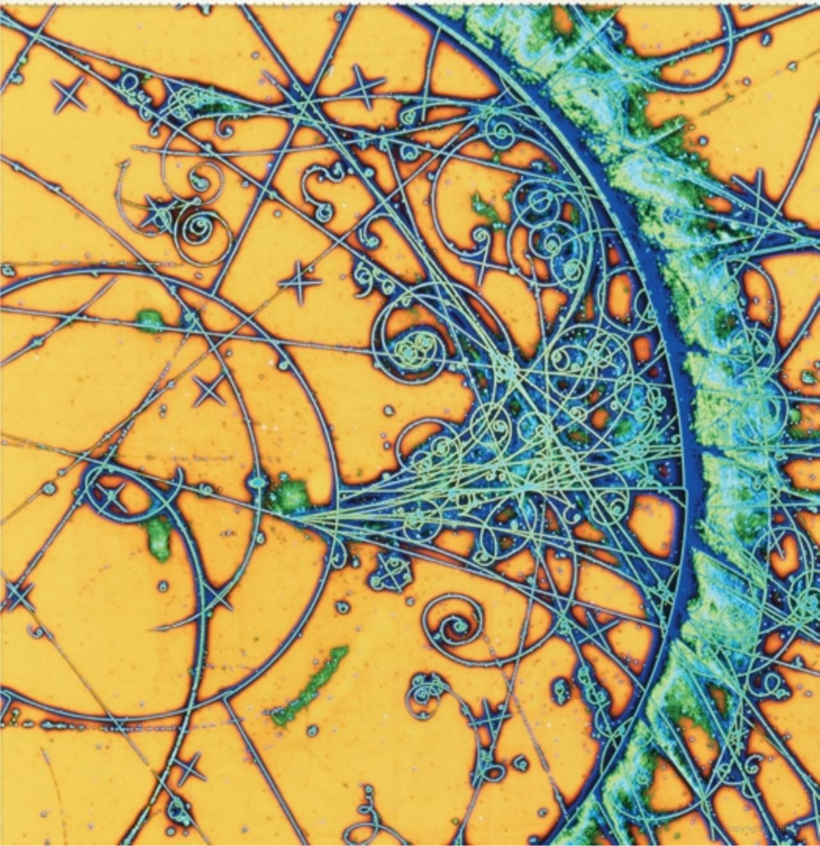
THE SCIENTIST AS REBEL

A NEW YORK REVIEW COLLECTION

FREEMAN DYSON



THIS IS A NEW YORK REVIEW BOOK

PUBLISHED BY THE NEW YORK REVIEW OF BOOKS

435 Hudson Street

New York, NY 10014

www.nyrb.com

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by Freeman Dyson

This edition published in 2008 in the United States of America by The New York Review of Books

The Library of Congress has catalogued the hardcover edition of this book as follows:

Dyson, Freeman J.

The Scientist as Rebel / by Freeman J. Dyson.

p. cm.

Includes bibliographical references.

ISBN-13: 978-1-59017-216-2 (alk. paper)

ISBN-10: 1-59017-216-7 (alk. paper)

1. Science. 2. Physics. 3. Science—History. 4. Science—Moral and ethical aspects. 5. Dyson, Freeman J.—Biography. 6. Scientists—United States—Biography. I. Title. Q158.5.D977 2006

500—dc22

2006022081

ebook ISBN: 978-1-59017-881-2

v3.1

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Preface

BENJAMIN FRANKLIN COMBINED better than anyone else the qualities of a great scientist and a great rebel. As a scientist, without formal education or inherited wealth, he beat the learned aristocrats of Europe at their own game. His victory encouraged him to believe that he and his fellow citizens in America, without much training in military strategy or international politics, could beat the aristocrats of Europe at warfare and diplomacy. Franklin's triumph as a rebel resulted from the fact that his rebellion was not impulsive but was carefully thought out over many years. For most of his long life, he was a loyal subject of the British King. He lived for many years in London, representing the Commonwealth of Pennsylvania in dealings with the British government, calmly taking the measure of his future enemies.

While he was in London, Franklin was an active member of the Society for the Encouragement of Arts, Manufactures and Commerce, which still flourishes today. The society encouraged inventions and manufactures by offering financial subsidies and prizes to inventors and entrepreneurs. The prizes were usually available to all subjects of the King in England or America, but they were often targeted to subsidize colonial enterprises that the society considered desirable. When Franklin first joined the society in 1755, he was an enthusiastic supporter of its efforts to encourage invention, which he saw as complementary to the efforts of his own Philosophical Society in America. But as the years went by, his attitude became more critical. He never openly disagreed with the society and remained a member in good standing, all through the War of Independence and afterward until his death. But he recorded privately, in the margin of a book, his true feelings about the system of prizes and subsidies offered by the society:

> What you call Bounties given by Parliament and the Society are nothing more than Inducements offered to us, to induce us to leave Employments that are more profitable and engage in such as would be less so without your Bounty; to quit a Business profitable to ourselves and engage in one as shall be profitable to you; this is the true Spirit of all your Bounties.

He wrote these words in 1770, five years before the outbreak of the war that ended British rule in the thirteen colonies.

Franklin became a rebel only when he judged the time to be ripe and the costs to be acceptable. As a rebel he remained a conservative, aiming not to destroy but to preserve as much as possible of the established order of society. As a diplomat in Paris, he fitted smoothly into the established order of prerevolutionary France. He would not have fitted so well into the France of Danton and Robespierre ten years later. The rebellion that Franklin embodied was a thoughtful rebellion, driven by reason and calculation more than by passion and hatred.

In spite of its title, this book is mostly not about rebel scientists. It is a collection of book reviews, prefaces, and essays on a variety of subjects. The majority were published in *The New York Review of Books*. I am grateful to *The New York Review* for inviting me to collect these in a book, and for allowing me to supplement them with other pieces that were published in other places. The bibliographical notes at the end explain where each piece was published and how it originated. The collection is divided into four sections according to subject matter, and arranged chronologically within each section. Section I deals with political issues arising out of science and technology. Section II deals with problems of war and peace. Section III deals with the history of science, and Section IV with personal and philosophical reflections. By accident rather than by design, at least one rebellious scientist appears in each section. But there are pieces about scientists such as John Cockcroft and Ernest Walton (Chapter 21) who were far from being rebels, and pieces such as the review of Max Hastings's *Armageddon* (Chapter 13) that are concerned with soldiers rather than with scientists.

One of the pleasures of writing for *The New York Review* is the fact that it publishes long reviews. The reviewer is asked to write about four thousand words, which means that the review can be an essay reflecting on the subject matter rather than a simple appraisal of a book. The short reviews in this collection were published in other journals. If this book is a sandwich, the meat is the series of twelve long reviews from *The New York Review*, most of them appearing in Section III. There are four other meaty items that were not in *The New York Review*. One is the Bernal lecture (Chapter 24), which Carl Sagan whimsically published as an appendix to the proceedings of a conference on communication with extraterrestrial intelligence. The other three (Chapters 8, 9, and 10) are chapters from my book *Weapons and Hope*, which is now out of print. The collapse of the Soviet Union made much of *Weapons and Hope* obsolete, but these three historical chapters may be worth preserving.

The essay "The Scientist as Rebel," with which this collection begins, originated as a talk given at a meeting of scientists and philosophers at Cambridge, England, in November 1992. The talk was dedicated to the memory of Lord James of Rusholme, who had died six months earlier at the age of eighty-three, full of years and honors, having risen to the top of the British educational establishment. The obituary notices that were published in newspapers after his death described him as a capable organizer and administrator who presided over the founding of York University and served as its vice-chancellor for the first eleven years of its existence, from 1962 to 1973. They said that he had conservative views on the subject of education, that he believed in old-fashioned scholarship and academic rigor, that he fought hard to make York University a community of scholars and an intellectual powerhouse on a level with Oxford. “Jude the Obscure,” he was quoted as saying, “need no longer look despairingly at the towers and spires of an inaccessible university, provided he has three good A-level passes, can satisfy one of a multiplicity of entrance requirements, and is prepared, if necessary, to do without spires.” He tried to make York University the home of an intellectual elite, an elite based upon brains and competitive examinations rather than money and social class. His elitist view of education came into collision with the dominant political currents of the 1950s and 1960s. The dominant view held that Jude should be enrolled in a university whether or not he was able to pass the A-level examinations. The dominant view held that higher education should be for everybody and not only for the bright. In the end, Lord James fought in vain against what he considered the folly of the politicians. Whenever he lost a battle in his campaign for strict intellectual standards, he liked to quote the lines of the poet Matthew Arnold:

Let the victors, when they come,
When the forts of folly fall,
Find thy body by the wall!

I dedicated “The Scientist as Rebel” to Lord James because he was, like Benjamin Franklin, a scientist and a rebel. Like Franklin, he achieved great things as a rebel because he was aiming to build a new society rather than to destroy an old one. Like Franklin, he built institutions to last. After he had achieved his goal of building a new university, he was a conservative administrator. But I knew him very well thirty years earlier, long before any of us dreamed that he might one day be sitting in the House of Lords. In those days he was plain Eric James, a teacher of chemistry in the school at Winchester where I was a boy. He had published a successful textbook, *Elements of Physical Chemistry*, that was widely used in schools. He was indeed a scientist, and he was a rebel and an outsider, who brought a draft of fresh air into the stuffy old chambers of Winchester College. But he also understood the value of tradition. He was big enough to see both sides of the picture. At Winchester, where intellectual traditions are taken for granted, we saw Eric the reformer. At York in the 1960s, when intellectual standards were everywhere under attack, we saw Eric the traditionalist. Between Winchester and York he spent seventeen years as high master of Manchester grammar school. At Manchester in the postwar years he occupied the middle ground in a society rebuilding itself. Manchester gave him the opportunity to combine the two main purposes of his life, the education of gifted children and the reform of society.

My most vivid memory of Eric comes from the summer of 1941. Since many of the regular farmworkers had been drafted into the army, schoolchildren and teachers were invited to help out on the farms during school vacations. We were encamped together for two rain-drenched weeks at Hurstbourne Priors in rural Hampshire, trying to rescue a sodden harvest of wheat and oats, with the grain already sprouting green out of the sheaves. In those days the farmers did not have heated drying sheds. A wet August meant a spoiled harvest. We worked in the fields all day and discussed the meaning of existence in our tents at night. Those two weeks were in retrospect the high point of my school days, breaking out of the academic cocoon and seeing something of the world outside, with Brechtian commentaries provided by Eric and his wife, Cordelia. Cordelia fought bravely for fifty years at Eric's side against the forts of folly. At Hurstbourne Priors Eric and Cordelia came into collision with Lord Lymington, who owned the land on which we were working. This was the same Lord Lymington who appears in Chapter 17 of this book, the review of James Gleick's biography of Newton. Lord Lymington had inherited Newton's manuscripts and carelessly dispersed them all over the world by selling them at auction in small lots. Eric and Cordelia entertained us at night with accurate imitations of Lord Lymington's high-pitched voice and fatuous oratory.

When Eric James died in 1992, the film *Dead Poets Society* was playing in movie theaters. It is a story about an upper-class American prep school and an English teacher who gets into trouble because he doesn't stick to the established curriculum. The theme of the film is rebellion. The established curriculum is asinine, the headmaster is a stuffed shirt, and the only redeeming feature of the school is the English teacher and a bunch of rebellious boys whom he encourages to break the rules. The film was a fitting memorial to Eric. Our school in Winchester was like the school in the film. The atmosphere was the same, with the rebellious boys and the smooth-talking headmaster. Instead of holding meetings in a cave at night, we took advantage of the wartime blackout to climb over the rooftops and up the chapel tower. And instead of a subversive English teacher we had our subversive chemistry teacher. Like the teacher in the film, Eric James had a passion for poetry. He had a Ph.D. in chemistry, but he understood that it made no sense to bore us with formal lectures about chemical reactions which we could learn about much quicker from textbooks. So he put aside the ferrous and ferric oxides and read us the latest poems of Auden and Isherwood and Dylan Thomas and Cecil Day Lewis, the poets who were then speaking for the younger generation in the first desperate years of World War II.

Forty years later I met Eric James at a party at York University, after his retirement as vice-chancellor. It was the first time I had seen him since I was seventeen. I started the conversation with a quote from one of the poems he had read to us forty years earlier, a poem by Day Lewis about the war in Spain:

They bore not a charmed life.
They went into battle foreseeing
Probable loss, and they lost.

Eric continued without a break from his own memory:

The tides of Biscay flow

Over the obstinate bones of many, the winds are sighing
Round prison walls where the rest are doomed like their ship to rust,
Men of the Basque country, the Mar Cantabrico.

Fortunately our headmaster, unlike the headmaster in the film, was wise enough to tolerate Eric James and give him a free hand. Eric was accepted into the English educational hierarchy, became a headmaster himself, founded a university, and was rewarded by a grateful government with a baronial title. It is hard to imagine a prep school chemistry teacher in the United States ending his career in so exalted a fashion. But Eric remained in his heart a rebel. Through forty years of active and creative life he remembered the sadness and the passion of the 1940s when we saw Hell break loose on Earth. That sadness and that passion are a part of our lives still. That sadness and that passion are what made Eric James a great teacher.

The life of Eric James demonstrates that there is no contradiction between a rebellious spirit and an uncompromising pursuit of excellence in a rigorous intellectual discipline. In the history of science, it has often happened that rebellion and professional competence went hand in hand. Several chapters in this book are devoted to famous scientists who were also famous rebels. Thomas Gold (Chapter 3) was a great astronomer with heretical opinions about many subjects. Joseph Rotblat (Chapter 12) was unique as a scientist who walked out of the wartime Los Alamos bomb project when he learned that the threat of a German atomic bomb had disappeared. Norbert Wiener (Chapter 22) was a great mathematician who refused on moral grounds to have anything to do with either industry or government. Desmond Bernal (Chapter 24) was one of the founding fathers of molecular biology, and also a faithful member of the Communist Party and a passionate believer in Marxism. Three chapters (23, 25, and 26) are devoted to my teacher Richard Feynman, the physicist who most closely resembled Eric James. Feynman was another rebellious spirit who combined a serious dedication to science with joyful adventures in the world outside.

