NATIONAL ACADEMY OF SCIENCES

PAUL SOPHUS EPSTEIN

1883—1966

A Biographical Memoir by

JESSE W. M. DUMOND

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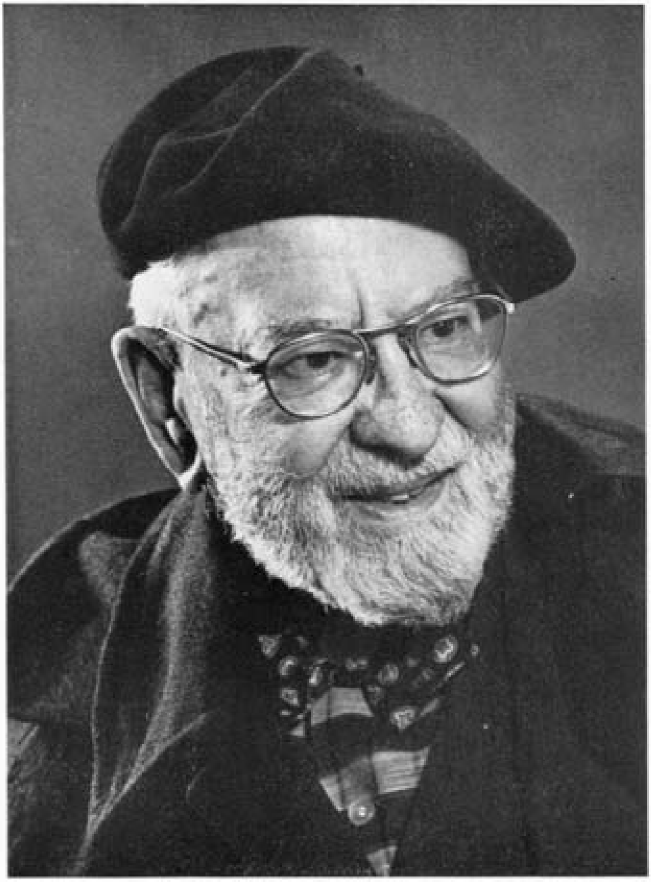

Paul S. Epstein

PAUL SOPHUS EPSTEIN

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BY JESSE W. M. DuMOND

PAUL SOPHUS EPSTEIN was one of the group of prominent and very gifted mathematical physicists whose insight, creative originality, and willingness to abandon accepted classical concepts brought about that veritable revolution in our understanding of nature which may be said to have created "modern physics," i.e., the physics which has been widely accepted during the Twentieth Century. Paul Epstein's name is closely associated with those of that group, such as H. A. Lorentz, Albert Einstein, H. Minkowski, J. J. Thomson, E. Rutherford, A. Sommerfeld, W. C. Röntgen, Max von Laue, Niels Bohr, L. de Broglie, Paul Ehrenfest, and Karl Schwarzschild.

Paul Epstein was born in 1883 in Warsaw, which was then a part of Russia. His parents, Siegmund Simon Epstein, a businessman, and Sarah Sophia (Lurie) Epstein, were of a moderately well-to-do Jewish family. He himself has told how, when he was but four years old, his mother recognized his potential mathematical gifts and predicted that he was going to be a mathematician. After receiving his secondary education in the Humanistic Hochschule of Minsk (Russia), he entered the school of physics and mathematics of the Imperial University of Moscow in 1901. In the third year of his undergraduate studies he started research in experimental physics under Professor Peter N. Lebedew, who in 1901 had become famous for his experimental demonstration of the pressure exerted on bodies by light or other electromagnetic radiation, an example of the Einstein principle of the inertia of energy.

After graduation, in 1905, Epstein served as laboratory instructor in physics, first at the Moscow Institute of Agriculture and later at the Imperial University, continuing his research at the same time. In 1909 he obtained his master's degree in physics and was appointed assistant professor (Privatdozent) at the Imperial University. In 1910 he decided to specialize in theoretical physics and obtained a leave of absence to do research under the famous Arnold Sommerfeld at the University of Munich (Germany).

