
The last fifty years— a revolution?

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In some periods great conceptual revolutions shake the world of physics; at other times research seems to plod ahead within the confines of an established framework. And the structure of the physics community must change in a way that somehow matches the changing style of research. What, then, has been the form of physics during our own lifetime, and how has it changed? This is a difficult, but not impossible question. Only history can give us an inkling of the answer.

To place ourselves here in 1981, on the fiftieth anniversary of the American Institute of Physics, we need to imagine how physicists fifty years ago saw their own place. Suppose there had been a

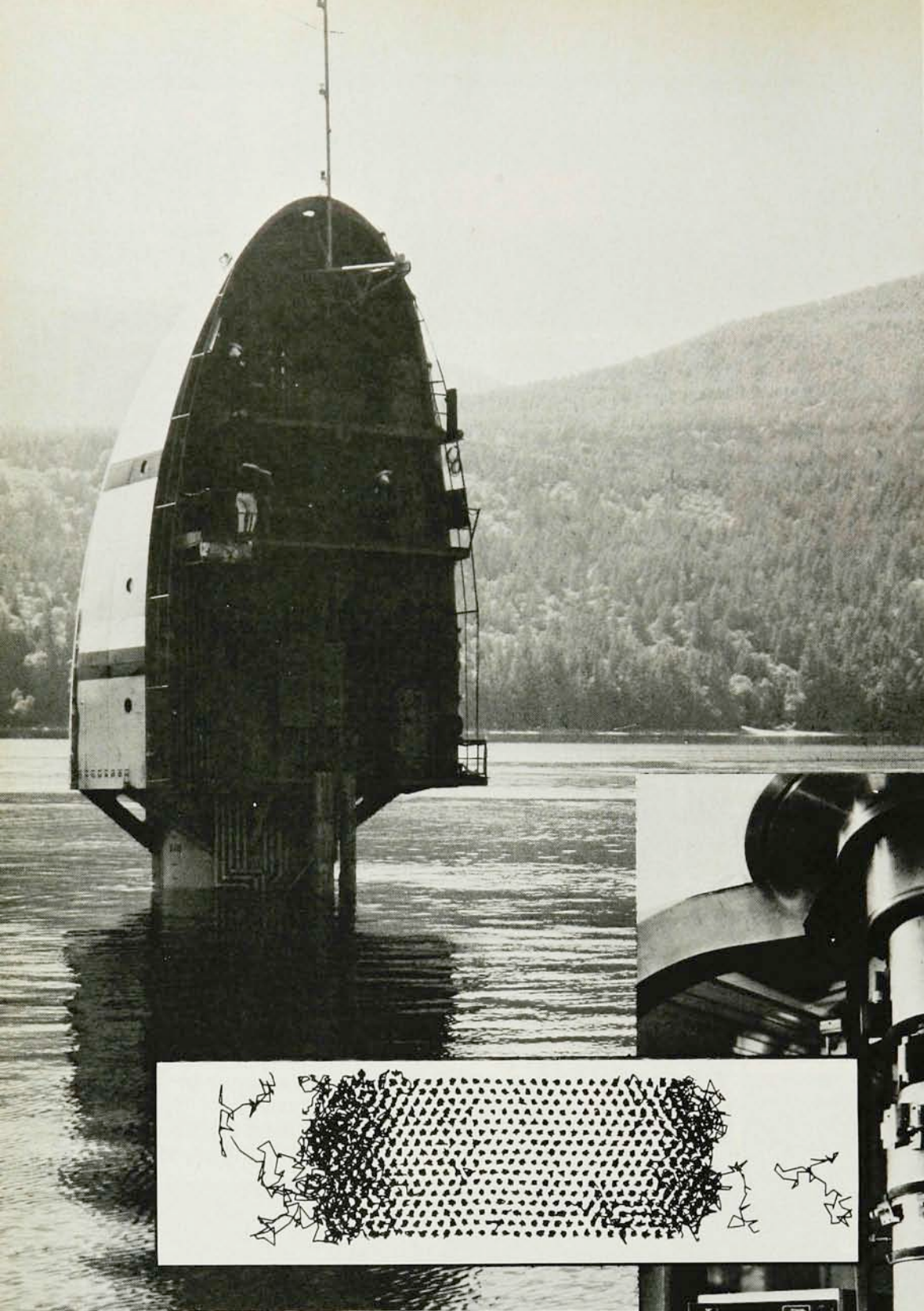
fiftieth anniversary of something back in 1931—what would those physicists have said about their position in time? In fact we have a good idea of that, because people back then wanted to orient themselves in time just as much as we do now, and they often recorded what they thought of their situation.

Physicists in 1931 saw themselves at the crest of a great, spreading wave of new knowledge. They were right to think so, considering what physicists had done in the half-century up to 1931. Most striking, perhaps, was the development of electromagnetic theory and practice. Only in 1888 did Hertz detect electromagnetic waves, sealing the process

Laser-assisted machining.

Lasers are based on old theory; what is new is their uses, which range from experiments in fundamental physics to the machining operation shown here. Uncovering the subtle complexities of Nature and making use of the results is the hallmark of modern physics. (Courtesy General Electric Company, Research and Development Center)

