

WOLFGANG PAULI

I will never forget the speech about me, and for me, that he gave at Princeton in 1945 after I got the Nobel Prize. It was like the abdication of a king, installing me as a kind of elected son, as his successor,” Wolfgang Pauli reminisced in a 1955 letter to Max Born.¹

The “king” was, of course, the 66-year-old Einstein. His realm was physics and Pauli was his appointed heir. The occasion was a banquet in Princeton honoring Pauli, who had been awarded the prize for his discovery of the exclusion principle. In 1969, eleven years after Pauli’s death, Born commented, “Since the time when he was my assistant in Göttingen, I knew he was a genius, comparable only to Einstein himself. As a scientist he was, perhaps, even greater than Einstein. But he was a completely different type of man, who, in my eyes, did not attain Einstein’s greatness.”²

Who was this prince of physics whose death in 1958 went unnoticed by *The New York Times*? Pauli was born on 25 April 1900 in Vienna. His father was a professor of colloid chemistry at the University of Vienna and Ernst Mach, the eminent physicist and radical empiricist philosopher, was his godfather.

The genie in the goblet

We introduce Pauli by letting him speak, describing his baptismal and scientific origins in a letter to his unlikely guru, the Swiss psychologist Carl Jung. Our English translation of a small excerpt can hardly convey the literary brilliance of this 31 March 1953 letter.

“Among my books sits a somewhat dusty case containing an art nouveau silver goblet in which lies a card. Now there appears to me to rise from this goblet a serene, benevolent, and cheerful spirit [Mach] from the bearded age. I imagine him amiably shaking your [Jung’s] hand, welcoming your particular definition of physics as a pleasing, if somewhat belated, sign of insight. . . . Finally, he expresses his satisfaction that you have banished all metaphysical judgments (as he was fond of saying) ‘into the shadow realm of a primitive animism.’

“This beaker is a baptismal goblet, and on the card is written in old-fashioned script disfigured with flourishes: Dr. E. Mach, Professor at the

Max Born thought that Pauli was, perhaps, an even greater scientist than Einstein. “But he was a completely different type of man,” wrote Born, “who, in my eyes, did not attain Einstein’s greatness.”

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University of Vienna. It so happened that my father, then intellectually completely under Mach’s influence, was very friendly with his family. Mach had affably expressed his willingness to play the role of my godfather. He was, no doubt, a stronger personality than was the Catholic priest. The result seems to be that, in this way, I

was baptized as ‘Antimetaphysical’ instead of Roman Catholic.

“In any case, the card rests in the goblet and, despite my greater spiritual transformations in later years, I still label myself as being ‘of Antimetaphysical ancestry.’ If I may put it somewhat simplistically, Mach regarded metaphysics as the source of all evil on Earth—psychologically speaking, the devil incarnate. This baptismal goblet with the card in it remained for me a symbol for the *aqua permanens* that chases away the evil metaphysical spirits. [Pauli’s father, a Jew by birth, had joined the Catholic Church in order to advance his academic career.]

“I don’t need to describe Mach in greater detail. To know him, you have but to read your own description of the extrovert type. He was a master of experiment and his apartment teemed with prisms, spectroscopes, stroboscopes, electrostatic generators, and other machines. Whenever I came to visit, he showed some nice experiment designed to eliminate or correct fallacious thinking. Taking for granted that his own psychological bent was universal, he advised everybody to practice economy of thinking—to use this inferior or auxiliary faculty as frugally as possible. His own thinking strictly and narrowly followed the observations of the senses and the laboratory instruments. [Mach was a notorious holdout against the idea of atoms and molecules.]

“I would like to quote here an anecdote that will amuse especially you. Mach, not at all prudish and very interested in all intellectual trends, once passed judgment on Freud’s psychoanalysis and his school. ‘These people,’ he said, ‘want to use the vagina as a telescope through which to view the world. That is not its natural function; it’s too narrow.’ These became household words at the University of Vienna for a time. That’s very characteristic of Mach’s instrumental thinking. Psychoanalysis aroused in him immediately the vivid, concrete image of the instrument improperly used—this female organ up against the eye, where it does not belong.”³

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FIGURE 1. WOLFGANG PAULI (1900–58), in a 1930s passport photo. (Gift of Karl v. Meyenn to the AIP Emilio Segrè Visual Archives.)

