III. Max Planck

"It is one of the most painful experiences of my entire scientific life that I have seldom—in fact I might say never—succeeded in gaining universal recognition for a new result, the truth of which I could demonstrate by a conclusive, albeit only theorerical proof."[314]

Max Karl Ernst Ludwig Planck was born in the Baltic port of Kiel (Duchy of Holstein, then part of Denmark) on the 23rd of April in 1858; he was the fourth child (Hermann, Hildegard, Adalbert, Max, and Otto) of Emma Patzig of Greifswald, second wife of widowed Johann Julius Wilhelm von Planck of Göttingen, a professor of civil law at the University of Kiel. Max Planck was a member of a long line of idealistic, generous, and incorruptible men dedicated to the law, the church, and the state; he was to make his own genial mark by conceiving a physical theory for which he is justly considered the spiritual father of modern physics and one of the immortals of science.

Young Max attended elementary school in the city of his birth: many years later, he still remembered the troops that occupied Kiel during a brief war over disputed territory. In 1867 Max's family, including two children (Hugo and Emma) by Professor Planck's first marriage, moved to Munich (33 Briennerstrasse). Life in the colorful Bavarian city and a liberal education greatly influenced his adolesence. He was only thirteen when Germany fought a war with France (where his brother, Hermann, was killed) and Bismarck founded a unified German Reich. In Munich Max entered the *Königliche Maximillian Gymnasium* (Ludwigstrasse). He received a good musical education and became an excellent pianist; he abandoned early any thought of a musical career, but music remained his life avocation. His mathematical talents were soon awakened under the stimulus of Professor Hermann Müller, a good-natured, fine didactician ("...*scharfsinnigen und witzigen Mann*"), who also taught astronomy and mechanics. The professor's explanation of the principle of conservation of energy and its universal validity struck Planck with the force of a revelation.[210] He was impressed by the harmony between the laws of human reasoning and the laws of nature."*The quest for the laws which apply to this absolute appeared to me*"—wrote Planck—"*as the must sublime scientific pursuit in life.*"[314]

In October 1874 Max Planck registered at the University of Munich; initially he favored mathematics, but he was soon attracted to physics. He attended lectures on *Analytische Geometry*, a course on *Höhere Algebra*, and another on *Mechanische Wärmetheorie.* Planck already preferred the interpretation, the reasoning, rather than the performance of experiments and was inspired by the fact that physical observations could be ordered into logical systems. He favored deductive, sometimes axiomatic, methods.

Before his graduation, Planck attended the University of Berlin in 1877–1878. The professor of physics was Hermann Ludwig Ferdinand von Helmholtz (1821–1894), who had come by way of physiology, was known to physicians as the inventor of the ophthalmoscope and to physicists for his decisive work in the establishment of the law of conservation of energy; the very prestigious and awe-inspiring von Helmholtz delivered badly organized lectures in a monotonous, barely audible voice to a dwindling audience. The other professor of physics was the renowned Gustav Robert Kirchhoff (1824–1887) who had contributed richly to the understanding of thermodynamics (*thermomechanik*); he delivered carefully prepared, well-organized lectures that were equally boring. "*I must admit*"—wrote Planck—"*that the lectures of these men netted me no perceptible gain.*"[314]

To quench his thirst for scientific knowledge, Planck read extensively: in thermodynamics he noted that the path of a process could be ignored, only the initial and final states were relevant. The laws of thermodynamics, he felt, account for much absolute truth, represent what is eternal and unchanging in Nature, and constitute veritable keys to the doors of the unknown. His solitary readings led him to the treatises on *Mechanische Wärmetheorie* of Rudolf Julius Emanuel Clausius (1822–1888) whose enlightening clarity made a great impression on him. From the study of engines and the pragmatic evaluation of work obtained from heat came the observation that it is not

Fig. III-1. *Privat Dozent* Max Planck (1880).

possible to change all heat into energy: in the course of events, while energy is never lost, a certain amount becomes unavailable for further use. Clausius worked out a version of the second law of thermodynamics which admitted that not all energy can turn into work but accounted for it quantitatively.[99] The measuring stick was *entropy,* a purely mathematical ratio, a fixed relationship between quantities tending always to increase. Planck's first scientific writings constituted a rephrasing of Clausius's ideas; however, he was not satisfied with Clausius's definition of irreversibility.

Planck passed the *Staatsexamen für das Höhere Lehrant* for a teaching certificate in mathematics and physics, and for a brief period, he taught these subjects in secondary schools. He presented his doctoral thesis on the second law of thermodynamics[299] and received his Ph.D. degree from the University of Munich on the 28th of July, 1879. A copy of his thesis presented to von Helmholtz remained unread, whereas Kirchhoff read his but disapproved of the application of entropy to irreversible processes. Attempts made by Planck to discuss his paper with Clausius, by mail or in person, met with elusive excuses: he was badly disappointed. In June 1880 Planck was given the *venia legendi* from the University of Munich for his probationary paper on equilibrium of isotropic bodies.[298]

An understanding of entropy and Planck's fascination with it is necessary in order to grasp his thought and contributions. He followed his habilitation paper (as *Privatdozent*) with others, always showing that certain facts of physics and chemistry followed from a knowledge of entropy. He considered entropy as a predilection of nature for the final state; because in all natural (irreversible) processes and because of the qualifications it imposes on energy changes and directions, he came to regard it as the most important property of physical systems. At the time that he studied and worked at it, no one else seemed interested in entropy. However, Josiah Willard Gibbs (1839–1903) of Yale University, another theorist, had followed the same line of thought and had published a little earlier. When the role of entropy was finally recognized widely it was Gibbs and not Planck who received the belated credit. (Fig. III-1.)

Planck remained *Privatdozent* at the university and for five years continued to live in his parents home in Munich; he lacked opportunities for interchange with other theoretical physicists and longed for a professorship, which did not seem to materialize. In May 1885 the University of Kiel offered an associate ("extraordinarius") professorship of physics to Heinrich Rudolf Hertz (1857–1894), who refused it; the offer was then made to Planck. He suspected that the invitation was not so much a recognition of his merits as the result of his father's friendship with the professor of physics at Kiel; in reality, he had made a most favorable impression on the university's keen representative ("...hat mir einen ausserondentlich gungstigen Eindruck gemacht, sowohl durch Klarheit und Bestimmtheit in der Erörterung wissenschaftlicher Probleme").[229] He was happy to accept the offer: "*it came*"—he said—"*as a message of deliverance...the happiest occasion in my life.*"[344] Professor Planck offered four simultaneous lecture courses and used the remaining time for his research. The new appointment provided greater security and the opportunity of establishing his own household: he married Marie Merck, his fiancée from Munich in March 1887, just before his twenty-ninth birthday.

