Super at the surface

Superconductivity can also be skin deep, says
s ananthanarayanan

SUPERCONDUCTING materials have effectively zero resistance to the flow of electricity. In an electrically driven world, like ours, using these materials could mean a great saving of energy. It would also make possible services that have been unthinkable because of the bulky electrical parts and heat due to high currents. Another advantage of superconductors is that even a thin one is as good as a thick one. And again, at high frequencies, the current, anyway, stays at the surface. There is, hence, much interest in finding ways to coat ordinary materials with a superconducting layer. The ordinary material would provide the mechanical support while the thin covering carries the electricity.

Dr Mahadevan Krishnan and associates from Alameda Applied Sciences Corp, California, and Jefferson Lab and State University of Norfolk, Virginia, have described in the Institute of Science journal, *Superconductor Science and Technology*, their work of coating the metal *niobium* as a thin film on a magnesium oxide base to show an equal and higher drop in electric resistance than displayed by the bulk niobium that has been the norm.

Enrique Valderrama, Mahadevan Krishnan, Kristi Willson-Elliott, Brian Bures and Colt James (left to right).

Superconductivity

Metals are usually conductors, thanks to the outer shell of their atomic structures having only a few electrons, which are loosely bound and free to conduct electricity. At lower temperatures, with less vigorous thermal agitation, the electrical resistance of metals falls and can reach low values. But in a superconductor, which need not be a metal, at a certain low temperature known as the critical temperature for that material, the resistance suddenly drops all the way to zero. This apart, there cannot be a magnetic field within a material that is superconducting. Thus, when there is a magnetic field, eddy currents arise, which cancel the field, so that the superconductor itself is free.

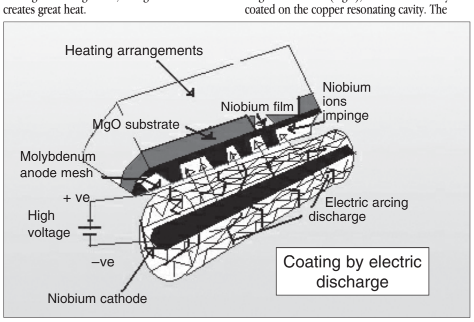
Superconductivity was discovered in 1911 in solid mercury, at the low temperature of 4.2° above absolute zero, which is nearly -269° Celsius. More materials were soon found to show superconductivity, including a compound of the metal niobium, which becomes one at 16° above absolute zero, in 1941. The explanation for superconductivity is mainly that at low temperatures, electrons form pairs, which enables them to act as particles that can all occupy the same energy state, and the mass of electrons begins to act like a "superfluid" without each coming in the others' way.

Zero resistance to electric current means that a current stream once set up would not die for a long, long time. A dramatic illustration of the effect is when a magnet is lowered on to the surface of a superconductor. The magnet sets up an electric circulation in the material, to counteract the magnetic field, so that the lowering of the magnet is resisted. As the current keeps going and does not diminish, the force on the magnet persists and it can hold the magnet up in the air indefinitely! Apart from such "levitation" displays, zero resistance materials can be formed in coils to create very strong electromagnets, which have applications in medical equipment, particle accelerators and possibly in high speed transport.

Superconductivity, where current can flow without a driving voltage, also allows the construction of very sensitive electronic devices and has a central role in the development of quantum computers.

Accelerators

An important use of superconducting magnetic coils is energising the electromagnets that drive particle accelerators. High-energy atomic particles, like electrons and protons, are useful in research and in industry. The particles are speeded up with the help of electric fields and their path is kept within limits by turning them round in circles, with magnetic fields. As the speeds approach that of light, the magnets need to be powerful indeed and they consume power, both for magnetisation as well for cooling the arrangement, as high electric current creates great heat.



