Draft: Max Planck – A conservative revolutionary

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Abstract

A Brief Biography

Max Planck has a deeply moving biography. He was not only one of the creators of modern Physics but also witness and actor of the most fateful events of the 20th century. Interwoven with these historic vicissitudes is his rather tragic personal life, having lost four of his five children, two of them through violence, the other, identical twins, in the aftermath of childbirth. His biographic literature is rather copious, starting with a scientific autobiography [1]. We refer here to the other biographical works we have used, in particular the investigations of the science historian Dieter Hoffmann [2-7]. We shall only mention some of the numerous short biographical accounts appeared in scientific journals and the general press when appropriate. For the sake of conciseness, we give Planck's biography in tabular form.

1858 Born April 23, 1858 in Kiel as the fourth child of the lawyer Johann Julius Wilhelm Planck and his wife Emma née Patzig. In his Lutheran baptismal record his name appears as Marx (sic) Karl Ernst Ludwig Planck. He published under the name of Max Planck but in the Web of Science he appears 12 times cited as MKE Planck.

1867 The family moves to Munich where his father had been appointed professor of law. Max attends the Maximilian school (gymnasium) and soon distinguishes himself as one of the better students, in particular in religion and mathematics but also in languages. He makes friends with children of the upper bourgeoisie. His teachers attest him not only extraordinary intelligence but also impeccable behavior. He enjoys playing music, in particular the organ during religious services.

1874 At age 16, he obtains the high school degree that allows him to enter the university. During the winter term he attends the philosophy faculty of the University of Munich, undecided as to what further course to take. He enjoys listening to lectures in Mathematics, a fact which makes him decide to transfer to physics. He sings in the university choir, composes, acts at operetta performances and enjoys student life.

1876 He composes an operetta under the title (in translation) "Love in the Woods" It is performed once at a fraternity. The score and text have been lost.

1877 Takes off in the spring for a hiking tour of Northern Italy with three classmates, visiting Venice, Florence, Genoa, Milan, Pavia, Brescia and the lakes. Travels by boat across the lakes and enjoys Bellagio, Villa Carlotta and Isola Madre; lengthy conversations with his travel mates about science, religion and their world picture, in which his conservative views often clashed with those of his friends.

1877-1878 During the winter term he attends the Friedrich-Wilhelm University of Berlin (which would later become his home as a teacher for 30 years). He listens to lectures by the famous physicists Helmholtz and Kirchhoff but is not particularly impressed by them: the first is too sloppy, the second too polished for his taste. In October 1878 he returns to Munich and takes an exam that qualifies him as a high school teacher. He substitutes for his former teacher in mathematics at the Maximilian Gymnasium.

1879 He obtains a doctoral degree with a dissertation on the second principle of thermodynamics. He regrets not to have had a real mentor in this important phase of his academic career.

1880 Only one year after his doctoral degree, he obtains his “habilitation” (certification of his ability to become university professor) with a thesis about equilibrium states of isotropic bodies. At present such procedure in Germany takes three or more years. It confers the academic title of “Privatdozent”, making the holder a member of the faculty, without pay, till he receives a formal offer (Ruf) as a tenured associate professor (extraordinarius). Thus Planck continued to live with his parents. The first such “Ruf” came from a forestry academy which would not have enabled him to do creative research. He turned it down. While waiting for the “Ruf” he produced a few low profile publications based on thermodynamics. They appeared in the *Annalen der Physik*, a journal which he helped to mold as editor from 1906 till 1928.

1885 He receives, from the University of Kiel, an offer of a position which was first meant for Heinrich Hertz. Hertz, however, turned it down and accepted an offer from the Technical University of Karlsruhe, which came together with large and well appointed experimental facilities. The offer then went to Max Planck, number two in the list. Planck spends some time writing an essay about “the essence of entropy” in order to apply for an award offered by the Göttingen University. He finishes it in Kiel and is granted the second prize (the first was not given, apparently because of a controversy between Helmholz and Weber, a Göttingen professor, in which Planck had sided with the former).

1987 Having stabilized his personal situation, he marries, on March 31, his fiancée Marie Merck, daughter of a well known Munich banker and sister of a high school mate. Within a year, their first child, Karl, is born. He publishes in the *Annalen der Physik* three papers on the ever increasing entropy which have received significant attention (48 citations as a whole, last cited in 1996).

1989 Planck receives a “Ruf” as “extraordinarius” and successor of Gustav Kirchhoff in Berlin. Again the offer had gone first to Heinrich Hertz who had become famous in Karlsruhe through his discovery of electromagnetic waves. Hertz, however, preferred a parallel offer from Bonn. Planck accepts the prestigious offer from Berlin.

1889 In April he takes up his new position in Berlin. Two daughters, Emma and Grete, identical twins, are born.

1890 He publishes two articles in the *Annalen der Physik* on thermal and electrical phenomena in electrolytes. They have become his two most cited articles (279 and

266 times resp., cited together 4 times in 2008 and 7 times in 2007, almost 120 years after publication).

1893 Son Erwin, executed by the Nazis in 1944, is born.

1992 He is promoted to “ordinarius” in Berlin.

1897 Somewhat disenchanted by the poor impact of his earlier work, he starts the investigation of black body radiation, an outstanding problem of thermodynamics and electromagnetic theory.

1900 In October 19 he announces his black body radiation law as an empirical equation which accounts for the most precise extant measurements. In December 14 he presents a theoretical derivation of that law using, as an “act of desperation” his hypothesis of energy quantization. Many historians feel that this work signals the birth of modern physics.

1905-1910 He comes out in support of Einstein’s special relativity theory. He writes several articles on the topic. One of them “the dynamics of bodies in motion” has been cited nearly 100 times, three times in 2008.

1909 His wife of 22 years, Marie, dies of a lung ailment, leaving him with four adolescent children. Nevertheless, he finds time to lecture at Columbia University in New York City.

1911 On March 14 he marries 24 years younger Marga von Hoesslin. In December their son Hermann is born. Nothing much is known about Hermann. He participated in the German campaign against Russia as an enlisted man, returned as an “Obergefreiter” (pfc) and died of polio in 1954. In October 1911 Planck attends the first Solvay conference, dealing with the theory of radiation and quanta.

1912 He is appointed permanent secretary of the Prussian Academy of Sciences, a position he held till his resignation in 1938 (at the age of 81).

1913 Planck is elected rector of the University of Berlin and is instrumental in bringing (in April) Einstein to positions in the Academy, the newly founded Kaiser Wilhelm Institute (KWI) of Physics and the Berlin University.

1914 Einstein arrives to Berlin in April. The first world war starts on August 1. Planck’s sons Karl and Erwin enroll in the Army. Planck, together with 93 well known German intellectuals, signs the notorious manifesto to the “Kulturwelt” blaming the Belgians for all sorts of atrocities, justifying the violation of Belgian neutrality and proclaiming the unity of German militarism and culture. Planck later realized its devastating effect on international scientific relations. In June 1915, when the going was rough, he signed a statement by 1347 intellectuals apologizing for the manifesto and in 1916 wrote a letter stating that in spite of the war international scientific relations were by all means to be preserved. Most of Einstein’s colleagues, including Jewish ones, had signed the infamous “Kulturwelt” document but Einstein did not. Together with a close friend he wrote a counter-appeal saying that the document was “unworthy of what until now the whole world has understood by culture”. He hardly found any cosigners but the document was finally published in Switzerland (he had a

Swiss passport). Planck's sons Karl and Erwin became army officers, to the pleasure of Max who expected from them great heroic deeds. Erwin is severely wounded in the battle of the Marne and taken prisoner.

