



Science and government

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Science policy depends on the state of science itself, which evolves in response to new instrumentation, theoretical methods, and analytical tools. The growth of science and the course of science policy are undeniably progressive.

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My task is to discuss the connection between science and government, not only today's challenges but also the future and how it all compares with 75 years ago, when the American Institute of Physics was formed. It is an easier task than one might think because the relationship between science and government, while subject to the same forces that shape the rest of society, has been surprisingly stable for at least half a century and is likely to remain so in the future. The challenges associated with that relationship are evolving in a relatively predictable way, and this is a good occasion to reflect on them.

This is not the first such opportunity extended to me by AIP. I spoke 25 years ago at the 50th anniversary meeting of AIP's Corporate Associates on a widely perceived crisis in instrumentation (see *PHYSICS TODAY*, January 1982, page 9). That crisis was epitomized, in my view, by the then-imminent termination of a large collider-accelerator, under construction at Brookhaven National Laboratory, that subsequently morphed into today's Relativistic Heavy Ion Collider. Already in 1981, particle physicists were aware of a looming energy gap between phenomena that play a role in the behavior of ordinary matter and a potentially vast hidden world whose symmetries are necessary for the logical consistency of the lower-energy theory. But I am getting ahead of myself.

Historic achievements, bleak conditions

As Spencer Weart reminds us (see page 32), the birth of AIP in 1931 was on the leading edge of a wave of discoveries in nuclear physics that would restart the field in entirely new directions. In that year, Wolfgang Pauli proposed the neutrino, and Paul Dirac, after some prodding from colleagues, predicted antimatter. At the inaugural meeting of AIP, Robert Van de Graaff demonstrated his new accelerator—the first to exceed 1 MeV—and in that year Ernest O. Lawrence's new cyclotron passed the same milestone. The following year, 1932, has been called the "Wonder Year" of nuclear physics: James Chadwick discovered the neutron, Harold Urey the deuteron, and Carl Anderson the positron; and John Cockcroft and Ernest Walton observed the first accelerator-induced nuclear reaction. Werner Heisenberg proposed that nuclei are made of protons and neutrons and introduced the concept of isotopic spin. Nuclear physics was off and running. Enrico Fermi's theory of beta decay appeared in 1934, and Hideki Yukawa's meson theory of nuclear interactions in 1935.

Those momentous achievements came amidst the most unpromising social conditions. The world economy was in depression and Adolf Hitler's star was rising, to the grave

detriment of European science. The works of Albert Einstein, among many others, were consigned to flames in the infamous Nazi book burning of 10 May 1933. Jewish physicists and their supporters fled the expanding persecution, and many found refuge in America. In the US throughout the 1930s, the environmental devastation of the Dust Bowl, added to the depressed economy, created further social dislocation and forced unprecedented federal spending on social programs.

Although public attitudes in the US toward the government's role in society were already being shaped by conditions during the Depression, World War II marked a historic turning point in the relationship between science and government. The war occurred at the center of a long transitional period from the Depression to the Soviet Union's launch of *Sputnik 1* in 1957. Before 1930, federal engagement in science funding was minimal. After 1960, federal spending on nondefense R&D grew to consume a significant and relatively steady fraction of the federal discretionary budget. There is good reason to suppose that for many decades more, the fraction will hold steady near the current 13–14% or even increase.

That same 30-year period marked a transition in physics too, and indeed in much of science, during which the recently discovered principles of quantum mechanics began to be applied to physical systems of practical interest. The 1933 Sommerfeld–Bethe model of the electronic properties of solids marks a reasonable birthdate for modern solid-state physics. Henry Eyring, Eugene Wigner, Michael Polanyi, and others were developing quantum chemistry at about the same time. Before 1930, quantum mechanics was in its infancy. After 1960, it was the main driving force for science, not only directly as the basis for understanding physical phenomena, but also indirectly as the source of technologies that enhanced the empirical study of all phenomena. Most of quantum theory's impact occurred after the war years in the enhanced understanding of materials and the introduction of new quantum-based technologies such as the laser and semiconductor electronics. Today, more scientists are engaged in condensed matter research than in any other field of physics. Nuclear physics gave birth to particle physics during the 1930–60 period and launched applications in medicine and electric power, not to mention its conscription for successive generations of nuclear weapons.

