Jordan, Pauli, Politics, Brecht, and a Variable Gravitational Constant

Pascual Jordan was one of the great theoretical physicists of the century. But his attempt to modify general relativity with a variable gravitational constant did nothing to enhance his reputation. Nor did his conspicuous membership in the Nazi Party.

Engelbert L. Schucking

November 1952: "Eisenhower Elected President" proclaimed the headline in *Die Welt*. Why did they do that, those crazy Americans? This will mean the Dulles brothers in power and Adenauer's rearmament of Germany. But I put politics out of my mind and rang the doorbell of the apartment on Hamburg's Bundesstrasse. A maid with a little white cap opened the door.

"My name is Schucking."

"I will announce you to the Herr Professor," she said and vanished. After a while, the stout Herr Professor Doktor Jordan appeared, tried to introduce himself—with some difficulty because of his stammer, but in a very friendly way—and motioned me into his study.

I told him that I wanted to work in relativity, and had come to him because he was now active in that field. His book *Schwerkraft und Weltall* (Gravity and the Cosmos) had just come out.[1] He gave me some page proofs from his book and suggested, as a problem, that I integrate a differential equation in his theory, which had a variable gravitational constant.

I learned later that there was a small problem with the first copies of the book: The publisher, Vieweg, had produced copies with all the pages blank. When Wolfgang Pauli received such a copy from the publisher, he remarked, "Jordan knows that I can think up what should be in it by myself."

My interview was finished when a dolled-up woman with butterfly-shaped glasses appeared and informed me that I ought to rise because a lady had entered the room. I did, and was introduced to Frau Professor Jordan. She held out her hand to be kissed, but I shook it instead and said good-bye.

My solution to the integration problem met with Jordan's approval. With a tiny stipend that he got for me from the Hamburg Rotary Club, I became his student.

"Always a formalist"

Pascual Jordan, born in 1902, was one of the greatest physicists of this century. (He owed his unlikely first name to a Spanish great-grandfather who had served with Napoleon's army and got stuck in Germany on the ill-fated retreat from Moscow.) He was the originator of the quantum theory of fields, which we now take to be the basis for all of physics. He was the first to realize that all things in the universe—photons, electrons, protons, atoms, and elephants—are field quanta.

ENGELBERT SCHUCKING *is a professor of physics at New York University in New York City.*

Of the triumvirate (with Max Born and Werner Heisenberg) that formulated quantum mechanics in the famous *Dreimännerarbeit* of 1925, Jordan was the principal architect of the theory. But in spite of his revolutionary contributions, he never achieved the acclaim of his colleagues Heisenberg and Pauli. Pauli patronized him. "Herr Jordan was always a formalist," he once told me, meaning that Jordan was not a true physicist but only a mathematician—a lower form of life. But it was, of course, the formalism that contained the true physics.

Jordan's persistent stutter and simple bad luck seriously hampered his career. Once, when I visited Born in the 1950s to help him in his attempts to debunk the photon rocketeer Eugen Sänger, I mentioned that I was working on Jordan's theories. "I hate Jordan's politics," Born responded, "but I can never undo what I did to him: In December of 1925 I went to America to give lectures at MIT. I was editor of the *Zeitschrift für Physik* and Jordan gave me a paper for publication in the journal. I didn't find time to read it and put it in my suitcase and forgot all about it. Then when I came back home to Germany half a year later and unpacked, I found the paper at the bottom of the suitcase. It contained what came to be known as the Fermi–Dirac statistics. In the meantime, it had been discovered by Enrico Fermi and, independently, by Paul Dirac. But Jordan was the first."

When I returned to Hamburg, I asked Jordan about this sad story: "Is that really what happened?" He just laughed and stuttered his confirmation. Then when I got home I looked in Jordan's monograph *Statistische Mechanik auf Quantentheoretischer Grundlage*. It mentioned neither Fermi nor Dirac. Nor, for that matter, did Jordan mention himself in this connection. Harking back to the exclusion principle, Jordan referred to his own brainchild as "the Pauli statistics."