1916 Son Karl is killed in action in Verdun on May 26. Max expresses, in a rather Wagnerian way, sorrow and pride concerning Karl's heroic death in the service of the fatherland, the emperor and God. Karl never got along well with his father who finds solace in the fact that that the Army had made a useful man out of him.

1917 Max's daughter Grete dies of childbirth on May 15, a baby daughter survives. Under the auspices of the Red Cross Erwin is interned in Switzerland. On October 1 Max becomes a member of the board of directors of the Kaiser Wilhelm Institute of Physics.

1918 The war ends with Germany's defeat, the Kaiser's abdication and the proclamation of the republic, all facts that compound Max's personal tragedies. His "Weltbild" collapses but he is able to find solace in helping rebuild German science. Max had been considered for the Nobel Prize in Physics since 1907 and regularly till 1919, the year in which he was belatedly given the prize which had not been awarded in 1918. He had been nominated a total of 75 times.

1919 Daughter Emma, after marrying her widowed brother in law, dies in November 21 in the process of childbirth. A daughter also survives. Max is belatedly granted the 1918 Nobel Prize "in recognition of the services he rendered to the advancement of physics by the discovery of the energy quanta". He joins the *Deutsche Volkspartei*, a liberal (in economic matters) nationalistic party, the right wing of the *Nationalliberale Partei* founded by Gustav Stresemann (co-winner of the 1926 Nobel Peace Prize and Chancellor during the Weimar Republic).

1920 In the Midsummer of 1920 (sic) he officially receives the 1918 Nobel Prize in Stockholm, together with his colleague Fritz Haber (Chemistry, also 1918) and the ultranationalist Johannes Stark (Physics, 1919) who was later to become a rabid anti-Semitic Nazi. He continues publishing about two low profile articles a year, not surprising in view of his increasing public service commitments and the fact that he always worked alone: he left no school. His personal tragedies and tragic political events must also have made a dent.

1926 Max is elected a member of the prestigious *Academie der Naturforscher Leopoldina*.

1927 He becomes emeritus at the Berlin University on October 1 and is succeeded by Erwin Schrödinger.

1929 Planck and Einstein become the first awardees of the Max Planck Medal of the German Physical Society, created to commemorate the 50th anniversary of his doctorate.

1930 He becomes President of the Kaiser Wilhelm Gesellschaft (KWG) till July 25, 1938 and, with his other public service appointments, the most influential person in German science.

1933 Without a majority of his Nazi party (NSDAP) in parliament Adolf Hitler is appointed Reichskanzler (Prime Minister) on January 30. On February 27 the Reichstag burns. On February 28 the parliament approves a decree suspending basic rights. Murders of presumed enemies of the NSDAP start. On March 6, new elections in which the NSDAP gets 44% of the votes, not enough to form a government. On March 24 the parliament approves the *Ermächtigungsgesetz* (with the votes of all parties except communists and socialists) enabling Hitler to rule by decree. The atrocities increase. Planck's point of view is that it is a transient situation needed to restore order, after a while the situation will settle down like in the case of natural catastrophes. On April 7 the "law for the restoration of the professional civil service" is approved by decree. According to it, university professors would become civil servants but ethnic Jews (religion played little or no role) were excluded from the civil service (with few exceptions, later struck down). Mass expulsions of non-Aryan professors start.

Max Planck was, at the time, vacationing in Italy. Some colleagues asked him to return immediately to Berlin but he followed the advice of his secretary at the KWG and continued his vacation. Later he mentioned that he was happy to see that the new law was put into effect without any incidents. The law was, by the way, similar to the disposition in the Italian racial laws of 1938, which also barred students with the wrong ethnicity from attending public schools and universities. Before Planck left for vacation, Einstein, at the time in the United States, announced that he would not return to Germany where there was no longer "civil liberty, tolerance, and equality of the citizens before the law". He sent in his resignation from the Prussian Academy. Planck, always willing to compromise, wrote to him "By your efforts your racial and religious brethren will not get relief from their situation, which is already difficult enough, but they will be pressed even more". He added that the value of an act lies not in its motives but in its consequences. The mass exodus started, the KWG being in a somewhat better shape than universities because of having positions paid by industry and being able to keep Jews of non-German citizenship (e.g. Lise Meitner). By and large no protest from Aryan colleagues was heard.

On May 17 Planck was granted an audience with Hitler to discuss this and, as we now know, other matters. At the end of a long and apparently satisfactory conversation on the future of science and the KWG, he asked Hitler not to dismiss highly competent non-Aryan scientists. He mentioned that there were to kinds of Jews, those beneficial and those pernicious to German society and that one should differentiate. Hitler went into one of his rages and said that the Jews themselves should do that and that for him Jews were all the same… Planck stood up and took leave. This story, carefully manicured, has been mentioned in Germany for years as one of the few proofs of the existence of an opposition and of Max Planck's integrity. Nowadays we know that matters were not as simple.

1935 A memorial service was organized in Berlin a year after the death of Fritz Haber. Haber, a Jewish
(ethnic but baptized) Nobel laureate, who had invented the ammonia synthesis, was not dismissed as a director of his KWI on the formal grounds of his merits in World War I. He, however, would have to implement the dismissal of Jewish colleagues, which he refused to do. Instead he chose emigration. Attendance of state employees to Haber's memorial service was forbidden by the minister of education who, however, left open the possibility of asking for a special dispensation. Planck and

Comment [MC1]: Ich habe here ein paar Worte umgedreht also Otto Hahn, in what has been portrayed as an act of defiance, attended the service without any subsequent sanctions. The fact that many foreign dignitaries were present, among them representatives of the Rockefeller Foundation, which was negotiating the funding of a new building for the KWI of Physics, reduces the impact of the act of defiance which Planck’s attendance to Haber’s memorial service has been told to represent.

1937 At the age of 80, Planck leaves the presidency of the KWG. He is succeeded by Carl Bosch (Nobel Laureate for Chemistry, 1931) till the latter’s death in 1940. Bosch often confronted the NSDAP hacks, sometimes inebriated. His successor from 1941 was Albert Vögler, an executive of a large steel conglomerate. While not a member of the NSDAP he certainly was a sympathizer and financial supporter, having been elected to parliament in 1933 on an NSDAP ticket. While not fully compliant to the Nazi hierarchy, he heavily compromised. He poisoned himself while being arrested at his home in 1945. We have found no scientific works of Vögler, who succeeded two Nobel laureates as MPG President and was succeeded by two more.

1938 On the occasion of Planck’s 80^{th} birthday Louis de Broglie is awarded the Max Planck Medal. The KWI for Physics, funded by the Rockefeller Foundation, is inaugurated under the directorship of Peter Debye, a Dutch Physical-Chemist who even as an Aryan, was forced to emigrate in 1942. Debye had proposed to name his Institute after Max Planck but Nazi members opposed it. So, it remained Kaiser Wilhelm Institute of Physics. Lise Meitner, a co-discoverer of nuclear fission and a close friend of the Plancks, had to leave Germany in a cloak-and-dagger operation: she was an Austrian ethnic Jew who lost her foreign passport as a result of the Anschluss.

1943 The Plancks leave their endangered home in Berlin and move to a friend’s house in Rogätz (Elbe).

1944 Their abandoned home in Berlin-Grunewald is bombed out. Planck’s library is destroyed.

1945 Planck’s son Erwin is executed as having been involved in the plot to assassinate the dictator. He had accepted a position in a future cabinet and had participated in drafting a new constitution. Planck and various associates and friends wrote letters to the highest officials asking for clemency, to no avail. Erwin, Max’s closest son and friend, was executed on January 23. After straggling with Marga through the woods around Rogätz in the search of food, they are captured by an American commando and taken to Göttingen, thus avoiding being captured by the advancing Russians. The English authorities decide to reconstruct the KWG and ask Planck (age 89!) to take over, temporarily, its presidency. Once more, he follows the call of duty.

