Max Planck

had been a student of Planck. Y.N.

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[A lecture given to the Education Group of the Institute at the Institute's House on November 19, 1958. Published in January 1959]

THE year 1958 marks the centenary of the birth of Max Planck. The second half of this century has seen one of the greatest revolutions through which science and philosophy have ever passed and which was initiated by his work. For the young physics student of today Planck's name ranks with those of Galileo and Newton. For them it has become the name of a basic principle of physics rather than that of a person. Most of us who knew him remember Planck only as a man in advancing years with a kindly manner and a correct, if somewhat old-fashioned, way of dressing. The dark suit with the starched shirt and the black bow tie fitted well with his quiet speech, and the careful choice of words would have marked him out as a typical member of the Prussian higher Civil Service had it not been for the penetrating eyes under the huge dome of his forehead. When I entered Berlin University in 1925 I belonged to the last class of students to whom Planck gave his famous course of lectures on theoretical physics. Three years later, at the age of seventy, he retired from his professorship which he had held for almost forty years.

However, Planck's retirement from teaching did not mark the end of his interest in physics and he remained a regular participant in the Berlin physics colloquium which was then the main forum for the discussion of current results and ideas. In this gathering his personality impressed itself less forcefully on to the memory of the young generation than that of some of the other members. There was Nernst, temperamental, uncompromising and full of intuition; Einstein, beautifully clear, with a gentle humour and hardly a doubt; von Laue, searching and forceful, if inarticulate; and Schrödinger, critical but enthusiastic. It seemed strange to us that it should have been Planck, with his meticulous and slightly pedantic manner of lecturing, who had provided the basic idea on which most of these discussions centred. It was even said, half jokingly, that Planck did not like the quantum theory and there is a grain of truth in this statement which perhaps holds the key to the understanding of his real greatness. Owing to his background and training, Planck had strong convictions about the nature of the laws of physics and it required an almost superhuman strength of logic and intellectual honesty to discover and uphold a concept which conflicted with the basis of his belief. He was an ultraconservative whom the love for truth had turned into an unwilling revolutionary.

Max Karl Ernst Ludwig Planck was born on April 23, 1858, at Kiel in the Duchy of Holstein where his father was Professor of Law. The Planck family has given Germany a number of distinguished scholars and civil servants. The father's cousin was also a Professor of Law, at Göttingen, and later became famous as the founder of the German Civil Code. There can be little doubt that the necessity of rule by laws was deeply ingrained in Max Planck's mind but he was drawn not so much to the codification of human activities as to the more fundamental laws of nature. In his scientific autobiography he explains his choice of study because he was impressed by the similarity between the laws governing thought and those 'in the sequence of impressions which we receive from the outer world'. The cautious and careful wording of this sentence is as characteristic of Planck as its meaning.

The conviction that the laws of physics must be 'absolute', not

admitting of any exception, returns again and again in Planck's papers and lectures throughout his long life. Family tradition and the stability of the world in which he spent the formative years made him feel that his conviction must be correct. Planck was a schoolboy of thirteen when Bismarck founded the German Reich and he lived through the holocaust of its final destruction in 1945,
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but he was already sixty when this stability was shaken for the first time. It was this search for the absolute law which determined not only Planck's particular field of research but also the way in which he approached it.

At school in Munich, where the family had moved in 1867, Planck received the law of conservation of energy 'like a message of salvation' and he recalls the impression which the example made on him by which this law was illustrated. A brick which had received energy by being lifted up to a high building would retain this energy for many years after which it could be released when the building crumbled and the brick fell on somebody's head. When leaving school Planck decided in favour of physics, his other interests being classics and music. He first studied in Munich and then went to Berlin where the writings rather than the lectures of Helmholtz and Kirchhoff furthered his interest in the law of energy conservation. Reading Clausius' papers, he learned for the first time of the qualifications which are imposed on energy changes by the second law. Far from regarding the latter as a complication, Planck was fascinated by the entropy concept because it indicated the direction of a process and thus gives more information than is contained in the first law. It is typical of Planck that his first original contribution to physics dealt with a more concise formulation of the concept of irreversibility which, he felt, had been too loosely defined by Clausius. On the basis of his considerations he deduced that, whereas for a reversible process there is no distinction between the original and the final state of the system, the final state of an irreversible process is distinguished by a 'preference' which nature expresses for it. Planck then showed that the Clausius entropy was the measure for this preference in a 'natural' process. He made this