Epstein's early research was in the theory of electromagnetic waves and particularly the theory of their diffraction. Two of his papers of this period were his doctoral thesis (1914), "Diffraction from a Plane Screen," and an article in the German Encyclopedia of Mathematical Sciences (1916), "Special Problems of Diffraction."

At the beginning of the First World War, in 1914, Epstein was at Munich. Being a Russian, he was regarded as an "enemy alien" and was automatically declared a civil prisoner. However, he was interned in a prisoner's camp only for a short time, thanks to the kindly intervention of Professor Sommerfeld. For the duration of the war he was allowed to live privately in Munich with access to the facilities for doing theoretical work and for publishing it, but of course was restricted from leaving Germany.

By 1916 Epstein had become deeply interested in problems of the quantum theory of atomic structure based on classical mechanics, and he shared the early development of this branch of physics with Niels Bohr and Arnold Sommerfeld. His most important paper in this connection was "Zur Theorie des Starkeffektes" (1916). In this paper he computed the electron orbits, atomic energy levels, and splitting of the spectral lines for a hydrogen atom in the presence of a superimposed electric field and compared his theoretical predictions with the experimentally-observed results then available. The dramatic story of the writing of the paper was told by Epstein years later. The story, which follows, was taken from a tape recording of an interview between the historian J. L. Heilbron and Paul S. Epstein on May 25, 1962.

Paul Epstein had been understandably anxious to escape from his captivity as an "enemy alien" in Munich, and to do this he had hopes of finding a position as a theoretical physicist somewhere outside Germany. Two places he had in mind were Leyden and Zurich. But to obtain such a position as the one in Zurich, he must write a habilitationsschrift, that is to say a thesis for becoming Privatdozent. Sommerfeld had just written his famous paper in which, by introducing the principle of relativity into Bohr's theory of atomic orbits, he had arrived at an explanation of the fine structure-splitting, till then unexplained by the simpler Bohr theory. A much more complicated case of line-splitting was known, however, and was as yet completely unaccounted for by any theoretical treatment. This was the effect, observed by Stark in 1913, when an atom is in the presence of an externally-imposed electric field. So Epstein proposed to Sommerfeld that he would tackle this difficult problem as the subject of his habilitationsschrift for Zurich, and Epstein's proposal was accepted at Zurich.

The Stark effect had been well known for three years and in fact, as chance would have it, at the very time of which we are speaking, Wagner, one of Röntgen's assistants in Munich, put on a demonstration of the Stark effect using a so-called "canal ray" tube. This was a vacuum electrical discharge tube in which the negative electrode or cathode was provided with holes. In such a tube most of the positive ions bombarded the cathode and "splashed out" the electrons from it so as to maintain the discharge, but a few of the positive ions would go on through the holes, and these were called "canal rays." Since vacuum technique was in a very primitive stage, the mean free path of an ion in such tubes was short, and the canal ray ions, excited by collisions with other ions, would emit spectral lines of much greater complexity than normal for that atomic species if the electric field in the near vicinity of the cathode were strong. The splitting up of the normally-to-be-expected spectral lines into these complicated spectra was the Stark effect. Wagner's timely demonstration of the effect in Munich was probably done with mercury vapor in the tube, but the theoretical explanation of the effect, even for the simplest atomic species, hydrogen, was difficult enough to be as yet an unsolved problem in terms of Bohr-Sommerfeld quantum theory.

This demonstration stimulated Epstein to start thinking vigorously how he might construct a theory to explain quantitatively the splitting of the line spectra. He had studied generalized mechanics from the French text of P. Appell, and he knew from this a certain theorem of the famous mathematician, Jacoby, furnishing a convenient method of integrating the differential equations of motion for a case such as this.