Planck had been working on a paper to be presented for a prize offered by the Philosophical Faculty of Göttingen; he completed it in Kiel. It was a clear and comprehensive work on the nature of energy with a ninety page historical introduction.[310] In 1887 the contest was ended; two other papers presented received no award, but Planck received only second prize. The faculty withheld approval of part of the work where Planck had sided with Helmholtz in a controversy with their own professor of physics. As a consequence of this contrariety, Planck was at last brought to the attention of von Helmholtz, who now read his papers and gained an appreciation of his student. One of Planck's papers on entropy in chemical reactions of dilute solutions brought him into controversy with Svante Arrhenius (1859–1927); although, as usual, Planck was right in defending the general validity of the laws of thermodynamics,[61] it took sometime before this was generally acknowledged.

In November 1888, after the death of Kirchhoff and doubtless because of von Helmholtz's influence, Planck was offered an assistant professorship of theoretical physics at the Faculty of Philosophy of Berlin and an appointment as director of the newly created Institute of Theoretical Physics; again, Hertz had been offered the position first and had declined. The appointment proved to be a turning point in Planck's career. In Berlin he finally found the congenial surroundings that contributed to his scientific understanding; he promptly attained professional recognition in the stimulating medium of intellectual giants; he was made a member of the *Physikalische Gesellschaft*, elected to the *Königlich-Preussiche Akademie der Wissenschaften* and promoted to professor ordinarius. At last he had someone in the person of Professor von Helmholtz, a man with a clear mind and a great power of judgment, with whom he could debate his points of view. In turn, Planck now had an opportunity to appreciate the modesty and the dignity of his old professor, whose greatness became evident to only a few who gained his respect and confidence. He came to worship his charming mentor with filial trust and devotion and to rate his praise higher than any public acclaim; admiringly, he joined Helmholtz in evening concerts at the professor's home in which both virtuosos performed enthusiastically.

Planck collaborated in posthumous editing of Clausius's book on mechanical theory and of Kirchhoff's lectures on electricity and magnetism.[247] In 1893 he delivered a memorial lecture on Heinrich Hertz that was greatly appreciated by Helmholtz.[301] Planck's own work, *Vorlesungen über Thermodynamik* (1897), a systematic and skillful presentation, in itself puts Planck in the forefront of clear and critical thinkers;[205] the text became a standard reference and went through ten editions in 30 years.[315]

A revival of the theoretical system of "energetics" brought about a controversy in reference to the analogy drawn between a weight falling from a greater to a lower height and the passage of heat from a higher to a lower temperature. Planck emphasized the basic difference between the two processes as between the first and second laws of thermodynamics; again, the acceptance of his thesis was ultimately brought about by the unrelated arguments of someone else. The Viennese physicist, Ludwig Boltzmann (1844–1896), working on a statistical relationship of thermodynamics and molecular motion, developed a remarkably accurate computation of the absolute number and mass of the molecules, permitting him to deduce the second law of thermodynamics in almost the same way as Clausius; Boltzmann identified the ratio, entropy, as a measure of disorder, and it was he, not Planck, who received the credit for winning physicists to Clausius's version of the second law. "*I was not to have the satisfaction*"—complained Planck half a century later—"*of seeing myself vindicated.*"[299]

Fig. III-2. Gathered around Frau Planck: Max and Karl, standing; Grete, Irwin, and Emma.

Boltzmann and Planck both had attacked the revival of "energetics," but neither one acknowledged the other's company. Planck had failed to appreciate the significance of Boltzmann's statistical approach to entropy: he felt that there was no place for probabilities in the absolute laws of nature. A student of Planck's argued against the applicability of Boltzmann's statistical interpretation; Boltzmann riposted sarcastically.[61] It was only later that Planck accepted, demonstrated, and fruitfully utilized Boltzmann's interpretation of entropy.

Planck entered a running controversy in connection with the thermal spectrum: his contribution to the theory of heat radiation combined his studies on *irreversibility* with the new concepts of electrodynamics. He asserted that the principle of entropy increase, although not having independent value, extended to thermal, chemical, electrical and other forces of Nature. Instead of the older concepts of "accord" and "discord" for heat absorption adopted by Irish John Tyndall (1820–1893), Planck introduced the principle of energy conservation for gases in order to explain the equilibrium between ether motion and the heated body.

Contemporaneously, there was an increasing interest in the electromagnetic theory of light of James Clerk Maxwell (1831–1879) of Scotland. Planck, who always regarded the search of the absolute as the loftiest goal of scientific activity, set to work on it seeking to relate his earlier thermodynamic studies with the new theory.

Robert Bunsen (1801–1899) and Kirchhoff had developed spectrum analysis. In his search for a perfect light source, Kirchhoff had produced a veritable little oven with blackened inner walls: when it was progressively heated to incandescence, it emitted visible light of shorter and shorter wavelength through a pinhole opening. The temperature of Kirchhoff's *black body* was precisely regulated and controlled through the use of a bolometer, invented by the American physicist Samuel Pierpont Langley (1834–1906). The energy of the emitted radiations was known to be unevenly distributed across the spectral frequencies, but the wavelength was not dependent on the material of the black body, only upon its temperature. John William Strutt, 3rd Baron Rayleigh (1842–1919), found a formula that agreed only with the observations made with black body rays of long wavelength. Wilhelm Carl Werner Otto Fritz Franz Wien (1864–1928), using a different approach, had deduced another that correlated well only with short wavelength rays of light. This discrepancy was referred to as the *black body mystery*; something fundamental obviously was missing. Whereas others had based their efforts on the dependence of wavelength on temperature, Planck suspected that the fundamental connection was dependence of entropy upon energy. It was in seeking to find a formula that would fit the entire range of spectral wavelengths tha Planck brought forth his famous hypothesis.