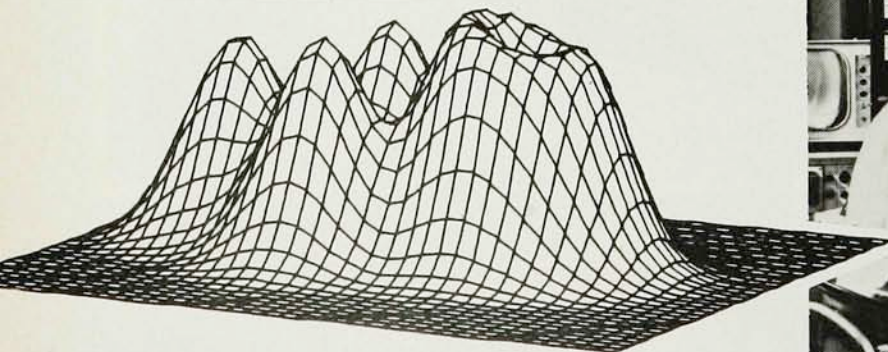
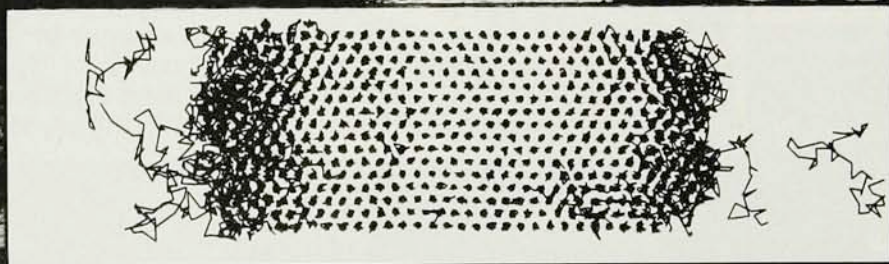
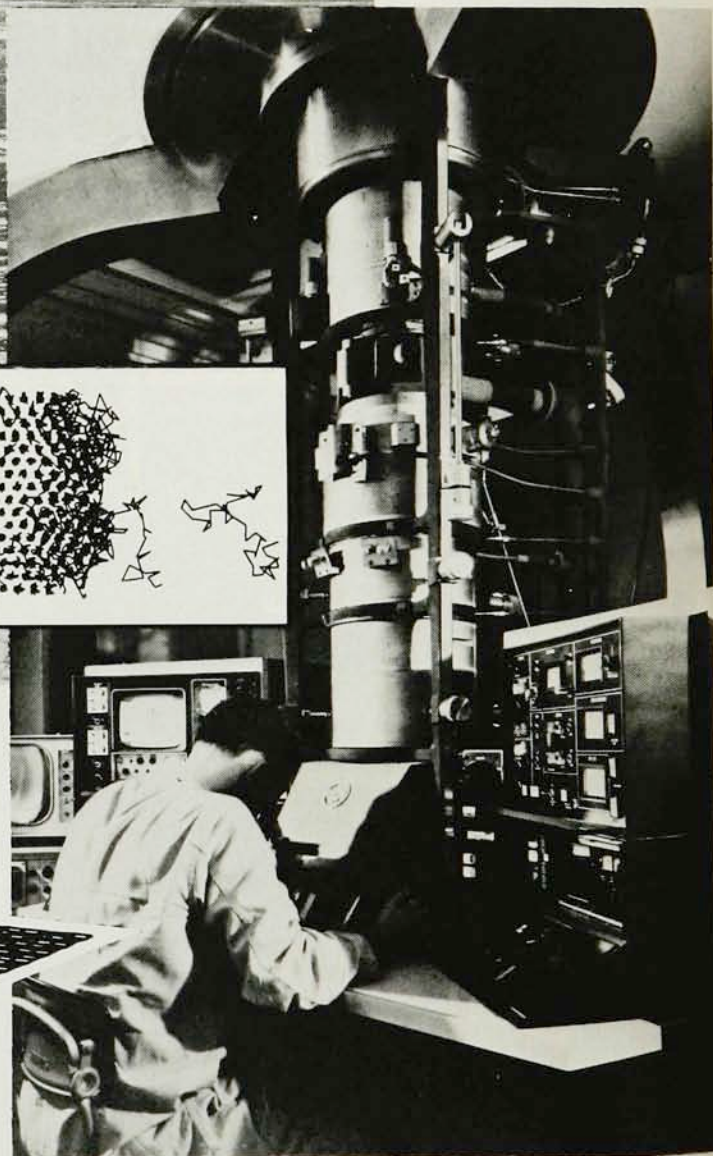




Modern sophistication.

People fifty years ago could scarcely foresee the power and insight that modern physicists bring to the study of complex phenomena. Sophisticated instruments probe at the borders between disciplines. Shown here are an electron microscope and the oceanographic instrument platform "Flip Ship."

Computers similarly broaden the range of theory. Here we see the density of the calculated fissioning state in silicon-28 [H. and R. Schultheis, Phys. Rev. C 22 (1980): 1588] and melting and vaporization at the surface of a heated theoretical solid [F. F. Abraham, Phys. Rev. B 23 (1981): 6145].



by which Maxwell's equations came to be accepted as definitive. It was between then and 1931 that most homes got their dozens of electric lights and their dozen or so little electric motors. In 1931 the silver-haired dean of American physicists, Robert Millikan, told the *New York Times* that this was the greatest change of the previous couple of generations: the substitution of electrical power, driven by fossil fuels, for human muscle power. No past time had known such a great change, he said, and he could not imagine that physics could bring any change so great in the next couple of generations.¹ The revolution in communications, symbolized by radio and telephone, was also largely completed.

In the more abstract kingdom of theory, the physicists of 1931 could look back on equally great changes. Fifty years before, statistical mechanics had barely started, and some leading scientists even refused to agree that atoms existed. Then the work of Boltzmann, Gibbs, and many others established the statistical atomic theory beyond question, solving one of the oldest problems of science. This atomic view had then been pressed forward to the discovery of that most fundamental particle, the electron. The discovery of x rays and radioactivity added to the excitement: At last the structure of matter was becoming known.

But that was only an appetizer. During their own careers the physicists of 1931 had overthrown the commonsense view of how atoms must behave, creating the new quantum mechanics. To many the quantum seemed incredible, bizarre. Yet by 1931 the quantum view had been capped with the Dirac theory. And the positron, just discovered, confirmed Dirac in a most surprising way.

And even that was not all. Einstein had replaced Newtonian mechanics with his special theory of

relativity, and had gone on to build a new general theory that explained gravity in a far deeper way than before. Just as the discovery of the positron had unexpectedly underwritten Dirac's theory, so the discovery of the expansion of the universe gave an astounding demonstration of the usefulness of Einstein's equations.

The only word for all of this is revolution. The physicists of 1931 were keenly aware that their generation had upset previous ways of seeing the universe, as thoroughly as Lenin's generation had upset the social structure of Russia. Said Millikan: "The discoveries which I myself have seen since my graduation transcend in fundamental importance all those which the preceding 200 years brought forth."² A revolution is a complete turnabout; that well describes what had happened to the world-view of physics in the fifty years up to 1931.

