unique combination of parameters which lead to the existence of the terrestrial magnetic field. The changes in polarity imply a dynamic origin, and the existence of the solar wind leads to temporal variations that depend on both the strength and direction of the field as well as on the solar wind flux. Certainly these new experimental results, when fully analyzed and incorporated into theoretical models, will make an important contribution to our concept of the origin of the solar system as it is currently observed.

References and Notes

1. S. Chapman and J. Bartels, *Geomagnetism* (Oxford Univ. Press, Oxford, 1940).
2. S. Chapman, in *Geophysics: The Earth's Environment*, C. DeWitt *et al.*, Eds. (Gordon and Breach, New York, 1963), p. 373.
3. L. Biermann, *Z. Astrophys.* **29**, 274 (1951).
4. E. N. Parker, *Astrophys. J.* **128**, 664 (1958).
5. J. W. Chamberlain, *ibid.* **131**, 47 (1960).
6. E. N. Parker, *Interplanetary Dynamical Processes* (Interscience, New York, 1963).
7. H. S. Bridge, A. Egidi, A. Lazaruns, E. Lyon, L. Jacobson, *Space Research* **5**, 969 (1965).
8. C. W. Snyder and M. Neugebauer, *ibid.* **4**, 89 (1964).
9. C. O. Hines, *Science* **141**, 130 (1963).
10. C. P. Sonett, D. L. Judge, A. R. Sims, J. M. Kelso, *J. Geophys. Res.* **65**, 55 (1960); P. J. Coleman, C. P. Sonett, D. L. Judge, E. J. Smith, *ibid.*, p. 1856.
11. J. P. Heppner, N. F. Ness, C. S. Scearce, T. L. Skillman, *ibid.* **68**, 1 (1963).
12. A. Bonetti, H. S. Bridge, A. J. Lazaruns, B. Rossi, F. Scherb, *ibid.*, p. 4017.
13. E. J. Smith, P. J. Coleman, D. L. Judge, C. P. Sonett, *ibid.* **65**, 1858 (1960); C. P. Sonett, E. J. Smith, D. L. Judge, P. J. Coleman, *Phys. Rev. Letters* **4**, 161 (1960).
14. E. J. Smith, C. P. Sonett, J. W. Dungey, *J. Geophys. Res.* **69**, 2669 (1964).
15. Sh. Sh. Dolginov, Ye. G. Yeroshenko, L. N. Zhuzgov, N. V. Pushkov, L. O. Tyurmina, *Artificial Earth Satellites* **3–5**, 490 (1960); ———, *Geomagnetism Aeronomy* **1**, 21 (1961).
16. Sh. Sh. Dolginov, Ye. G. Yeroshenko, L N. Zhuzgov, *Space Res.*, in press.
17. R. A. Hoffman and P. A. Bracken, *J. Geophys. Res.* **70**, 3541 (1965).
18. L. J. Cahill and P. J. Amazeen, *ibid.* **68**, 1835 (1963); J. W. Freeman, J. A. Van Allen, L. J. Cahill, *ibid.* **68**, 2121 (1963).
19. J. W. Freeman, *ibid.* **69**, 1691 (1964).
20. L. J. Cahill, in *Space Physics*, D. P. LeGalley and A. Rosen, Eds. (Wiley, New York, 1964), p. 301.
21. N. F. Ness, C. S. Scearce, J. B. Seek, *J. Geophys. Res.* **69**, 3531 (1964).
22. N. F. Ness, C. S. Scearce, J. B. Seek, J. M. Wilcox, *Space Res.*, in press.