In typical Paulinean fashion

Mach's godson's first publication dealt with Hermann Weyl's gauge theory of gravity and electromagnetism. As Weyl remembered it: "He dealt with it in truly Paulinean fashion—namely, he dealt it a pernicious blow."⁴ At age 20, Pauli had finished his magisterial account of special and general relativity, an article 237 pages long in the *Encyclopedia of the Mathematical Sciences*, with 394 footnotes. It remains one of the best treatments ever of the relativity theories. In a rave review, Einstein wrote, "No one studying this mature, grandly conceived work would believe that the author is a man of twenty-one. One wonders what to admire most, the psychological understanding for the development of the ideas, the sureness of mathematical deduction, the profound physical insight, the capacity for lucid, systematic presentation, the knowledge of the literature, the complete treatment of the subject matter, or the sureness of critical appraisal."⁵

After Pauli's review of relativity, his main interest shifted to the quantum puzzle, to which he and his fellow student Werner Heisenberg were introduced in Arnold Sommerfeld's seminar at Munich. Pauli soon introduced the atomic magneton and named it after Niels Bohr. He worked on the anomalous Zeeman effect and he discovered nuclear magnetism. In 1925, before the Heisenberg and Schrödinger formulations of the new quantum mechanics, Pauli posited his famous exclusion principle, which explained the structure of atoms in conformity with the periodic table. Within four years, he had become the world's foremost expert on the old Bohr–Sommerfeld quantum theory.

Pauli's approach to physics was described by Heisenberg in 1968:

Pauli's whole character was different from mine. He was much more critical, and he tried to do two things at once. I, on the other hand, generally thought that this is really too difficult, even for the best physicist. He tried, first of all, to find inspiration in the experiments and to see, in a kind of intuitive way, how things are connected. At the same time, he tried to rationalize his intuitions and to find a rigorous mathematical scheme, so that he really could prove everything he asserted. Now that is, I think, just too much. Therefore Pauli has, through his whole life, published much less than he could have done if he had abandoned one of these two postulates. Bohr had dared to publish ideas that later turned out to be right, even though he couldn't prove them at the time. Others have done a lot by rational methods and good mathematics. But the two things together, I think, are too much for one man.⁶

The creation of quantum mechanics and quantum electrodynamics in the years between 1925 and 1933 was an epiphany unique in history. It is bracketed by two