The scientist who described most eloquently the role of the rebel in science was the paleontologist Loren Eiseley. Unfortunately Eiseley does not have a chapter in this book. He was a wonderful writer, best known to the general public through his books *The Immense Journey* and *The Unexpected Universe*, which tell poignant stories about the creatures, living and dead, that Eiseley encountered in the course of his work as a naturalist and fossil hunter. The most personal of his books is his autobiography, *All the Strange Hours*. In it Eiseley explains why he is a rebel, why he is a poet, why he feels less kinship with his academic colleagues than with a doomed prisoner escaped from jail on a winter's night and hunted to death in the snow. Eiseley's image of the prisoner bleeding in the snow, Day Lewis's image of the Spanish sailors rusting in Franco's prison, both are images of the human condition as valid today as they were sixty years ago.

—Freeman Dyson, Princeton, 2006

I

Contemporary Issues in Science

1

THE SCIENTIST AS REBEL

THERE IS NO such thing as a unique scientific vision, any more than there is a unique poetic vision. Science is a mosaic of partial and conflicting visions. But there is one common element in these visions. The common element is rebellion against the restrictions imposed by the locally prevailing culture, Western or Eastern as the case may be. The vision of science is not specifically Western. It is no more Western than it is Arab or Indian or Japanese or Chinese. Arabs and Indians and Japanese and Chinese had a big share in the development of modern science. And two thousand years earlier, the beginnings of ancient science were as much Babylonian and Egyptian as Greek. One of the central facts about science is that it pays no attention to East and West and North and South and black and yellow and white. It belongs to everybody who is willing to make the effort to learn it. And what is true of science is also true of poetry. Poetry was not invented by Westerners. India has poetry older than Homer. Poetry runs as deep in Arab and Japanese culture as it does in Russian and English. Just because I quote poems in English, it does not follow that the vision of poetry has to be Western. Poetry and science are gifts given to all of humanity.

For the great Arab mathematician and astronomer Omar Khayyam, science was a rebellion against the intellectual constraints of Islam, a rebellion which he expressed more directly in his incomparable verses:

> *And that inverted Bowl they call the Sky,*
> *Whereunder crawling cooped we live and die,*
> *Lift not your hands to It for help,*
> *—for It*
> *As impotently rolls as you or I.*

For the first generations of Japanese scientists in the nineteenth century, science was a rebellion against their traditional culture of feudalism. For the great Indian physicists of this century, Raman, Bose, and Saha, science was a double rebellion, first against English domination and second against the fatalistic ethic of Hinduism. And in the West, too, great scientists from Galileo to Einstein have been rebels. Here is how Einstein himself described the situation:

> When I was in the seventh grade at the Luitpold Gymnasium in Munich, I was summoned by my home-room teacher who expressed the wish that I leave the school. To my remark that I had done nothing amiss, he replied only, "Your mere presence spoils the respect of the class for me."

Einstein was glad to be helpful to the teacher. He followed the teacher's advice and dropped out of school at the age of fifteen.

From these and many other examples we see that science is not governed by the rules of Western philosophy or Western methodology. Science is an alliance of free spirits in all cultures rebelling against the local tyranny that each culture imposes on its children. Insofar as I am a scientist, my vision of the universe is not reductionist or antireductionist. I have no use for Western isms of any kind. I feel myself a traveler on the "Immense Journey" of the paleontologist Loren Eiseley, a journey that is far longer than the history of nations and philosophies, longer even than the history of our species.

A few years ago an exhibition of Paleolithic cave art came to the Museum of Natural History in New York. It was a wonderful opportunity to see in one place the carvings in stone and bone that are normally kept in a dozen separate museums in France. Most of the carvings were done in France about 14,000 years ago, during a short flowering of artistic creation at the very end of the last ice age. The beauty and delicacy of the carving is extraordinary. The people who carved these objects cannot have been ordinary hunters amusing themselves in front of the cave fire. They must have been trained artists sustained by a high culture.

And the greatest surprise, when you see these objects for the first time, is the fact that their culture is not Western. They have no resemblance at all to the primitive art that arose 10,000 years later in Mesopotamia and Egypt and Crete. If I had not known that the old cave art was found in France, I would have guessed that it came from Japan. The style looks today more Japanese than European. That exhibition showed us vividly that over periods of 10,000 years the distinctions between Western and Eastern and African cultures lose all meaning. Over a time span of 100,000 years we are all Africans. And over a time span of 300 million years we are all amphibians, waddling uncertainly out of dried-up ponds onto the alien and hostile land.

And with this long view of the past goes Robinson Jeffers's even longer view of the future. In the long view, not only European civilization but the human species itself is transitory. Here is the vision of Robinson Jeffers, expressed in different parts of his long poem "The Double Axe."

> *"Come, little ones.*
> *You are worth no more than the foxes and yellow*
> *wolfkins, yet I will give you wisdom.*
> *O future children:*
> *Trouble is coming; the world as of the present time*
> *Sails on its rocks; but you will be born and live*

Afterwards. Also a day will come when the earth
Will scratch herself and smile and rub off humanity:
But you will be born before that."

"Time will come, no doubt,
When the sun too shall die; the planets will freeze, and the air on them; frozen gases, white flakes of air
Will be the dust: which no wind ever will stir: this very dust in dim starlight glistening
Is dead wind, the white corpse of wind.
Also the galaxy will die; the glitter of the Milky Way, our universe, all the stars that have names are dead.
Vast is the night. How you have grown, dear night, walking your empty halls, how tall!"[1]

Robinson Jeffers was no scientist, but he expressed better than any other poet the scientist's vision. Ironic, detached, contemptuous like Einstein of national pride and cultural taboos, he stood in awe of nature alone. He stood alone in uncompromising opposition to the follies of the Second World War. His poems during those years of patriotic frenzy were unpublishable. "The Double Axe" was finally published in 1948, after a long dispute between Jeffers and his editors. I discovered Jeffers thirty years later, when the sadness and the passion of the war had become a distant memory. Fortunately, his works are now in print and you can read them for yourselves.

Science as subversion has a long history. There is a long list of scientists who sat in jail and of other scientists who helped get them out and incidentally saved their lives. In our century we have seen the physicist Lev Landau sitting in jail in the Soviet Union and Pyotr Kapitsa risking his own life by appealing to Stalin to let Landau out. We have seen the mathematician André Weil sitting in jail in Finland during the Winter War of 1939–1940 and Lars Ahlfors saving his life. The finest moment in the history of the Institute for

Advanced Study, where I work, came in 1957, when we appointed the mathematician Chandler Davis a member of the institute, with financial support provided by the American government through the National Science Foundation. Davis was then a convicted felon because he refused to rat on his friends when questioned by the House Un-American Activities Committee. He had been convicted of contempt of Congress for not answering questions and had appealed his conviction to the Supreme Court.

While his case was under appeal, he came to Princeton and continued doing mathematics. That is a good example of science as subversion. After his institute fellowship was over, he lost his appeal and sat for six months in jail. Davis is now a distinguished professor at the University of Toronto and is actively engaged in helping people in jail to get out. Another example of science as subversion is Andrei Sakharov. Davis and Sakharov belong to an old tradition in science that goes all the way back to the rebels Benjamin Franklin and Joseph Priestley in the eighteenth century, to Galileo and Giordano Bruno in the seventeenth and sixteenth. If science ceases to be a rebellion against authority, then it does not deserve the talents of our brightest children. I was lucky to be introduced to science at school as a subversive activity of the younger boys. We organized a Science Society as an act of rebellion against compulsory Latin and compulsory football. We should try to introduce our children to science today as a rebellion against poverty and ugliness and militarism and economic injustice.

The vision of science as rebellion was articulated in Cambridge with great clarity on February 4, 1923, in a lecture by the biologist J.B. S. Haldane to the Society of Heretics. The lecture was published as a little book with the title *Daedalus*. Here is Haldane's vision of the role of scientist. I have taken the liberty to abbreviate Haldane slightly and to omit the phrases that he quoted in Latin and Greek, since unfortunately I can no longer assume that the heretics of Cambridge are fluent in those languages.

> The conservative has but little to fear from the man whose reason is the servant of his passions, but let him beware of him in whom reason has become the greatest and most terrible of the passions. These are the wreckers of outworn empires and civilizations, doubters, disintegrators, deicides. In the past they have been men like Voltaire, Bentham, Thales, Marx, but I think that Darwin furnishes an example of the same relentlessness of reason in the field of science. I suspect that as it becomes clear that at present reason not only has a freer play in science than elsewhere, but can produce as great effects on the world through science as through politics, philosophy or literature, there will be more Darwins.
>
> We must regard science, then, from three points of view. First, it is the free activity of man's divine faculties of reason and imagination. Secondly, it is the answer of the few to the demands of the many for wealth, comfort and victory, gifts which it will grant only in exchange for peace, security and stagnation. Finally it is man's gradual conquest, first of space and time, then of matter as such, then of his own body and those of other living beings, and finally the subjugation of the dark and evil elements in his own soul.[2]

I have already made it clear that I have a low opinion of reductionism, which seems to me to be at best irrelevant and at worst misleading as a description of what science is about. Let me begin with pure mathematics. Here the failure of reductionism has been demonstrated by rigorous proof. This will be a familiar story to many of you. The great mathematician David Hilbert, after thirty years of high creative achievement on the frontiers of mathematics, walked into a blind alley of reductionism. In his later years he espoused a program of formalization, which aimed to reduce the whole of mathematics to a collection of formal statements using a finite alphabet of symbols and a finite set of axioms and rules of inference. This was reductionism in the most literal sense, reducing mathematics to a set of marks written on paper, and deliberately ignoring the context of ideas and applications that give meaning to the marks. Hilbert then proposed to solve the problems of mathematics by finding a general process that could decide, given any formal statement composed of mathematical symbols, whether that statement was true or false. He called the problem of finding this decision process the *Entscheidungsproblem*. He dreamed of solving the *Entscheidungsproblem* and thereby solving as corollaries all the famous unsolved problems of mathematics. This was to be the crowning achievement of his life, the achievement that would outshine all the achievements of earlier mathematicians who solved problems only one at a time.

The essence of Hilbert's program was to find a decision process that would operate on symbols in a purely mechanical fashion, without requiring any understanding of their meaning. Since mathematics was reduced to a collection of marks on paper, the decision process should concern itself only with the marks and not with the fallible human intuitions out of which the marks were reduced. In spite of the prolonged efforts of Hilbert and his disciples, the *Entscheidungsproblem* was never solved. Success was achieved only in highly restricted domains of mathematics, excluding all the deeper and more interesting concepts. Hilbert never gave up hope, but as the years went by his program became an exercise in formal logic having little connection with real mathematics. Finally, when Hilbert was seventy years old, Kurt Gödel proved by a brilliant analysis that the *Entscheidungsproblem* as Hilbert formulated it cannot be solved.

Gödel proved that in any formulation of mathematics, including the rules of ordinary arithmetic, a formal process for separating statements into true and false cannot exist. He proved the stronger result which is now known as Gödel's theorem, that in any formalization of mathematics including the rules of ordinary arithmetic there are meaningful arithmetical statements that cannot be proved true or false. Gödel's theorem shows conclusively that in pure mathematics reductionism does not work. To decide whether a mathematical statement is true, it is not sufficient to reduce the statement to marks on paper and to study the behavior of the marks. Except in trivial cases, you can decide the truth of a statement only by studying its meaning and its context in the larger world of mathematical ideas.

It is a curious paradox that several of the greatest and most creative spirits in science, after achieving important discoveries by following their unfettered imaginations, were in their later years obsessed with reductionist philosophy and as a result became sterile. Hilbert was a prime example of this paradox. Einstein was another. Like Hilbert, Einstein did his great work up to the age of forty without any reductionist bias. His crowning achievement, the general relativistic theory of gravitation, grew out of a deep physical understanding of natural processes. Only at the very end of his ten-year struggle to understand gravitation did he reduce the outcome of his understanding to a finite set of field equations. But like Hilbert, as he grew older he concentrated his attention more and more on the formal properties of his equations, and he lost interest in the wider universe of ideas out of which the equations arose.

His last twenty years were spent in a fruitless search for a set of equations that would unify the whole of physics, without paying attention to the rapidly proliferating experimental discoveries that any unified theory would finally have to explain. I do not need to say more about this tragic and well-known story of Einstein's lonely attempt to reduce physics to a finite set of marks on paper. His attempt failed as dismally as Hilbert's attempt to do the same thing with mathematics. I shall instead discuss another aspect of Einstein's later life, an aspect that has received less attention than his quest for the unified field equations: his extraordinary hostility to the idea of black holes.

Black holes were invented by J. Robert Oppenheimer and Hartland Snyder in 1939. Starting from Einstein's theory of general relativity, Oppenheimer and Snyder found solutions of Einstein's equations that described what happens to a massive star when it has exhausted its supplies of nuclear energy. The star collapses gravitationally and disappears from the visible universe, leaving behind only an intense gravitational field to mark its presence. The star remains in a state of permanent free fall, collapsing endlessly inward into the gravitational pit without ever reaching the bottom. This solution of Einstein's equations was profoundly novel. It has had enormous impact on the later development of astrophysics.

We now know that black holes ranging in mass from a few suns to a few billion suns actually exist and play a dominant role in the economy of the universe. In my opinion, the black hole is incomparably the most exciting and the most important consequence of general relativity. Black holes are the places in the universe where general relativity is decisive. But Einstein never acknowledged his brainchild. Einstein was not merely skeptical, he was actively hostile to the idea of black holes. He thought that the black hole solution was a blemish to be removed from his theory by a better mathematical formulation, not a consequence to be tested by observation. He never expressed the slightest enthusiasm for black holes, either as a concept or as a physical possibility. Oddly enough, Oppenheimer too in later life was uninterested in black holes, although in retrospect we can say that they were his most important contribution to science. The older Einstein and the older Oppenheimer were blind to the mathematical beauty of black holes, and indifferent to the question whether black holes actually exist.

How did this blindness and this indifference come about? I never discussed this question directly with Einstein, but I discussed it several times with Oppenheimer and I believe that Oppenheimer's answer applies equally to Einstein. Oppenheimer in his later years believed that the only problem worthy of the attention of a serious theoretical physicist was the discovery of the fundamental equations of physics. Einstein certainly felt the same way. To discover the right equations was all that mattered. Once you had discovered the right equations, then the study of particular solutions of the equations would be a routine exercise for second-rate physicists or graduate students. In Oppenheimer's view, it would be a waste of his precious time, or of mine, to concern ourselves with the details of particular solutions. This was how the philosophy of reductionism led Oppenheimer and Einstein astray. Since the only purpose of physics was to reduce the world of physical phenomena to a finite set of fundamental equations, the study of particular solutions such as black holes was an undesirable distraction from the general goal. Like Hilbert, they were not content to solve particular problems one at a time. They were entranced by the dream of solving all the basic problems at once. And as a result, they failed in their later years to solve any problems at all.

