Chapter 2
University: Berlin 1925–1931

> *"It was a moment of extreme elation when, plotting the first graph, I saw this new evidence and suddenly the strain of innumerable nights spent in the laboratory had vanished into nothing"*
> The World of Walter Nernst *K. Mendelssohn, 1973*

In 1925, Kurt Mendelssohn entered the University of Berlin.[1] He had at one point thought about being a stockbroker. However, at the university he studied physics, mathematics, chemistry and psychology. He took great pride in having studied under Einstein, Planck, Schrödinger and other leaders of the new "Modern Physics".

He started research at the University's Physikalisch Chemisches Institut (Institute for Physical Chemistry) in 1927 studying under his cousin Franz Simon (Fig. 2.1) who was 12 years older. Franz Simon had done his dissertation at Berlin under Walter Nernst who formulated the third law of thermodynamics. Simon, Nernst and another of Nernst's students, F. A. Lindemann, would have a profound influence on Mendelssohn's life.

In order to understand Kurt Mendelssohn's work at Berlin and its impact on his later activities, a few sentences on the third law of thermodynamics are in order. Nernst's development of the third law was motivated by the problem of predicting chemical reactions. Specifically, did a given set of chemical components react spontaneously, did the reaction require the addition of energy or were the components in chemical equilibrium? It was known that the important parameter was the difference in the free energies of the reactants and products of the reaction. For a reaction at constant temperature and pressure, if the free energy of the products was less than that of the reactants the reaction would be spontaneous. If the free energy of the products was more than that of the reactants, energy would have to be added for

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The original version of this chapter was revised. The correction to this chapter is available at https://doi.org/10.1007/978-3-030-61199-6_11

[1] After World War II this University, located in East Berlin, was renamed the Alexander Humboldt University.

J. G. Weisend II, G. T. Meaden, *Going for Cold*, Springer Biographies,
https://doi.org/10.1007/978-3-030-61199-6_2

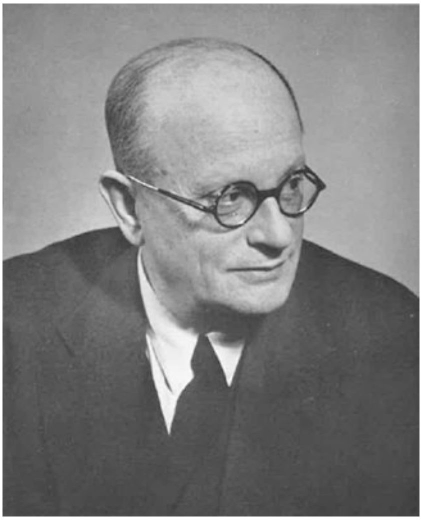

Fig. 2.1 Franz Simon "Franz Eugen Simon", *Biographical Memoirs of Fellows of the Royal Society,* Volume 4 (1958)

the reaction to take place. If the free energies of the reactants and products were equal then the system was in chemical equilibrium.

This is simple enough, but the problem was that while the total energy of a substance could be measured there was no obvious way to determine the free energy from the total energy. Nernst postulated that at a temperature of absolute zero, the difference between the free energy and total energy of a substance must be zero and that the difference must approach zero as absolute zero temperature is approached. With this hypothesis, it was now possible to calculate the free energy of a substance as a function of temperature starting at near absolute zero temperature. This required knowing the specific heat and thermal expansivity of the substance (i.e. the temperature rise and expansion due to a known heat input) as a function of temperature. Thus, to prove his theory, Nernst and his group had to reach very low temperatures and make precision measurements of specific heat and thermal expansivity. Over a number of years, Nernst aided by Frederick A. Lindemann, his brother Charles Lindemann, Franz Simon and others made measurements that supported Nernst's hypothesis. As a result of their efforts, the third law of thermodynamics is accepted today as one of the fundamental laws of nature.