1946 He is invited (and accepts) to attend the Newton celebrations of the Royal Society in London. It hurt him that he was introduced as “representing no country” (Germany had ceased to exist). Otto Hahn takes over the presidency of the newly reestablished KWG whose name is changed to Max Planck Gesellschaft while Max Planck is still alive. In June he gives his last lecture in Göttingen.

1947 In August he fell and had to be hospitalized. He died in October 1947 and is buried in Göttingen.

B Scientific Work

Theoretical physics at the end of the 19th century

In the second half of the 19th century, when Planck started his academic career, physics was widely seen as an experimental endeavor – in spite of the early works of Galileo (1564-1642) and Newton (1643-1727), the first theoretical physicists in the modern sense. Theory was confined to mathematics as an ancillary science, e.g., providing interpolation formulae and error statistics for experiments. Experimental physics had become the key science within the physics institutes at the German universities [4]. The directors were full professors, leading well equipped “empires”, the paternalistic structure of the times giving them the status of monarchs. Associate professors who wanted to avoid conflicts, and eventually be promoted, became active in research fields where less equipment was needed, in particular in theoretical physics. Moreover, the more profitable main lectures were given by the full professors, whereas special lectures like those in theoretical physics were held by associate professors (receiving much lower tuition fees (*Hörergelder*) because of the smaller number of students). At the end of the 19th century, there were only two universities with chairs in theoretical physics: at the Friedrich Wilhelms University in Berlin (Gustav Kirchhoff, 1824-1887), and at the University of Göttingen (Woldemar Voigt, 1850-1919). At the beginning of the 20th century the situation rapidly changed. The development of mathematical physics in the first half of the 19th century (Euler, Fourier, Poisson) had already shown the potential of the new discipline, but it was in particular Max Planck and Albert Einstein (1879-1955), who caused a breakthrough concerning acceptance and recognition. A chair in theoretical physics was no longer a necessary evil but an important necessity.

Thermodynamics

Beside the time-honored mechanics, electrodynamics (which by then included optics) and thermodynamics were the central basis of physics at the end of the 19th century. There were speculations about nothing less than the unification of these three fields of physics. The discussion about the hypothetical ether implied the possible unification of mechanics and electrodynamics, while the relationship between mechanics and thermodynamics was clarified on the basis of statistical physics and the hypothesis that all matter is composed of atoms. Planck’s dissertation at the University of Munich, where he had studied physics between 1874 and 1879 (with an intermission of two semesters in Berlin), dealt with the second law of thermodynamics and was a careful recapitulation and exegesis of the works of Rudolf Clausius (1822-1888), who had introduced the concept of entropy and the second law of thermodynamics. Planck removed some ambiguities and contradictions and extended the concept of entropy to irreversible processes and a measure of irreversibility. In his scientific autobiography [1] Planck discussed the poor impact of his dissertation: “None of my professors at the university had any understanding for its contents. I found no interest, let alone approval, even among the very physicists who were closely connected with the topic.” Here we also find the famous statement that "A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents die and a new generation grows up that is familiar with it." Irony of history: He did not immediately see the consequences of his most important discovery.

At the start of his career as a researcher (1879) Planck became fascinated by the subject of entropy. He was confronted with the statistical interpretation of Ludwig Boltzmann (1844-1906) who had postulated the relationship between microscopic parameters and the macroscopic properties of matter. At that time, Planck rejected the statistical approach, because, he felt, it would contradict the absolute universal validity of the laws of nature which he strongly believed in. For him, probability would imply exceptions from that invariable validity. He therefore preferred the macroscopic phenomenological approach of Clausius and Wilhelm Ostwald (1853-1932) and consequently refused the atomistic view of matter. We should mention here that the famous formula combining entropy with probability ($S = k_B \ln W$) has not been introduced by Boltzmann but by Planck, who named k_B the Boltzmann constant. As we shall see later, he even reported the earliest and rather precise determinations of k_B. However, Planck's skepticism about the probability concept and his opposition to atomism did not wane until he realized its potential for a convincing theoretical explanation of the black body radiation.

Black body radiation

After Hermann von Helmholtz (1821-1894) had introduced the concept of free energy, Planck applied it to chemical thermodynamics, in particular to the equilibrium of gas reactions, a very important discipline for the expanding chemical industry. Planck soon became one of the leading experts in thermodynamics. However, the American physicist Josiah Willard Gibbs (1839-1903) developed more fundamental and general ideas concerning the "theory of chemical equilibrium". His work was published in 1876, but was overlooked in Europe and not translated until 1892. The situation differed from that in the present day, the US not having yet become the top nation in science. Although not fully equivalent to his own contributions, Planck recognized the priority of Gibbs's work. Maybe somewhat frustrated about his lack of a scientific breakthrough, Planck turned to the theory of heat radiation.

The rapid development of the lighting industry in the last decades of the 19th century, and the competition between electric and gas light, required precise experiments and better standards for the luminosity of light sources. Moreover, an understanding of the processes involved in light absorption and emission was needed. For such reasons, the German industry (in particular Werner von Siemens) and the German government established the German bureau of standards, named Physikalisch-Technische Reichsanstalt (PTR, now PTB), with Hermann von Helmholtz as its first director. Its charge was to perform the most accurate measurements of fundamental constants and to push research on unsolved basic problems in physics.

The concept of the black body radiation had been introduced in 1859 by Kirchhoff who defined a black body as an object that absorbs all thermal radiation falling on it. When it is cold, no radiation is reflected or transmitted and the object appears black. When it is hot, it becomes an ideal source of thermal (and also optical) radiation. Several physicists investigated the spectral distribution of the black body radiation. An important contribution was the discovery of the Stefan-Boltzmann law, which states that the total energy radiated per unit surface area of a black body in unit time is directly proportional to the fourth power of the black body's temperature ($I \sim T^4$).

The next important step was a discovery of Wilhelm Wien (1864-1928) in the year 1893, the so-called displacement law, i.e., the inverse proportionality between the wavelength of the peak in the spectral distribution of the black body emission and its temperature. Three years later (1896) Wien presented a semi-empirical radiation law (Wien's energy distribution law) that described well the experimental data available at the time.

Enters Max Planck

In 1887 it was generally accepted that thermal and optical radiation were related to electromagnetic waves, as described by Maxwell's equations. The latter, however, were time reversal invariant and, as such, alien to the concept of irreversibility as embodied by the thermodynamic concept of entropy. Planck realized that in order to describe black body radiation with Maxwell's equations it was necessary to extend the concept of entropy S to such waves (an inverse temperature would then be obtained as the derivative of entropy with respect to added thermal energy). He thus embarked in a program to rigorously introduce thermodynamics into electrodynamics and electromagnetic (em) wave propagation. His initial work was presented in great detail and an almost axiomatic way in five lectures he gave at the regular sessions of the Prussian Academy of Sciences, three in 1897 and two in 1898 and 1899. The complete texts can be found in Ref. [8], Vol. I, pp. 493-600.