FIRST WORK (IRREVERSIBILITY)

LATER NATURAL RADIATION

work the subject of his doctoral thesis and later pointed out that its effect on the physicists of the day was strictly zero. Conversation with his Munich professors convinced him that they had no interest in it and he suspected that he received the degree only because they knew his class work. Helmholtz did not read the thesis and Kirchhoff disapproved of it because he did not like the application of entropy to irreversible processes. Clausius was the last hope but he did not reply to letters and when Planck went to Bonn in the hope of meeting him personally, he did not find Clausius at home.

This was in 1879. Planck's method of attacking the energy problem was that of pure thermodynamics and he did not deviate from it for another twenty years. It was a corollary of his basic belief in the identity of the laws of physics and of thought that the former can be discovered by thought processes. In this search for the absolute law, the strict but generalized formalism of thermodynamics appealed to him particularly. He was impressed by the fact that in pure thermodynamics the path of a process could be ignored, only the initial and final states being of relevance. He felt sure that the energy laws must have the same absolute validity as those of Newtonian mechanics.

At first the lack of interest shown by his colleagues did not deter Planck from following up his work on the second law with a number of papers in which he deduced from it the equilibrium conditions of physical and chemical systems, dealing first with phase changes and then with gas mixtures. He was, however, depressed when he learned later that he had merely repeated the earlier work of Willard Gibbs and that the results of his work were no fresh contribution to knowledge.

In 1885 Planck was offered an assistant professorship in Kiel and he records that his delight was not even tempered by the suspicion that he owed the position less to his scientific reputation than to the fact that the head of the department was an old friend of his father. He felt that the professorship gave him the opportunity for wider scientific activity and he wished to make the most of it. The work on the second law was further extended and his well-known papers on the dissociation of gases and on the properties of dilute solutions fall in this period. This work led to a controversy between Svante Arrhenius and Planck in which the former pointed out that in electrolytic dissociation the particles are charged, to which Planck replied that the laws of thermodynamics have general validity, whether the particles are charged or not. A little earlier, Planck had sided with Helmholtz in his dispute with Weber. This work had lost him the sympathy of the faculty in Göttingen and with it the first prize which Planck had hoped to win with a treatise on the nature of energy. On the other hand, the paper created interest in Berlin and in 1889 he was asked to come to Berlin as successor to Kirchhoff. There he remained not only to his retirement but almost to the end of his long life. The move to Berlin meant for Planck the beginning of the most fruitful phase of his life. He delighted in the company of men who, in his own words, 'were then the world's scientific leaders'. His friendship with Helmholtz changed from admiration to true devotion and Planck records that he rated Helmholtz's praise higher than any public success. Among the other physicists the successive directors of the Physical Institute, Kundt and Rubens, seem to have been his closest friends.

The appointment to the Berlin professorship also had its effect on Planck's colleagues at the other universities, who began to correspond with him and the time when his own letters had remained unanswered was now definitely over. He became interested in the theory of electrolytes developed by Nernst in Göttingen and the ensuing correspondence led to a co-operation in ideas which was to become extremely fruitful in the next three decades. Another correspondence on the same subject, however, led to wide disagreement and eventually to very outspoken argument. This was the exchange of views between Planck and Wilhelm Ostwald.

After the formulation of the law of conservation of energy in the middle of the nineteenth century, Rankine had proposed a theoretical system which he called 'energetics' and in which it was hoped to explain all the physical phenomena in terms of energy. Not much headway was made at the time but more than thirty years later the great chemist Ostwald revived these ideas not only as a basis for theoretical physics but as a philosophical concept. He felt certain that the energy concept held the key to a unified description of all the known laws of nature and that the system of energetics would rapidly remove all existing discrepancies and uncertainties in physics. Unfortunately, his own and the enthusiasm of his followers led to hasty and somewhat vague formulation of the basic principles of energetics.