In the history of science it happens not infrequently that a reductionist approach leads to a spectacular success. Frequently the understanding of a complicated system as a whole is impossible without an understanding of its component parts. And sometimes the understanding of a whole field of science is suddenly advanced by the discovery of a single basic equation. Thus it happened that the Schrödinger equation in 1926 and the Dirac equation in 1927 brought a miraculous order into the previously mysterious processes of atomic physics. The equations of Erwin Schrödinger and Paul Dirac were triumphs of reductionism. Bewildering complexities of chemistry and physics were reduced to two lines of algebraic symbols. These triumphs were in Oppenheimer's mind when he belittled his own discovery of black holes. Compared with the abstract beauty and simplicity of the Dirac equation, the black hole solution seemed to him ugly, complicated, and lacking in fundamental significance.

But it happens at least equally often in the history of science that the understanding of the component parts of a composite system is impossible without an understanding of the behavior of the system as a whole. And it often happens that the understanding of the mathematical nature of an equation is impossible without a detailed understanding of its solutions. The black hole is a case in point. One could say without exaggeration that Einstein's equations of general relativity were understood only at a very superficial level before the discovery of the black hole. During the fifty years since the black hole was invented, a deep mathematical understanding of the geometrical structure of space-time has slowly emerged, with the black hole solution playing a fundamental role in the structure. The progress of science requires the growth of understanding in both directions, downward from the whole to the parts and upward from the parts to the whole. A reductionist philosophy, arbitrarily proclaiming that the growth of understanding must go only in one direction, makes no scientific sense. Indeed, dogmatic philosophical beliefs of any kind have no place in science.

Science in its everyday practice is much closer to art than to philosophy. When I look at Gödel's proof of his undecidability theorem, I do not see a philosophical argument. The proof is a soaring piece of architecture, as unique and as lovely as Chartres Cathedral. Gödel took Hilbert's formalized axioms of mathematics as his building blocks and built out of them a lofty structure of ideas into which he could finally insert his undecidable arithmetical statement as the keystone of the arch. The proof is a great work of art. It is a construction, not a reduction. It destroyed Hilbert's dream of reducing all mathematics to a few equations, and replaced it with a greater dream of mathematics as an endlessly growing realm of ideas. Gödel proved that in mathematics the whole is always greater than the sum of the parts. Every formalization of mathematics raises questions that reach beyond the limits of the formalism into unexplored territory.

The black hole solution of Einstein's equations is also a work of art. The black hole is not as majestic as Gödel's proof, but it has the essential features of a work of art: uniqueness, beauty, and unexpectedness. Oppenheimer and Snyder built out of Einstein's equations a structure that Einstein had never imagined. The idea of matter in permanent free fall was hidden in the equations, but nobody saw it until it was revealed in the Oppenheimer-Snyder solution. On a much more humble level, my own activities as a theoretical physicist have a similar quality. When I am working, I feel myself to be practicing a craft rather than following a method. When I did my most important piece of work as a young man, putting together the ideas of Sin-Itiro Tomonaga, Julian Schwinger, and Richard Feynman to obtain a simplified version of quantum electrodynamics, I had consciously in mind a metaphor to describe what I was doing. The metaphor was bridge-building. Tomonaga and Schwinger had built solid foundations on one side of a river of ignorance, Feynman had built solid foundations on the other side, and my job was to design and build the cantilevers reaching out over the water until they met in the middle. The metaphor was a good one. The bridge that I built is still serviceable and still carrying traffic forty years later. The same metaphor describes well the greater work of unification achieved by Stephen Weinberg and Abdus Salam when they bridged the gap between electrodynamics and the weak interactions. In each case, after the work of unification is done, the whole stands higher than the parts.

In recent years there has been great dispute among historians of science, some believing that science is driven by social forces, others believing that science transcends social forces and is driven by its own internal logic and by the objective facts of nature. Historians of the first group write social history, those of the second group write intellectual history. Since I believe that scientists should be artists and rebels, obeying their own instincts rather than social demands or philosophical principles, I do not fully agree with either view of history. Nevertheless, scientists should pay attention to the historians. We have much to learn, especially from the social historians.

Many years ago, when I was in Zürich, I went to see the play *The Physicists* by the Swiss playwright Friedrich Dürrenmatt. The characters in the play are grotesque caricatures, wearing the costumes and using the names of Newton, Einstein, and Möbius. The action takes place in a lunatic asylum where the physicists are patients. In the first act they entertain themselves by murdering their nurses, and in the second act they are revealed to be secret agents in the pay of rival intelligence services. I found the play amusing but at the same time irritating. These absurd creatures on the stage had no resemblance at all to any real physicist. I complained about the unreality of the characters to my friend Markus Fierz, a well-known Swiss physicist, who came with me to the play. “But don’t you see?” said Fierz. “The whole point of the play is to show us how we look to the rest of the human race.”

Fierz was right. The image of noble and virtuous dedication to truth, the image that scientists have traditionally presented to the public, is no longer credible. The public, having found out that the traditional image of the scientist as a secular saint is false, has gone to the opposite extreme and imagines us to be irresponsible devils playing with human lives. Dürrenmatt has held up the mirror to us and has shown us the image of ourselves as the public sees us. It is our task now to dispel these fantasies with facts, showing the public that scientists are neither saints nor devils but human beings sharing the common weaknesses of our species.

Historians who believe in the transcendence of science have portrayed scientists as living in a transcendent world of the intellect, superior to the transient, corruptible, mundane realities of the social world. Any scientist who claims to follow such exalted ideals is easily held up to ridicule as a pious fraud. We all know that scientists, like television evangelists and politicians, are not immune to the corrupting influences of power and money. Much of the history of science, like the history of religion, is a history of struggles driven by power and money. And yet this is not the whole story. Genuine saints occasionally play an important role, both in religion and in science. Einstein was an important figure in the history of science, and he was a firm believer in transcendence. For Einstein, science as a way of escape from mundane reality was no pretense. For many scientists less divinely gifted than Einstein, the chief reward for being a scientist is not the power and the money but the chance of catching a glimpse of the transcendent beauty of nature.

Both in science and in history there is room for a variety of styles and purposes. There is no necessary contradiction between the transcendence of science and the realities of social history. One may believe that in science nature will ultimately have the last word and still recognize an enormous role for human vainglory and viciousness in the practice of science before the last word is spoken. One may believe that the historian's job is to expose the hidden influences of power and money and still recognize that the laws of nature cannot be bent and cannot be corrupted by power and money. To my mind, the history of science is most illuminating when the frailties of human actors are put into juxtaposition with the transcendence of nature's laws.

Francis Crick is one of the great scientists of our century. He has recently published his personal narrative of the microbiological revolution that he helped to bring about, with a title borrowed from Keats, *What Mad Pursuit*. One of the most illuminating passages in his account compares two discoveries in which he was involved. One was the discovery of the double-helix structure of DNA, the other was the discovery of the triple-helix structure of the collagen molecule. Both molecules are biologically important, DNA being the carrier of genetic information, collagen being the protein that holds human bodies together. The two discoveries involved similar scientific techniques and aroused similar competitive passions in the scientists racing to be the first to find the structure.

Crick says that the two discoveries caused him equal excitement and equal pleasure at the time he was working on them. From the point of view of a historian who believes that science is a purely social construction, the two discoveries should have been equally significant. But in history as Crick experienced it, the two helixes were not equal. The double helix became the driving force of a new science, while the triple helix remained a footnote of interest only to specialists. Crick asks the question, how the different fates of the two helixes are to be explained. He answers the question by saying that human and social influences cannot explain the difference, that only the transcendent beauty of the double-helix structure and its genetic function can explain the difference. Nature herself, and not the scientist, decided what was important. In the history of the double helix, transcendence was real. Crick gives himself the credit for choosing an important problem to work on, but, he says, only Nature herself could tell how transcendentally important it would turn out to be.

My message is that science is a human activity, and the best way to understand it is to understand the individual human beings who practice it. Science is an art form and not a philosophical method. The great advances in science usually result from new tools rather than from new doctrines. If we try to squeeze science into a single philosophical viewpoint such as reductionism, we are like Procrustes chopping off the feet of his guests when they do not fit onto his bed. Science flourishes best when it uses freely all the tools at hand, unconstrained by preconceived notions of what science ought to be. Every time we introduce a new tool, it always leads to new and unexpected discoveries, because Nature's imagination is richer than ours.

Postscript, 2006

This essay was originally written as a lecture addressed to a meeting in 1992 that was supposed to discuss "the continuing primacy of reductionism as a key to understanding nature as we approach the twenty-first century." That explains why I devoted so much time to attacking reductionism. It turned out that many of the other participants at the meeting shared my views.

After the essay appeared in *The New York Review*, I received many good letters in response, some agreeing with me and some disagreeing. The best of them was from Saunders Mac Lane, a legendary figure in the world of mathematics. His letter and my reply were published in the October 5, 1995, issue of the *Review*. He objected vehemently to my statement that the later years of the great mathematician Hilbert were sterile. He had known Hilbert personally and professionally. His letter concludes, "Dyson simply does not understand reductionism and the deep purposes it can serve. Hilbert was not sterile." In my reply I said, "I too was exhilarated and inspired by the enormous deepening of mathematical understanding that grew in the 1930s out of the ruins of Hilbert's program of formalization. Only, Mac Lane would use the words 'upon the foundations' where I say 'out of the ruins.' Solid foundations and ruined hopes are not incompatible. Both were essential parts of the legacy that Hilbert left to his successors.… I do not deny the power and the beauty of reductionist science, as exemplified in the axioms and theorems of abstract algebra.… But I assert the equal power and beauty of constructive science, as exemplified in Gödel's construction of an undecidable proposition.… Hilbert himself was, of course, a master of both kinds of mathematics."

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1. Robinson Jeffers, *The Double Axe and Other Poems, including eleven suppressed poems (Liveright, 1977)*.
2. J. B. S. Haldane, *Daedalus, or Science and the Future* (London: Kegan Paul, 1924).

2

CAN SCIENCE BE ETHICAL?

ONE OF MY favorite monuments is a statue of Samuel Gompers not far from the Alamo in San Antonio, Texas. Under the statue is a quote from one of Gompers's speeches:

> What does labor want?
> We want more schoolhouses and less jails,
> More books and less guns,
> More learning and less vice,
> More leisure and less greed,
> More justice and less revenge,
> We want more opportunities to cultivate our better nature.

Samuel Gompers was the founder and first president of the American Federation of Labor. He established in America the tradition of practical bargaining between labor and management which led to an era of growth and prosperity for labor unions. Now, seventy years after Gompers's death, the unions have dwindled, while his dreams—more books and fewer guns, more leisure and less greed, more schoolhouses and fewer jails—have been tacitly abandoned. In a society without social justice and with a free-market ideology, guns, greed, and jails are bound to win.

When I was a student of mathematics in England fifty years ago, one of my teachers was the great mathematician G. H. Hardy, who wrote a little book, *A Mathematician's Apology*, explaining to the general public what mathematicians do. Hardy proudly proclaimed that his life had been devoted to the creation of totally useless works of abstract art, without any possible practical application. He had strong views about technology, which he summarized in the statement "A science is said to be useful if its development tends to accentuate the existing inequalities in the distribution of wealth, or more directly promotes the destruction of human life." He wrote these words while war was raging around him.

Still, the Hardy view of technology has some merit even in peacetime. Many of the technologies that are now racing ahead most rapidly, replacing human workers in factories and offices with machines, making stockholders richer and workers poorer, are indeed tending to accentuate the existing inequalities in the distribution of wealth. And the technologies of lethal force continue to be as profitable today as they were in Hardy's time. The marketplace judges technologies by their practical effectiveness, by whether they succeed or fail to do the job they are designed to do. But always, even for the most brilliantly successful technology, an ethical question lurks in the background: the question whether the job the technology is designed to do is actually worth doing.

The technologies that raise the fewest ethical problems are those that work on a human scale, brightening the lives of individual people. Lucky individuals in each generation find technology appropriate to their needs. For my father ninety years ago, technology was a motorcycle. He was an impoverished young musician growing up in England in the years before World War I, and the motorcycle came to him as a liberation. He was a working-class boy in a country dominated by the snobberies of class and accent. He learned to speak like a gentleman, but he did not belong in the world of gentlemen. The motorcycle was a great equalizer. On his motorcycle, he was the equal of a gentleman. He could make the grand tour of Europe without having inherited an upper-class income. He and three of his friends bought motorcycles and rode them all over Europe.

My father fell in love with his motorcycle and with the technical skills that it demanded. He understood, sixty years before Robert Pirsig wrote *Zen and the Art of Motorcycle Maintenance*, the spiritual quality of the motorcycle. In my father's day, roads were bad and repair shops few and far between. If you intended to travel any long distance, you needed to carry your own tool kit and spare parts and be prepared to take the machine apart and put it back together again. A breakdown of the machine in a remote place often required major surgery. It was as essential for a rider to understand the anatomy and physiology of the motorcycle as it was for a surgeon to understand the anatomy and physiology of a patient. It sometimes happened that my father and his friends would arrive at a village where no motorcycle had ever been seen before. When this happened, they would give rides to the village children and hope to be rewarded with a free supper at the village inn. Technology in the shape of a motorcycle was comradeship and freedom.

Fifty years after my father, I discovered joyful technology in the shape of a nuclear fission reactor. That was in 1956, in the first intoxicating days of peaceful nuclear energy, when the technology of reactors suddenly emerged from wartime secrecy and the public was invited to come and play with it. This was an invitation that I could not refuse. It looked then as if nuclear energy would be the great equalizer, providing cheap and abundant energy to rich and poor alike, just as fifty years earlier the motorcycle gave mobility to rich and poor alike in class-ridden England.

I joined the General Atomic Company in San Diego, where my friends were playing with the new technology. We invented and built a little reactor which we called the TRIGA, designed to be inherently safe. Inherent safety meant that it would not misbehave even if the people operating it were grossly incompetent. The company has been manufacturing and selling TRIGA reactors for forty years and is still selling them today, mostly to hospitals and medical centers, where they produce short-lived isotopes for diagnostic purposes. They have never misbehaved or caused any danger to the people who used them. They have only run into trouble in a few places where the neighbors objected to their presence on ideological grounds, no matter how safe they might be. We were successful with the TRIGA because it was designed to do a useful job at a price that a big hospital could afford. The price in 1956 was a quarter of a million dollars. Our work with the TRIGA was joyful because we finished it quickly, before the technology became entangled with politics and bureaucracy, before it became clear that nuclear energy was not and never could be the great equalizer.