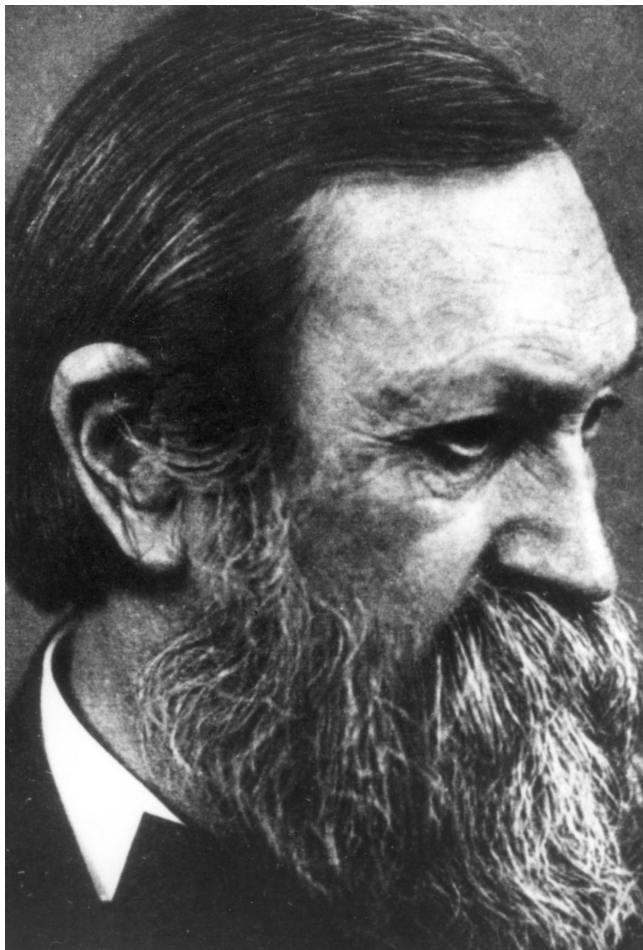


FIGURE 2. PHYSICIST–PHILOSOPHER ERNST MACH (1838–1916) was Pauli's godfather. (Burndy Library, MIT, courtesy of AIP Emilio Segrè Visual Archives.)

FIGURE 3. THE FOUR-YEAR-OLD PAULI in Vienna in July 1904. (CERN, courtesy of AIP Emilio Segrè Visual Archives.)

review articles by Pauli in the *Handbuch der Physik*, known to the cognoscenti as the Old and New Testament.⁷ The first is an encompassing account of what was known about the microworld before the new quantum mechanics. It is a clinical review of the bewildering experiments and the desperate attempts to make sense of them. Seven years later, in the second edition of the *Handbuch*, Pauli gives the definitive description of the new language that physicists now use to describe all of nature. Robert Oppenheimer called it “the only adult introduction to quantum mechanics.”

Instances of inspiration in this historic epiphany have become folklore:

▷ Heisenberg, a hay-fever fugitive from Göttingen’s pollen, crouching on a sandstone promontory on Helgoland, finds a key insight while waiting for the Sun to rise over the North Sea.

▷ Erwin Schrödinger, ensconced with a still unidentified mistress on Christmas vacation in the Swiss Alps, writes a monumental paper during what Weyl called “a late-erotic outburst of his life.” Paul Dirac described this paper as containing “much of physics and all of chemistry.”

▷ A desperate Dirac, on a Sunday in the fall of 1925, finds the key to quantization: turning Poisson brackets into commutators. But because it’s Sunday, he has to wait anxiously for the library to open on Monday morning so he can find out whether Poisson brackets really are what he thinks they are.

▷ Bohr’s great triumph at the 1927 Solvay Conference comes when he invokes general relativity to explode an argument against Heisenberg’s uncertainty principle that Einstein thought would be unbeatable.

These flashes of insight were but a few scenes of the unfolding drama. Pauli contributed a number of key episodes. Some of these scenes were probably in the Hamburg nightclubs. He beat Schrödinger to the theory of the hydrogen atom by using matrix mechanics, treating the atom even in crossed fields. He formulated the quantum theory of spin by doubling the Schrödinger representation into a two-component wavefunction. The following year, Dirac repeated Pauli’s trick to get the four-component spinors of the relativistic theory.

In his essay on paramagnetism, Pauli started the modern theory of solids. Max Jammer has called attention to a remarkable footnote in that paper.⁸ It contains the probability interpretation of wave mechanics in a clearer and more general formulation than Born’s earlier suggestion. Quantum statistical mechanics and Fermi’s golden rules appear in Pauli’s contribution for the 1928 *Festschrift* honoring Sommerfeld. In papers with Heisenberg and Pascual Jordan, Pauli introduced relativistic quantum field theory. In 1930 he proposed the existence of the neutrino.

Much of Pauli’s seminal work remains unpublished. For example, his proof of the equivalence of matrix and wave mechanics appears in a letter to Jordan, and he writes down the uncertainty relation for time and energy

