Atomism Prevails

In the 19th century, there had been a crucial distinction between *chemical* and *physical* atomism, as described by August Kekulé (1829-96), the founder of the theory of chemical structure [354]:

> *I regard the assumption of atoms, not only as advisable, but as absolutely necessary in chemistry, I will go even further, and declare my belief that chemical atoms exist, provided the term be understood to denote those particles of matter which undergo not further division in chemical metamorphoses. Should the progress of science lead to a theory of the constitution of chemical atoms—it would make but little alteration in chemistry itself. The chemical atom will always remain the chemical unit…whether matter be atomic or not, thus much is certain that, granting it to be atomic, it would appear as it now does.*

The concept of the chemical atom had become indispensable regardless of whether matter was actually composed of atoms or not. However, for physicists the atoms in atomic theory were real in the sense that they gave meaning to phenomena that were inhomogeneous on an atomic scale. Lord Rayleigh's (1842-1919) explanation for why the sky is blue in terms of scattering by air molecules depended on the wavelengths of visible light being comparable to the average spacing between molecules. The value of Avogadro's number could be determined using many different methods, each sensitive to the atomic scale in a different way, but with each method consistently giving a similar result. In 1870, Lord Kelvin (1825-1907) described several different physical relations, all of which had been used to determine comparable values for Avogadro's number: the relation between mean-free path and viscosity of a gas; the relation between capillary energy and heat of vaporization; and relation between electrical contact energy and chemical heat [349]. Although Ostwald had been correct in claiming that the Gibbs' ensemble formulation of statistical mechanics does not explicitly invoke atoms, the Gibbs' grand canonical ensemble can be used to calculate the value of the number fluctuations in a fluid and compared to the observed value from opalescence measurements to determine a value for Avogadro's number that is consistent with other methods. By the last decade of the 19th century, atomic theory was consistent with known physics and chemistry except for heat and electromagnetism. As will be discussed in the section *Is Irreversibility Intrinsic?*, this was accomplished by Boltzmann's formulation of statistical mechanics which was explicitly based on the scattering of molecules and was also consistent with Gibbs' theory. This allowed all of macroscopic thermodynamics to be based on an underlying atomic theory. Although the identification of heat with the kinetic motion of molecules had been suggested as early as the 17th century by Francis Bacon (1561-1626) and Robert Hooke (1635-1703), Boltzmann's theory could explicitly relate the temperature to the average energy of the molecular degrees of freedom using Maxwell's law of equipartition of energy.

Despite the apparent successes in the application of Boltzmann's theories, Planck would still be led to say in 1895 [355]:

See the print edition of The Quantum Measurement Problem for quotation.

Three years later, Boltzmann would write pessimistically [356]:

See the print edition of The Quantum Measurement Problem for quotation.

However, at the beginning of the 20th century, the reality of atoms became undeniable. Ostwald maintained his position on energism until the work of Jean Baptiste Perrin (1870-1942), who had long believed that atoms were real, determined Avogadro's number from observations of Brownian motion in colloids. After this, Ostwald could no longer reject discontinuity of matter. In 1909, Oswald wrote [357, p. 249]

> *I am now convinced that we have recently come into possession of experimental proof of the discrete or grainy nature of matter, for which the atomic hypothesis had vainly sought for centuries, even millennia.*

Brownian motion had been known since 1827 and had been interpreted in terms of kinetic theory by 1879. Perrin's experimental confirmation of Einstein's 1905 theory of Brownian motion was carried out in 1910. Sadly, this was four years after Boltzmann's death by suicide. Mach also apparently changed his mind, as physicist Stefan Meyer recalled in 1950: Mach saw the apparatus developed by Erstel, Geitel, and Crookes that allowed the flashes created by single α-particles to become visible on a screen, whereupon Mach exclaimed [348], "Now I believe in atoms." However, in spite of this, Mach's writing continued to imply denial, as in this 1910 reply to a criticism by Planck [348]:

See the print edition of The Quantum Measurement Problem for quotation.

Lise Meitner (1878-1968) was a student of Boltzmann with a dissertation on heat conduction in an inhomogeneous body directly related to kinetic theory. She attended his lectures from 1902 until his death in 1906. Meitner later recalled the difficulties he encountered by the resistance to kinetic theory [358]:

> *Boltzmann had no inhibitions whatever about showing his enthusiasm while he spoke, and this naturally carried his listeners along. He was also very fond of introducing remarks of an entirely personal character into his lectures—I particularly remember how in*

describing the kinetic theory of gases, he told us how much difficulty and opposition he had encountered because he had been convinced of the real existence of atoms, and how he had been attacked from the philosophical side, without always understanding what the philosophers had against him.

Looking Back, L. Meitner, Bulletin of the Atomic Scientists, November 1, 1964, Taylor & Francis Ltd, reprinted by permission of the publisher. http://www.informaworld.com

The loss of Boltzmann led Meitner to move to Berlin where she became the first woman that Max Planck allowed to attend his lectures. The following year she became Planck's assistant and began the collaboration with chemist Otto Hahn that twenty-two years later would involve her in the discovery of nuclear fission. Meitner and

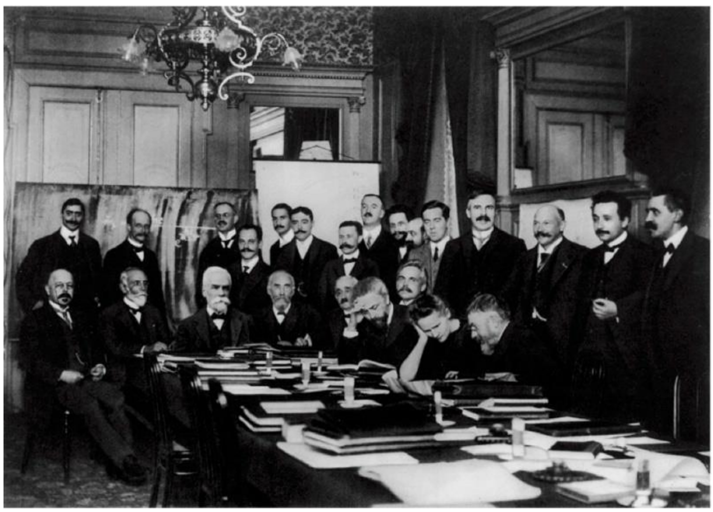

Figure 5.7 Photograph of the 1st Solvay Conference in 1911 Seated (L-R): W. Nernst, M. Brillouin, E. Solvay, H. Lorentz, E. Warburg, I. Perrin, W. Wien, M. Curie, and H. Poincaré. Standing (L-R): R. Goldschmidt, M. Planck, H. Rubens, A. Sommerfeld, F. Lindemann, M. de Broglie, M. Knudsen, F. Hasenöhrl, G. Hostelet, E. Herzen, J.H. Jeans, E. Rutherford, H. Kamerlingh Onnes, A. Einstein, and P. Langevin.

Hahn led the group that first discovered nuclear fission of uranium. Meitner and her nephew Otto Frisch were the first to correctly interpret the results as being nuclear fission. Remarkably, Meitner's research had spanned the eras from the denials of atomism up to the splitting of the atom. For the majority of the scientific community, the atomic debates ended at the 1st Solvay Conference in 1911, Figure 5.7, which brought together several generations of prominent scientists to focus on the details of the history and successes of atomism, and the new developments of radiation theory and quanta [346]. Atoms and molecules were no longer hypothetical but existential.