A social revolution

Physics had known a social revolution too, almost as radical as the new theories. This was particularly true in America. Back when Millikan and the other senior physicists of 1931 began their education, American physics scarcely existed. Then came the foundation of The American Physical Society and the *Physical Review*, which together defined the existence of an American physics community. These were joined by other institutions, such as the American Association of Physics Teachers, brand-new in 1931. There were something like 3000 physicists in the United States in 1931, where fifty years earlier there had been at best a couple of dozen. In that year 1931 the *Physical Review*, for the first time, was cited more often in the physics literature than its chief rival, the German *Zeitschrift für Physik*.

This rise of American physics

was a world-historical change, more significant in the long run than the bloody useless battles of the First World War. The leaders of physics, when they thought about the effects of that war, thought particularly of how physicists had proved themselves in industry. As recently as 1900 there had scarcely been such a thing as an industrial physicist, but in 1931 about one-fifth of the members of the Physical Society were in industry. There was talk of forming a society of industrial physicists—splitting up the Physical Society.³

Along with this growth had come an important change in the public attitude toward physics. Our science had always been respected for its deep understanding of nature, and also for its promise of making life on earth easier. But in the fifty years up to 1931 the admiration had redoubled. The discoveries of quantum mechanics and relativity put physics, for the first time, beyond the reach of the intelligent layman. Einstein was the first physicist ever to be regarded, even by intellectuals, with the uncomprehending awe once reserved for sorcerers. Meanwhile, the practical value of science had been proven in the war and in the industrial laboratories. The physicists of 1931 could look in any magazine and find advertisements declaring that some particular toothpaste or refrigerator was made better by laboratory scientists. That was something new, something revolutionary.

How confident was the public in 1931 about science? Nothing shows it better than peoples' desire to make themselves radioactive. Radium could help cancer patients, of course, but that was not all; many people thought that a little radioactivity could be a healthful stimulant. Spas in many countries were proud to advertise the natural radioactivity of their waters. A 1929 pharmacopoeia listed no less than eighty patent medicines based on radioactivity.

You could take radium by capsule, tablet, compress, bath salts, liniment, cream, inhalation, injection or suppository. You could eat mildly radioactive chocolate candies, then brush your teeth with radioactive toothpaste. The manufacturers claimed that their nostrums would give relief from tuberculosis, tumors, rickets, baldness and flagging sexual powers.⁴

Despite all the enthusiasm for science, the public had some doubts. The increasing application of physics to industry in war and peace, and the increasing failure of most people to understand physics, led to criticism. Physics was said to stifle the spontaneous, unthinking wholeness of life, to destroy moral values, to reduce workers to robots or throw them out of work entirely.

New problems require new solutions. Many leaders of physics in 1931 saw a serious need to keep the public trust in physics. They also needed to deal with the rise of industrial physics, which threatened to cause a schism between industrial and academic physicists. But most pressing, they had to reorganize the finances of physics journals, for the journals were losing money as the physics community became increasingly specialized. It was to meet all these needs that the American Institute of Physics was founded. The newborn AIP had the practical task of making publication more economical by consolidating the production of the various physics journals. But it had even more important tasks, as the people who founded it saw things: To cement a bond between industrial and academic physics, and to serve up reliable information on physics to the press and the public. With the founding of the AIP, the structure of American physics was put in order.

When physicists of 1931 looked ahead to our own time, they were sure that physics would continue to grow and spread into every field of human activity. They said that power would become still cheaper and more widely used. They expected that by the 1980s we would have widespread use of television, transportation much better than steamships and some kind of industrial robots. In all this they were quite accurate.

Physicists were less accurate when they looked at their own science. In 1931 the problem of the nucleus had grown so pressing that it seemed to tremble on the edge of a grand solution, and many hoped for a new revelation, as exciting and surprising as quantum mechanics or relativity. Niels Bohr even suggested in 1931 that the law of conservation of energy might have to be junked. In George Gamow's draft for a textbook, wherever he talked about the internal constitution of the nucleus he drew a little skull and crossbones in the margin, to warn the reader how uncertain the current speculations were.⁵

While nuclear physicists awaited their revelation, others worked in another direction to undermine the recently won achievements of quantum mechanics. These others were few but they were led by the greatest of all, Einstein. The union of electromagnetic and gravitational theory seemed not far off. And would that not put both general relativity and quantum mechanics to rest, as mere shadows of some far grander and deeper unified field theory? Such were the dreams of 1931.

Uncovering new subtleties

Where are we now in 1981?
Are our times much like the times

of the people fifty years ago? Is the history of physics in our lifetimes much like the history that they lived through, or are there qualitative differences? There can be no simple answer, for physics is an uncommonly diverse subject, but I can mention a few particularly salient features.

The study of nuclear forces and particles has not brought the new revelation, the overthrow of quantum mechanics. Instead of wholly new laws, we have been uncovering ever more layers of complexity. Quite a lot has been said recently, in connection with the 1980 Nobel prizes,⁶ about theoretical developments, so I will touch on some of the experimental results. First there were the mesons, and then a number of other particles, particularly the strange particles—as the name implies, quite a surprise for physicists. This particle zoo, as it was called, gradually sorted out; the discovery of the omega minus gave an encouraging confirmation that the zoo had a comprehensible layout. And lately there came the experiments that most of us would call the confirmation of quarks: another layer of complexity.