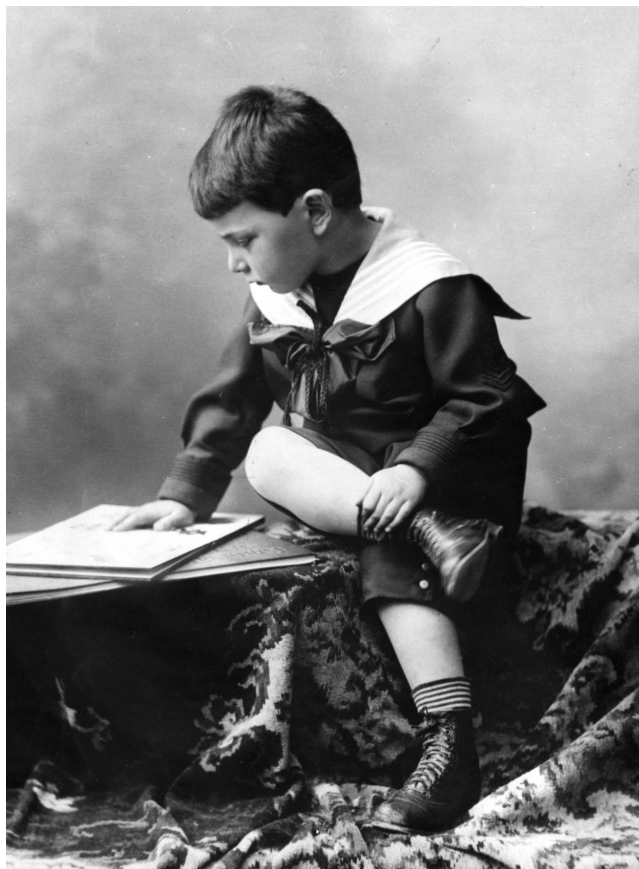


FIGURE 4. PAULI AND ALBERT EINSTEIN in Leiden, 1926, photographed by Paul Ehrenfest. (CERN, courtesy of AIP Emilio Segrè Visual Archives.)

A personal memoir of 1958

It was a long straight staircase that led from the lobby to the office. Entering the office, the first thing I saw was a hat rack. On the sweatband of the rack's single felt hat was printed in bold letters: PROF. W. PAULI, BERGSTRASSE 35, ZOLLIKON. Then I noticed its owner at the desk. He had his back to me and seemed to be in the middle of a calculation. Having spotted a wrong sign in one of his equations, Pauli turned around, saying triumphantly: "Falsches Vorzeichen schleicht sich durchs Schlüsselloch ein [wrong sign is sneaking in through the keyhole]." See figure 6.

He asked me whether I knew the quotation. When I said I didn't, he pulled from one of the drawers his copy of the famous Copenhagen parody of Goethe's *Faust*, instigated by Max Delbrück and illustrated with George Gamow's ingenious drawings. In this 1932 performance at Niels Bohr's institute, Pauli had been cast as Mephistopheles, the greatest character in German literature (see the drawing). Faust's beloved Gretchen became Pauli's creation, the neutrino. One of the cameo roles in the parody was "the wrong sign," the theoretician's bane.

Pauli lent me the illustrated script so that I could make a copy. I had just arrived at the old Physics Institute of the ETH (the Swiss Federal Polytechnic) in Zurich, after having given a talk at Heisenberg's new Max Planck Institute in Munich. I told Pauli that Heisenberg had been the official speaker on the occasion of the 800th anniversary of the founding of the city of Munich. In his speech, Heisenberg had characterized the citizens of Munich as combining the reliability of the Austrians with the amiability of the Prussians. "That Heisenberg," he laughed, "is still a jack-of-all-trades [Hans Dampf in allen Gassen]."

Pauli said he had to go downstairs and lecture. I asked if I could attend and he nodded. The lecture was about the *H*-theo-



PAULI AS MEPHISTOPHELES in a 1932 parody of Goethe's *Faust* at Niels Bohr's institute in Copenhagen. The drawing is one of many by George Gamow illustrating the script.¹⁵

rem in quantum mechanics. The *H*-theorem, first enunciated by Ludwig Boltzmann, deals with macroscopic irreversibility in microscopically reversible theories. Pauli and Markus Fierz had written a paper about it in 1937, and Leon Van Hove had recently published a new approach to this difficult problem. Not knowing either paper, I understood very little. The lecture consisted of long pauses during which Pauli studied Van Hove's paper. Between these pauses, he would keep his back turned to the respectfully silent audience, apparently engaged in a dialogue with the blackboard. Sometimes, with the chalk poised in his right hand, he would hesitate, and a minute might pass before he started writing. This exercise of thinking in public was very much in accord with Pauli's motto: "Man muss nicht soviel reden [one shouldn't talk so much]."

