DNA synthesis in animal cells as well as in animal viruses.

One of the most valuable features of the book is its illustrations elucidating different concepts. The diagrams of DNA superhelicity (both negative and positive) and replication mechanisms are clear and for the most part self-explanatory. Wherever feasible, the book contains tables summarizing and comparing properties of nucleases, polymerases, DNA's, phage genes, bacterial genes, animal viruses, and so on. The illustrations and tables reflect the author's clarity of thought and ability to organize huge amounts of information into a coherent story. Areas of research now under intensive investigation are clearly identified and discussed with timely suggestions. This edition overcomes the limitations of the 1974 rendition. So much solid information on DNA metabolism has accumulated since 1974 that new results now represent a smaller fraction of our knowledge of DNA replication.

The book is enormously important for those of us who teach and carry out research. Research on DNA synthesis, replication, and repair has grown beyond the scope of any standard biochemistry textbook. *DNA Replication* is a "must" for all students of nucleic acid biochemistry. The book is a testimony to the importance (and ultimate relevance) of good basic research. It is of interest to note that the 1974 edition ended with a plea for genetic engineering and its potential for new discoveries; the new edition ends with the realization of this potential.

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Letters Between Physicists

Wolfgang Pauli: Wissenschaftlicher Briefwechsel mit Bohr, Einstein, Heisenberg, u.a. Vol. 1, 1919–1929. A. HERMANN, K. v. MEYENN, and V. F. WEISSKOPF, Eds. Springer-Verlag, New York, 1979. lii, 578 pp. $80. Sources in the History of Mathematics and Physical Sciences 2.

In January 1925 Heisenberg, acknowledging receipt of Pauli's manuscript on the exclusion principle, wrote:

> Today I read your paper and it is certain that I take greater joy in it than anyone, not only because you have driven the swindle to an unsuspected swindling height . . . by introducing individual electrons with four degrees of freedom; but especially I am elated that you (et tu, Brute!) have returned to the land of the Philistine formalists.

Decoding this message rewards the effort. It expresses in Heisenberg's boyish humor his and Pauli's ambivalent attitude toward the atomic physics they sought simultaneously to improve and to replace. Six months after writing this letter, Heisenberg created matrix mechanics. The extraordinary correspondence under review documents this creation from its proximate beginnings in the late swindles of the old Bohr-Sommerfeld theory through the establishment of what some regard as the new swindles of the Copenhagen interpretation.

As terminus technicus "swindle" (*Schwindel*) signified a mixture of quantum rules and classical physics, in particular an ad hoc adjustment of the conditions defining the stationary states. Heisenberg had been an accomplished swindler from his first published work, in which he introduced half-integral angular momenta in order to account for multiplet splitting (*1*). Half quantum numbers then had no dynamical significance, as they eluded Bohr's correspondence principle (CP), which required numerical agreement between quantities reckoned according to classical procedures and those computed according to Bohr's rules in the limit of large quantum numbers. For example, when $n \gg i$, the classical harmonics $i\omega_n$ of motion in a Kepler ellipse of ground frequency ω_n should asymptotically equal the frequencies $\nu(n, n-i)$ of the radiation emitted in quantum transitions from the nth to the $(n-i)$th orbit. On this scheme a half quantum number made no sense.

"Philistine formalism" referred to proceeding without justification in terms of the physical model, without a grounding in the harmony of interlacing electron orbits, in the "atomic music of the spheres" (*2*). Pauli had once succumbed to this Philistinism, which he deplored as subversive of coherent physical theory. Hence Heisenberg's playful chiding: the exclusion principle seemed to him a Philistine swindle, Philistine in offering no explanation, based upon the model, of the unfriendliness of equivalent electrons, and a swindle in defining equivalence by introducing into the model electrons with four degrees of mechanical freedom.

Heisenberg's chiding was misplaced; it was prompted by his, not by Pauli's, brand of physics. Pauli had not endowed the electron with a fourth degree of mechanical freedom but with a "classically nondescribable ambiguity" that seemed to him to lie beyond the reach of the CP. Also, Pauli did not intend his new principle to be merely formal. He thought it ranked with the postulates regulating the stationary states and pointed the way toward a quantum mechanics without electron orbits. What he had in mind may be gathered from measures for reform that he recommended to his correspondents during the winter and spring of 1924–25.

Pauli urged the Bohr school to concede that the "language of models is not adequate to [describe] the simplicity and beauty of the quantum world." The CP alone could not bring what was needed, for it rested on the applicability of the classical concepts in the appropriate limit. Pauli's new principle indicated the sort of additional ingredient required: whoever succeeds in combining your "nonsense" with mine, he wrote Bohr, will have the solution to the quantum riddle. And how should one approach this odd summation? "Uniting this red and white rose will certainly require a fierce battle with our unconsciously held preconceptions." To begin with, he told Bohr, in a prescient formulation of the difficulty, one should hold to the old dynamics and seek a new kinematics. "I regard the angular momentum and the energy values of the stationary states as more real than the orbits." The Cheshire cat was to be constructed from its smile.