On October 19th, 1900 Planck presented a paper concerning Wien's spectrum formula[303] to the *Physikalische Gesellschaft* of Berlin: it contained his empirical formula, based on two constants, and accounted for the distribution of spectral frequencies in black body radiations. Heinrich Rubens (1865–1922) stayed up all night comparing his black body measurements with Planck's formula; he appeared the next morning at Planck's door to announce that he had found excellent agreement. Planck felt intuitively that the simplicity and adequacy of his formula could only be because it represented something *fundamental*. It was his view that he had failed to invest his formula with physical meaning: "*After some weeks of the most intense work in my life*"—he said later—"*clearness began to dawn upon me, and an unexpected view revealed itself in the distance*"—a clear example of the intuitive power of the exceptional mind: a sudden illumination arising from the depths of the unconscious after long cogitation. He had discovered the sought-after meaning in a brilliant achievement of rigorous logic; he sacrificed the equipartition of energy and then decided to have recourse to Boltzmann's previously rejected statistical interpretation of the second law of electrodynamics; thus, self-critically he was able to derive his interpolation formula. While walking in the woods near his home in the Grunewald, Planck turned to his son and said: "*Today I have made a discovery as important as that of Newton.*"[15,61]

On December 14th, 1900 Planck appeared again before the Physical Society and declared that his earlier expression could best be derived from an entirely new hypothesis: that energy did not flow continuously but in bursts of indivisible units that he called the "*elementary quantum of action,*" a minimum quantity directly related to the frequency (wavelength) of the electromagnetic wave with which they are associated. The ratio between the energy and the quantum of rays, an invariable factor, Planck called h ($h = 6.55 \times 10^{-27}$ erg sec). The idea of these *quanta* seemed to attack the century-old accepted view that light consisted of waves, thus breaking with classical thinking. Although Planck did note that this idea could find applications in other fields of physics and chemistry, he did not anticipate, as he admitted decades later, that his work would have extraordinary consequences. *Planck's constant*, as it was eventually evident, is one of Nature's invariables; understanding and application of it brought formidable epistemological revisions.

It is an eloquent commentary on Planck's character that in the first edition (1897) of his text on thermodynamics,[302] he argued against Boltzmann's system; in the second edition (1905) he revised his views and credited Boltzmann with the revelation of the physical meaning of the second law, yet made no mention of his own theory. In 1906 in his book *Vorlesungen über die Theorie der Wärmestrahlung,*[315] Planck made a masterful presentation of the successive steps that led to the quantum hypothesis. The idea of quanta was considered at best as a clever solution and had been ignored at first. It was the work of Albert Einstein (1879–1955) that brought wide recognition of the importance of Planck's work. Einstein showed (1905) that Planck's hypothesis gave the quantitatively correct interpretation of several physical phenomena.[169] It took two more decades to consolidate a self-contained quantum theory;[205] this gap alone gives the measure of Planck's inspiration and insight.

Working with monochromatic light rays, Philipp Edward Anton Lenard (1862–1947)† had been the first to observe that electrons were bounced from strips of metal, and whereas the intensity of the light did not affect their speed, the changes in wavelength did.[268] For years Lenard's observations remained unexplained until Einstein revealed them as *photoelectric effects.* Einstein used statistical mechanics to analyze electromagnetic radiations, calculated their entropy and concluded that radiation consisted of discrete quanta of energy, later called *photons* by Gilbert Newton Lewis (1875–1946): Einstein deduced a law that gave the relation between the various magnitudes with *Planck's constant* as a basic factor; he regarded the quantization of all energy exchanges, absorption as well as emission as a generalization of Planck's theory. Planck himself was reluctant to accept Einstein's interpretation and generalization. He was far from being absorbed by his own creation and continued to give his attention to a variety of other subjects, including the theory of relativity.

In 1904 Jules Henri Poincaré (1854–1912) asserted the impossibility of determining the absolute motion of an inertial system by dynamical, optical, or electromagnetic means. This led Hendrich Antoon Lorentz (1853–1928) to do work on the phenomena of moving bodies and to postulate that neither space nor time retained for themselves an independent reality, thus promulgating a "theory of relativity." In his "special" theory of relativity, a separate publication from that relating to the photo-electric effect, Einstein (1905) accepted this postulate as a fundamental law of nature and introduced another: that the speed of light is universally constant and independent of the speed of the source. Eventually, the theory of relativity proved to be the missing keystone in the structure of physics.[210] In 1906 Planck was among the first to take up the theory of relativity; he stated that since the relative presupposes the existence of the absolute, relativity underscored his own search for absolute laws.[314] Planck published a number of papers relating thermodynamics to relativistic mechanics using Einstein's equivalence of mass and energy. To a greater extent than other scientists, he took his readers along the exciting path of his ideas and of the concepts involved, providing them with textual commentaries. Planck reached the conclusion that the classical separation of internal from external energy, in which the former is independent of velocity, was no longer tenable; he was successful in testing some of the basic assumptions of the theory of relativity.

Walther Hermann Nernst (1864–1941), who had formulated a third law of thermodynamics, had been brought from Göttingen to Berlin in 1905; his law resulted from attempts to find a method of calculating chemical equilibrium from thermal data. By the application of quantum theory, Nernst was able to test the specific validity of the law. In 1911 Planck supplemented Nernst's formulation by stating that at absolute zero, the entropy is equal to zero for chemically homogeneous solids or liquids.

Planck and Einstein had corresponded since the turn of the century; they did not meet until September 1909 in Salzburg at the congress of the Naturforscher Gesellschaft at which Einstein was invited to deliver a paper, "*The development of our views on the nature and constitution of radiations.*" Lise Meitner,† a young Viennese physicist studying in Berlin under Planck, was in the audience.[277] Einstein asserted: "...the next phase of the development of theoretical physics will bring us a theory of light that can be interpreted as a kind of fusion of the wave and emission theories." Rising to open the discussion, Planck said: "*That seems to me to be a step that, in my opinion, is not yet called for.*" His caution has been often misconstrued as uncertain-

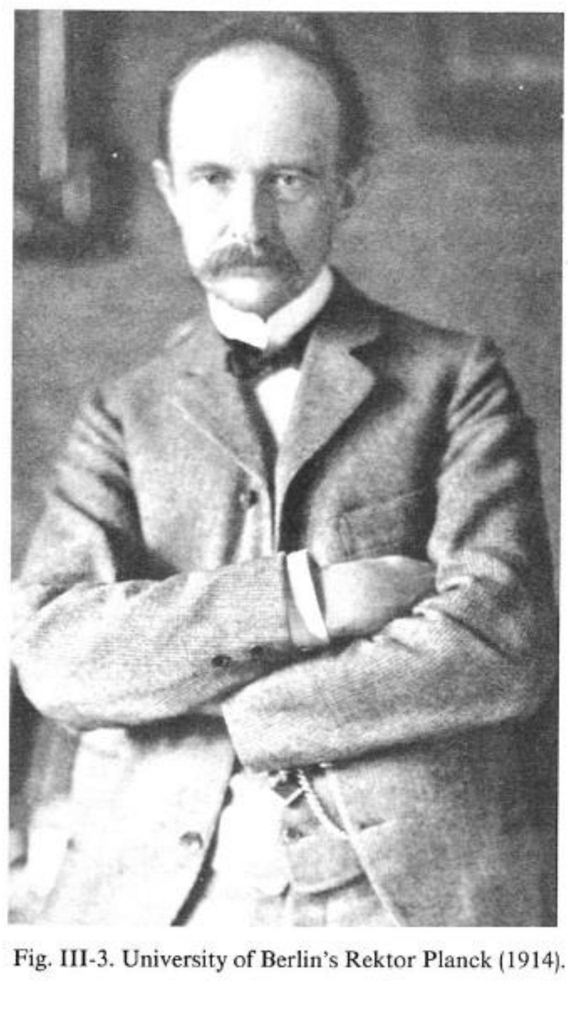

Fig. III-3. University of Berlin's Rektor Planck (1914).

