

# Arnold Sommerfeld

## Physicist and Teacher Beyond Compare

### Introduction – Gymnasium and University in Königsberg

The German tradition in physics – as in music, philosophy and literature – has been an exceptional one over a very long period of time. Recall the likes of Gustav Kirchhoff, Hermann von Helmholtz, Heinrich Hertz and Wilhelm Röntgen during the 19th century; to be followed by Max Planck, Wilhelm Wien, Albert Einstein, Max von Laue into the 20th. But even in such exalted company Arnold Sommerfeld occupies a very special place, as the father of theoretical physics in Germany, and arguably the greatest teacher the world of physics has ever seen. He combined excellence in research, teaching, mentoring and scholarship to a degree never equalled by any other. To do justice to such a personality in a few pages is not at all easy.

Arnold Johannes Wilhelm Sommerfeld – hereafter Sommerfeld – was born on December 5, 1868, to Cäcile Mathias and Franz Sommerfeld, a medical doctor, in Königsberg, then in Prussia. This was the city where the philosopher Immanuel Kant (1724–1804) was born and lived all his life; and also where the great mathematician David Hilbert (1862–1943), who straddled both the 19th and 20th centuries, was born. In 1946, after World War II, this city became Kaliningrad in the Soviet Union, now Russia. It is good to remember the years of birth of some other physicists and mathematicians of those and slightly later times with whom Sommerfeld interacted so closely over an entire life time: Felix Klein in 1849, Hendrik Lorentz in 1853, Max Planck in 1858, Hermann Minkowski and Wilhelm Wien in 1864, Albert Einstein in 1879, Max Born in 1882, Niels Bohr and Hermann Weyl in 1885, and Erwin Schrödinger in 1887.

In school (gymnasium) in Königsberg from 1875 to 1886, Sommerfeld excelled in both the sciences and humanities. He wrote much later:

“To my energetic and intellectually vigorous mother I owe an infinite debt.”

At the University in Königsberg from 1886 to 1891, he was taught by the mathematicians Hilbert, Hurwitz and Lindemann; and completed a PhD under Lindemann’s guidance on ‘The arbitrary functions in mathematical physics’. This was exposure to the finest mathematics of the time.

### Göttingen – Clausthal – Aachen

After another year for a teaching diploma, and then a year of military service, he moved in 1893



to Göttingen, ‘the seat of high mathematical culture’. In 1894 he became assistant to Felix Klein, of whom he wrote:

“Overwhelming was the impression which I received, in lectures and discussions, from Felix Klein’s grand personality... I have always regarded Klein as my real teacher, not only in things mathematical, but also in mathematical physics and in connection with mechanics”.

It was in 1895 with Klein’s guidance that Sommerfeld did his first truly outstanding piece of research – the problem of diffraction of light by a straight edge. (This work is described in an article elsewhere in this issue.) He also assisted Klein during 1895–1896 in organizing the latter’s lectures on tops and gyroscopes – this resulted later in the 4-volume work *Theorie der Kreisels* by the two of them completed in 1909–1910. At Klein’s request, Sommerfeld became editor of Volume V of the ‘*Encyclopadie der mathematischen Wissenschaften*’ from 1898 to 1926.

From Göttingen, Sommerfeld moved in 1897 to Clausthal-Zellerfeld as Professor of Mathematics at the *Bergakademie* (mining academy). He was to stay at Clausthal till 1900. In this period he married Johanna Hopfner; they had three sons and a daughter.

The years 1900–1906 were spent at the Technical University at Aachen, as Professor of Applied Mechanics. In these years he took up work in hydrodynamics, the field in which much later his students Ludwig Hopf and Werner Heisenberg would both write their doctoral theses.

### **The Munich Years – Teacher Par Excellence**

Finally in 1906 he came to the University of Munich as Professor of Theoretical Physics, a position for which he was selected by Röntgen and Lorentz. Here he stayed for the rest of his working life, as Director of his own Institute, until retirement in 1938. It is incredible to read of his weekly load at Munich: four hours of basic courses, two hours of specialized classes, a seminar and a Colloquium. As Sommerfeld said later:

“I used to organize my lectures in such a way that they were too easy for advanced students and too difficult for beginners.”

