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*-theorem 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 gravitional waves do not exist."

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]

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