A million German opportunists

Born was certainly right in hating Jordan's politics. In May 1933 Jordan had joined the Nazi Party, together with a million other German opportunists.[2] I remember that after the war, when Pauli came to Hamburg to consult on who should succeed his former boss Wilhelm Lenz (of the Lenz–Ising model) as professor, Pauli exclaimed during a reception at the university that (chemistry Nobelist) "Richard Kuhn had no excuse for having been a Nazi. But Herr Jordan had: He was a professor at Rostock!" (Rostock was considered the Outer Mongolia of German universi-

© 1999 American Institute of Physics, S-0031-9228-9910-010-3

ties.) Jordan winced. He had been a full professor of theoretical physics at Rostock from 1933 to 1944.

Before the Nazis came to power in January 1933, Jordan had been a conservative nationalist. Under the pseudonym Domeier, he had published his elitist views in the right-wing journal *Deutsches Volkstum* (German Heritage).[3] My Göttingen teacher Hans Kopfermann may have had Jordan in mind when he wrote to Niels Bohr in May 1933, "There is a tendency among the non-Jewish younger scientists to try to join the movement and to act as much as possible as a moderating element, instead of standing disapprovingly on the sidelines."

But Jordan became a rather idiosyncratic sort of moderator. In November 1933, he joined an SA (*Sturmabteilung*) unit, becoming a storm trooper complete with brown uniform, jackboots, and swastika armband but, at the same time, a defender of Einstein, Freud, the positivist philosophers, and other arch-villains of Nazi ideology. He tried to sell the regime on relativity and quantum acausality as idealistic theories that would serve as weapons in the fight against Bolshevik materialism. He ridiculed Ludwig Bieberbach's racist "German mathematics." "The differences between German and French mathematics," Jordan wrote, "are not any more essential than the differences between German and French machine guns."[4]

PASCUAL JORDAN at Niels Bohr's Copenhagen institute in 1936.

NIELS BOHR ARCHIVE, COPENHAGEN

Although Jordan advertised science in militaristic language as the great weapon of the Nazi realm, his own contribution to the war was modest. Having volunteered for the Luftwaffe in 1939, he worked mostly as a meteorologist at airfields—and also at the notorious Peenemünde rocket center. Unwittingly, it seems, he helped the Allied cause by spilling certain vital secrets of the Peenemünde operation to the Springer editor Paul Rosbaud, who was, in fact, a British spy.[5]

In spite of his bizarre political activities, Jordan was personally a shy and kind man. With Pauli's support, Jordan was "rehabilitated" after the war. In 1953, thanks to Pauli's intercession, he advanced from visiting to full professor at the University of Hamburg. "It would be incorrect," Pauli commented at the time, "for West Germany to ignore a person like P. Jordan."

The problem that Jordan had in mind for me was to solve the differential equation

$$\left[3\dot{R}+(\zeta-3)\frac{R}{t}\right]\left[\dot{R}+(\zeta-1)\frac{R}{t}\right](2c^2+\ddot{R}R+2\dot{R}^2)$$
$$-\zeta(2c^2+\ddot{R}R+2\dot{R}^2)^2+3\ddot{R}R\left[\dot{R}+(\zeta-1)\frac{R}{t}\right]^2=0$$

This was Jordan's generalization the Friedmann equation for the radius $R(t)$ of an expanding or contracting universe. He treated the universe as a hypersphere filled with incoherent matter and a time-dependent scalar field—Jordan's variable gravitational "constant."

Jordan had apparently tried quite hard to solve this monstrous equation, but he had not succeeded. Therefore, in keeping with a hallowed tradition, he posed it as a problem for this graduate student. I was not keen on the idea, because this was clearly an insoluble problem. All one could hope to do with such a horribly nonlinear equation was to construct a theory for the qualitative behavior of its solutions and find various approximate solutions to be patched together with appropriate numerical bounds.

