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SUBJECT AREA EDITORS

Foreword

The editors of the *Encyclopedia of Physical Science and Technology* had a daunting task: to make an accurate statement of the status of knowledge across the entire field of physical science and related technologies.

No such effort can do more than describe a rapidly changing subject at a particular moment in time, but that does not make the effort any less worthwhile. Change is inherent in science; science, in fact, seeks change. Because of its association with change, science is overwhelmingly the driving force behind the development of the modern world.

The common point of view is that the findings of basic science move in a linear way through applied research and technology development to production. In this model, all the movement is from science to product. Technology depends on science and not the other way around. Science itself is autonomous, undisturbed by technology or any other social forces, and only through technology does science affect society.

This superficial view is seriously in error. A more accurate view is that many complex connections exist among science, engineering, technology, economics, the form of our government and the nature of our politics, and literature, and ethics.

Although advances in science clearly make possible advances in technology, very often the movement is in the other direction: Advances in technology make possible advances in science. The dependence of radio astronomy and high-energy physics on progress in detector technology is a good example. More subtly, technology may stimulate science by posing new questions and problems for study. The influence of the steam engine on the development of thermodynamics is the classic example. A more recent one would be the stimulus that the problem of noise in communications channels gave to the study of information theory.

As technology has developed, it has increasingly become the object of study itself, so that now much of science is focused on what we have made ourselves, rather than only on the natural world. Thus, the very existence of the computer and computer programming made possible the development of computer science and artificial intelligence as scientific disciplines.

The whole process of innovation involves science, technology, invention, economics, and social structures in complex ways. It is not simply a matter of moving ideas out of basic research laboratories, through development, and onto factory floors. Innovation not only requires a large amount of technical invention, provided by scientists and engineers, but also a range of nontechnical or "social" invention provided by, among others, economists, psychologists, marketing people, and financial experts. Each adds value to the process, and each depends on the others for ideas.

Beyond the processes of innovation and economic growth, science has a range of direct effects on our society.

Science affects government and politics. The U.S. Constitution was a product of eighteenth century rationalism and owes much to concepts that derived from the science of that time. To a remarkable extent, the Founding Fathers were familiar with science: Franklin, Jefferson, Madison, and Adams understood science, believed passionately in empirical inquiry as the source of truth, and felt that government should draw on scientific concepts for inspiration. The concept of "checks and balances" was borrowed from Newtonian physics, and it was widely believed that, like the orderly physical universe that science was discovering, social relations were subject to a series of natural laws as well.

Science also pervades modern government and politics. A large part of the Federal government is concerned either with stimulating research or development, as are the National Aeronautics and Space Administration (NASA) and the National Science Foundation, or with seeking to regulate technology in some way. The reason that science and technology have spawned so much government activity is that they create new problems as they solve old ones. This is true in the simple sense of the "side effects" of new technologies that must be managed and thus give rise to such agencies as the Environmental Protection Agency (EPA). More importantly, however, the availability of new technologies makes possible choices that did not exist before, and many of these choices can only be made through the political system.

Biotechnology is a good example. The Federal government has supported the basic science underlying biotechnology for many years. That science is now making possible choices that were once unimagined, and in the process a large number of brand new political problems are being created. For example, what safeguards are necessary before genetically engineered organisms are tested in the field? Should the Food and Drug Administration restrict the development of a hormone that will stimulate cows to produce more milk if the effect will be to put a large number of dairy farmers out of business? How much risk should be taken to develop medicines that may cure diseases that are now untreatable?

These questions all have major technical content, but at bottom they involve values that can only be resolved through the political process.

Science affects ideas. Science is an important source of our most basic ideas about reality, about the way the world is put together and our place in it. Such "world views" are critically important, for we structure all our institutions to conform with them.

In the medieval world view, the heavens were unchanging, existing forever as they were on the day of creation. Then Tycho Brahe observed the "new star"—the nova of 1572—and the inescapable fact of its existence forced a reconstruction of reality. Kepler, Galileo, and Newton followed and destroyed the earth- and human-centered universe of medieval Christianity.

Darwin established the continuity of human and animal, thus undermining both our view of our innate superiority and a good bit of religious authority. The germ theory of disease-made possible by the technology of the microscope destroyed the notion that disease was sent by God as a just retribution for unrepentant sinners.

Science affects ethics. Because science has a large part in creating our reality, it also has a significant effect on ethics. Once the germ theory of disease was accepted, it could no longer be ethical, because it no longer made sense, to berate the sick for their sins. Gulliver's voyage to the land of the Houynhyms made the point:

By inventing a society in which individuals' illnesses were acts of free will while their crimes were a result of outside forces, he made it ethical to punish the sick but not the criminal.

Knowledge—most of it created by science—creates obligations to act that did not exist before. An engineer, for instance, who designs a piece of equipment in a way that is dangerous, when knowledge to safely design it exists, has violated both an ethical and a legal precept. It is no defense that the engineer did not personally possess the knowledge; the simple existence of the knowledge creates the ethical requirement.