Half a century later Planck refers to his correspondence with Ostwald as critical but always friendly. Finally, the matter came to a head when in 1896 Boltzmann subjected in the *Annalen der Physik* Ostwald's book and one of his lectures to detailed and devastating criticism. In a paper immediately following that of Boltzmann, Planck associated himself with the attack on Ostwald without, however, mentioning the latter's name. Neither did he make reference to Boltzmann's paper, but it is noteworthy that the *Annalen* were edited 'in collaboration with the Physical Society of Berlin and especially with M. Planck'. Boltzmann's paper is dated: 'Vienna, November 2, 1895' and Planck's: 'Berlin, December, 1895'. Both Boltzmann and Planck were extremely outspoken and the title of Planck's paper *Gegen die neuere Energetik* (Against the newer energetics) has the ring of a Lutheran thesis. He simply showed, on the example of an ideal gas, that one of Ostwald's definitions, the volume energy, has no physical significance.

Planck's curious attitude in associationg himself with the attack on Ostwald but not associating himself with Boltzmann receives its explanation in the same volume of the *Annalen*. Also in December 1895, Zermelo, a young pupil of Planck's, had submitted a paper in which he tried to show that Boltzmann's statistical interpretation of thermodynamics was not applicable. Zermelo based his attack on a theorem by Henri Poincaré according to which any dynamic condition of a set of point masses is bound to recur after some time and this would be at variance with an irreversible process. Boltzmann, within three months and still in the same volume of the *Annalen*, had no difficulty in demonstrating that, while Poincaré's theorem was correct, it could not be applied to thermal processes. He was slightly irritated and suggested that Zermelo would probably suspect the dice to be loaded since he had been unable to throw a one a thousand times running, because the probability for such an event was not zero.

It is quite clear that Boltzmann was right and that Zermelo, and with him Planck, had failed to appreciate the significance of the statistical approach. Planck's failure must appear very human because he freely admitted later on that he did not wish to see the significance of statistical methods. His whole outlook in physics was determined by the search for absolute laws of nature and he felt that the laws of probability could not have a place in such a basic theorem as the second law of thermodynamics because he wanted this law to express a certainty. When in the following year his famous textbook *Thermodynamik* appeared, he reiterated his conviction in the preface. There are, he said, three different theoretical methods in thermodynamics. The first, that of Maxwell and Boltzmann, is based on the concept of kinetic molecular motion which, besides requiring detailed assumptions concerning the structure of matter, involves difficulties of principle. The second method, of Helmholtz, does not demand such a detailed picture and only in general terms assumes heat to be based on motion. However, this limitation of assumptions also entails a severe limitation of applicability. The third method, the one favoured by Planck and on which he bases his book, makes no assumptions at all either about the nature of matter or that of heat. Instead the whole treatment is developed logically from very general, empirically determined, laws of nature. The inference is, of course, that these are absolute laws, and, since the logical conclusions in the human mind represent a true replica of physical causality, they must lead to true results.

I have mentioned these events in some detail because it is important to be clear about Planck's ideas on the nature of physical laws three years before he formulated the quantum concept. Only in this way can we appreciate the magnitude of his achievement.

Planck's predecessor, Kirchhoff, had considered the establishment of thermal equilibrium in a radiation enclosure and had come to the conclusion that the intensity and spectral distribution depend solely on temperature. The surprising result that the radiation was independent of the nature of the radiating matter immediately attracted Planck's interest because he realized that the relation between black body radiation (*Hohlraumstrahlung*) and temperature must represent another of the absolute laws of physics. Moreover, two independent experimental investigations into the energy distribution of radiation were being pursued at that time in Berlin, and Planck was in close contact with the progress of the research.

The first attempt to find a radiation formula failed. Planck had based it on Maxwell's electrodynamic theory and hoped to show that a system of linear oscillators with different frequencies would lead to energy exchange between the frequencies and to the establishment of the observed radiation distribution. This did not turn out to be so and the treatment in addition provoked Boltzmann's criticism. In his disappointment Planck turned to the other absolute law which had held his attention so long and began to investigate the relation of energy with entropy rather than with temperature. It was this approach which eventually yielded the significant result and, surveying the trend in physics publications at the time, it is clear that it was Planck alone who by the choice of his previous work and his scientific inclination was predestined to use this particular theoretical method. He himself said that the lack of interest in the entropy concept on the part of his colleagues provided him with the peace of mind necessary to complete his calculations without fear of being disturbed or of being anticipated.