The advance of science and policy

Science policy, in my view, necessarily depends to a great extent on the state of science itself, and not only on social con-



Early science policy. Prior to the Depression and the Dust Bowl (above) in the 1930s, the US government was minimally engaged in science funding. After the Soviet Union launched *Sputnik 1* in 1957 (left), federal spending on nondefense R&D began to grow.

ditions and the willingness of governments to fund research. What's more, the state of science is not simply a function of which fields

get funding. Science evolves in response to the growing powers of instrumentation, theoretical methods, and the associated tools for analysis, including digital computing. The growth of science, and consequently the course of science policy, is undeniably progressive. The accumulation of knowledge guarantees that science's future will differ from its past. Fields mature, saturate, and merge as the frontiers of discovery advance. In our era, attitudes toward science, and toward physics in particular, have been shaped by the immensely fertile period when quantum mechanics was first seriously exploited in the decades after World War II. But that period is now behind us and attitudes are necessarily changing.

The relation of so-called basic research to applications important for society is very different today from the cold war era, not only because the cold war ended, but also because science is advancing. Behind the leading edge at which physics—and now astronomy—seeks the basic constituents and laws of matter lies a huge territory of complex phenomena for which the underlying laws are already known. That knowledge—resting mostly on quantum electrodynamics—gives research in this territory an “applied” flavor relative to the “fundamental” work at the remote frontier where the laws are still in doubt. In this largely known domain, the reductionist task is more or less complete, and the greatest challenge now is to grapple with the extraordinary complexity of phenomena with many degrees of freedom, ranging from high-temperature superconductivity to the behavior of living things.

Scientists working in this vast domain of complexity are rapidly increasing their ability to grasp and model phenomena of critical importance to society. Empirical methods in biology and even in psychology are now augmented by

insights gained from studying microscopic physical mechanisms; new drugs and therapies result. A deep understanding of the functional properties of materials is bringing forth steady improvements in magnetic materials, batteries, solar cells, solid-state light sources, catalysts, structural materials, and the speed and power of semiconductor electronics. Physicists are confident that all the relevant phenomena can be explained by quantum electrodynamics, but understanding and exploiting the science requires a large and expensive infrastructure of technology and organization within the scientific community.

Those important technical advances all occur at low energies and do not depend on understanding subnuclear degrees of freedom. The high-energy frontier now lies far away from the ordinary concerns of humankind, except through the excitement its exploration may stimulate in young minds and through spinoffs from the technical advances required to achieve the enormous energy densities of frontier experiments. Thus, the arguments for societal support of high-energy and nuclear physics must be essentially different from the arguments for funding studies at lower energies. When AIP was founded 75 years ago, the energy frontier was at an urgently consequential threshold: Nuclear fission was discovered in 1938. Hitler's army marched into Poland the following year, a month after Einstein signed his famous letter to President Franklin D. Roosevelt on the feasibility of nuclear weapons. For a time, fundamental physics became entangled with the fate of nations.

During the war, the frontiers of human history and of fundamental physics remained entwined. But with the discovery of the Λ and K particles in 1951 and the achievement shortly thereafter of laboratory energies beyond 1 GeV, the high-energy frontier began to pull away from mundane human affairs. The widening gap between particle physics and human affairs was not immediately apparent in the post-war period; Congress supported a sequence of increasingly large accelerators until the cold war's end, which historians mark at 1991. In October 1993, Congress terminated the

Setting priorities. Alvin Weinberg (below) said in 1960, "We cannot allow our over-all science strategy . . . to be settled by default." Frank Press (right) was President Jimmy Carter's science adviser and, later, president of the National Academy of Sciences. In the 1980s, Press advocated that the science community work to set science funding priorities.



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fessional societies' publications, but rarely in more public settings and almost never in the hearings and reports that inform federal science priorities. From my perspective, however, the issue of priorities across scientific fields and programs is of the utmost importance at the highest policy level.

