Max Planck and the genesis of the energy quanta in historical context

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The German physicist Max Planck (1858–1947) is considered as the founder of quantum mechanics as he had proposed the quantum nature of energy. On 29 November 1937, the German Ministry of External Affairs informed Planck about the travelling possibilities to India. This was in connection with an invitation of the Indian Science Congress Association at its 25th anniversary. The document KultW 17804 II dated 10 December 1937 suggests that Planck declined the invitation as he was too old for such a journey. On the occasion of Planck's 150th birth anniversary, the following note is intended to give a short review about his life, scientific achievements and in particular the genesis of energy quanta hypothesis. Indian scientists came in contact not only with Planck, but also with other European theoretical physicists. In the end a brief review about the development of theoretical physics in India in the first half of the 20th century is given.

Some of the renowned German physicists such as Arnold Sommerfeld, Werner Heisenberg and Max Born visited India in the 1920s and 1930s. During this period Indian physicists had close contact with the German scientific community. S. N. Bose wrote 'Planck's law and the light quantum hypothesis'[1]. This led to the foundation of Bose–Einstein statistics. In the 1950s, Bose visited Planck's student Max von Laue (1879–1960), who called 14 December 1900 as the 'birthday of quantum theory' as on that day Planck introduced the energy quantum hypothesis. On the occasion of the 100th death anniversary of Italian scientist Alessandro Volta, renowned physicists like Niels Bohr, Max Planck, Arnold Sommerfeld and Meghnad Saha were invited to Como (Figures 1 and 2). During his lifetime Planck became a legendary figure. After the Second World War, in 1948 the Kaiser Wilhelm Society for the Advancement of Science (founded in 1911) was renamed as Max Planck Society (in German, Max Planck Gesellschaft – MPG). Today the MPG has 80 research institutes with more than 12,000 workers[2]. On the occasion of Planck's 150th birth anniversary, it will be worth knowing under what circumstances the hypothesis came into existence. It was one of the important factors for the development of atomic physics and quantum mechanics. Interestingly, it was the period during which Indian physicists like Bose, C. V. Raman and Saha appeared on the international stage and interacted with the Western scientific community.

In this note Planck's biography and scientific achievements are given. At the end a brief review about the contribution of Indian scientists to theoretical physics and development of the field in the first half of the 20th century is provided.

Max Planck

Max Planck was born in Kiel. In 1867, the family moved to Munich due to professional reasons. After finishing schooling, Planck studied physics and mathematics. In 1877/78, he spent a semester in Berlin and came in contact with great scientists of that time, such as Herman von Helmholtz and Gustav R. Kirchhoff. His Ph D thesis and postdoctoral work (Habilitation) dealt with thermodynamics, in particular entropy – a topic which interested him throughout his life. In 1920, Planck reformulated Nernst's theorem, which later came to be known as the third law of thermodynamics. It states that it is impossible to reach a temperature of absolute zero degrees. Planck also contributed to the statistical physics. His well-known work is the Fokker–Planck equation, which describes the time evolution of the probability density function of the position of a particle.

Planck did not follow the advice of his Ph D supervisor Philipp von Jolly to not continue work in theoretical physics as, with the discovery of the two laws of the thermodynamics, there was nothing new to discover[3]. He decided to work on the new theories of electrodynamics and thermodynamics. At the end of the 19th century 'the question at the heart of the debate was whether time-honoured Newtonian mechanics could still be held as the valid description of all of nature'[4]. Planck was impressed by Rudolph Clausius, who had introduced 'entropy'[5]. Now, the second law of thermodynamics could be formulated to state that the entropy of an isolated system always remains a constant or increases.

Between 1880 and 1885 Planck worked as an unpaid lecturer in Kiel. In 1885, he was appointed professor of theoretical physics. Planck later recalled that he was not happy with the position as it was not due to his scientific capabilities, but the connections of his father with Gustav Karsten, a professor of physics[6]. He gave lectures on electricity, optics and thermodynamics. These topics in combination with Maxwell's electromagnetic theory formed the basis of his researches on radiation theory.

After Heinrich Hertz who discovered electromagnetic waves declined the post, in January 1888 Planck was offered professorship at the Freidrich Wilhelms University, Berlin[7]. Hertz died at the beginning of 1894. Planck intensively researched on Hertz's scientific work. As a consequence he learnt to apply thermodynamics on the emission and absorption processes. It was the beginning of his research, which later led to the derivation of Planck's law.

Planck occupied many important positions, such as Secretary of the Prussian Academy of Sciences, President of the Kaiser Wilhelm Society and Chairman of the German Physical Society. He was awarded honorary doctorates by different national and international universities. In 1918, he was awarded the Nobel Prize 'in recognition of the services he rendered to the advancement of physics by his discovery of energy quanta'. Planck was Fellow/Member of different science academies such as those at Vienna, Uppsala, Copenhagen, Dublin, Rome, Stockholm, London, Amsterdam, Athens, Edinburgh, Boston and Washington[8].