23. In a study of the interaction of the solar wind with the geomagnetic field, a coordinate system has been introduced which reflects the importance of the solar origin of the plasma. Direct measurements of the solar wind indicate velocities between 3 and 7×10^7 cm/sec. The heliocentric orbital motion of the earth through interplanetary space is only 3×10^6 cm/sec, so that the direction of the solar plasma flow shows an aberration from the Sun-Earth-line of only 3 to 6 degrees. A right-handed geocentric solar ecliptic coordinate system comprising an X_{se}-axis directed from the Earth to the Sun and the Z_{se}-axis normal to the ecliptic plane has been found to be a useful reference in which to study measurements of fields and plasmas. In this coordinate frame, θ is the latitude and Φ the longitude as measured east of the Sun.
24. D. B. Beard, *Rev. Geophys.* **2**, 335 (1964).
25. W. I. Axford, *J. Geophys. Res.* **67**, 3791 (1962); P. J. Kellogg, *ibid.*, p. 3805.
26. N. F. Ness and J. M. Wilcox, *Phys. Rev. Letters* **13**, 461 (1964).
27. R. H. Levy, H. E. Petschek, G. L. Siscoe, *Am. Inst. Aeronaut. Astronaut. J.* **2**, 2065 (1964).
28. J. R. Spreiter and W. P. Jones, *J. Geophys. Res.* **68**, 3555 (1963).
29. J. G. Corday, *ibid.* **70**, 1278 (1965); P. D. Noerdlinger, *ibid.* **69**, 369 (1964); F. L. Scarf, W. Bernstein, R. W. Fredricks, *ibid.* **70**, 9 (1965).
30. J. W. Dungey, *Phys. Rev. Letters* **6**, 47 (1961).
31. J. H. Piddington, *J. Geophys. Res.* **65**, 93 (1960).
32. L. A. Frank, *ibid.* **70**, 1593 (1965).
33. L. J. Cahill, *IGY Bull.* **79**, 231 (1964).
34. N. F. Ness, *J. Geophys. Res.* **70**, 2989 (1965).
35. J. H. Piddington, *Planetary Space Sci.* **13**, 363 (1965).
36. A. J. Dessler, *J. Geophys. Res.* **69**, 3913 (1964); ——— and R. D. Juday, *Planetary Space Sci.* **13**, 63 (1965).
37. W. I. Axford, H. E. Petschek, G. L. Siscoe, *J. Geophys. Res.* **70**, 1231 (1965).
38. K. W. Behannon and N. F. Ness, Goddard Space Flight Center preprint X-612-65-417 (1965).
39. I. A. McDiarmid and J. R. Burrows, *J. Geophys. Res.* **70**, 3031 (1965).
40. B. J. O'Brien, *Science* **148**, 449 (1965).
41. E. N. Parker, *Phys. Fluids* **1**, 171 (1958).
42. N. F. Ness and D. J. Williams, *J. Geophys. Res.* **71**, 322 (1966).
43. J. A. Van Allen, *ibid.* **70**, 4731 (1965).
44. E. J. Smith, L. Davis, Jr., P. J. Coleman, C. P. Sonett, *ibid.* **70**, 1571 (1965).
45. E. J. Smith, L. Davis, P. J. Coleman, D. E. Jones, *Science* **149**, 1241 (1965).
46. R. Hide and P. H. Roberts, in *Physics and Chemistry of the Earth*, L. H. Aherns *et al.*, Eds. (Pergamon, London, 1961), vol. 4, p. 27.
47. W. V. R. Malkus, *J. Geophys. Res.* **68**, 2871 (1963).
48. A. Cox, R. R. Doell, G. B. Dalrymple, *Science* **144**, 1537 (1964).