Ingenious SS Sturmführer

I had ideas of my own for a thesis—for instance, to develop quaternionic quantum mechanics. I had read the thesis of the ingenious SS Obersturmführer Otto Teichmüller. He had worked out the spectral theory of self-adjoint operators in quaternionic Hilbert space.[6] (A few years later, having terrorized the Mathematics Institute at Göttingen, Teichmüller went to war and was eventually reported missing in action.)

Alternatively, I thought about working on spinors in the Einstein theory. But Jordan would have none of it. "That cannot lead to anything new," he declared. "Nobody is working on my theory. If you want to do a thesis, you have to work on *my* theory." I thought his theory was crazy. It was an attempt to turn Dirac's numerology into a field theory.

George Gamow recalled that in 1937 he was sitting in his room at Niels Bohr's institute in Copenhagen when Bohr came in waving the latest issue of *Nature*. "Look what happens to people when they get married!" exclaimed Bohr. He was referring to the fact that Dirac had just married Eugene Wigner's sister Margit and, concurrently, had proposed a radical hypothesis:[7] Because the immense number 10^{39}, the ratio of electric to gravitational attraction in the the hydrogen atom, was roughly equal to the age of the universe in nuclear units of time (10^{-23} seconds), the force ratio could be explained, *without the slightest observational evidence*, by assuming that Newton's gravitational constant G is, in fact, decreasing like the reciprocal of the age of the universe. Soon thereafter, Dirac shelved this weird idea for some thirty years. But not Jordan. Apparently the only one who still took it seriously, Jordan tried to turn G into a scalar field.

During the war at the rocket center at Peenemünde, Jordan[8] developed a generalization of Pauli's projective relativity that gave rise to a scalar field which he identi-

NIELS BOHR ARCHIVE, COPENHAGEN

PHYSICS CONFERENCE at Bohr's institute in 1936. In the front row (left to right) are Wolfgang Pauli, Pascual Jordan, Werner Heisenberg, Max Born, Lise Meitner, and Otto Stern. Niels Bohr is standing behind Pauli.

fied with G, the gravitational coupling. Jordan's book *Schwerkraft und Weltall* was largely an elaboration of this theory, which turned out to be mathematically equivalent to a speculative generalization, by Einstein and Peter Bergmann,[9] of Theodor Kaluza's theory with a variable g_{55}.

I thought this theory was pretty ugly, because there was no obvious choice for a Lagrangian density. Moreover, a second-order partial differential equation for G would hardly yield the desired solution $G \sim t^{-1}$. Quite apart from other constants, the first time derivative of G would now be a new cosmological parameter undetermined by theory.

"My husband is like a tank"

But Jordan could not be stopped. "My husband is like a tank," said Frau Jordan. He thought diminishing gravity would make the Earth expand, thus accounting for continental drift. Moreover, because his cosmos had some 10^{78} particles, its mass should be increasing as t^2 (10^{78} being the square of 10^{39}). Having known Jordan when he was still a lean youngster, Pauli remarked that the now-stout professor had projected his mass increase onto the cosmos.

Jordan conjectured that the mass increase occurs explosively through white-hole formation, creating baby universes that would turn into Victor Ambartsumian's stellar associations. (See the article by Geoffrey Burbidge, Fred Hoyle, and Jayant Narlikar in PHYSICS TODAY, April 1999, page 38.) Later, my task was to examine Jordan's very unpleasant field equations for time-dependent solutions that might support such wild surmises.

When Willibald Jentschke's electron-synchrotron center, DESY, was starting up in Hamburg in the early 1960s, a reporter for the *Hamburger Abendblatt*, familiar with Jordan's ideas, asked him whether the collision of high-energy particles in the machine might not give birth of a star in the suburban Hamburg neighborhood, with all its dire consequences, Jordan answered—to Jentschke's great relief—that the accelerator's energy wasn't high enough.