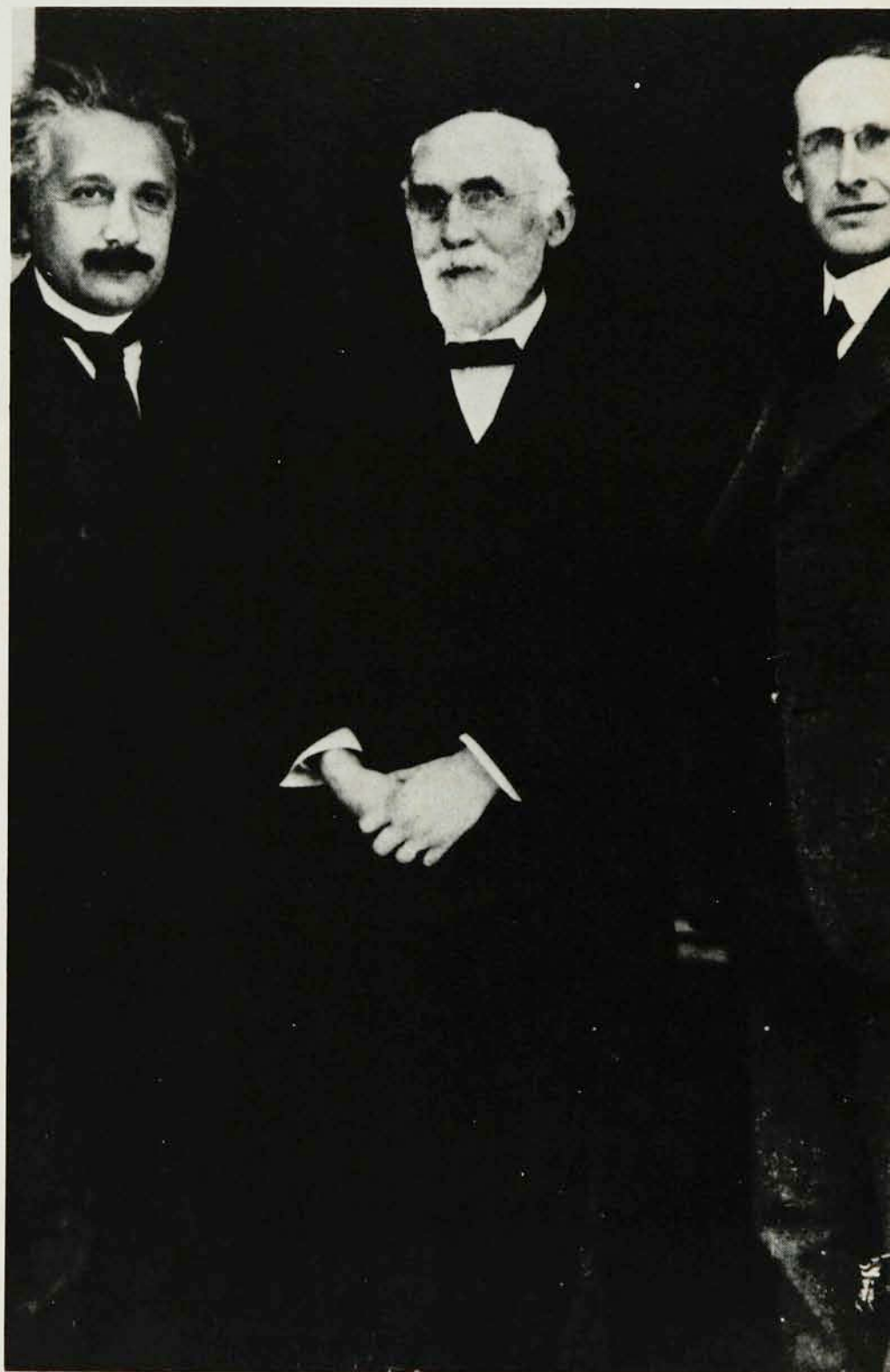
Did all this add up to the sort of revelation that physicists of 1931 had seen in their past or hoped to achieve with nuclear physics? I think the answer must be no—not exactly. Certainly the appearance of new particles has been surprising and exciting. People in 1931 really thought that with the electron and proton (and conceivably the neutrino) they had counted up all the fundamental particles. That sort of thinking has been overthrown. Yet the overthrow was in no way comparable in scope to the discovery of the electron or to quantum mechanics. The idea of fundamental particles is as useful now as it was then;

they just turn out to be more numerous and subtle than people expected.

I am not speaking now of the new unified force theories. After all, these still involve a pile of empirical parameters. Historians of the future may well say that the year 1981 marks the center of a slow revolution in our view of forces and particles, but it is too early for a historian to write about that yet.

What has been most striking is not the revolutionary nature of these fundamental theories but their continuity, their tortuous step-wise development out of earlier theories. In some ways it has been less a process of inventing a new theory, in the sense of a new world-view, than a process of separating out the valid theories from the almost infinite variety spread forth by quantum mechanics. Contrary to what many scientists expected in 1931—above all Einstein—quantum mechanics remains and is more solid than ever.

But it has not remained unchanged. There was, of course, confirmation that it really worked, right down to the incredibly fine detail revealed by the Lamb shift. That was more than some expected. But there was also a new approach to quantum electrodynamics associated with the names Feynman, Tomonaga, Schwinger and Dyson. In one sense this is only a better means of calculation, but we must beware of saying "only" a means of calculation, when that is all any theory comes down to when you go into the laboratory. It was not easy for many people to swallow renormalization, and it was not easy to swallow the notion, so clearly pointed out by the diagrams of particles interacting, that a positron can be represented as an electron going backwards in time.



Albert Einstein, Hendrik Antoon Lorentz and Arthur Stanley Eddington in 1923.

These theorists pursued an underlying unity and simplicity. Similar work over the last half-century has advanced less rapidly than work in their day. (Photograph courtesy of AIP Niels Bohr Library.)



Entire attendance at 1930 meeting, and recent single session. Growth of the physics community changed its character. The participants at the 1930 Washington meeting of the American Physical Society would have had little time to chat during the crowded sessions of any meeting since the 1960s. (Photographs courtesy AIP Niels Bohr Library)



On top of these subtleties came the discovery of parity violation. Even more fundamental was the violation of CP, which is to say, the experimental proof of time asymmetry, an even more fundamental reversal than the reversal of an electron into a positron. These discoveries surely did upset old preconceptions. Yet again, I will not call them revolutionary in the sense that quantum mechanics had been. No old system of ideas was turned on its head. Rather, people were set free to consider a greater range of ways the universe can behave—this freeing-up was indeed necessary to open the way to the new unified force theories.

As with quantum mechanics, so with the general theory of relativity, the years have seen not an overthrow but a strengthening. The unification of electromagnetism with gravitation—the project on which Einstein spent half his life—is not yet done, nor does quantum mechanics seem any easier to reconcile with a theory of curved spacetime. Yet this does not mean there has been no progress. To begin with, general relativity has passed exacting experimental tests, much as quantum mechanics did, and that is great progress. And there have been wonderful developments in the theory—not new equations but new theorems spinning out from the old equations, each more astonishing than the last.