In this endeavor, he now found it convenient to accept Boltzmann's atomistic point of view and thus relate entropy to disorder in the case of a large set of massive particles (see Ref. [8], Vol. I, pp. 493-504). In order to reach thermodynamic equilibrium (a maximum of S) these particles must interact, either through collisions with each other or with the container walls. Planck tries next to find parallel concepts for em waves (their corpuscular aspect had to wait till Einstein's 1905 Nobel winning work). He then introduces the concept of natural radiation (incoherent partial waves) as opposed to coherent monochromatic waves. Around a given wave number v one has an infinite number of em waves, depending on their propagation direction, polarization, phase, and exact value of v. Hence, one can compare a set of massive particles to a natural set of em waves of frequency v. One must, however, introduce some kind of mechanism to have the em waves interact with each other so as to be able to establish equilibrium.

Planck does that by introducing in a black body cavity one or more small fictitious dipole oscillators which absorb and reradiate (with an arbitrary direction, polarization, and frequency if v covers a small but finite interval). He first treats concentric waves with one dipole at the center of the cavity. The total energy of the waves and the oscillating dipole can be easily calculated. At that point he proceeds to postulate (he calls it "to define") two functions (one for the oscillator, the other for the waves) whose sum, he checks, invariably increases with time, till a maximum is reached at thermodynamic equilibrium. He thus calls these functions entropy. They enable him to define a temperature T for the em waves in equilibrium inside the cavity. From the equilibrium state that maximizes the entropy for a given T he retrieves Wien's law for the radiation intensity K_v per unit area, unit solid angle and frequency interval dv:

$$K_\nu d\nu = \frac{b\nu^3}{c^2} e^{-\frac{a\nu}{T}} d\nu$$

where the two constants *a* and *b* are, in present day's notation: $b = h$ (Planck's constant, which of course he did not call it so) and $a = h/k_B$. k_B was first called Boltzmann's constant by Planck. From an analysis with the above equation of experiments by Lummer, Paschen, Pringsheim, and Wanner, Planck derives h = 6.885 x 10^{-27} erg x sec and k_B = 1,43 x 10^{-16} erg / degree C, rather close to presently accepted values (the values he obtained later using his full radiation law are even closer to the accepted ones).

In a seminar, given on October 19, 1900 at the German Physical Society (DPG), Ferdinand Kurlbaum reported significant deviations from Wien's law, in particular at small frequencies, of his black body measurements at the PTR together with Heinrich Rubens. In the same session (he must have had Kurlbaum's data before) Planck suggested an empirical modification of Wien's law, based on the replacement of $e^{-(a\nu/T)}$ by $[e^{(a\nu/T)}-1]^{-1}$. At high values of ν the modified expression coincides with the original one, but discrepancies appear at low values which better represented the experimental data reported in the same session of the DPG. This fact led Planck to start a search for a theoretical explanation of the new (Planck's) radiation law which he reported at a meeting of the DPG held on December 14, 1900. This date is considered by many as the beginning of modern physics. Both lectures were published in the proceedings of the DPG [9-10] (see also Ref. [8], Vol. 1, pp. 687-689, pp. 698-706). A summary of these articles appeared in the following year 1901 in the *Annalen der Physik* [11] (see also Ref. [8], Vol. 1, pp. 717-727).

The decisive step in this work, called by Planck an *act of desperation* (as he 1931 mentioned in a letter to Robert Williams Wood) [12]), is the assumption that within a cavity there is a large number *N* of equal oscillating dipoles in equilibrium with the em radiation. He had earlier derived the relation between the energy of the em field as a function of that of the oscillators. He now assumes that the energy of each oscillator is not continuous but actually an integer multiple of a small (quantum of) energy *ε*. He called these oscillators „energy cells". In his lecture at the DPG meeting on December 1900 he regarded energy "as made up of a completely determinate number of finite equal parts, and for this purpose I use the constant of nature h" [9]. He is then able to derive the law that bears his name under the assumption that *ε* is proportional to *ν,* the proportionality constant being *h*.

$$K_\nu \, d\nu = \frac{b\nu^3}{c^2} \frac{1}{e^{\frac{a\nu}{T}} - 1} d\nu$$

Initially, Planck saw his constant as a mathematical artifice, from which he hoped to get rid of later or which could be included somehow into classical physics. Figure 1 demonstrates convincingly the longevity of Planck's equation, showing a rather impressive fit of recent experimental data for the cosmic background microwave radiation resulting from the big bang, corresponding to *T*= 2.735 K [13].

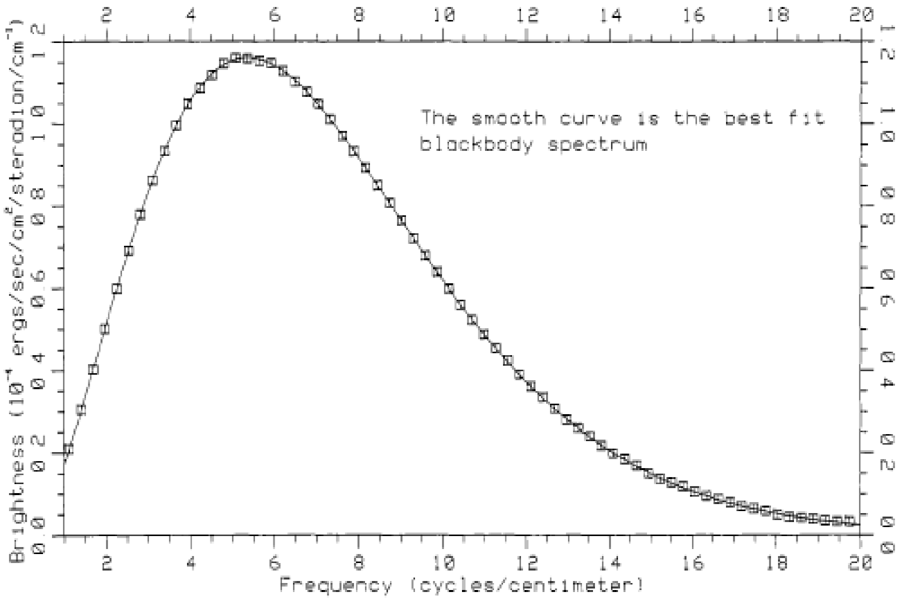

FIG 1: Fit of the measured cosmic background microwave radiation with Planck's equation for T = 2.735 K [13]. The first author, J.C. Mather, shared with his colleague G.F. Smoot the 2006 Nobel prize for physics.

It has often been stated that Planck became a revolutionary against his will. Indeed, between 1901 and 1906 he did not publish anything on black body radiation and quantization [7]. In the year 1910 he still instructed to „proceed as conservatively as possible in introducing the quantum of action *h* into the theory, i.e., only those modifications should be made to the existing theory as have proven to be absolutely necessary." [14]. Planck's presentation of Einstein on the occasion of his election as member of the Prussian Academy of Sciences in 1913 again reveals his conservative attitude when he stated that Einstein " in his speculations may sometimes have gone a bit too far, e.g., with his hypothesis of the light quanta, but it is difficult to hold this against him" [15]. Not surprisingly, in 1908, when Planck became a candidate for the Nobel prize, the prize committee decided to wait for a final clarification of the relevance of quantization – until 1920 when Planck received the long overdue prize (retroactively for the year 1918). He has been nominated more often than any other previous candidate (75 times).

According to Max von Laue and many science historians, the events that took place at the December 1900 meeting of the DPG signal the birth of quantum physics. However, none of Planck's publications contains any statement about the physical meaning of his constant, indicating that his concept has to be clearly distinguished from what we nowadays understand as quantization [7]. The philosopher of science Thomas S. Kuhn discussed this in detail and concluded that Planck does not deserve the credit [16]. Einstein's publication on the hypothesis of light quanta in 1905 was definitely the first clear statement of energy discontinuity or quantization. Before 1905 very few physicists discussed Planck's findings. However, as the history of many other discoveries reveals, the role of the participants is mostly rather complex and the demand for one “hero” and a particular date is not realistic. Nevertheless, Planck’s use of the elementary quantum of action was the first step in introducing quantization into physics.

