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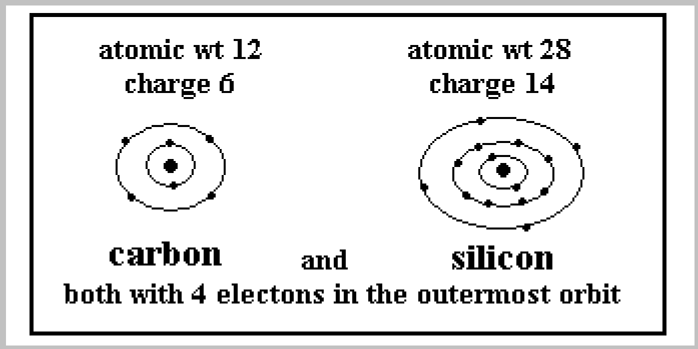
From semi- to superconductor?

Silicon, the modern day messiah, may draw another ace, says S.Ananthanarayanan.

Silicon, like carbon, has enabled materials that define the modern world. Carbon is central in plastics, polymers, hydrocarbons, all of organic chemistry, and silicon holds sway in transistors, microcircuits, computer chips – there is scarcely an activity that is not affected by carbon or silicon. Etienne Bustarret and colleagues at Grenoble, France, report that silicon can take the third super avatar of our times – a superconductor!

Silicon and carbon

The special place of carbon and silicon is thanks to the electron structure of their atoms. Atoms consist of a heavy, positively charged core, surrounded by electrons to balance the positive charge. The electrons are distributed in 'shells', with the outermost shell containing not more than 8 electrons. When the number reaches 8, a new shell is started, and so on. The 8 electron, or a 2 electron periphery is the stable state and the 'noble' gases are chemically inert thanks to just that.



All chemical activity, where atoms pair up, consists of outer electron shells trying to 'share' and reach the 'octet' state. In common salt, sodium, with 1 electron sticking out, joins chlorine, which has 7 electrons in the outer shell, or 1 short; but calcium, which has 2 outer shell electrons, joins with 2 chlorine atoms, and so on.

But with carbon and silicon, there are 4 outer electrons and it is half way house! Wherefore the great variety of chemicals based on carbon and also the remarkable properties of silicon.

Semiconductors

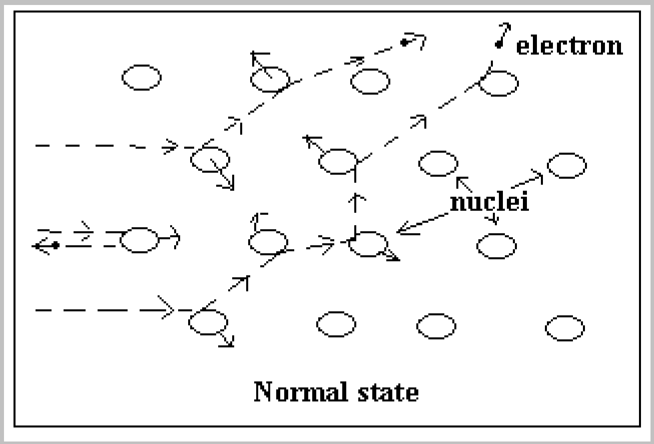
Pure silicon is electrically non-conducting. This is because the crystals balance their need for electrons and free charges to carry currents are rare. But if just a few atoms are replaced by phosphorus, which has 5 outer electrons, or with boron, which has 3, then, there is an extra electron, or the lack of one (called a ‘hole’), loosely bound and available to carry a current. This kind of ‘doped’ silicon becomes a semiconductor.

Using combinations of the two types (boron type or phosphorus type) leads to things like ‘gates’ or amplifiers (a kind of electrical ‘lever’) and hence diodes, transistors, ICs, the whole electronic revolution.

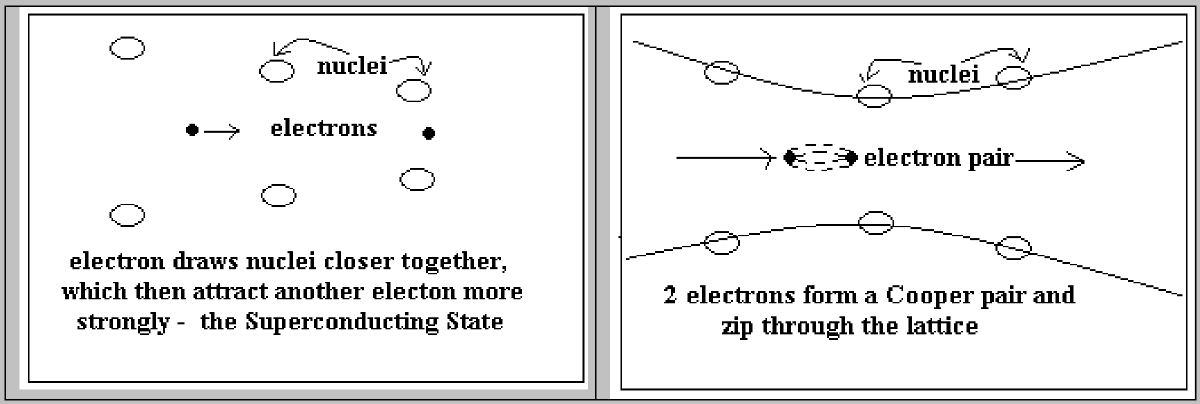
In metallic conductors, the outer shell electrons are loosely bound, and directly become available to carry currents. But electrons in all conductors have to negotiate the lattice of other electrons and nuclei, all vibrating due to thermal energy. In moving through this obstacle course, the electrons collide and react and lose energy, which shows up as the ‘resistance’ of the conductor and heat – and so it is with the best metallic conductors.

Superconductors

The resistance of metals reduces with temperature, because the lattice vibrates less when the conductor is cooled. It was thought that this fall in resistance would taper till the resistance settled down to some minimum due to just the lattice. But surprisingly, it was found that at very low temperatures, nearly absolute zero, the temperature when things have the lowest possible energy, the resistance does not stop falling, it suddenly drops to zero!



This mystery has been studied deeply and an explanation has been given, based on the quantum theory. Simply stated, the lattice is considered like a stretched rubber sheet on which electrons are like mutually repelling ball bearings. Any ball bearing would create a depression, into which a nearby bearing would roll. When this happens, the first bb would get repelled and it would shift the depression, which would again draw the second bb on. And so on. As the players in this sport are charged, subatomic particles, there is also the effect of a property of electrons known as ‘spin’ and the pairs formed have opposite spins. In short, the electrons, when energies are low enough, form pairs, called ‘Cooper pairs’, after Leon Cooper, one of the fathers of the theory, and these are able to pass obstacles and carry current without resistance!



Silicon too

In doped silicon, the extra electron or hole, moves in a loose orbit, which merges with that of a nearby electron, and this results in part-metallic conduction. But superconductivity is scarcely a possibility. Bustarret and colleagues used high energy lasers to force boron atoms into the silicon lattice to a density normally not possible – parts in a hundred, in place of parts per million. And when chilled real cold, this highly doped silicon showed superconductivity! Nothing to compare with the higher temperature superconductors that have been developed, but if superconductivity is possible with silicon, it opens a world of possibilities!