Science in America

Since World War II the United States has spent more than $500 billion on research and development, and U.S. achievements in particle physics, genetics, astronomy, agronomy, and other fields have been unprecedented. (Americans have won nearly half of all Nobel Prizes awarded for science since 1946.) But congressional critics and increasing numbers of scientists now question the direction of the American science effort. Should research be targeted toward more immediate, practical goals? Are the big research universities outmoded? Do we need new types of scientific institutions? The current debate has a peculiar history. In the 19th century, American scientists lamented the contemporary emphasis on practical science as well as the new republic's lack of a European-style university tradition. The surprising thing about American science, in their view, was not that it had made so *little* progress but that it had made so *much*. Here historian Nathan Reingold reviews the rise of American science; Philip Abelson, a physicist, chemist, and geologist, describes its new frontiers; and John Holmfeld, a congressional staff specialist, reports on the shifting focus of federal science policy.

O PIONEERS!

by Nathan Reingold

In 1800, the score of professional scientists in the United States was scarcely distinguishable from the somewhat larger group of devoted amateurs—like the gentleman-scholar Thomas Jefferson and the multi-talented Benjamin Franklin. As befitted a nation of farmers, sailors, and craftsmen, most Americans pursued such sciences as zoology, botany, geology, and astronomy—sciences rooted in the world around them. There was a constitutional mandate to "promote" the useful arts and sciences by regulating patents and copyrights, but the federal government's involvement in science was otherwise haphazard, tied to Antarctic naval expeditions or the western explorations of Lewis and Clark.

Today there are 500,000 American scientists in research and development alone, with 1 million more in other scientific or technology-based fields. Annual private and federal spending on research and development exceeds $40 billion. And astronomy, botany, and the rest have been joined by a host of other disciplines so diverse and some of them so arcane that one might now define a "generalist" as a scientist who knows his own sub-speciality and one other sub-specialty. Despite this fragmentation of knowledge, U.S. science and technology have no peer.

How did the United States get to be No. 1? That seems like one question but it is really a dozen. A comprehensive answer must consider the progress of scientific knowledge, which may have a certain logic in retrospect, as well as the evolution of federal subsidies for research, which does not. An explanation must include the development of European science and the growth of American industry, education, and national wealth. The discussion must encompass the recurrent public controversies over what "science" really is and over the long-term value of "basic" versus "applied" science. And it must note the persistent insecurity in the broader American scientific community over its own status in society.

These factors are easier to identify than to put together. Physicist Samuel P. Langley observed in 1888 that we often hear scientific development "likened to the march of an army towards some definite end; but this, it seems to me, is not the way science usually does move. . . ." A better metaphor might be to compare these forces to ocean waves of different frequency that suddenly get "in step" to produce a giant wave with extraordinary momentum.

Such waves are preceded by deep troughs. Until the Civil War, the United States depended, in scientific terms, largely on Western Europe. "Who reads an American book?" asked the

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English wit Sydney Smith in 1820. There was some good native science—Nathaniel Bowditch's work in mathematics and navigation comes to mind—but not much. If the natural philosophers ("scientist" was a word not coined until 1840) in Paris and Berlin thought much about the United States, then like the great German naturalist Alexander von Humboldt they thought of it as a vast natural laboratory rather than as a place to build one.