Frank Press, President Jimmy Carter's science adviser (1977–80) and president of the National Academy of Sciences (1981–93), deserves far more credit than he has received for forcibly bringing the issue to the attention of the science community and working for rational approaches to the intricate process of science funding. In a 1988 address to the NAS, Press divided science programs into three priority categories and named specific projects that should be in each while he urged scientists to take responsibility for setting priorities.² "The issues," said Press, "are funding levels and priorities. Our political leadership has no way of gauging the amount of resources necessary to maintain the strength of American science and technology. What it does see is that the inevitable competition for funds leads to conflicting advice from within the scientific community." Press's proposal for how to proceed was not popular, and science policy leaders quickly distanced themselves from it. But the "default" approach that Weinberg had deplored was creating painful stresses as the 20th century entered its last decade.

If such a thing as a world science policy exists, its history is one of disengagement by governments before World War II, followed by a period dominated by cold war competition between the US and the Soviet Union. Other developed countries continued their prewar patterns of federally sponsored universities and research laboratories sustained with grants or subsidies that were small relative to the amounts being invested by the superpowers. From my own contacts with foreign scientists during the cold war period, it appeared that other nations viewed the huge investments in big physics, weapons, and space programs as a peculiar phenomenon of little relevance to their own domestic objectives.

Even before the cold war ended, that attitude began to change. The subsequent dot-com era, despite its burst bubble, dramatized the profound social and economic impact of technologies founded on federally sponsored research. During the last decade of the 20th century, many developed countries launched initiatives to bring their pattern of support for higher education and research much closer to the American model.

Superconducting Super Collider project. A few months earlier, Congress had sustained the International Space Station by a margin of just one vote. Those signs of wavering support for "big science" signaled the beginning of a new transition period in American science policy that is now in an advanced stage.

A matter of priorities

It was Alvin Weinberg who defined particle physics and human space exploration as big science, in an essay that appeared just as post-Sputnik federal science funding began to soar. His 1961 article in *Science*¹ drew attention to an issue that at the time received too little notice by the science community:

It is presumptuous for me to urge that we study biology on Earth rather than biology in space, or physics in the nuclear binding-energy region, with its clear practical applications and its strong bearing on the rest of science, rather than physics in the Bev region, with its absence of practical applications and its very slight bearing on the rest of science. What I am urging is that these choices have become matters of high national policy. We cannot allow our over-all science strategy, when it involves such large sums, to be settled by default, or to be pre-empted by the group with the most skillful publicity department. We should have extensive debate on these over-all questions of scientific choice: We should make a choice, explain it, and then have the courage to stick to a course arrived at rationally.

Scientists debate such matters with colleagues over beer or coffee, and sometimes in the letters columns of their pro-

J. Robert Oppenheimer reading to his children. Oppenheimer observed that society supports science for two “disturbingly different” reasons: It is useful and its pursuit is ennobling. (Photo from Mrs. J. Robert Oppenheimer, courtesy of AIP Emilio Segrè Visual Archives.)

In higher education, that meant greater financial independence for the universities, more reliance on performance as a basis for funding, and deeper integration with the nongovernmental sector; in research, it meant a sharper focus on economic competitiveness and more federal research funding, including the widespread adoption of a 3% target for the sum of governmental and industrial R&D as a percentage of gross domestic product—consciously similar to expenditures in the US and Japan.

A transition in attitudes toward science is taking place, triggered not only by the end of the cold war but also by the maturing of the fruits of postwar technologies into a new technical infrastructure whose impact on society has been compared with the industrial revolution. Those changing attitudes have been discussed in many publications. For example, the link between federal research investment and long-term economic strength was a main theme of the 1998 report by US Representative Vernon Ehlers (R-MI), which he produced for the US House of Representatives at the request of speaker Newt Gingrich. The report was intended to replace Vannevar Bush’s famous 1945 report, *Science: The Endless Frontier*, with a vision of science more relevant to our era.³ Ehlers’s *Unlocking Our Future: Toward a New National Science Policy* documents an argument for federal support of science that reflects important themes and views about how science works in our society and what is needed to sustain it in the future. Ehlers refers to contemporary studies of the evolving relation between basic and applied science, and particularly to the distinction between those approaches and what Gerald Holton has called Jeffersonian science,⁴ a mode of research that focuses on “an area of basic scientific ignorance that lies at the heart of a social problem.”