Now at that time there was a famous mathematician, Karl Schwarzschild, of powerful ability whom P. S. Epstein, as behooved a much younger and less widely known man, in fact only a young Privatdozent, held in great respect and considerable awe. Epstein only saw Sommerfeld infrequently, owing to restrictions imposed on him because of his "enemy alien" status in Munich, but at one of the meetings which he was permitted to attend through Sommerfeld's intervention, the latter told Epstein, "I wrote Schwarzschild that he should work on this article " (meaning the Stark effect). Epstein relates that he "was a little crestfallen, because I regarded this as a stab in the back, since he [Sommerfeld] knew that I was writing about it and," Epstein continued, "Schwarzschild was a mathematician of unbelievable energy; he could do everything in a twinkling; of course I couldn't reproach him [Sommerfeld], but I decided: 'Now I have no prospects unless Schwarzschild should go to heaven.' " Epstein goes on to tell how the next day when he was going to bed he saw his way through what he needed for the solution. He got up at 5 o'clock the next morning and by 10 o'clock he had the formula! And then the same morning he showed his result to Sommerfeld. "And what do you know, the same afternoon he [Sommerfeld] got a letter from Schwarzschild, and Schwarzschild had the wrong formula! It was the same order of magnitude, but didn't agree on the positions of the lines. So Sommerfeld wrote Schwarzschild, 'This morning Epstein brought me the formula of the Stark effect, and this afternoon we got your letter. But Epstein's formula agrees with the observations.' "

When Schwarzschild had first obtained his result, he immediately announced in the Berlin Academy that he would speak about it. He did so, however, *before* having written to Sommerfeld and Epstein, so the report he gave to the Academy before he actually lectured contained his erroneous result. By that time Epstein had already submitted his announcement of *his* result for publication, and it came out dated just one day before Schwarzschild delivered the above-mentioned lecture to the Academy. So Epstein had the priority over Schwarzschild by one day. In his lecture Schwarzschild had apparently corrected his error verbally (undoubtedly giving credit to Epstein for the correction), and when he received the galley or page proof of the printed version he corrected the error and removed all of the discrepancies. Thus Schwarzschild's final published version came out correctly.

In substantially all textbooks and histories of physics the theory of the Stark effect is attributed jointly to Epstein and Schwarzschild.* It is clear, however, that they really solved the

* See, for example, *History of Physics* by Max von Laue, translated by Ralph E. Oesper, Academic Press, Inc., New York, N.Y., 1950.

problem *independently* and that Epstein's solution came first and did indeed correct an error in Schwarzschild's solution. This incident, recounted directly from Epstein's own lips, illustrates dramatically the competitive tensions that existed among this group of European physicists in those early days of the development of the quantum theory of atomic structure.

Paul Epstein's intimate knowledge of those exciting times and gifted scientists at the turn of the century was a source of great inspiration to us younger men who attended his classes in theoretical or mathematical physics a little later after he had come to Caltech (in 1921). I shall never forget his account of von Laue's accidental learning of the hypothesis (first clearly formulated by Ludwig A. Sieber) that crystals are latticework structures of atoms. It seems that von Laue first learned of this when, in hopes of a consultation, he sought out Sommerfeld, who happened to be sitting in a little summer pavilion in one of the gardens of the University of Munich with his student, P. P. Ewald, discussing Ewald's famous thesis in which the idea of the "reciprocal lattice" had emerged as a mathematical device of great power. Von Laue was electrified when he overheard the conversation and grasped the idea of the crystalline atomic lattice. Here, made by Nature herself, was the equivalent of the artificial ruled grating (of Henry Rowland), the ideal tool, perhaps, which might indeed have the appropriate fineness of structure to answer the burning question with which von Laue had been deeply occupied—whether or not the Röntgen rays, discovered 17 years earlier, in 1895, were undulatory in nature and, like visible light waves, capable of being diffracted by a grating or lattice.