Planck's private life was troubled and tragic. In March 1887, he married Marie Merck. They had four children – two boys and two girls. During the First World War Planck's elder son was killed and

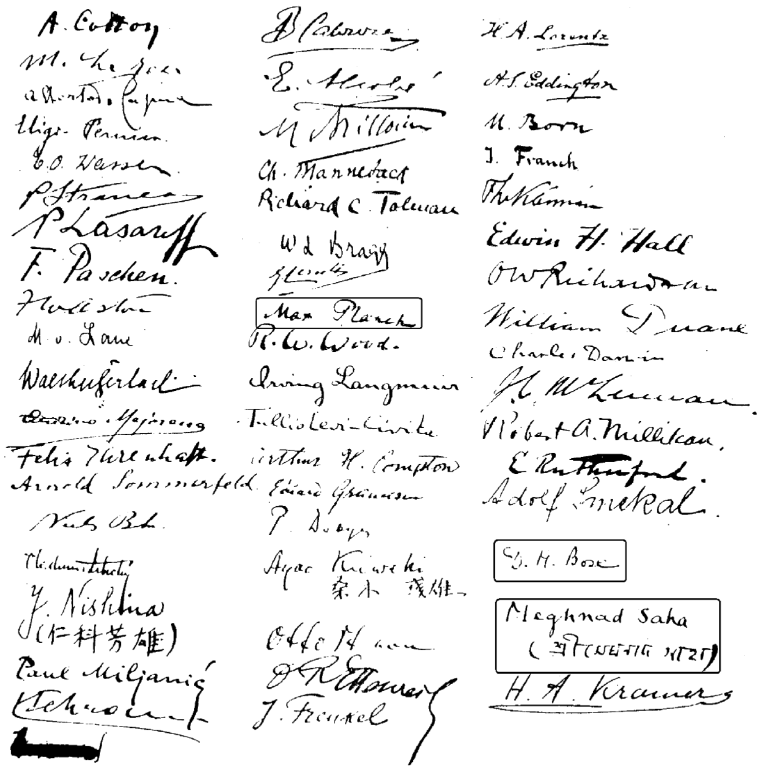

Figure 1. Signatures of the participants who attended the conference on the occasion of the 100th death anniversary of Alessandro Volta at Como. Max Planck, D. M. Bose and M. N. Saha are emphasized. Courtesy Centro Stampa Comunale, Como.

Figure 2. Como conference participants – September 1927. Max Planck, D. M. Bose and M. N. Saha are encircled. Courtesy Niels Bohr Archive, Copenhagen.

his younger son Irwin was taken prisoner by the French. Later, he became an influential figure in German politics. Planck suffered a personal tragedy when Irwin was executed for an unsuccessful attempt to assassinate Adolf Hitler[9]. While giving birth to her first child, Planck's elder daughter died in 1917. His second daughter died two years, also during childbirth. After the death of his first wife, Planck married his niece Marga von Hösslin, who bore a son. During the last weeks of the Second World War, Planck's home was destroyed by bombing.

Genesis of energy quanta

When Planck had started his scientific carrier, it was believed that physics had reached a peak and there was nothing new to discover. Light and electricity were accepted as waves due to the vibrations of a body. In 1871, the British scientist J. C. Maxwell proposed laws which explained the wave nature of electromagnetic radiation. Thermodynamics was supposed to be complete. Heat was seen as energy that could be changed into different forms. The last step in this direction was the second law of thermodynamics. It stated that thermal processes are irreversible, i.e. heat flows from higher to lower temperature and not vice versa. However, J. W. Gibbs, USA and the Austrian scientist, L. Boltzmann had proved that the law depends on the number of atoms in a physical system, and thus had shown the limits of the law[8]. The scientific community was divided into two groups: one preferred to work with the term 'energy', while the other tried to explain phenomena in terms of 'atoms and molecules'. Mechanics and chemistry were considered as part of thermodynamics, and to be interpreted in terms of atoms, molecules and their movements. At the end of the 19th century, the question was whether it will be possible to find a theory which could be applied to phenomena in terms of 'energy' and 'atoms'.

Long before Planck started his scientific carrier, in 1860 G. R. Kirchhoff proposed the definition of a black body – a body which absorbs whole of the incident radiation[10]. The radiation emitted by such a body is independent of the material of the body and depends only on temperature. In the following years, further studies led to the invention of different radiation laws, e.g. Wien's displacement law. It made possible the calculation of energy density (radiation energy density per unit frequency) for all temperatures, if it is known for one temperature. In Berlin, O. Lummer and E. Pringsheim undertook experimental studies of Wien's law. They observed that though the law held good for short wavelengths, it failed for long wavelengths.