Planck and Einstein

A fascinating aspect in Planck’s biography is his relation to Albert Einstein, both on the scientific and the personal level. Planck was deeply impressed by the revision of the Newtonian concept of time in Einstein’s Special Theory of Relativity. He quickly accepted its basic tenets and put it on the agenda for lectures and discussions in Berlin – and as a thesis topic for many of his PhD students. Although reluctant with regards to Einstein’s quantum hypothesis of light, he finally became the most important patron of the young Einstein. Planck played a key role when Einstein moved to Berlin and became member of the Academy of Sciences, professor without teaching duties at the University and director of a newly created Max Planck Institute of Physics. Although the staunch conservative attitude of Planck, both with respect to science and politics, and the unconventional Einstein were not compatible, their personal relation was coined by mutual respect and admiration.

However, Planck’s unrealistic, illusory and compromising attitude during the first years of the Nazi-power became a severe strain for their relation [17]. They finally broke contact after Einstein’s emigration and Planck’s criticism of it (see biography above). Thereafter Einstein only wrote a letter of condolence to Planck’s wife on the occasion of his death, praising their friendship and the happy times they had spent together in Berlin. Compared to Planck, it is now admitted that Einstein established the definitive concept of energy quantization but, like Planck, he had difficulties going a step further and agreeing with the probabilistic interpretation of quantum theory. Planck approved many of the advancements resulting from the developments in quantum mechanics but did not play a significant role in them.

Planck as one of the first managers of modern science

As mentioned in the biography, his appointments at the Berlin University, at the Prussian Academy and the KWG converted Planck, in spite of his rather modest personality, into the most important representative of German physics. Several other important appointments followed, which probably catapulted him into the most powerful person in all of German science. We mention here the presidency (1921-1922) of the *Deutsche Gesellschaft für Naturforscher und Ärzte* (German Society of Researchers and Physicians) and charter membership of the executive board of the *Notgemeischaft der Deutschen Wissenschaft* (Emergency Association of German Science) from its foundation in 1920 till 1932. The name was changed in 1929 into the present *Deutsche Forschungsgemeinschaf*t (DFG).

This organization had been created by Planck, von Laue and others to raise funds to relieve their lack in German science resulting from the war and the subsequent depression. While a civil servant, Schmidt-Ott, ex Prussian minister of Culture, was place at its top, Planck became the ranking scientific officer and was deeply involved in engaging institutions (universities, academies and other scientific societies, state governments, the Rockefeller Foundation, national and foreign industrial organizations, such as Siemens and General Electric) and individuals (such as the Japanese industrialist Hajime Hoshi). A feather in the cap of this organization is the grant given in 1925 to the theorists who developed quantum mechanics (Heisenberg, Born), a fact which was criticized by more conventional physicists who were not receiving support. Planck defended this policy with the statement “Quantum mechanics is at the center of interest of the physicists of all countries…”.

Planck was appointed Senator of the KGW in 1916, becoming its president from 1930 till 1937, thus having to steer one of the largest science funding organizations world wide through the rather stormy waters of Nazi rule. As already mentioned in his biography, here he misjudged at the beginning the real nature of the Nazi philosophy and rulers, giving himself to the illusion that it was only a temporary evil which may even help to restore, at least in part, his conservative society. In his tenure of office at the KWI (1930 till 1937), covering the pre-war Nazi period, he, of course had to contemporize.

Some of his reproachable actions were in principle harmless: “Heil Hitler” in letters, addressing Hitler as “Mein Führer”, Nazi salute (always raising the hand rather shyly), others were not as trivial: dismissing non-aryan colleagues (although he tried to rescue some with moderate success), participating in the organization and governance of some from our point of view rather objectionable Institutes (such as the infamous KWI for Anthropology, Human Genetics and Eugenics, directed as of 1940 by Freiherr von Verschuur who was connected with the infamous Dr. Mengele, an ex graduate student of Verschuur. At some point Planck held a meeting with Nazi authorities in which the decision was made of teaching the theory of relativity and mentioning his author, but adding that even without Einstein someone else would have come up with the theory. Planck paid dearly for his misjudgment of the Nazi evil. As discussed in the biography, his dear son Erwin was sentenced by the *Volksgericht* (Peoples Court) and executed in January 1945.

Comment [MC2]: I made a minor change

Planck, while fulfilling his managerial duties, never forgot to keep contact with science, even doing scientific work himself. He had (from 1892 till 1925) 25 graduate students and seven degree holders who obtained the “habilitation”. Planck never coauthored any articles with them, although in one particular case of a graduate student (Kurd von Mosengeil), who had had a serious accident, Planck worked on his thesis to make it acceptable for publication in the *Annalen der Physik*. It is thus difficult to say that, like in the case of Max Born [18] he left a school, although two of his charges were awarded the Nobel Prize (Max von Laue and Walther Bothe) and an additional one should have been awarded it (Walther Meissner, for the Meissner-Ochsenfeld effect). He boasted, while active in Berlin, of attending regularly the seminars of the Prussian academy and the Berlin Physical Society (later renamed as German after Planck’s suggestion), having attended more meetings than any of his colleagues. Few present day science organizers follow his example. He regularly spoke at the meetings of those learned societies, the proceedings of his talks, some highly cited, are available in his collected works [8]: 34 articles correspond to presentations at the Prussian academy and 17 to presentations at the Physical Society meetings.

C Bibliometric Analysis

One way to estimate the impact of a researcher is to count the number of times that his papers have been included in the reference lists of other papers. The number of citations is often taken as a measure of the attention an article, a researcher or an institute has attracted. Although citation numbers reflect strengths and shortcomings and are therefore frequently used for research evaluation, the number of citations cannot easily be equated with the overall significance: (1) The final importance of the more recent papers may not yet be clear, and (2) the results of old papers may now be so well known that they appear in textbooks rather than being cited. The question arises as to whether the impact of early pioneers of science like Max Planck can be quantified by bibliometric methods usually applied to present day scientists. Carefully establishing and interpreting the citations of Planck as a case study seems to be a reasonable way to proceed.

Methodology

The data presented here are based on Planck's collected works analyzed using the Thomson Reuters citation indexes under the Web of Science (WoS), especially the Science Citation Index (SCI). The WoS is accessible under the Web of Knowledge (WoK), the search platform provided by Thomson Reuters (the former Thomson Scientific, emerged from the Institute for Scientific Information, ISI) [19]. In addition, the INSPEC database for Physics, Electronics, and Computing and SCIsearch (SCI accessible under the database provider STN International) have been consulted for the present study [20]. The WoS goes back to 1900 in its General Search mode, the SCI under STN International only goes back to 1974.

The WoS offers two search modes. The *General Search* mode gives access to the articles (no books, no conference proceedings unless they appear in *source journals*) published since 1900 and covered by the so-called WoS *source journals*: about 9000 journals currently selected by the staff of Thomson Reuters as contributing significantly to the progress of science. The *Cited Reference Search* mode gives access to all references appeared in *source journal* articles (cited either correctly or containing errors). The cited references are not limited to articles published in *source journals* but include any other published material (e.g., the Bible or the Koran). In other words: The citing papers are limited to *source journal* articles published since 1900, but the papers cited therein are not limited concerning document type or publication year.