Forty years after the invention of the TRIGA, my son George found another joyful and useful technology, the technology of CAD-CAM, computer-aided design and computer-aided manufacturing. CAD-CAM is the technology of the postnuclear generation, the technology that succeeded after nuclear energy failed. George is a boatbuilder. He designs seagoing kayaks. He uses modern materials to reconstruct the ancient craft of the Aleuts, who perfected their boats by trial and error over thousands of years and used them to travel prodigious distances across the northern Pacific. His boats are fast and rugged and seaworthy. When he began his boatbuilding twenty-five years ago, he was a nomad, traveling up and down the north Pacific coast, trying to live like an Aleut, and built his boats like an Aleut, shaping every part of each boat and stitching them together with his own hands. In those days he was a nature-child, in love with the wilderness, rejecting the urban society in which he had grown up. He built boats for his own use and for his friends, not as a commercial business.

As the years went by George made a graceful transition from the role of rebellious teenager to the role of solid citizen. He married, raised a daughter, bought a house in the city of Bellingham, and converted an abandoned tavern by the waterfront into a well-equipped workshop for his boats. His boats are now a business. And he discovered the joys of CAD-CAM.

His workshop now contains more computers and software than sewing needles and hand tools. It is a long time since he made the parts of a boat by hand. He now translates his designs directly into CAD-CAM software and transmits them electronically to a manufacturer who produces the parts. George collects the parts and sells them by mail order to his regular customers with instructions for assembling them into boats. Only on rare occasions, when a wealthy customer pays for a custom-built job, does George deliver a boat assembled in the workshop. The boat business occupies only a part of his time. He also runs a historical society concerned with the history and ethnography of the north Pacific. The technology of CAD-CAM has given George resources and leisure, so that he can visit the Aleuts in their native islands and reintroduce to the young islanders the forgotten skills of their ancestors.

Forty years into the future, which joyful new technology will be enriching the lives of our grandchildren? Perhaps they will be designing their own dogs and cats. Just as the technology of CAD-CAM began in the production lines of large manufacturing companies and later became accessible to individual citizens like George, the technology of genetic engineering may soon spread out from the biotechnology companies and agricultural industries and become accessible to our grandchildren. Designing dogs and cats in the privacy of a home may become as easy as designing boats in a waterfront workshop.

Instead of CAD-CAM we may have CAS-CAR, computer-aided selection and computer-aided reproduction. With the CAS-CAR software, you first program your pet's color scheme and behavior, and then transmit the program electronically to the artificial fertilization laboratory for implementation. Twelve weeks later, your pet is born, satisfaction guaranteed by the software company. When I recently described these possibilities in a public lecture at a children's museum in

Vermont, I was verbally assaulted by a young woman in the audience. She accused me of violating the rights of animals. She said I was a typical scientist, one of those cruel people who spend their lives torturing animals for fun. I tried in vain to placate her by saying that I was only speaking of possibilities, that I was not actually myself engaged in designing dogs and cats. I had to admit that she had a legitimate complaint. Designing dogs and cats is an ethically dubious business. It is not as innocent as designing boats.

When the time comes, when the CAS-CAR software is available, when anybody with access to the software can order a dog with pink-and-purple spots that can crow like a rooster, some tough decisions will have to be made. Shall we allow private citizens to create dogs who will be objects of contempt and ridicule, unable to take their rightful place in dog society? And if not, where shall we draw the line between legitimate animal breeding and illegitimate creation of monsters? These are difficult questions that our children and grandchildren will have to answer. Perhaps I should have spoken to the audience in Vermont about designing roses and orchids instead of dogs and cats. Nobody seems to care so deeply for the dignity of roses and orchids. Vegetables, it seems, do not have rights. Dogs and cats are too close to being human. They have feelings like ours. If our grandchildren are allowed to design their own dogs and cats, the next step will be using the CAS-CAR software to design their own babies. Before that next step is reached, they ought to think carefully about the consequences.

What can we do today, in the world as we find it at the end of the twentieth century, to turn the evil consequences of technology into good? The ways in which science may work for good or evil in human society are many and various. As a general rule, to which there are many exceptions, science works for evil when its effect is to provide toys for the rich, and works for good when its effect is to provide necessities for the poor. Cheapness is an essential virtue. The motorcycle worked for good because it was cheap enough for a poor schoolteacher to own. Nuclear energy worked mostly for evil because it remained a toy for rich governments and rich companies to play with. “Toys for the rich” means not only toys in the literal sense but technological conveniences that are available to a minority of people and make it harder for those excluded to take part in the economic and cultural life of the community. “Necessities for the poor” include not only food and shelter but adequate public health services, adequate public transportation, and access to decent education and jobs.

The scientific advances of the nineteenth century and the first half of the twentieth were generally beneficial to society as a whole, spreading wealth to rich and poor alike with some degree of equity. The electric light, the telephone, the refrigerator, radio, television, synthetic fabrics, antibiotics, vitamins, and vaccines were social equalizers, making life easier and more comfortable for almost everybody, tending to narrow the gap between rich and poor rather than to widen it. Only in the second half of our century has the balance of advantage shifted. During the last forty years, the strongest efforts in pure science have been concentrated in highly esoteric fields remote from contact with everyday problems. Particle physics, low-temperature physics, and extragalactic astronomy are examples of pure sciences moving further and further away from their origins. The intensive pursuit of these sciences does not do much harm, or much good, to either the rich or the poor. The main social benefit provided by pure science in esoteric fields is to serve as a welfare program for scientists and engineers.

At the same time, the strongest efforts in applied science have been concentrated upon products that can be profitably sold. Since the rich can be expected to pay more than the poor for new products, market-driven applied science will usually result in the invention of toys for the rich. The laptop computer and the cellular telephone are the latest of the new toys. Now that a large fraction of high-paying jobs are advertised on the Internet, people excluded from the Internet are also excluded from access to jobs. The failure of science to produce benefits for the poor in recent decades is due to two factors working in combination: the pure scientists have become more detached from the mundane needs of humanity, and the applied scientists have become more attached to immediate profitability.

Although pure and applied science may appear to be moving in opposite directions, there is a single underlying cause that has affected them both. The cause is the power of committees in the administration and funding of science. In the case of pure science, the committees are composed of scientific experts performing the rituals of peer review. If a committee of scientific experts selects research projects by majority vote, projects in fashionable fields are supported while those in unfashionable fields are not. In recent decades, the fashionable fields have been moving further and further into specialized areas remote from contact with things that we can see and touch. In the case of applied science, the committees are composed of business executives and managers. Such people usually give support to products that affluent customers like themselves can buy.

Only a cantankerous man like Henry Ford, with dictatorial power over his business, would dare to create a mass market for automobiles by arbitrarily setting his prices low enough and his wages high enough that his workers could afford to buy his product. Both in pure science and in applied science, rule by committee discourages unfashionable and bold ventures. To bring about a real shift of priorities, scientists and entrepreneurs must assert their freedom to promote new technologies that are more friendly than the old to poor people and poor countries. The ethical standards of scientists must change as the scope of the good and evil caused by science has changed. In the long run, as Haldane and Einstein said, ethical progress is the only cure for the damage done by scientific progress.

The nuclear arms race is over, but the ethical problems raised by nonmilitary technology remain. The ethical problems arise from three "new ages" flooding over human society like tsunamis. First is the Information Age, already arrived and here to stay, driven by computers and digital memory. Second is the Biotechnology Age, due to arrive in full force early in the next century, driven by DNA sequencing and genetic engineering. Third is the Neurotechnology Age, likely to arrive later in the next century, driven by neural sensors and exposing the inner workings of human emotion and personality to manipulation. These three new technologies are profoundly disruptive. They offer liberation from ancient drudgery in factory, farm, and office. They offer healing of ancient diseases of body and mind. They offer wealth and power to the people who possess the skills to understand and control them. They destroy industries based on older technologies and make people trained in older skills useless. They are likely to bypass the poor and reward the rich. They will tend, as Hardy said eighty years ago, to accentuate the inequalities in the existing distribution of wealth, even if they do not, like nuclear technology, more directly promote the destruction of human life.

The poorer half of humanity needs cheap housing, cheap health care, and cheap education, accessible to everybody, with high quality and high aesthetic standards. The fundamental problem for human society in the next century is the mismatch between the three new waves of technology and the three basic needs of poor people. The gap between technology and needs is wide and growing wider. If technology continues along its present course, ignoring the needs of the poor and showering benefits upon the rich, the poor will sooner or later rebel against the tyranny of technology and turn to irrational and violent remedies. In the future, as in the past, the revolt of the poor is likely to impoverish rich and poor together.

The widening gap between technology and human needs can only be filled by ethics. We have seen in the last thirty years many examples of the power of ethics. The worldwide environmental movement, basing its power on ethical persuasion, has scored many victories over industrial wealth and technological arrogance. The most spectacular victory of the environmentalists was the downfall of the nuclear industry in the United States and many other countries, first in the domain of nuclear power and more recently in the domain of weapons. It was the environmental movement that closed down factories for making nuclear weapons in the United States, from plutonium-producing Hanford to warhead-producing Rocky Flats. Ethics can be a force more powerful than politics and economics.

Unfortunately, the environmental movement has so far concentrated its attention upon the evils that technology has done rather than upon the good that technology has failed to do. It is my hope that the attention of the Greens will shift in the next century from the negative to the positive. Ethical victories putting an end to technological follies are not enough. We need ethical victories of a different kind, engaging the power of technology positively in the pursuit of social justice.

If we can agree with Thomas Jefferson that these truths are self-evident, that all men are created equal, that they are endowed with certain inalienable rights, that among these are life, liberty, and the pursuit of happiness, then it should also be self-evident that the abandonment of millions of people in modern societies to unemployment and destitution is a worse defilement of the earth than nuclear power stations. If the ethical force of the environmental movement can defeat the manufacturers of nuclear power stations, the same force should also be able to foster the growth of technology that supplies the needs of impoverished humans at a price they can afford. This is the great task for technology in the coming century.

The free market will not by itself produce technology friendly to the poor. Only a technology positively guided by ethics can do it. The power of ethics must be exerted by the environmental movement and by concerned scientists, educators, and entrepreneurs working together. If we are wise, we shall also enlist in the common cause of social justice the enduring power of religion. Religion has in the past contributed mightily to many good causes, from the building of cathedrals and the education of children to the abolition of slavery. Religion will remain in the future a force equal in strength to science and equally committed to the long-range improvement of the human condition.

In the world of religion, over the centuries, there have been prophets of doom and prophets of hope, with hope in the end predominating. Science also gives warnings of doom and promises of hope, but the warnings and the promises of science cannot be separated. Every honest scientific prophet must mix the good news with the bad. Haldane was an honest prophet, showing us the evil done by science not as inescapable fate but as a challenge to be overcome. He wrote in his book *Daedalus* in 1923, "We are at present almost completely ignorant of biology, a fact which often escapes the notice of biologists, and renders them too presumptuous in their estimates of the present condition of their science, too modest in their claims for its future." Biology has made amazing progress since 1923, but Haldane's statement is still true.

We still know little about the biological processes that affect human beings most intimately—the development of speech and social skills in infants, the interplay between moods and emotions and learning and understanding in children and adults, the onset of aging and mental deterioration at the end of life. None of these processes will be understood within the next decade, but all of them might be understood within the next century. Understanding will then lead to new technologies that offer hope of preventing tragedies and ameliorating the human condition. Few people believe any longer in the romantic dream that human beings are perfectible. But most of us still believe that human beings are capable of improvement.

In public discussions of biotechnology today, the idea of improving the human race by artificial means is widely condemned. The idea is repugnant because it conjures up visions of Nazi doctors sterilizing Jews and killing defective children. There are many good reasons for condemning enforced sterilization and euthanasia. But the artificial improvement of human beings will come, one way or another, whether we like it or not, as soon as the progress of biological understanding makes it possible. When people are offered technical means to improve themselves and their children, no matter what they conceive improvement to mean, the offer will be accepted. Improvement may mean better health, longer life, a more cheerful disposition, a stronger heart, a smarter brain, the ability to earn more money as a rock star or baseball player or business executive. The technology of improvement may be hindered or delayed by regulation, but it cannot be permanently suppressed. Human improvement, like abortion today, will be officially disapproved, legally discouraged, or forbidden, but widely practiced. It will be seen by millions of citizens as a liberation from past constraints and injustices. Their freedom to choose cannot be permanently denied.

Two hundred years ago, William Blake engraved *The Gates of Paradise*, a little book of drawings and verses. One of the drawings, with the title *Aged Ignorance*, shows an old man wearing professorial eyeglasses and holding a large pair of scissors. In front of him, a winged child is running naked in the light from a rising sun. The old man sits with his back to the sun. With a self-satisfied smile he opens his scissors and clips the child's wings. With the picture goes a little poem:

In Time's Ocean falling drown'd,
In Aged Ignorance profound,
Holy and cold, I clip'd the Wings
Of all Sublunary Things.[1]

This picture is an image of the human condition in the era that is now beginning. The rising sun is biological science, throwing light of ever-increasing intensity onto the processes by which we live and feel and think. The winged child is human life, becoming for the first time aware of itself and its potentialities in the light of science. The old man is our existing human society, shaped by ages of past ignorance.

Our laws, our loyalties, our fears and hatreds, our economic and social injustices, all grew slowly and are deeply rooted in the past. Inevitably the advance of biological knowledge will bring clashes between old institutions and new desires for human self-improvement. Old institutions will clip the wings of new desires. Up to a point, caution is justified and social constraints are necessary. The new technologies will be dangerous as well as liberating. But in the long run, social constraints must bend to new realities. Humanity cannot live forever with clipped wings. The vision of self-improvement, which William Blake and Samuel Gompers in their different ways proclaimed, will not vanish from the earth.

Postscript, 2006

Nine years later, the gap between rich and poor has grown wider. New technologies have continued to make stockholders richer and workers poorer. The main thesis of this essay, that technological progress does more harm than good unless it is accompanied by ethical progress, is even truer today than it was in 1997.

Only a few statements need to be corrected. The cell phone is no longer a toy for the rich but is becoming ubiquitous. I sat recently in the waiting room of the Social Security Administration office in Trenton, among a crowd of the poorer citizens of New Jersey, and was happy to see that many of them are now carrying cell phones. My son George continues to operate his boat business in Bellingham, but he is now better known as a writer and historian.