Planck once recalled that he decided to become a physicist because the law of conservation of energy (that is, energy can neither be created nor destroyed) fascinated him. For him the physical laws of science had solid foundation as they are objective, their existence is independent of thoughts and wishes[6]. Planck, who believed in the existence of universal laws of nature, was not satisfied with Wien's derivation that contained statistical elements like molecular disorder. He wanted to have a formula free from the molecular or atomic concept, but based on more a general term like energy. His intention was to formulate a law that justified his entropy concept, which was fundamental to the second law of thermodynamics. In 1897, Planck chalked out a grand programme and started a series of five memoirs on irreversible radiation processes[11]. In 1899 he found an expression for the entropy of an oscillator using which he could derive Wien's radiation law[12]. However, experimentalists like Lummer and Pringsheim had shown that Planck's derivation did not hold for long wavelengths[13]. Later, Planck derived the following expression for the spectral distribution: $U(\nu, T) = \alpha\nu^3[\exp(\beta\nu/T) - 1]^{-1}$. This expression holds for long as well as short wavelengths. The factors α and β are constants. Later β was replaced by a constant h. In November 1900, Planck related entropy to molecular disorder. In order to find this molecular disorder, he had to find a way to divide the total energy among different oscillators. This he did by introducing the term ε (= $h\nu$) for the energy of an individual oscillator. In the expression, h was a universal constant and ν the frequency of the radiation. This distribution was called quantanization. With this the fundamental principle of the classical mechanics was opposed, according to which the energy of a mechanical system was seen as a continuum. The paper regarding the process of quantanization was presented to the German Physical Society on 14 December 1900. H. Ruben and F. Kurlbaum at Berlin showed that among all the known laws of radiation (due to Wien, M. Thiesen, Rayleigh and Planck), Planck's law fits best to the experimental observations[14].

From energy quanta to quantum mechanics

A number of excellent books and articles deal with the advent of energy quanta, light quanta and quantum mechanics. Planck's own version about the discovery is to be found in *A Survey of Physical Theory*[15]. Some historians of science give credit to Albert Einstein for being the founder of quantum mechanics, while others take the side of Planck. One of the arguments against Planck is his letter from 1931, in which he stated that the energy quanta was a purely formal assumption and 'I really did not give it much thought except that no matter what the cost, I must bring about a positive result'[4]. Elsewhere, energy quantum hypothesis has been called 'lucky guessed interpolation'[16]. A special issue of the popular journal *Spektrum der Wissenschaft* brought out in co-operation with the MPG has been entitled as *Max Planck – Revolutionär wider Willen* (Max Planck – Revolutionary against his will). Here, Planck has been compared with Christopher Columbus and Nicolaus Copernicus, who missed their targets but found something new which changed the history.

After proposing the energy quanta hypothesis, neither Planck nor his contemporaries were aware about this revolutionary hypothesis, until in 1905, Albert Einstein showed that not only energy, but also light needs to be seen as quanta in radiation processes. In order to explain the black-body spectrum in terms of Wien's law, Einstein applied the concept of light quanta. He had shown that the energy of the oscillator responsible for the emission and absorption of light would change as multiples of $h\nu$. Einstein's hypothesis of light quanta (later named as photon) had to face opposition in the scientific community (in particular by Planck), as it was against the theory of the wave nature of light, which was being applied successfully until then[17]. However, phenomena like specific heat at low temperature and ultraviolet spectrum in X-rays could not be explained using the classical theory. Such discussions on the quantum problem on the occasion of the first Solvay Conference (1911) were the starting point for a new field of research, namely quantum theory (later named as quantum mechanics by M. Born).

In 1913, Bohr proposed an atomic model for which he applied Planck's hypothesis. According to the model the electrons revolve around the nucleus of an atom at defined distances. When they jump from one orbit to the other, a definite amount of the energy is radiated or absorbed. With it a new field, that is, atomic physics began, and also the observed spectroscopic data could be explained. In 1921, the periodic system was finally explained by Bohr with the application of the atomic theory. Other scientists who contributed to atomic physics and quantum mechanics were Sommerfeld (Figure 3) and Born. All the three physicists had close contact with Indian scientific community. It will be worth to see, whether these contacts influenced the development of theoretical physics in India?

