History of Superconductivity\textsuperscript{1-3} has seen a series of sudden surprises. 1\textsuperscript{st} surprise is the discovery\textsuperscript{4} of superconductivity itself, by Prof. Heike Kamerlingh Onnes in Leiden, Holland, in 1911 [H.K. Onnes, Comm. Leiden 120b], with his clarification in 1913 [H.K. Onnes, Comm. Leiden, Suppl. Nr. 34]. Our journey will take us finally to the very surprising discovery (2008) and subsequent study of superconductivity in magnetic materials like BaFe\textsubscript{2}As\textsubscript{2}\textsuperscript{2,3} popularly known as iron superconductors.

Many materials lose electrical resistance, $R$, completely, and expel all magnetic flux from inside on cooling it below what is called (superconducting) critical temperature ($T_c$) - under certain magnetic field, $H$, and current density, $J$. That infinitely conducting state is called the superconducting state, and the phenomenon is called Superconductivity. Using $H > H_c$ or $J > J_c$ will also destroy the superconducting state – with $H_c$ and $J_c$ being called (superconducting) critical field and (superconducting) critical current density, respectively. In fact, $T_c$ is a function of $H$ and $J$. A Type II superconductor allows, above $H_{c1}$ (the Lower Critical Field) and below $H_{c2}$ (the Upper Critical Field), magnetic flux to pass through the superconductor in form of fluxtubes that are in normal state within the superconducting surrounding\textsuperscript{1} Applying a field $H > H_{c2}$ destroys the superconducting state. In general, $H_{c2}$ of Type II superconductors far exceed $H_c$ of Type I superconductors. Type II has higher $J_c$ too. Practical superconducting wires and tapes are, therefore, invariably made from Type II superconductors.

Helium (B.P. = 4.2 K) was first liquified\textsuperscript{5} by Prof. H.K. Onnes in 1908, using the Joule-Thomson (or Joule-Kelvin) principle. His group then started measuring electrical resistivity of pure metal samples down to lowest temperatures reached by cooling the sample in a liquid helium Dewar. This led, quite unexpectedly, to the above-mentioned discovery of superconductivity – first in mercury. It is unknown to many that these measurements were carried out [1] by von Holst, a young co-worker of Onnes.
Incidentally, Dewar, the research laboratory version and actually the fore-runner of common vacuum flask, was invented by the famous Scottish chemist and physicist Sir James Dewar. Prof. Dewar (1842–1923) and Prof. Onnes (1853-1926) were in neck to neck race to liquify helium, the only inert gas that defied liquification till then. But Prof. Dewar, at one stage, lost his full stock of helium, stored in a glass container due to its accidental breakage, and lost the race. Prof. Onnes won, liquefying helium in 1908. He had the foresight to import from British India what he called “a shipload of helium” (actually a shipload of radioactive monazite sand of Kerala) so as to have a huge stock of “helium” with room temperature storage.

Present day superconducting magnets, the major application of superconductivity, mostly use magnet wires of high $H_{c2}$ and high $J_c$ materials like Nb-Ti and Nb$_3$Sn ($T_c = 18$ K) so that the self-field itself does not destroy superconductivity. But the restrictions on $H_c$ or $H_{c2}$ and $J_c$ were not clear in the initial years of discovering $R = 0$ below $T < T_c$. Passing high current ($I$) to produce high magnetic field was assumed to be possible due to zero $I^2R$ heating. But the wires become normal as soon as the current density and/or the magnetic field exceeded the critical value/s, and produced $I^2R$ heating, large enough to evaporate liquid helium and even melt the magnet. So, many of the initially fabricated superconducting magnets failed even at $T < (T_c$ determined at zero $H$, using negligible $J$). This 2nd surprise was unpleasant. But it could be overcome on discovering and respecting all the three critical parameters.

Here came the need for superconductors with higher $T_c$, $H_{c2}$ and $J_c$. Highest $T_c$ records of 23.2 K for Nb$_3$Ge in 1974 and 18 K for Nb$_4$Sn in 1954 did not improve for decades, in spite of worldwide efforts. Break, the 3rd and very important surprise, came in 1986 with the discovery of unprecedented $T_c$ of 35 K in a Ba-La-Cu-O ceramic (LaBaCuO$_4$) by J.G. Müller and K.A. Bednorz in IBM (Zurich). It was a 2-fold surprise in terms of going to a bad conductor, an oxide, to get a better superconductor, and discarding the fear that there may be a theoretical upper limit to $T_c$. Importance of this discovery was fully realised after the 1987 discovery of superconductivity in another cuprate, YBa$_2$Cu$_3$O$_{7-\delta}$, much above boiling point of easily available liquid nitrogen. A flurry of activity worldwide have been looking for higher $T_c$ and characterizations. Many such High Temperatures Superconductors (HTSCs) with Cu-O layers as the seat of superconductivity have been discovered.

Understanding superconductivity theoretically has been in steps, rather brilliant steps, but slow. Pairing, of conduction electrons in momentum space on cooling below $T_c$ into Cooper Pairs, was shown to be possible through exchange of virtual phonons or lattice-vibrations in superconductors. Bardeen-Cooper-Schrieffer or BCS Superconductivity arises on cooling, as these bound pairs of electrons or holes condense into a superfluid that allows electrical current to flow without any resistance. These “Cooper pairs” have a low binding energy, which means that they are easily destroyed by thermal energy on heating the sample above $T_c$. BCS theory offered microscopic explanation of superconductivity around 1957. Magnetic pair breaking destroyed such superconductivity on adding even a trace of any magnetic impurity in a metallic superconductor. Pairing is certain, while pairing mechanism can be non-BCS in certain superconductors.

4th and stunning surprise in superconductivity is Fe pnictide / chalcogenide superconductors that showed $T_c$ up to 56 K to get HTSC tag. Here, the seat of superconductivity has been proved to be Fe-As or Fe-Te/Se layers having magnetic ions like Fe (or often Ni instead of Fe) as a major component – a setback to the above-mentioned concept of magnetic impurities destroying superconductivity.

These magnetic superconductors open up a new avenue to superconductivity including HTSC, while there is continuing development of the excellent applications of the earlier superconductors to medical investigations, fast transport, powerful magnets and precise measurements. Interestingly, metallic character of these so-called Iron Superconductors offers better fabricability to make superconducting wires and cables.
References