By 1900 Haage and Wind had tried to determine, by diffractions of x rays through fine slits, whether Röntgen's radiations were undulatory in nature and, if so, of what order of wavelength. These first results were inconclusive, but later, Walter and Pohl repeated the slit-diffraction experiment with greater refinement. Not until 1912, however, through the good fortune that the microphotometer of P. P. Koch * had just been invented and developed, did it become possible to study quantitatively the slight broadening of the photographically-recorded lines of Walter and Pohl. From this broadening they concluded that the x rays observed had wavelengths of the order of 4×10^{-9} cm.†

Von Laue immediately set two young experimental physicists, Friedrich and Knipping, at the University of Munich the task of trying to see if a beam of x rays could be diffracted by scattering from a crystalline solid. Their experiment was fraught with many difficulties and tribulations. At that time the only way of getting the high voltage electrical power to operate a Röntgen ray tube was with a "spark coil" or "Ruhmkorff coil." Public electrical power (for lighting the university) was only of the constant voltage, direct current variety. The light sources were so-called "arc lamps" in which the light came from a direct current arc maintained between two graphite electrodes. Such a lamp has a nonlinear current-voltage characteristic which tends strongly to *amplify* any small accidental fluctuations in the supplied voltage. In order to operate the Ruhmkorff coil, one needed an *intermittent* electrical supply to it with an appropriate "interrupter" ‡ and capacitor for generating high frequency oscillations. But the transient fluctuations of the general voltage supply induced by the interrupter were strongly amplified by all of the arc lights in the university,

* P. P. Koch, *Ann. Phys.*, *38*, 507 (1912).

† I am indebted for my dates and information on these early slit-diffraction experiments to the famous text of A. Sommerfeld, *Atomic Structure and Spectral Lines*, translation of H. L. Brose, E. P. Dutton and Co., New York, N.Y., 1923.

‡ A "Wehnelt interrupter," which interrupted the current about a thousand times per second, was used. I owe some of these details to a delightful account of the von Laue, Friedrich, and Knipping experiment at the University of Munich written by Max von Laue himself, which was printed and privately distributed by North American Philips, Inc., on the 50th anniversary of Röntgen's famous discovery.

which emitted deafening rattling noises every time the x-ray tube was in action. Knipping had constructed an automatic device which switched on the current from the university's electrical system for about five seconds and then switched it off again for twice that length of time. Fortunately the experiment started during vacation, but before the two scientists got any diffraction photographs, classes started and the nuisance of the "talking arc lamps" drowning out all the lectures can be readily imagined. Quoting from von Laue's account: "Due to some psychological law this primitive music was contagious to the students. They thought it a great joke to hum along with it. The merriment grew greater and greater until finally the whole lecture was ruined." Von Laue continues: "The rector of the university naturally ordered a strict investigation into the cause of the disturbance. All of the many committees which are part of a university were set in motion. But in vain. We physicists, who could have explained the whole thing, knew nothing about it!

"At the end of the first three weeks of the new semester the matter accidentally came to light. A mechanic, who had been ordered to look for the source of the disturbance, came into the cellar where the Wehnelt interrupter stood, listened, and at once reported it to the higher authorities. Then the waves of general indignation broke over all of our heads. All the various committees came and certainly did not show us the most agreeable side of their natures." They demanded an immediate remedy or else suspension of the experiments.

"Faced with this need, we turned to Röntgen to ask whether we might draw our current from his institute. We needed only to carry a conducting wire across the university court from the window of one institute to that of the other. And as soon as it was established that the university would thus no longer be disturbed, Röntgen gladly gave his consent.

"Just as matters had reached this point, the building committee walked into Sommerfeld's institute. They were the most powerful of all the university committees and apparently the least popular with the professors. They, too, wanted to let us feel the force of their anger, but we did not give them a chance to speak. Instead, we at once told them of the arrangement that we had made with Röntgen. They were nevertheless suspicious. They went to Röntgen themselves to have this confirmed. They returned a few minutes later in a state of indignation. We had deceived them. Röntgen was absolutely opposed to supplying current from his institute. We must therefore discontinue our experiments at once.