Bohr and Heisenberg at first rejected this radical and scarcely intelligible program. At Copenhagen they clung to what Pauli called the "imperialism of the correspondence principle." Perhaps, Bohr hoped, the four quantum numbers referred to electron orbits in the inner and outer parts of the atom; it was rash and premature to declare the incompetence of the CP. On the contrary, the "swindle" had been so well described that, with the help of the CP and the concept of virtual oscillators, the riddle might soon be solved. Pauli doubted that illumination was nigh and that light could ever come from virtual oscillators, the instruments (he said) of Bohr's "reactionary Copenhagen putsch" against the photon. As for Heisenberg, he continued

into the early spring of 1925 happily spreading what he and Pauli called "corruption" (*Schimmel*) (*3*). The three principals then met in Copenhagen. It appears that Heisenberg was persuaded to stop corrupting physics. In June he "fabricated" a new mechanics by doing precisely what Pauli had suggested, by adding two nonsenses—the CP treatment of intensities and the quantum mechanical relations among frequencies—to obtain a new mechanics, or calculus, involving only quantum mechanical quantities that in principle could be measured. As Pauli had expected, the breakthrough came by keeping the dynamical relations among these quantities and changing their definitions (*4*).

The foregoing account suggests the riches recoverable from the Pauli correspondence. One can follow the struggle over the anomalous Zeeman effect ("it would not, but would not, come out"), over the introduction of electron spin (which Pauli opposed as another counterrevolutionary putsch), over the integration of matrix and wave mechanics (the latter "abscheuliche Mist," abominable crap, to Heisenberg), over the uncertainty principle ("one no longer knows what the words 'wave' and 'particle' mean"), over the negative energy states in the Dirac theory, over the singularities in quantum electrodynamics. Future volumes (two are planned) will document the development of nuclear theory, spinors, symmetry principles, the theory of beta decay and the neutrino, the violation of parity, and more.

A word about what cannot be found is also in order. There is very little about personalities and politics, nothing about the travail of the Weimar Republic, nothing about art and culture, nothing to support the provocative claim that, in creating quantum mechanics, Weimar physicists were responding defensively to a hostile intellectual milieu (*5*). The letters provide only a few glimpses of Pauli's private life: he does not read a newspaper, he is perhaps overly fond of the café and the cabaret (tastes deprecated by the wholesome Heisenberg), he considers himself unsociable. "I've noticed that drinking wine is good for me. After the second glass . . . I usually take on the manners of a social being (which I never am in a more sober state)." In general, despite their banter, the letters are formal and serious; only toward the end of the period covered in the present volume, after intense collaborations lasting six years and more, did Pauli and his major correspondents begin to address one another with the familiar "du."

When, occasionally, Pauli's reserve breaks down, he appears as an emotionally immature young man protecting an easily bruised psyche by adopting a severely critical attitude toward the work of others. When he went to Copenhagen in 1922 as Bohr's assistant, it was as the Wunderkind who had written a classic treatise on relativity at the age of 21. He naturally had the idea that no problem was too difficult for him. But he could not solve the tantalizingly easy problem that Bohr gave him, the elucidation of the anomalous Zeeman effect in terms of the model: all he could salvage from the work was a bit of Philistine formalism. He accordingly regarded his year in Copenhagen as a "scientific failure" and temporarily withdrew from active work in atomic physics. Before leaving Copenhagen he had a tantrum, brought on by Bohr's decision to take Kramers, his assistant and Pauli's special friend, on a trip to England. Pauli felt that he needed Kramers in his despondency, and, to punish Bohr, absented himself from the physics institute.

This little fit may help to remind us of the forced intellectual labor that accompanied the birth of quantum mechanics. The main actors, Pauli and Heisenberg, were young exotics nourished on fundamentals by Sommerfeld and Born and rushed into bloom in the philosophical hothouse run by Bohr. The few persons who contributed directly to the invention of quantum mechanics knew one another well, and they suffered the strain of intimate collaboration and acute competition. Infrequently they snapped under the strain, as in Pauli's tantrum and in a tiff, documented in the correspondence, between Bohr and Heisenberg over the formulation of the uncertainty principle.

Much time and labor have gone into transcribing and annotating the letters. The editors have been especially energetic in identifying published papers alluded to by the correspondents. Otherwise their attainment is not outstanding. The quality of transcription is perhaps indicated by several small errors and omissions in the rendering of a letter also given in facsimile. No attempt is made to elucidate the physics or, as the cases of *Schwindel* and *Schimmel* suggest, to unlock the private vocabulary of Pauli and his collaborators.