Planck's most-cited papers

The WoS *General Search* for “Planck M” as author name revealed 111 articles for the period 01-01-1900 till the date of search (01-06-2008). However, this number is misleading in two aspects: (1) Planck's pre-1900 articles are not covered by the WoS and (2) at least 21 out of the 24 articles past 1950 were published by a namesake, an oncologist. Hence, there are a total of 90 articles accessible as source records under the WoS. An additional search in the Physics Abstracts database (INSPEC) in the time period 1898 till 1950 revealed 74 articles, including 3 pre-1900 papers. According to a recent count, there are at least 18 articles published in the *Annalen der Physik* prior to 1900 [21]. This journal, which he edited between 1907 and 1928, was his preferred choice for publishing his work, starting 1881 and ending 1941. A citation analysis based on the WoS *Cited Reference Search* mode (i.e. including the pre-1900 papers) reveals Planck's most-cited papers as given in Table 1. The coverage of the pre-1950 physics literature by the WoS seems to be sufficiently complete to justify the analysis.

TAB 1: The most-cited articles by Max Planck. Source: Thomson Reuters Web of Science (WoS), date of search: 01-06-2008.

Author(s)	Journal	Title	# Citations
M. Planck	Annalen der Physik 39/275, 161-186 (1890)	Excitation of electricity and heat in electrolytes	279
M. Planck	Annalen der Physik 40/276, 561-576 (1890)	The potential difference between two dilute solutions of binary electrolytes	266
M. Planck	Annalen der Physik 4/309, 553-563 (1901)	The energy distribution law of the normal spectrum	198
M. Planck	Verhandlungen der Deutschen Physikalischen Gesellschaft 202/237 (1900)*	On the theory of the energy distribution law of the normal spectrum	184
M. Planck	Sitzungsberichte der Preußischen Akademie der Wissenschaften 324-341 (1917)**	An essay on statistical dynamics and its generalization to quantum theory	117
M. Planck	Annalen der Physik 331/26, 1-34 (1908)	The dynamics of moving systems	95
M. Planck	Annalen der Physik 306/1, 69-122 (1900)	On irreversible radiation processes	91

* Both articles are not included as WoS source records
** This paper contains Planck's contribution to the Fokker-Planck equation.

Misspelled citations (incorrect with regard to the numerical data: volume, starting page, and publication year) are a general problem in citation analysis. The references of early articles are particularly susceptible concerning "mutations". Between 1881 and 1941 Planck published altogether 45 papers in the *Annalen der Physik* [5]. This still prestigious journal (before WW II comparable to *Physical Review* at present) is cited with an above average error rate, due to the changes in the journal name, editors, location of editorial office and the various series. We included here the misspelled citations by hand (provided that we were able to identify them and assign them to a specific Planck paper).

One may have surmised that Planck's most-cited articles are those about black body radiation and energy quantization published in1900 [9-10] and summarized in 1901 [11], but this is not the case. However, if we add up the citations of these three articles, we obtain almost 400 citations. If we include the preceding five communications on irreversible radiation processes published between 1897 and 1899 in *Sitzungsberichte der Preußischen Akademie der Wissenschaften* (see Ref. [8], Vol. 1, pp. 493-600) we find altogether 450 citations. This situation is rather similar to that encountered in the case of Einstein: His most-cited articles are not those dealing with the theory of special and general relativity, but the paper dealing with the so-called EPR paradox [22] (3364 citations) followed by an article in which the molecular radius and Avogadro's number are determined using viscosity data [23] (1924 citations plus 1166 citations for an erratum [24]). Obviously, important early articles may not have been cited according to their importance. Sometimes they are even rarely cited, as compared to much less fundamental works (see below).

The graph displaying the time-dependent evolution of a single article is sometimes called its citation history. Each article develops its own life span as it is being cited. With time, the citations per year (citation rate) normally evolve following a similar pattern: They generally do not increase substantially until one year after publication. They reach a summit after about three years, the peak position depending somewhat on the research discipline. Subsequently, as the articles are displaced by newer ones and interest in the field wanes, their impact decreases, leading to the accumulation of citations at a lower rate. Finally, most papers are barely cited or forgotten. Figure 2 shows the citation history of the three most-cited Planck papers given in Table 1.

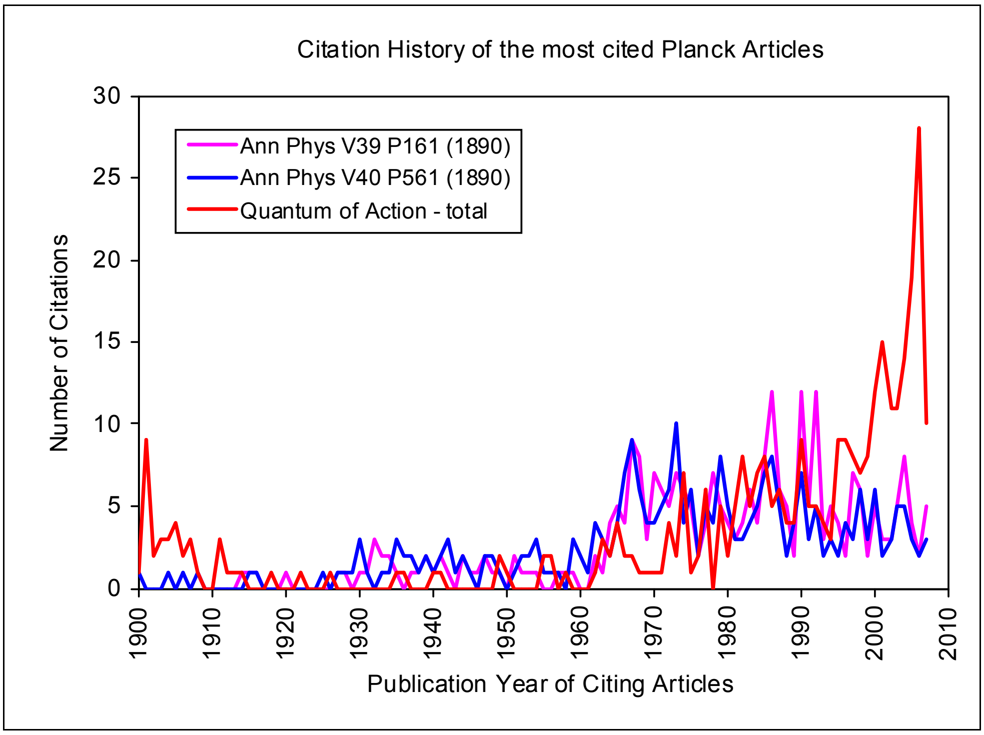

FIG 2: Time-dependent number of citations (citation history) of the three most-cited articles by Max Planck. Misspelled citations (incorrect with regard to the numerical data: volume, starting page, and publication year) are included here if we were able to identify them.

In contrast to the standard "canonical" time pattern mentioned above, the citations of the most-cited Planck papers are highly delayed (such papers have been called "sleeping beauties"). Note that the impact peak of the quantization papers around 2005 coincides with the centennial of Einstein's *annus mirabilis*. We have analyzed the recent citations of Planck's two most cited papers (published in 1890 and having to do with electrolytes). We find a total of 10 for the years 2005-2008. The citing papers cover a vast range of subjects, including Darwinian dynamics, in vivo skin electroporation, electrodiffusion, fuel cells, cation exchange, electrochemistry of metallurgical processes, transport through membranes, and soldered interconnections.

The citations of the three Planck articles introducing his famous constant waned relatively soon after publication, being almost negligible during the time of the development of quantum mechanics (around 1925/1926). Figure 3 shows the number of citations per year within the first three decades. The citations of the famous 1905 paper by Albert Einstein [25] on the light-quantum hypothesis (522 citations), introducing the phonon in the discussion of the photoelectric effect and responsible for his Nobel prize, are shown for comparison.