"So the four of us sat there, Sommerfeld, Friedrich, Knipping, and I [von Laue], and did not know what we should do next. Luckily our quandary did not last long. The solution came a few minutes later in the person of a mechanic, a fat, affable Bavarian, from the Röntgen institute. In his deep bass and local dialect, which considerably increased the humor of the situation, he said, 'The Geheimrat (meaning Röntgen) told me to tell you that you can go ahead and put up the wire. He is keeping to his agreement. It is just that whenever the building commission people come to him, the Geheimrat always says NO to them!' "

It was thus that the experiments of von Laue, Friedrich, and Knipping were continued until the end. They had tried at first to study the radiation diffracted by a crystal at very large angles, i.e., in the backward direction to the incident beam. When at last they tried placing the photographic plate *on the far side* of the crystal (copper sulfate), they obtained on the plate a central spot, produced by the direct beam going through the crystal, and, forming a pattern around the central spot, a group of symmetrically arranged spots of lesser intensity whose arrangement and symmetry depended on how the crystal was oriented relative to the beam. Röntgen, who was deeply impressed, did not believe at first that the spots represented an interference phenomenon through x-ray diffraction by the crystal lattice. The complete explanation became evident only after further work by the British physicists W. W. Bragg, his son Lawrence, and H. G. J. Moseley at Cambridge as well as certain other work at Munich by E. Wagner and J. Brentano. The five scientists worked with two crystals which demonstrated the monochromatization of the rays in the first crystal.

Professor Epstein, after coming to Caltech, would recount to his students very dramatically the occasion of the first success of the von Laue, Friedrich, and Knipping experiment—indisputably one of the truly great "breakthroughs" of early Twentieth Century physics—much as I have given it here.

The group of physicists from the University of Munich had the pleasant custom of meeting for luncheon and coffee at the little round marble-topped tables out-of-doors in the garden of the Café Lutz just across the way. The custom was so well established and accepted that the waiters of the café would dutifully see to it that the particular table for this group, at which on previous days they may have been discussing mathematical physics while writing the equations in pencil on the marble top, would be saved from day to day without washing it off so the discussions could continue. On a certain beautiful warm spring day in the Easter holidays of 1912 von Laue arrived a few minutes late at the accustomed table. Paul Epstein, P. P. Koch, the mathematician Rosenthal, and the physicists E. Wagner and W. Lenz were already there. But an unusual atmosphere prevailed at the physicists' table. Instead of conversing as usual, each one silently read a newspaper. Von Laue sat down, ordered coffee, and took up a newspaper waiting for a conversation to begin. But none did. One of the company made a remark, shortly after another did the same, and so on around the table, all of which struck von Laue as incomprehensible and mystifying. Finally what must have happened, but which he had not yet heard about, dawned on him, and he said, "Well, gentlemen, I assume from your remarks that the interference experiment had a positive result and that each one of you has been told this confidentially. I knew nothing about it until now." And this was indeed what had occurred.

It was while walking home from the Café Lutz, von Laue related, that the idea came to him of the theory of three dimensional space-lattice interference with which his name will be associated as long as our physics and chemistry of the Twentieth Century are remembered.

I have told this story to illustrate how Paul Epstein's arrival at Caltech in 1921 brought to this campus all the intellectual excitement and drama of what had been taking place in the great scientific centers of Europe. It had been R. A. Millikan's avowed purpose to do exactly this. He had insisted on special funds for this purpose as a condition of leaving the University of Chicago and coming to Caltech, as he himself said in his autobiography, "to build the best physics department of which I am capable." Some of the great scientists who came here, each for a substantial period of lectures, were C. G. Darwin, H. A. Lorentz, Paul Ehrenfest, Max Born, and Arnold Sommerfeld. Sommerfeld stayed only for shorter periods, but made several visits over the years. But since Paul Epstein had accepted a permanent appointment at Caltech his influence on all of us, both graduate students and postdoctoral men, was enormous. He was here, save for a few sabbatical leaves of absence, almost continually for 32 years, and for a great part of this time he taught substantially *all* of the advanced courses in theoretical and mathematical physics.

For example, in the three terms of the academic year 1925–1926 at Caltech, our records show that Professor P. S. Epstein taught the following seven advanced physics courses of one term each: Thermodynamics, Statistical Mechanics, Röntgen Rays and Crystal Structure, Theory of Electricity and Magnetism, Heat Radiation and Quantum Theory, Physical Optics, and the Quantum Theory of Spectral Lines. In addition to these he taught simultaneously a three-term course, Partial Differential Equations of Mathematical Physics. Thus his teaching load averaged three of these heavy courses per term. While carrying a comparable teaching load for many years, he found no difficulty also in writing some seventy or more papers and contributions to encyclopedias and an important 400-page text on thermodynamics.