Coating by electric discharge

One comparatively conventional solution would be to use superconductors for the electromagnet coils. But with the dimensions of large accelerators this is neither feasible nor economical. An alternative is the *Superconducting Radio Frequency accelerator*. In this arrangement, electromagnetic standing waves are allowed to build up within cavities that resonate at particular frequencies, typically from 200 million cycles to three billion cycles a second. A resonating cavity is like the body of a violin that vibrates at the frequencies of the string, and which takes up and magnifies the sound of a string that is bowed. Metallic resonating cavities can similarly respond to a specific electromagnetic frequency and store huge energy in the tuned standing waves. A charged particle entering such a cavity would then be strongly accelerated and deflected by the intense electrical and magnetic fields. When the cavity is made of superconducting material, very high amplitude waves can be maintained with minimal need for cooling.

Side-stepping the need for cooling is, however, not important, and then there is still the need for low temperatures to create superconductivity. More important reasons for preferring superconductor cavities are, first, that very high fields at which ordinary materials would melt are possible and, second, that the low electrical loss with superconductors allows for geometry, where the charged particle beam can be larger in cross section. But for all this, SRF accelerators are difficult to employ, particularly in numbers for a "linear accelerator", as it is difficult to manufacture consistent series of quality SRF cavities, which are made by stamping and welding pure niobium sheets.

Superconducting films

This is where the work of Dr Krishnan and group becomes relevant. He and his colleagues grew single crystal films of niobium on a base of magnesium oxide (MgO), which in turn may be coated on the copper resonating cavity. The method used was to set up a pulsed electric discharge, or flashing like in arc welding, between an electrode of niobium and a molybdenum electrode in the form of a cylindrical mesh. The electric discharge created plasma, or a gas of ionised niobium, which sped through the mesh to be sprayed on the MgO base. The temperature of the MgO base, on which the niobium deposits, the voltage of the electrical arc, the pulse-rate, the operating pressure, voltage applied to the MgO base and an applied magnetic field could be varied and controlled. In practice, the discharge ran as a helix, or a spiral, over the MgO base in about a millisecond, once every four seconds and in some 4,000 such passes, a one-micron thick coat of niobium was formed.

Niobium deposit on copper rf cavity.

A measure of the effectiveness of the material is the *Residual Resistivity Ratio*, or how many times the electrical resistance drops when the material is cooled from room temperature to absolute zero. The second temperature, of course, cannot be reached and an approximation is made. The ratio for ordinary copper is some 40-50, against the ratio of 300 and better for cavities made of the best bulk niobium. Past efforts to grow niobium films have resulted in the ratio rising to 100, and in the case of a deposit on a sapphire base, to 199. The results of deposit on MgO have been poor and MgO has generally not been considered a suitable base. But considering that MgO is suitable for use with copper, the present study has included niobium deposit on MgO.

The result of the process used, of the deposit on a specifically oriented single crystal MgO base, has been a resistivity drop as high as 541, a level rarely reached without heroic efforts with bulk niobium. Further study, using X-Ray analysis of the niobium layer, has shown that the orderliness of crystal orientation of the layer depends on the temperature of deposition and that the same also correlates with the resistivity drop ratio. There is a similar dependence on the manner in which the MgO base was cooled when deposited. It is also found that the best resistivity drop ratio occurs with the niobium crystal orientation that has the least suitable match with MgO, which suggests that there are other factors to consider. It appears that the electric arc process, at 50,000° Celsius, drives niobium ions moving at 10 km/sec into the substrate surface and promotes interlock between the crystals of the base and the covering, a result that less energetic coating processes could not achieve.

But the work demonstrates that effective superconducting action can be developed in cavities for use in particle accelerators, by a process of coating the cavity components with superconducting material, rather than constructing the components with the material itself. The process, we can see, covers the gamut of technologies, starting with plasma and ending with a defect-free surface that works at a temperature near absolute zero!

"(The) use of these thin film devices in facilities like Cern's Large Hadron Collider and other upcoming facilities would cut the costs substantially," says Dr Krishnan, founder of the Alameda Applied Sciences Corporation and lead author of the paper.

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Seconds out

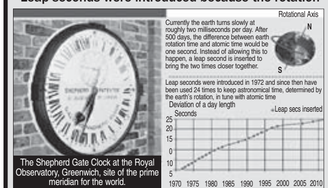
steve connor **reports on a bid to alter the world's time**

TIME will never be the same again if the international organisation responsible for setting the world's clocks votes later this month in favour of a controversial plan to abolish the "leap" second — the extra second added to the time signal once every few years.