† See Biographical Notes on page 171.

ty about his own accomplishments.[15] Waves and particles were to remain the imprecise aspects of the same reality.

In 1909 Planck's wife died of probable pulmonary tuberculosis ("Lungenkatarrh"), leaving him with their two sons and twin daughters (Fig. III-2). In March 1911 when he was 53 years old, he married his wife's niece, Marga von Hoesslin, who became mother to his children and his constant companion for the remainder of his life.

Planck was unexcelled as a teacher of theoretical physics. He was a dedicated perfectionist and prepared his lectures with extreme care and delivered them with enthralling clarity. Planck was an early morning train commuter: he honed his lecture notes while traveling third class in the company of clerks and shop girls.[293] At the university on Unter den Linden, his eight o'clock class filled the room to capacity. He spoke in a quiet and pleasant voice without recourse to his notes; to hear him, said one of his students, was an esthetic pleasure. Planck usually introduced his subject with a simple equation on the blackboard; then, progressively and from general principles, more complicated equations unfalteringly and clearly developed. The students learned to discuss fully the questions raised. Planck had no mannerisms and only one or two pet phrases, e.g.: "*We may proceed one step further*" (Wir können noch einen Schritt weiter gehen).[293] He was said to be approachable but not inviting, friendly but cautiously reserved; when he was asked for an opinion, he often postponed his answer. He had an unusual following of admiring listeners; students were often moved by respect, affection, and even reverence towards him.[277] (Fig. III-3.)

Planck had a limited number of graduate students, among them Max von Laue (1879–1960) and Lise Meitner (1878–1968)†; he would merely give the students a subject for their dissertation and expect them to finish their own thesis unassisted.

Ernest Solvay (1836–1922), a Belgian chemist and industrialist who had profitably patented a soda process, had a physical theory of his own and was desirous to have it discussed by experts.[275] Walther Nernst suggested to him the sponsoring of a conference of leading physicists who would be free to discuss also the current problems of physics; Planck agreed with the project. An invitation was issued to a score of physicists with the offer of a refund of expenses and an honorarium: in the summer of 1911 they met at the Hotel Metropole in Brussels. In spite of Planck's reluctance, the theme of the conference was: *radiation and quanta*. Among those present were Planck, Einstein, Nernst, Madame Curie, Poincaré, Perrin, Rutherford, Langevin, Sommerfeld: Lorenz presided; Maurice de Broglie, Frederick Alexander Lindeman, and Victor Moritz Goldschmidt were the secretaries: they were a collection of natural introverts talking different languages, distrustful and jealous of each other but passionately unified by their common scientific thrust (Fig. III-4). It took the vast scientific authority, the linguistic versatility and all the incomparable tact of Chairman Lorenz to keep the intense discussions well focused and the sometimes harsh remarks overlooked.*

The remark was made by de Broglie that among those present, Poincaré and Einstein were in a class by themselves. Planck's contribution to the conference was an attempt to develop a modified statistical mechanics that was considered by some as a second quantum theory. Planck thought enough of it to include it in the second edition (1913) of his book *Wármestrahlung.*[61,315]

In Brussels Max Planck and Walther Nernst were greatly impressed by Einstein and upon their return to Berlin, engaged in a delicate project to attract and to have him accepted in Berlin. Planck had said (1910): "*If Einstein's theory should prove correct he will be considered the Copernicus of the twentieth century.*" In August 1913 Planck and Nernst went to Zurich to offer Einstein the directorship of the *Kaiser Wilhelm Gesellshaft zur Forderung des Wissenschaften.* A generously endowed membership in the Prussian Academy of Sciences and a professorship of physics at the University of Berlin were additional inducements. Einstein was allowed time to think it over while they visited the Rigi; when he met the returning visitors at the funicular's station, he was wearing a red rose on his lapel, the announced sign of his acceptance. In the spring of 1914 he moved to Berlin. In response to Einstein's inaugural address to the Akademie, Planck was candid: "*Even if one is not satisfied with the special theory of relativity because it favors uniform motion, one should recognize this as a particular advance in knowledge...*"[276] For all of his professional life, Planck admired Einstein's work, particularly as it did not relate to quantization. Despite the vast differences in their attitudes, characters and allegiances, through compromising political situations and misunderstandings, he remained a friend and protector of his genial younger colleague; in return, despite prevailing bigotry, embarrassing experiences and eventual departure, Einstein retained his respect and affection for Planck.

Ernest Rutherford (1871–1937) had discovered the atomic nucleus and conceived a planetary arrangernent of electrons.[350] Niels Henrick David Bohr (1885–1962) showed that the electronic constitution of the atom was governed by Planck's constant. This discovery (1913)[43,44] contributed further to the rapidly accumulating body of evidence in favor of the quantum theory. Sommerfeld extended Bohr's theory to other systems, starting the development of *quantum mechanics* in which Planck took an active part.

During one year (1913–14), Planck held the exalted position of Rector of the University of Berlin (Fig. III-3). As the First World War began, there was no mention of it in the Rector's address to the student body. A manifesto justifying the German invasion of Belgium was signed by 93 German intellectuals, including Erlich, Röntgen, and Planck; Einstein and oth-

† See Biographical Notes on page 171.

* See Subject Notes on page 183.