Physics in the Last Twenty Years

Emilio Segrè

Between 1895 and 1925, advances in physics probably came at a faster pace than in any comparable period since its beginning in modern form at the end of the 16th century.

Not only were entirely new phenomena, such as radioactivity, discovered, but also the very intellectual basis of physics was revolutionized by relativity and quantum theory. I would like to mention a few of the main conquests of these three startling decades in order to better evaluate more recent developments.

The 19th century closed with the discovery of the electron, x-rays, and radioactivity. The 20th century opened with the hypothesis of the quanta of light, one of the strangest and most revolutionary ideas ever introduced in science. At that time classical physics had reached the peak of its perfection; according to some of its most illustrious students, the end of physics was perhaps in sight. Just at that time, ironically, a conservative perfectionist, to whom revolution was abhorrent, Max Planck, found himself compelled, in order to explain black-body radiation, to introduce a hypothesis that contradicted almost everything that was known in physics at the time. His singular position is best illustrated by the fact—almost unique, as far as I know—that he had no precursors or rivals thinking along similar lines.

Einstein, who followed 5 years later with the special theory of relativity, radically changed our concepts of space and time, but he was far from alone in his line of thought.

The two great theoretical ideas, quantum theory and relativity—especially the first—were then applied to a marvelous supply of experimental facts which were discovered in the first decades of this century. The photoelectric effect, Rutherford's model of the atom, the Franck-Hertz experiment, the Stern-Gerlach experiment, the Compton effect, and the experimental discovery of de Broglie waves are some of the steps in this amazing progression.

The crowning achievement of this period was the development of a consistent form of quantum mechanics and the nearly complete understanding of the structure of the atom.

The author is professor of physics at the University of California, Berkeley. This article is adapted from an after-dinner address presented 27 December 1965 at the Berkeley meeting of the AAAS.

Radical Departures

Quantum mechanics implies a very radical departure from the previous scientific tradition. Most of physics had been modeled on Newtonian mechanics, which had served as a sort of model for other branches of physics; in quantum mechanics the kinematic concepts are completely changed and replaced by more abstract structures, such as transition probabilities, matrix elements, and so on. This was the most radical revolution undergone by physics since its inception and was substantially completed by 1930.

At that time, we may say, the pioneering phase of atomic physics had ended, and physics had to turn to new subjects in order to find something radically new. This was clearly realized by some of the leading physicists of the time. As a consequence, the younger generation attacked the nucleus, and we saw a succession of discoveries in the years immediately preceding World War II. Within 3 or 4 years we have the discoveries of the neutron by Bothe, Joliot-Curie, and Chadwick; of artificial radioactivity by Joliot-Curie; of deuterium by Harold Urey; of slow neutrons by Fermi and his collaborators; and finally, just before the beginning of World War II, the discovery of fission by Hahn and Strassmann. While all this was going on in Europe, here in America the big machines were beginning to be built, chiefly through the efforts of Ernest Lawrence. By the mid-1930's there were efficient cyclotrons producing transmutations in quantities inconceivable a few years earlier.

The Physicists

Now I want to leave physics and take a look at the physicists. The physicists of 1930, as a social group, are very similar to the physicists of 1900. They have perhaps shaved their whiskers, but the laboratories in which they work, the patterns of their careers, and their nationalities are the same as in the previous generation. The research work is concentrated in universities, whose physics departments have research budgets on the order of 15,000 present-day dollars per year. The very successful scientists receive yearly salaries of approximately 20,000 present-day dollars. They are highly respected. Most of them are either Herr Professor (or even Herr Geheimrat) or Monsieur le Professeur. A few are Sir or even Lord (or, in Italy, Senatore). There were not many Americans in the older generation, but in the younger one a number of Rockefeller fellows coming to America and National Research fellows returning from Europe bring the new physics to the United States. Physicists know each other by name and very often personally. They travel frequently; some, from both sides, have crossed the Atlantic, in 10 days.

The year 1933, when Hitler came to power, had a decisive influence on physics. It triggered a large migration of scientists from the continent of Europe to England and America. Although important work went on in Europe until 1939, preparations for war and war itself dealt a blow to science such that Europe has never recovered the position of preeminence it had before the war.

Postwar Changes

During the war, great technological progress was made, primarily in the United States. But above all, a radical change in the methods and the sociology of science, if I may use this term, occurred. The war ended with the astonishing explosion of three atomic bombs, and military and political leaders who had been confronted a few years before with radar, rockets, and new scientific ways of conducting the war were presented now with unprecedented political problems arising from the new discoveries in science.