Pauli had met my boss, Otto Heckmann, director of the Hamburg Observatory, at a Solvay Conference in Brussels where Heckmann had reported on some of the homogeneous, anisotropic cosmological models we had concocted. To learn more about these solutions of the Einstein field equations with incoherent matter, Pauli had invited me to come to Zurich and give a talk in his theory seminar.

Three years earlier, when Pauli was visiting Hamburg, I had talked to him about the global structure of the Schwarzschild solution. By embedding the manifold isometrically into a six-dimensional space, I had shown that the usual solution for distances from a spherical mass greater than the mass's Schwarzschild radius is only a

quarter of the full solution. Pauli didn't know that and was quite intrigued. The following day, when the talk got around to gravitational waves, I suggested that one ought first to look for plane gravitational waves. "Hah! Yesterday you were much better," crowed Pauli. "Plane gravitational waves do not exist."

in a letter to Heisenberg. In November 1925, when Hendrik Kramers discovers, independently of Dirac, the magic quantization key that turns Poisson brackets into commutators, the last line of his seminal paper states that "Pauli has also already pointed to this interpretation of the commutation relations."⁹

Staying out of the potato race

Pauli almost never cared about recognition for his work, though he took great care in giving credit to other authors. Even when he had found their results independently, and often earlier, he didn't mention that in his published papers. Unlike Heisenberg and many others, he was not ambitious or competitive. Even the reclusive Dirac may have been affected by the atmosphere of being in a race. When Dirac visited Göttingen, Born entertained his guests, as Göttingen professors were wont to do, with silly competitions like racing while balancing a big potato on a tiny spoon. After Dirac lost such a potato race, Otto Heckmann came upon him later, secretly practicing this idiotic game.

Pauli's principal concern was always to clarify the greater picture for himself, to obtain a consistent and coherent description of the totality of the phenomena. In

this lifelong endeavor, he wrote thousands of letters analyzing details and trying to get things right. Many of these carefully crafted letters could have graced the pages of *Naturwissenschaften* or *Nature*. In the 1920s, Pauli's letters were passed around, copied, and studied by many. His contribution of key ideas and his trenchant, impartial analyses should have earned him a place as coauthor of many papers on quantum mechanics. He insisted on the idea that authorship was unimportant in this collective attempt to decipher the book of Nature. But this almost Bourbaki-like spirit was unrealistic at a time when most of those involved in this heroic enterprise were postdocs competing for the few university positions opening up only slowly as the old guard died off. ("Nicolas Bourbaki" is the pseudonym adopted by a group of French mathematicians who began publishing collectively in the 1930s.)

What clearly emerges from reading the letters and papers from the incubation period of quantum mechanics is that, among the score of people creating the new picture of physics, two protagonists stand out, combining awesome mathematical power with a global awareness of the experimental data. These two—Pauli and Heisenberg—were the phenomenologists *par excellence* in the labyrinth

Not knowing the (wrong) theorem Pauli was relying on, I took this rebuke silently. But I was stung by his remark. And now, three years later, I felt my Zurich talk would be a chance to get even. Pauli had just updated his 1920 survey of relativity by adding 23 supplementary notes to its English translation. I was now, in my youthful arrogance, about to show him how little he knew about relativity.

In the first half of my talk, I sketched what was new in relativity, like plane gravitational waves, Petrov classification, and many old forgotten solutions. It was a direct affront to Pauli, who sat in the first row—and he enjoyed it. After the talk we went to a wet after-session with Walter Heitler and Pauli's assistant Charles Enz. I was standing with Pauli next to the driver of the streetcar when two streetcars collided in front of us. Pauli's face was flushed as he excitedly turned to me and exclaimed, "Pauli effect!" (Pauli had a reputation for being so disastrously clumsy with laboratory equipment that it was assumed that any mishap within kilometers of his presence was somehow a manifestation of a "Pauli effect.")

