is already too long, and that nothing could be squeezed out to make room. To which I would gladly respond, "Just let me try." In fact, a few scientists have asked the History Standards writers to reconsider the omissions—again in the spirit of correcting a false image of our culture.

I will briefly mention a third example where an enterprise with national scope, distinguished patronage, and years of labor resulted in a severely flawed educational presentation of science and technology in our time. This is of course the exhibit "Science in American Life," now showing as a permanent installation at the National Museum of American History of the Smithsonian Institution in Washington (not to be confused with the plans for the Enola Gay exhibition at the National Air and Space Museum). There has been a great deal of public commentary, pro and con. As *Science* magazine put it (5 August 1994), after the commissioning of this exhibit by the American Chemical Society at the cost of $5.3 million, there ensued a "five-year battle between an advisory committee appointed by the ACS and curators at the Smithsonian's Museum of American History. At the heart of the battle was the portrayal of science." As one of the historians associated with the project in the early stages reported, "the chemists came in for a rude shock." "They wanted something like the Du Pont slogan—'better living through chemistry'—[but the head curator] and others wanted pollution and death." A second member of the advisory committee added, "We spent most of our political capital making sure it wasn't a complete exposé of the hazards of science." And yet a third member of the advisory committee wrote: "Several historians assigned to the curatorial team made no secret of their disdain for 'big science' and of everything they believed it represented. Their political ideology opposed industry, and dismissed chemical manufacturers as 'polluters.' Eventually the lead curators . . . wound up creating a largely negative [exhibit]."

This is not the place to rehearse the flaws of that exhibit, which I have now seen. What I do want to tell here is why, in this case, as with the National Standards for Science, there is, after all, hope that the prejudicial and unbalanced representation of science for the education of a national audience is going to be corrected. The main reason for this rethinking is that while all the individual objections from scientists and others at first made no impression on the Smithsonian and its curators, at last a scientific society—specifically the American Physical Society—blew the whistle loudly. Asked to do so by his elected council of the society, the president of the APS, the Nobelist Burton Richter, reported to the Secretary of the Smithsonian that APS members who had visited the exhibit "Science in American Life" had found the portrayal of science trivializing its accomplishments and exaggerating any negative consequences. They were concerned that the presentation was seriously misleading, and inhibited the public's ability to make informed decisions on the future use of science and technology. Acknowledging that examples of misuse do belong in such an exhibit, he stressed that what was missing was balance.

He offered the services of the APS to work with the Smithsonian and with others to develop a more appropriate exhibition, and indeed arranged for the whole Executive Committee of the APS to visit the Smithsonian staff in Washington. On that occasion, the flaws were pointed out, and the possibility of a rethinking seemed achievable.

Three-and-a-half months later, in February 1995, the chairman of the Board of Directors of the American Chemical Society also made the principal concerns of his society known to the Smithsonian. He described the constant frustration, over several years, as the Smithsonian staff consistently ignored the advice given them by an advisory committee jointly put together by the ACS and the Smithsonian. He spoke of arrogance and high-handedness on the part of some of the museum personnel assigned to the project, the demonstration of a strong built-in bias against science, and the tendency to revise and rewrite history. He too offered to provide advice and personal attention to result in a more balanced presentation, one that would repair the damage done to the reputations of both organizations.

As a result of these communications, the Smithsonian has promised to revise at least the most egregious parts of the "Science in American Life" exhibit. When that actually happens, the principle I am advocating will have been demonstrated again: *The moral authority of science, as of any professional field, depends importantly on asserting its sense of self.*

To our Romantic rebels, and to the other purveyors of the equation that science equals pollution and death, the intervention of the scientists in the Standards story, and of the physical and chemical societies in the Smithsonian exhibit, will probably be only additional proofs of their point of view. Theirs is a win-win position: if scientists do not object to an unbalanced presentation, then it will have its intended effect on the populace. And if scientists do object and bring about reconsiderations of the documents and exhibitions, that will be said only to illustrate how scientists wield undue influence.

But the fact is, as I noted, that the scientists and their organizations until recently have usually been too negligent and reluctant to speak out and defend themselves against the dissemination of false images. They seem to begrudge any moment away from the exciting work in their labs. Perhaps they are now beginning to discover the danger of letting others define the ideological, educational, and cultural context of science in today's society.

## NOTES

1 I refer you to the details in other essays in his book, and also to my analysis in the chapter "What Place for Science at the 'End of the Modern Era'?" in my book *Einstein, History, and Other Passions.*
2 Philip M. Stern, *The Oppenheimer Case*, pp. 128–130.
3 "Role of the History of Science and Technology in the Proposed National Standards for Schools," pp. 1–2.
4 "National Standards for United States History," pp. 201–203.

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# AFROCENTRIC PSEUDOSCIENCE
## The Miseducation of African Americans

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MINORITIES ARE UNDERREPRESENTED in science and engineering. Children in these groups need examples of the role people like them play and have played in science. In 1987, the Portland, Oregon School District published the *African-American Baseline Essays,* a set of six essays providing resource materials and references for teachers on the knowledge and contributions of Africans and African Americans. Unfortunately, this widely distributed attempt will increase scientific illiteracy and impede the recruitment of African-American children into scientific careers.[1] Our discussion will focus on the Science Baseline Essay written by Hunter Havelin Adams,[2] listed as a research scientist at Argonne National Laboratory. Actually, Mr. Adams was an industrial hygiene technician who "does no research on any topic at Argonne," and whose highest degree was a high school diploma.[3]

There are serious problems with this Baseline Essay, but because of the current pressure on school districts to incorporate multicultural material into the classroom and because of the dearth of this kind of material, it has been widely distributed. Hundreds of copies of the Baseline Essays have been sent to school districts across the country. They have been adopted or are being seriously considered by school districts as diverse as Fort Lauderdale, Detroit, Milwaukee, Atlanta, Chicago, Prince George County, Maryland, and Washington, D.C. Scientists and educators need to be aware of the tone of and the errors in the Baseline Essay, and of the harm its widespread adoption may cause to the goal of diminishing scientific illiteracy in this country.[4]

## USEFULNESS OF THE MATERIAL

One of the goals of the Baseline Essay is "mastering the basic concepts of mathematics and science,"[5] but this text cannot be used as is by a teacher in the classroom to teach *science.* Most of the material is presented as "look how great Egypt and Egyptians were," no in-depth explanations of any scientific principles are provided, and no connection is made between the topics covered and specific K–6 classroom activities. The level of presentation and detail of the Science Baseline Essay resembles a social science or a history of

science presentation rather than one that would allow grade school teachers (who have very little science training) to explain any of the scientific concepts mentioned to a class. The lesson plans for grades 5–8 available from the Portland School District are pretty straightforward classroom exercises but, in fact, use very few of the ideas put forth in the Baseline Essay. One of the reasons for this is that many of the topics mentioned in the Baseline Essay (glider flight, batteries, quantum mechanics) are not suitable for a grade school curriculum.

The Baseline Essay does not distinguish between the serious academic sources (i.e., referred journals or books from academic presses), intermediate sources (popular science journals), very old sources (which might be obsolete), and unreliable or very questionable sources (newspapers, magazines, vanity press books, or "New Age" publications). They are all treated as equally reliable. The citation style is not helpful either for teachers who want to get more information or for readers who want to verify quotations. Quotations in the text are often cited only by author and title, and a full reference is not included in the bibliography. Even when books are included in the bibliography, page numbers are not given in the footnote.

## CLAIMS THAT THE NATURE OF SCIENCE DEPENDS ON WHO DOES IT

One of the Afrocentric strategies is to claim that Western science is just one of many equally valid approaches to the study of nature, and that therefore, African or Egyptian mythical, magical, or folk knowledge is science. The Baseline Essay cites Wade Nobles's definition of science: "the formal reconstruction or representation of a people's shared set of systematic [sic] and the cumulative ideas, beliefs, and knowledge stemming from their culture."[5] This is not an acceptable definition of science. Science is both a special kind of information and a method. A. N. Strahler defines it thus,

> *Scientific knowledge*: the best picture of the real world that humans can devise, given the present state of our collective investigative capability. By "best" we mean (a) the fullest and most complete *description* of what we observe, (b) the most satisfactory *explanation* of what is observed in terms of relatedness to other phenomena and to basic or universal laws, and (c) description and explanation that carry the greatest probability of being a true picture of the real world . . . scientific knowledge is imperfect and must be continually restudied, modified and corrected . . . *Scientific method*: the method or system by which scientific knowledge is secured. It is designed to minimize the commission of observational errors and mistakes of interpretation.[7]

To this must be added acceptance by the *scientific community* because the attempts at verification or falsification of scientific claims by this community are a crucial part of the scientific method.

The Baseline Essay quotes Ruth Bleier (with no page number), "The dominant categories of cultural experience—*race, gender, religion, and class* will be reflected in the institution of science itself: in its structure, theories, concepts, values, ideologies and practices." (words in italics added by Adams).[8] The Baseline Essay, referring later to this passage, states, "In this light, the

common concepts of mathematics, of physical theories such as mass, momentum, and energy; electric charge and magnetic field, the quantum wave function; entropy; distance and time; and even myth, are actually no more than useful organizing strategies our consciousness has developed for ordering the chaos of information it receives from its environment." The clear implication is that concepts such as mass, entropy, momentum, and distance will depend on and vary with the sex and/or race of the person dealing with them. But serious feminist critiques of science do not say this. Feminists criticize science because it is organized and run patriarchally and because this then determines research strategies and interpretations of data, particularly biological data, as in some sociobiological explanations of the role of males and females. No feminist scientist has claimed that the structure of DNA will differ if the analysis is done by a man or by a woman. Similarly the definition of momentum as mass times velocity or of mass as force times acceleration will not differ regardless of the race or culture of the observer. It is also irresponsible to put myth in the same category and level as concepts such as the quantum theory. This postmodern perspectivist model of science has been likened by Gross and Levitt to the Melanesian cargo cults of World War II: "It bears only a vague and superficial resemblance to the real thing, and its internal logic is laughably different. Still, those who built it hope with the aid of their theoretical magical rituals, to gain control over the real thing."[9] My fear is that grade school teachers, the intended audience for the Baseline Essay, will not be sophisticated enough in science to make these distinctions.