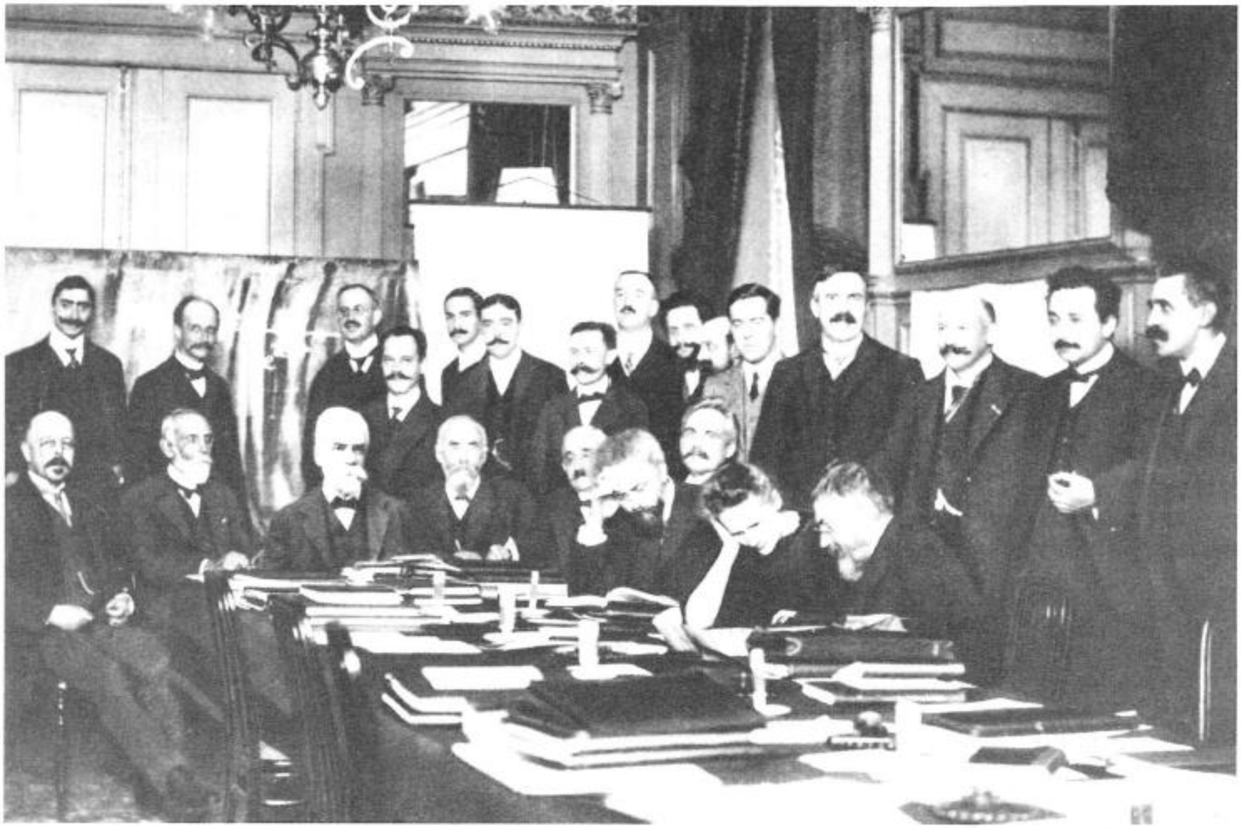

Fig. III-4. Participants in the First Solvay Conference (1911). *Seated:* Walther Hermann Nernst (1864–1941), Germany (Nobel 1920); Louis Marcel Brillouin (1854–1948), France; Ernest Solvay (1838–1922), Belgium; Hendrick Antoon Lorentz (1853–1928), Netherlands (Nobel 1902); Emil Gabriel Warburg (1846–1931), Germany; Jean Baptiste Perrin (1870–1942), France (Nobel 1926); Wilhelm Carl Werner Otto Fritz Franz Wien (1864–1928), Germany (Nobel 1911); Maria Salomé Sklodowska Curie (1867–1934), France (Nobel 1903, 1911); Jules Henri Poincaré (1854–1912), France. *Standing:* Victor Mortiz Goldschmidt (1888–1947), Belgium; Max Planck (1858–1947), Germany (Nobel 1918); Heinrich (Henri Leopold) Rubens (1865–1922), Germany; Arnold Johannes Wilhelm Sommerfeld (1868–1951), Germany; Frederick Alexander Lindemann, later Viscount Cherwell (1886–1957), Germany; Maurice de Broglie (1875–1962), France; Martin Hans Christian Knudsen (1871–1949), Denmark; Friedrich Hasenöhrl (1874–1915), Austria; G. Hostelet and Edouard Herzen, Solvay's Belgian associates; James Hopwood Jeans (1877–1946), England; Ernest Rutherford (1871–1937), England (Nobel 1908); Heike Kammerling Onnes (1853–1926), Netherlands (Nobel 1913); Albert Einstein (1879–1955), Germany (Nobel 1922); Paul Langevin (1872–1946), France.

ers of the University of Berlin preferred to make a separate declaration of their faith in European unity. In the beginning of the war, Planck's youngest son, Erwin, was wounded and made prisoner in France; Karl Planck (1888–1916) was killed near Verdun in May 1916. Planck's twin daughters, Grete and Emma, both died in childbirth (1917 and 1919); both had married Ferdinand Fehling, a professor of history at Heidelberg. "Planck's bad luck touches me deeply"—said Einstein—"I could not hold back my tears; he keeps his composure, but one senses the hidden nagging sorrow."[229] Planck and his wife, Marga, assumed the care of his orphaned infant grandchildren along with their own seven-year-old son, Hermann.

The Plancks lived at 21 Wangenheimstrasse in the Grunewald suburb of Berlin, in the midst of a veritable colony of university professors; their neighbors marveled at the sound of fine music that came through their windows. Planck was an accomplished musician who had once demonstrated a new harmonium before the German Physical Society; he had composed songs, performed as a choirmaster, written an operetta and participated in amateur theatricals. After Helmholtz's death, the tradition of musical evenings was transferred to Planck's home, where, in the company of friends, he enjoyed playing the piano, often with Einstein and his violin. It must have been inspiring to behold: two of the outstanding thinkers of the century giving themselves to the passion of music, trading the hard logic of scientific truth for the sympathetic vision of artistic truth, vibrating together in the joyful interpretation of someone else's genius.