Theoretical physics in India between 1900 and 1950

In the beginning of the 1910s, the so-called old quantum theory was developed by Bohr and Sommerfeld. But it 'not only failed to work in the cases of the two-electron helium atom and of more complex atomic systems, but eventually failed even to explain the behaviour of the hydrogen atom under the influence of particular forces'[18]. Quantum mechanics was established between 1925 and 1932 by Born, W. Heisenberg, E. Schrödinger, W. Pauli, P. Dirac and others. This theory was able to give solutions related to the atomic constitutions of matter. A study by A. Kozhevnikov and O. Novik[19] shows that 203 papers were published on quantum mechanics between July 1925 and March 1927 with 120 and 30 respectively, contributed from Germany and England[17]. The following Indian physicists either contributed to modern physics or interacted with the Western scientists who were related to this field[20]: G. D. Deodhar, M. K. Ghosh, D. S. Kothari, C. V. Raman, B. B. Ray, H. Rau and Saha. In order to get better insight into the contributions of Indian physicists, further research is needed. However, we have one case study of the physicist B. B. Ray, who worked with the Nobel laureates Bohr and M. Siegbahn[21]. On 6 March 1926 Ray wrote to Bohr from Berlin: '... personally I shall not be sorry if the whole outbursts of Born and Jordan is completely withdrawn and I fear if the atomic physics had to progress on the line of Born and Jordan, you will find very few people left in the atomic physics circle'. It seems Ray's attitude towards theoretical physics did not change in future. In 1992 an Indian historian observed: 'The impact of the discovery of the quantum dynamics was felt quite late in India in the field of solid state physics ... B. B. Roy (Ray) ... professor

Figure 3. From left to right: K. S. Krishnan, A. Sommerfeld and C. V. Raman. In 1928, Sommerfeld visited India on an invitation from Raman and Saha. Courtesy: Raman Research Institute, Bangalore.

working with X-rays at Calcutta University, did not look kindly at all on the quantum mechanics of Heisenberg, Born and Jordan[22].

In general theoretical physics began in India at the end of the second decade of the 20th century. On the occasion of the 25th anniversary of the Indian Science Congress Association, Saha wrote a report on the 'Progress of physics in India during the past twenty-five years'. While dealing with theoretical physics, he placed his paper from the year 1917 in the first place. Other names listed are: S. N. Bose, K. C. Kar, R. C. Majumdar, N. S. N. Nath, N. R. Sen and H. J. Bhabha[23]. Other sources showing the development of theoretical physics in India are two bibliographies[24,25] on the '. . . physics, astronomy, astrophysics and geophysics in India: 1800–1950'. They are based on the analysis of 151 national and international journals and periodicals. The researches in 'Quantum mechanics and quantum statistics', and 'Wave mechanics and wave statistics' are taken as subparts of general physics. According to this classification, in the first half of the twentieth century Indian authors produced only 35 and 19 papers respectively, in the two fields. The authors have listed the two important papers of Bose related to the derivation of Planck's law on quantum mechanical basis under the category 'optics and radiation'. Even if we include these papers, the total number of papers published on quantum mechanics remains below 60.

In the beginning of the 20th century, Indian mathematicians were better organized than the physicists. In 1907, the 'Analytical Club' was founded (later named as Indian Analytical Club) and finally renamed as the Indian Mathematical Society[26]. In 1934 the Indian Mathematical Society published its *Silver Jubilee Commemoration Volume*. So far as theoretical physics is concerned, in June 1953 the first issue of the *Indian Journal of Theoretical Physics* was published. In general India's contribution to theoretical physics and in particular to quantum mechanics, though not negligible, was only meagre. One of the reasons was colonial education system for the exploitation of the colonies' resources. Practical and experimental work was the central point. This is evident from the Irvine Committee which in the 1930s gave report on the Indian Institute of Science, Bangalore. While opposing the appointment of a faculty for theoretical physics, the committee expressed its opinion as follows: 'Modern mathematical physics, with its attractive fields of speculation and experiment, has little direct contact with industry, . . .'[27].

Indian physicists like Bose and Saha could not afford to work in theoretical physics, they were forced to choose experimental work. In the 1930s, Raman tried to bring the famous theoretical physicists Schrödinger and Born to India, but without success[27].

Conclusions

Scientific ideas are not a matter of chance. They come from a deep understanding of the subject matter. At first sight, introduction of energy quantum hypothesis by Planck looks like a 'shot in the dark'. However, the analysis of his scientific work and discussion of the prevailing research fields of the time, clearly show that it was due to far-sightedness that the hypothesis came into existence.

In the first three decade of the 20th century Indian scientists interacted not only with the British but also with other European scientists. In particular, they were welcomed by German and Italian scientists. This was due to their achievements as well as due to 'political sympathy' with scientists from the British colonies.

A field of research can get established in a country only if it is supported by the regime and the countrymen. During the colonial period theoretical physics remained an unwanted subject, as it was of no use to exploit colonial resources.

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