## CLAIMS THAT SCIENCE ALSO INVOLVES THE SUPERNATURAL

The Baseline Essay claims that the Egyptians had a concept called *Ma'at* that guided their research and represented the "first set of scientific paradigms." These "scientific paradigms" include "existence via Divine Self-Organization," "acknowledgement of a Supreme Consciousness," and the existence of "transmaterial cause and effect," i.e., supernatural causation. Therefore, "the fundamental scientific paradigms of the ancient Egyptians . . . are antithetical to contemporary ones. . . . Many Western scientists conduct their process of science from a totally different basis, one of which has as its 'main concern,' non-ethical considerations such as cost effectiveness."[10] Apart from the non sequitur of the main concern of Western scientific methodology being "cost effectiveness," which has nothing to do with the basic principles of science, Adams is correct that *Ma'at* in antithetical to Western science. The key question is whether children in public schools are going to be taught that religion (under the guise of "Egyptian science") equals science. This is the same question that was roundly forbidden by both lower courts and the United States Supreme Court in the case of so-called scientific creationism. The essence of the decision of Judge Overton in *McLean vs. Arkansas*[11] was that scientific explanations cannot involve the supernatural.

Apart from the questionable constitutionality of teaching religion (be it Christian or Egyptian) in the public schools, it is a great disservice to give to children such a distorted view of what constitutes science. At some point,

these students will enroll in a real science class and will be at a disadvantage because of their quaint and erroneous view of what constitutes science.

One could teach Egyptian religion and ethics in social studies as comparative religion, but that is quite a distance from teaching that Egyptian religion is an essential component of Egyptian "science" and that it is superior or equal to "Western" science. Teaching morality and ethics is compatible with teaching science, i.e., there *are* ethics involved, honesty, truth, respect for others, even ethical contemplation of the consequences of research, but these are independent of the exclusive use of natural laws to explain and understand scientific phenomena. The Second Law of Thermodynamics does not have a supernatural component. Its application in particular cases might have consequences that raise moral and ethical questions, which require discussion, but this is quite different from teaching that supernatural (or transmaterial) causes are acceptable explanations in science.

This whole section of the Baseline Essay is very disturbing. What is its purpose in the curriculum? Do we want to teach *science* as it is usually conceived, or religion? How is a teacher to teach this section to his or her class? To say that African science invokes the supernatural, but that Western science does not, with the implication that "Egyptian science" is equal or superior to Western science will only perpetuate scientific illiteracy. How will students distinguish science from astrology, channeling, crystal healing, telekinesis, psychic surgery, and a myriad of other "New Age" pseudoscience that is floating about?

It is possible to teach that ancient people, Egyptian, Maya, Inca, etc., did scientific observation of the skies (i.e., careful observation, record keeping over the years, mathematical handling of the data, hypothesis testing, etc.). This serves the legitimate and presumed purpose of multicultural education: to show that groups other than European white males engaged in scientific activities and that they have contributed to the advancement of knowledge. What must be done is to point out that, although the activities were scientific, the original motivation for carrying out the activity was religious, because those cultures, just as Europe before the Scientific Revolution, felt that the supernatural influenced everything. It is possible to teach Mayan or Egyptian religious concepts in social science as historical events, while teaching their scientific, astronomical aspects as science stripped of their mystical attributes.

## CLAIMS THAT PARAPSYCHOLOGY AND SUCH ARE SCIENCE

Adams does not distinguish between science and pseudoscience. In 1987, he claimed a scientific basis for astrology, "At birth every living thing has a celestial serial number or frequency power spectrum . . . this is the basis for astrology."[12] The Baseline Essay clearly implies that the zodiac and astrology are scientific ("astropsychological treatises")[13] and later claims that "the Ancient Egyptians were known the world over as the masters of "magic" (psi): precognition, psychokinesics, remote viewing and other undeveloped human capabilities."[14] The Baseline Essay claims that there is a misunderstanding and that

> we first must know the extremely significant distinction between (non-science) "magic" and (science) psychoenergetics. . . . Psychoenergetics (also known in the scientific community as parapsychology and psychotronics) is the multidisciplinary study of the interface and interaction of human consciousness with energy and matter. . . . Psi, as a true scientific discipline, is being seriously investigated at prestigious universities all over the world (e.g., Princeton and Duke). We are concerned here only with psi in Egypt, not "magic" . . . its efficacy depended on a precise sequence of actions, performed at specific times and under controlled environmental conditions, facilitated by the "hekau" (the Egyptian term for professional psi engineers). . . . Today in a similar manner, psi is researched and demonstrated in controlled laboratory and field experiments.[15]

The only evidence for these claims is one of Adams's previous lectures.[16]

The overwhelming majority of scientists consider parapsychology, by whatever name, to be pseudoscience. The problem is that this essay, presented with the imprimatur of the Portland School Board, supposedly written by a scientist, and supposedly reviewed by other scientists, will lead scientifically unsophisticated teachers to believe that magic *is* science. The Baseline Essay compounds the problem by including Aaron T. Curtis, an "electrical engineer and psychoenergeticist," along with George Washington Carver, Benjamin Banneker, and Ernest E. Just in a list of African-American contributors to science and technology.[17]

A further example is the claim that "Egyptians diagnosed and treated trans-material disturbances. To the minds of the Egyptians, in fact to most African people, all elements of life, whether human beings, animal, plants, gods, and even inanimate matter such as stones and stars, are imbued with trans-material primordial energy."[18] The ancient Egyptians call this creative energy "za" (known as "prana" to the Hindus and "chi" to the Chinese,[19] which human beings could manipulate. . . . This "magico-spiritual" aspect of African medicine still baffles Western-trained scholars and practitioners, and as such is dismissed, belittled, and downplayed. However, recent research is uncovering the "hard" evidence of the validity of this aspect of African medicine." According to the Baseline Essay, the laying-on-of-hands procedure called "therapeutic touch" promoted by Doloris Krieger has been shown to work and is a rediscovery of ancient Egyptian practices. Therapeutic touch is very controversial and is far from being "proven to work in clinical trials" or of being accepted in mainstream medicine. All medicine, including both Western and non-Western, consisted primarily of placebo effects until the twentieth century. The effects cited by the Baseline Essay (reduction of blood pressure, reduction of stress, enhancing [as well as harming] the immune system) can be explained by the placebo effect and by psychoneuroimmunology and can be elicited by any number of procedures including touch, therapeutic or not.[20] A literature survey of therapeutic touch[21] concluded, "the current research base supporting continued nursing practice of therapeutic touch is, at best, weak. Well-designed, double-blind studies have thus far shown transient results,[22] no significant results,[23] or are in need of independent replication."[24] The practice of therapeutic touch by nurses will never gain professional credibility without clear, objective evidence to support it. Without this evidence, the nurse prac-

titioners of therapeutic touch will be relegated to the practice of "placebo mumbo jumbo." There is a very long distance between claims that the mind and emotions or people can affect their immune system and lower their resistance to illness, which is a legitimate area of study, psychoneuroimmunology, and claims that rocks have a mind and that Egyptians, or anybody, can manipulate physical reality from afar by psychic powers.

## EXAGGERATED CLAIMS WITH LITTLE EVIDENCE

The Baseline Essay also makes some extraordinary claims about the past and present astronomical knowledge of the Dogon of Mali.

> They knew of the rings of Saturn, and the moons of Jupiter, the spiral structure of the Milky Way, where our star system lies. They claimed that billions of stars spiral in space like the circulation of blood in the human body. . . . Perhaps the most remarkable facet of their knowledge is their knowing intricate details of the Sirius star system, which presently can only be detected with powerful telescopes. The Dogon knew of the white dwarf companion star of Sirius, the brightest star in the sky. They knew its approximate mass ("it is composed of 'sagala,' an extremely heavy, dense metal such that all the earthly beings combined cannot lift it") its orbital period (50 years) and its axial rotation period (one year). Furthermore, they knew of a third star that orbits Sirius and its planet [sic]. The X-ray telescope aboard the Einstein Orbiting Observatory recently confirmed the existence of the third star.[25] The Dogon with no apparent instrument at their disposal appear to have known these facts for at least 500 years.[26]

No evidence is presented to support these claims. The sole citation is a previous paper by Adams.[27] In it, Adams made additional claims, which were endorsed by Van Sertima,[28] that the Dogon knew these things for at least 700 years (not 500 as in the Baseline Essay) and that the ancient Egyptians also possessed this knowledge. The sole source for all of these claims about Dogon astronomical knowledge is the research of two French anthropologists, Marcel Griaule and Germaine Dieterlen, and more directly a book by Temple.[29] Griaule and Dieterlen do not claim that this knowledge was ancient or Egyptian, and Temple argues that this knowledge comes from aquatic inhabitants of a planet in the Sirius system that have visited earth in the past.

Whatever the source of Dogon cosmology it was not based on a visual observation of Sirius B. The visual magnitude of stars is a logarithmic scale—the larger the number the dimmer the star. The usual limit under the best of conditions for naked eye observations is 6.5, although some exceptional individuals with much training can observe stars of 7.8 magnitude. Sirius A, a very bright star, has a magnitude of $-1.4$ while Sirius B has a magnitude of 8.7.[30] It is impossible to see Sirius B with the naked eye.[31] Adams and Van Sertima further claim that the Egyptians used telescopes to see Sirius B. "The Russians have recently discovered a crystal lens, perfectly spherical and of great precision, used in ancient Egypt.[32] It is a short and simple step to place one lens in front of another to make a basic telescope, and chances are that it could have happened many times." Because of its proximity to the bright Sirius A, Sirius B is very hard to see even with a telescope. Under the best conditions at least a 5-inch telescope is required and when it is closest to Sirius A, about half the time, a 100-inch telescope would be needed.[33]

The Baseline Essay claims that, "Egyptians had a theory of species evolution at least 2000 years before Charles Darwin developed his theory of species evolution." The sole evidence for this is a quotation from "The Book of Knowing the Evolutions (the becomings) of Ra (the creator sun god)":

> The words of Neb-er-ter who speaks concerning his coming into existence: "I am he who *evolved* himself under the form of the god Khepra (scarab beetle), that was *evolved* at the "first time." I the *evolver* of evolutions, *evolved* myself from the primordial matter which I had made . . . which has *evolved* multitudes of evolutions at their "first time."[34]

This is an unremarkable cosmological text. Students of comparative religions could produce dozens of similar texts from various religions in which the gods create (evolve?) themselves. For example, in Aztec mythology, Teotihuacan is "the place where gods made themselves." The use of the word *evolve* in its ordinary dictionary meaning of "to develop, to achieve gradually; to undergo change" in no way proves that the user meant the same thing as Charles Darwin's extended theory. The concept of evolution of the species, as proposed by Darwin, involves a whole series of other concepts such as (1) a species being defined as a reproductively isolated group of individuals; (2) that species produce many more offspring than those that survive; (3) that depending on particular environments, certain characteristics will confer advantages on some individuals, and that these individuals will have a reproductive advantage over other individuals; (4) that these characteristics will be inherited by offspring and that over long periods of time this will result in the "evolution, i.e., change over time" of new species. It is ludicrous to claim that the passage cited in the Baseline Essay encompasses or preempts Darwin. As Samuel Gill points out,[35] there are two basic principles that apply to this situation: (1) the burden of proof is on the claimant, and (2) the extraordinary claims require extraordinary proof. The Baseline Essay has clearly failed this test.