Robert Andrews Millikan (1868–1953) had carried out (1914) an exhaustive test of Einstein's photoelectric law:[282] he obtained a value for Planck's constant that agreed with the one computed by Planck. In 1918 Max Planck received the Nobel Prize "in recognition of the services rendered by him to the development of physics and specially by his discovery of the elementary quanta."[306] Nernst received his own recognition

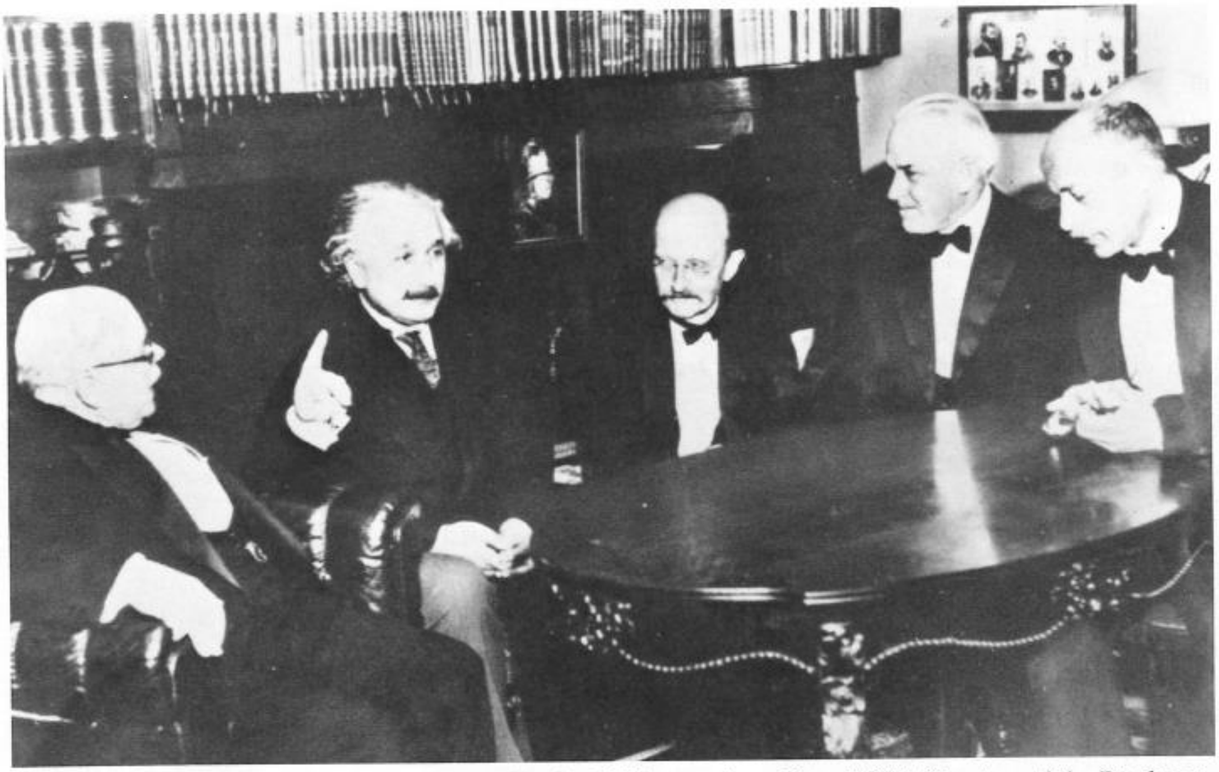

Fig. III-5. Nobel laureates Nernst, Einstein, Planck, Millikan, and von Laue (1928). (Courtesy of the Boerhaave Museum, Leiden, The Netherlands.)

by the Nobel Prize of Chemistry in 1920. (Fig. III-5.)[290] Einstein, who in the meantime had built his "general" theory of relativity (1916), received the 1921 Nobel Prize "for his services to theoretical physics and specially for his discovery of the law of photoelectric effect".* Postwar antisemitism centered on Einstein and for more than a decade kept Planck busy shielding his friend and colleague while repeatedly discouraging him from accepting tempting offers from Zurich, Leiden, and the United States. While he was presiding over a meeting of the *Naturforscher Gesellschaft* on the theory of relativity at the Badhalle of Bad Nauheim near Frankfurt, Planck became pale as he raised his voice trying to maintain order.[325]

In 1923 Arthur Holly Compton (1892–1962) verified experimentally and worked out a quantal equation predicting the change of wavelength of scattered radiations. This was a discovery which further affirmed the theory of quanta but emphasized a wave–particle duality.

In the aftermath of the war, the Franco–Belgian boycott of German scientists and their exclusion from the Solvay conferences was strongly outweighed by the Nobel Prizes that went to Berlin (Nernst, Haber, Planck, Einstein). In 1927 the "enemy scientists" were again invited to Brussels: the ferment of the Solvay conference was *electrons and photons*. Max Born (1882–1970) and W. Heisenberg (1901–1976) presented a paper on quantum mechanics that, in their view, was a simple extension of the theories of Planck, Einstein, and Bohr[31b]; they restated their recently formulated "uncertainty principle." Bohr presented his "complementarity theory" that had also been recently stated at the Volta Conference. As if this were not sufficiently overwhelming, Erwin Schrödinger (1877–1961) presented his views on "wave mechanics." Einstein expressed concern with the extent to which causal account in space and time was abandoned in quantum mechanics[305]; it was during this discussion that he uttered his disbelief in God playing dice ("...ob der liebe Gott würfelt"). From modest beginnings and scope, the Solvay conferences eventually proved most fruitful in elucidating the quantum paradox.

In 1928 at age 70, Planck retired from his chair and received the Silver Shield of the Reich from President von Hindenburg. His successor was Erwin Schrödinger. Planck welcomed wave mechanics as the solution of the crisis of the law of causality. In his reply to Schrödinger's inaugural lecture to the Akademie, Planck said: "*You have been the first to show how the spacio-temporal processes in an atomic system can in fact be completely determined [if]...one regards as their elements not the motions of particles but of material waves; and [you have also shown] how the mysterious discontinuous proper values of the energy of the system can be calculated with absolute accuracy from your differential equation...while the...physical significance of the waves can be left undecided.*"[61]

Planck continued to patronize the famous Thursday afternoon Physics Colloquia for the excellence of which he was thought to be responsible. Other prominent members of the faculty, visitors and students who attended these conferences through the years appreciated them as models of extemporaneous interchange.

* See Subject Notes on page 183

Planck dressed with stiff collar and bow tie; he appeared superbly professional and always master of the situation; Nernst was loquacious and attractively temperamental; Einstein was gentle but with hardly a doubt; von Laue was forceful but inarticulate.[279] Tall and trim Planck was aloof and distinguished among them; he looked intently from behind his rimless glasses; a moustache drooping at the commissures gave the only note of discord; he offered a handshake with a predictable pump stroke, but his happy disposition was equally invariable. He displayed an entirely independent way of thinking[279] and may have given an impression of slight pedantry, but nothing was further removed from his character.

