

## Peter Debye

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*“Not to despair and always be ready to grab the Good which whisks by, without granting the Bad any more room than is absolutely necessary. That is a principle of which I have already made much use. Hopefully, the new year will bring more good than our little faith allows us to see at this moment.”*

Professor Peter J W Debye, December 30, 1939

Petrus (Peter) Josephus Wilhelmus Debye was an extraordinary physical chemist of the 20th century. In fact, the American Chemical Society chose to name its annual award for a physical chemist as the ‘Peter Debye Award in Physical Chemistry’.

Debye was born at Maastricht, Netherlands on March 24, 1884. His primary education was in his home town. He joined Aachen Institute of Technology (Technische Hochschule) for his first degree in electrical technology which he received in 1905. His first appointment was as an assistant in Technical Mechanics. He had also studied mathematics and classical physics in Aachen, the later under Arnold Sommerfeld. Sommerfeld has made outstanding contributions in theoretical physics himself and has supervised the PhD thesis of more physics Nobel Laureates than anyone else [1]. Given this, his claim that Peter Debye was his most important discovery assumes enormous significance [2]. However, Debye was not one of the physics Nobel Laureates Sommerfeld had guided. He won it in chemistry in the year 1936 and this is what the announcement says [3]: “By your investigations on dipole moments and also on X-ray and electron interferences in gases you have widened and deepened our knowledge of molecular structure to such an extent that the Royal Academy of Sciences has awarded you the Nobel Prize for Chemistry.” As a microwave spectroscopist in the 21st century, looking at the structure of weakly-bound complexes with a non-zero dipole moment, it seems that Debye’s contributions have directly benefitted our community. His contributions to the measurement of molecular dipole moments were so influential that the unit for dipole moment is named after him as the Debye ( $= 3.33564 \times 10^{-30}$  Coulomb meter).

After two years as an assistant in Technical Mechanics, Debye’s next appointment would be difficult to predict today. In 1906, he joined a similar position in Theoretical Physics at Munich University. Sommerfeld had moved to Munich and he had taken Debye along with him. In 1908 Debye obtained his PhD in theoretical physics and in 1910 he qualified as a university lecturer. Debye moved frequently during his stint in Europe. He spent two years in Zurich University as



professor of theoretical physics from 1911 and returned to Netherlands in 1912 to join as a professor of theoretical physics at Utrecht University. Two years later, he moved to Göttingen to Chair the Theoretical Department of the Physical Institute. Looking at Debye's repeated appointments as a theoretical physicist, one would be surprised to find that he lectured on experimental physics at the University of Göttingen until 1920. He had become the Director in this period and did not stop teaching. Today's busy and focused scientists, especially in the Indian Institutes, can learn a lot by looking at this theoretical/experimental physicist's career that led to a Nobel Prize in Chemistry. Debye's association with the experimental physicist Max Wien during his earlier days at Aachen had certainly helped Debye grow as an experimental physicist as well. In the next 20 years, Debye worked in Zurich (Professor of Physics and Principal of the Eidgenössische Technische Hochschule), Leipzig, Max Planck Institute of the Kaiser Wilhelm Institute for Physics in Berlin-Dahlem and at the University of Berlin. He also served as the Editor of *Physikalische Zeitschrift* between 1915–1940. His career as a physicist ended in Europe in 1939, during the turmoil of the Second World War. His career as a chemist started in 1940 in the United States of America when he joined Cornell University as a professor of chemistry and Principal of the Chemistry Department. Unlike his days in Europe when he kept moving from one place to another, Debye stayed put at Cornell, where he continued as an Emeritus professor after resigning his post as Chairman in 1952.

Debye's contributions to physics and chemistry have been phenomenal. Most students of physics and chemistry would be familiar with the Debye model for heat capacity of solids and Debye–Hückel theory of electrolytic solutions. In plasma physics as well as in colloid chemistry, the Debye length is defined as the distance over which the mobile charge carriers such as electrons screen out electric fields. The Debye model for vibrations of atoms in a solid extends Einstein's model for heat capacity of solids by considering the contributions from low frequency phonons. Debye also extended the Bohr's model of atomic structure by introducing elliptical orbitals. The Debye–Hückel theory is an improvement of Arrhenius theory of electrical conductivity. Thus these contributions bearing Debye's names are important extensions of the models proposed earlier. However, prior to this, his first major scientific contribution was the application of the concept of dipole moment to the charge distribution of asymmetric molecules. He derived equations relating the dipole moment to temperature dependence of the dielectric constant. These equations are still being used and not surprisingly, Mansel Davies wrote in the *Journal of Physical Chemistry* in 1984 [4]: "It is difficult to summarize briefly Debye's role in Physics and Chemistry. Suffice it to say that one essential aspect was his masterly ability to formulate mathematically the physical essentials of the problem".