Under the heading of "Egyptian Aeronautics," the Baseline Essay argues[36] that a model of a glider was discovered in a tomb near Saquara, and that "this ancient Egyptian glider looks contemporary and bears a strong resemblance to the American Hercules transport aircraft . . . it definitely was not a toy. It was a scale model of a full-sized glider!" Without any further evidence, the Baseline Essay cites the *Guinness Book of World Records,* "[Dietches] has researched evidence of the use of gliders in Ancient Egypt from 2500 B.C.–1500 B.C. He says that the Egyptians used their early planes for travel, expeditions, and recreation!" This is the extent of proof for this extraordinary claim. In fact, the model is that of a bird and the ratio of the length of its wingspan to its body length is approximately 1:1 whereas most gliders have a ratio of 2:1.[37]

There are numerous other extraordinary claims backed up by little or no evidence, such as the ability of ancient Egyptians to predict pregnancy by urinating on barley seeds,[38] that they anticipated many of the philosophical aspects of quantum theory[39] that they knew the particle/wave nature of light,[40] and that "enclosed with the Great Pyramid are the value of pi, the principle

of the golden section, the number of days in the tropical year, the relative diameters of the earth at the equator and the poles, and ratiometric distances of the planets from the sun, the approximate mean length of the earth's orbit around the sun, the 26,000–year cycle of the equinoxes, and the acceleration of gravity.[41]

## WHAT CAN BE DONE?

The pressure to teach Afrocentric science differs from that pushing "scientific creationism." Afrocentric science is pushed from the top down, from school boards, superintendents, and math-science departments in urban school districts. It is difficult for teachers to resist, and in many cases, particularly in grade schools, teachers do not have enough scientific knowledge to criticize the material.

One possible strategy is to use the Baseline Essay to teach critical thinking, one of the principal aims of the reform in teaching science, by subjecting its claims to scientific scrutiny. By doing this, students can learn science and the process of inquiry, and as a by-product will expose the fatuity of the Baseline Essay. For example, students could be asked to verify what is required for full size gliders to fly.[42]

The Baseline Essay asserts, with no evidence or citation, that the ancient Egyptians had discovered the law governing the oscillation of the pendulum: "The heartbeat also provided them with a convenient measure of time; from its average rhythm they determined the length of the plumb line that would cause it to oscillate to that rhythm. They discovered the rate of oscillation of a pendulum (plumb bob) varies in inverse ratio to the square of its length, which in this case is 0.69 meters, or about 27 inches."[43] Students could calculate the period of a 69-cm pendulum or very simply make a pendulum with this length and test whether it oscillates at 72 oscillations/minute.

The Baseline Essay claims that the Egyptians could electroplate gold: "Electroplated gold and silver objects have been found in Egypt from roughly the Middle Kingdom (2100 B.C.) to the Greek era of the Ptolemies (350 B.C.)."[44] One could teach a lot of chemistry in debunking this statement. Students should be asked to find out how to dissolve gold and how gold is electroplated, what voltage would be required, and how the Egyptians would have achieved this.[45]

Gerald Holton[46] proposes that antiscience be fought by instituting broad reforms to improve teaching science such as Project 2061. Unfortunately, this is a long-term project, and in our specific case it is insufficient because Project 2061 has no multicultural content. There is a great need to develop multicultural materials in science to fill the demonstrated need that is currently being filled by materials such as the Baseline Essay. These materials, however, must be absolutely accurate historically as well as scientifically.

Holton urges a vigorous opposition to the inclusion of pseudoscience into the schools. As a first step, school systems that claim to be using an "African-centered education," "Afrocentric," or "multicultural" curricula should be urged to divulge the sources they use to teach science. Almost invariably they will include works discussed here.

People who are genuinely concerned with improving science education in the schools and with increasing the number of minority scientists should vigorously oppose the inclusion of material into the curriculum that makes unsupported claims, introduces religion under the guise of science, and claims that the paranormal exists. The critical need to increase the supply of minority scientists requires that they be taught science at its best rather than a parody.

## NOTES

1 There are other Afrocentric works on science that are also severely flawed. One is *Blacks in Science*, edited by Ivan Van Sertima, which is a mixture of worthwhile articles, biographical sketches of African-American scientists, and problematical articles by Hunter Adams, Beatrice Lumpkin, John Pappademos, and Charles Finch as well as an article claiming the existence of gliders in ancient Egypt. Lumpkin's essay has been critiqued by Lowe (*Skeptical Inquirer*), and Pappademos's scholarship has been questioned by Palter ("*Black Athena*, Afrocentricity, and the History of Science"). The dean of Afrocentric studies, Molefi Kete Asante, has written a short, poorly documented imitation of the Portland Baseline Essays ("African–Puerto Rican Centric Curriculum Guide"). The title is misleading because nothing is included about the Spanish or the Taino Indian background of Puerto Ricans in this work.
2 Hunter Havelin Adams, "African and African-American Contributions to Science and Technology," hereafter cited as Baseline Essay.
3 D. Baurac, Letter to Christopher Trey; M. Marriot.
4 B. R. Ortiz de Montellano, "Multicultural Pseudoscience. Spreading Scientific Illiteracy among Minorities—Part I"; "Magic Melanin. Spreading Scientific Illiteracy among Minorities—Part II"; "Afrocentric Creationism"; "Avoiding Egyptocentric Pseudoscience: Colleges Must Help Set Standards for Schools"; "Melanin, Afrocentricity and Pseudoscience"; I. M. Klotz, "Multicultural Perspectives in Science Education: Our Prescription for Failure."
5 Baseline Essay, p. 4.
6 Ibid., p. v.
7 A. N. Strahler, *Understanding Science*, pp. 27–28.
8 P. vi. Adams also deleted various phrases and several paragraphs from the original text (Ruth Bleier, "Introduction," in *Feminist Approaches to Science,* pp. 2–4) with no indication of having done so.
9 Paul R. Gross & Norman Levitt, *Higher Superstition: The Academic Left and Its Quarrels with Science,* p. 41.
10 Baseline Essay, pp. 11–14.
11 *McLean v. Arkansas Board of Education.*
12 Hunter Havelin Adams, Lecture, 1st Melanin Conference, broadcast, "African-American World View."
13 Baseline Essay, pp., 29–30.
14 Ibid., pp. 41–42.
15 Ibid. *HkEy* (hekau) means magician (R. O. Faulkner, *A Concise Dictionary of Middle Egyptian*, p. 179; G. Pinch, *Magic in Ancient Egypt,* pp. 50–53).
16 Hunter Havelin Adams, "Psychoenergetic Aspects of Ancient Egyptian Lifeways."
17 Baseline Essay, pp. 81–82.
18 Ibid., p. 44. This is nothing more than the widespread religious belief of *animism,* well known to anthropologists, but which no one claims to be an objective reality.
19 *Za, prana,* and *chi* are not equivalent and are certainly not coterminous with animism. What we have here is the usual semidigested mixture of beliefs common to New Agers.
20 H. Brody, *Placebos and the Psychology of Medicine,* p. 55; Morton, pp. 46–50.
21 P. E. Clark & M. J. Clark, "Therapeutic Touch: Is There a Scientific Basis for the Practice?"

22 B. Grad, R. Cadoret & G. Paul, "An Unorthodox Method of Treatment of Wound Healing in Mice."
23 G. Randolph, "The Difference in Physiological Response of Female College Students Exposed to Stressful Stimulus, When Simultaneously Treated by either Therapeutic or Casual Touch."
24 B. Grad, "A Telekinetic Effect on Plant Growth."
25 The paper cited as evidence for this (T. Chlebowski, J. P. Halpern & J. E. Steiner, "Discovery of a New X-ray Emitting Dwarf Nova 1E 0643.0-1648") does not claim that the X-ray-emitting dwarf 9′ south of Sirius is a third companion. Sirius is 8.7 light years away from Earth, while this new star is 325 light years away and could hardly "orbit Sirius."
26 Baseline Essay, p. 60.
27 Hunter Havelin Adams, "African Observers of the Universe: The Sirius Question."
28 In I. Van Sertima, ed., *Blacks in Science. Ancient and Modern*, pp. 7–26.
29 M. Griaule & G. Dieterlin, "Un Système Soudanais de Sirius"; *Le renard pâle*; R. G. Temple, *The Sirius Mystery.*
30 C. W. Allen, *Astrophysical Quantities*, p. 235.
31 Bradley Schaefer, personal communication, May 18, 1995.
32 A sphere would be useless as a lens because the focal length would be extremely short, and because the image produced would be greatly distorted by spherical and chromatic aberration. This baseless claim has been endorsed by Sandra Harding, the feminist philosopher of science (*Whose Science? Whose Knowledge?*, pp. 223–224).
33 B. E. Schaefer, "Glare and Celestial Visibility."
34 Baseline Essay, p. 19. Emphasis added.
35 Samuel Gill, "Carrying the War in to the Never-Never Land of Psi."
36 Baseline Essay, pp. 52–54.
37 R. S. Barnaby, *Gliders and Gliding,* p. 132.
38 Baseline Essay, p. 48.
39 Ibid., p. 20.
40 Ibid., p. 26.
41 Ibid., p. 38. The latter is the same old discredited pyramidology that has been around for over a hundred years since the publications of Charles Piazzi Smyth (R. S. Bianchi, "Pyramidiots"; M. Gardner, *Fads and Fallacies in the Name of Science*, pp. 173–185). Gardner showed that the same kind of numerology can derive the speed of light from the dimensions of the Washington Monument, and Jager ("Adventures in Science and Cyclosophy") showed that quantities such as the ratio of the masses between a proton and an electron, the gravity constant, the velocity of light, and the distance between the sun and the earth can be derived from measurements on his bicycle.
42 At that time, in a flat country like Egypt, a catapult would be the only feasible way to launch a glider. Making the reasonable assumption of a 200-kilogram glider flying 10 miles per hour into a 10-mile-per-hour headwind (Barnaby, *Gliders and Gliding*, p. 50; L. B. Barringer, *Flight Without Power*, p. 102), one can calculate the kinetic energy involved. In turn, because of conservation of energy, the equivalent potential energy can be found; and from that the size of the catapult required can also be found. The catapult required to launch this small glider would be many times the size of the largest catapult constructed in antiquity (E. W. Marsden, *Greek and Roman Artillery. Historical Development,* pp. 86–88). Further complicating the problem is that there were no catapults in 2000 B.C.; and that if, in fact, the scheme had been carried out, the force of the launch would almost certainly have stripped the wings from the glider.
43 Baseline Essay, p. 39.
44 Ibid., p. 51
45 Objects can be plated with gold by dipping them into a solution of gold (S. Field and A. D. Weill, *Electro-Plating. A Survey of Modern Practice,* pp. 286–294). Unfortunately, dissolving gold requires aqua regia (a mixture of nitric and hydrochloric acids), and making these acids requires the ability to distill, which was not invented