While the war developments opened the eyes of the political rulers and of the public at large to the possibilities of new applications of science, scientists themselves learned the power of large-scale operations with which they had been unfamiliar before the war. The administration and operation of physics entered the war in a certain state. It emerged transformed, like an insect which enters a cocoon as a caterpillar and comes out a butterfly.

Although governments of all countries had been always conscious of the practical, political, military, and economic importance of science, from the days of Archimedes of Syracuse to those of Napoleon, the scale of operations that prevailed after the war was unprecedented.

New methods of operation have appeared. For instance, the great national or international laboratories, such as the Radiation Laboratory in Berkeley, the Brookhaven National Laboratory, CERN in Geneva, and Dubna near Moscow, have provided the standard way of acquiring large accelerators which are so expensive to construct and operate as to be beyond the means of single universities and have set a pattern for even larger efforts, such as those connected with the space program. The sums now involved are becoming significant even by comparison with the federal budget. We must remember that before the war sums devoted to research had been extremely small, an insignificant fraction of the federal budget and an even more insignificant fraction of the national product.

In order to give an idea of the division of effort among branches of physics, I quote, from *Physics Today* of a few years ago, figures on the field of study for graduate students or Ph.D. candidates in the United States. We find, in round figures: high-energy physics, 11 percent; nuclear physics, 16 percent; solid-state physics, 27 percent; atomic physics, 7 percent; theoretical physics, 19 percent; electronics and waves, 7 percent; and miscellaneous, 13 percent. A very recent census in *Physics Today* gives, for Ph.D. physicists *and* astronomers, irrespective of age: high-energy physics, 8 percent; nuclear physics, 15 percent; solid-state physics, 19 percent; atomic and molecular physics, 9 percent; theory, 11 percent; electronics and waves, 8 percent; with the remainder scattered in several fields, including astronomy.

The number of physicists in the United States has skyrocketed from around 3000 in 1940 to approximately 20,000 in 1965. In fact, there has been an exponential growth, with a doubling time of about 10 years; this growth has been a worldwide phenomenon.

Main Conquests

Nonconservation of parity. We turn now to the most important question: What have been the main conquests of physics in the postwar era? From the fundamental point of view the outstanding discovery has been the nonconservation of parity in weak interactions—a discovery made by Lee, Yang, Wu, Ambler, and others. This and the development of quantum electrodynamics are the only postwar discoveries that have added something new to our knowledge of the very foundations of physics. The discovery of the nonconservation of parity seems to show an intrinsic asymmetry in space, or, better, to connect our ideas on symmetry in space and time to the particle-antiparticle symmetry. Although this was perhaps the discovery of greatest importance in the period 1940–1965, we had in the previous 40 years perhaps half a dozen fundamental advances of seemingly comparable importance. There is, however, a suspicion that this discovery may be only the top of an iceberg, with the bulk to come.

Particle physics. If the nonconservation of parity is the most outstanding theoretical advance, what are the experimental conquests? Here the outstanding progress has been in the physics of particles. Indeed, we can say that this new chapter of physics is in large part a postwar development. It was a development neither anticipated nor expected in the 1930's. Although there were indications in cosmic-ray work of the existence of other particles besides the electron and nucleon, and although Yukawa had predicted the π-meson, or pion, in 1934–35, it was not until 1945 that it was found, by Lattes, Occhialini, and Powell. Discovery of the pion was soon followed by discovery of other particles, such as the K-mesons. These discoveries are in large part due to the development of new techniques or to great improvements in old ones. For instance, the use of photographic emulsions to detect particles, which has been one of the most prolific techniques, goes back to the work of Kinoshita in 1912. But only through the development of better emulsions in 1945 did it acquire the refinement necessary for the subsequent discovery of the pion.