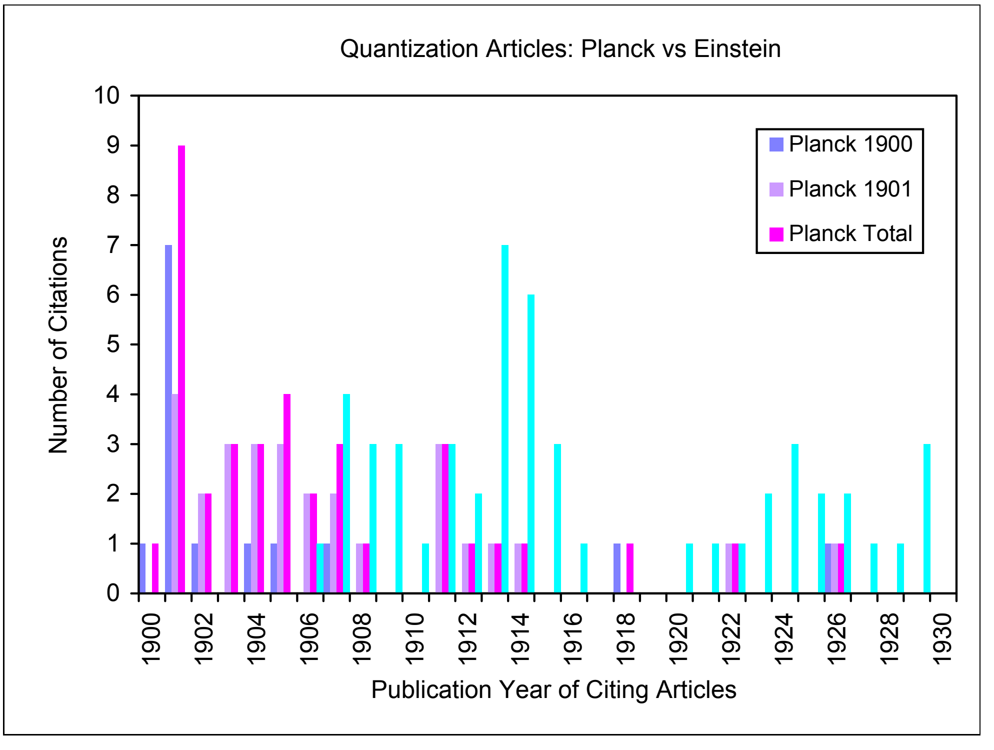

FIG 3: Time-dependent number of citations of the 1900/1901 articles by Planck on energy quantization [9-11] and of the 1905 paper by Einstein dealing with the light quantum hypothesis and introducing the phonon [25].

The citations of Planck's quantization papers soon waned, with only 9 citing papers between 1910 and 1930. A further analysis reveals that the majority of the citations appear in papers published by PTR physicists working at that time on the spectral characteristics of the black body radiation (i.e. Paschen, Lummer, Pringsheim, Kurlbaum, Rubens) and also by Planck himself. By and large, at the beginning of the 20th century Planck's introduction of the concept of energy quantization was not widely mentioned in the physics literature. Even Planck himself did not further discuss the physical significance of his constant. Today, in particular Einstein's paper on the light quantum hypothesis is seen as the beginning of our present understanding of quantum theory, absorbing and incorporating Planck's approach.

Except for Max Born, none of the founders of quantum mechanics, like Werner Heisenberg or Erwin Schrödinger, cited the quantization papers by Planck or the photoelectric effect paper by Einstein. Within the time period 1900 till 1925 there are only 2 citations by articles published in the *Physical Review*. The citing papers of Planck's quantization articles past 1920 are reviews and/or mainly discuss Planck's constant in an historical or philosophical context. The classical papers establishing quantum mechanics (by Heisenberg, Schrödinger, Born, Dirac, Pauli, and Jordan) received much more citations within the first years after their appearance.

Based on the WoS *Cited Reference Search* mode and the time period 1880-1950 (the publication years relevant for Planck), we determined the time curve of the overall number of citations of all publications by Planck (articles as well as books and any other published material) as shown in Figure 4. Such seminal work is often cited by mentioning the author's name or name-based items *(informal* citations [26], also called *eponyms*) instead of citing the full references as a footnote (*formal* citations). Therefore, we included in Figure 4 the separate time curve of the *informal* citations based on the INSPEC database ("Planck" appearing in the titles, the abstracts or the keywords). The time curve of the total number of records covered by INSPEC is shown as an illustration of the time evolution of the physics literature.

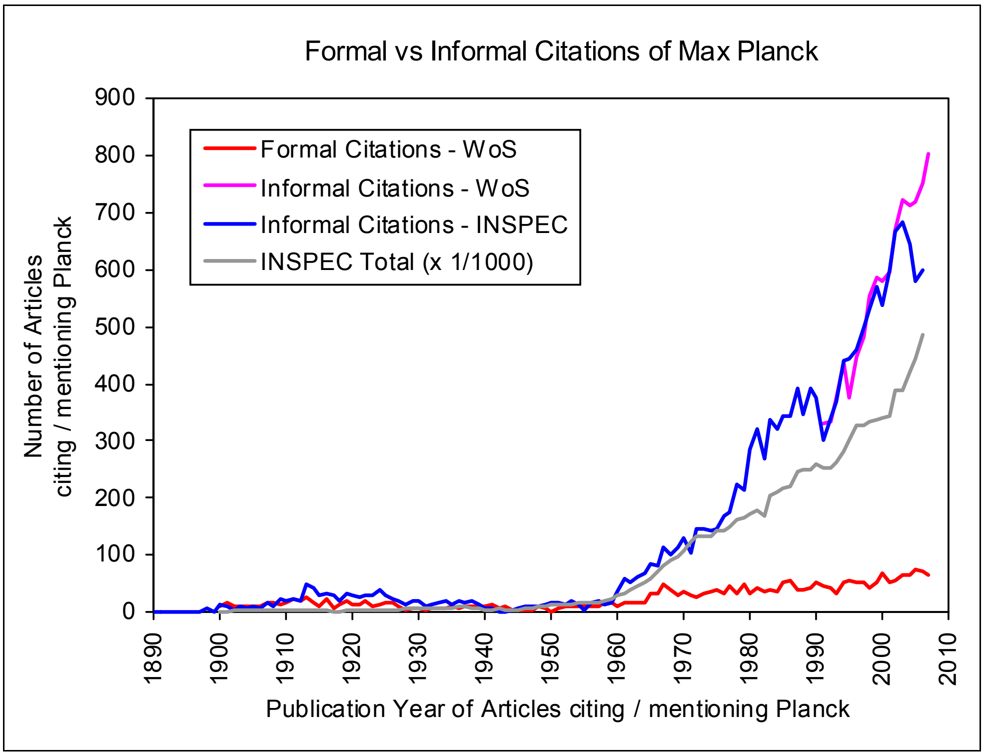

FIG 4: Time dependent number of *formal* citations referring to the works of Max Planck (articles and books) versus *informal* citations ("Planck" appearing in the titles, the abstracts or the keywords) based on INSPEC. The time curve of the total number of records covered by INSPEC is shown as an illustration of the time evolution of the physics literature. Currently, the publication year 2007 under INSPEC is not complete and hence not included here.

Out of almost 16,000 articles mentioning Planck's name, about 8300 refer to the so-called Fokker-Planck equation. The Fokker-Planck equation describes the time evolution of the probability density function of the position and velocity of particles. Planck derived the equation already independently reported in the year 1914 by Adriaan Fokker (1887-1972) [27] which has become most important for statistical mechanics. Note the large difference between the formal citations of the original papers (Planck: 117, Fokker: 132) and informal citations (8300).