until after A.D. 1100 (A. J. Ihde, *The Development of Modern Chemistry*, pp. 16–18; C. Singer & E. J. Holmyard, *A History of Technology*, vol. 1, p. 254). The Baseline Essay (p. 51) claims that the Egyptians had iron-copper batteries on the basis of batteries discovered in Iraq (not Egypt). However, electrodeposition from a gold anode to a copper cathode would require at least 1.5 volts. Keyser's extensive study of these batteries flatly points out that electroplating gold by electric current was impossible ("The Purpose of the Parthian Galvanic Cells: A First-Century A.D. Battery Used for Anesthesia"). Keyser's model of a battery using acetic acid (the strongest acid available in antiquity) produced a voltage of 0.49 volts.

46 Gerald Holton, *Science and Anti-Science*, pp. 178–180.

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# INDEX OF CONTRIBUTORS


Alcock, J. E., 64–78

Bornstein, G., 459–469
Bricmont, J., 131–175
Bunge, M., 96–115

Cantor, P. A., 445–458
Cole, S., 274–287
Crews, F., 470–482

Denfeld, R., 246–255

Fishman, L., 87–95
Fox, R., 327–345

Gilkey, L., 523–525
Goldstein, S., 119–125
Goodstein, D., 31–38
Greenberg, H., ix–xi
Gross, B. R., 79–86
Gross, P. R., 1–7

Haack, S., 57–63, 259–265
Held, B. S., 198–206
Herschbach, D. R., 11–30
Holton, G., 551–560

Jackman, S., 346–368

Kenshur, O., 288–297, 526–536
Kleppner, D., 126–130
Koertge, N., 266–273, 413–419
Kurtz, P., 493–504

Lefkowitz, M., 301–312
Levitt, N., 39–53
Lewis, M. W., 209–230
Lichter, S. R., 231–245

Nanda, M., 420–436

Ortiz de Montellano, B. R., 561–572

Radcliffe Richards, J., 385–412
Rosovsky, H., 539–542
Roth, A. M., 313–326
Rothman, S., 231–245
Ruskai, M. B., 437–441

Sampson, W., 188–197
Scott, E. C., 505–522
Sommers, C. H., 369–381

Trefil, J., 543–550

Weissmann, G., 179–187, 483–489

# SUBJECT INDEX


AAUW, 375, 376, 378
academic freedom, and religious views, 511
ACS, 558, 559
*Acta Eruditorum*, 42
actor-actant theory, 282, 283
acupuncture, 193
  placebo effects of, 195
Adams, Hunter Havelin, 561, 562, 564–566
affirmative action, 414, 415
Africa
  as cultural model of Egypt, 325
  as ignored by Egyptologists, 325
  influence of Egypt on, 323
  as origin of Greek culture, 411
African civilization, 303, 304 (*See also* Egypt, ancient *and* Egyptologists)
  and ancient Greece, 304
  and European civilization, 321
African medicine, 565
African science, 564
*African-American Baseline Studies,* 561
  and increase of scientific illiteracy, 561
  Science Baseline Essay of, 561
African-Americans, 319, 320, 361
  and Afrocentric perspective, 325
  and Egyptian cultural heritage, 321, 323
Afrocentrism, 305, 313, 323–325, 537
  teaching of, 326
  and works on science, 569
Afrocentrists, 299, 307, 320, 505
  Eurocentric approach of, 324
  and Nubia, 317, 318
  and propaganda, 538
AIDS virus, 23
Alexander, 308, 310
Alexandria, 304, 319
allopathy, 188
alternative medicine, 14, 188, 192, 194
  definition of, 190
  terminology of, 190
alternativism, 5
American Association for Public Opinion Research, 353
American Association for the Advancement of Science, 106, 193
American Association of University Women (AAUW), 374 (*See also* AAUW)
American Cancer Society, 192
American Chemical Society (ACS), 558 (*See also* ACS)
American Council for Science and Health, 243
American Enterprise Institute, 107
American Medical Association, 107, 192
American Physical Society, 243, 369, 558
American Revolution, 26
*American Scientist*, 35
ANN, 94, 95
Anthony, Susan B., 438
anthropology, 327, 336, 341
  and epistemological relativism, 336
  humanistic, 334, 336, 339, 343, 345
  and knowledge systems, 423
  as science, 333
  symbolic, 337
antienvironmentalist, 221, 222, 228
antievolutionism, 505, 520
  influence of, 517
  as irrationalism, 520
  and teaching evidence against evolution, 509
antimodernism, 299, 421
antipositivism, 353, 355
antirationalism, 443
antirealism, 2, 199, 257
  and active knower, 202
  and constructivist/constructionist psychotherapy, 198, 200
  and psychotherapy, 201
  and quantum physics, 203
antireason, 1, 491
antiscience, 1, 97, 126, 491, 537, 568, 524
  academic, 97, 110
  and anti-intellectualism, 84
  and background beliefs, 81, 82
  and political paranoia, 84
Aquinas, Saint Thomas, 79
Archimedes, 89, 108
Arendt, Hannah, 354
Aristotle, 47, 79, 81, 83, 303, 304, 306,
  and Egypt, 307
Arnold, Matthew, 47
  and science education, 44
arrow of time, 131, 143, 148, 167, 168
  and irreversibility, 137

subjectivity of, 149
and unstable dynamic systems, 141
artificial neural network (ANN), 93 (*See also* ANN)
Asante, Molefi Kete, 304, 305
asbestos, as carcinogen, 233–235
Association of Women in Psychology, 418
astrology, 106, 403, 495, 496, 498
scientific basis for, 564
authoritarianism, 109
Ayer, A. J., 329

Bacon, Francis, 14, 15, 18, 211, 213, 214, 266, 347, 540
Baruch, Bernard, 26
Barzun, Jacques, 40, 41, 44
Baseline Essay, 562–565, 567, 570 (*See also African-American Baseline Studies*, Science Baseline Essay of)
Baudrillard, Jean, 150, 356, 357, 361
Bayesians, 103
Bayle, Pierre, 491, 528, 530, 532, 533, 535
beams, supersonic, 22–24
Becker, Gary, 102, 103
behaviorism, 331, 338
belief
and constructivism, 90
and fear, 90, 91
and feelings, 87
and intuition, 92
religious, abundance of, 68
social transmission of, 66
transcendental, 70
Bell, Alexanber Graham, 557
Bell, J. S., 117, 121–123
and incompleteness of quantum description, 129
Bénard cell, 155, 171
Bénard instability, 154
Benhabib, Seyla, 421, 422, 431
Bentham, Jeremy, 348
Bergson, Henri, 147
Berkeley, George, 18, 43
Berlin, Isaiah, 552
Bernal, Martin, 321–323
Bernoullis, the, 44
bias, 323, 332, 333
as distinguishable from fact, 341
and historians, 301, 302
and history, bias in, 301, 302
metaphor of, 331
political unavoidability of, 321
Bible Science Association, 510, 517
Bible, 501
Big Bang, 52, 514
as evidence of creation, 515
"Big Science," 5
biomedicine, 177
Blake, William, 1, 40, 459, 460, 464
hostility to science of, 15
hostility to cosmology of, 43
Boas, F., 339
Bohm, David, 117, 121
and completion of quantum physics, 123
Bohr, Niels, 117, 119
and atomic model, 19, 20
Boltzmann entropy, 150–52, 156, 158, 170
Boltzmann, Ludwig, 117, 131, 141, 142, 144, 147–149, 153, 155, 157, 158
and irreversibility, 132, 138
Born, Max, 121, 123
and irreversibility, 143
Boyle's Law, 275, 336
Boyle, Robert, 42
and epistemological validity of laboratory science, 290
Breuer, Josef, 479
Browne, Thomas, 529, 533
Brownian motion, 149
Brownowski, Jacob, 12, 15, 27
Buckyball, 23
Buffon, Georges, 42
Buridan's ass, 80, 154
Butler, Samuel, 58

Calvin, John, 80
Campus Crusade for Christ, 510
cancer
and animal studies, 237
and capitalism, 241
controversies regarding, 237, 238
environmentalist survey of, 234, 235
and institutional ratings of, 241
and man-made agents, 231, 234
and scientists versus environmentalists, 241
and the media, 235–237, 239, 240
and the *New York Times*, 240
and *Scientific American*, 240
rates of, 233
and reputations of scientists, 240
risk of, and public information, 242
and scientific and environmentalist communities, 237
and television news, 240
Cancer Control Society, 189
cancer scientists, survey of, 231–234
Caribs, 487, 488
Carroll, Lewis, 44
Cartesian dualism, 215, 217, 225
chaos theory, 50, 104, 153, 162
chaos, 161, 162, 169, 170, 172
and deterministic worldview, 132