From Telegraph to Cyclotron

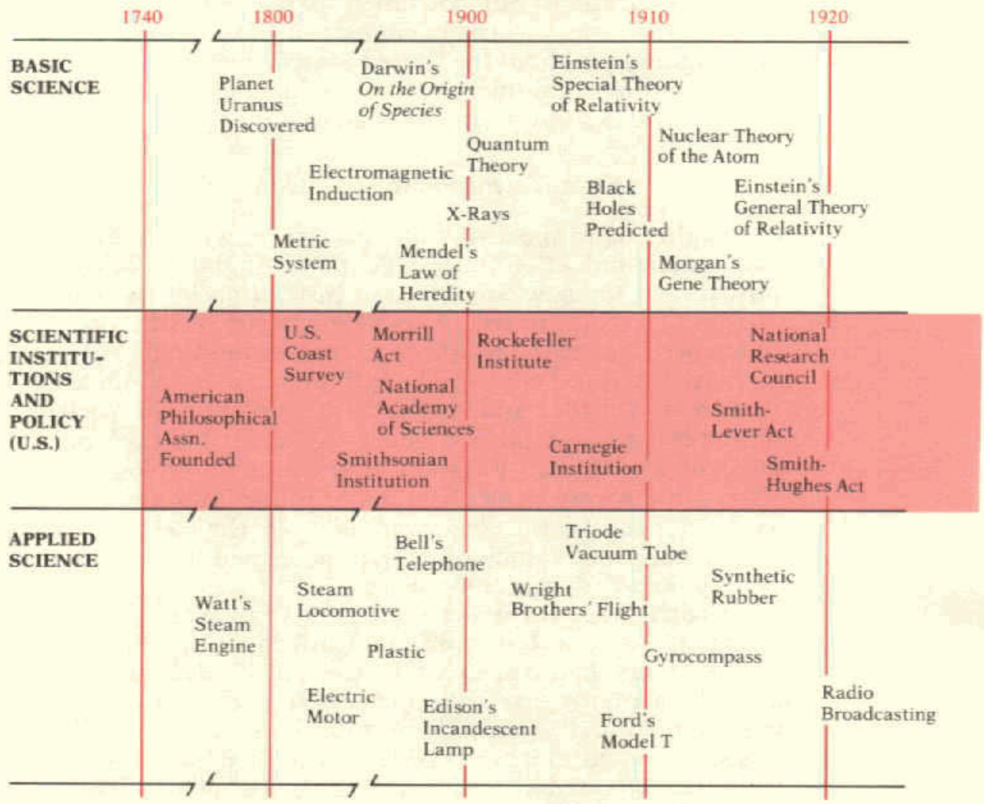
But beginning in the 1840s, Joseph Henry, who discovered electromagnetic induction independently of England's Michael Faraday, turned the new Smithsonian Institution into a center for "abstract" science. In the 1860s Yale granted its first doctorate in science (the second would go to the outstanding theoretical physicist J. Willard Gibbs). The U.S. Department of Agriculture was created in 1862 and, through a system of tax-supported land-grant colleges established under the Morrill Act, planted the seeds of a sustained program of research in biology and chemistry—the government's first major plunge into the world of basic science. As the Army opened up the West, geologists and naturalists, including the one-armed John Wesley Powell, explored the virgin territories.

American science leapt ahead after the Civil War. Although mathematician Simon Newcomb could still complain that not a single U.S. entry had appeared in Germany's *Jahrbuch der Mathematik* in many years, the general record in just about every other field had improved enormously. In 1865, Britain's Royal Society noted in its catalogue that the backward American republic accounted for no less than 5 percent of all scientific articles published.

Before the Civil War, America's industrial revolution had done little to advance basic science. To be sure, the mills were humming and "every spindle turning," as Hezekiah Niles's *Weekly Reporter* observed in the 1830s, but industry as yet had little use for the scientific disciplines. Then, with the 1870s came the expansion of the Gilded Age, the steam-powered railroads and factories. A nation of inventors and tinkerers had turned into a burgeoning industrial giant. Crotchety Henry Adams would rail against the "dynamo," but scientists and engineers rallied to its support, as did most laymen.