Applying the energy-entropy relation to Wien's radiation law, Planck was delighted to discover an extremely simple relation which he thought at first to be of general validity. However, just then the radiation measurements of Kurlbaum and Rubens in Berlin were being extended to longer wavelengths and the results began to show an unmistakable deviation from Wien's formula actually 4 years later

towards the law postulated at about the same time by Lord Rayleigh on the basis of statistical considerations. On October 19, 1900, Kurlbaum communicated this work to the Berlin Physical Society, but the authors had informed Planck beforehand of the trend of their measurements. By an ingenious combination of the two laws Planck arrived at his famous radiation formula in which by the use of two constants the relations of Wien and Rayleigh-Jeans appeared as the limiting cases. In a contribution to the discussion after Kurlbaum's lecture, Planck submitted his own equation. Rubens called on him the next morning to say that in the night he had compared their experimental values with the new formula and had found complete agreement.

exactly

In this discussion remark, Planck first explained his approach along the entropy consideration and then stated that he had formed a number of arbitrary expressions for the entropy. From these he had selected that which was by far the simplest logarithmic relation between entropy and energy. He thus claimed no more than an empirical relation, based on the choice of simplicity for a fundamental law. This fateful choice was thus based on Planck's firm belief in the analogy of human thought processes to the laws of nature.

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The title chosen by Planck for this short paper is significant. It reads: *Uber eine Verbesserung der Wien'shen Spektralgleichung* (Concerning an improvement of Wien's spectrum formula). In his modesty he felt that he had not yet made a fundamental contribution because, although finding the correct equation, he had failed to invest it with physical meaning. In the following two months Planck discovered that meaning in a unique achievement of rigorous logic and devastating self-criticism.

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In its integrated form Planck's radiation formula gives for the entropy S of an oscillator of frequency ν,

$$S=\left\{\frac{a'}{a}\left(\frac{U}{a'\nu}+1\right)\log\left(\frac{U}{a'\nu}+1\right)-\frac{U}{a'\nu}\log\frac{U}{a'\nu}\right\}$$

where U is the energy and a' and a constants. In order to gain insight into the physical significance of this expression. Planck was forced to have recourse to Boltzmann's statistical interpretation of the second law. How very hard this change of attitude must have been for Planck is clear from his own words, written forty-two years later: 'Until then I had not been interested in the relation between entropy and probability. It did not appear attractive to me because any law of probability admits to exceptions and because, at that time, I ascribed to the second law validity without exception.' He makes no bones about the fact that he was driven to 'Boltzmann's method' because he could not see any other way. He then goes on to point out that the determination of a probability requires counting and 'therefore it was above all necessary to regard the energy as the sum of discrete equal elements'. He presented the argument in exactly the same form in his first publication of the quantum principle when on December 14, 1900, he addressed again the Berlin Physical Society, introducing in the same sentence 'the natural constant $h = 6{\cdot}55 \times 10^{-27}$ erg. sec'.

He had arrived at it by considering a number N of equal oscillators with average energy U and by assuming the total energy to be made up of a number P of equal energy elements ε so that $NU = P\varepsilon$. Forming the complexion which gives the number of ways in which the P energy elements can be distributed over N, and which is the required probability, he calculated the entropy of the oscillator system as:

$$NS = k \log \frac{(P+N)!}{P!\ N!}$$

which can be written in the form:

$$S = k\left\{ \left(\frac{P}{N}+1\right) \log \left(\frac{P}{N}+1\right) - \frac{P}{N} \log \frac{P}{N}\right\}$$

This theoretical expression is identical with the semi-empirical interpolation formula if a'/a is set equal to k and a' becomes the new universal constant h.

There is a curious contrast in this first paper between the manner in which the energy quanta are introduced—almost as a mathematical oddity—and a sentence in the introduction in which he clearly said that he believes his work to be of far reaching importance 'for other fields of physics and also of chemistry'. There can thus be no doubt that even at this early stage Planck had realized the significance of his theory but it is equally clear that he had no intention of emphasizing, or even acknowledging, its revolutionary character. Instead, his efforts were now directed towards finding a place for his quantum of action in the framework of classical physics. He freely admitted more than forty years later that he had not suspected the break away from classical theory to be 'so radical'. Logic, to which Planck gave even greater weight than to his concept of absolute laws, had forced him to acknowledge the correctness of the hateful statistical approach. It was now forcing him to doubt the whole system of classical physics in which he had been trained. He thoroughly mistrusted, not the validity, but the physical significance of the concept which he had created in spite of himself. Planck, whose ancestors made it their business to uphold the law, was in no hurry to overthrow classical physics, a task which in the end he left to Einstein, and very little was heard about the quantum theory for another five years.