Pauli asked me whether I thought the evolution of life could be explained by random mutations. I said yes, citing the resistance of bacteria to penicillin and of mosquitoes to DDT. If this can happen in just a few years, why shouldn't a trilobite, in 500 million years, evolve into a Pauli? He had heard these arguments before and wasn't convinced by them. He wanted to see calculated probabilities for large-scale evolution.

Enz invited me home to dinner. He told me that Pauli had recently been the official speaker at an occasion honoring Einstein. In the audience were high government officials. Pauli read from his manuscript. Whenever he found an error in his text, he stopped in mid-sentence, drew out his fountain pen, corrected the text and went on, oblivious of the squirming audience.

It was early when I arrived back at my hotel. I felt like exploring the nightlife of Zurich. I didn't find it. She must have left for Paris or Hamburg.

When I was Heckmann's assistant in Hamburg, I moonlighted as science writer for the weekly *Der Spiegel*. On 24 February 1958 Heisenberg had given a talk to the physics colloquium at Göttingen, revealing his new "world equation" of matter, which made banner headlines in *Die Welt* and other German newspapers. Apparently he had not mentioned that his nonlinear spinor equation was the result of a long collaboration with Pauli. I didn't know that, and thought that Heisenberg's

claims were nonsense. But I couldn't say that in print, because all opinions in the magazine had to be masked as quotations from authoritative sources. Mistakenly, I thought that Pauli, the conscience of physics, would help me to express my view. I called the ETH and was told that Pauli was in Berkeley.

Given Pauli's known disdain for the popular media—he didn't even read newspapers—it would be difficult to get a statement out of him. So I decided to try a roundabout route. I assumed that Pauli would know the following Einstein episode: When Cardinal O'Connell of Boston had told a group of Catholics that Einstein's general theory of relativity "cloaked the ghastly appearance of atheism" and "befogged speculation, producing universal doubt about God and His creation," Rabbi Herbert Goldstein of the Institutional Synagogue in New York became alarmed about the faith of his hero. The rabbi cabled Einstein the five-word question, "DO YOU BELIEVE IN GOD? PREPAID REPLY 50 WORDS." This elicited from Einstein the famous statement, "I believe in Spinoza's God who reveals himself in the orderly harmony of what exists, not in a God who concerns himself with fates and actions of human beings."

I thought, therefore, that Pauli might respond when he received my telegram in Berkeley with the six-word question, "DO YOU BELIEVE IN HEISENBERG'S EQUATION? 100 WORD ANSWER PREPAID." Pauli answered, but he waffled and did not produce the clear-cut "nonsense" I had hoped for. He cabled back, "QUESTION NOT YET READY FOR A DECISION."

In November 1958, Pauli visited us at the Hamburg Observatory again. On one occasion in the 1920s, he had come to the observatory to see his friend Walter Baade, one of the century's greatest astronomers. The Pauli effect, on that occasion, had almost destroyed the observatory's great refractor telescope. Baade was now in Pasadena, and Pauli told me his secret for reaching Baade, who often didn't open his mail. Pauli would send him a postcard calculated to arrive at the time of the full moon, when astronomers like Baade would not be busy observing.

While we were walking along the Gojenbergsweg in Hamburg's Bergedorf district, looking out over the marshland of the river Elbe, Pauli said a number of times how glad he was that he had withdrawn his name from the world-equation paper. Pauli died less than a month later.

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of spectroscopy. They felt themselves to be the *real* physicists, dismissing Jordan, Dirac, Born, Schrödinger, Louis de Broglie, and others as mere formalists. (See the article about Jordan and Pauli in *PHYSICS TODAY*, October 1999, page 26.) The main act in the drama of the new physics is not, as Michael Frayn imagines in his play *Copenhagen*,¹⁰ (see *PHYSICS TODAY*, May 2000, page 51) the discourse between Bohr and Heisenberg, but rather the Heisenberg–Pauli dialogue. Bohr, the revered father figure, no longer had the leading role he played before 1925.