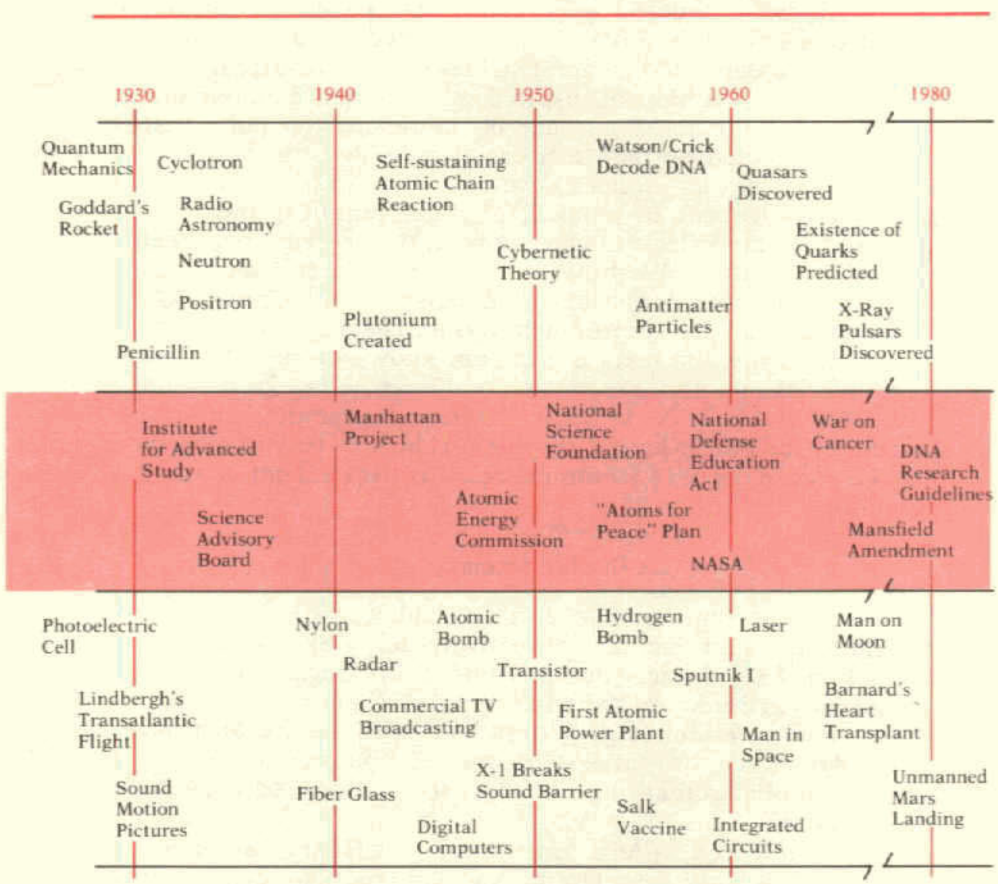
In practical science, Bell and Edison gave us electrical sound and light. In abstract science, America began to approach parity with Europe. Swiss-born Louis Agassiz pursued important researches into rocks and fossils while creating Harvard's

DEVELOPMENTS SINCE 1740 IN BASIC AND APPLIED SCIENCE



Museum of Comparative Zoology. J. Willard Gibbs was working in thermodynamics; geologists James Hall and James Dwight Dana studied mountain formation and coral structures. In 1877, with the new 26-inch refractor telescope at Washington's Naval Observatory, astronomer Asaph Hall discovered Deimos and Phobos, the two satellites of Mars. Two years later, A. A. Michelson measured the speed of light.

From the 1890s on, the pace of discovery accelerated. Working closely with their European colleagues, American scientists began to explore the structure of the atom. In 1906, Lee De Forest ushered in the age of radio with his triode vacuum tube. In 1910, T. H. Morgan launched what is now called "classical



genetics" based on experiments with the fruit fly, *Drosophila melangastor*. A year later, Robert A. Millikan, who like other Americans of his generation had studied in Germany, calculated the electric charge on the electron.

In the next decades followed the early work in computers; the world of high energy physics opened by E. O. Lawrence's 1931 cyclotron; the discovery in 1932 of the neutron and positron; and the isolation, that same year, of deuterium by Harold Urey at Columbia. In 1944, Oswald Avery demonstrated that DNA was the material carrier of heredity. From the turn of the century through the Depression and World War II to the present, the story is one of continuous growth. Such projects as the atomic bomb, nuclear energy, and the space program not only demonstrated sophistication in engineering and technology; they also depended on great strides in basic research.

Oddly, success has not inspired self-confidence among our scientists. Despite the assurance of public-opinion polls that they are respected by the American people, despite the heavy outlays of taxpayers' dollars devoted to research, despite the publicized advances in particle physics, genetics, and electronics, they fear a slackening of support; they agonize over real or predicted cuts in Washington's "basic research" spending. They shake their heads over the shrill polemics of the anti-DNA, anti-nuclear, and pro-environment absolutists. And as if to confirm their own worst fears of rampant know-nothingism, they sometimes take a perverse satisfaction in surveys like the poll conducted by *The Times* of London, which showed that while 15 percent of the public have faith in a "scientific" way of reasoning, 42 percent believe communication with the dead is a fair possibility.

A Double Strategy

If we could communicate with the dead, we would probably find that American scientists have always felt a bit insecure. As far back as 1832, physicist Joseph Henry decried what he saw as the nation's attitude toward what he called "abstract" science. In his view, a nation of go-getters had little use for abstract knowledge. Even its name—"abstract," "basic," or "pure" science—implied something valued for its own sake, of no use to a wider public.