In addition to his heavy load of lecturing, Professor Epstein took responsibility for several important academic activities. Along with R. A. Millikan, he was in charge of the weekly seminars, held each Thursday, which were attended by the entire physics department and frequently by men of other disciplines. At these seminars one of the graduate students usually would be asked to report on recently published developments in physics. For example, I recall clearly being asked by "Eppie" to report on certain papers of Louis de Broglie, in which the future Nobel Laureate developed, in its original and most elementary form, his famous idea of the waves associated with the electron.* Clearly he had selected me to do this because of my familiarity with the French language and my interest in French science in general. I recall that my audience ridiculed de Broglie's epoch-making ideas as I reported them at that time. Two years later, however, C. J. Davisson and L. H. Germer at the Bell Telephone Laboratories, seeking an entirely different postulated phenomenon (tunneling of electrons through crystal lattices), actually stumbled upon the fact of electron diffraction in crystals and the complete quantitative verification of de Broglie's prediction of the associated phase waves.

Another of Eppie's academic chores was to supervise our Caltech physics library and the purchase of its books and

* Rayonnement Noir et Quanta de Lumière, *J. Phys.*, *3*, 422–428 (1922); A Tentative Theory of Light Quanta, *Philos. Mag.*, *47*, 446–458 (1924); Recherches sur la Théorie des Quanta, *Ann. Phys.*, *3*, 22–128 (1925).

periodicals. In commemoration of this useful service over many years, a bronze bust of our dear old friend now stands on the seventh floor of the new Millikan Library, in the Physics and Mathematics section. An Epstein Memorial Fund to honor his memory has been established through donations from more than fifty of the many students whom he taught.

Besides these professional activities, Epstein was deeply interested in the ideas of Sigmund Freud about psychoanalysis. His interest had apparently been awakened during his two years in Zurich, where he had acquired an almost professional knowledge of the subject. In California, after he became Professor of Physics at Caltech, he joined a local informal group studying pyschoanalysis. The first Freudian psychoanalyst who settled in Los Angeles was Thomas Libbin (circa 1927), and Epstein immediately brought together jointly with Libbin a "Psychoanalytic Study Group" that operated for many years and was finally merged (in 1950) with the Los Angeles Institute for Psychoanalysis. In fact Professor Epstein was one of a number of members of the group who provided affidavits for prominent foreign psychoanalysts invited to immigrate in order to help build up a Psychoanalytic Institute in Los Angeles.

Epstein, though not an active Zionist, was deeply interested in the Jewish people. He knew well and was a friend of the famous mathematician Abraham Fraenkel (1891–1965), a long-time resident of Jerusalem, then Palestine, who may be said to have been the "grand old man" most responsible for the organization and planning of all secondary and advanced education when the State of Israel was established. Abraham Fraenkel was a prominent member of the faculty in the old campus of Jerusalem and remained for many years active in the new campus of the Hebrew University at Jerusalem. Within the American National Society of Friends of the Hebrew University he organized the Academic Council of Southern California and served for many years as its president.

After the Second World War Professor Epstein became concerned with the inroads that communism was making among some of the young intellectuals of America and was invited to join the American Committee of the Congress for Cultural Freedom. In 1951, he served as one of the three U.S. delegates to the seminar conducted by the Congress in Strasbourg, France.