The further idea that “basic” and “applied” are not stages on a one-dimensional continuum of progress—the view in 1945—but rather form dimensions of a science state-space reached a wide audience in Donald Stokes’s popular book *Pasteur’s Quadrant*.⁵ In an effort to define a measure that would more accurately represent the government’s investment in the kind of science that generates new knowledge and new technologies, a National Research Council (NRC) committee chaired by Frank Press proposed a new budget category of “Federal Science and Technology.”⁶ A version of that category is now tracked by the federal Office of Management and Budget and reported in the president’s annual budget proposal to Congress.

As valuable as those studies were, none addressed the issue of priorities that Weinberg had identified in 1961 and Press grappled with in 1988. Not that priorities were ignored altogether: A system of committees, boards, and panels had grown up along with the federal science budget to advise



funding agencies on opportunities within each major field. And the NAS and NRC continued to issue periodic authoritative assessments of entire fields. But it fell to Congress to decide, for example, on the relative merits of a super collider and a space station. And such decisions are indeed Congress’s to make.

Generally popular with Congress, science and its companion technologies and applications nevertheless compete for political attention not only with each other but also with the entire remainder of the domestic discretionary budget; the job of an appropriations subcommittee chairman is exceptionally difficult. In his provocatively titled but informative essay “Does Science Policy Exist, and If So, Does It Matter?” Daniel Sarewitz has described the intricate process by which federal science budgets are contrived.⁷ Complex as it is, the process does unfold within our democratic form of government and generally does respond to views that are widely enough held.

By the turn of the 21st century, many observers were expressing concern about funding imbalances among fields, particularly between the physical and life sciences, and some were acting on that concern. For example, to ensure access to physical-science tools for investigators funded by the National Institutes of Health, Harold Varmus (NIH director, 1993–2000) funded the construction of beamlines at the Department of Energy’s x-ray synchrotron light sources and spoke eloquently of the importance of physics to biology and medicine.⁸ Although no agreement existed on the relative funding among fields, a consensus was growing that the physical sciences needed and deserved more funding.

The new century

I need not remind you that the new century opened with a dramatic demonstration of the increased destructive power available to individuals and small groups with modern tech-

nology. The Bush administration responded to the September 11, 2001, attacks with significantly increased funding for those areas of science and technology that might serve the war against terrorism. That response was entirely within the envelope of what I would call normal science policy. Although heightened concerns about homeland security have created problems for the conduct of science—difficulties in acquiring visas for students and visiting scientists come to mind, even though many such difficulties have since been ameliorated—they do not change the underlying arguments for federal funding of scientists, nor do they resolve the underlying problem of setting priorities among the fields of science.

In the year following the terrorist attacks, Georgia Institute of Technology president Wayne Clough chaired a subcommittee of the President's Council of Advisors on Science and Technology (PCAST) that issued a report, "Assessing the US R&D Investment," which stated, among other things, that "all evidence points to a need to improve funding levels for physical sciences and engineering."⁹ At the time, the country was still suffering the economic consequences of the burst dot-com bubble and was realigning budget priorities in response to the terrorist attacks. Establishing an entirely new science and technology initiative for homeland security was the highest science priority, followed by completing an administration commitment to double the NIH budget. Nevertheless, the administration continued to expand funding for targeted areas of physical science—including the recently introduced National Nanotechnology Initiative—and maintained funding for the Networking and Information Technology R&D program. The NSF budget continued to increase at a rate above inflation. In the first term of the Bush administration, combined federal R&D funding soared at a rate unmatched since the early years of the Apollo program, a jump of 45% in constant dollars over four years.

As the Bush administration concluded its first term, further reports, including two more from PCAST⁹ and one from the Council on Competitiveness,¹⁰ linked federal programs for research and education to economic competitiveness. The following year, 2005, witnessed a growing wave of reports and publications with similar themes, culminating in a widely publicized report from the NAS.¹¹ In his 2006 State of the Union message, President Bush announced the American Competitiveness Initiative (ACI), which is designed, in part, to strengthen US basic research capability in the physical sciences. Three agencies were singled out for major budget increases over the next 10 years: NSF, DOE's Office of Science, and NIST.