Many of the concepts that are taken for granted today in chemistry were proved by Debye using careful experimental measurements. Debye began his Nobel acceptance speech as follows [5]: “Long before we had at our disposal the means offered to us today by the quantum theory to discuss the structure of atoms and molecules, it was clear that in debating this subject we had to deal with electrical structures”. He could measure the distortion present in the electrical distribution in the atoms/molecules by exposing them to static electric field and showed that molecules such as  $\text{H}_2\text{O}$  and  $\text{NH}_3$  have 40 times more susceptibility compared to a neon atom, although all these three have the same number of electrons. This he attributed to the asymmetric charge distribution in the two molecules, leading to a permanent dipole moment<sup>1</sup>. He showed that the dipole moment of 1,2-dichloroethane changes with temperature and reasoned that the change is due to the internal rotation about the C–C bond. The trans conformer will have zero dipole moment and the gauche forms will have non-zero dipole moment. With increase in temperature, the trans/gauche equilibrium will be affected leading to the change in measured dipole moment. Debye used X-ray and electron diffraction measurements as well. Beginning crystallographers would benefit by reading his Nobel Lecture [3] where he states that Ne,  $\text{H}_2\text{O}$ ,  $\text{NH}_3$  and  $\text{CH}_4$  scatter almost like monatomic gas of same total nuclear charge, and so interatomic positions of H atoms cannot be determined by the X-ray diffraction method.

Following his discovery of asymmetric charge distribution in molecules, Debye realized that this could lead to attractive forces between them explaining the van der Waals equation. Debye derived an expression for intermolecular forces due to dipole-induced dipole interaction, which is one component of the van der Waals forces. In an earlier article in *Resonance* [6], this author had suggested that the ‘van der Waals molecules’ in which dipole-induced dipole interactions dominate be called Debye molecules. Debye discussed intermolecular forces at the Baker Lecture series at Cornell University. In fact, his tenure at Cornell University followed this. Debye has won numerous awards and recognitions during his long and illustrious career [2]. The American Chemical Society bestowed its highest honor by awarding him the Priestley Medal.

There was a brief controversy about Debye’s political leaning during the tumultuous period of 1936–1939, when he was at the Max Planck Institute. However, detailed historical investigations have revealed that Debye had been apolitical. The quote given at the beginning of this

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<sup>1</sup> Trans conformer has a center of inversion and the two C–Cl bonds point in opposite directions canceling the bond moments. It has a net zero dipole moment. In the gauche conformer, the two C–Cl bonds are at 60 degrees and the net dipole moment is non-zero. The internal rotation about the C–C bond is hindered and it can result in trans to gauche conversion. Trans form is more stable than the gauche form and as  $T$  increases the equilibrium is shifted.



article, taken from a recent book on Debye [7], reveals Debye's mind as that of a simple and well-meaning individual behind an extraordinary scientist. Debye died of a second heart attack on November 2, 1966 in Ithaca, where he chose to stay after joining as a professor of chemistry at Cornell University.

### Acknowledgement

I thank Prof. K L Sebastian for a careful reading and useful comments.

### Suggested Reading

- [1] [http://en.wikipedia.org/wiki/Arnold\\_Sommerfeld](http://en.wikipedia.org/wiki/Arnold_Sommerfeld)
- [2] [http://en.wikipedia.org/wiki/Peter\\_Debye](http://en.wikipedia.org/wiki/Peter_Debye)
- [3] [http://nobelprize.org/nobel\\_prizes/chemistry/laureates/1936/press.html](http://nobelprize.org/nobel_prizes/chemistry/laureates/1936/press.html)\_Award Ceremony Speech.
- [4] M Davies, *J. Phys. Chem.*, Vol.88, p.6461, 1984.
- [5] [http://nobelprize.org/nobel\\_prizes/chemistry/laureates/1936/press.html](http://nobelprize.org/nobel_prizes/chemistry/laureates/1936/press.html) Presentation Speech.
- [6] E Arunan, *Resonance*, Vol.15, p.667, 2010.
- [7] G van Ginkel, *Prof. Peter. J W Debye in 1935–1945, An Investigation of Historical Sources*, RIPCIN, The Netherlands, 2006.

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