In the famous volume of the *Annalen* in 1905, which also contains his work on relativity and on Brownian motion, Einstein published a paper on 'the production and transformation of light' in which he replaces the classical aspect of light as a continuum by corpuscular radiation of energy quanta. He uses this to explain the experimental data on the photo-electric effect and on the ionization potentials. Two years later there followed his quantum theory of the specific heat of solids which, in the range of temperatures then accessible, yielded a brilliant interpretation of Weber's experimental results on diamond.

Einstein was then still at Berne which precluded any close collaboration between him and Planck at that time. Moreover, the way in which Einstein's first paper is presented shows that he regarded his own idea of the quantized nature of all energy exchanges as new and as a generalization of Planck's introduction of h in the radiation formula. Indeed, apart from the surprising sentence—already quoted—in the introduction to Planck's fundamental paper, Planck avoided for a long time generalization of his theory and in particular he evidently did not like to acknowledge the physical existence of energy quanta. It has to be remembered that his work of 1900 had involved two distinct steps and that he disliked both. The first had been the victory—in his own considerations—of Boltzmann's statistical interpretation. How profoundly this had affected him is shown in the preface to the second edition of his *Thermodynamik* in 1905. In his severe self-criticism and honesty he refers here to the opinions expressed in the first edition and revises them completely, crediting Boltzmann with the revelation of the physical meaning of the second law. In support he quotes the work on black body radiation by Wien, Rubens and Kurlbaum, and by others. However, the second step, the quantum theory—now in its fifth year—is not mentioned.

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This preface is dated January 1905, two months before Einstein's first paper was written. In the spring of 1906 Planck published his *Wärmestrahlung* based on his lectures in the winter 1905–6. The preface mentions his radiation theory, but the reader is told in the following sentence that it is by no means complete. Einstein's work is quoted neither here nor in the preface to the second edition in 1912. Finally, in 1921, Planck makes full acknowledgement of Einstein's contributions but even then he cannot quite overcome his cautious attitude with regard to the light quanta. He points out that in the ideas about the propagation of light two different concepts, that of a 'smooth' and that of a 'spotted' wave front, remain irreconcilable.

and NOBEL

In between the two Einstein papers another important development had taken place: Nernst's enunciation of the third law of thermodynamics. This was much closer to Planck's way of thinking than Einstein's photon gas and in the 1912 preface of *Wärmestrahlung* he makes enthusiastic reference to it. His own formulation of Nerst's theorem, zero entropy at absolute zero, he regards as 'the true basis of the quantum hypothesis' but, typically, qualifies the statement by saying 'so far'. With Nernst's appointment to a professorship in Berlin in 1905 Planck's collaboration with him became even closer and while Nernst, the experimentalist and theoretical chemist, lacked Einstein's insight into the meaning of the quantum theory, he made up for it by an unequalled degree of common sense. The quantization of the specific heat of the ideal gas is an example of this. As early as 1914 Nernst postulated the existence of 'gas degeneracy' simply because he felt—and rightly so—that his theorem was a universal law and as such was unlikely to be limited in its validity to condensed phases. Considerations of this kind led Planck over the zero point energy of $\frac{1}{2}h\nu$ per oscillator to a fuller understanding of the meaning of the third law.

While Planck does not appear to have been too happy with Einstein's interpretation of the quantum theory, he was greatly impressed with his theory of relativity. Planck was not worried by the relativity principle. He pointed out that, since the relative presupposes the existence of something absolute, relativity underlines his own search for absolute laws. He was delighted with the invariance of the light velocity, postulated by Einstein as the cornerstone of his theory because this invariance led to a more absolute description of the space-time relation than is provided by classical theory. Much later Planck likened the invariance of the light velocity in relativity to his own quantum of action as the basic principles of the two great physical theories of our time. From 1906 onwards Planck published a number of papers on relativity and among them a long one in 1908 in which he relates relativistic mechanics and thermodynamics through Einstein's law of the equivalence of mass and energy. This paper also contains a remarkable instance of what might almost be called scientific clairvoyance. He comments on the immense energy which is locked up in the rest mass of matter and then goes on to say that, while only ten years earlier the idea of obtaining this energy must have appeared remote, the discovery of radioactivity had brought it into the range of the possible. He must have felt like a prophet of doom when, almost forty years later and two years before his death, he learned about the destruction of Hiroshima and Nagasaki.

