The Discovery: Kamerlingh Onnes in Leiden

1

In the last years of the nineteenth century, Heike Kamerlingh Onnes set up a laboratory for low-temperature experiments in Leiden, which soon became the world leader in this field. Kamerlingh Onnes was interested in the thermodynamic properties of gases and liquids at low temperatures. He was inspired by the research work of Johannes Diderik van der Waals at the University of Amsterdam. He had published his Law of Corresponding States in 1880.

At that time, competition between several laboratories in Europe had broken out in the generation of low temperatures and the associated liquefaction of gases. An important impetus for the large-scale liquefaction of gases was the announcement in 1895 of the application of the Joule–Thomson effect by Carl von Linde in Germany and William Hampson in England. The Joule–Thomson effect causes a slight reduction in the temperature of gases during isenthalpic expansion. In the same year, von Linde was able to produce liquid air for the first time by combining the Joule–Thomson effect with the countercurrent heat exchanger already proposed by Werner Siemens in 1857. In this Linde process, the highly compressed air in the heat exchanger is additionally cooled by the returning gas until its condensation temperature is reached. This process also forms the basic principle for the liquefaction of neon, hydrogen and, most recently, helium in an effort to achieve even lower temperatures.

On July 9/10, 1908, the team of Kamerlingh Onnes succeeded for the first time in liquefying helium as the last remaining noble gas, thus achieving the then record value of 4 K (−269 °C) at low temperatures. In 1911, Kamerlingh Onnes then made an astonishing discovery during cooling: below a certain temperature, the electrical resistance of certain metals disappears completely and can no longer be detected experimentally. This was the first time the phenomenon of “superconductivity,” as it was subsequently called, had been observed. On April

R. P. Huebener, *History and Theory of Superconductors,* Springer essentials,
https://doi.org/10.1007/978-3-658-32380-6_1

28, 1911, Kamerlingh Onnes reported on this for the first time to the Academy in Amsterdam.

After Kamerlingh Onnes had opened up a much lower temperature range than had been possible until then, he became interested, among other things, in the question of how the electrical resistance of metals behaves at these low temperatures. At that time, there were three predictions about how the resistance changes at low temperatures as the temperature decreases: (1) the resistance decreases and reaches zero, (2) it remains constant, and (3) it increases again. Mercury appeared to be particularly suitable for accurate measurements because its low melting point makes it relatively easy to produce with a high degree of purity. The measurements should be disturbed by impurities as little as possible. Therefore, a thin glass capillary filled with mercury was used for the measurements. On April 8, 1911, Heike Kamerlingh Onnes and his team observed how the electrical resistance of the sample decreased with decreasing temperature. However, when the temperature finally reached 4 K, the curve showed a sharp bend, and the resistance dropped to an unmeasurably small value (Fig. 1.1).

After superconductivity was discovered in mercury, it was also found in other metals, alloys and metallic compounds. Among the first superconducting metals found, besides mercury, are: aluminum, lead, indium, zinc and tin.

When Kamerlingh Onnes soon began to investigate the question of whether superconductivity could be used technically for the energy industry even at high electric currents, he had to discover that the magnetic field generated by the currents was very harmful to superconductivity. In addition to the critical temperature T_C, which must not be exceeded, there is also a critical magnetic field H_C, above which superconductivity disappears. The temperature dependence of the critical magnetic field $H_C(T)$ is shown in Fig. 1.2: From the value zero at $T = T_C$, the critical magnetic field increases with decreasing temperature and reaches its maximum value at $T = 0$.

The so-called *intrinsic magnetic field* of an electric current has the same effect as a magnetic field generated by an external magnetic coil. In the literature, this connection is called *Silsbee's rule*. Thus, in addition to the critical quantities T_C and H_C, there is also a critical electric current density I_C, which must not be exceeded if superconductivity is to be maintained.

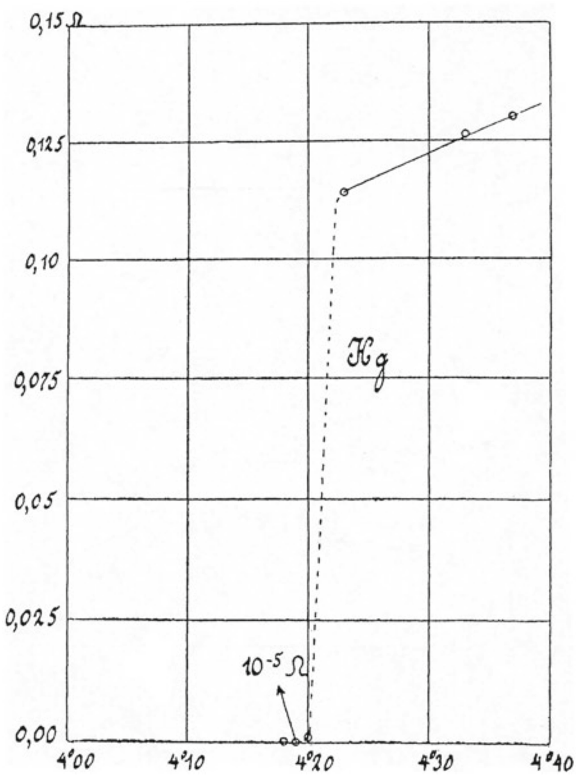

Fig. 1.1 Discovery of superconductivity. Electrical resistance in ohms of a mercury sample plotted against temperature in Kelvin. (H. Kamerlingh Onnes)

Fig. 1.2 Temperature dependence of the critical magnetic field H_C. (schematic)