Consider, for example, the relations among cosmology, thermodynamics and relativity. It has gradually dawned on physicists

that the direction of entropy, the direction of time, is somehow embedded in the general relativity solution for the expanding universe, in the elementary sense that time's arrow points the direction away from the Big Bang. Moreover, we have learned how even that "singular" solution of the equations, a black hole, can have its own time scale, a lifetime determined by statistical, indeed quantum emissions.

A hundred years ago, in 1881, there was simply Newtonian time, a concept scarcely different from that handed down from Aristotle, a concept of crystalline simplicity. By 1931 this was done away with, replaced by relativistic time—a new way of putting time into our equations, an astounding revolution. Yet Einstein's idea of time was as easy as Newton's, once you got used to it, and even simpler; that was why physicists liked it. But what has happened since then? Relativistic time is still basic. But the concept has been wonderfully enriched. Time is reversible; time symmetry is not even conserved; time plays fantastic tricks around spacetime singularities; time is tied up with all the majestic expansion of the universe. The physicist's conception of time is today far more complex than in 1931, much richer and more subtle.

So when I say that there has been no revolution in the last fifty years comparable to those of the fifty earlier years, I'm not heaping scorn on recent progress. Physics does not always have to advance in a revolutionary way.

Sometimes it advances precisely by coming to more complexity, more layers, more calculations and models, more subtlety. No doubt the universe is characterized by great simplicities, not all of them known; but the universe is also characterized by an intricate physical texture, which it is also the task of the physicist to understand.

Freeman Dyson makes a similar point when he divides scientists into "unifiers" and "diversifiers."⁷ As an example of a unifier he suggests Einstein, always searching for underlying unities; a diversifier would be someone like the great majority of our colleagues in biology, always studying the marvelous diversity of specific creatures.

This is in fact a fundamental division in the way humans can approach the universe. Many years ago, in the classic study of mysticism, Underhill pointed out that mystics may approach God in two ways. They may see God as transcendent, wholly other; or they may see God as present in all things, diverse and evolving.⁸ In a similar way, the search for some transcendent unity beneath the surface of things was an important root of modern science, but the love of diversity, of particular things in the world, was no less important.

The two feelings could be combined in one person. Galileo was certainly a unifier, and he found fundamental laws beneath the motions of things. But he was also a diversifier. The old unitary theory of his day saw the sun as a perfect sphere, and the planets car-



ried around the sky on perfect crystal spheres. Galileo, peering hour after hour through his telescope, discovered the moons of Jupiter and the sunspots, and messed up that beautiful, clean theory. Galileo loved change and diversity; dirt, he said, was better than diamonds. If the whole earth were a perfect crystal sphere, said Galileo, he would consider it just "a wretched lump . . . in a word, superfluous."⁹

A Broader Scope

Both unifiers and diversifiers are important in science. But there may be times when one type of thinking can make swifter progress than another. And in physics of the last fifty years, while much attention has gone to the efforts of unifiers, I think much of the finest work has been in the direction of diversity.

Take, for example, astrophysics. Compared with what we know now, the people in 1931 knew almost nothing. They did not even know whether red giants are an early stage of the evolution of stars, or (as is the case) come later. Today, the evolution of stars is better understood than the transformations of a tadpole into a frog. Then, more recently, there was all the development of radio astronomy. A whole new universe, the so-called violent universe, is now open to us.

Yet none of this is what I would call revolutionary. Some of what astronomers guessed in 1931 turned out to be wrong, but no

strongly held astronomical world-picture was overturned. It was not that astronomers had a wrong idea of the radio universe or of stellar evolution, so much as that they admittedly did not understand these things at all. Modern astrophysics has not been like a revolution overturning an established government; it has been more like a wave of colonization that sets up new nations in an uninhabited territory.¹⁰

This colonization was made possible because of the alliance of astronomy and physics. Nuclear physics and spectroscopy and electronics and optics have all been essential to the advance of modern astronomy. Indeed, for some time now about half of all new astronomers have brought their PhDs from physics. In return, physics has been enriched beyond measure by what the astronomers know.

This kind of cross-fertilization is another aspect of what I have been talking about: the increase in richness and complexity that has been the main feature of physics for the past half century. Astrophysics is not the only example. Another would be geophysics. The 1930s saw a massive invasion of oilfields by physicists with gravimeters and the like. Since then there has been a true scientific revolution among our colleagues in geology, the development of plate tectonics—the view, stoutly resisted by many old-timers, that the continents slip about like so many cakes of ice on a churning ocean. While many lines of evidence converged on this rev-

elation, not least in importance were techniques brought in from physics, such as measurements of the radioactive ages and magnetic orientations of rocks.

It was not by a fluke that physics became an indispensable part of the tool chest of many other sciences. The great discoveries preceding 1931, statistical mechanics, radioactivity, the electron and all, laid a firm conceptual foundation not just for physics itself, but for all the sciences. It remained only to apply these tools to the thousands of old problems that awaited them. And who could do this better than physicists?

The most exciting example of all was molecular biology. In 1931 physicists and biologists had little to do with one another. Then came the discovery of artificial radioactivity. By the end of the 1930s, in laboratories around the world—Berkeley, Paris, Copenhagen, Tokyo—cyclotrons or other particle accelerators were being built. But most of them were not built primarily to explore the nucleus. These devices were funded above all to provide artificially radioactive isotopes for biological and medical research.

The new coalition between physics and biology spread after the Second World War. Erwin Schrödinger went so far as to suggest that if physicists went into biology they might discover, in those huge complex molecules, revolutionary new laws of physics. That was a fantasy, but physicists, inspired by Schrödinger, gave biologists important help in deciphering

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the genetic code. More important, the analytical ways of thought pioneered by physicists conquered certain fields of biology. And most important of all were the physical techniques, especially radioactive tracers. It is hard to say where molecular biology would be today without all that—certainly far behind where it is now.

When physicists back in 1931 looked ahead they foresaw something of this. "Questions of life and health," said Arthur Holly Compton, "will probably be in the forefront." And Millikan said, "It is rather in the field of biology than of physics that I myself look for the big changes in the coming century." They predicted this because they foresaw that physics was bound to enter and inspire biology.¹¹

The last fifty years, then, have revealed an ability of physics, a surprisingly powerful ability, to help make sense out of the most complicated phenomena, even in fields far from home. But most striking has been the way that physics has done this in its own central area, the understanding of everyday matter.