The writer was fortunate to have been one of some half dozen or more graduate students in physics, the first group who attended Professor Epstein's three-term course, Partial Differential Equations of Mathematical Physics, given when he first arrived at Caltech. He was master of three languages, Russian, German, and French, but his English at that time was still halting and afflicted with a heavy foreign accent reminiscent of all of the three languages more familiar to him. He would write the equations on the blackboard, but his first attempts to explain them in English were hampered painfully by deficiencies in his vocabulary. However, we were all amazed by the rapidity with which he progressed in his facility with English. A little later I learned that he had worked diligently to build up his English vocabulary, as by reading the newspapers and working the crossword puzzles with an English–German dictionary close at hand. It has been rumored also that he loved to read the Encyclopaedia Britannica for relaxation, starting with the A's and going systematically straight through the alphabet. He was gifted with an amazingly retentive memory. Nothing which interested him ever seemed to escape him. One of my fellow graduate students once remarked aptly, "Eppie's memory is like sticky flypaper!" I once asked Eppie if he could advise others how to acquire so wonderful a memory as his. His answer: "Jesse, to have a good memory the first thing you must do is to *trust* your memory."

During my studies as a graduate student working for the doctor's degree at Caltech I attended essentially every course Professor Epstein ever gave, and I am sure that I have learned far more physics from him than from anyone else. During none of his lectures can I recall ever seeing him refer to notes, nor have I ever seen him consult a table of definite integrals! Nevertheless his lectures, though completely logical, were never prepared in advance. He once told me that he made it a principle to lecture in this way, extemporaneously, only planning in his mind what he would say as he walked from his home to Caltech, a distance of perhaps half a mile. The result was excellent, because it forced him to do his reasoning *viva voce* in front of his class and on the blackboard. Thus we could watch him think and reason—an excellent lesson in how to do the same ourselves. I can only recall two other lecturers who were his equal in this facility and freedom of presentation, H. A. Lorentz and Arnold Sommerfeld. Eppie frequently made mistakes, but seemed able to sense quite promptly that something was wrong and would hunt for the error, frequently with our participation in the search. Because of this his classes were never dull, but what also added greatly to their interest was his extensive knowledge of the history of the physical sciences and of the characters of the people, from charlatans to geniuses, who had discovered or created its concepts and facts. The story of the discovery of x-ray diffraction from crystals, which I have recounted here, is only one of dozens with which his lectures were seasoned.

When Professor Epstein arrived at Caltech to teach, the advent of so celebrated a scientist from the cultural centers of Europe received considerable newspaper publicity. A certain club of socially prominent and highly influential ladies in Los Angeles (the name of which I have forgotten) sought to lionize him socially, as though he were some famous artist or orchestra conductor. They invited Eppie to lecture to their group on Science. He decided to put an end to such requests once and for all by a very characteristic and forthright method. He accepted graciously, with the proviso that they furnish him with blackboard and chalk. On the appointed day he went to their clubhouse and with perfect equanimity delivered a lecture on Planck's quantum theory, complete with all the mathematics. He knew perfectly well, of course, that his audience understood not one sentence of his talk nor one symbol on the blackboard. Few people in this world could have managed to do this successfully, because most speakers are to some extent psychologically dependent on a display of understanding and approval from their audience. Eppie, being very nearsighted and a little hard of hearing, was sufficiently insulated from the ladies to be able to talk almost as naturally as though he were addressing a class at Caltech or the National Academy of Sciences. He was rewarded with the result he had hoped for—they never invited him again!

In 1930, nine years after his arrival at Caltech, Paul Epstein married Alice Emelie Ryckman. Their home at 1484 Oakdale Avenue in Pasadena was the scene of many a warm and hospitable festivity, treasured in the memory of his students and associates.

The Epsteins had one daughter, Sari, now Mrs. Frank Mittelbach. The deep affection Eppie felt for his wife is clear in the dedication of his text on thermodynamics to her.

With the growth of the Caltech faculty, many of the subjects that had so heavily overloaded Eppie's teaching schedule were gradually taken over by newly-appointed members of the physics department. To the end of his career, however, he maintained responsibility for thermodynamics and statistical mechanics. In addition to his excellent text on thermodynamics, he wrote two extended articles on Willard Gibbs and his scientific contributions which were published by the Yale University Press in 1936.

In 1927 and 1929 Paul Epstein served as exchange professor at the Institute of Technology at Aachen, Germany.