However cautious Planck had been concerning the physical significance of his quantum of action, from the year 1913 onwards it became the guiding principle of modern physics. In that year Bohr's first paper on the quantized atom model was published and in spite of the war progress in the application of the quantum principle became rapid. Planck himself took his full share of the work but, even so, from then the initiative in quantum physics passed into the hands of a new generation. Planck retained his interest in various fields of physics to a remarkable age. His last strictly scientific paper, in which he tried to bridge the gulf between wave and particle mechanics, was published when he was eighty-two, again in the *Annalen*. –1940 ?

However, from 1930 until his death Planck showed an ever-widening interest in the philosophical implications of scientific research. The search for absolute laws and his belief in the parallelism between the laws of nature and human thought were the mainspring of his scientific work. He was deeply religious and scorned the narrow outlook of positivism which he had already attacked sharply in his controversy with Mach twenty years earlier. Philosophical articles and some reminiscences form most of his last publications. However, Planck's very last paper, written in the year of his death, strikes a sombre note. It is nothing more than a short paragraph in the *Physikalische Blätter* with the title 'My visit to Adolf Hitler'. In it he describes his useless attempt to retain in Germany outstanding Jewish scientists, such as Haber. In his capacity as Secretary of the Prussian Academy of Sciences, Planck had to call on Hitler in the spring of 1933 and had hoped to use this opportunity of influencing official Nazi policy. Hitler's wild and senseless tirade which he received in reply convinced Planck that nothing could be done.

When, in 1947, Planck wrote the account of this interview, Hitler had inflicted on him the last, but perhaps the most painful, of his many personal losses. Planck's first wife died in 1909. There were four children of this marriage; two boys, Karl and

Erwin, and twin girls, Emma and Grethe. Karl was killed near Verdun in 1916. Emma died at the birth of her first child and when her sister Grethe married the widower, she too died in childbirth. Erwin, who had entered the diplomatic service, was accused of having taken part in the plot to assassinate Hitler, and was cruelly put to death by the Nazis shortly before the end of the war. The two grandchildren whom the death of his twin daughters had left with Planck were largely educated in his house, together with his own young son Hermann, born of Planck's second marriage. It is clear from chance remarks that Planck was acutely aware of the responsibility which he, a man now over sixty, felt for the upbringing of this rather young family.

The evenness of temper which expressed itself before the students in the somewhat dry manner in which his lectures were delivered has been remarked upon by his closer associates. To fill in a few details regarding Planck's personality, I must draw on their accounts, published or given to me verbally. They all were impressed by Planck's simple friendliness and by the hospitality offered at his house in the Wangenheimstrasse in the Grunewald suburb of Berlin. He appeared to them approachable but never inviting or showing any familiarity. The cautious reserve, so well expressed in his published papers, extended to the discussions with his co-workers, and Lise Meitner records that whenever she asked his opinion on a problem, Planck would say, 'I will give you my answer tomorrow.'

His faith in God, which was so closely linked with his idea of the laws of nature, seems to have helped him to bear with great fortitude his personal losses. He did not become embittered and remained all his life an essentially happy man. The concept of the well-ordered universe in which Planck lived had a strong influence on his own mode of life, which also was extremely well ordered. There would be a sizeable walk every day as well as half an hour of piano playing. His work was done standing at a high, old-world writing table. In the vacation he always took long holidays which were mainly spent in the Alps. He was an enthusiastic mountaineer and Born mentions that he visited Planck once in Trafoi when the latter, although well over sixty, had just returned from climbing a 12,000-ft. peak.