and irreversibility, 131, 141
and order, 152
chaotic dynamic systems, 134, 146
and universal determinism, 135
charm theory and social factors, 279
Chaucer, Geoffrey, 41
chemical bonds, 22
Christ, 528, 529, 506
Christian Coalition, 501
Christian Leadership Ministries, 510
Christian perspective
and scholarship, 505, 516, 517
in science, 513
and teaching , 512, 513
Christianity, 2
credibility of, 530
as ideology, 512
as beyond reason, 528
and skepticism, 527
Clement of Alexandria, 306, 309
Cleopatra, 318
Coleridge, Samuel Taylor, 460
Columbus, Christopher, 487, 488
Committee for Freedom of Choice, 189
complementarity, 119, 120, 129
conditioning, 66, 341
classical, 65
enculturation as, 331
operant, 65, 70
superstitious, 70
construct, 198, 199
and confusion arising from the term, 202
construction, 199, 202
cultural, 459
and literature, 465
linguistic, 201
and reality, 202
literary, 467
social, 266
constructionism, 87, 204
cultural, 18
social, 198, 200, 267
and application of scientific results, 270
as antirealist doctrine, 201
constructivism (constructivist view), 198, 200, 257, 275, 276, 296
as antirealist doctrine, 201
and belief, 90
failure of, 280
and knowledge, 89
and Bruno Latour's rejection of, 289
and psychic pressures, 87
research program of, 281
and science as irrational, 87
scientifific, 289
social, 83, 275, 277, 553
and absence of evidence, 285
and sociology of science, 291
and social constructionism, 201
constructivist-relativist, 105, 106
constructivists, 274–279, 293
and reviewing books, 281
cultural, 20
rhetorical trick of, 280
social, 161, 274, 279
Copenhagen interpretation, 117, 120, 129, 148
Copernican revolution, 13
Cortez, Hernando, 488
Craige, John, 530, 533
Creation Research Society, 507
creation science, 510, 523, 524
and denial of empirical knowledge, 505
and school curricula, 507
teaching of, 509
creation, special, 506, 515
and antievolutionists, 5–6
creationism, 403, 491, 501, 505, 506, 508, 515, 518, 520
continuous, 506
and division of science, 514
progressive, 506
scientific, 509, 563, 568
and teaching Biblical Christianity, 508
and supernatural causation, 514
Creationist Institute, 502
Crick, Francis, 12, 280
critical thinking, 499
and the media
in the schools, 502, 503
and science, 74
criticism, contemporary literary
and hegemony of critic, 455
literary texts, 445
cultural determinism, 331
cultural literacy, 537, 544
change in, 547
genesis of idea of, 545
as matrix of knowledge, 545
culture
and rationalist aspiration, 426
as source of rationality, 425
Curie, Madame Pierre, 554

Dallas School of humanism, 344
Darwin, Charles, 153, 155, 156, 501, 507, 508, 567
Darwinism, 518
de Broglie, Louis Victor, 121, 123
de Chardin, Pierre Teilhard, 105
De Man, Paul, and support of Nazis, 461
deconstruction, 188, 194, 334, 339, 342, 443, 452, 461
and the New Historicism, 453

and Bruno Latour's rejection of, 289
and postmodernism, 226
and relativizing knowledge claims, 289
deconstructionists, 210, 303, 330, 453
deism, 516
Delaney clause, 237–239
democracy
as rooted in a method of inquiry, 493
Derrida, J., 335, 342
Descartes, René, 211–214, 289, 420–423, 425, 427, 429, 549,
and determinism, 154, 155, 161
cultural, 331
and fundamental laws, 134
and predictability, 133
and probabilities, 134
and reductionism, 162
determinism
and chaotic dynamic systems, 235
cultural, 331
and Descartes, 154, 155, 161
and Hobbes, 293
and Laplace, 134
Dewey, John, 301,
Diderot, Denis, 43
Dilthey, W., 335, 337
Diodorus of Sicily, 307
discursivity, 472, 475
and M. Foucault, 472
DNA, 22
Doctorow, E. L., 486, 487
Dogon people, astronomical knowledge of, 566
Dostoevsky, Fëdor, 81, 333, 474
double-blind studies, 181, 195
Dryden, John, 42
Durkheim, Emil, 100, 291, 339, 423, 425, 428, 473

Ecofeminism, 207, 212, 246
conservatism of, 251, 254
and Plumwood, Val, 214
as religion, 250
technophobic aspect of, 253
and women's intelligence, 249
and women's rights, 250
Ecofeminist Visions Emerging, 248
ecofeminist, 215
ecology, 209, 218
spiritualized, 219
ecophilosophy, 210–212, 217, 221
conservative roots of, 222
ecoradical, 211, 214, 217, 222, 225, 227
and attack on reason, 217
and modernity, 219,
ecoradicalism, 210, 211, 213, 216, 218–220, 222, 224, 228
and conservatism, 228
ecosentimentalism, 483–485, 488
ecosystem, global 210
Eddy, Mary Baker, 510
Edison, Thomas, 557
education (*See also* science education, *and* scientific literacy)
and Afrocentric curricula, 568
and challenge to science, 552
and critical thinking, 503
cultural and moral dimension of, 51
and decline in respect for reason and science, 537
higher, and devaluation of the humanities, 539
improving science teaching in, 569
and "inquiry" method of teaching, 554
liberal arts, 25, 27
multicultural, 537
and science, central ideas of, 549
and scientific literacy, 548
and spiritual content, 537
value of mathematics in, 47
Egypt, ancient, 299, 301, 303–305, 314, 315, 318, 321, 322, 326
aeronautics of, and glider, 567
and blackness of Egyptians, 315, 317
and Egyptian science as religion in the schools, 563
and electroplating technology, 568, 570
greatness of, 319, 561
and Greek culture, 321, 322
and Greek philosophy, 305–307
and influence on Africa, 323
and influence on Europe, 321–323
and mystery system, 309, 310
and particle/wave nature of light, 567
and Plato, 308
and Pythagoras, 308
and quantum theory, 567
religion of, and teaching of social studies, 564
and scientific paradigms, 563
and supernatural causation, 563
and theory of evolution, 567
and Western culture, 323
Egypt, modern, 317, 319
and color, 315, 316
Egyptian Exploration Society, 324
Egyptians (*See* Egypt, ancient)
Egyptologists, 306, 317–319, 323
and Afrocentrism, 313–315, 317, 319–321, 325
as Eurocentric, 318, 324
and Eurocentric motives, 304
and scholarly conspiracy, 324
and goals of Afrocentric Egyptology, 325
Einstein, Albert, 26, 105, 127, 333, 335
and quantum theory, 120, 121

Elementary and Secondary Education Act, 378, 379
Eliot, T. S., 459
Elizabethans, 463
  and relation of cultural practices to historic texts, 464
  stagecraft of, 450
empiricism, 338
  as cultural construct, 459
Enlightenment, 153, 209, 210, 211, 214, 221, 223, 226, 253,, 290, 300, 346, 347, 362, 365, 421, 423, 426, 431, 432, 493, 520, 527, 540
  and the autonomous self, 422
  double vision of, 291
  and dualism, 214, 292
  feminist and postcolonial critics of, 424
  and the Gulags
  and Bruno Latour, 289, 290, 431
  liberal politics of, 222
  and modern science, 425
  and Nazi death camps, 431
  and procedural principles of knowledge, 429
  and progress, 433
  second, 223
  and rejection of science, 1
  and "Romantic Rebellion," 552
  and Russian communism, 540
  and scientific rationalism, 526
  and value of reason, 222
entropy of Clausius, 151, 152
entropy, 150, 152–154, 160, 170–172 (*See also* Boltzmann entropy *and* Gibbs entropy)
  and Boltzmann entropy, 150
  of Clausius, 151, 152
  contextual, 150
  and thermodynamics, 151, 163, 169
environmental philosophy, 209–211, 214, 218, 219
  and cosmology, 220
  and the Enlightenment, 223
environmental science, 220, 221
environmentalism, 223, 228, 231, 243
  and deconstruction, 227
  and ecofeminism, 246
  and the media, 242
  and relationship with science, 209
Epictetus, 80
epistemological positions, mutability of, 527, 534, 535
epistemology, 80, 292, 366, 386, 401, 408–411
  and amenability to transformation, 534
  antirealist, 198
  changes in, and feminism, 394, 396, 397–399, 401, 409, 410
  constructivist, 266
  and co-optation of ideas, 534
  as democratic, 264
  and emancipation, 396, 407, 526, 527
  feminist, 385–387, 391–399, 401, 403, 404, 406, 409–411, 413, 414–417, 433
    aims of, 395
    content of, 400
    impossibility of, 399
    justification of, 398
  and first-order beliefs, 394, 409
  objectivist, 200
  and politics, 395, 404, 409
  postmodern, 200
  realist, 199
  relativistic, 335
  of science, and the supernatural, 518
  as secondary to ethics, 398
  and second-order beliefs, 388
  and social negotiation, 264
  "sociological turn" in, 267
  traditional, 399
  traditional, and feminism, 394–396, 398, 399
ergodicity, 132, 145, 146, 160, 166
  and irreversibility, 147
ESP, 495, 498
ethnocentrism, 336
ethnomethodology, 99, 100, 275
ethology, 331, 339
Euclid, 40, 42
Eurocentrism, 177
Europe, western, 215, 216 (*See also* the West, Western . . .)
Europeans, medieval, 212, 215
evidence, 301, 305, 306
  and evolution, theory of, 153
  historical, 301, 320
  legal, 103
  and revelation, 423
  as social construct, 218
  varying standards of, 262
evolution theory, 153
  and source of morality, 507
evolution, 155, 172, 267, 494
  evidence against, 509
  human, 516
  opposition to, 520
  as science, 517
  teaching of, and sciency literacy, 505, 517
  theistic, 506
  and theological conservatism, 517
  theory of, 153
existentialism, 97, 99, 329

faith
  and knowledge, 529

and probabilism, 532
and probability, 530, 532
and reason, 432
False Memory Syndrome Foundation, 107
falsifiability and credibility, 342
Fascism, 61, 222, 329, 459, 461, 462, 524
Faulkner, William, 551
FDA, 189, 192, 193
feminism, 100, 228, 339, 385, 386, 403, 406, 410, 438
as an applied subject, 392, 399
and changes in belief, 391, 392
derivativeness of, 406
and epistemology, 385–387, 391–399, 404, 406, 409–411, 414–417
aims of, 395
and first-order beliefs, 390
foundations of, 387, 398
and impossibility of feminist theories, 402
and justification of theories, 402
progress in, 390–392
as revolutionary ideology, 246
and radical environmentalism, 225
and second-order beliefs, 390
traditional, 389, 396, 397
and traditional epistemology, 394
and traditional views, 388
and truth, 433
feminist epistemology (*See* epistemology)
feminist theory, radical, 100
feminists, 207, 215, 219, 267, 330, 387, 505
and moral values, 388
early challenges to, 389
of the Third World, 421
and postmodernism, 422
Feyerabend, Paul, 81, 82, 149, 335
and sociology of science, 109
Feynman, Richard, 14, 18
fideism, 491, 532, 534
and skepticism, 527, 528
First Amendment, 523, 524
Establishment clause of, 508, 511
first-order beliefs, 387, 394
changes in, 394, 399
and epistemology, 394, 396, 409, 410
and feminism, 390
absence of feminist reasons for, 400
and standards, 392
Firth, Raymond, 337, 341
Fishman, Loren, 5, 55
Food and Drug Administration (FDA), 181, 270 (*See also* FDA)
Foucault, Michel, 101, 180, 335, 355, 361, 427, 461, 472
and discursivity, 472
and knowledge as power, 480
Frankfurt School, 354, 364
Franklin, Benjamin, 14, 25, 26, 557
fraud, 32
and the biomedical sciences, 31, 37
Caltech rules for, 31, 34
and career pressure, 33
civil, 31, 32
scientific, 31, 36
and funding, 36
motives for, 33
and peer review, and conflict of interest, 36
rarity of, 31, 36
free speech, 349, 360
free will, 293
Freud, Sigmund, 470, 472–474 , 477, 478
and Wilhelm Fliess, 477
hermeneutics of, 480
and D.H. Lawrence, 474
and magical thinking, 479
and Mann, Thomas, 474
and mythical thought, 479
as Neo-Platonist, 479
and Friedrich Nietzsche, 475
philosophical side of, 477
Freudianism, 443, 473
and the universities, 471, 479
Freudians, 328
Friedman, Milton, 103
Fuller, Buckminster, 23
Fuller, Margaret, 484, 485
functionalism, 337, 338, 339–340
and objective standards, 341
fundamentalism, 221, 227, 251, 430, 433, 501, 519
and absolute truth, 523
and contemporary culture, 524
and evidence, 423

