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Superconductivity – Surprises and Stories - Editorial

DE UDAYAN

Physics Dept., Egra SSB College, Purba Medinipur, W Bengal, India.

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History of Superconductivity[1-3] has seen a series of sudden surprises. 1st surprise is the discovery[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 $BaFe_2As_2$,[2,3] popularly known as iron superconductors.

Many materials loose 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 > Jc will also destroy the superconducting state – with Hc and Jc being called (superconducting) critical field and (superconducting) critical current density, respectively. In fact, Tc 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[1] Applying a field $H > H_{c2}$, destroys the superconducting state. In general, H_{c2} of Type II superconductors far exceed Hc 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[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.

CONTACT De Udayan ude2006@gmail.com Physics Dept., Egra SSB College, Purba Medinipur, W Bengal, India.

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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_3Sn (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 I2R heating. But the wires become normal as soon as the current density and/or the magnetic field exceeded the critical value/s, and produced I2R heating, large enough to evaporate liquid helium and even melt the magnet. So, many of the initially fabricated superconducting magnets failed even at T < (Tc determined at zero H, using negligible J). This 2^{nd} 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 Tc records of 23.2 K for Nb_3Ge in 1974 and 18 K for Nb_3Sn in 1954 did not improve for decades, in spite of worldwide efforts. Break, the 3^{rd} and very important surprise, came in 1986 with the discovery[2] 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 Tc. Importance of this discovery was fully realised after the 1987 discovery [2] of superconductivity in another cuprate, $YBa_2Cu_3O_{(7-\delta)}$, 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.[2] We are skipping now discoveries of (i) fulleride superconductors (metal doping of fullerenes like C60, C70), with T_c up to 33 K, and (ii) MgB_2 (with T_c of 40 K) & related borocarbide superconductors - all reviewed in.[2]

Understanding superconductivity[1,2] 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[1] 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[1] 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.

4^{th} and stunning surprise in superconductivity is Fe pnictide / chalcogenide superconductors[2,3] 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.

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