However, as is frequently the case in science, the nature of the question changed. Nernst developed the third law to allow the prediction of chemical reactions and his result was used successfully for this purpose. But an alternative way of expressing the third law said that as absolute zero temperature is approached, the entropy[2] goes to zero and any entropy difference also goes to zero. The third law really says fundamental things about matter at absolute zero. At a temperature of absolute zero, the entropy of any substance is zero (this represents the zero point energy). Furthermore, since any cooling process requires an entropy difference, the third law says

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[2] The entropy is a thermodynamic quantity best thought of as representing the degree of disorder in a system.

that while you may get infinitesimally close the absolute zero it is impossible to reach it.[3]

The absolute temperature scale used in science has the unit Kelvin (K) 0 K = −273 °C or − 459 °F. Helium liquefies at 4.2 K at atmospheric pressure whereas room temperature is about 300 K. Cryogenics, the study of materials and phenomena at low temperatures, is generally defined as concerning itself with processes below 120 K. Nernst's group became interested not in chemistry but in the study of materials at very low temperatures, that is, cryogenics.

After completing his doctorate in 1921, Simon remained at the Physikalisch Chemisches Institut where he continued to work on problems in cryogenics and thermodynamics. He organized a cryogenics group and had a hydrogen liquefier and a helium liquefier built. His laboratory was the fourth in the world to liquefy helium, the others being in Leiden, Toronto and the Physikalisch Technische Reichsanstalt in Berlin.

Graduate school is designed to teach how to conduct research as much as it is designed to teach a given specialty. Kurt Mendelssohn described the process: "Research, like any other job, has, of course, to be learned. Even the most gifted and successful scientist knows that the sparks of genius and the moments of inspiration are few and far between. The rest of his life will be devoted to patient work, careful planning and perfection of those techniques which he has to master for the exploration of his chosen field" [1].

Kurt Mendelssohn's work in Simon's group was centered in two areas, specific heat measurements at cryogenic temperatures and the construction of small helium liquefiers. The first of these led to his doctorate, the second led to Oxford.

Kurt Mendelssohn's thesis project was the measurement of the specific heat of solid hydrogen. It was known at this time that hydrogen existed in two states, parahydrogen in which the nuclear spins are oriented antiparallel to each other, and orthohydrogen in which the nuclear spins are oriented parallel to each other. The Pauli exclusion principle—part of the radical new theory of quantum mechanics—predicted that the energy of orthohydrogen at absolute zero should be higher than that of parahydrogen. Consequently, the specific heat of orthohydrogen should rise as the temperature approaches absolute zero before a rise is seen in the specific heat of parahydrogen. This is the effect that Mendelssohn was trying to measure. This was a very difficult experiment, due to the low temperatures and small effects involved. However, Mendelssohn was finally able to measure a rise in the specific heat of orthohydrogen at 5 K while the specific heat of parahydrogen continued to decrease with temperature down to 3 K, the lowest temperature reached in the experiment. The results were consistent with the predictions of quantum mechanics and thrilled Mendelssohn as he described them in the quotation at the start of this chapter.

The results also cleared up a potential problem with Nernst's third law of thermodynamics. Earlier measurements of the chemical potential of hydrogen ran

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[3] The current world record is about half a nanoKelvin (5×10^{-10} K).

