# Obituary



## Peter Debye

### 24 March 1884 – 2 November 1966

By the death of Peter Debye on 2 November 1966 in Ithaca, N.Y., the world has lost one of its great physicists, whose grip on the physical situation, mastery of experimental and mathematical methods, realism and down-to-earthness has thrust forward many branches of pure and industrial research of such variety that he was made successively the holder of famous chairs of Physics and of Chemistry.

Debye was born in Maastricht, The Netherlands, a town close to the German border. His father was foreman in a machine workshop, and much of his son's liveliness and quick perception was inherited from him. After finishing school in Maastricht, Peter began the study of Engineering at the near-by Poly-

technic School in Aachen. Here he happened to take courses with Sommerfeld, who was then the young Professor of Technical Mechanics. Sommerfeld did not fail to recognize this brilliant student and soon made him his assistant, and, in 1906, took him along to Munich as assistant and doctorand. The subject of Debye's thesis was a new and much improved theory of the rainbow, based on the strict theory of diffraction of light by a small dielectric sphere. I cannot remember that this thesis was ever published in full, for it had outgrown the usual volume of a Ph. D. thesis, and Teubner, the publishers, had offered to accept it as a book. But in these early years one important and topical subject after the other appeared more urgent to Debye and was tackled by him in a masterful way, so that the finishing of a book on a classical problem of lesser urgency was not so attractive. A mathematical method developed for the thesis was published separately in

*Math. Annalen* (1910) and has since served in many places; this was the method of Steepest Descent (*Sattelpunktsmethode*) of evaluating complex integrals.

In the years when Debye was in Munich, 1906–1911, physics was in a very turbulent state. On the one hand there was the upheaval of fundamentals in consequence of Einstein's theory of relativity. On the other hand the quantum of energy, $hv$, which Planck introduced in 1900 in order to arrive at the correct spectral distribution of black-body radiation, remained at that time an isolated *ad hoc* assumption. Einstein, in one of his four famous papers of 1905, was the first to detect other manifestations of $h$: he assumed a solid body to contain mechanical resonators of frequency $v$ and distributed energy on them according to the same function that Planck had used for his radiation resonators. This gave the solid body a thermal-energy content, and its derivative, the heat capacity, which vanished at low temperatures in a manner reconcilable with Nernst's early measurements. Further measurements showed that Einstein's formula did not suffice; Nernst & Lindemann increased the general bewilderment by suggesting two kinds of resonators, of frequencies $v$ and $\frac{1}{2}v$. It was at this stage that Debye saved the situation by applying Planck's distribution to the proper modes of vibration of an elastic solid – a very daring procedure seeing that these body-pervading states were substituted for the atomic or molecular resonators Planck and Einstein had been thinking of. Debye was an avid reader of classical mathematics and physics, and in particular of Lord Rayleigh's papers and his Theory of Sound. Proper modes of vibration had a high priority in his mind.

I will not dwell on the ingenious way by which Debye obtained the distribution of proper frequencies by first finding that of an elastic sphere according to the continuum elastic theory, and then simply cutting off this infinite spectrum when the number of frequencies corresponding to the finite number of molecules is reached. It is a catch-as-catch-can method based, however, on deep physical insight. Its success was resounding, and its simplicity and appeal so great that for a long time Debye's method overshadowed the mathematically sounder but less readily applicable work of Born and Kármán.

The combination of classical mechanics, electrodynamics and optics with Planck's quantum-governed energy distribution and other forms of statistics characterizes most of Debye's further work. In 1913, when the interpretation of Laue–Friedrich–Knipping's X-ray diffraction photographs was still having teething troubles, Debye, then a newly married Professor of Theoretical Physics at Utrecht, tackled the problem of diffraction of X-rays by a crystal made irregular by its temperature motion. This seemed an extremely hard problem at that time, and indeed, Debye solved it in stages. His third paper, in 1914, deals with a three-dimensional crystal with atomic displacements coordinated in elastic waves and introduces the temperature

factor in its present form. The interpretation of the constant in the exponent was wrong by a factor of 2, as shown eleven years later by Ivar Waller – hence the name Debye–Waller factor.

Debye was given no chance in Utrecht to check his theoretical work by measurements. He therefore accepted a call to the University of Göttingen, where he remained from 1914 to 1920. Niels Bohr's first epochal papers on quantized electron orbits in atoms had appeared in 1913, and Debye argued that the truth of these atomic models could be established by observing the X-ray interference effects due to the spacing of the electrons on their orbits. He and Paul Scherrer indeed obtained interference rings, using lithium fluoride as scatterer of monochromatic X-rays. But these rings were much too sharp to be caused by the small distances within the atom, and Debye and Scherrer quickly realized the nature of crystal-powder diffraction and developed the indexing and discussion of the rings. The powder diffraction method quickly became the favourite method of crystal analysis and identification in most chemical, mineralogical and metallurgical laboratories. As one of the first applications, Scherrer elucidated the nature of metallic colloidal solutions and showed how to determine the sizes and structures of particles far below the resolving power of the light microscope.