Whenever I visited Jordan at 132 Ise Strasse, his new office in a posh Hamburg neighborhood near the Aussenalster, to report on the progress of my calculations, he supplied me with stacks of scratch paper consisting of letters he had received whose backs were blank. Peeking at those letters, I gathered that a major part of Jordan's income was apparently derived from honoraria for talks to all sorts of societies, church groups, and adult education centers—about physics and God, society, the universe, psychology, biology, extrasensory perception, and whatnot.

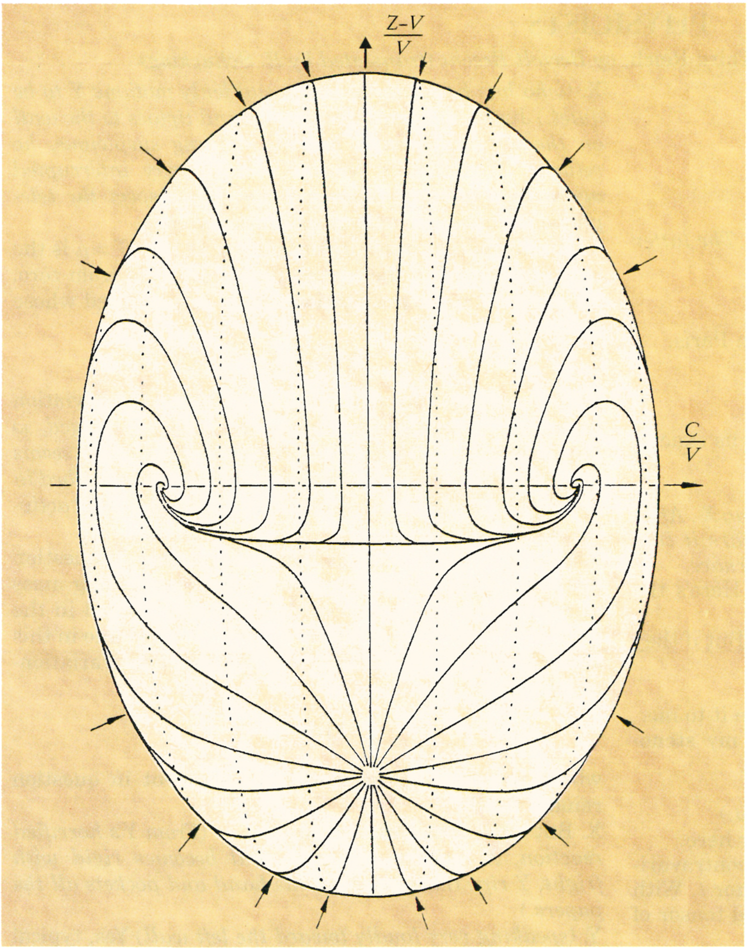
Only recently, when I saw Karl von Meyenn's publication of Pauli's letters from the early 1950s, did I learn that he had encouraged Jordan to pursue his theory. In October 1952 Pauli wrote to Jordan, "In itself, Dirac's idea of a variable κ [$= 8\pi G$] appears to me as a natural one, and I am convinced at the moment that the action principles of the type used in your book on p. 132 are the only reasonable formulation of the Dirac idea. I do not dare judge yet whether this corresponds to physical reality or not."[10]

Once, when Pauli visited Hamburg, Lenz introduced him by saying that Pauli had often called something wrong that turned out to be right, but had never judged anything right that turned out to be wrong. But Pauli's early judgment in Jordan's case came as a surprise to me. Still, when Jordan gave a talk about his theory with Pauli sitting in the first row swaying rhythmically, Pauli got up after the lecture, pointed his finger at Jordan, and said into the expectant silence: "A theory, Herr Jordan, does not become true just by talking about it." Jordan laughed. It was a defense tactic when, because of his stammer, he couldn't get a word in fast enough.

But Jordan could think fast. Pauli once quoted back to him an awful sentence dripping with Nazi ideology from Jordan's popular writings in the 1930s and said,"Herr Jordan, how could you write such a thing?" To which Jordan retorted, "Herr Pauli, how could you read such a thing?"