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1. *The Portable Blake*, edited by Alfred Kazin (Viking, 1946).

3

A MODERN HERETIC

THE FIRST TIME I met Thomas Gold was in 1946, when I served as a guinea pig in an experiment that he was doing on the capabilities of the human ear. Humans have a remarkable ability to discriminate the pitch of musical sounds. We can easily tell the difference when the frequency of a pure tone wobbles by as little as one percent. How do we do it? This was the question that Gold was determined to answer. There were two possible answers. Either the inner ear contains a set of finely tuned resonators that vibrate in response to incident sounds. Or the ear does not resonate but merely translates the incident sounds directly into neural signals that are then analyzed into pure tones by some unknown neural process inside our brains. In 1946 the professional physiologists who were experts in the anatomy and physiology of the ear believed that the second answer must be correct, that the discrimination of pitch happens in our brains and not in our ears. They rejected the first answer because they knew that the inner ear is a small cavity filled with flabby flesh and water. They could not imagine the flabby little membranes in the ear resonating like the strings of a harp or a piano.

Gold designed his experiment to prove the experts wrong. The experiment was simple, elegant, and original. During World War II he had been working for the Royal Navy on radio communications and radar. He built his apparatus out of war-surplus navy electronics and headphones. He fed into the headphones a signal consisting of short pulses of a pure tone, separated by intervals of silence. The silent intervals were at least ten times as long as the period of the pure tone. The pulses were all the same shape, but they had phases which could be reversed independently. To reverse the phase of a pulse means to reverse the movement of the speaker in the headphone. The speaker in a reversed pulse is pushing the air outward when the speaker in an unreversed pulse is pulling the air inward. Sometimes Gold gave all the pulses the same phase, and sometimes he alternated the phases so that the even pulses had one phase and the odd pulses had the opposite phase. All I had to do was to sit with the headphones on my ears and listen while Gold put in signals with either constant or alternating phases. I had to tell him from the sound whether the phase was constant or alternating.

When the silent interval between pulses was ten times the period of the pure tone, it was easy to tell the difference. I heard a noise like a mosquito, a hum and a buzz sounding together, and the quality of the hum changed noticeably when the phases were changed from constant to alternating. We repeated the trials with longer silent intervals. I could still detect the difference, when the silent interval was as long as thirty periods. I was not the only guinea pig. Several other friends of Gold listened to the signals and found similar results. The experiment showed that the human ear can remember the phase of a signal, after the signal stops, for thirty times the period of the signal. To be able to remember the phase, the ear must contain fine-tuned resonators that continue to vibrate during the intervals of silence. The result of the experiment proved that pitch discrimination is mainly done in the ear and not in the brain.

Besides having experimental proof that the ear can resonate, Gold also had a theory to explain how a fine-tuned resonator can be built out of flabby and dissipative materials. His theory was that the inner ear contains an electrical feedback system. The mechanical resonators are coupled to electrically powered sensors and drivers, so that the combined electromechanical system works like a finely tuned amplifier. The positive feedback provided by the electrical components counteracts the damping produced by the flabbiness of the mechanical components. Gold's experience as an electrical engineer made this theory seem plausible to him, although he could not identify the anatomical structures in the ear that functioned as sensors and drivers. In 1948 he published two papers, one reporting the results of the experiment and the other describing the theory.

Having myself participated in the experiment and listened to Gold explaining the theory, I never had any doubt that he was right. The professional auditory physiologists were equally sure that he was wrong. They found the theory implausible and the experiment unconvincing. They regarded Gold as an ignorant outsider intruding into a field where he had no training and no credentials. So for thirty years his work on hearing was ignored, and he moved on to other things.

Thirty years later, a new generation of auditory physiologists began to explore the ear with far more sophisticated tools. They discovered that everything that Gold had said in 1948 was true. The electrical sensors and drivers in the inner ear are now identified. They are two different kinds of hair cells, and they function in the way Gold said they should. The community of physiologists finally recognized the importance of his work, forty years after it was published.

Gold's study of the mechanism of hearing is typical of the way he has worked throughout his life. About once every five years, he invades a new field of research and proposes an outrageous theory that arouses intense opposition from the professional experts in the field. He then works very hard to prove the experts wrong. He does not always succeed. Sometimes it turns out that the experts are right and he is wrong. He is not afraid of being wrong. He was famously wrong at least twice, once when he promoted the theory of a steady-state universe in which matter is continuously created to keep the density constant as the universe expands, and once when he predicted that the moon would be covered with electrostatically supported dust into which the astronauts would sink as soon as they stepped onto the surface. When he is proved wrong, he concedes defeat with good humor. Science is no fun, he says, if you are never wrong. His wrong ideas are insignificant compared with his far more important right ideas. One of his important right ideas was the theory that pulsars, the regularly pulsing celestial radio sources discovered by radio astronomers in 1967, are rotating neutron stars. Unlike most of his right ideas, his theory of pulsars was accepted almost immediately by the experts.

Another of Gold's right ideas was rejected by the experts for an even longer time than his theory of hearing. This was his theory of the ninety-degree flip of the axis of rotation of the earth. In 1955 he published a revolutionary paper with the title "Instability of the Earth's Axis of Rotation." He proposed that the earth's axis might occasionally flip over through an angle of ninety degrees within a time of the order of a million years, so that the old north and south poles would move to the equator, and two points of the old equator would move to the poles. The flip would be triggered by movements of mass that would cause the old rotation axis to become unstable and the new rotation axis to become stable. For example, a large accumulation of ice at the old north and south poles might cause such an exchange of stability. Gold's paper was ignored by the experts for forty years. The experts at that time were focusing their attention narrowly on the phenomena of continental drift and the theory of plate tectonics. Gold's theory had nothing to do with continental drift or with plate tectonics, and it was therefore of no interest to them. The flip predicted by Gold would occur much more rapidly than continental drift, and would not change the positions of continents relative to one another. The flip would only change the positions of continents relative to the rotation axis.

In 1997 Joseph Kirschvink, an expert on rock magnetism at the California Institute of Technology, published a paper presenting evidence that a ninety-degree flip of the rotation axis actually occurred during a geologically short time in the Early Cambrian Era. This discovery is of great importance for the history of life, since the time of the flip appears to coincide with the time of the "Cambrian Explosion," the brief period when all the major varieties of higher organisms suddenly appear in the fossil record. It is possible that the flip of the rotation axis caused profound environmental changes in the oceans and triggered the rapid evolution of new life-forms. Kirschvink gives Gold credit for suggesting the theory that makes sense of his observations. If the theory had not been ignored for forty years, the evidence that confirms it might have been collected sooner.

Gold's most controversial idea is the nonbiological origin of natural gas and oil. He advocates a theory that natural gas and oil come from reservoirs deep in the earth and are relics of the material out of which the earth condensed. The biological molecules found in oil show that the oil is contaminated by living creatures, not that the oil was produced by living creatures. This theory, like his theories of hearing and of polar flip, contradicts the entrenched dogma of the experts. Once again, Gold is regarded as an intruder ignorant of the field that he is invading. In fact, Gold is an intruder but he is not ignorant. He knows the details of the geology and chemistry of natural gas and oil. His arguments supporting his theory are based on a wealth of factual information. Perhaps it will once again take us forty years to decide whether the theory is right. Whether the theory of nonbiological origin is ultimately found to be right or wrong, the collection of evidence to test it will add greatly to our knowledge of the earth and its history.

Finally, the most recent of Gold's revolutionary proposals is the subject of his book *The Deep Hot Biosphere*.[1] His theory says that the entire crust of the earth, down to a depth of several miles, is populated with living creatures. The creatures that we see living on the surface are only a small part of the biosphere. The greater and more ancient part of the biosphere is deep and hot. The theory is supported by a considerable mass of evidence. I do not need to summarize the evidence here, because it is clearly presented in the book. I prefer to let Gold speak for himself. The purpose of my foreword is only to explain how the theory of the deep hot biosphere fits into the general pattern of Gold's life and work. Gold's theories are always original, always important, usually controversial, and usually right. It is my belief, based on fifty years of observation of Gold as a friend and colleague, that the deep hot biosphere is all of the above: original, important, controversial, and right.

Postscript, 2006

Thomas Gold died in June 2004. Shortly before he died, an experiment was done at the Carnegie Institution of Washington Geophysical Laboratory to test his theory that natural gas is generated deep in the earth's mantle.[2] The experiment, carried out with tiny quantities of mantle materials exposed to high temperature and pressure in a diamond anvil cell, demonstrated abundant production of methane. The authors sent a message to Gold to tell him that his theory had been confirmed, only to learn that he had died three days earlier.

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1. Springer-Verlag, 1999.

2. H. P. Scott et al., "Generation of Methane in the Earth's Mantle: *In Situ* High Pressure–Temperature Measurements of Carbonate Reduction," *Proceedings of the National Academy of Sciences*, Vol. 101, No. 39 (September 28, 2004), pp. 14023–14026.

4

THE FUTURE NEEDS US

PREY[1] IS A thriller, well constructed and fun to read, like Michael Crichton's other books. The main characters are the narrator, Jack, and his wife, Julia, parents of three lively children, successfully combining the joys of parenthood with the pursuit of brilliant careers in the high-tech world of Silicon Valley. Julia works for a company called Xymos that is developing nanorobots, tiny machines that can move around and function autonomously but are programmed to work together like an army of ants. Jack works for a company called MediaTronics that makes software to coordinate the actions of large groups of autonomous agents. His programs give intelligence and flexibility to her machines.

Things start to go wrong when Jack loses his job and is left to take care of the kids, while Julia is working longer and longer hours at her laboratory and losing interest in the family. She is engaged in a secret struggle to develop her nanorobots into a stealthy photo-reconnaissance system that can be sold to the United States Army. To increase the power and performance of the system, she incorporates living bacteria into the nanorobots so that they can reproduce and evolve rapidly. She reprograms them with Jack's newest autonomous-agent software so that they can learn from experience.

Even with these improvements the nanorobots fail to meet the army's specifications, and Xymos loses its army funding. After that, Julia desperately tries to convert the photo-reconnaissance system into a medical diagnostic system that can be sold on the civilian market. Her idea is to train the nanorobots to enter and explore the human body, so that they can locate tumors and other pathological conditions more precisely than can be done with X-rays and ultrasound working from the outside.

Experimenting with the medical applications of her nanorobots, she uses herself as a guinea pig and becomes chronically infected. The nanorobots learn how to establish themselves as symbionts within her body, and then gradually gain control over her mind. In her deranged state, she deliberately infects three of her colleagues at the laboratory with nanorobots. She also lets a swarm of nanorobots loose into the environment where they prey upon wildlife and rapidly increase in numbers.

The main part of the story concerns Jack's slow realization that something is seriously amiss with his wife and with the project in which she is engaged. Only at the end does he understand the full horror of her transformation. With the help of a loyal young woman friend, he confronts Julia and douses her with a spray of bacteriophage that is lethal to the bacteria inside her. But Julia and her infected colleagues are no longer able to survive without the symbiotic nanorobots that have taken over their minds. Under the spray of bacteriophage they collapse and die, like the Wicked Witch of the West in *The Wizard of Oz* when Dorothy throws a bucket of water over her. After Julia's demise, Jack and his girlfriend finish the job of destroying the nanorobots inside and outside the laboratory with fire and high explosives. In the final scene, Jack is back with his kids, wondering whether the nanorobots are gone for good, or whether the Xymos corporation may still be developing other nanorobot projects that will turn into nightmares.

What are we to make of this fairy story? There are two ways to look at it. On the one hand, we may enjoy it as a story and not worry whether some parts of it might come true. On the other hand, we may read it as an urgent warning of dangers lying ahead if present-day technological developments are allowed to continue. The author says plainly, in an introductory chapter with the title "Artificial Evolution in the Twenty-first Century," that he intends his story to be taken seriously.

It is easy to demonstrate that the details of the story are technically flawed. Consider for example the size of the nanorobots. In a commercial presentation advertising the Xymos medical diagnostic system, Julia says, "We can do all this because the camera is smaller than a red blood cell." The camera is one of her nanorobots. It must be as small as that, since Julia describes it swimming in the human bloodstream inside the capillaries that carry blood through the lungs. The capillaries are only just wide enough for red blood cells to pass through. But later in the book Jack encounters swarms of nanorobots chasing him in the open air like a swarm of ants or bees. These nanorobots are flying through the air as fast as he can run. Fortunately for Jack and unfortunately for the story, the laws of physics do not allow very small creatures to fly fast. The viscous drag of air or water becomes stronger as the creature becomes smaller. Flying through air, for a nanorobot the size of a red blood cell, would be like swimming through molasses for a human being. Roughly speaking, the top speed of a swimmer or flyer is proportional to its length. A generous upper limit to the speed of a nanorobot flying through air or swimming through water would be a tenth of an inch per second, barely fast enough to chase a snail. For nanorobots to behave like a swarm of insects, they would have to be as large as insects.

Other technical flaws in the story are easy to find. The swarms of nanorobots flying in the open air are said to be powered by solar energy. But the solar energy falling onto their very small area is insufficient to power their movements, even if we credit them with a magical ability to use solar energy with 100 percent efficiency. I could continue with a list of technical details that are scientifically impossible for one reason or another, but that would miss the main point of the story. The story is about human beings and not about nanorobots. The main point is that Julia is a credible human being. She is a capable and well-meaning woman in a responsible position, with the fate of a company resting on her shoulders. She decides that the only way to save the company from bankruptcy is to push ahead with a risky technology. Unable to face the failure of her company and her career, she continues with her experiments regardless of the risks. She is a gambler playing for such high stakes that she cannot afford to lose. In the end she loses not only her company and her career but her family and her life. It is a credible human story, and in the end the technical details do not matter.

This story reminds me of Nevil Shute's *On the Beach*, published in 1957, a novel describing the extinction of mankind by radiological warfare. Shute's poignant translation of apocalyptic disaster into the everyday voices of real people caught the imagination of the world. His book became an international best seller and was made into a successful film. The book and the film created an enduring myth, a myth which entered consciously or subconsciously into all subsequent thinking about nuclear war. The myth pictures nuclear war as silent inexorable death from which there is no escape, with radioactive cobalt sweeping slowly down the sky from the northern to the southern hemisphere. The people of Australia, after the northern hemisphere is dead, live out their lives quietly and bravely to the end. The Australian government provides a supply of euthanasia pills for citizens to use when the symptoms of radiation sickness become unpleasant. Parents are advised to give the pills to their children first before they become sick. There is no hope of survival; there is no talk of building an underground Noah's Ark to keep earth's creatures alive until the cobalt decays. Shute imagined the human species calmly acquiescing in its extinction.