In another sense, science has a positive effect on ethics by setting an example that may be followed outside science. Science must set truth as the cardinal value, for otherwise it cannot progress. Thus, while individual scientists may lapse, science as an institution must continually reaffirm the value of truth. To that extent science serves as a moral example for other areas of human endeavor.

Science affects art and literature. Art, poetry, literature, and religion stand on one side and science on the other side of C. P. Snow's famous gulf between the "two cultures." The gulf is largely artificial, however; the two sides have more in common than we often realize. Both science and the humanities depend on imagination and the use of metaphor. Despite widespread belief to the contrary, science does not proceed by a rational process of building theories from undisputed facts. Scientific and technological advances depend on imagination, on some intuitive, creative vision of how reality might be constructed. As Peter Medawar puts it: [Medawar, P. (1969). Encounter 32(l), 15-23]: All advance of scientific understanding, at every level, begins with a speculative adventure, an imaginative preconception of what might be true—a preconception that always, and necessarily, goes a little way (sometimes a long way) beyond anything that we have logical or factual authority to believe in.

The difference between literature and science is that in science imagination is controlled, restricted, and tested by reason. Within the strictures of the discipline, the artist or poet may give free rein to imagination. Although we may critically compare a novel to life, in general, literature or art may be judged without reference to empirical truth. Scientists, however, must subject their imaginative construction to empirical test. It is not established as truth until they have persuaded their peers that this testing process has been adequate, and the truth they create is always tentative and subject to renewed challenge.

The genius of science is that it takes imagination and reason, which the Romantics and the modern counterculture both hold to be antithetical, and combines them in a synergistic way. Both science and art, the opposing sides of the "two cultures," depend fundamentally on the creative use of imagination. Thus, it is not surprising that many mathematicians and physicists are also accomplished musicians, or that music majors have often been creative computer programmers.

Science, technology, and culture in the future. We can only speculate about how science and technology will affect society in the future. The technologies made possible by an understanding of mechanics, thermodynamics, energy, and electricity have given us the transportation revolutions of this century and made large amounts of energy available for accomplishing almost any sort of physical labor. These technologies are now mature and will continue to evolve only slowly. In their place, however, we have the information revolution and soon will have the biotechnology revolution. It is beyond us to say where these may lead, but the implications will probably be as dramatic as the changes of the past century.

Computers affected first the things we already do, by making easy what was once difficult. In science and engineering, computers are now well beyond that. We can now solve problems that were only recently impossible. Modeling, simulation, and computation are rapidly becoming a way to create knowledge that is as revolutionary as experimentation was 300 years ago.

Artificial intelligence is only just beginning; its goal is to duplicate the process of thinking well enough so that the distinction between humans and machines is diminished. If this can be accomplished, the consequences may be as profound as those of Darwin's theory of evolution, and the working out of the social implications could be as difficult.

With astonishing speed, modern biology is giving us the ability to genuinely understand, and then to change, biological organisms. The implications for medicine and agriculture will be great and the results should be overwhelmingly beneficial.

The implications for our view of ourselves will also be great, but no one can foresee them. Knowledge of how to change existing forms of life almost at will confers a fundamentally new power on human beings. We will have to stretch our wisdom to be able to deal intelligently with that power.

One thing we can say with confidence: Alone among all sectors of society and culture, science and technology progress in a systematic way. Other sectors change, but only science and technology progress in such a way that today's science and technology can be said to be unambiguously superior to that of an earlier age. Because science progresses in such a dramatic and clear way, it is the dominant force in modern society.

Erich Bloch
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Preface

We are most gratified to find that the first and second editions of the *Encyclopedia of Physical Science and Technology* (1987 and 1992) are now being used in some 3,000 libraries located in centers of learning and research and development organizations world-wide. These include universities, institutes, technology based industries, public libraries, and government agencies. Thus, we feel that our original goal of providing in-depth university and professional level coverage of every facet of physical sciences and technology was, indeed, worthwhile.

The editor-in-chief (EiC) and the Executive Board determined in 1998 that there was now a need for a Third Edition. It was apparent that there had been a blossoming of scientific and engineering progress in almost every field and although the World Wide Web is a mighty river of information and data, there was still a great need for our articles, which comprehensively explain, integrate, and provide scientific and mathematical background and perspective. It was also determined that it would be desirable to add a level of perspective to our Encyclopedia team, by bringing in a group of eminent Section Editors to evaluate the existing articles and select new ones reflecting fields that have recently come into prominence.

The Third Edition Executive Board members, Stephen Hawking (astronomy, astrophysics, and mathematics), Daniel Goldin (space sciences), Elias Corey (chemistry), Paul Crutzen (atmospheric science), Yuan Lee (chemistry), George Olah (chemistry), Melvin Schwartz (physics), Edward Teller (nuclear technology), Frederick Seitz (environment), Benoit Mandelbrot (mathematics), Allen Bard (chemistry) and Klaus von Klitzing (physics) concurred with the idea of expanding our coverage into molecular biology, biochemistry, and biotechnology in recognition of the fact that these fields are based on physical sciences. Military technology such as weapons and defense systems was eliminated in concert with present trends moving toward emphasis on peaceful uses of science and technology. Aaron Klug (molecular biology and biotechnology) and Phillip Sharp (molecular and cell biology) then joined the board to oversee their fields as well as the overall Encyclopedia. The Advisory Board was completed with the addition of John Bollinger (engineering), Michael Buckland (library sciences), Jean Carpentier (aerospace sciences), Ludwig Faddeev (physics), Herbert Friedman (space sciences), R. A. Mashelkar (chemical engineering), Karl Pister (engineering) and Gordon Slemon (engineering).