Debye was less interested in finding crystal structures than in using diffraction for the exploration of the distribution of electrons round the nucleus of atoms. He confirmed the ionic charges of lithium and fluorine in LiF by extrapolating the atomic form factors to zero scattering angle (1916), and showed, in 1919, that metals do not have a sodium-chloride-like arrangement of positive cores and electrons, as had been contended at the time.

The later work of Debye and his co-workers makes use of light, X-ray, and electron scattering for the study of the structures of single molecules, fluids, and high polymers. The discussion is in most cases a combination of classical interference theory and classical statistics. A variety of physically significant quantities is derived from the measurements: first- and second-order moments of the charge distribution, atomic distances and correlations, the end-to-end distance of chain polymers. Debye studied experimentally X-ray and electron diffraction of single molecules in gases by impact of X-rays or cathode rays on a molecular beam, for instance of carbon tetrachloride, in a common vacuum. He was the first successfully to apply the rotating-sector method for reducing the forward scattering in electron diffraction. He measured the anisotropy of light scattering in a flowing viscous liquid and in strained high polymers and interpreted the results in terms of molecular or chain orientation. It seems fair to say that Debye invented more methods of obtaining information from diffuse scattering than anybody else. For that reason alone, whoever is interested in the structure of matter owes him a great debt.

I am not aware of Debye having taken an active part in the development of wave mechanics or advanced quantum theory, except that, in a paper of 1923, he developed the theory of the Compton effect independently of Compton, whose paper preceded Debye's by a few weeks. But he did make a brilliant contribution to the dynamics of solids at a Congress on the Kinetic Theory of Matter in Göttingen, Easter 1913. His own papers on heat capacity and on the thermal scattering of X-rays are based on the assumption of linear forces between the atoms or linear elastic forces. It is impossible to explain with these the two general properties of solids, the thermal expansion and the slow conduction of heat. Debye showed in his contribution how to tackle the formidable problem posed by assuming non-linear forces, using again a catch-as-catch-can style. He showed how in a body with non-linear forces heat waves build up local and temporal fluctuations of density and of elasticity, so that for the passage of such waves the body resembles a medium turbid for light. A thermal wave is therefore dissipated and has only a finite range before it is converted into 'thermal noise'. In heat conduction energy does not ride with high velocity on the back of an elastic wave from the hot end of a bar to the cold end, but it diffuses along the bar from high to low energy concentration. Debye's theory was not yet perfect, but it laid a foundation; it took 15 years before Peierls added an important feature, the *Umklapp* processes.

Let me at least mention three further subjects that will always be connected with Debye's name:

(i) The explanation of the van der Waals forces between molecules;

(ii) the theory of polar molecules, which opened a wide field of molecular structure studies on the basis of dielectric measurements, and

(iii) the general theory of strong electrolytes, the Debye–Hückel theory.

All three subjects were started between 1920 and 1923, and they are all based on the interaction of dipoles and quadrupoles in a statistical manner. Each of the subjects has led to a great volume of further research of a physico-chemical nature. The latest interest of Debye centered on the determination of long-range molecular forces from the observation of light scattering by liquid systems in their critical state.

Debye had a brilliant career in many renowned academic positions; he received many awards and honours for his outstanding work, including the Nobel Prize for Chemistry in 1936. Neither success nor honours made him abandon his interest in all matters scientific, and in the young scientists who looked to him for encouragement and help. He was fortunate in finding a sudden death by heart failure which spared him the horrors of an incipient cancer. Thus he remained interested and active up to his last days. His name will remain alive in future generations through the Debye–Waller factor, the Debye temperature, the Debye–Hückel theory, and – perhaps the highest distinction for a scientist – through the unit of electric moment named after him.

P. P. EWALD

# Notes and News

### Second Materials Research Symposium
### sponsored by the Institute for Materials Research
### of the National Bureau of Standards

#### 16–19 October 1967

The Second Materials Research Symposium, sponsored by the Institute for Materials Research of the U.S. National Bureau of Standards on *Molecular Dynamics and Structures of Solids* will be held at Gaitersburg, Maryland, U.S.A. from 16 to 19 October 1967.

The primary emphasis of the Second Materials Research Symposium will be placed on the correlation of structural and dynamic information obtained by various experimental techniques applied to the study of solids. The Symposium will include studies of inorganic solids (including hydrogen-bonded systems), organic crystals, polymers, and biomolecules. The scope of the conference has been limited by omitting consideration of metals and alloys, simple ionic compounds such as alkali halides, and the effects of localized defects.

Invited lecturers will emphasize the complementary nature of infrared and nuclear magnetic resonance spectroscopy, neutron inelastic scattering, and neutron and X-ray diffraction techniques as applied to the studies within the scope of the Symposium. Contributed papers, however, will not be limited to research using only these techniques; the presentation of pertinent results of other techniques such as thermodynamic measurements, dielectric measurements, and Mössbauer spectroscopy is encouraged. Papers demonstrating the correlation between several experimental techniques will be particularly welcome.