In the evening after Jordan's talk, we had dinner with Pauli in a posh restaurant on the Rothenbaum Chaussee, the avenue where Pauli had had his epiphany in 1925: the discovery of the exclusion principle. I remember how Pauli relished his blue carp with horseradish and told his Zermelo anecdotes from his Göttingen days.

Ernst Zermelo, who created a system of axioms for set theory, was a *privatdozent* at Göttingen when Herr Geheimrat Felix Klein held sway over the fabled mathematics department. As Pauli told it, "Zermelo taught a course on mathematical logic and stunned his students by posing the following question: All mathematicians in Göttingen belong to one of two classes. In the first class belong those mathematicians who do what Felix Klein likes, but what they dislike. In the second class are those mathematicians who do what they like, but what Felix Klein dislikes. To what class does Felix Klein belong?"



SOLUTION CURVES of Pascual Jordan's speculative cosmological equation on page 27, in projective transformation. The curves were computer-generated in 1955 by H. König and reproduced in the second edition of Jordan's book.[11] Z is a parameter of the theory. The pretty picture strengthened Jordan's hope for his "extended gravitational theory." He was also pleased to see that the analytic approximation sketch worked out by his student Schucking agreed with König's numerical result.

Jordan, having listened intently, broke into roaring laughter. Pauli paused, took a sip of wine and said disapprovingly, "Herr Jordan, you have laughed too soon." He continued: "None of the awed students could solve this blasphemous problem. Zermelo then crowed in his high-pitched voice, "But, *meine Herren*, it's very simple. Felix Klein isn't a mathematician." Jordan laughed again. Pauli drained his wine glass approvingly and concluded with "Zermelo was not offered a professorship at Göttingen."

By studying the books on differential equations by Ince and Kamke, I succeeded in reducing Jordan's equation to a more manageable first-order differential equation and worked out the theory of its solutions. Jordan asked H. König, a professor of mathematics at the Clausthal Mining Academy, to plot numerically the solutions of this equation for a special value of a particular parameter.[11] He invited König and me to lunch at the gourmet restaurant in Hamburg's main railway station, to compare results. It was pleasing to see that my sketch and König's graph (the figure above) were identical. Jordan was exuberant about the pretty picture. "The fact that the extended gravitational theory could give rise to such beautiful mathematical investigations," he wrote, "strengthens my hope that it has succeeded in eavesdropping on Nature's secret harmonies." I was less optimistic. After lunch, König and Jordan seemed to have some secret project at the Iron Curtain, which started a few miles from Clausthal. I left them to their plots.

I read Jordan's *Schwerkraft und Weltall* carefully. In its first part, he had tried to give a new introduction to relativity from an algebraic point of view. Since the subject was apparently new to him, some of this treatment was quite original—for example, his axiomatic characterization of the covariant derivative, which was also discovered later by Jean Louis Koszul. But the book also had many misprints and some outright mistakes. Whereas I had studied Einstein's papers and the books by Hermann Weyl, Arthur Eddington, and Tulio Levi-Civita, Jordan's source had been mainly Pauli's *Enzyklopädie* article.

Pauli less than perfect

Pauli's report in the *Enzyklopädie der Mathematischen Wissenschaflen* was one of the best treatments of relativity, but it was not perfect, as Pauli was the first to point out. I said to him: "Your article is unique. One can think of examples of great inventions by the young, such as Galois. But I know of no case where a young man has reviewed a theory in such a magisterial and comprehensive way." Pauli swayed back and forth like a chasid at prayer. "There is an example," he responded after a pause and more swaying. "Gauss! My article isn't perfect. I missed the Bianchi identities." I hadn't noticed that; but if one regards the Riemann tensor as the gravitational field strength, he had missed the analog of half the Maxwell equations. Pauli rectified this lapse in an appendix to the English translation of his article.

I learned about Pauli's *modus operandi* for mending such mishaps when he prepared a new edition of his 1933 *Handbuch* article on quantum mechanics, known by the cognoscenti as the "New Testament." He took time off from watching the elephants, his favorite animals at Hagenbeck's Zoo in Hamburg, and went to the physics department's library to look up his article and scan the margins, page by page, for comments and corrections by its readers.