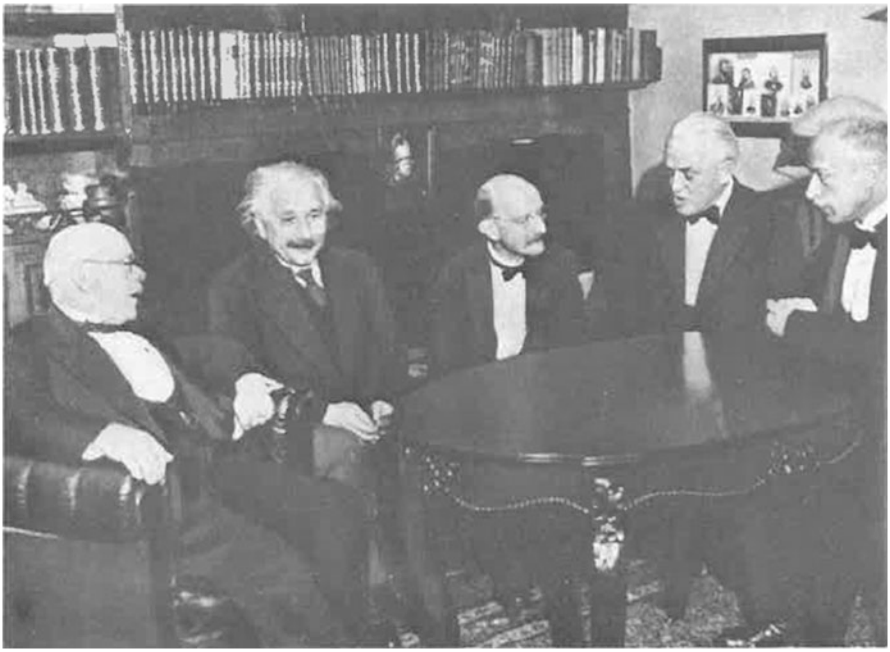

Fig. 2.2 Five Nobel Laureates Together: Nernst, Einstein, Planck, Millikan and von Laue at von Laue's house in Berlin, 1923 [1]

counter to that predicted by the third law. Simon had theorized that the problem was not with Nernst's law but rather due to exactly the type of specific heat rise that Mendelssohn had measured, which was why Simon had given him this as his thesis topic.

That a single thesis project could provide support to both the third law of thermodynamics and to quantum mechanics illustrates the intellectual atmosphere of the time. Experimental and theoretical work was developing the concepts of quantum mechanics and relativity which fundamentally changed our understanding of the universe. This work was being done by a small group of scientists, known to each other and principally located in Northern Europe. An illustration of the connections between scientists at this time is shown in Fig. 2.2.

In his 1973 book, *The World of Walther Nernst,* Kurt Mendelssohn portrays the rapid changes of which he was a part (Fig. 2.3).

Mendelssohn's thesis experiment operated at temperatures as low as 3 K. These temperatures required the use of liquid helium, which was not easy to come by at that time. Early on, Simon had decided that rather than build a single large helium liquefier that continuously makes liquid helium for the whole laboratory he would develop miniature liquefiers that produced just enough liquid helium for each individual experiment. In effect, each experiment would have its own liquefier. This approach had three advantages. First, there would be no need for a complicated central helium facility that had to be maintained. Second, it minimized the amount of

Fig. 2.3 Kurt Mendelssohn while working on his thesis (Courtesy of M. Mendelssohn)

hard-to-get helium gas required for each experiment. Lastly, since each student would have to build his own liquefier they would develop a detailed practical understanding of the liquefaction of helium. "Simon set great store by this arrangement, since he regarded skill in cryogenic techniques as an essential part of the low temperature physicist's qualifications" [2].

The first miniature liquefiers built by Simon used the desorption method. In this technique, helium gas was cooled to roughly 20 K by heat exchange with a liquid hydrogen bath. The cold gas was then forced under pressure to absorb on to an activated charcoal layer. When the gas pressure is reduced, helium starts to desorb from the charcoal. However, the helium that remains absorbed on the charcoal is cooled to less than 5 K in this process. By next raising the helium pressure to slightly less than two atmospheres, the helium liquefies. An advantage of this technique does not require the use of high pressures. This type of liquefier was integral to Mendelssohn's thesis experiment.

In 1930, Kurt Mendelssohn was awarded his Ph.D. in physics and decided to stay at the university to work as Simon's assistant.

References

1. K.A.G. Mendelssohn, *The World of Walter Nernst*, (University of Pittsburg Press 1973).
2. N. Kurti, "Franz Eugen Simon", Biographical Memoirs of Fellows the Royal Society, Volume 4 (1958).