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Opinion

Search for Room Temperature Superconductor- A Revolutionary Change

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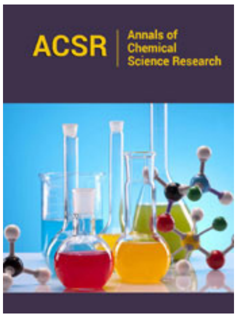
ISSN : 2688-8394



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Submission: October 29, 2021

Published: November 18, 2021

Volume 2 - Issue 5

How to cite this article: Behera D. Search for Room Temperature Superconductor- A Revolutionary Change. Ann Chem Sci Res. 2(5). ACSR. 000549. 2021. DOI: 10.31031/ACSR.2021.02.000549

Opinion

The persistent quest for room temperature superconductor has been achieved recently and ignites the hope for revolutionary change. The pioneering work of Onnes [1] gives rise to discovery of superconductivity in 1911. In this work on Mercury, Hg shows no electrical resistance and persistent current flows for a long time with no Joules heating. This is the unique in material that becoming superconductor. The associated diamagnetic behavior with complete removal of magnetic field from the interior of the material satisfies the complete Meissner effect [2]. The phenomenon of superconductivity has been explained by John Bardeen, Leon Cooper and J.R. Schrieffer (BCS) theory where a current of electron pairs (Cooper pairs) flows without resistance in certain materials at low temperature (superconductor). According to BCS theory, superconductivity arises when a negatively charged particle (electron) slightly distorts the lattice atoms in the material, drawing a + vely charged cloud (Polaron) and create electron-phonon interaction.

This attracts a second electron and forms weakly electron-phono-electron interaction (Cooper pairs). As Cooper pairs are more stable than a single electron, it moves in the material with no electrical resistance and the Cooper pairs are more resistive to lattice vibration below the transition temperature Tc. The contribution of phonons to resistivity is marginalized or reduced at low temperature due to freezing of lattice vibrations. In the process, energy of the system is reduced and a phase transition is established from a disordered state (normal state) to ordered state (superconducting state). At very low temperature (in absolute zero temperature) the phenomenon gives birth to the 5th state of matter i.e., Bose-Einstein Condensation (BEC). In this state all quantum states boil down to single quantum state forming a "Condensate". BCS state is weakly-correlated pairs of electrons whereas BEC is strongly correlated of diatomic molecules in the atomic Fermi gas. For more understanding, BEC state is a Bose-Einstein Condensate of two-atom (diatomic) molecules (bound fermions) while BCS state is made of pair of atoms. For BEC the molecules with opposite momenta are in the momentum space. The formation of BEC occurs when low-energy atoms clump together and enter the same energy state.

From the discovery of superconductivity in 1911 by Onnes [1] in mercury (Hg) with transition temperature Tc of 4.2 K (boiling point of liquid Helium) to current situation where different types of materials show superconductivity. The gradual development occurs in metals (elements), alloys, metallic oxides, perovskites, ceramics, alkalide-fullerides, heavy fermions, pnictides, fullerence and suphur-hydrides. It has been observed that bad conductors are good superconductor whereas good conductors (noble metals) are poor superconductor. Silver, copper and gold are the best electrical conductors known at room temperature, do not show any sign of superconductivity above a few millidegrees. This happens due to strong interaction of electron and phonon. The bonding is strong in insulators as compared to conductors. This is one of the mechanisms of BCS theory.

Recently in 2021 Dalai et al. [3] have reported superconductivity in Ag implanted Au thin films to have transition of 2.0K. The work proposes the enhancement of Tc with varying the thickness with Ag ion implanted Au thin films. The discovery of superconductivity in ceramic materials (oxides) such as $YBa_2Cu_3O_7$- δ (YBCO), one of the families of cuprates with Tc of 92K breaks the barrier of availability of costly liquid Helium. As Tc of this material is above 77K (boiling point of liquid nitrogen (LN2) its facilities the experimental activates to explore new superconducting materials. Further, researchers have discovered new superconducting high Tc materials such as $HgBa_2Ca_2Cu_3O_{10+d}$ (Hg1223) with Tc of 135 K. For a decade or so from its discovery this was the height Tc for the materials. The quest for materials with high Tc has been succeeded with several materials with application of high pressure. So, the material Hg1223 can achieved Tc of 164 K with pressure of 25 Gpa.

Much development on high temperature superconductors was done on hydrogen-based compounds. Several research were conducted to enhance the transition temperature of the superconducting materials. The work by Drozdov et al. [4] in 2015 by pressurizing hydrogen and sulfur has cracked the Tc of 200 K barrier [4]. Further, the work in 2018 in a high-pressure compound with lanthanum and hydrogen has cracked the Tc of 250 K barrier. It has been reported that lanthanum hydride (LaHx) was synthesized by laser heating of lanthanum in hydrogen atmosphere at pressure P=170GPa. The sample shows a superconducting step at 209 K at pressure 170GPa. By releasing the pressure to 150GPa, the Tc increases to 215K-the record-breaking Tc during that time. This finding supports a way of achieving Tc higher than the one in H3S (203 K) in hydrides.

Now we have superconductors at room temperature with application of high pressure. Can we have superconductor at room temperature with normal atmospheric pressure, is a big challenge for us. Last year in 2020 Physicist, Snider [5] in University of Rochester, New York have reported a compound of carbon, Sulphur and hydrogen to be room temperature superconductor, but the pressure required is 267GPa i.e., more than 2 million times Earth's atmospheric pressure. Pure hydrogen when squeezed becomes a metal and behaves as room temperature superconductor. To reduce pressure effect, other elements are added to metallic hydrogen. Attempts are being explored to reduce the pressure of the system. Scientists are optimistic for the room temperature superconductor at much reduce pressure or even at normal atmospheric pressure for a revolutionary change.

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