While I was preparing Jordan's book for a second edition,[11] I learned from him about an aspect of Einstein's theory that was entirely new to me—its Cauchy problem. Jordan, a former student of Richard Courant's, was now praising the second volume of "the wonderful book by Courant and Hilbert." This had led him to the remarkable 1937 and 1938 papers by Karl Stellmacher on causality and gravitational waves.[12] These seminal papers on the Cauchy problem in Einstein's theory, still widely unknown to relativists, were produced in Göttingen's Mathematics Institute, where Teichmüller was wreaking his Nazi havoc. Bertolt Brecht exploited this bizarre setting in scene 7 ("Physicists") of his play *Fright and Misery in the Third Reich*,[13] which premiered in Paris in 1938. See the box on page 30.)

PHYSICISTS

A scene from Fright and Misery in the Third Reich, *by Bertolt Brecht (translated by E. Schucking)*

Here come the Teutonic scholars
With fake beards over their molars
And eyes wide and scared sick.
They no longer want one that's right.
Nay, one with an Aryan face bright,
An authorized *Deutsche Physik.*

In a physics institute. Two scientists, X and Y. The latter has just come in. He acts like a conspirator.

Y. I've got it!
X. What?
Y. The answer to our questions to Mikowsky in Paris.
X. About the gravitational waves?
Y. Yes.
X. And?
Y. Do you know who wrote us about it, giving us exactly what we need?
X. Well?
Y writes a name on a piece of paper and gives it to X. After X has read it, Y takes the paper back and tears it into small pieces, and then throws them into the furnace.
Y. Mikowsky passed our question on to him. Here's the answer.
X. (*grabs it*) Give it to me! (*suddenly he stops*) But if they catch us corresponding with him. . . .
Y. They must not, on any account!
X. But without it we can't go on. Come on, give it to me.
Y. You can't read it. I've transcribed it into my stenographic system. That's safer. I'll read it to you.
X. You must be careful!
Y. Is Rollkopf in the lab? (*He points to the right.*)
X. (*pointing left*) No, but Reinhardt is. Sit over here.
Y. (*reads*) We are dealing with two arbitrary contravariant vectors, ϕ and ν, and a contravariant vector t. With their help, we form the components of a mixed tensor of the second rank whose structure is given by

$$\sum_{l}^{r} = C_{lhi}\phi^h v^i t^r$$

X. (*who has been taking notes, suddenly motions Y to be quiet.*) Just a moment! (*He gets up and tiptoes to the wall on the left. Apparently hearing nothing suspicious, he returns. Y continues reading, occasionally interrupted again in a similar manner. Then they inspect the telephone for bugs, open the door suddenly, etc.*)
Y. For incoherent pressureless matter at rest, $T = \mu$ is the only component of the energy tensor different from zero. Therefore a static gravitational field is generated whose equation gives

$$\nabla^2 f = 4\pi\kappa\mu.$$

With a suitable choice of space coordinates, the deviation from $c^2\,dt^2$ is very small. (*Somewhere a door is banged, so they want to hide their notes. But then it no longer seems necessary. From now on, however, they become absorbed in the physics and seem to forget how dangerous their activity is.*)
Y. (*reads on*) On the other hand, the masses in question are very small compared with the field-generating mass at rest. Thus the motion of the bodies embedded in the gravitational field is given by a geodesic world line in this static gravitational field. As such, it obeys the variational principle

$$\delta\int ds = 0,$$

where the ends of the world line segment in question remain fixed.
X. But what does Einstein say to. . . . (*From Y's horrified reaction, X realizes his lapse and becomes rigid with fright. Y rips the notes from his hand and pockets all the papers.*)
Y. (*speaking very loudly toward the left wall*) Yes, typical Jewish sophistry! What does that have to do with physics? (*Relieved, they go back to their notes and go on working silently, with the greatest caution.*)