Planck detested all ostentation and subjected until his old age his hardened and healthy frame to daily journeys in the 'hard' class of the Berlin suburban trains. This was the only place outside the lecture room or scientific meetings where I ever saw Planck, except for one, unexpected, occasion when I saw him at a late-night Berlin West-end cabaret. He must have been just seventy and he had taken his wife and a friend. They came in late and Planck laughed good-humouredly when the comedian on the stage commented on the advanced age and the very bald head of the newcomer. The forbidding and reserved figure who had remained distant to the young student for three years had suddenly become warm and human.

His last visit to this country took place at the occasion of the Royal Society's Newton celebrations in 1946. Planck was made one of its Foreign Members in 1926, seven years after he had been awarded the Nobel Prize. Planck travelled extensively, if for no other reason to accept honorary degrees from universities and membership of national academies all over the world. Although Planck's great discovery was made when he was already forty-two, and although he himself did nothing to advance it for years after, he lived to see the enormous change which it produced in physics, chemistry and biology. From 1930 he was the President of the national German research foundation, the Kaiser Wilhelm Gesellschaft which is now the Max Planck Gesellschaft. He had become the outstanding figure in German physics long before his death and when in the early twenties the theory of relativity and Einstein personally were wildly attacked, it was Planck's undisputed authority which put an end to these anti-Semitic machinations. DID HE?

It is hardly possible to think of two men of science who were more different in temperament, views, upbringing and background than Planck and Einstein. This opposition of personalities, coupled with common interest in physics and common love for music brought about a curious but close personal friendship. I have mentioned earlier that Planck's cautious reserve towards Einstein's radical championship of the quantum theory did not signify any disapproval of Einstein as a theoretical physicist. On the contrary, Planck at first showed outwardly a much greater regard for Einstein's relativity theory than for his own quantum of action. Together with Nernst and Haber, Planck used his influence with the Prussian Academy of Sciences to bring Einstein to Berlin. The Academy, in 1913, created a special chair for Einstein to allow him to follow his research in closest contact with the most outstanding exponents of German physics. Einstein with his violin and Planck at the piano often spent long hours together, playing chamber music. Planck had retained and developed his early interest in music and he was a very good pianist who liked to play and improvise on themes of classical music or on folk songs.

Contrary to Sommerfeld who created a world-famous school of theoretical physics in Munich, Planck had only a small number of pupils whose research work he directed. His lectures did not fire the undergraduates with enthusiasm and the young graduates were possibly frightened by the high standards and by Planck's reserve and cautious approach. Foremost among the few who worked closely with him are von Laue and Lise Meitner. Zermelo has already been mentioned. There were also Reiche, and Abraham, who wrote the well-known textbook on electromagnetism. Another very promising pupil, von Mosengeil, died quite young.

It is difficult for the outsider to visualize the dilemma and anguish which the rise of Nazism must have caused in Planck's mind. Through the tradition of his family and by the experience of his own long life, love of Germany was deeply engrained in his personality. Moreover, service of his country and regard for the authority of its rulers were matters which could not be questioned by a man of Planck's background. It is significant that he did not seek an audience with Hitler to protest against the treatment of his Jewish colleagues, but that he took the opportunity of a routine call which he had to make to the new Head of State to intercede on behalf of Haber because of the latter's service to Germany in the First World War. The failure of his mission in 1933 seems to have prevented any further attempts on his part to express difference of opinion with the State authorities. He remained in his position at the Academy and as President of the Kaiser Wilhelm Gesellschaft for the Advancement of Science. However, while no statement of opposition from Planck is recorded, it is significant that in his (posthumously published) diary, Goebbels mentions Planck's name, saying that he was 'reserved, to put it mildly' in his attitude towards the Nazis.

Perhaps Planck hoped that law and order would eventually re-establish themselves in Germany, but it is also possible that, with his clarity of vision, he may have long foreseen the final catastrophe. When it came, it not only took his son, but drove him from his home. His house near Berlin was destroyed and his beloved library was burned. Well over eighty now, he was given shelter on the estate of a friend near Magdeburg. The region became the last battlefield of the retreating German army. Eventually, the Americans dispatched a military vehicle to take him to Göttingen, where he settled for the remaining two and a half years of his life. However, in spite of his great age and disregarding the difficulties of travel and accommodation, Planck felt it was his duty to give lectures in many parts of Germany. He had witnessed the collapse and annihilation of his world, but physics and the quantum theory lived on. Planck rendered service to them to his last day.

2017.01.19

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