The myth of *On the Beach* is technically flawed in many ways. Almost all the details are wrong: radioactive cobalt would not substantially increase the lethality of large hydrogen bombs; fallout would not descend uniformly over large areas but would fall sporadically in space and time; people could protect themselves from the radioactivity by sheltering under a few feet of dirt; and the war is supposed to have happened in 1961, too soon for even the most malevolent country to have acquired the megatonnage needed to give a lethal dose of radiation to the entire earth. Nevertheless, the myth did what Shute intended it to do. On the fundamental human level, in spite of the technical inaccuracies, it spoke truth. It told the world, in language that everyone could understand, that nuclear war means death. And the world listened.

Prey is not as good as *On the Beach*, but it is bringing us an equally important message. The message is that biotechnology in the twenty-first century is as dangerous as nuclear technology in the twentieth. The dangers do not lie in any particular gadgets such as nanorobots or autonomous agents. The dangers arise from knowledge, from our inexorably growing understanding of the basic processes of life. The message is that biological knowledge irresponsibly applied means death. And we may hope that the world will listen.

From this point on, I assume that the basic message of *Prey* is true. I assume that the growth of biological knowledge during the century now beginning will bring grave dangers to human society and to the ecology of our planet. The rest of this review is concerned with the question of what we should do to mitigate the dangers. What is the appropriate response to dangers that are hypothetical and poorly understood? In this matter, as in other situations where public health hazards and environmental risks must be assessed and regulated, there are two strongly opposed points of view. One point of view is based on the "precautionary principle." The precautionary principle says that when there is any risk of a major disaster, no action should be permitted that increases the risk. If, as often happens, an action promises to bring substantial benefits together with some risk of a major

The idea of nanotechnology is to build machines on a tiny scale that are as capable as living cells, but made of different materials so that they are more rugged and more versatile. One kind of nanomachine is the assembler, which is a tiny factory that can manufacture other machines, including replicas of itself. Drexler understood from the beginning that a replicating assembler would be a tool of immense power for good or for evil. Fortunately or unfortunately, nanotechnology has moved more slowly than Drexler expected. Nothing remotely resembling an assembler has yet emerged. The most useful products of nanotechnology so far are computer chips. They have no capacity for replicating either themselves or anything else.

My last quote from Bill comes from an article he published in *The Washington Post*, summing up the dangers that he foresees and recommending a program of action to avoid them:

> We who are involved in advancing the new technologies must devote our best efforts to heading off disaster. I offer here a list of first steps suggested by our history with weapons of mass destruction:
>
> (1) Have scientists and technologists (and corporate leaders as well) take a vow, along the lines of the Hippocratic Oath, to avoid work on potential and actual weapons of mass destruction....
>
> (2) Create an international body to publicly examine the dangers and ethical issues of new technology....
>
> (3) Use stricter notions of liability, forcing companies to take responsibility for consequences through a private-sector mechanism—insurance....
>
> (4) Internationalize control of knowledge and technologies that have great potential but are judged too dangerous to be made commercially available....
>
> (5) Relinquish pursuit of that knowledge and development of those technologies so dangerous that we judge it better that they never be available. I too believe

in the pursuit of knowledge and development of technologies; yet, we already have seen cases, such as biological weapons, where relinquishment is the obvious wise choice.

Next comes my response to Bill. I agreed that the dangers he described are real, but I disagreed with some details of his argument, and I disagreed strongly with his remedies. I began by speaking about the history of biological weapons and gene-splicing experiments, and the successes and failures of efforts to regulate them. Bill ignores the long history of effective action by the international biological community to regulate and prohibit dangerous technologies. Gene-splicing experiments began in many countries when the technique of sticking pieces of DNA together was discovered in 1975. Two leading biologists, Maxine Singer and Paul Berg, issued a call for a moratorium on all such experiments until the dangers could be carefully assessed. There were obvious dangers to public health, for example if genes for deadly toxins could be inserted into bacteria that are normally endemic in human populations. Biologists all over the world quickly agreed to the moratorium, and experiments were halted everywhere for ten months. During the ten months, two international conferences were held to work out the guidelines for permissible and forbidden experiments. The guidelines established rules of physical and biological containment for permitted experiments involving various degrees of risk. The most dangerous experiments were forbidden outright. These guidelines were adopted voluntarily by the biologists and have been observed ever since, with changes made from time to time in response to new discoveries. As a result, no serious health hazards have arisen from the experiments in twenty-five years. This is a shining example of responsible citizenship, showing that it is possible for scientists to protect the public from injury while preserving the freedom of science.

The history of biological weapons is a more complicated story. The United States, Britain, and the Soviet Union all had large programs to develop and stockpile biological weapons during and after the Second World War. But these were low-key efforts compared with the programs to develop nuclear weapons. Unlike the well-known physicists who pushed the nuclear bomb programs ahead with great enthusiasm, the biologists never pushed hard for biological weapons. The great majority of biologists had nothing to do with weapons. The few biologists who were involved with the weapons program were mostly opposed to it.

The strongest of the opponents in the United States was Matthew Meselson, who had the good luck to be a neighbor and friend of Henry Kissinger in 1968 when Nixon became president. Kissinger became national security adviser to President Nixon. Meselson seized the opportunity to convince Kissinger, and Kissinger convinced Nixon, that the American biological weapons program was far more dangerous to the United States than to any possible enemy. On the one hand, it was difficult to imagine any circumstances in which the United States would wish to use these weapons, and on the other hand, it was easy to imagine circumstances in which some of the weapons could fall into the hands of terrorists.

So Nixon in 1969 boldly declared that the United States was dismantling the entire program and destroying the stockpile of weapons. This was a unilateral move, not requiring any international agreement or ratification by the American Senate. The development of weapons was duly stopped and the weapons were destroyed. Britain quickly followed suit. In 1972, as a result of Nixon's initiative, an international convention was signed by the US, the UK, and the USSR, imposing a permanent prohibition of biological weapons on all three countries. Many other countries subsequently signed the convention.

As we now know, the Soviet Union violated the Biological Weapons Convention of 1972 on an extensive scale, continuing to develop new weapons and to accumulate stockpiles until its collapse in 1991. After the collapse, Russia declared its adherence to the convention and announced that the Soviet program had now finally been stopped. But many of the old Soviet research and production centers remain hidden behind walls of secrecy, and Russia has never provided the world with convincing evidence that the program is not continuing. It is quite possible that stockpiles of biological weapons continue to exist in Russia and in other countries. Nevertheless, the 1972 convention remains legally in force and most countries have signed it. Even if the convention is unverifiable and even if it is violated, we are far better off with it than without it. Without the convention, we would not have any legal ground for complaint or for preventive action whenever a biological weapons program anywhere in the world is discovered. With the convention, the danger of biological weapons is not eliminated but it is significantly reduced. Again, biologists in general and Meselson in particular deserve credit for making this happen in the real world of national politics and international rivalries.

The last part of my reply to Bill Joy concerns remedies for the dangers that we all agree exist. Bill says, "Internationalize control of knowledge" and "Relinquish pursuit of that knowledge … so dangerous that we judge it better that [it] never be available." Bill is advocating censorship of scientific inquiry, either by international or national authorities. I am opposed to this kind of censorship. It is often said that the risks of modern biotechnology are historically unparalleled because the consequences of letting a new living creature loose in the world may be irreversible. I think we can find a good historical parallel where a government was trying to guard against dangers that were equally irreversible.

Three hundred and fifty-nine years ago, the poet John Milton wrote a speech with the title *Areopagitica*, addressed to the Parliament of England. He was arguing for the liberty of unlicensed printing. I am suggesting that there is an analogy between the seventeenth-century fear of moral contagion by soul-corrupting books and the twenty-first-century fear of physical contagion by pathogenic microbes. In both cases, the fear was neither groundless nor unreasonable. In 1644, when Milton was writing, England was engaged in a long and bloody civil war, and the Thirty Years' War, which devastated Germany, had four years still to run. These seventeenth-century wars were religious wars, in which differences of doctrine played a great part. In that century, books not only corrupted souls but also mangled bodies. The risks of letting books go free into the world were rightly regarded by the English Parliament as potentially lethal as well as irreversible. Milton argued that the risks must nevertheless be accepted. I believe his message may still have value for our own times, if the word "books" is replaced by the word "experiments." Here is Milton:

> I deny not, but that it is of greatest concernment in the Church and Commonwealth, to have a vigilant eye how books demean themselves as well as men; and thereafter to confine, imprison, and do sharpest justice on them as malefactors.... I know they are as lively, and as vigorously productive, as those fabulous dragon's teeth; and being sown up and down, may chance to spring up armed men.

The important word in Milton's statement is "thereafter." Books should not be convicted and imprisoned until after they have done some damage. What Milton declared unacceptable was prior censorship, prohibiting books from ever seeing the light of day. Next, Milton comes to the heart of the matter, the difficulty of regulating "things, uncertainly and yet equally working to good and to evil":

> Suppose we could expel sin by this means; look how much we thus expel of sin, so much we expel of virtue: for the matter of them both is the same; remove that, and ye remove them both alike.
>
> This justifies the high providence of God, who, though he commands us temperance, justice, continence, yet pours out before us even to a profuseness all desirable things, and gives us minds that can wander beyond all limit and satiety. Why should we then affect a rigor

5

WHAT A WORLD!

IT IS REFRESHING to read a book full of facts about our planet and the life that has transformed it, written by an author who does not allow facts to be obscured or overshadowed by politics. Vaclav Smil is well aware of the political disputes that are now raging about the effects of human activities on climate and biodiversity, but in *The Earth's Biosphere: Evolution, Dynamics, and Change*[1] he does not give them more attention than they deserve. He emphasizes the enormous gaps in our knowledge, the sparseness of our observations, and the superficiality of our theories. He calls attention to the many aspects of planetary evolution that are poorly understood, and that must be better understood before we can reach an accurate diagnosis of the present condition of our planet. When we are trying to take care of a planet, just as when we are taking care of a human patient, diseases must be diagnosed before they can be cured.

The book has two themes, a major and a minor one. The major theme is the description of the biosphere. The biosphere is the interacting web of plants and rocks, fungi and soils, animals and oceans, microbes and air that constitutes the habitat of life on our planet. To understand the biosphere, it is essential to see it from both sides, from below as a multitude of details and from above as a single integrated system. This book gives a comprehensive account of biological details and a summary of the global cycles of matter and energy that tie the system together. Every detail and every cycle is documented with references to the technical literature. There are forty pages of bibliography, containing more than a thousand references, ranging from John Ray's 1686 *History of Plants* to the 2001 report of the Intergovernmental Programme on Climatic Change. The bibliography will make this book a useful work of reference for students and teachers. The text is also intended to be read by ordinary citizens who are not students or teachers but have a serious interest in environmental problems.

The minor theme of the book is the life and work of Vladimir Vernadsky. Vernadsky did not invent the word "biosphere," but he was the first to make it a central concept unifying the study of the earth with the study of life. In Russia he is honored as one of the leading figures of twentieth-century science, while in the West his name is hardly known. Vaclav Smil, who is himself a bridge between East and West, educated in Prague and living in Canada, uses this book as an opportunity to bring Vernadsky to life and to make the West aware of his ideas. Every chapter begins with a quotation from Vernadsky's book *The Biosphere*, which summarized his thinking and was written for a wide audience. The first chapter, with the title "Evolution of the Idea," begins with Vernadsky saying, "A new character is imparted to the planet by this powerful cosmic force. The radiations that pour upon the Earth cause the biosphere to take on properties unknown to lifeless planetary surfaces, and thus transform the face of the Earth." The last chapter, with the title "Civilization and the Biosphere," begins with the quotation "Man, alone, violates the established order."

The meaning of this last quotation becomes clearer when we place it in its context. Man violates the established order not only by burning coal and oil but by farming and weeding. This is what Vernadsky wrote:

> In cultivated areas it is only at the expense of great effort that civilized man can secure crops unmixed with

> weeds which spring up everywhere. Before man appeared on the Earth, the vegetation everywhere must have reached its maximum possible development, a state of equilibrium, attained through centuries of growth. Such a state can be seen in the virgin steppes which still exist in parts of Russia.… As far as the eye could see, there was nothing but the waist-high growth of feather-grass, a continuous clothing to the Earth, protecting it against the heat of the sun. Moss and lichen, profiting by the conservation of the moisture in the soil, remained green throughout the heat of summer under the shadow of the leaves.
>
> Man, alone, violates the established order and, by cultivation, upsets the equilibrium.… He sees this when he is obliged to oppose the pressure of life in defending against this invader fields which he wants to cultivate. He sees it, too, if he watches the surrounding world of nature with attentive eyes; the secret, silent, inexorable fight for existence waged all around him by green vegetation. Sensing this movement, he may experience the reality of the assault of the forest on the steppe-land, or the gradual suffocation of the forest by the rising tide of lichens from the tundra.

In these words we hear the authentic voice of Vernadsky, talking like the doctor Mikhail Astrov in Chekhov's play *Uncle Vanya*. His statement of the facts is scientifically accurate, but is expressed in the language of drama and poetry. Vernadsky and Chekhov were contemporaries. Both belonged to the circle of philosophizing intellectuals that Chekhov portrays so poignantly in his plays. Vernadsky was a Chekhov character who also happened to be a world-class scientist.

Vernadsky was a geochemist, born in 1863 in Kiev, the son of a professor of political economy. In 1889 he worked as a student with Pierre Curie in Paris, and in 1902 he became a full professor at Moscow University. After the first Russian revolution of 1905, which forced the Tsar to give some share in the affairs of government to a representative assembly called the Duma, Vernadsky was an important political figure. He was one of the founders of the Constitutional Democratic Party, generally known by its acronym Kadet. The Kadet party tried to provide the loyal opposition that Russia desperately needed in order to achieve far-reaching political reform without bloodshed. Unfortunately, the majority of intellectuals supported social revolutionary parties and did not believe in gradual reform.

