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Super liquids and super conductors

This year's Nobel Prize for Physics has gone to Abrikosov, Ginzberg and Legett for their work on superconductivity and superfluidity. **S.Ananthanarayanan** takes a look at what their work was about.

Certain materials, at extremely low temperatures, are found to flow or to conduct electricity without any resistance.

How does resistance arise?

When a liquid flows through a tube, the layer of liquid in contact with the sides of the tube can be thought of as being almost at rest. The part in the center would be moving the fastest, with the speed getting slower as we go closer to the sides. Even the part in the center is not moving freely, but only after overcoming some resistance from the rest of the liquid.

This resistance arises because, at the microscopic level, liquids, or sides of tubes, are not 'smooth' as they appear, but consist of atoms and molecules that are 'bumpy' and interact with each other.

Superfluidity

But ironically, when liquid helium is cooled right down to nearly absolute zero, or the lowest temperature there is, it suddenly loses all resistance to flow. A vortex created in superfluid helium would not get damped and die out, which would happen ordinarily, but would go on forever. Superfluid helium in a drinking glass would not stay put but would creep up the sides and siphon itself all out, temporarily violating the laws of mechanics. If a beam of light were shone into the glass, the liquid helium would use the energy of the beam to rise in a fountain, without losing any energy in the friction of flow!

Bose and Einstein

The scientist S N Bose had discovered a rule that particles of light are indistinguishable and this affects how they distribute themselves when sharing a given quantity of energy. Einstein saw that this rule would also apply to certain atomic particles and had predicted that such particles should try fitting all together into the same, low energy state once the energy involved was low enough. This, in fact is what is happening with helium atoms when they cooled to very low temperatures. As they tend to be all sin the same state, they tend to 'follow' rather than 'oppose' the motion of a neighbouring particle.

Uncertainty principle

There is also a law of nature that both the speed and the position of a particle cannot be exactly specified at the same time. At very low temperatures, the motion of atoms is slow indeed. There is hence less scope for uncertainty in their speed. This means that their positions should get increasingly uncertain. The result is that helium atoms become ‘fuzzy’, rather than distinct, and the collection of helium atoms seems to merge into a kind of ‘combined atom’.

Helium-4 and helium –3

This rule of collapsing to the same energy state applies only to atomic particles in pairs. It applies to the helium atoms because helium-4, the normal kind, has 4 atomic particles, or two pairs. It was soon found that even helium-3, a form of helium that has only three particles, also showed superfluidity, although at even lower temperatures. This was a mystery, as three particles cannot form pairs.

Legett, known for his intuitive leaps, was able to resolve the problem by considering that helium-3 atoms formed pairs of atoms, with six particles in all, and the two together behaved like a Bose particle.

Superconductivity.

The electrons that conduct electricity in metals are affected by other electrons and the atoms of the metal, and face resistance. At low temperatures, again, some materials were found to lose all electrical resistance. A disk of a metal placed above a magnet would develop an eddy current as it fell towards the magnet, tending to prevent the fall. If the material were superconducting, the current could stop the fall entirely and the disc would levitate!

As electrons were single particles, the Bose rules did not apply to them. A theory was soon found that the electrons in fact formed pairs, which brought the Bose rules into force. A feature of superconductivity was that it disappeared abruptly when subjected to increasing magnetic fields. Still, in some materials, the effect continued and reduced gradually.

Ginzberg initiated and Abrikosov developed an explanation that the electrons pairs in these materials formed vortices that delayed the effect of the magnetic field in switching off the effect.