The most serious flaw in the scholarly apparatus is the poverty of reference to historians' accounts of the physics of the 1920's. An opportunity has been lost to emphasize a class of literature in which physicist readers of the letters should be interested, and of which they are in general unaware. This literature does not merely add detail to accounts drawn up by physicists. Historians look at the history of physics from a point of view different from that of most physicists. The historian may be as interested in failure as in success, and as much concerned about the culture producing science as about the science itself. He or she regards past physics as a part of the intellectual and social history of a bygone culture, whereas the physicist may esteem the history of the discipline chiefly as a source of anecdote or inspiration.

In ignorance of the historians' literature the editors have made a blunder they might have avoided. On 30 June 1924 Pauli congratulated Landé on a paper in which the discrepancies between observation and theory "have above all become still sharper" (*sich zunächst noch verschärfen*) and added, "That is how it often is in physics before the real solution comes." The editors, mistranscribing *noch* as *nicht*, make Pauli express satisfaction in a palliation that neither he nor Landé wished. The error not only inverts the sense of the passage, it also suppresses an important point: in 1924 Bohr's group was seeking to advance by sharpening dilemmas and pointing up paradoxes. This program and the passage, correctly transcribed, are analyzed in a paper well known to historians (*6*).

Neglect of historians' history also mars the introduction to the volume by Armin Hermann, professor of the history of physics at the University of Stuttgart. Hermann inventories the uses and importance of letters in writing the history of science: they provide valuable biographical information, throw light on the development of ideas, on the motivation for work, on the choice of problems. Above all, they convey the spontaneity, perplexity, and enthusiasm that have no place in published research reports. It was not always so. In 1759 Robert Symmer invented the two-fluid theory of electricity by reasoning about the sparks thrown off by his socks, a circumstance he did not neglect to mention to the Royal Society of London; it is modern style that requires the suppression of all extrinsic evidence that scientific papers are written by human beings.

In letters, as Hermann insists, the personalities and passions may be recovered. Yet it appears that he may not be prepared to follow out the logic of his method. His smooth portrait of Pauli neglects evidence from the very letters that, he says, should humanize our ac-

counts of the growth of science. For example, he repeats the unlikely retrospective judgment of Pauli's friends that Pauli's often biting criticism did not wound its targets, except, perhaps overly sensitive persons like Max Born (*7*). This opinion scarcely squares with the following "Bavarian sermon" from Heisenberg: "It is really disgusting that you can't stop bitching. Your eternal abuse of Copenhagen and Göttingen is a screaming scandal. You will have to leave us alone" (*8*).

The edition originated in a work of love, the collection of Pauli's letters made by his widow from letters supplied by their physicist recipients. Pauli's "wissenschaftlicher Briefwechsel" has therefore meant in practice his correspondence with physicists. This is a narrow conception of Wissenschaft, and quite inadequate to capture the range of Pauli's intellectual interests in his middle years, when he was a close student of Jungian psychology. It is to be hoped that later volumes of this series will include Pauli's correspondence with distinguished colleagues in other disciplines, for example Jung and Erwin Panofsky. The editors have an unusual opportunity to bring forward the full record of a powerful and far-ranging mind. No such public record yet exists for any modern physicist. A start has been made on a project of great importance.

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References and Notes

1. See D. Cassidy, "Heisenberg's first wave model of the atom: The formation of a professional style," *Hist. Stud. Phys. Sci.* **10**, 187 (1979).
2. A. Sommerfeld, *Atombau und Spektrallinien* (Braunschweig, ed. 3, 1922), P. v. Pauli and Heisenberg liked to call Sommerfeld's physics school the "Institut für Zahlenmystik."
3. None of the three standard modern meanings fits; "corruption" is authorized by T. Heinsius, *Volkthümliches Wörterbuch* (Hanover, 1818–22), but "diddle" (taking *Schimmel* as dialect for *Schummel*) may better convey the sense. Here the editors are no help.
4. See D. Serwer, "*Unmechanischer Zwang:* Pauli, Heisenberg, and the rejection of the mechanical atom, 1923–1925," *Hist. Stud. Phys. Sci.* **8**, 189 (1977), and E. MacKinnon, "Heisenberg, models and the rise of matrix mechanics," *ibid.*, p. 137.
5. P. Forman, "Weimar culture, causality, and quantum theory, 1918–1927: Adaptation by German physicists and mathematicians to a hostile intellectual environment," *Hist. Stud. Phys. Sci.* **3**, 1 (1971).
6. P. Forman, "The doublet riddle and atomic physics *circa* 1924," *Isis* **59**, 156 (1968). A "Bibliography on the history of 20th century physics" will be published in September 1980 by the Office for History of Science and Technology, University of California, Berkeley.
7. See the review of Born's autobiography in *Science* **204**, 740 (1979).
8. Bavarian eludes translation: "Betreffend Ihrer beiden letzten Briefe muss ich Ihnen noch ein Predigt halten, und Sie entschuldigen, wenn ich auf Bayrisch fortfahre: Es ist wirklich ein Saustall, dass Sie das Pöbeln nicht aufhören können. Ihre ewige Schimpfereien auf Copenhagen und Göttingen sind einfach ein schreiender Skandal. Sie werden uns doch lassen müssen" (p. 250).