The dreaded E-word

It was much to Jordan's credit that he did not shun the dangerous E-word when writing about relativity during the Nazi era, while a circumspect Heisenberg managed to avoid it. Lenz tried a different tack. He had found a (spurious) derivation of the Schwarzschild line element from special relativity that he wanted to publish in *Naturwissenschaften.* To avoid the E-word, he tried to enlist the help of Max von Laue in aryanizing relativity by crediting the theory to Henri Poincaré. Laue was disgusted and, in 1939, wrote to Einstein that he found this "as reprehensible as [it was] foolish." In 1944, Lenz turned his notes over to Arnold Sommerfeld, who published them in 1949 in his lectures on electrodynamics. They were then taken up by Leonard Schiff, refuted by Alfred Schild, and hopefully thus laid to rest.

I contributed a bit to Jordan's theory, which he incorporated into the second (1955) edition of *Schwerkraft und Weltall.* I earned my doctorate by producing some exact, nonstatic, spherically symmetric solutions of his theory. Their physical interpretation remains obscure.[14]

To find a solution for the fusion of two separate universes into one—which I called a four-dimensional trouser world—I concocted metrics whose spatial sections were three-dimensional generalizations of lemniscates, with a time-dependent parameter given by the equations

$$[(x-a)^2 + y^2 + z^2 + u^2][(x+a)^2 + y^2 + z^2 + u^2] = R^4(t)$$

$$dl^2 = dx^2 + dy^2 + dz^2 + du^2.$$

For the unwieldy calculations of these double-bang models, Jordan's discarded letters no longer provided adequate scratch paper. So I used the backs of scrolls of wallpaper. I ran into contradictions that I interpreted as the nonexistence of exact solutions for the trouser ansatz in Jordan's theory. The scrolls are now lost. Perhaps they reverted to their original destination on somebody's walls.

In the summer of 1953, Pauli gave a course at the ETH in Zurich on relativity—his first love. His student Charles Enz turned his lecture notes into an 111-page manuscript. Pauli wrote to Oskar Klein that he had given the course "in order to learn the Jordan theory." But this learning process took a distinctly Pauline form. The French mathematician Yves Thiry, who had independently developed the mathematical framework of the Jordan theory, had sent his thesis[15] to Pauli. Pauli wrote to Jordan that he had resolved not to open the package. "[It lies] on my table . . . so terribly bulky (and without a reasonable summary) that it is much simpler not to open the book and just figure out what must be in it." Jordan agreed. "Your method for treating Thiry's [thesis] appears to me quite sound," he wrote back.

While studying Jordan's theory, Pauli discovered the

AIP EMILIO SEGRÈ VISUAL ARCHIVES

WOLFGANG PAULI in July 1940. Pauli needed this passport photo, taken in Zurich just after the fall of Paris, to get to Princeton, where he had been offered a position at the Institute for Advanced Study. Though Pauli had been a professor in Zurich since 1928, he was denied Swiss citizenship. His native Austria having been annexed by Hitler, Pauli had to apply for a German passport. The German consulate in Zurich, having classified him as a "half-Aryan," granted him a passport without the dreaded "J".[10]

important role of conformal transformations for its metric and pointed out that Jordan had misinterpreted his scalar field. According to Pauli, Jordan's κ was not $8\pi G$ but its inverse. Adding to this confusion was a paper by Markus Fierz,[16] pointing out that the scalar field had nothing to do with gravitation, but was rather the dielectric constant of the vacuum.

Still widely unknown

Pauli's monumental unpublished contributions to physics, and his dreams of a universal science encompassing mind and matter, are now slowly emerging as a result of von Meyenn's erudite editions of his correspondence. They show him as one of the century's greatest minds. But the depth of Jordan's contributions to physics has not yet found its proper appreciation. While his work on quantum biology, inspired by Bohr's mysticism, has not stood the test of time, his work on the foundations of physics is, regrettably, still widely unknown.