In his research career, after his arrival at Caltech, Epstein at first continued his work on Bohr's form of the quantum theory, culminating it in 1922 with three papers in the *Zeitschrift für Physik* and one in the *Physical Review.* Later Epstein took part in the development of quantum mechanics initiated by Heisenberg and Schroedinger. An important paper in the *Physical Review* (1926), "The Stark Effect from the Point of View of Schrödinger's Quantum Theory," * should be mentioned in this connection.

In 1930, Epstein was elected to the National Academy of Sciences.

P. S. Epstein also devoted considerable attention to borderline problems related simultaneously to both physics and several cognate sciences. Examples are "Zur Theorie des Radiometers" (1929), "Reflection of Waves in an Inhomogeneous Absorbing Medium" [the Heaviside Layer] (1930), "On the Air Resistance of Projectiles" (1931). Other examples of borderline problems which Epstein studied were the settling of gases in the atmosphere, the theory of vibrations of shells and plates, and the absorption of sound in fogs and suspensions. Two of his articles in this category outside of physics are especially worthy of mention. Both appeared in a monthly literary and scientific magazine, *Reflex,* published in the 1930's in Los Angeles, California, and edited by Dr. S. M. Melamed. The first of these articles, "The Frontiers of Science," is a highly scholarly presentation of certain central problems of both philosophy and religion set forth in their relationship to recent concepts on the frontiers of physics and mathematics. His discussion of the old philosophical and religious problem of free will *vs.* the concept of "scientific determinism" and the "law of causality" is particularly noteworthy since, in one form or another, all of human-

* See also in this connection "The New Quantum Theory and the Zeeman Effect" (1926); "The Magnetic Dipole in Undulatory Mechanics" (1927).

kind has struggled for centuries with these questions. Epstein invokes the "principle of indetermination" of Werner Heisenberg, enunciated in 1927 and points out that, built into the very structure of Nature herself, there is a basic principle which precludes mankind from making with indefinitely high accuracy the requisite physical measurements to predict the future from a knowledge of the present with the ideal certainty postulated by S. Laplace in the Seventeenth Century. This article is indeed a rewarding one to the reader.

Epstein's other article in *Reflex* is "Uses and Abuses of Nationalism." In it he reveals a deep and farsighted understanding of certain patterns in the history of the political development of nations. In this discussion Eppie's complete alignment on the side of liberalism becomes self-evident. He takes the history of France as the vehicle for his argument and perceives the Dreyfus affair in the Nineteenth Century as an important turning point, away from imperialism and militarism at home and toward friendly cooperation abroad. In the opinion of the writer this article of Epstein's revealed his deep prescience in world affairs. It was written long before de Gaulle made the wise decision to withdraw France from its military commitments, first in Southeast Asia and later in Algeria. Other nations could well "profit by this example."

It is a pity that these two articles, splendidly exemplifying Paul Epstein's remarkable scholarship, erudition, and prescience in humanistic matters well outside his own fields of specialization, should be lost from the far wider circulation they deserve. The writer wishes to suggest that they be republished.

After Paul Epstein's retirement as Emeritus Professor at Caltech in 1953 he served as a consultant for several large industrial companies. Prominent among the many reports submitted by him in such work was his "Theory of Wave Propagation in a Gyromagnetic Medium" (1956).

Paul Epstein died at his home in Pasadena on February 8, 1966, at the age of 83, after suffering with admirable stoicism a prolonged and painful illness (herpes zoster or shingles). He was beloved of many students and colleagues, and his long and useful life stands as a splendid tribute to his brilliant mind and his altruistic sharing of it with others.

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KEY TO ABBREVIATIONS

Am. J. Phys. = American Journal of Physics
Ann. Physik. = Annalen der Physik
Naturwiss. = Die Naturwissenschaften
Phys. Rev. = Physical Review
Physik. Blatt. = Physikalische Blätter
Physik. Z. = Physikalische Zeitschrift
Proc. Nat. Acad. Sci. = Proceedings of the National Academy of Sciences
Rev. Mod. Phys. = Review of Modern Physics
Verhandl. Deut. Physik. Gesell. = Verhandlungen der Deutschen Physikalischen Gesellschaft
Z. Physik. = Zeitschrift für Physik

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