Activity 1 – Superconductivity and Quantum Materials

1 What is Superconductivity?

Superconductivity is an active area of research that falls within the larger field of solid state physics. This fascinating phenomenon is surprisingly widespread and exists in many materials, typically at very low temperatures (below approximately 130 K[1]). These materials are characterised by very unusual properties such as zero electrical resistance and the expulsion of magnetic fields when they are cooled below a characteristic temperature known as the critical or transition temperature ($\mathbf{T_c}$).

1.1 Discovery of Superconductivity

Superconductivity was unexpectedly discovered over 100 years ago in 1911 by Heike Kamerlingh Onnes and his research group at Leiden University in the Netherlands. Professor Onnes had recently developed the ability to liquefy helium, allowing measurements of the properties of metals at lower temperatures than had ever been achieved before.

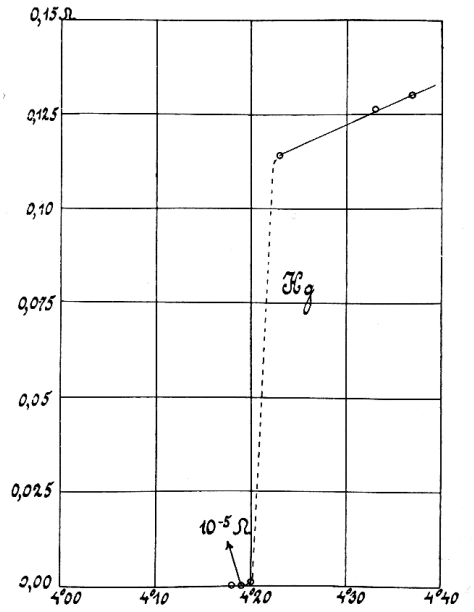

Figure 1: Heike Kamerlingh Onnes' original data showing superconductivity in Mercury (Hg). (Obtained under a creative commons license via Wikipedia).

During his investigations he was measuring the resistance of mercury at very low temperatures when, at 4.2 K, he noticed that the resistance suddenly dropped to zero. This famous result is reproduced in Figure 1, showing the resistance drop between 4.3 K and 4.1 K by five orders of magnitude, from ~ 0.11 Ω at a temperature of 4.3 K of less than 3×10^{-6} Ω at 4.1 K. Professor Onnes' research led to him receiving the Nobel Prize in Physics in 1913.

After this initial discovery, many more elemental superconductors have been found and in fact it seems that superconductivity is not a rare phenomenon at all, as can been seen in Figure 2. Up until 1986 superconductivity was thought to have been a

[1] The Kelvin is the SI unit of absolute temperature, where 0 K = -273.15 °C

purely low temperature phenomenon (below 30 K), however, this all changed with the discovery of high-temperature superconductivity in layered copper oxide materials. This discovery has led to a huge field of research and the subsequent development of many technologies that rely on superconductors such as superconducting quantum interference devices (SQUIDS) and MRI machines. Research into superconductors at Cambridge is conducted by the Quantum Matter Group (Physics), the Bulk Superconductivity Group (Engineering) and the Device Materials Group (Materials Science).

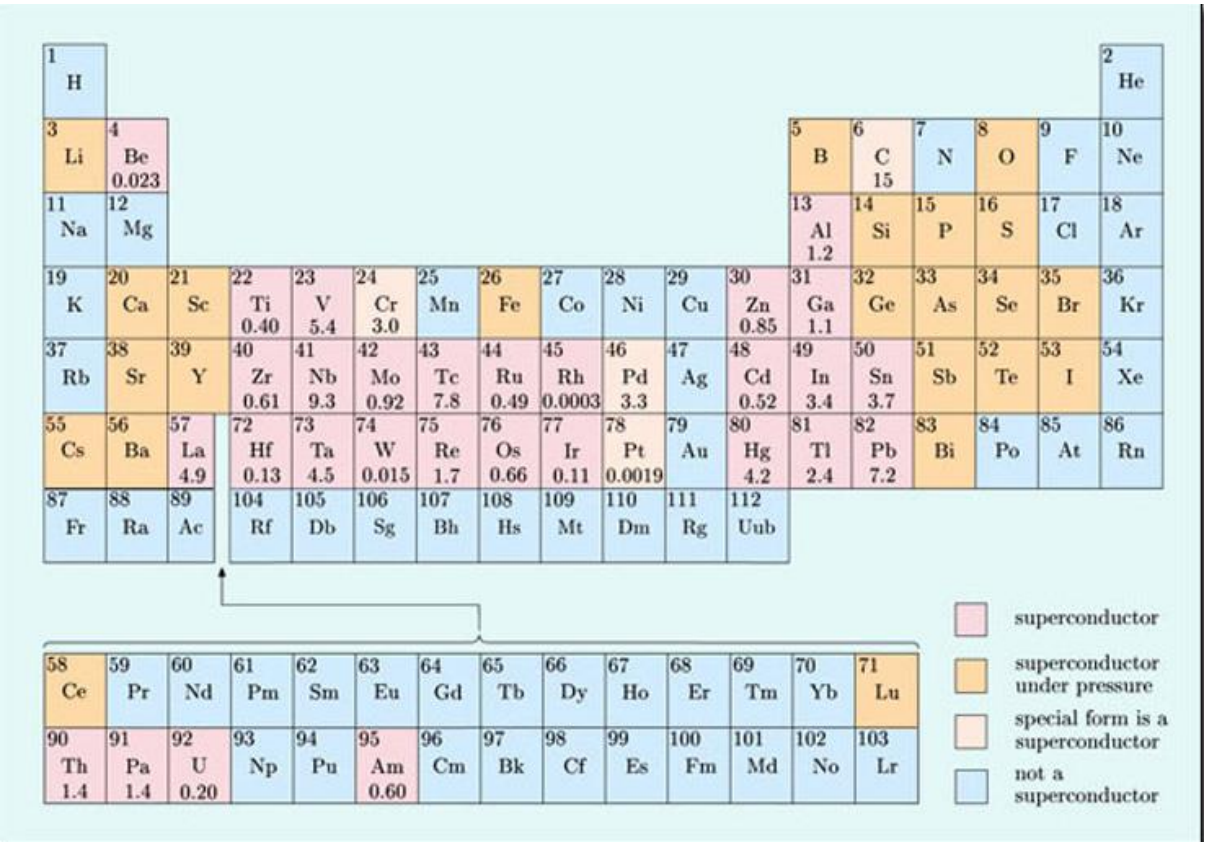

Figure 2: The periodic table of superconducting elements along with their transition temperatures. (Obtained under a creative commons license) [Ref 1].

1.2 The Scope of this Resource

You will be familiar with Ohm's famous law relating voltage (V) to electrical current (I) and resistance (R): I = V/R. But what are the origins of electrical resistance, and what makes superconductors have zero resistance? Does this imply an infinite current? Or is Ohm's law not correct in this situation?

In this topic you will learn about the history and properties of superconductors, from their first discovery in the early twentieth century, through the development of a new theory explaining their behaviour in the 1950's to the exciting discovery of the so-called 'high-temperature' superconductors in the 1980's. You will then learn about the recent developments in superconductor research and their place in the emerging field of quantum materials; materials whose properties are determined by the quantum nature of interacting electrons.