Of Accelerators and Theories

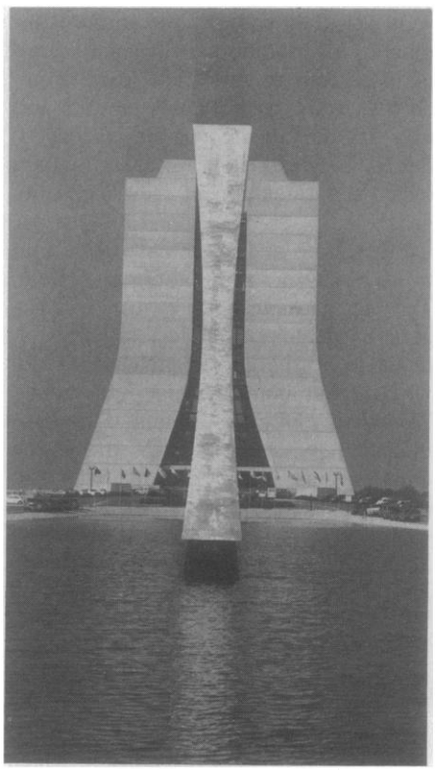
Aesthetics and Science. Proceedings of the International Symposium in Honor of Robert R. Wilson. Batavia, Ill., Apr. 1979. Fermi National Accelerator Laboratory, Batavia, Ill., 1980. viii, 120 pp., illus. $20.

This volume is dedicated to Robert Rathbun Wilson, whose career its title embodies. Wilson is at one and the same time a premier builder of particle accelerators and a sculptor whose works have attained some modest recognition. The book contains the proceedings of an international symposium held on the occasion of his retirement as director of the Fermi National Accelerator Laboratory (Fermilab).

Because of the nature of such an occasion, only two of the five papers included actually address the subject promised in the title. One of these, however—that of the astrophysicist Subrahmanyan Chandrasekhar—is of sufficient merit to justify the whole enterprise.

Two of the papers recapitulate Wilson's career. Hans Bethe offers reminiscences of days at Los Alamos and Cornell, and Leon Lederman, Wilson's successor at Fermilab, summarizes Wilson's achievements there. The latter paper is leavened by the wit that has made Lederman one of the best stand-up comics in the world of science.

A third paper, by Wolfgang Paul, is a history of particle accelerators. Its principal merit lies in giving due credit at last to a number of pioneers who were first with the ideas on which modern accelerators are based but who for one reason or another never got a chance to put these ideas into practice.



Fermilab. [From *Aesthetics and Science*]

Addressing the main subject, Victor Weisskopf contrasts the holistic approach of art to the particularism of science. He marvels that the latter has, despite its modest immediate goals, led to deep insights of surpassing beauty: "The detour through the diversity of experience paid off." He regards these two worldviews as complementary, in the sense applied to that word by Niels Bohr—embodying irreconcilable opposites both of which are essential to get at the complete reality of nature.

But these are conventional sentiments, and Weisskopf adds little to them, other than a measure of style and grace.

Chandrasekhar shows far more daring, tackling a truly deep question: How is it that theories born of a quest for beauty turn out also to be true? He addresses the question both in the context of great world schemes, such as Einstein's general relativity, and small jewels, such as Weyl's "premature" two-component neutrino, which seemed wrong at its birth because it violated parity symmetry but proved 30 years later to be right.

Chandrasekhar goes beyond the facile solution implied by Keats's phrase "beauty is truth, truth beauty." He observes that beauty is not essential to make a theory useful (with "renormalization" in quantum electrodynamics as a perfect example). But it does make us take seriously a theory's pretension to represent a deep insight worthy of a place at the heart of our world view.

He also takes a stab at formulating a specific esthetic of science, taking as one starting point Francis Bacon's dictum that "there is no excellent beauty that hath not some strangeness in the proportion." It is peculiar asymmetries blended harmoniously with satisfying symmetries that catch the eye and excite the imagination. The contributions of Kerr and of Reissner and Nordstrom to general relativity are cited as examples, signposts pointing to deeper truths yet to be unraveled.

Though far from a definitive treatment of the subject, Chandrasekhar's observations are well worth the effort to read and ponder.

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