Perhaps we will never know the true extent of Pauli's contribution to the creation of quantum mechanics. From the crucial years 1925–27, we have 34 letters from Heisenberg to Pauli, but only three of the dozens that Pauli wrote to Heisenberg have survived. The fate of the others is in doubt. It was claimed they had been destroyed in a fire. But, according to another version, they were taken from Heisenberg when he was arrested by the British in 1945 at the end of the war in Europe.

We can imagine the magnitude of the loss when we read Pauli's 12-page letter of 19 October 1926, where he adumbrates the uncertainty relations by pointing out that "one can look at the world with the *p*-eye and one can look

at it with the *q*-eye. But if one wants to open both eyes at the same time, one goes crazy."¹¹ This letter is, strange to say, not mentioned by Heisenberg in his recollections about collaborating with Pauli.¹² From reading Heisenberg's responses to the missing Pauli letters, one gets the impression that much of Heisenberg's work was inspired by Pauli's ideas and suggestions.

Much of Pauli's work in his later years was centered on quantum field theory. With Victor Weisskopf, he accomplished the quantization of spin-zero fields. (See the article by Weisskopf in *PHYSICS TODAY*, December 1985, page 36). With Felix Villars, he achieved regularization of the theory. He proved two fundamental pillars of quantum field theory: the spin–statistics theorem and the *TCP* theorem. Pauli anticipated the Yang–Mills theory in letters to Abraham Pais, and he introduced the degeneracy of the vacuum ground state. Both of these ideas would later find their places in the standard model of particle physics.

Matter and mind

There was another, rather bizarre side to Pauli that is only now beginning to come into view with the publication of more than a thousand letters showing his attempts to



FIGURE 5. PAULI WITH WERNER HEISENBERG (right) and Otto Stern in Copenhagen in 1937. (Courtesy of AIP Emilio Segrè Visual Archives.)

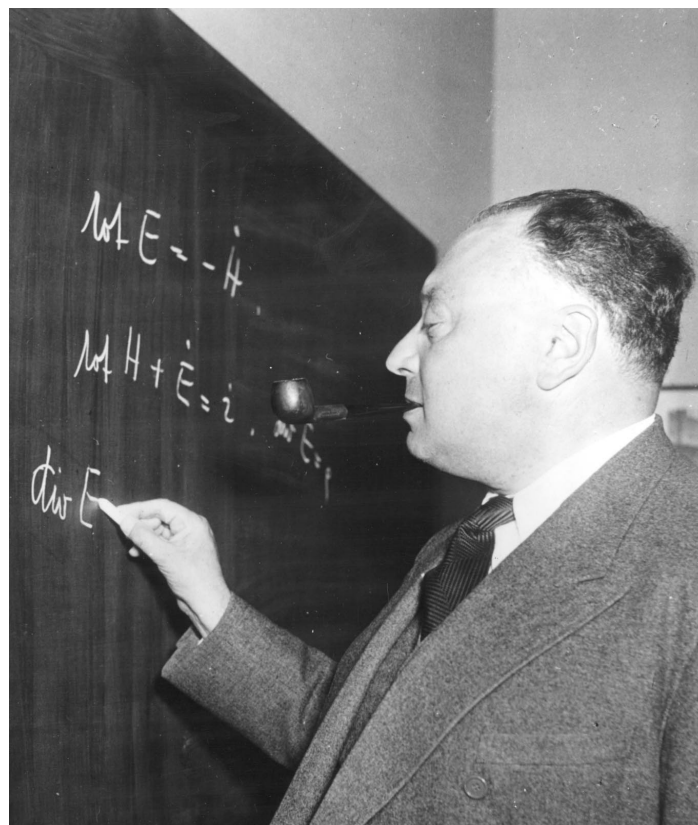


FIGURE 6. PAULI WRITING THE MAXWELL EQUATIONS in his ETH Zurich office in 1953. The $\dot{\mathbf{E}}$ term in the second equation has the wrong sign. (Copyright Keystone Photopress, Zurich.)

explore the unconscious and find a common language for the description of mind and matter. Jung, in his 1935 essay “Dream Symbols of the Process of Individuation,” wrote: “My material consists of more than 1000 dreams and visual impressions of a scientifically educated younger man. For the purpose of the present investigation I have studied the first 400 of these dreams.”¹³ The anonymous dreamer, as we know now, was Wolfgang Pauli.