Experts from around the world are scheduled to vote on eradicating the leap second at a meeting in Geneva next week of the International Telecommunications Union, the UN agency responsible for timekeeping standards. Debate about the merits and drawbacks of the leap second has raged for many years but observers believe this ballot could mark its final demise, although not before another one is added to the midnight signal on 30 June 2012.

The leap second was first introduced in 1972 and since then has been used on 24 occasions to keep astronomical time — which is based on the rotation of the earth — in synchrony with international atomic time, based on the highly regular vibrations of a caesium atom.

Leap seconds were introduced because the rotation of the earth is slowing down very slightly, by about two thousandths of a second per day, which means that without leap seconds atomic time would go an extra second ahead of astronomical time once every 500 days or so.



The Shepherd Gate Clock at the Royal Observatory, Greenwich, site of the prime meridian for the world.

A leap second is added when necessary to atomic time to decrease the difference between astronomical time and coordinated universal time.

And to complicate matters the slowing down of the earth's rotation is not constant, which means it has to be monitored constantly. Many organisations, including Britain's Royal Observatory, have been happy with the leap-second arrangement to keep astronomical time in harmony with atomic time. But other organisations, such as the International Bureau of Weights and Measures in Paris, are not, and are now pressing for its demise.

"The proposal has been put forward and a decision is likely to be made one way or the other. There is little support for it here in Britain but considerable support elsewhere and there's a very real possibility that it may go through," said Jonathan Betts, senior curator of horology at the Royal Observatory. "We think this would be a shame. We feel that it's important not to lose the link between the measurement of time and the sun, which after all has been fundamental to the human timescale. It would disconnect us from nature, which is not what people want."

Those in favour of abolishing the leap second argue that many critical systems, such as the GPS instruments used in aircraft navigation or computer-trading systems used in international finance, depend on highly accurate timekeeping, which might fail if people forget to update them.

"The argument in favour of the change says that it's dangerous setting these systems manually — they are worried about introducing errors. But we've been doing such adjustments for decades without any problems," Dr Betts said.

The Independent, London

Key insights into pathways

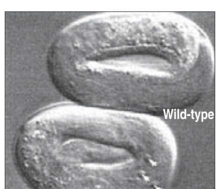
tapan kumar maitra **explains the use of genetic model systems to study cell signalling**

MODERN cell biologists use a variety of experimental tools to study key cell biological events, including biochemistry and cell fractionation, light and electron microscopy, and the tools of modern molecular biology. In addition, a genetic analysis of mutants that show defects during specific signalling events has provided key insights into cell signalling pathways. The use of such genetic model systems, including the budding yeast, *Saccharomyces cerevisiae*, the nematode worm, *Caenorhabditis elegans*, and the fruit fly, *Drosophila melanogaster*, revolutionised our ability to connect the functions of specific proteins with important signalling pathways.

For example, studies in budding yeast identified mutants with defects in the cell cycle that provided key information regarding how the cell cycle was controlled. Here, focus on how genetic model systems have uncovered key proteins that regulate two cell-signalling pathways: the Receptor Tyrosine Kinase pathway and apoptosis.

A genetic analysis of signal transduction downstream of RTKs was conducted at about the same time in two systems: the compound eye of *Drosophila* and the egg-laying structures, or vulva, of the nematode, *C. elegans*. Now consider how the *Drosophila* eye was used to identify components of cell signalling.

The compound eye of *Drosophila* is composed of roughly 800 individual "eyes" called *ommatidia* (singular, *ommatidium*). Each ommatidium consists of 22 cells. Eight of these are photoreceptors and are named on the basis of their position (Rl-R8). A mutation in an RTK known as *sevenless* (abbreviated: sev) results in loss of the R7 cell, which differentiates as a cone cell instead. Subsequent studies identified a cell surface ligand on the neighbouring cell, R8, that activates the sevenless receptor. It was called *bride of sevenless* (abbreviated: Boss). Boss protein on R8 binds to the Sev receptor on R7, initiating signalling.