Through the years from 1908 to 1918, Vernadsky remained a member of the central committee of the Kadet party, struggling to establish democratic government in Russia against bitter opposition from the Tsar's bureaucrats on the right and the social revolutionaries on the left. After the Bolshevik Revolution, most of the Kadet leaders were executed. Vernadsky was spared because he was a famous scientist and had some friends in Lenin's inner circle, but his political life was over. He spent some years as an exile in Paris, giving lectures at the Sorbonne on geochemistry and writing his book *The Biosphere*. In 1926, at the age of sixty-two, he returned peacefully to Russia and published the book in Leningrad. He refused to join the Communist Party, but continued to live until his death in 1945 as one of the respected elder statesmen of Soviet science.

In Russia the disciplines of geochemistry and biology remained unified, with Vernadsky's vision of the biosphere as a central theme. After Vernadsky's death, his books and papers continued to be read and studied. Russian biologists aimed to understand life by integrating it into ecological communities and planetary processes. Meanwhile, in the West, biology developed in a strongly reductionist direction, the aim being to understand life by reducing it to genes and molecules. Reductionist biology was enormously successful and came to dominate the thinking of Western biologists.

There is in fact no incompatibility between reductionist and integrative biology. Genes and molecules and ecologies and biospheres are all essential parts of the world we live in. To understand our world fully, both kinds of biology are needed. If science had been uncontaminated by politics, the reductionist and integrative approaches to biology in the West and the East would have blended together during Vernadsky's lifetime and merged into a balanced view of the biosphere. But in the 1930s, biology in the Soviet Union was almost destroyed by Trofim Lysenko's murderous campaign against Mendelian genetics. In Russia reductionist biology was forbidden, and in the West the Russian tradition of integrative biology was discredited because Lysenko appeared to approve of it. In the West Vernadsky's ideas were ignored and his books were unread. A complete translation of *The Biosphere* into English was only published in 1998.[2] After seventy years of dominance of reductionist biology, Vernadsky's language now seems quaint and old-fashioned.

One of the great might-have-beens of history is the world that would have emerged if the statesmen of Europe had had the wisdom to deal peacefully with the Serbian crisis of 1914. If World War I had never happened, the rapid economic growth that Russia experienced from 1905 to 1914 would probably have continued. The Bolsheviks would probably have remained a small group of outlaws without any wide following, and would not have had an opportunity to seize power. The Tsar's government might have evolved into a constitutional monarchy, and the Kadet party might have emerged as the leader of a liberal parliamentary regime. In that imaginary world, Vernadsky might have been prime minister of Russia, guiding his country along the path of economic and scientific development, ending with full integration into the world community. After reading some of his writings, I have little doubt that he would have chosen to stay in politics if he had had the chance. He would not then have had time to resume his work as a scientist and write *The Biosphere*. Instead of being the founder of a new discipline of science, he might have been the savior of his country.

From Vernadsky and his dreams, I turn now to the major theme of Smil's book, which is the difficulty of understanding the behavior of the biosphere on a global scale. Even the nonliving processes governing weather and climate are can still be helpful. The little pores in the leaves of plants have to be kept open for the plant to acquire carbon dioxide from the air, but the plant loses a hundred molecules of water through the pores for every one molecule of carbon dioxide that it gains. This means that increased carbon dioxide in the air allows the plant to partially close the pores and reduce the loss of water. In dry conditions, increased carbon dioxide becomes a water-saver and gives the plant a better chance to keep on growing.

The fundamental reason why carbon dioxide abundance in the atmosphere is critically important to biology is that there is so little of it. A field of corn growing in full sunlight in the middle of the day uses up all the carbon dioxide within a meter of the ground in about five minutes. If the air were not constantly stirred by convection currents and winds, the corn would not be able to grow. The total content of carbon dioxide in the atmosphere, if converted into biomass, would cover the surface of the continents to a depth of less than an inch. About a tenth of all the carbon dioxide in the atmosphere is actually converted into biomass every summer and given back to the atmosphere every fall. That is why the effects of fossil fuel–burning cannot be separated from the effects of plant growth and decay.

There are five reservoirs of carbon that are biologically accessible on a short timescale, not counting the carbonate rocks and the deep ocean, which are only accessible on a timescale of thousands of years. The five accessible reservoirs are the atmosphere, the land plants, the topsoil in which land plants grow, the surface layer of the ocean in which ocean plants grow, and our proved reserves of fossil fuels. The atmosphere is the smallest reservoir and the fossil fuels are the largest, but all five reservoirs are of comparable size. They all interact strongly with one another. To understand any of them, it is necessary to understand all of them. That is why planetary ecology is not an exact science like chemistry.

As an example of the way different reservoirs of carbon dioxide may interact with each other, consider the atmosphere and the topsoil. Greenhouse experiments show that many plants growing in an atmosphere enriched with carbon dioxide react by increasing their root-to-shoot ratio. This means that the plants put more of their growth into roots and less into stems and leaves. A change in this direction is to be expected, because the plants have to maintain a balance between the leaves collecting carbon from the air and the roots collecting mineral nutrients from the soil. The enriched atmosphere tilts the balance so that the plants need less leaf area and more root area. Now consider what happens to the roots and shoots when the growing season is over, when the leaves fall and the plants die. The new-grown biomass decays and is eaten by fungi or microbes. Some of it returns to the atmosphere and some of it is converted into topsoil.

On the average, more of the aboveground growth will return to the atmosphere and more of the belowground growth will become topsoil. So the plants with increased root-to-shoot ratio will cause an increased net transfer of carbon from the atmosphere into the topsoil. If the increase in atmospheric carbon dioxide due to fossil fuel–burning has caused an increase in the average root-to-shoot ratio of plants over large areas, then the possible effect on the topsoil reservoir will not be small. At present we have no way to measure or even to guess the size of this effect. The aggregate biomass of the topsoil of the United States is not a measurable quantity. But the fact that the topsoil is unmeasurable does not mean that it is unimportant.

Roughly speaking, half of the contiguous United States, not including Alaska and Hawaii, consists of mountains and deserts and parking lots and highways and buildings, and the other half is covered with plants and topsoil. Just to see how important an unmeasurable increase of topsoil may be, let us imagine that the increased root-to-shoot ratio of plants might cause an average net increase of topsoil biomass of one tenth of an inch per year over half the area of the contiguous United States. A simple calculation shows that the amount of carbon transferred from the atmosphere to the topsoil would be five billion tons per year. This amount is considerably more than the measured four-billion-ton annual increase of carbon in carbon dioxide in the atmosphere. So the increase of carbon dioxide in the atmosphere over the entire earth could be canceled out by an increase of topsoil biomass of a tenth of an inch per year over half of the contiguous United States.

A tenth-of-an-inch-per-year increase of topsoil would be exceedingly difficult to measure. At present we do not even know whether the topsoil of the United States is increasing or decreasing. Over the rest of the world, because of large-scale deforestation and erosion, the topsoil reservoir is probably decreasing. We do not know whether intelligent land management could ensure a growth of the topsoil reservoir by four billion tons of carbon per year, the amount needed to stop the increase of carbon dioxide in the atmosphere. All that we can say for certain is that this is a theoretical possibility and ought to be seriously explored.

Another problem mentioned by Smil that has to be taken seriously is a slow rise of sea level, which could become catastrophic if it continues to accelerate. We have accurate measurements of sea level going back two hundred years. We observe a steady rise from 1800 to the present, with an acceleration during the last fifty years. It is widely believed that the recent acceleration is due to human activities, since it coincides in time with the rapid increase of carbon dioxide in the atmosphere. But the rise from 1800 to 1900 was probably not due to human activities. The scale of industrial activities in the nineteenth century was not large enough to have had measurable global effects. A large part of the observed rise in sea level must have other causes. One possible cause is a slow readjustment of the shape of the earth to the disappearance of the northern ice sheets at the end of the ice age 12,000 years ago. Another possible cause is the large-scale melting of glaciers, which also began long before human influences on climate became significant. Once again, we have an environmental danger whose magnitude cannot be predicted until we know much more about its causes.

The most alarming possible cause of sea-level rise is the rapid disintegration of the West Antarctic ice sheet, which is the part of Antarctica where the bottom of the ice is far below sea level. Warming seas around the edge of Antarctica might erode the ice cap from below and cause it to collapse into the ocean. If the whole of West Antarctica disintegrated rapidly, sea level would rise by five meters, with disastrous effects on billions of people. However, recent measurements of the icecap show that it is not losing volume fast enough to make a significant contribution to the presently observed sea-level rise. It appears that the warming seas around Antarctica are causing an increase in snowfall over the icecap, and the increased snowfall on top roughly cancels out the decrease of ice volume caused by erosion at the edges. This is another situation in which we do not know how much of the environmental change is due to human activities and how much to long-term natural processes over which we have no control.

Another environmental danger that is even more poorly understood is the possible coming of a new ice age. A new ice age would mean the burial of half of North America and half of Europe under massive ice sheets. We know that there is a natural cycle that has been operating for the last 800,000 years. The length of the cycle is 100,000 years. In each 100,000-year period, there is an ice age that lasts about 90,000 years and a warm interglacial period that lasts about 10,000 years. We are at present in a warm period that began 12,000 years ago, so the onset of the next ice age is overdue. If human activities were not disturbing the climate, a new ice age might begin at any time within the next couple of thousand years, or might already have begun. We do not know how to answer the most important question: Does our burning of fossil fuels make the onset of the next ice age more likely or less likely?

There are good arguments on both sides of this question. On the one side, we know that the level of carbon dioxide in the atmosphere was much lower during past ice ages than during warm periods, so it is reasonable to expect that an artificially high level of carbon dioxide might stop an ice age from beginning. On the other side, the oceanographer Wallace Broecker[3] has argued that the present warm climate in Europe depends on a circulation of ocean water, with the Gulf Stream flowing north on the ocean surface and bringing warmth to Europe, while a countercurrent of cold water flows south in the deep ocean. So a new ice age could begin whenever the cold, deep countercurrent is interrupted. The countercurrent could be interrupted when the cold surface water in the Arctic becomes less salty and fails to sink, and the water could become less salty when the warming climate increases the Arctic rainfall. Thus Broecker argues that a warm climate in the Arctic may paradoxically cause an ice age to begin. Since we are confronted with two plausible arguments leading to opposite conclusions, the only rational response is to admit our ignorance. Until the causes of ice ages are understood in detail, we cannot know whether the increase of carbon dioxide in the atmosphere is increasing or decreasing the danger.

The biosphere is the most complicated of all the things we humans have to deal with. The science of planetary ecology is still young and undeveloped. It is not surprising that honest and well-informed experts can disagree about facts. But beyond the disagreements about facts, there is another deeper disagreement about values. The disagreement about values may be described in an oversimplified way as a disagreement between naturalists and humanists. Naturalists believe that nature knows best. For them the highest value is respect for the natural order of things. Any gross human disruption of the natural environment is evil. Excessive burning of fossil fuels, and the consequent increase of atmospheric carbon dioxide, are unqualified evils.

Humanists believe that humans are an essential part of nature. Through human minds the biosphere has acquired the capacity to steer its own evolution, and we are now in charge. Humans have the right to reorganize nature so that humans and biosphere can survive and prosper together. For humanists, the highest value is intelligent coexistence

6

WITNESS TO A TRAGEDY

THOMAS LEVENSON IS a filmmaker who produces documentary films for public television. He has a sharp eye for the dramatic events and personal details that bring history to life. His book *Einstein in Berlin*[1] is a social history of Germany covering the twenty years from 1914 to 1933, the years when Albert Einstein lived in Berlin. The picture of the city's troubles comes into a clearer focus when it is viewed through Einstein's eyes. Einstein was a good witness, observing the life of the city in which he played an active role but remained always emotionally detached. He wrote frequent letters to his old friends in Switzerland and his new friends in Germany, recording events as they happened and describing his hopes and fears. His daily life and activities come intermittently into the narrative but are not the main theme. The main theme is the tragedy of World War I, a tragedy that began in 1914 but did not end in 1918. This tragedy continued to torment the citizens of Berlin through the years from 1918 to 1933 and led them finally to put their fate in the hands of Hitler. Hitler was able to gain his power over them because he promised to erase the tragedy and bring them back to the happy days of the empire when Germany was prosperous and united.

Every aspect of Einstein's life, the personal, the political, the scientific, and the philosophical, has been described in detail and analyzed in depth by his various biographers. The world does not need another Einstein biography. Fortunately, Levenson's book is not a biography. He has borrowed everything he needs from the published correspondence and the existing biographies of Einstein, with full acknowledgments and an excellent bibliography. The new and original aspect of this book is the context in which Einstein is placed. The context is a study in depth of the social pathology that gripped Berlin from the day Einstein arrived there in 1914 to the day he left in 1932.

The tragedy is a play in two acts, the first act being the years of war and the second act the years of the Weimar Republic. The most remarkable feature of the first act was the general belief among Einstein's friends in Berlin that the war was winnable. The war was widely welcomed as an opportunity for Germany to achieve its proper status as a great power. Einstein observed that his academic friends and colleagues were even more deluded with patriotic dreams of grandeur than the ordinary citizens that he met in the street. In a conversation with his Swiss friend Romain Rolland in 1915, he described how Berlin had gone to war. "The masses were immensely submissive, domesticated," he said. "The elites were worse. They were hungry, driven by their urge for power, their love of force, and the dream of conquest." As late as the summer of 1918, after the failure of the final German offensive on the western front, many of the leading German academics were still confident of victory.

The state of mind of the mandarins in Berlin was very different from the state of mind of their enemies in Paris and London. In Paris the war was seen as a desperate struggle for survival. The guns on the western front were close enough so that everyone in Paris could hear them. In Britain the war was seen as a tragedy that had done irreparable harm to Britain and to European civilization, no matter who won it. When the war came to an end in November 1918, the British public looked back on it as an unspeakable horror that should never under any circumstances be allowed to happen again. But a large part of the German public looked back on it differently, as a test of strength that they could have won if they had not been stabbed in the back by traitors at home. This book explains how that fatal German sense of betrayal came into being.

The second act of the tragedy is the story of the slow collapse of the Weimar Republic and the rapid rise of Hitler. Einstein was a firm supporter of the republic, but he saw which way the wind was blowing. One episode in the tragedy epitomizes the whole story. Erich Remarque's book *Im Westen Nichts Neues* was published in 1929 and immediately became an international best seller. It is the finest of all fictional accounts of World War I, seen through the eyes of a group of young Germans who die pointlessly in the carnage of the western front. In 1930 it was made into a Hollywood film, *All Quiet on the Western Front*. The film was shown all over the world, except in Germany. When the distributors of the film tried to show it in Berlin, Hitler's friend Joseph Goebbels organized a riot in the theater. Further Nazi demonstrations and violent protests against the film followed. And then the Weimar government banned the film throughout Germany. The Weimar authorities did not allow the German public to see the film because the Nazis considered it unpatriotic. This episode explains a mystery in my own family. One of my relatives is a lady, now ninety-four years old, who lived in Germany all her life and grew up in the Weimar years. Many years ago, I gave her Remarque's book to read and she found it very moving. "This book is wonderful," she said. "Why didn't they let us read it when it was published? That was before the Hitler time, but we were told that it was disgusting and shameful and respectable people should not read it." So the respectable Germans of her generation, even those who were not Nazis, did not read Remarque. I always wondered why, and now I know.[2]

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1. Random House, 2003.