The physicists of 1931 would certainly be gratified to see the advances that have been made in understanding collective phenomena, not only in inaccessible places like the nucleus or a neutron star, but even in ordinary matter. For example, behavior near the critical point is understood now in a far more satisfying way than formerly; the unifiers have done well here. But no field exemplifies so clearly as solid-state physics the urge to look into diversity and understand it.

The band theory, the study of point defects and their consequences, the theory of superconductivity and the study of lattice vibrations are just part of a list that could go on for pages. I wish I could tell in a few words the story of this field, because in many ways the history of solid-state physics, its growth into condensed-matter physics, has been at the heart of the history of physics over the last fifty years. We all know of the great applications, not only the long-predicted televisions and robots, but also the computers, with their little-anticipated power to help along every field of science. But I

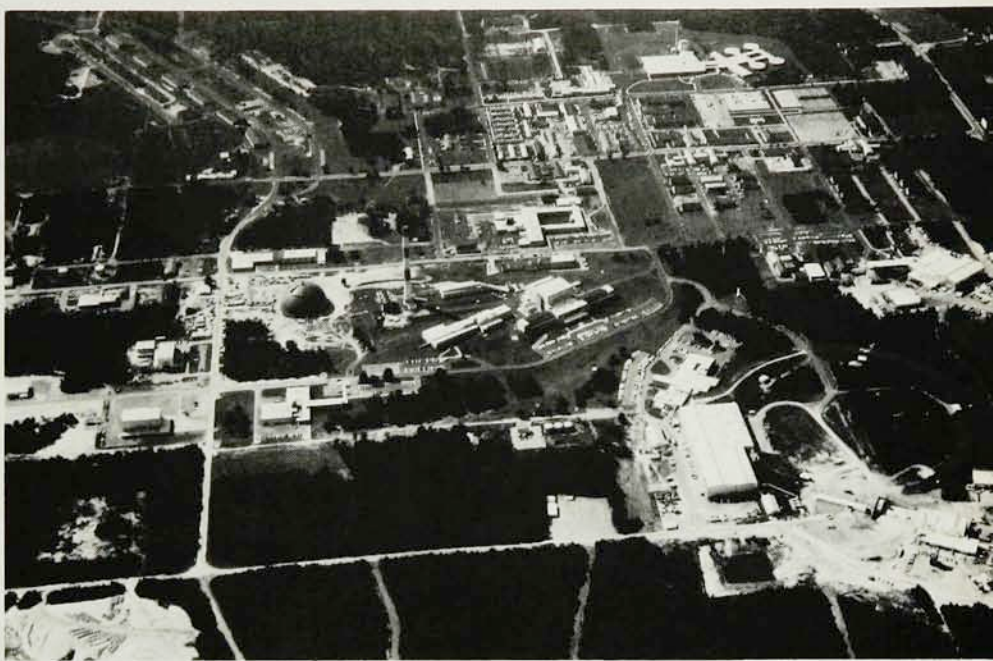
think many people do not realize the fundamental interest of this field. The condensed-matter physicists are the ones who provide an explanation of the physical characteristics of everyday matter: they can literally tell us why the things we see and handle look and feel as they do. This is primary among the ancient, homely tasks of physics, and it is a task that has been largely accomplished in our time.

I wish, I say, that I could tell the story of this development, but I can't. The story has not yet been put together by historians. Why has fundamental solid-state physics gotten less public attention than many other fields? I suspect it is because the field is obviously not revolutionary. Once again, it has been more a matter of people colonizing unknown territory, through steadfast continuous work, rather than overturning what was known. Cyril Stanley Smith has written about this.¹² Solid-state physics, he feels, was held back because of an overemphasis on "good, clean" Newtonian methods. Only when people accepted a messier, more approximate way of dealing with things could solid-state physics be done. "I rather suspect," Smith writes, "that solid-state physics has in it some of the future of science in dealing realistically, not purely statistically, with complicated systems, and not being purely reductionist as almost all physics was until 1940 or so." He calls the history of solid-state physics "the history of an emerging science of buildings, not of bricks." I think something like that could be said for much of the history of physics over the past fifty years.

Certainly there are times when revolutionary ideas are adopted—and nobody would dare say such times may not be here today. However, there are also times for diversity, for the advance of a science of buildings, not of bricks, and those can be exciting and important times too.

An institution transformed

Turning now from physics as an intellectual field to physics as a



Brookhaven National Laboratory in 1962, as seen from the air, looking south. Only national governments could support science on such a scale. (Photograph courtesy of AIP Niels Bohr Library.)

community of people, what has happened in the past fifty years? Again I do not see revolutionary changes. There has been nothing comparable to the preceding burst of activity that took American physics from a nonentity to a field with its own journals, societies and Institute. Today as in 1931, physicists are organized in the Physical Society and others, with the *Physical Review* and some other journals. Today there are still a fifth of the Physical Society members in industry, with most of the rest employed by academic institutions. Yet underneath this there have been changes. And just as in physics itself, the changes were no less important for being complex and subtle rather than revolutionary.

For example, those people employed by academic institutions today are in large measure paid by the federal government. This is particularly obvious for the quarter of them who work at government-contract laboratories, perhaps less so for professors who indirectly draw part of their pay from the government's tuition subsidies. This dependence on federal money would have horrified Millikan, a sturdy free-enterpriser. Yet he should have foreseen it, for even in his day the United States was a

holdout, a country of privately employed physicists in a world where the salaries of most physicists were paid by national governments. This great change in American physics does not seem so revolutionary, then, when seen in the perspective of world history. Physics tends to be strongly supported by the state, a fact that has been clear in most countries for many years.

Another change is also not surprising, except in its scope: the rise of American physics to world dominance. In 1931 Millikan predicted that by our time, "the United States and Germany will probably be the world leaders in science." Only two years later Hitler came to power, and the cream of Central European scientists began to make their way to American shores. Since then, the United States has been the location for more important theories, experiments and instruments than all the rest of the world put together. This dominance of a field of science by one country is without precedent in modern history.