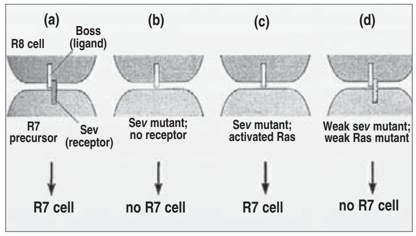


Cell death in C.elegans. Wild-type (top) and ced-1 mutant (bottom) embryos (DIG microscopy). Although cell deaths can be seen in both embryos as small "buttons", these cell corpses only accumulate in the ced-1 embryo, because phagocytosis of dead cells fails (arrows).

Mutations in the Ras pathway can either bypass or enhance defects in RTK signaling: (a) In normal larvae, Boss ligand on the surface of the R8 cell activates the Sev receptor on the adjacent R7 precursor cell, leading to its normal differentiation; (b) In Sev mutants, lack of the Sev receptor results in failure of the R7 precursor cell to receive the signal from R8, and the cell does not become an R7 cell; (c) When the fly lacks functional Sev protein, but the R7 cell expresses a dominant, active form of Ras, a normal R7 cell can form; and (d) When Sev contains a weak mutation that normally allows an R7 cell to form, but the R7 precursor cell also carries a weak mutation in Ras, no R7 cell is produced.

To identify additional components of the Sev pathway, conditions were found in which just enough functional Sev receptor was present to allow R7 to develop (such conditions are called a "sensitized background" by geneticists). Mutations were then isolated in which eye defects were caused only when the flies also carried this sensitising defect in Sev. Researchers reasoned that such mutations would affect the same pathway that Sev/Boss activates. By using this approach, several important components of RTK signalling were identified. In conjunction with biochemical studies on cultured cells, these pioneering studies showed that these proteins were not only important but that they were essential for RTK signalling to occur.

In other studies, the effects of multiple mutations in the Sev pathway were examined. For example, when a double mutant is made that lacks functional Sevenless but also carries a dominant mutation in Ras that results in reduced GTPase activity (such a mutation makes Ras constitutively active — it is overstimulated), R7 differentiates, even though it cannot receive the signal from R8. This provides evidence that the Sev pathway normally works by activating Ras. When Ras is activated on its own, the events at the cell surface are no longer necessary. Through these and similar studies in *C. elegans*, signalling pathways downstream of RTK signalling was clarified.



C. elegans is uniquely suited to studying cell death. Its life cycle is very short, it is optically transparent and its embryos are remarkably consistent in their development. In fact, they are so consistent that the lineage of every cell in the adult animal is known with complete precision. This means that the sequence of cell divisions that results in each of the 1,090 cells produced during development can be traced back to the single-celled fertilised egg, a feat achieved largely through the work of John Sulston at the Medical Research Council in Cambridge, England.

Sulston also showed that 131 cells undergo precisely timed programmed cell deaths during normal embryonic development in *C. elegans*. Largely through the work of Robert Horvitz and colleagues at the Massachusetts Institute of Technology, several mutants that were defective in some aspect of cell death, called *ced mutants*, were identified and the genes associated with these mutants were characterised. For example, the corpses of dead cells normally are engulfed — literally eaten via *phagocytosis* — by other cells. Horvitz and colleagues identified several mutations that block phagocytosis of dead cells so that their corpses persist, making them easy to see in the light microscope.

Using such mutants, it is possible to look for other mutations that prevent cell death so that there are too few or no corpses. One of the first genes to be characterised at the molecular level was *ced-3*, which encodes a member of the caspase family of proteins, key enzymes in the sequence of events that trigger apoptosis.

Another gene, *ced-9*, encodes the *C. elegans* version of *Bcl-2* — a protein that plays a key role in regulating leakage of molecules from mitochondria that can trigger apoptosis. By examining animals carrying mutations in more than one of the ced genes, Horvitz and colleagues were able to determine at which step in apoptosis the proteins encoded by the ced genes act. In conjunction with work proceeding on cultured cells at about the same time, the work of Horvitz and colleagues provided key insights into apoptosis. For this work and his work on cell signalling in the vulva, Horvitz, along with Sulston and geneticist Sydney Brenner, shared the Nobel Prize in Physiology for Medicine in 2002.

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