The Physics Colloquia were enriched by specially invited guests who stimulated the regulars. Among the eminent guests invited to Berlin was Niels Bohr (Fig. III-6); his visit (1920) was long remembered. Bohr presented his view of electronic orbits and indicated that an exact determination of electron jumps could not be made. Einstein objected to any theory that left to chance the time and direction of elementary processes; both he and Bohr raised questions that the other could not answer, but neither one would give up his interlocutor. Bohr, Einstein and Planck talked among themselves all during the visit. The students understood very little; they commissioned Lise Meitner to invite Bohr to a luncheon with them at Dahlem, but excluding the professors ("Bonzenfrei").[277]

Arnold Sommerfeld (1868–1951) once wrote Planck a note in which he stated:

> *"You cultivate the virgin soil*
> *while picking flowers was my only toil"*
> (Der Sorgsam urbar macht des neue Land
> Dieweil ich hier und da ein Blumenstrausschen fand.)

to which Planck replied:

> *"All picked flowers let's combine*
> *and in the brightest wreath them bind."*[314]
> (Was ich gepflückt, was du gepflückt
> Das wollen wir verbinden,
> und da sich ein zum andern schickt
> Den schönstern Kranz draus winden.)

Planck and his wife were ardent alpinists and undertook carefully planned climbing expeditions that lasted several weeks. We know of no account of Planck's alpinism, only that he pursued it with serious dedication. Through the years, his signature appeared on the guest books of a variety of mountain resorts: the Ortler in Italy when he was over 60 years of age, Jungfrau in Switzerland when he was 72, Gross Venediger in Austria when he was 79. Doubtless, he endured the self-imposed anxieties, the hazards, and the pains of mountain climbing for a look at the azur silhouette of the lofty peak and the shrouded mountain yonder and for the exquisite vast view that offers wings to the imagination: for the spiritual rewards, rather than for the conquest.

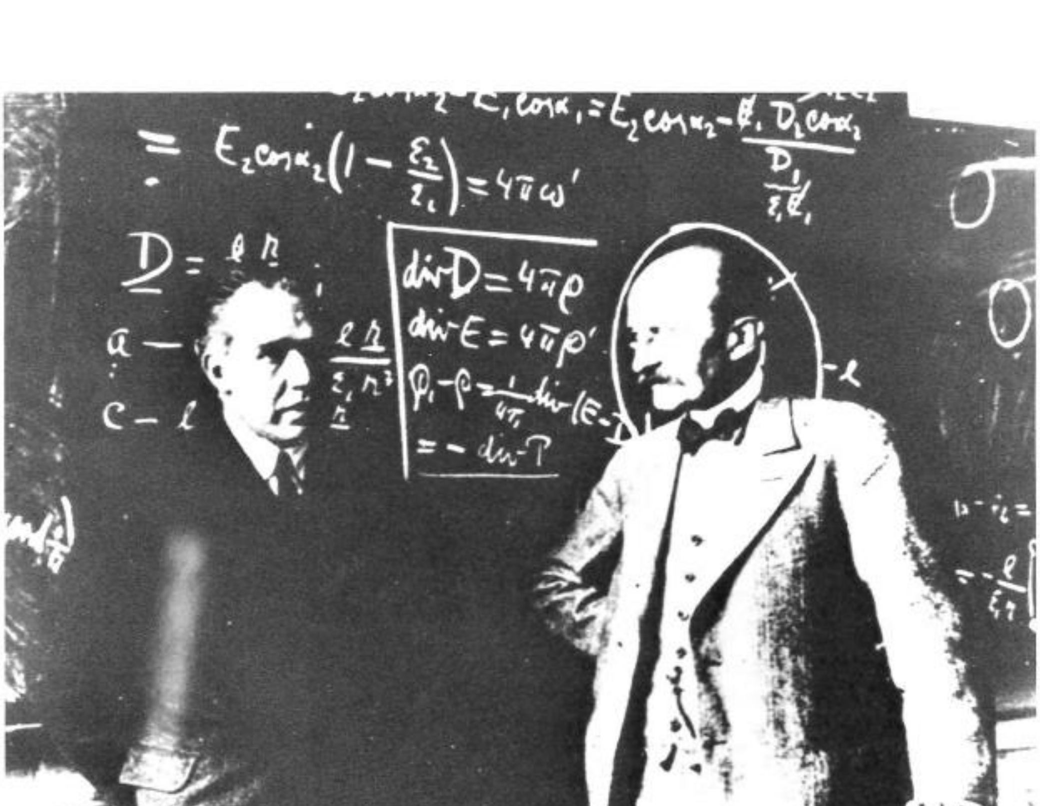

Fig. III-6. Planck with Physics Colloquium's guest speaker Niels Bohr (1920).

Fig. III-7. Max Planck, Secretary of the Prussian Academy of Sciences (1930). Planck's signature.

Planck explained the charms of thermodynamics and lectured on the nature of physical theory to other scientists; eventually he spoke to larger groups about these matters and his own concepts of the philosophy of science. He was responsive to ever-increasing demands for lectures to lay audiences and for articles in lay publications; he proved unsuspectedly prolific as well as influential. Unquestionably, he was one of the most heard and read philosophers of science of his time.[309] (Fig. II-7.) A bibliographic list of his nontechnical writings is impressively extensive.

As a philosopher of science, Planck postulated an inalterable goal: the attainment of a single bond for the ensemble of all forces of nature (*Einheit des physikalischen Weltbildes*). He argued that the concepts of causality and freedom of the will are only apparently contradictory[304]; from without, the will obeys the determination of cause and effect, whereas from within the will is free. Causality, he felt, is not subordinate to logic; it is rather a category of reason (*Vernunft*), like a signpost intended to help us find our way in a maze of occurrences and to point out the path of fruitful research. Still, one cannot do without the products of imagination (*Einbildungskraft*) that cannot be reduced to causality. Old theories, he said, have disintegrated on the impact of new experimental techniques; we need new working hypotheses generated from appropriate total views (*Weltanschauung*), rather than from strict scientific knowledge; yet, he also pointed out, if a hypothesis proves fruitful, we become accustomed to it, and gradually it seemingly acquires an intuitive clarity (*Anschaulichkeit*) of its own.[305]

Planck's searching mind also made its incursion into the realm of religion.[309] As many another original

Fig. III-8. Pencil sketch of Planck at work, by Kapp, autographed by the subject (1932). (Courtesy of the Niels Bohr Library.)