Alexis de Tocqueville, a contemporary of Henry, contended that Americans would excel in the world of practical science but would never rise to theoretical eminence. Just as it was thought that a democratic society could produce popular or "vernacular" cultures but not "high" ones (an aristocracy was required for that!), so it was felt that Americans would always make a better mousetrap but would never add much to the world's knowledge of mice.

Henry feared what Tocqueville took as fact. Behind his fear was a belief that technological achievement depended on the advance of abstract science. In the America of the 1840s, to the extent that basic research existed at all it was usually scrambled together into applied fields. There were no graduate schools and only one research institute—the Smithsonian, founded in 1846 and headed by Henry. The age of the learned and professional societies such as the National Academy of Sciences still lay in the future. In one sense, the American situation was unenviable; in another, it was an opportunity.

To counteract this perceived neglect of basic science, the leading American scientists of the pre–Civil War era evolved two deliberate strategies to advance theoretical knowledge while at the same time taking care of the utilitarian needs of a growing industrial society. That is to say they defined both a "broad strategy" and an "enclave strategy."

Jefferson's Precedent

The enclave strategy evolved before the Civil War when Joseph Henry designed the Smithsonian Institution—despite bitter opposition from those who wanted only a museum and library—as America's first center for abstract research sheltered from the pressures of immediate industrial or social demands.

This approach was continued by such organizations as the Rockefeller Institute (1901, now Rockefeller University), the Carnegie Institution (1902), and the Institute for Advanced Study at Princeton (1930). It persists today in some government labs and in the federally funded, specialized centers within the great research universities, such as the Scripps Oceanographic Institute at the University of California. Here, the emphasis is largely on pure science pursued for its own sake.

While Henry struggled with the Smithsonian, his friend A. D. Bache framed a broad approach to take advantage of the already "mixed" character of applied and basic science. A great-grandson of Benjamin Franklin and first president of the National Academy of Sciences, Bache for years headed the Coast and Geodetic Survey, whose function was to issue maps and charts.

Bache's idea was simple. Americans, he felt, would never support scientific institutes like the Smithsonian to the degree that kings and aristocratic patrons supported such centers in Europe. But government agencies like the Coast Survey and the Army's Topographical Engineers had statutory missions that, with a little imagination, could be defined to include substantial amounts of abstract science. Essentially, Bache was following Jefferson's strategem. As President, Jefferson had defended the Lewis and Clark expedition in Congress on commercial grounds; to the Spanish Minister, through whose territory the party would have to pass, he described it as a geological mission.

In the Coast Survey, for example, Bache defined seismology, terrestrial magnetism, and other subjects as essential to the routine production of high-quality maps and charts. Similarly, when the Smithsonian reluctantly acquired museum functions, Henry and his successors continued to sponsor basic research, seeing it as necessary for quality control in public exhibits. Finally, the creation of state agriculture colleges, designed to improve American farming techniques, inevitably led to research into genetics, soil chemistry, and climate.

What happened was this: In theory, American science maintained a distinction between applied and basic research; in fact, it maintained the distinction only in theory. Like the earth and the moon, the two were distinct yet inseparable, influencing and reinforcing each other in subtle ways. Vannevar Bush's work with practical engineering equations led him to develop the differential analyzer, which ultimately had theoretical implications. And Irving Langmuir's theoretical work in electron emission produced a better light bulb.

The Rise of the University

This tandem pursuit of basic and applied science was one of the vital differences between the evolution of European science and that of its precocious child in the New World. In Europe, the two were pursued as a bifurcated effort. In America, with some exceptions, they never really were. This mixture remained even when the rise of the elite universities, philanthropic foundations, and science-based industries in the 20th century combined to eclipse government-conducted research.

By 1900, for example, there were more physicists in American universities than in those of any other country, and their numbers were growing faster than anywhere else outside of Japan. Rising proportions of high school graduates swelled college enrollments. (In 1900, 6.4 percent of the population had graduated from high school; in 1940, more than half.) With the pioneering success of Johns Hopkins University, graduate schools flourished. By 1940, the 382 doctorates granted annually in all fields at the turn of the century had increased by 1000 percent.