Gaia, 211, 213
galaxies, 22
Galileo, 89, 90–92, 211, 347, 501
Gauss, Karl Friedrich, 44
Geertz, Clifford, 337, 338, 425
Gellner, Ernest, 420, 422, 423, 425, 427–432, 478
and Sigmund Freud, 475
and independent reality, 426
and truth as transcendent, 421
gender difference theory, 437–439
gender differences
as attributable to nature, 389
and moral psychology, 370
Gender Equity Package, 378, 379
Genesis, 212
Genetics Society of America, 106
germ theory of disease, 13
Gibbon, Edward, 528

Gibbs entropy, 152
Gibbs, Josiah Willard, 143
Gilligan, Carol, 369–374, 376, 377
Gimbutas, Marija, 212, 250
girls, adolescent
  and self-esteem, 375
    and boy/girl gap, 375
    and "self silencing," 370
    and standardized tests, boy-girl differences in, 377
Gnostics, 307
God, 501, 518, 540
  authority of, 528
  belief in, 500
    and evolution, 517, 520
  and certain knowledge, 424
  as creator, 506, 508, 515
  existence of, 516
  as hypothesis, 514
  and purpose, 519
  and special place of humans, 516
  submission to, 529
Goethe, Johann Wolfgang von, 1, 459, 479
  hostility to cosmology of, 43
Goodheart, Eugene, 471, 473, 475, 480
*Great Instauration, The*, 15, 266
Greece, ancient, 212, 301, 317
  and African civilizations, 305
  and Aristotle, 303
  and invention of history, 310
  and origin of culture from Africa, 411
Greek philosophers, 303, 308
  and the Egyptians, 305–307, 310
Greens, 209, 210, 218–220, 222, 223
Gross, Paul R., 16, 126, 243, 413, 459, 460, 563
Gulags, 431

Haack, Susan, 55, 79, 81, 459
harassment, sexual, 373
Harding, Sandra, 18, 101
Harvard Center for Risk Analysis, 243
Hawthorne, Nathaniel, 474
  and Oedipus complex, 474
Heidegger, Martin 97, 329, 342, 527
  and support of Nazis, 461
Heisenberg uncertainty principle, 83, 335
  and accuracy of knowledge, 129
  and objective knowledge, 128
  and reality, 126
Heisenberg, Werner, 117, 119, 143
hermeneutics, 339
Herodotus, 307, 392
Higginson, Thomas Wentworth, 484, 485
*Higher Superstition: The Academic Left and its Quarrels with Science*, 16, 126, 301
Himmler, Heinrich, 185
historians
  Afrocentrist, 303, 304
  and bias, 301, 302
historicism, 301, 454
  "New," 303
history
  ancient, 303
  bias in, 301, 302
  as cultural projection, 302
  as fiction, 302
  and science, 296
history-without-facts, 303
Hitler, Adolf, 332, 502
Hobbes, Thomas, 42, 347, 348, 351, 357
  and determinism, 293
  and epistemological validity of laboratory science, 290
  and political science, 350
Holmes, Oliver Wendell, 186
homeopathy, 188, 195, 393, 408
Homer, 302
Hooke, Robert, 42
humanism, 337, 338, 339–343, 443
  and hubris, 423, 540
  and Bruno Latour, 288, 289, 295
  and mathematics, 9
  secular, in public schools, 511
  and science, 289
Hume, David, 43, 80, 329, 330, 423, 424, 427
Husserl, Edmund, 97, 329, 342
Huxley, T. H., 505
Huygens, Christian, 42
hybrids, 289, 293, 294
  and the Edinburgh School, 292
hypotheses, falsifiable, 328, 340

ICR, 517, 518
idealism, 210
  transcendental, 98
ideology, 292
  and evidence, 243
  and hypothesis formation, 271
  as scholarship, 512
  and science, 295
  supernatural, 505
IDT, 508, 509
ignorance, 107–109
  political, rationality of, 357, 359
  willful, 108, 109
*Iliad*, 302
imperialism, Native American, 487
industrial revolution, 211, 213, 351, 430, 542
  and Cartesian dualism, 215
  and scientific revolution, 225

Institute for Creation Research (ICR), 507, 510, 514, 515, 518 (*See also* ICR)
intellectual integrity, 57, 59, 60, 61
  and advance of inquiry, 59
  and moral value, 59
intellectuals, 48
  definition of, 45
  and mathematics, 46
intelligent design theory (ID), 508–511 (*See also* IDT)
  as creation science, 509
International Association for Cancer Victims and Friends, 189
intuition, 71, 72, 89
  and belief, 87, 92
  and pattern recognition, 93, 94
  as rational, 94
irrationality
  and feminism, 386
  rescue from, 405
irreversibility, 139, 142, 146, 151–153, 155, 156, 158, 160, 163–165, 169–171
  and arrow of time, 137
  and chaos, 141
  and ergodicity, 147
  explanation of, 138
  and French philosophy, 149
  and macroscopic laws, 140
  misconceptions about, 144
  subjectivity of, 142, 143, 148

James, George G. M., 308–310
James, William, 74, 185, 494
Jaynes, E. T., 134, 144, 145, 150, 152
Jefferson, Thomas, 26, 27
Jensen, Arthur, 106
Jesus, 500, 529
Johnson, Samuel, 18
Jones, Ernest, 474
Judeo-Christian tradition, 212

Kac Ring Model, 144, 146, 151, 156, 160
Kant, Immanuel, 43, 337, 423–425, 427
Keats, John, 460, 485
Kierkegaard, Søren, 80, 329
*King Lear*, 451, 452, 454, 463–465
  conflated text of, 455
  and contemporary productions, 450
  modern texts of, as constructions, 464
  restoration of, 446
  and revisionists, 448
  two texts of, 447
Kipling, Rudyard, 420, 421
Kleppner, David, 4, 117
knowledge, objective, 18, 199
  African, 562
  and the Enlightenment, 526
  and faith, 529
  patriarchal standards of, 404
  phallocentric, 394
  possibility of, 423
  as power, 355
  as relative, 200, 201
  scientific, 416
    definition of, 562
    social construction of, 423
  as social construction, 3, 263, 264, 427
  subjective, 200
  transcultural, 428
  and women, 397
Krebs, Ernst, Jr., 189
Kuhn, Thomas, 18, 50, 331, 335, 340, 423, 325, 472, 473
Kurgans, 251, 254

La Mettrie, Julien, 214
Laetrile, 188, 189, 192, 193
Lagrange, Joseph Louis, 44
Laplace, Pierre Simon de, 44, 131, 132, 133, 136
  and determinism, 134
laser, 20
  light of, 22
Latour, Bruno, 81, 89, 91, 92, 105, 149, 257, 275–280, 282, 283
  and animus against social science, 294
  and anthropology, 292
  and critique of sociology, 219
  and the Enlightment, 289, 290, 431
  and humanists, 288, 289
  and hybrids, 295 (*See also* hybrids)
  and methodology, 293
  and the study of science, 288
Lavoisier, Antoine, 12
learning, experiential, 65, 66, 74
    and magical thinking, 71
    and transcendental belief systems, 68
  intellectual, 66
    and scientific-humanist belief systems, 68
  relation between experiential and intellectual, 66, 67
Lehrer, Ronald, 475, 476
Leibniz, Gottfried Wilhelm von, 42, 45
Lerner, Max, 181, 191, 192
Levi, Primo, 61
Lévi-Strauss, Claude, 337
Levitt, Norman, 5, 9, 16, 126, 243, 413, 459, 460, 563
liberalism
  as consistent with science and relativism, 357
  and democracy, 347
  as methodology, 361

and political science, 348
and relativism, 347, 348
and science, 346–348
*Limits of Science, The*, 14
Liouville's theorem, 152, 170
literacy, scientific (*See* scientific literacy)
literary studies, politicization of, 445
Locke, John, 350, 531, 533
logic, as patriarchal, 417
logical positivism, 329, 336, 553
London School of Economics, 328, 337, 338
Longfellow, Henry Wadsworth, 483, 484
Louis XVI, 27
Lowell, James Russell, 177, 179, 483, 484, 487, 488
Luddites, 80, 84
Luther, Martin, 80
Lysenko, T. D., 331, 332