The pion is connected with specific nuclear forces. It has often been called the glue that keeps the nuclei together. However, the glue is complicated and certainly contains other ingredients, such as the K-mesons. The study and classification of all these particles is one of the main subjects of present-day physics. The experimental results are many and definite. For example, mass charge, lifetime spin, parity, and other quantum numbers have been assigned to many many particles. The concept of Strangeness—a new quantum number introduced by Gell-Mann and Nishijima—has been of great help in the classification of these particles; the concept of isotopic spin, introduced as long ago as 1932 by Heisenberg, Wigner, and others in connection with nuclear physics, has acquired great importance. However, when all is said, we must recognize that we are very far from a satisfactory knowledge in this field. Theory is lagging behind here, and I would not venture a prediction as to when we will have a satisfactory systematization of particle physics, although it is clear that this is one of the major and most active areas of research. It is an area that absorbs about 20 percent of all physicists, if one includes the theoreticians. There are no practical applications in sight.

Low-energy nuclear physics. In low-energy nuclear physics, the availability of reactors and of accelerators has multiplied the empirical data by a huge factor. This has opened the way to great systematic investigations of fields already studied before the war. Alpha, beta, and gamma radioactivities have yielded so many data that it has been possible to recognize new regularities unknown until recently. These regularities have been explained in terms of nuclear models. The shell model of Mayer and Jensen and the unified or collective model of Aage Bohr and Mottelson are the outstanding models. These models characteristically correlate beautifully a great number of facts; they have also considerable predictive value. On the other hand, they are weak in the foundations. Attempts to put them on solid footings have given rise to learned and complicated papers, which, however, have not yet reached any final conclusion.

The effort in low-energy nuclear physics, including theory, absorbs perhaps a little over 20 percent of the manpower available. The value of these studies for practical applications is modest. Reactor engineering has derived some profit from them, but reactor engineering, by now, is really rather independent of nuclear physics.

Solid-state physics. Solid-state physics acquired great popularity after the war. Unlike high-energy physics it has important and numerous practical applications, and it is one of the branches of physics most actively pursued. It is estimated that it may absorb about one-third of all physicists, including theoreticians. The practical aspect of solid-state physics in part explains the emphasis on this field. Here the foundations of the subject, nonrelativistic quantum mechanics, are extremely solid and well known; however, the analysis, from first principles, of the phenomena observed is often mathematically too complicated for practical purposes. The two most celebrated of the solid-state phenomena are perhaps superconductivity and the behavior of helium at low temperatures. Superconductivity was discovered by Kamerlingh Onnes in 1911; it is the vanishing of the electrical resistance of a substance when it is cooled below a certain temperature. This curious effect was investigated experimentally and theoretically with great alacrity after its discovery, and it is still being investigated. Many explanations of it have been attempted, but, as far as I know, none is considered completely exhaustive. The best we have—and a great advance it is—was proposed a few years ago by Bardeen, Cooper, and Schrieffer.

Liquid helium at low temperatures changes suddenly at 2.19°K into a different liquid called helium II, devoid of viscosity and having other strange properties. The paramount theoretical investigator in this field has been the Russian physicist Landau.

Solid-state investigations of semiconductors, which have yielded the important practical application of the transistor, are connected with the achievement of unprecedented chemical purity in substances such as germanium and silicon. A large industry and a revolution in the arts of electronics have been the consequence of these studies.

Solid-state physics has shown a large number of new phenomena, none of them of such fundamental importance as the discoveries of particle physics, but many of them of great elegance. Among these—to mention a few—are the cyclotron resonances, the Esaki tunnel effect, the behavior of thin films in many circumstances, and nuclear induction.

A large number of these studies depend on the preparation of special substances. The great progress made in this field pervades our technology. The products range from plastics to ferrites (insulating ferromagnetic materials), from new alloys to new glasses. The new materials, the greatly improved vacuum technology, and the common availability of liquid helium are some of the major forward steps at the borderline between science and technology.