A 40 page topical outline of physical sciences and technology was prepared by the EiC and then reviewed by the board and modified according to their comments. This formed the basis for assuring complete coverage of the physical sciences and for dividing the science and engineering disciplines into 50 sections for selection of section editors. Six of the advisory board members decided to serve also as section editors (Allen Bard for analytical chemistry, Elias Corey for organic chemistry, Paul Crutzen for atmospheric sciences, Yuan Lee for physical chemistry, Phillip Sharp for molecular biology, and Melvin Schwartz for physics). Thirty-two additional section editors were then nominated by the EiC and the board for the remaining sections. A listing of the section editors together with their section descriptions is presented on p. v.

The section editors then provided lists of nominated articles and authors, as well as peer reviewers, to the EiC based on the section scopes given in the topical outline. These lists were edited to eliminate overlap. The Board was asked to help adjudicate the lists as necessary. Then, a complete listing of topics and nominated authors was assembled. This effort resulted in the deletion of about 200 of the Second Edition articles, the addition of nearly 300 completely new articles, and updating or rewrite of approximately 480 retained article topics, for a total of over 780 articles, which comprise the Third Edition. Examples of the new articles, which cover science or technology areas arising to prominence after the second edition, are: molecular electronics; nanostructured materials; image-guided surgery; fiber–optic chemical sensors; metabolic engineering; self-organizing systems; tissue engineering; humanoid robots; gravitational wave physics; pharmacokinetics; thermoeconomics, and superstring theory.

Over 1000 authors prepared the manuscripts at an average length of 17-18 pages. The manuscripts were peer reviewed, indexed, and published. The result is the eighteen volume work, of over 14,000 pages, comprising the Third Edition.

The subject distribution is: 17% chemistry; 5% molecular biology and biotechnology; 11% physics; 10% earth sciences; 3% environment and atmospheric sciences; 12% computers and telecommunications; 8% electronics, optics, and lasers; 7% mathematics; 8% astronomy, astrophysics, and space technology; 6% energy and power; 6% materials; 7% engineering, aerospace, and transportation. The relative distribution between basic and applied subjects is: 60% basic sciences, 7% mathematics, and 33% engineering and technology. It should be pointed out that a subject such as energy and power with just a 5% share of the topic distribution is about 850 pages in total, which corresponds to a book-length treatment.

We are saddened by the passing of six of the Board members who participated in previous editions of this Encyclopedia. This edition is therefore dedicated to the memory of S. Chandrasekhar, Linus Pauling, Vladimir Prelog, Abdus Salam, Glenn Seaborg, and Gian-Carlo Rota with gratitude for their contributions to the scientific community and to this endeavor.

Finally, I wish to thank the following Academic Press personnel for their outstanding support of this project: Robert Matsumura, managing editor, Carolan Gladden and Amy Covington, author relations; Frank Cynar, sponsoring editor; Nick Panissidi, manuscript processing; Paul Gottehrer and Michael Early, production; and Chris Morris, Major Reference Works director.

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FROM THE PREFACE TO THE FIRST EDITION

In the summer of 1983, a group of world-renowned scientists were queried regarding the need for an encyclopedia of the physical sciences, engineering, and mathematics written for use by the scientific and engineering community. The projected readership would be endowed with a basic scientific education but would require access to authoritative information not in the reader's specific discipline. The initial advisory group, consisting of Subrahmanyan Chandrasekhar, Linus Pauling, Vladimir Prelog, Abdus Salam, Glenn Seaborg, Kai Siegbahn, and Edward Teller, encouraged this notion and offered to serve as our senior executive advisory board.

A survey of the available literature showed that there were general encyclopedias, which covered either all facets of knowledge or all of science including the biological sciences, but there were no encyclopedias specifically in the physical sciences, written to the level of the scientific community and thus able to provide the detailed information and mathematical treatment needed by the intended readership. Existing compendia generally limited their mathematical treatment to algebraic relationships rather than the in-depth treatment that can often be provided only by calculus. In addition, they tended either to fragment a given scientific discipline into narrow specifics or to present such broadly drawn articles as to be of little use to practicing scientists.

In consultation with the senior executive advisory board, Academic Press decided to publish an encyclopedia that contained articles of sufficient length to adequately cover a scientific or engineering discipline and that provided accuracy and a special degree of accessibility for its intended audience.

This audience consists of undergraduates, graduate students, research personnel, and academic staff in colleges and universities, practicing scientists and engineers in industry and research institutes, and media, legal, and management personnel concerned with science and engineering employed by government and private institutions. Certain advanced high school students with at least a year of chemistry or physics and calculus may also benefit from the encyclopedia.

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TRW, Inc.

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