Fig. III-9. At home, Planck worked at a standing desk (1938).

thinker, he seemed reluctant to credit himself with the genial inspiration of an instant and sought a creditable *external source.* In his view, religion is compatible with a rigorous scientific point of view, whereas science, "*when not conceived merely rationally,*" invites a faith in the future, a faith in an "*external reality.*" Causality demands that men remain responsible to their consciences. Science, he said, brings to light ethical values, such as veracity and reverence by the "*glance at the divine secret in one's own breast.*"[245] Both science and religion consistently struggle against skepticism and dogmatism, against incredulity and superstition. Just as science should aim for exact maxims, there should be absolute values in ethics. Neither science nor ethics, he added, can be considered ideally complete.[303] Youthful yearning for a comprehensive world view, warned Planck, need not decay into extremes of mysticism and superstition: those who adopt immature social theories become dispossessed of their natu-

Fig. III-10. Octogenarian Planck with great-granddaughter (1946).

In an essay on *Naturwissenschaften* (1943), Planck said: "*I am furthermore convinced that we will need still more profound, at present not even predictable, changes in our physical concepts before the quantum theory will have the degree of perfection that used to be ascribed to the classical theory.*"[276] (Fig. III-9.)

Erwin Planck (1893–1945) was among the numerous personalities implicated in the *Valkyrie operation*, a plot designed to assassinate Hitler on July 20th, 1944 and to put Berlin under military control. The bomb brought to the map room of the Wolf's Lair (*Wolfschanze*) in Rastenburg, East Prussia by Colonel Claus Schenk (1907–1944), Count von Stauffenberg, failed in its intended purpose: several of the principals were summarily executed before the day was over. Erwin Planck, who had become secretary of state under Chancellor Bruning (1930–32) and had been an aide to Chancellor Schleicher and von Papen, was imprisoned, tried, and sentenced to die.* Planck pleaded for his son's life in a letter to Hitler: "*As an expression of the gratitude of the German people for my life's work, which has become an imperishable intellectual possession of Germany, I ask for my son's life.*"[291] In January 1945 Erwin Planck was executed. "*I have lost my closest and best friend,*" said Planck, and he sat at the piano *to remember* the melodies dear to his son.

The Plancks had gone to live in their country home at Rogaetz on the Elbe, near Magdeburg, where they eventually found themselves in the theater of

ral inhibitions as well as of impartiality... Planck, a churchwarden of long service in Grunewald, professed his belief in an omniscient divinity "*identical in character with the power of natural law.*"

As permanent secretary to the Prussian Academy of Sciences, Planck reported to Chancellor Hitler in the spring of 1933; he used the opportunity to plead, alas unsuccessfully, for retention of some Jewish scientists, particularly of Fritz Haber (1868–1934), who had earned a Nobel Prize for Germany in 1918. Haber died in exile; in defiance of official interdiction, Planck presided over a posthumous tribute to Haber in Harnackhaus in the Dahlem suburb of Berlin.[291] ("*Haber hat uns die Treue gehalten, wir werden ihm die Treue halten.*") He finally resigned (1937) the secretaryship of the Academy under official harrassment. (Fig. III-8.)

During the Second World War, the fourth that he had witnessed in his lifetime, Planck's home and his precious library were destroyed by fire; while he was lecturing in Kassel, he was trapped in an air raid shelter for several hours. He wrote (1940) on attempts to a synthesis of wave and corpuscular mechanics.[310]

Fig. III-11. Sculptured head of Planck. (Courtesy of the Boerhaave Museum, Leiden, The Netherlands.)

Fig. III-12. Two Mark currency coin of the Bundesrepublik of Germany honoring Planck.

Fig. III-13. German and Swedish postage stamps honoring Planck.

war; they were transported to safety in Göttingen (May 16, 1945). U. S. Army Colonel Gerard Peter Kuiper (1905–1973),† a member of the ALSOS* mission, drove Planck to safety in his jeep. Under the hasty circumstances of the occasion the Plancks worried about provisions to be carried and also fetched a bottle of old Rhine wine to offer to their chivalrous rescuer. In June 1945 Planck delivered a lecture on the "*Phantom Problems of Science*"[312] in which he asserted that these pseudoproblems, usually resulting from wrong connections or assumptions, are more common than it is generally assumed; on this occasion, he also stated that even the most intelligent person is no more capable of observing himself than is the fastest runner of passing himself.[277] In 1947 he was already in his eighties, tired and frail (Fig. III-10) when he accepted the Royal Academy's invitation to the Newton's celebration in England; his purpose was to reopen the bridge of interrelationships between physicists of both countries. On October 4th, 1947 he expired at the University Hospital of Göttingen from the complications resulting from a bad fall and fracture. Planck's funeral services were held in the crowded church of Saint Alban in Göttingen. Orations were offered by Otto Hahn and Max von Laue. His remains rest in the Göttingen Stadtfriedhof; his tombstone bears only his name and the enduring formula of Planck's constant.

Upon the initiative of American occupation authorities, the Kaiser Wilhelm Institutes of Germany became the *Max Planck Gesellschaft zur Fordering der Wissenschaften* (Fig. III-11.) In 1938 astronomers had celebrated his 80th birthday by naming an asteroid *Planckiana*. A two-mark silver coin bearing his effigy was made currency in 1947. (Fig. III-12.) A 30-pfennig postage stamp was also issued by the German government. (Fig. III-13.) In 1958 the German Physical Society celebrated the one hundredth anniversary of his birth in Berlin with participants from both sides of the wall: the initial sessions took place at the State Opera House in East Berlin; later, all participants continued their discussions at the Kongress Halle in West Berlin.[399] The principal address was given by Werner Heisenberg: Otto Hahn (1879–1968), Lise Meitner, and Max von Laue were in attendance. That year, the German Physical Society awarded the Planck Medal to Wolfgang Pauli (1900–1958)† of Switzerland.

"*No man is born with a legal claim to happiness, success and prosperity in life*"—said Planck in the winter of life—"*The individual has no alternative but to fight bravely in the battle of life and to bow in silent surrender to the will of a higher power that rules over him.*"[313] Einstein wrote to Planck's widow: "His gaze was directed to eternal truths, yet he played an active part in all that concerned humanity and the world around him. How different and how much better it would be for mankind if there were more like him."[98] "His greatness has been acknowledged by his contemporaries"—wrote Max Born—"Will posterity confirm this judgment? We who have witnessed the incredible transformation of science which his work has brought about in less than half a century have no doubt it will."[61]

* See Subject Notes on page 183.

† See Biographical Notes on page 171.