The time evolution of citations is a result of two competing phenomena: the aging of the articles (obsolescence, replacement, oblivion) and the growth of the scientific literature. The articles covered by the SCI as well as by INSPEC increased approximately by a factor of hundred throughout the 20th century. The proliferation of science implies a proliferation of potentially citable articles, resulting in increasing ratios of references per article (reference count) and therewith of the average number of citations per article (citation rate). We may speculate about how much more a citation around 1900 is worth compared to a present day citation and may decide that citation numbers have inflated by a factor between ten and hundred.

Finally, we summarize the citation analysis by listing the citation numbers with respect to articles & books and to articles only, for the time period January 1900 to June 2008:

- Impact of articles only based on the WoS *General Search* mode: 679 citing papers comprising 840 citations (citations of the pre-1900 articles not covered by the WoS as source records are excluded).

- Total impact (pre-1900 articles & books included) based on the WoS *Cited Reference Search* mode: 2767 citing papers comprising approximately 3000 citations (some papers cite more than one Planck article and/or book).

- Impact of articles published in *Sitzungsberichte der Preußischen Akademie der Wissenschaften* and in *Verhandlungen der Deutschen Physikalischen Gesellschaft*: altogether 674 citations.

The large difference between I and II is caused by (1) the pre-1900 articles which are not covered by the WoS, (2) the various Planck publications which did not appear in WoS source journals (e.g. some articles, books, lectures, and talks) and (3) the above average citation error rate due to the specific history of Planck' most important journal *Annalen der Physik* (see above).

Planck's *h*-index

A new index (*h*-index, *h*-number) was introduced recently by Jorge E. Hirsch as a measure of the cumulative impact of a person's scientific work within a given discipline [28]. It can be easily obtained under the WoS *General Search* mode, provided there are either no highly cited namesakes or they can be removed. The *h*-index is simply defined as the number of articles in *source journals* that have had h citations or more. The index increases roughly linearly with the scientific age of the scientist and depends on his specific research field. The *h*-index reflects a researcher's contribution based on a broad body of publications rather than based on a few high-impact papers. This avoids an overestimation of single or few highly cited papers, sometimes being methodological contributions, reviews or articles with a number of coauthors in which it is impossible to assign individual contributions. The *h*-index favors researchers who consistently produce influential papers.

The *h*-indexes given in Table 2 were determined on the basis of the WoS *General Search* mode. In this mode only the citations of the papers covered by the WoS *source journals* are included. The *h*-index of Max Planck rises from 12 to 14 if the citations to the pre-1900 articles not covered by the WoS are taken into account.

Note that the impact of early papers, and thereby the *h*-number of pioneers like Max Planck are much lower than those of current top-scientists (e.g., P.W. Anderson, h = 103; Giorgio Parisi, h = 77). The increasing number of citable papers within the last century results in increasing average citation rates. In addition, the *h*-index is a measure both for performance as well as output. The publication habits (in particular the average number of papers per year and the number of coauthors per paper) has increased significantly. Around 1900 scientists like Planck used to publish 1-2 articles per year. Hence, the citation numbers (and the *h*-numbers) of early scientists are not directly comparable to those of present day researchers.

TAB 2: Comparison of Max Planck with some Nobel laureate contemporaries by using *h*-numbers.

Researcher	*h*-number
Max Planck	12/14*
Wilhelm Wien	10/13*
Niels Bohr	22
Albert Einstein	46
Enrico Fermi	31

* *h*-number corrected with respect to the pre-1900 articles not covered as source records by the WoS (under the *General Search* mode). They have been estimated using the *Cited Reference Search* mode.

In general, evaluation, particularly where individuals are involved, has to be done very carefully, because one is dealing with people's careers. This caveat does not apply to early pioneers, but in their case the danger of distortion is even larger.

Planck’s books and published lectures

Planck was one of the leading theoretical physicists at his time. Not surprisingly, his lectures given at the University of Berlin appeared as books. In addition, Planck became one of the most important representatives of German science. His many talks given in his role as permanent secretary of the Prussian Academy of Sciences, as rector of the University of Berlin, and as president of the KWG have been published. Planck’s books can be classified into the following categories:

- Scientific autobiography [1] and the various biographical notes.
- Dissertation, Habilitation, and Nobel lecture.

- Lectures published in book form and given in Ref. [29-32].
- Talks (about science, philosophy, and religion) collected in Ref. [8].

Books or book articles are no WoS source records and are therefore not searchable via the WoS General Search mode. The references assigned to books within the articles of the WoS source journal articles, however, are completely captured in the WoS. The citations of individual books (and of articles not published in source journals) are determined using the WoS Cited Reference Search mode. As a result of our analysis, Planck's lectures received altogether almost 700 citations. See for comparison Richard Feynman's famous *Lectures on Physics* (4500 citations). Planck's scientific autobiography was cited about 200 times. We should mention here that citations do not measure the full impact of books, but only the reference based attention within the ensemble of articles published in the WoS source journals. In contrast to books, research articles can be much better evaluated by this method.

Obliteration by incorporation

The works of Max Planck, in particular those in the field of quantum physics (but also his contributions to thermodynamics), are a typical example of "obliteration by incorporation", a phenomenon first described in 1949 by the sociologist Robert K. Merton [33-34]. The process of obliteration or palimpsest (the latter expression referring to a piece of parchment used more than once, i.e., being erased to make room for newer work) affects seminal works (i.e., truly ground-breaking research) offering novel ideas that are rapidly absorbed into the body of scientific knowledge. Such work is soon integrated into textbooks and becomes increasingly familiar within the scientific community. As a result of the absorption and canonization, the original sources (mainly articles or books) fail to be cited, either as full references (formal citations) and even as names or subject specific terms (informal citations) [28].

The ideas survive sometimes becoming substantial elements of the basis and groundwork of modern science, but overbuilding the groundwork implies obliterating the sources. For example, the articles of Albert Einstein on the Theory of Relativity (published 1905 and 1916, respectively) are rarely cited in current research papers (as compared to less fundamental work), although they are the basis of modern cosmology and mainly caused Einstein's popularity. It may even happen that a transmitter, being familiar with the origin of a concept und assuming that the same is true for his readers, brings the idea back to life without citing the source and eventually becomes identified with its originator.

Eugene Garfield, the inventor of the citation indexes and the founder of the ISI (Institute for Scientific Information, Philadelphia), concisely stated in one of his essays [35]: "Obliteration – perhaps even more than an astronomical citation rate – is one of the highest compliments the community of scientists can pay to the author…. It would mean that his contribution was so basic, so vital, and so well-known that scientists everywhere simply take it for granted. He would have been obliterated into immortality". Bearing that in mind, we should not expect that the formal or even the informal citations of the works of Max Planck can be taken as a real measure of the influence of his ideas in modern science. There is no metrics for quantifying fundamentality, significance or even elegance, which are terms belonging to a completely different category.

Conclusions

We have considered Max Planck not only as a towering scientist, one of the fathers of modern physics, but also as a prominent historical figure, a witness, an actor and a tragic victim of some of the major cataclysms of modern history. In his public political life he was confronted with overwhelming dilemmas. His handling of them has been the object of considerable controversy, especially in recent years, a fact which is not privy to him but also applies to many of his "Aryan" German contemporaries. His main contributions to science, especially his treatment of the black body radiation and his introduction of Planck's constant h and Boltzmann's constant k_B, have been discussed. Citations analysis has been applied to his published works and shown to be of limited value, a fact which also applies to other old pioneers. The concept of informal citations (eponyms) brings better to the fore his present day impact.

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