Magic, 55, 565
Egyptians as masters of, 564
magical thought, 64, 69, 70, 77
and Sigmund Freud, 479
and experiential learning, 71
and parapsychology, 76
magnetic resonance imaging, 21
Malinowski, Bronislaw, 337, 341
Malone, Adrian, 12, 13
Marcuse, Herbert, 101, 354
Markov chains, 167
Marsden, George, 512,513
Marx, Karl, 330, 359
Marxist revolution, and educated elite, 462
Marxists (Marxism), 331, 335, 338, 339, 350, 353
and contemporary literary criticism, 457
materialism, historical, 362
mathematical research, and funding, 39
mathematics
and education, 51
and emergence of technocrats, 43, 44
feminist perspectives in, 438
and humanistic culture, 6, 39, 43, 45
illiteracy in
global consequences of, 48
and inexactitude of thought, 48, 51
and the liberal arts, 40
as prophylactic against deficiencies of thought, 49
resentment and envy of, 50
of the 17th century, 41
and understanding the world, 46, 47
Mather, Cotton, 477
Maxwell, James Clerk, 134, 149
McLuhan, M., 356, 357
Medawar, Peter, 14, 18, 27
medicine (*See also* alternative medicine)
holistic, 189, 190, 192, 196
unconventional, 183
Mendel, Gregor, 515
Mendelian genetics, 329, 330
Merchant, Carolyn, 211, 249, 426
Merton, Robert K., 105, 257, 274–278, 416, 417
Mertonians, 278, 281
and relativism, 282
Mesmer, F., 180, 185
Michelangelo, 445, 446
midwives, 409, 410, 416
Mill, John Stuart, 335, 348–350, 357, 360, 401
and democracy, 493
and women's diferences, 389, 393
Mind Projection Fallacy, 134, 136, 154
miracles, 531, 533, 536
and science, 514
modernity, 209, 210, 215, 217, 220, 221, 223, 225, 227, 283, 291, 420, 432
and ecoradicals, 219
and Bruno Latour, 290
postcolonial critics of, 433
and reactionary politics, 221
and the West, 213
Mohammed, 500
molecular amplifiers, 22
beam, 19, 20, 22
oscillator, 22
structure, 22
Monod, Jacques, 148
Monte Carlo fallacy, 71
Moral Majority, 501
moral standards, as social constructions, 513
Morris, Henry, 507, 508, 515
Morrison, Philip, 25
Morse, Samuel F. B., 557
Moses, 500
Moyers, Bill, 180–185
Mulkay, Michael, 105, 106
Mussolini, Benito, 110, 461

N-K cells, 181, 182
Nabokov, Vladimir, 18
narrative, 199
and psychotherapy, 200, 201
National Academy of Sciences, 180, 544, 552, 555
National Association of Science, 83
National Endowment for the Humanities, 555
National Institutes of Health, 32, 34, 184
National Organization for Women, 246
National Research Council, 552

National Science Education Standards, 4, 552, 555, 558
  first draft of, as based on postmodernism, 553
  second draft of, and social constructivism, 553
National Science Foundation (NSF), 34, 284, 329, 552
  Inspector General of, 32, 34, 35
National Science Teachers Association, 552
National Science Teaching Standards, 544
*National Standards for United States History*
  and slighting of role of science and technology, 556, 557
natural selection, 153, 156, 169
Nature, 486, 487
  design in, 519
  language of, 16
  and objective knowledge, 18
  rules of, 18
  and scientific literacy, 548
  sentimentalism about, as a disease, 483
  and truth, 19
  as unfriendly, 488
Nazis, 108, 185, 251, 262
  death camps of, and the Enlightenment, 431
  and Martin Heidegger, 97
  and racism, 106
near-death experience (NDE), 65, 496, 497, 499
negotiation, social, 264, 267, 275, 278, 279
neocreationism, 508
  and attacks on evolution, 509
  at the university level, 510
New Age, 2, 177, 180, 183, 185, 186, 219, 221, 246, 253, 487, 495, 562
  as age of unreason, 485
  and feminism, 250
  and Gaia principle, 378
  and healing, 181, 182, 184
New Criticism, 451, 453, 459
New Critics, 459, 466
New Historicism, 445
New York Academy of Sciences, 4, 5, 378
Newton, Isaac, 11, 18–20, 26, 27, 42, 44, 101, 211, 212, 214, 275
  and Christianity, 214
  *Principia* of, 18, 27, 42
  *Method of Fluxions* of, 43
Nietzsche, Friedrich, 425, 527
  and preemption of Freud, 476
  and Marx, 476
nihilism, 443
nihilists, postmodern, 12, 299
NMR, 20, 21
  spectroscopy, 20
"Nobel Legacy," the, 11, 12
noble savage, 483, 486
non-Western societies, knowledge systems of, 426
nonreality, construction of, 199, 201
NSF, 35
  Inspector General of, 32, 34, 35
Nubia, 317, 318, 323
nuclear magnetic resonance, 20 (*See also* NMR)
nuclear spin, 20, 21
  structure, 21

Objectivism, 218–220
objectivity, 2, 122, 416, 417
  assault on, 378
  challenges to, 188
  and Sigmund Freud, 478
  and context of justification, 270
  Kantian, 204
  postmodern critique of, 461
  and quantum physics, 123
  and reality, 204
  scientific, 343
Office of Alternative Medicine, 188, 191, 194
Office of Research Integrity of the Public Health Service, 32, 35
Office of Technology Assessment, 190
Office of Unconventional Medical Practices (UMP), 184 (*See also* UMP)
Olmsted, Frederick Law, 487
Oppenheimer, Robert, 555
Oxford Catholics, 337, 338

Paley, William, 519
  and IDT, 508
paradisciplines, 414, 415, 416
paranormal phenomena, 491, 494–496, 498
  media coverage of, 502
Parapsychological Society, 497
parapsychology, 74–76, 106, 495, 497, 565
  and pseudoscience, 564, 565
  and religion, 75
  as a science, 75
Parsons, Talcott, 416, 417
Parteo, Vilfredo, 101, 102
Pascal, Blaise, 72
Pasteur, Louis, 13
patriarchal institutions, 431
patriarchal practices, 421
patriarchal thinking, 413
patriarchy, Western, 422
Paul, Saint, 80, 528, 529
Pauling, Linus, 189, 190, 280
Paulos, John Alan, 47, 48

Pavlov, I. P., 331
peer review, 36, 37
  and referees, 36, 37
    and conflict of interest, 36
Peirce, Charles Sanders, 57, 58, 61
Penrose, R., 140, 141, 146, 153
Pepys, Samuel, 42
*Personal Knowledge*, 18
perspectivism, 473
Petrarch, 483, 484
phallocentricity, 386
phenomenological sociology, 98
phenomenology, 97–99
philosophy, 79, 95
  Greek, 303, 308
    and the Egyptians, 305–307, 310
PHS, 35
physics
  foundations of, 117
  and reality, 117
Piaget, Jean, 68
Piltdown man, 33, 105
placebo effect, 565
  and acupuncture, 193
  and therapeutic touch, 565, 566
plagiarism, 34, 35
Planck, Max, 143
Plato, 79, 212, 304, 426
  and Egypt, 307, 308
Plumwood, Val, 210–212, 214, 215
Poe, Edgar Allan, 483, 484, 487
Poincaré cycles (recurrences), 157, 159, 164, 165
Poincaré recurrence theorem, 144, 149
Poincaré, Jules Henri, 48, 103, 104, 134, 138
Polanyi, Michael, 17, 18
political science
  as liberal science, 350
  and public opinion, 347
  and survey research, 353
political scientist, 304
  and generalizations, 303
politics and meaning, 361
Popper, Karl, 109, 143, 148, 149, 328, 334
  and scientific method, 341
  and the Second Law, 153
positivism, 99, 338, 354, 360
postmodernism, 49, 97 117, 120, 188, 194, 198, 200, 210, 216–219, 221 223–225, 227, 257, 357, 362, 420, 433, 520
  and assault on science, 95
  and cognitive equivalence of all knowledge claims, 423
  and deconstruction, 226
  ecological, 228
  and evidence as construct, 218
  Green version of, 223
  and reason, 55
  and rejection of Enlightenment, 494
  and rejection of objective scientific knowledge, 494
  roots of, 226
  and science, 220
  and science as socially constructed, 1
  and truth of scientific knowledge, 553
poststructuralism, 210, 219, 433, 453, 459
  and personal agency, 467
  and support of murderous regimes, 461
pragmatism, 349
Prigogine, Ilya, 117, 131, 132, 135, 147, 150, 153, 154
  and Boltzmann, 143
  and irreversibility, 138, 141, 144
  and Liouville's theorem, 152
probabilism, fideistic defense of, 533
probabilities, and ignorance, 136
probability, 531
  and degrees of credibility, 533
  and faith, 530
  and knowledge claims, 532
propaganda, 188, 192, 196
  Afrocentrist, 538
  religious, 501
Protestantism, 425
pseudobelief, 58
pseudoinquiry, 57, 58, 61
pseudoscience, 104, 105, 564, 481
  academic, 101, 107, 110
  and Herbert Spencer, 337
pseudoscientists, 97, 378, 539
psychic phenomena, 496
psychoanalysis, 328, 470
  and artistic endeavor, 474
  and empiricism, 481
  as Faustian, 479
  and the humanities, 480
  and "repressed abuse," 471
  and the science impaired, 478
psychokinesis, 495
psychology
  adolescent, 375
  moral, and gender differences, 370
  and Oedipus complex, 471
    and Gnostic divination, 477
psychotherapists, 177
psychotherapy, 178, 198 (*See also* therapy)
  as narrative, 200, 201
Ptolemaic system, 90
Public Health Service, 34 (*See also* PHS)
public opinion
  American, incoherence of, 356

and poll, 352
and social change, 354
and specificity, lack of, 357
study of, 350, 352
and "Old Left" critique, 353
progress in, 353
Purcell, Henry, 21, 22
Pyrrhonism, 528, 532, 534
Pythagoras, 47
Pythagoras, and visit to Egypt, 308

Quantum mechanics, 117, 119, 121, 122, 126, 128, 133, 161–163, 164, 335
and antirealism, 203
and atomic and molecular identity, 129
and common sense, 127
limitations of, 130
and objectivity, 123
quantum philosophy, 117, 119, 120–123
quantum theory, 20, 120, 162 (*See also* quantum mechanics)
Quetelet, Adolphe, 351
and average man, 353, 357
and statistics, 364
Quine, Willard, 335