Those choices signal a policy that is clearly oriented toward future economic competitiveness. NSF is the lead agency for both the nanotechnology and information technology initiatives and, with NIH, is the major sponsor of university-based research. DOE science is the primary sponsor of all physical science research, and its national laboratories house the world's most productive user facilities, including bright x-ray light sources and a forthcoming world-leading neutron source (see PHYSICS TODAY, May 2006, page 44). NIST also operates a significant user facility in its Center for Neutron Research, and performs fundamental research in support of the all-important function of establishing standards for innovative technology. The ACI also aims to improve the incentives for industrial research, especially in small- and medium-sized businesses, by improving the research and experimentation tax credit and making it permanent. The ACI also includes important programs to improve science and math education and training that I will not mention further here. A publication describing the initiative in detail is available at [http://www.ostp.gov/html/](http://www.ostp.gov/html/ACIBooklet.pdf)

ACIBooklet.pdf.

The ACI improves funding for many if not all areas of physical science, but emphasizes fields likely to produce economically important technologies in the future (see PHYSICS TODAY, April 2006, page 36). Opportunities still exist in particle physics and in space science and exploration, but they are not emphasized in the ACI. Not that the US is withdrawing from those fields. Their vigor will be augmented by some of the increased budgets for NSF and DOE. But the ACI does signal an intention to fund the machinery of science in a way that ensures continued leadership in fields likely to have the greatest impact on future technology and innovation. The ACI rises to the challenge Alvin Weinberg made nearly half a century earlier when he pointed out that some areas of science have more bearing on societally important issues than others.

Other grand challenges exist for future science policy, but all are related to this one: In the absence of resources adequate to fund every promising endeavor, which ones should society support? Many years ago, J. Robert Oppenheimer observed¹² that society supports science for two "disturbingly different" reasons: Science is useful, and the pursuit of science is ennobling. Perhaps those qualities are complementary in the sense of quantum physics—narrowing the focus on one makes the other more uncertain. If so, finding the state in which both are optimized is a worthy goal for science policy.

This article is adapted from a talk given at AIP's 75th-anniversary celebration, held in Washington, DC, on 3 May 2006.

References

1. A. M. Weinberg, *Science* **134**, 161 (1961).
2. F. Press, reprinted in *Sci., Technol., Hum. Val.* **13**, 224 (1988).
3. V. Bush, *Science: The Endless Frontier*, US Office of Scientific Research and Development, Washington, DC (July 1945), available at <http://www.nsf.gov/about/history/vbush1945.htm>; *Unlocking Our Future: Toward a New National Science Policy*, committee print 105-B, Committee on Science, US House of Representatives, Washington, DC (September 1998), available at http://www.house.gov/science/science_policy_report.htm.
4. G. Holton, *Science and Anti-Science*, Harvard U. Press, Cambridge, MA (1993).
5. D. E. Stokes, *Pasteur's Quadrant: Basic Science and Technological Innovation*, Brookings Institution Press, Washington, DC (1997), available at <http://brookings.nap.edu/books/0815781776/html>.
6. Committee on Criteria for Federal Support of Research and Development, *Allocating Federal Funds for Science and Technology*, National Academies Press, Washington, DC (1995), available at <http://www.nap.edu/catalog/5040.html>.
7. D. Sarewitz, "Does Science Policy Exist, and If So, Does It Matter?: Some Observations on the US R&D Budget," available from the Center for Science, Policy and Outcomes at Arizona State University, http://www.cspo.org/products/papers/budget_seminar.pdf.
8. H. Varmus, *The Impact of Physics on Biology and Medicine*, paper presented at Centennial Meeting of the American Physical Society, 22 March 1999, available at <http://www.mskcc.org/mskcc/html/1812.cfm>.
9. PCAST reports are available at <http://www.ostp.gov/pcast/pcast.html>.
10. *Innovate America: Thriving in a World of Challenge and Change*, Council on Competitiveness, Washington, DC (December 2004), available for purchase at <http://www.compete.org>.
11. Committee on Prospering in the Global Economy of the 21st Century, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, National Academies Press, Washington, DC (2006), available at <http://www.nap.edu/catalog/11463.html>.
12. Oppenheimer's reflections on complementarity applied to human affairs can be found, for example, in J. R. Oppenheimer, *Science and the Common Understanding*, Simon and Schuster, New York (1953). ■