2. The lady who did not read Remarque until it was too late was my mother-in-law, Gisela Jung. She died in March 2003. A few sentences

of this review have been rewritten to avoid overlap with the review of Yuri Manin's *Mathematics and Physics* (Chapter 14).

II

War and Peace

nor muddleheaded. We made only one mistake; none of us in those days could imagine that England would survive six years of war against Hitler, achieve most of the political objectives for which the war had been fought, suffer only one third the casualties that we had had in World War I, avoid the massive and indiscriminate use of poison gas and biological weapons, and finally emerge into a world in which our moral and humane values were largely intact. When Chamberlain led us into war in 1939, his view of the outcome was probably as dark as ours, only he was sustained in his determination by the feeling that he had no honorable alternative.

I come at last to Tom Stonier's book *Nuclear Disaster*,[1] which is a thorough and straightforward study of the consequences of nuclear war. Stonier is a biologist, and this fact gives his analysis breadth which has been lacking in earlier studies by physical scientists. His conclusions are not quantitative but are clear and stark. He asserts that the United States would not survive in anything resembling its present form after a major thermonuclear exchange. He documents his conclusion with detailed discussion of the medical, ecological, and social problems of survival in a physically mutilated and contaminated country. He finds that although each problem by itself might well be overcome by energetic action and organization, all the problems together are likely to present insuperable difficulties. The life of the surviving postwar population is pictured as being "nasty, brutish and short" for many generations.

Stonier's knowledge of the physical and biological effects of nuclear explosions is solid and professional. His description of the economic and social effects is entirely plausible. Nevertheless, his total assessment of the long-range effect of nuclear war is necessarily dependent on his personal judgment. Nobody can say for sure whether a population subjected to unprecedented horrors and privations would respond with apathetic despair or with heroic discipline. The problem here is to predict the psychological, moral, and spiritual reactions of people in circumstances for which we have no valid historical parallel.

Stonier describes at some length the reactions observed during and after the Irish potato famine of 1845–1848. This description is of absorbing interest, but its relevance to the problem of nuclear war is at best conjectural. In the end, readers of the book must decide for themselves, following their individual tastes or prejudices, whether they accept or reject Stonier's gloomy prognosis for the long-range recovery of civilization.

Just because the conclusions of Stonier's book depend so heavily on subjective judgment, it is important to view the book with a wider historical perspective. For this reason I began with Oppenheimer's speech and with the lessons of the 1930s. In the 1930s we held views about war very similar to those of Stonier, and these views turned out to be wrong. The experts who so grossly overestimated the effectiveness of bombing in 1939 made many technical errors, but their major mistake was a psychological one. They failed completely to foresee that the direct involvement of civilian populations in warfare would strengthen their spirit and social cohesion. The unexpected toughness and discipline of populations under attack was seen not only in England but even more strikingly in Germany, Japan, and the Soviet Union. Would the same qualities be shown in the United States after a nuclear attack? Stonier thinks not. I am not sure.

So we come back finally to the simple and profound words of Oppenheimer's speech. What we said about war in 1939 did not prevail. We learned in 1939–1945 that a war could still be fought and won without destroying the soul of a country. We learned that yielding to threats is the greater evil, and this is the lesson that most of us are now living by. When we in America apply this lesson to our dealings with the Soviet Union in the year 1964, are we misled by a false sense of human history? Is it a false sense of human history that teaches us that nationalism is still the strongest force in the world, stronger than the hydrogen bomb and stronger than humanity? These are some of the questions which

Stonier's book does not answer.

Oppenheimer was certainly right in his basic perception, that history changed its course in 1945. Never again can a major war be fought in the style of World War II. And yet, international politics are being conducted on all sides as if the lessons of World War II still applied. History proceeds at its old slow pace, even if the course is changed. The transition from virulent nationalism to a world united must be stretched out over centuries. Meanwhile, we have to live in a precarious balance, between the apocalyptic warnings of Stonier on the one side and a possibly false sense of human history on the other. In spite of all uncertainties, it remains true that the catastrophes envisaged by Stonier may happen. It is well that we should be reminded of these dangers, and we must be grateful to Stonier for having reminded us of them, with his sober, thoughtful and eloquent book.[2]

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1. Meridian Books, 1963.

2. This is the oldest piece in the collection, written in 1964. I have included it because the dilemma that it describes is still as real today as it was in 1964.

8

GENERALS

AT 2:30 PM ON August 31, 1946, the former chief of the Operations Staff of the German armed forces, Colonel-General Alfred Jodl, made his final statement to the Nuremberg War Crimes Tribunal:

> Mr. President and Justices of the court. It is my unshakable belief that history will later pronounce an objective and fair judgment on the senior military commanders and their subordinates. They, and with them the German armed forces as a whole, faced an insoluble problem, namely, to wage a war which they had not wanted, under a supreme commander who did not trust them and whom they only partially trusted, with methods which often contradicted their doctrines and their traditional beliefs, with troops and police forces not fully subject to their command, and with an intelligence service which was partly working for the enemy. And all this with the clear knowledge that the war would decide the existence or nonexistence of the beloved fatherland. They were not servants of Hell or of a criminal. They served their people and their fatherland.
>
> For myself, I believe that no man can do better than to struggle for the highest goal which he is in a position to achieve. That and nothing else was the guiding principle

> of my actions all along. And that is why, no matter what verdict you may pass on me, I shall leave this court with my head held as high as when I entered it many months ago. If anyone calls me a traitor to the honorable tradition of the German army, or if anyone says that I stayed at my post for reasons of personal ambition, I say he is a traitor to the truth.
>
> In this war, hundreds of thousands of women and children were destroyed by carpet-bombing, and partisans used without scruple whatever methods they found effective. In such a war, severe measures, even if they are questionable according to international law, are not crimes against morality and conscience. For I believe and profess: duty toward people and fatherland stands above every other. To do that duty was my honor and highest law. I am proud to have done it. May that duty be replaced in a happier future by an even higher one: duty toward humanity.

On October 10 he wrote a final letter to his friends in the German army:

> Dear friends and comrades. In the months of the Nuremberg trial I have borne witness for Germany, for her soldiers, and for history. The dead and the living crowded around me, giving me strength and courage. The verdict of the court went against me. That came as no surprise. The words which I heard from you were for me the true verdict. I was never proud in my life until now. Today I can and I will be proud. I thank you, and one day Germany will thank you, because you did not run away from one of her truest sons in his hour of need and death. Your future lives must not be filled with sadness and hate. Think of me only with respect and pride, just as you think of all the soldiers who died on the battlefields of this cruel war as they were required to do by law. Their lives were sacrificed to make Germany more powerful, but you should believe that they died to

And is altered in fulfilment.

For the title of her book she took Eliot's words: "Beyond the End." Eliot wrote these words in the quietness of wartime England, in the early years of the war, when no end was in sight. The passage continues with lines which Luise Jodl must have known but did not choose to quote:

> *There are other places*
>
> *Which also are the world's end, some at the sea jaws,*
>
> *Or over a dark lake, in a desert or a city....*

One of those other places was Nuremberg, where Luise found herself in October 1946, alone among the ruins, faced with the tasks of piecing together the fragments of her husband's life and distilling some meaning from the dishonor of his death.

Perhaps the most brilliant field commander on either side in World War II was Hermann Balck. He commanded the motorized infantry regiment which led the decisive German breakthrough into France in 1940. Fighting later on the eastern front, he constantly surprised the Russians with unexpected moves and tactics. In the spring of 1945 he led the last German offensive of the war, holding off the Russian armies in Hungary long enough so that he could retreat in good order into Austria and finally surrender his troops to the Americans. He was, unlike Jodl, a real Prussian. He fought as Jodl was not permitted to fight, in the front lines with his soldiers. He was accused of no war crimes. In 1979, at the age of eighty-five, he entertained an American interviewer with his reminiscences.[2]

On Prussia:

> You need to see Prussia's situation in Europe, first of all. Prussia was a small country surrounded by superior forces. Therefore, we had to be more skillful and more swift than our enemies. That started perhaps with Frederick the Great at the battle of Leuthen where he

> defeated, and defeated thoroughly, a force of Austrians about twice as big as his own. In addition to being more clever than our opponents, we Prussians also needed to be able to mobilize much more quickly than our enemies.

On the breakthrough across the Meuse River in 1940:

> We knew in advance that we had to execute the crossing and I had already rehearsed it on the Moselle with my people. During this practice I had a couple of good ideas. First, every machine gun not occupied in the ground action was employed for air defense. Second, every man in the regiment was trained in the use of rubber boats. When we got to the Meuse, the engineers were supposed to be there, to put us across. They never arrived, but the rubber boats were there. So you see, if I hadn't trained my people, the Meuse crossing would have never happened. Which once again leads to the conclusion that the training of the infantryman can never be too many-sided....
>
> The operation lay under intense French artillery fire. I had thrust forward to the Meuse with one battalion after some brief fights with the French outposts, and I had set up my regimental command post up front there on the Meuse, along with the forward battalion. I went along with them to make sure that some ass wouldn't suddenly decide to stop on the way. You know, the essence of the forward command idea is for the leader to be personally present at the critical place. Without that presence, it doesn't work.

On a tank battle in Russia in 1942:

> I was heavily engaged in an attack with the 11th Panzer Division. Corps Headquarters called up at 7 o'clock in the evening and said that there had been a serious breakthrough 20 kilometers to my left, and that I should

hurry over and take care of the breakthrough. I said, "Well, let me clean up the situation here and then I'll take care of the breakthrough." They said, "No, the situation on your left is terrible, and you've got to cease your attack immediately and clean up the breakthrough as fast as possible." I immediately gave the verbal order extricating us from the attack and directing the division to move and prepare for the new counterattack against the breakthrough 20 kilometers away. We launched our counterattack at 5 o'clock the next morning, and achieved such surprise that we bagged 75 Russian tanks without the loss of a single one of our own. Of course, one of the key reasons why we were able to achieve such quick movement was that I marched with the units. After all, the men were dead tired and nearly finished. I rode up and down the columns and asked the troops whether they preferred to march or bleed. To compare our speed with the Russians, I would estimate that a Russian armored division would have required at least 24 hours longer to have achieved the same movement we achieved in 10 hours. I had much less experience against the Americans, so I can only guess that the Americans would have been slightly faster than the Russians.

On attack and defense:

It's quite remarkable that most people believe that attack costs more casualties. Don't even think about it; attack is the less costly operation.... The matter is, after all, mainly psychological. In attack, there are only 3 or 4 men in the division who carry the attack; all the others just follow behind. In defense, every man must hold his position alone. He doesn't see his neighbors; he just sees whether something is advancing towards him. He's often not equal to the task. That's why he's easily uprooted. Nothing incurs higher casualties than an unsuccessful defense. Therefore, attack wherever it is possible. Attack

> has one disadvantage; all troops and staffs are in movement and have to jump. That's quite tiring. In defense you can pick a foxhole and catch some sleep.

On generalship:

> There can be no fixed schemes. Every scheme, every pattern is wrong. No two situations are identical. That is why the study of military history can be extremely dangerous. Another principle that follows from this is: never do the same thing twice. Even if something works well for you once, by the second time the enemy will have adapted. So you have to think up something new. No one thinks of becoming a great painter simply by imitating Michelangelo. Similarly, you can't become a great military leader just by imitating so-and-so. It has to come from within. In the last analysis, military command is an art: one man can do it and most will never learn. After all, the world is not full of Raphaels either.

When Balck was a prisoner of war he resolutely refused to cooperate with American officers who asked him to contribute his reminiscences to an American historical project. Thirty years later, he had mellowed sufficiently to allow himself to be interviewed. The constant theme of his military career was learning to do more with less. He was always inventing new tricks to confound the enemy in front of him and the bureaucrats behind him. If I had to choose an epigraph for a biography of Balck, I would not take it from T. S. Eliot but from the old Anglo-Saxon poem commemorating the Battle of Maldon:

> *Thought shall be harder, heart the keener,*
> *Courage the greater, as our strength lessens.*

Balck, like the Saxons who fought the Danes at Maldon in the year 991, belonged to a tradition of soldiering older than

Soldatentum, older than chivalry. Balck fought well because he enjoyed fighting well, and because he had a talent for it. As a professional soldier, he took his job seriously but not solemnly.

Jodl and Balck exemplify two styles of military professionalism, the heavy and the light, the tragic and the comic, the bureaucratic and the human. Jodl doggedly sat at his desk, translating Hitler's dreams of conquest into daily balance sheets of men and equipment. Balck gaily jumped out of one tight squeeze into another, taking good care of his soldiers and never losing his sense of humor. For Jodl, Hitler was Germany's fate, a superhuman force transcending right and wrong. Balck saw Hitler as he was, a powerful but not very competent politician. When Jodl disagreed with Hitler's plan to extend the German advance south of the Caucasus Mountains by dropping parachutists, the disagreement was for Jodl a soul-shattering experience. When Balck appealed directly to Hitler to straighten out a confusion in the supply of tanks and trucks, Hitler's failure to deal with the situation came as no surprise to Balck. "As it turned out," reports Balck, "Hitler never was able to gain control over the industry." Jodl went on fighting to the bitter end because he had made Hitler's will his highest law. Balck went on fighting because it never occurred to him to do anything else.

I chose my two examples of military professionalism from Germany because the German side of World War II displays the moral dilemmas of military professionalism with particular clarity. Both Jodl and Balck were good men working for a bad cause. Both of them used their professional skills to conquer and ravage half of Europe. Both of them continued to exercise their skills through the long years of retreat when the only result of their efforts was to prolong Europe's agony. Both of them appeared to be indifferent to the sufferings of the villagers whose homes their tanks were smashing and burning. And yet the judgment of Nuremberg made a distinction between them. Whether or not the Nuremberg tribunal was properly constituted according to international law, its decisions expressed the consensus of