Rabi, Isidor Isaac, 20, 21, 24, 25, 27
race as social concept, 317, 318
racial categories
and black/white distinction, 316, 317
Eurocentric criteria for, 316
social nature of, 318
racism, "scientific," 106
and Mendelian ratios, 333
radio frequencies, 21
radioastronomy, 22
and radiofrequency spectroscopy, 22
rationalism, 491
and hubris, 537
scientific, 526
rationality
and culture, 423, 425
and gynophobia, 426
and independent reality, 428
and individual autonomy, 427
and science, 55
scientific, 420, 421
feminist critiques of, 425
and transcendence of culture, 426
and universality, 427
substantive, 350, 363
and women, 424, 426
realism, 198, 199, 257
scientific, 299
reality
construction of, 199
creation of, 201
distortion of, 200, 201
experience of, 200
extralinguistic, 204
independent, 199, 200
access to, 205
knowable, 199
as linguistic construction, 202, 205
mental constructions as, 205
objective, 198, 205, 427, 433
and methodology of science, 513
social construction of, 347
subjective, 199
as text, 289
reason
affirmation of, 420
and autonomy, 422
and common sense, 80
as culture, 426
and democracy, 491
and emancipation, 422
and faith, 432
masculine bias of, 420
postcolonial critics of, 426
and postcolonial women, 421
postmodernist critique of, 421
rejection of, 2
scientific, and power, 427
and truth, 424
Western male concept of, 423
and women's autonomy, 431
reasoning
fake, 61
and evidence, 58
and indifference to truth, 59
probabilistic, 71, 73
recovered memory, 470, 480
reductionism, 164, 171, 186, 194
reductivism, 292, 294
Latour's rejection of, 292
and sociologists, 291, 293
Religious Right, and theocracy, 523, 525
reincarnation, 497, 499
relativism, 177, 192, 257, 276, 281, 282, 300, 335, 336, 346, 435, 461
antiscientific, 341
cognitive, falsity of, 434
of constructivists, 284
cultural, 339
epistemological, 275, 299, 340
and liberalism, 347, 348
and John Stuart Mill, 349
moral, 513
and science, 347
relativist-constructivist, 274–276, 282
program of, 283
relativity, 126, 128
and common sense, 127

general, 127
special, 127, 167
religion, 499
beliefs of, 294
persistence of beliefs of, 494
and the political process, 500
and rational inquiry, 491
and scientific skepticism, 500
Renaissance, 303
reporting (media), "balanced," 195, 196
and environmental issues, 242
resonant changes of state, 21, 22
Rhine, Joseph Banks, 75, 495
Roman Catholic church, 216
and evolution, 506
Romantic style, and reaction against rational thought, 43
Romanticism, 460
and the New Critics, 461
and reason, 461
Rome, ancient, 303
Rorty, Richard, 57, 60, 61, 81, 82, 335
Rousseau, Jean Jacques, 373, 483, 485, 488
Russell, Bertrand, 40, 50, 79
Ryle, Gilbert, 79, 88

Sagan, Carl, 12, 25, 106
Salem witch trials, 179
Sartre, Jean-Paul, 81
Schrödinger, Erwin, 120
Sci-Tech-Studies (STS), 6
science (*See also* sociology of science)
accessibility of, 25
Afrocentric, 568
and authority, 81, 82
as biased, 323
and changes in commitment, 554
cognitive content of, and social factors, 277, 279, 280
and common sense, 80, 502
and comprehension, 14
and control, 14
and critical thinking, 74
creativity in, 18
and culture, 226
as egalitarian, 82
and emancipation, 432
epistemology of, and the supernatural, 518
as epistemological system, 333
feminist perspectives in, 438
feminist critiques of, 563
and fraud, 31
and free inquiry, 271
freedom of, 17
goal of, 16
history of, 25
hostility towards, 9
and hubris, 333, 334
ideals of, 329
and independent reality, 426
as irrational, 87, 92
and liberalism, 346–348, 362
and male domination, 81, 82
metaphors for, 15
as language, 16
as path finding, 16, 17
as problem solving, 16, 17
method of, 388, 562
changing standards of, 394
as ethos, 429
misconduct in, 31, 37
and "fabrication, falsification [and] plagiarism" (ffp), 34
organization of, 261
outcome of, and social processes, 278
pathological, 378
as patriarchal, 563
perspectivist model of, 563
as politics, 266
pragmatic success of, and postmodernist critics, 428
postmodern attack on, 360
public perception of, 9
and public policy, 14
and religion, 74, 75, 491
reproducibility of results of, 33
resentment of, 207
and "science criticism," 24
as self-correcting, 31, 33
of society, 290 (*See also* social science, sociology, sociology of science, sociologists of science)
as social enterprise, 74, 106, 257, 280
and the social order, 431
and sociobiological explanations, 563
study of, 288
and technology, 333
confusion between, 333
as texts, 289
and theism, 515
truth of, 332, 334, 335
and deconstruction, 334
misuse of, 333
as relationship between knower and known, 337
and triviality, 329, 332
and ultimate questions, 27
uses of, 329, 333, 334
*Science and Antiscience*, 16
*Science and Human Values*, 15
science education, 14, 24
and Arnold, Matthew, 44
and economics, 25

and general culture, 25
and history, 26
and mathematics, 27
and political science, 26
quality of, 551
"Science in American Life" (exhibit), 4
at Smithsonian Institution, and political ideology, 558
science literacy, and teaching of evolution, 505
science studies
and the Edinburgh school, 292
and the political left, 49
scientific community, 562
scientific culture, 424
scientific illiteracy, 561, 564
scientific literacy, 537, 543
and ability to do science, 547
definition of, 543
and Nature, 548
scientific revolution, 212, 214, 421, 426, 432, 540, 564
and patriarchal thinking, 413
scientists
community of, 17
political views of, 232
Scientology, 502
Scopes, John T., 508
Second Law of Thermodynamics, 144, 147, 153, 154, 163, 165, 169, 564
and entropy, 151, 152
second-order beliefs
absence of feminist reasons for, 400
and feminism, 390
secular humanism, in public schools, 511
self-esteem
and African-American boys and girls, 376
fake crisis in, 378
and gap between boys and girls, 375
and girls, adolescent, 375
sexism, male, 247
Shakespeare, William, 24, 445, 446–448, 451, 455, 463, 464
artistic judgment of, 449
and historicism, 454
as modernist, 456
Sheldrake, Rupert, 211
Shelley, Percy Bysshe, 460
Sidgwick, Henry, 74, 75, 494
skepticism, 296, 526
Academic, 534
and Pierre Bayle, 528
and Christianity, 527
as emancipatory, 527
and fideism, 527, 528, 533
mitigated, 526, 532, 535
Pyrrhonian, 532
Skinner, B. F., 214
Smith, Adam, 541
Smith, Joseph, 500
Smithsonian Institution
and bias against science, 559
and trivializing portrayal of science, 558
Snow, C. P., 24, 45, 128
social sciences, 290, 291
and exact sciences, 49
and Bruno Latour, 295
as pathological, 369
and reductionism, 291
social construction of, 284
and Bruno Latour, 291
and survey research, 354
Society for Psychical Research (SPR), 74, 494, 495 (*See also* SPR)
Society for the Social Study of Science, 274, 281
sociobiology, 332, 340
sociologists of science, 276, 277
and social constructivists, 284
sociology, 292
classical, 294
elitist, 293
sociology of knowledge, 87, 259, 264, 330, 335
sociology of science, 87, 109, 257, 259, 262, 264, 274, 294
constructivist, 282
Edinburgh School of, 262, 292, 296
and evidence, 260
post-Mertonian, 105
and social construction, 284
sociologists of science, 276, 277
and social constructivists, 284
Socrates, 304, 305, 308
SPR, 75
St. Vincent Millay, Edna, 40
Stalin, 332, 502
"standpoint" criticism, 3,4
statistical mechanics, 117, 162, 164, 169
statistics, 351, 353
delevopment of, 351
Steinem, Gloria, 247, 377
Stengers, Isabelle, 131, 135, 147, 150, 154
and irreversibility, 141
and Liouville's theorem, 152
Stern, Otto, 19–22
Stevens, Wallace, 467
Stich, Stephen, 57, 60, 61
structuralism, 350
structuralists, and social anthropology, 328
subjective probability, 103
subjectivism, 98, 105
subjectivity, 120, 201

supernatural causes
  and creationism, 514
  Egyptian science and, 563
  as explanations in science, 564
survey research, criticisms of, 352
Swift, Jonathan, 80, 328

Tacitus, 302
Tainos, 487, 488, 569
Tate, Nahum, 450, 465
technology
  feminist, 107
  and science, 333
Tertullian, 80, 529
theocracy
  and Islam, 524
  and Religious Right, 523, 525
theories
  impossibility of, as feminist, 402
  and knowledge, 3
  patriarchal, 402
  phallocentric, 402
theory ladenness, 427
theory saturation, 427, 428
therapies (medical)
  complementary, 191
  nontraditional, 191
  unconventional, 191
therapy (psychotherapy), 198
  antirealism in, 204
  and constructivism, 203
  constructivist/constructionist, 200
    and antirealism, 201
    logical inconsistency of, 201
  individualizing of, 203
    and antirealism, 204
  narrative paradigm for, 200
  systematization of, and completeness, 204
  systems of, 203
thermodynamics, 165, 170, 171
  and entropy, 151, 163, 169
Thomas, Lewis, 25
Thoreau, Henry David, 483
tobacco, as carcinogen, 233, 234, 237
trajectory, 131, 136, 139, 142, 145, 160, 163, 167
  and probabilities, 135
TRF, 278–280, 283
Trilling, Lionel, 180, 480
truth, 16, 57
  assault on, 378
  as context-dependent, 100
  as epistemologically relative, 336
  and evidence, 58
  and feminists, 433
  indifference to, 59
  and the inquirer, 58, 59
  and instrumental value, 60
  and moral value, 60
  and need for science, 341
  objective, 96
  as purpose of inquiry, 55
  and social context, 335
  and truth, 335

UFOlogy, 495, 498
UMP, 184, 185
Urkowitz, Steven, 449, 450
utilitarianism, 348
utility, subjective, 104

Velikovsky, Immanuel, 105, 106
Verlaine, Paul, 84
Voltaire, 27, 40, 43, 528
von Neumann, John, 121, 123, 150

Walter of Chatillion, 40
Watson, James, 12, 280
wave-particle duality, 123
  and antiscientists, 129
Weber, Max, 330, 335, 336, 423–425, 428, 429, 473
West, the, 213, 221, 224, 225, 421
  and colonialism, 431
  critics of, 79
  and Freud, 478
  intellectual history of, 60
Western civilization, 216, 217, 303, 483
Western culture, 216, 370, 372
Western philosophy, 215, 219, 226
Western rationalist tradition, 426
Western science, 216, 562, 564
Western thought, 213, 214
Whitman, Walt, 460
Wigner, E. P., 121, 122, 150
Wittgenstein, Ludwig, 79, 95, 423, 425
  and Freudian unconscious, 477
women
  and knowledge, 397
  psychological development of, 372
  and rationality, 424, 426
Women's Environment and Development Organization, 247
Women's Foreign Policy Council, 247
women's studies
  and paradisciplines, 414
  place of science and epistemology in, 402
Woolgar, Steve, 275, 27–280, 282
Wordsworth, William, 459, 460, 486

XY fetus, 19

Yeats, W. B., 463, 465–467

Zermelo, E., 138, 144, 149

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