It was government funds as much as anything that allowed this, promoting a great increase in the number of physicists. Where there were some 3000 physicists in America in 1931, there are over

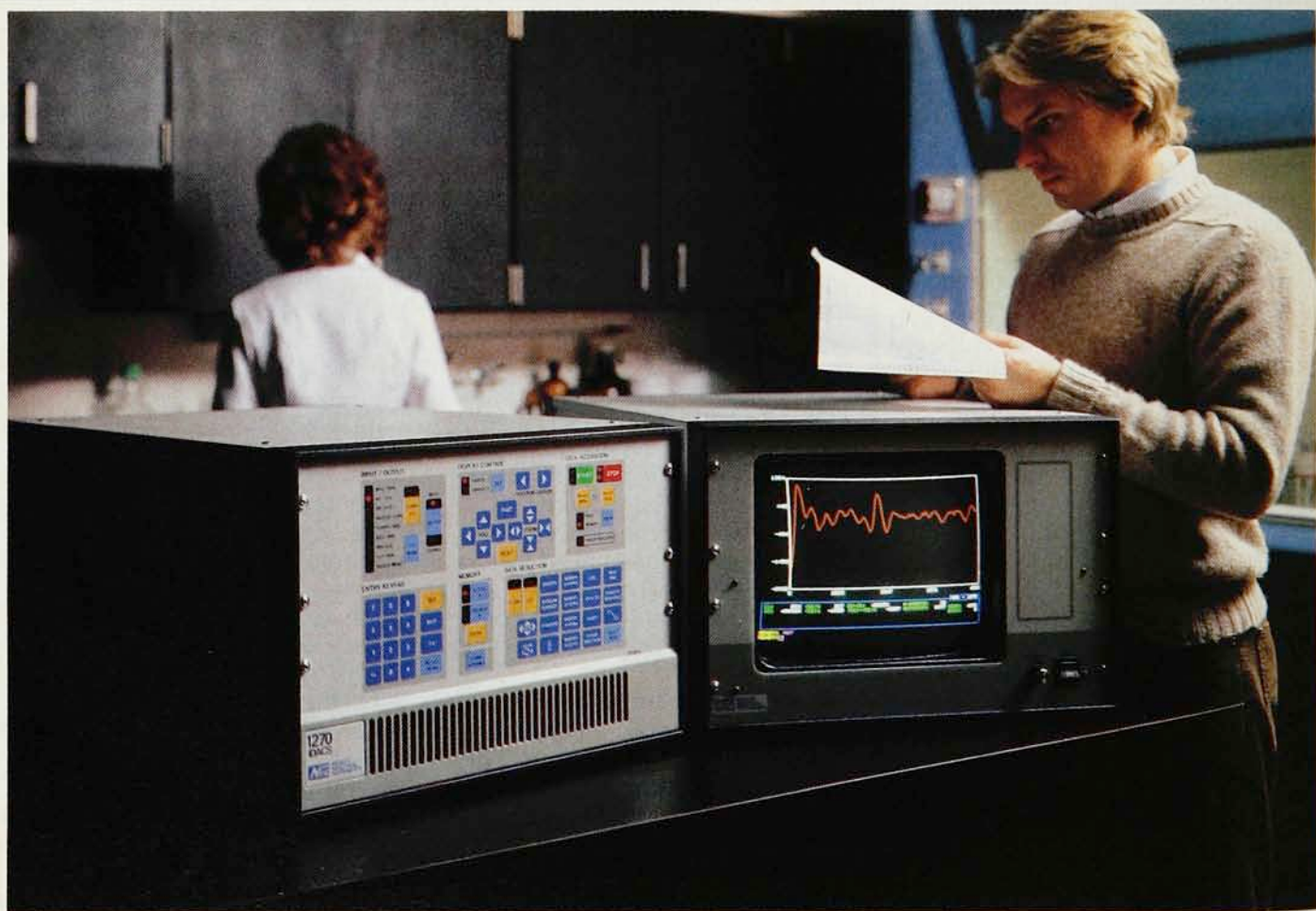
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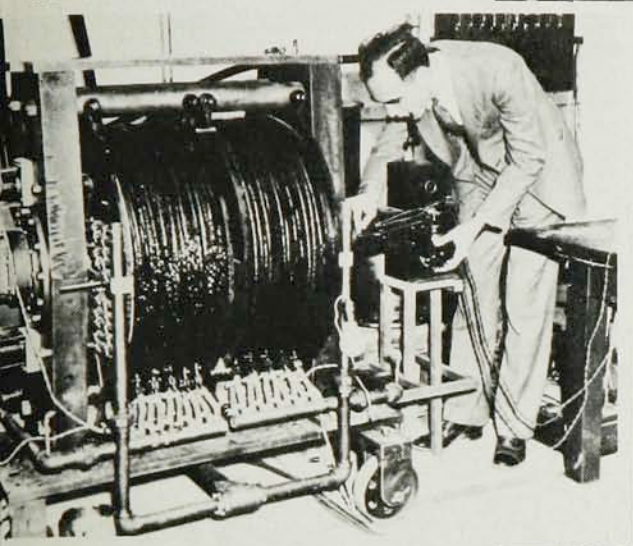
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Research teams and equipment grew vastly in fifty years. Carl Anderson (above) designed by himself the device he used to discover the positron in 1931; Samuel Ting's team (right) fitted easily into one corner of the apparatus they used to discover the J/ψ particle in 1974.



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30 000 now. Any physicist in 1931 could have predicted some such increase, simply by extrapolating the exponential growth that had already been going on for generations. In fact, an extrapolation would have indicated close to 100 000 physicists in the 1980s. However, around 1968 the growth reached saturation—the maximum number of physicists that society was willing to support. The end of exponential growth demanded a number of painful readjustments, which are still underway.

It would have been harder for the physicists of 1931 to understand what the increase in numbers would mean for their way of life. The break came sometime in the 1950s when American physicists could no longer all know one another as the people in a small town know one another. Relationships shifted. Some obvious indicators are the innumerable parallel sessions at meetings, the insuperable thickness of the *Physical Review*, and the need for weighty grant applications rather than a simple chat with your patron.