More important, the universities branched out to service every cranny of an increasingly complex industrial society. To be sure, scientists still pursued the higher mathematics; astronomers gazed at the stars; and physicists followed closely the theoretical work of Albert Einstein and Niels Bohr and Ernest Rutherford. But university scientists also developed hybrids of corn and new kinds of wheat to feed a growing population. In short, even as they followed their noses into the theoretical unknown, scientists looked around en route for ways to harness

THE FIRST DEBATE

Americans are now used to scientist-advocates, be the issue recombinant DNA, the environment, or nuclear safety. But the phenomenon is a recent one; until the first debate in the late 1940s over the military use of atomic energy, U.S. scientists had kept a low profile.

Was the atomic bomb a breakthrough or a breakdown? After a first flush of enthusiasm, scientists began to wonder. One group, headed by physicist William Higinbotham, launched the apocalyptic *Bulletin of the Atomic Scientists*, whose "clock" logo showed war inching ever closer. (The examples above are from before and after the first Russian atomic blast in 1949.) Others, including the "father" of the bomb, J. Robert Oppenheimer, drew up what eventually became the Baruch Plan (1946). The plan called for destruction of all nuclear weapons, with peaceful applications of atomic energy to be regulated by a new international agency. It was rejected by the Soviets.

America's only recourse was to stay ahead in the arms race. So argued those leading scientists (such as Edward Teller and E. O. Lawrence) who helped create the hydrogen bomb. Though opposed by Oppenheimer, Enrico Fermi, and Hans Bethe (Fermi wanted to "try once more" for disarmament), an American H-bomb was detonated in 1952; the Soviets followed suit in 1953. It was not a halcyon time for liberal physicists. As historian Daniel Kevles later noted, scientists were still listened to by the government, "but the voice most listened to seemed to be Edward Teller's." Later debates arose over nuclear testing and the neutron bomb.

what they found; when harnessed, it sometimes pulled them further.

Science was soon to acquire a home in industry as well when the work of such practical wizards as Edison and Bell took corporate form in the shape of ambitious new companies like General Electric and Bell Telephone. There was no mistaking the motives of these companies—they wanted profits. But technology does not exist in a vacuum; pure research was regarded as an essential component of scientific commerce. In 1927 H. D. Arnold, then president of Bell Laboratories, put the matter succinctly. Bell was interested, Arnold wrote, simply in producing more electrons to run its radios and telephones and, soon, its television sets. And Bell wanted its electrons cheaply. But the best road to this end, Arnold explained, "must include a thorough understanding of the broad facts of electron emission." Work in this area won Bell Laboratories' physicist C. J. Davisson the Nobel Prize (1937). Bell received another Nobel for developing the transistor (1956).

Policeman and Paymaster

What developed in the United States was a phenomenally diverse scientific enterprise, and in diversity it found vitality. Basic research was conducted not only by a few specialized federal agencies but by industry and the universities as well. It was paid for not only by the government but also by private philanthropy, by the great foundations, by university tuition, by industry, and by ordinary citizens who put down hard cash for a new radio, television, or telephone. And it so evolved that the accretion of new theoretical knowledge was often taking place on the same workbench, so to speak, where technicians and engineers were trying to turn theory into something men could use. There was little chance, despite the fears Lyndon Johnson voiced in 1966, that new scientific innovations would be "locked up in the laboratory." Indeed, some Americans now seem to fear that some discoveries will *not* be locked up.

Does all of this help to explain the evolution of American science? Some skeptics will surely note that the facts of history are like the letters of the alphabet—you can make them spell what you want. Others might contend that the rise of American science is essentially the same success story we have witnessed in Russia and in Japan: A rich nation's investments paying off.

And yet the special elements of the American story—the driving insecurity of scientists, the complementary broad and narrow strategies, the diversity of effort, the pragmatic partnership of science with education and industry—are too clear to be ignored. Even when, during World War II, the federal role in science took a quantum leap, and even after the government became both a policeman and a paymaster of science, these phenomena continued to shape American science and science policy.

Samuel Langley was right: Scientific progress in this country has not been the march of an army toward a goal clearly in sight. Instead, it has been something less controlled—and therefore, perhaps, more open to initiative and imagination. "In this Democratic Country," Joseph Henry observed, "we must do what we can when we cannot do what we would."