Max Jammer, one of the foremost historians of quantum mechanics, did point out that the bulk of the monumental 1925 Born–Jordan paper *Zur Quantenmechanik* was written by Jordan. In it, Jordan used the mathematical tools of the Courant–Hilbert book, which had just come out. The book was based on the notes Jordan had taken at Courant's lectures. It has also been argued that Jordan's *habilitation* lecture was crucial for Heisenberg's discovery of the uncertainty relations.

Even Jordan's pioneering work in quantum field theory was not immediately appreciated. His formalism of creation and annihilation operators, now the basic language of physics, was still viewed with suspicion by Pauli in 1933. "It is doubtful whether a really deep-seated physical connection lies at the root of this approach," wrote Pauli, "and it can be shown that all the results of quantum mechanics can be obtained without applying these methods."

In a seminal paper in 1935, Jordan showed how his formalism could treat the physics of multiparticle systems—now the standard treatment in condensed matter physics—and generate the representations of the unitary and permutation groups that are now used in particle physics. In 1979, Wigner proposed Jordan for the Nobel Prize in Physics, but the Swedish Academy awarded the prize that year to Sheldon Glashow, Abdus Salam, and Steven Weinberg—three practitioners of the art that Jordan had invented.

After his development of quantum field theory, Jordan began in 1930 a quest for a new mathematics that would make it possible to overcome the theory's contradictions. He discovered a new version of quantum mechanics based on commutative, nonassociative algebras—the Jordan algebras—that created a new universe of mathematics.[18] This led to the discovery of one of the most beautifully symmetric structures—the Albert algebra of 3×3 Hermitian matrices of octonions. After the war, Jordan found that its idempotents are the points and lines of the Moufang plane.

In his search for the ultimate formalism of physics, Jordan became engaged in creating the theory of *schrägverbände* (skew lattices), until death caught up with him at his home in July 1980, while he was filling in formulae in a manuscript at the kitchen table.

An expanded version of this memoir appears in On Einstein's Path, *edited by Alex Harvey and published by Springer, New York (1999).*

References

1. P. Jordan, *Schwerkraft und Weltall*, Vieweg, Braunschweig, West Germany (1952).
2. K. Henschel, ed., *Physics and National Socialism*, Birkhauser, Boston (1996), appendix F, p. 35.
3. R. Beyler, "From Positivism to Organicism: Pascual Jordan's Interpretations of Modern Physics in Cultural Context," PhD thesis, Harvard U. (1994), p. 207.
4. M. N. Wise, in *Science, Technology and National Socialism*, M. Renneberg, M. Walker, eds., Cambridge U. P. Cambridge, England (1994), p. 226.
5. A. Kramish, *The Griffin*, Houghton Mifflin, Boston (1986).
6. O. Teichmüller, J. Reine u. Angew. Mathematik **174**, 73 (1935).
7. P. A. M. Dirac, Nature **139**, 323 (1937).
8. P. Jordan, Ann. der Phys., 6. Folge **1**, 219 (1947).
9. P. G. Bergmann, Ann. Math. **49**, 255 (1948).
10. W. Pauli, *Scientific Correspondence*, K. v. Meyenn, ed., Springer, New York (1996), vol. 4, part 1, p. 737, and vol. 3, p. XXVIII.
11. P. Jordan, *Schwerkraft und Weltall*, 2nd ed., revised with E. Schucking, Vieweg, Braunschweig, West Germany (1955), p. 202.
12. K. Stellmacher, Mathematische Annalen **115**, 136 (1937), and **115**, 740 (1938).
13. B. Brecht, *Gesammelte Werke,*, Suhrkamp, Berlin, (1988), vol 4. (plays), p. 197.
14. E. Schucking, Z. Phys. **148**, 72 (1957).
15. Y. Thiry, J. Math. Pures et Appl. **30**, 275 (1951).
16. M. Fierz, Helv. Phys. Acta **24**, 128 (1956).
17. P. Jordan, Z. Phys. **94**, 531 (1935).
18. P. Jordan, J. von Neumann, E. Wigner, Ann. Math. **35**, 29 (1934). ■