Atomic physics. Atomic physics, often combined with the study of electronics and waves, occupies perhaps another 15 percent of the physicists. Microwave technology, developed for radar during the war, has generated several lines of research. On the one hand, it has greatly expanded the field of molecular spectroscopy, while, on the other hand, it has generated the maser technique, making possible optical feats which only 30 years ago would have been considered completely unfeasible.

The remaining 13 percent of the physicists are busy with miscellaneous activities connected with a great variety of subjects ranging from gravitation to acoustics, from the improvement of optical instruments to plasma physics and gas discharges.

Computer technology. Before I complete this brief review I must mention another development which is having a great impact on physics: the development of computing machines. These are deeply affecting the whole field of applied mathematics. In physics they make possible computations which were unthinkable before the war. They also process vast amounts of experimental material with unprecedented speed. They are becoming a standard tool, and most of our present students learn a certain amount of computer technique.

With this I have completed my task of briefly describing the postwar physics. I am well aware that I have omitted many important items, but space and time have their exigencies.

What are the prospects for the future? Here I know I am sticking my neck out in a dangerous way. On the other hand, you may be interested in hearing guesses, if only to be able, a few years from now, to show how wrong they were.

First of all, many illustrious men of science, physicists in particular, have made the mistake of thinking that the end of physics was in sight. They have consistently been proved wrong by the opening up of completely new fields. Hence, I must make allowance for possible radically new discoveries.

Of the fields where we already have some knowledge, I venture to say the field of elementary particles is the one most likely, in the foreseeable future, to produce intellectually interesting results. The task ahead is a great challenge and will probably test the forces of an entire generation. The outcome should be an understanding of the systematics of the particles, including their masses, quantum numbers, and interactions.

While nuclear physics will give increasingly refined results, it will reach a stage similar to the present state of molecular spectroscopy, where the interest is more in applications and systematics than in new fundamental ideas.

Solid-state physics will be of ever-increasing practical importance. The creation of new materials with unexpected and unprecedented properties will give us some first-class technological surprises. However, here I do not expect the discovery of new principles.

Spectacular results, leading to new deep insights amounting to a revolution, are in the making in biology. These results will be due in part to the applications of physics and may provide some big surprises, even for physics.

Finally, space exploration and the study of the interior of the earth are new departures. Here we do not yet see any new phenomena, but we are penetrating in unexplored regions. It is possible that these regions will not yield anything extraordinary, such as extraterrestrial life. However, they present phenomena on scales impossible to reproduce in the laboratory, and a change in orders of magnitude is a well-known source of surprises. Furthermore, we must not forget that particle physics originated with the study of cosmic rays.

Steroid Oral Contraceptives

The chemical developments which led to the currently employed steroid contraceptive agents are reviewed.

Carl Djerassi

The social, economic, and political problems associated with the "population explosion" have received great attention in recent years, as testified by the appearance of monographs (*1*), special reports (*2*), and numerous articles, including several in *Science* (*3*). It is generally agreed by most authors that control of conception constitutes an indispensable component of any solution of this world problem and that the extensive clinical use of steroid oral contraceptives has been one of the most spectacular and promising new approaches to such control. The biological and clinical work leading to the development of the steroid contraceptive agents now being used has been ably summarized by one of the pioneers in the field, Gregory Pincus, in *The Control of Fertility* (*4*), but neither in that book nor in the voluminous clinical literature, encompassing several hundred articles, is there any coverage of the history of the chemical developments which made these biological studies possible, or citation of the original chemical publications.

Every synthetic drug must, by definition, have its origin in a chemical laboratory. How this chemical entity ultimately becomes a drug depends on circumstances. Frequently, such substances are synthesized in connection with some chemical problem and, as an afterthought, submitted for wide pharmacological screening. Alternatively, a given substance may be con-

The author is professor of chemistry at Stanford University, Stanford, California. At the time of the work described in this article he was associate director and, later, vice president in charge of research of Syntex, S.A., in Mexico City, Mexico.