As Jung describes one of these dreams:

Dream #59 (Great Vision). It is a vertical and a horizontal circle with a common center. That is the world clock. It is carried by a black bird. The vertical circle is a blue disc with a white rim divided in $4 \times 8 = 32$ parts. A pointer rotates on it. The horizontal circle consists of four colors. On it stand four little men with pendula, and around it lies the once dark and now golden ring that had previously been carried by four children.

The clock has three rhythms or pulses: In the small pulse, the pointer of the blue vertical circle advances by $1/32$ nd. The medium pulse is a complete rotation of the pointer. Simultaneously the horizontal circle advances by $1/32$ nd. In the big pulse, 32 medium pulses yield one revolution of the golden ring.

[Jung’s] Commentary: This strange vision made a deep, long-lasting impression on the dreamer, an impression of “the highest harmony,” as he [Pauli] put it.

The search for symmetry and harmony in the laws of Nature was the central theme of Pauli’s work in physics. His attempts to find the roots of Nature’s order in the human mind led him to a study of Kepler. Pauli sought to investigate the human psyche as deeply as he explored the physical world. But he did not feel ready to publish his psychic investigations. Like Newton, he saw a great ocean of truth before him. To paraphrase the poet Rainer Maria Rilke,¹⁴ he succeeded in

*Transmuting himself into the equations
Just as the stone mason doggedly sculpts himself
Into the cathedral stone’s cool indifference.*

References

1. Pauli to M. Born, 25 April 1955. Pauli’s scientific correspondence is published in six volumes in K. v. Meyenn, ed. *Wolfgang Pauli, Wissenschaftlicher Briefwechsel*, Springer-Verlag, New York (1979–2000).
2. A. Einstein / H. & M. Born *Briefwechsel 1916–1955*, with commentary by M. Born, Nymphenburger Verlagshandlung, Munich (1969) p. 226.
3. Pauli to C. Jung, 31 March 1953, in Ref. 1.
4. H. Weyl, *Science*, **103**, 216 (1946).
5. A. Einstein, *Naturwissenschaften* **10**, 184 (1922).
6. W. Heisenberg, IAEA Bulletin special supplement (1968), p. 45.
7. R. Kronig, V. Weisskopf, eds., *Collected Scientific Papers by Wolfgang Pauli*, vol. 1, Interscience, New York (1964), p. 269, translated by P. Achuthan, K. Venkatesan in *General Principles of Quantum Mechanics*, Springer-Verlag, Berlin (1980).
8. M. Jammer, *Naturwissenschaftliche Rundschau* **37**, 1 (1984).
9. D. ter Haar, *Master of Modern Physics*, Princeton U. Press, Princeton, N.J. (1998), p. 150.
10. M. Frayn, *Copenhagen*, Methuen Drama, London (1998).
11. Pauli to W. Heisenberg, 19 October 1926, in Ref. 1.
12. M. Fierz, V. Weisskopf, eds., *Theoretical Physics in the Twentieth Century*, Interscience, New York (1960) p. 40.
13. C. Jung, *Eranos Jahrbuch 1935*, O. Fröbe-Kapteyn, ed., Rhein-Verlag, Zurich (1936), p. 119.
14. R. M. Rilke, *Requiem für Wolf Graf v. Kalckreuth*. The original German is: “Hart sich in die Worte zu verwandeln / wie sich der Steinmetz einer Kathedrale / verbissen umsetzt in des Steines Gleichmut.”
15. K. v. Meyenn, K. Stolzenburg, R. Sexl, *Niels Bohr*, Vieweg, Braunschweig, Germany (1985), p. 308, Translated in G. Gamow, *Thirty Years that Shook Physics*, Doubleday, Garden City, N.Y. (1966), p. 165. ■