On the research front, quoting from Peter Ewald, Sommerfeld

“...was one of the central figures in achieving the transformation through which physics passed in the two decades from 1910 to 1930.”

He was mentor to a galaxy of greats in the ‘European half’ of 20th century physics – Peter Debye (in Aachen in 1908), Wolfgang Pauli (1921), Werner Heisenberg (1923), Hans Bethe (1928), all



Nobel Laureates; then Walter Heitler, Rudolf Peierls, Peter Ewald, Otto Laporte, E C G Stüeckelberg, Gregor Wentzel, Alfred Lande and Leon Brillouin – all names familiar to every serious student of physics. As Einstein put it so aptly:

“What I especially admire about you is that you have, as it were, pounded out of the soil such a large number of young talents.”

He gave the first ever courses on relativity and quantum theory as he was contributing to them himself. As his Institute in Munich grew, it became one of the three great European centres of that time, each expressing a characteristic flavour or attitude to theoretical physics – close to experiment in Munich, more mathematical with Born in Göttingen, and more philosophical with Bohr in Copenhagen. Heisenberg expressed it this way:

“I learned optimism from Sommerfeld, mathematics in Göttingen, and physics from Bohr.”

### **Sommerfeld’s Major Contributions to Physics**

Turning to Sommerfeld’s own accomplishments in physics, there was work on the classical theory of electromagnetism, in particular a solution to the problem of a radiating hertzian dipole over a conducting earth, which has been widely applied. Then there were the many extensions of the Bohr model of the atom in the framework of the Old Quantum Theory: the generalization from circular to elliptical orbits for the electron in the atom; in 1914–1915, the introduction of the ‘magnetic quantum number’  $m$  in addition to angular momentum  $l$ ; in 1916, the extension of Bohr’s quantum condition to the case of multiply periodic systems by him and independently by Wilson; also in 1916, the relativistic correction to the Bohr energy level formula leading to the fine structure of the hydrogen spectrum and the introduction into physics of the ‘Sommerfeld fine-structure constant’  $\alpha = e^2/\hbar c \cong 1/137$  (see article by Biman Nath, p.383) In 1920, he introduced a ‘4th quantum number’ traditionally written as  $j$ . Of this period and all this work, it is said that Sommerfeld believed in the Bohr theory more strongly than did Bohr himself! In fact, after his first meeting and discussion with Bohr in 1922, Heisenberg later wrote:

“... I was at once impressed by the difference in his way of seeing quantum theory from Sommerfeld’s way.”

As for the Sommerfeld fine structure formula, it turned out to be a ‘lucky accident’, the now accepted derivation being via the relativistic Dirac wave equation for the electron found in 1928. Quoting from Abraham Pais, while Sommerfeld’s “fine structure formula is quite correct,..., his derivation is wide off the mark, turning it into ‘perhaps the most remarkable numerical coincidence in the history of physics’(Kronig)”.



Sommerfeld's 4th quantum number would lead in time to the Pauli exclusion principle, and then on to the profound idea of electron spin. After the coming of wave mechanics, which he readily accepted, in 1927 he used the new Fermi–Dirac statistics to present his electron theory of metals, a great advance over the earlier Drude theory.

In addition to teaching and research, Sommerfeld was prolific in the writing of books as well. The *Theorie der Kreisels* has already been mentioned. Between 1919 and 1946 appeared the six editions of his '*Atombau und Spektrallinien*' – veritably the 'bible' for physicists spanning several generations. To this he added in 1928 a special volume on *Wave Mechanics*. Then, after retirement, he turned to the task of writing down his courses of lectures in Munich given regularly from 1906 to 1938. This occupied him from 1942 to 1951, with some of the later volumes completed by others, and resulted in the six volumes of *Lectures in Theoretical Physics*. Again a classic of the literature for physics teaching, recently reprinted by Levant Books, Kolkata.