Another indicator is the rise of team research, and the clustering around great instruments, a way of

working that would have been wholly alien to the physicists of 1931. Yet that is no revolution, really, for the old-style physics still goes on where it can. It is again a matter of increased complexity, of diversity, of deeper levels of understanding and organization making it possible to break into new territory. (Perhaps in some way the nature of the social organization parallels the nature of the knowledge it makes available; that deep question cannot be answered here.)

As one indicator of the increased complexity of the physics community, look at the American Institute of Physics itself. There has been no revolution, for it is still the old AIP established fifty years ago. But what a difference! Instead of a director and one secretary operating in a free-wheeling way out of a tiny office, AIP is today an organization as diverse as a large bank, with 400 employees clustered around computer terminals and the like. Besides its old task of publishing journals (now using physics-based electronics technology, of course), it addresses the problems jointly faced by the various physics societies through an array of sophisticated

mechanisms: a public affairs committee, representation in copyright clearance organizations, a marketing apparatus, manpower studies, a public information service and even a history center. In short, AIP and the physics community, along with the subject of physics itself, have become far more complex and more intricately interconnected with the rest of the world in the past half century.

In this matter of connections with the rest of the world, there is one more thing I must talk about. Robert Millikan and Arthur Compton would have been most surprised to see it. That is the fact that today, as through the past forty years, something like a quarter of all American physicists are employed rather directly in military research. Beyond this, the armed forces have given generous support even to research that seems quite pure—for generals too have grown sophisticated, and understand the long-term sway of science. Most physicists, like myself, have benefited at one time or another from Department of Defense contracts. I think that the physicists of 1931 would find it overpoweringly strange that so many scientists now work on

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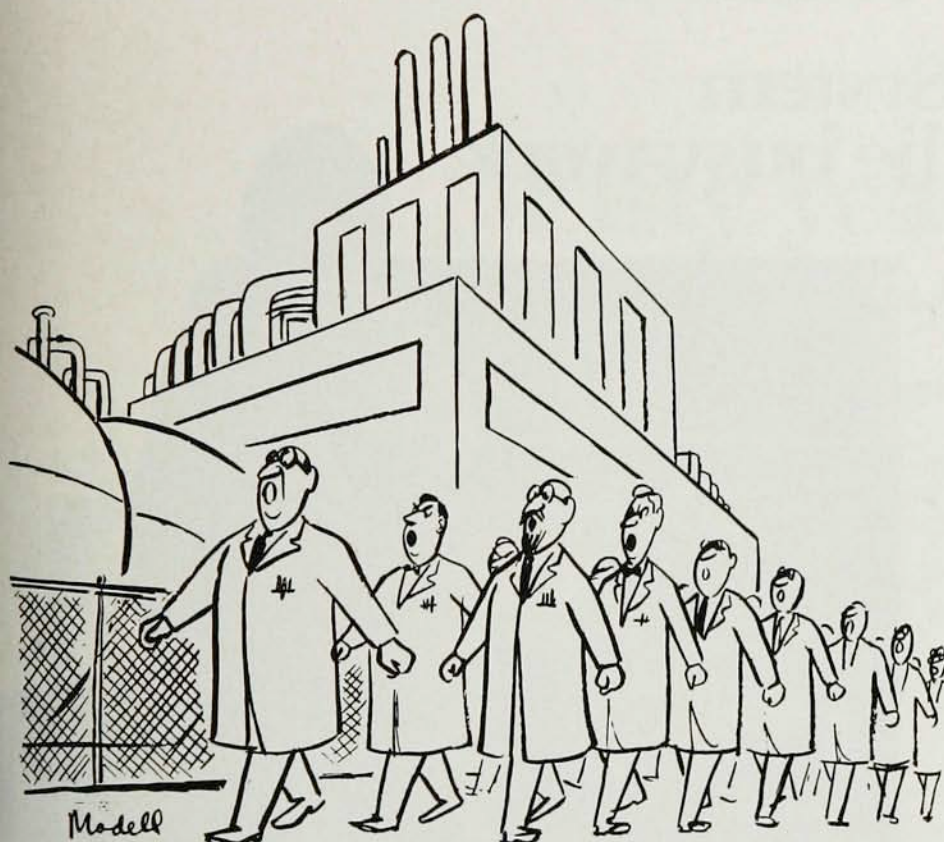
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Twenty-three-year-old cartoon. Close new connections of physics with the military since World War II altered the physics community and increased the public's ambivalence toward science. (Drawing by Modell; © 1958 The New Yorker Magazine, Inc.)



"From the cyclotron of Berkeley to the labs of M.I.T.,
We're the lads that you can trust to keep our country strong and free."

weapons, and I think that some, for example Compton, would be distressed. They believed that the physics research of today is the main factor in determining the world of tomorrow. So they would want to know what sort of a world we have it in mind to create.

It may well be that this revolution, this infection of physics by military problems, also has something to do with changes in public attitudes toward our science. I do not think there has been a complete revolution here; the public is still mostly enthusiastic about our enterprise. Yet consider how people think of radiation. Nobody wants to become radioactive any more. On the contrary, people have become as unreasonable in their fear of radioactivity, as they were unreasonable in their hopes for it fifty years ago. The change can be dated very precisely: it was caused by Hiroshima. Since then, any public support for physics has had within it a certain fear-

ful reservation, and rightly so, if you consider our situation. This is another of those subtle changes, a new complexity, a new wisdom I suppose, that we must live with.

Fortunately, many physicists themselves have responded by taking their social responsibilities more seriously, and dealing with them in a more understanding and sophisticated way. The growing recognition that even in the abstract acts we perform in our research, physicists are human beings living in society, is one of the most subtle and most hopeful of all the changes we have seen.

To answer, finally, the question I began with, I do not think that physics in our times has been like the physics of fifty years ago. Our times have been less revolutionary, but more diverse and penetrating; less welcoming to dreams of vast revelations, but no less exciting and rewarding. Of course, this history shows us no way to predict whether our fifty years of

development have built a platform for another revolutionary leap, or whether the steady process of extending and reinforcing the structure of our science will continue for many years. But the history does show that if we are to keep physics vigorous, we must always be ready for changes in our social arrangements and even in our approach to knowledge.

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