### Post Cards from Einstein, Nobel Nominations

The fact that Sommerfeld was held in the highest esteem by the physics community worldwide needs no repetition. As this year, 2015, marks the centenary of Einstein's creation of the General Theory of Relativity, it is revealing to see how he conveyed his deepest feelings on the progress of his work to Sommerfeld. Those were the days when post cards were in regular use, and that was how they communicated with one another. Here are sentences from two postcards Einstein wrote to Sommerfeld in November 1915 and February 1916:

November 28, 1915:

“Dear Sommerfeld,

You must not be cross with me that I am answering your kind and interesting letter only today. But in the last month I had one of the most stimulating, exhausting times of my life, indeed also one of the most successful. I could not think of writing....”

February 8, 1916:

“Dear Sommerfeld,

... You will be convinced of the general theory of rel. when you have studied it. That is why I am not mentioning a word in its defense.

Hearty congratulations on your fine discovery and best regards, yours,

Einstein”



The records of the Nobel Foundation show that Sommerfeld was nominated an enormous number of times for the Prize in physics, in fact every year from 1917 to 1937 (except one). As it happened, he never won this high recognition. It is tempting to agree with Pais when he says:

“I belong to those who regret (even more after recent studies) that Sommerfeld’s work was never sufficiently recognized by the Nobel Committee”.

### Connections with India

Sommerfeld had regard for and warm relationships with Indian physicists of about a century ago, including of course C V Raman. He visited India during October 1928, and gave lectures at Calcutta, Madras and Bangalore. He had said:

“... it was in this ancient land of civilization that, during the last years, strong shoots of modern physics had grown, by which India suddenly emerged in the competition of research as an equal partner with her European and American sisters”.

He also visited Rabindranath Tagore at Santiniketan. After his talk at Presidency College, Madras, in conversation with the eighteen year old Subrahmanyan Chandrasekhar, Sommerfeld told him about the new Fermi–Dirac statistics, and gave him the proof sheets of his own article on the electron theory of metals. What then followed is of course history. When Sommerfeld left India, he expressed

“...deepest affection for the highly gifted, unhappy nation...with sincere gratitude for the many acts of friendliness and honourings.”

An account of the visit is given by Rajinder Singh in *Current Science* Vol.81, pp.1489–1494, 2001.

### The Later Years

Sommerfeld lived through both World Wars, and witnessed the rise and demise of Nazism in Germany. Quoting from Morris Kline:

“Sommerfeld’s life was saddened toward the end of his career by events in Germany. Antisemitism ...became virulent in the Hitler period...Sommerfeld was obliged to witness the emigration of famous colleagues, including Einstein”.

Already around 1934 Sommerfeld had written to Einstein:

“...I would now be willing to see Germany disappear as a power and merge into a pacified Europe.”



On his part Einstein issued a strong statement in which Sommerfeld appears. Borrowing from Pais' biography of Einstein:

“ ‘...I will have nothing further to do with Germans...It is otherwise with those few who remained firm within the range of the possible.’ To him those few included Otto Hahn, Max von Laue, Max Planck, and Arnold Sommerfeld.”

On account of the loss of scientific strength in Germany due to World War II, Sommerfeld continued to teach even up to the age of 79. Three of his students – Pauli, Heisenberg and Heitler – had gone on after their doctoral degrees to work as assistants to Born in Göttingen. Here is Born's appreciation:

“Theoretical physics is a subject which attracts youngsters with a philosophical mind who speculate about the highest principles without sufficient foundations. It was just this type of beginner that he knew how to handle, leading them step by step to a realization of their lack of actual knowledge and providing them with the skill necessary for fertile research...He had the rare ability to have time to spare for his pupils, in spite of his duties and scientific work...” .

Kline's tribute supplements this:

“(He) was at the forefront of the work in electromagnetic theory, relativity and quantum theory and he was the great systematizer and teacher who inspired many of the most creative physicists in the first thirty years of this century.”

Sommerfeld died in Munich on April 26, 1951 at 82 as a result of injuries sustained in a road accident while walking with his grandchildren.

Truly he was one of the most respected and illustrious figures belonging to an incredibly rich scientific tradition, combining the roles of teacher and physicist in a manner never equalled.

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