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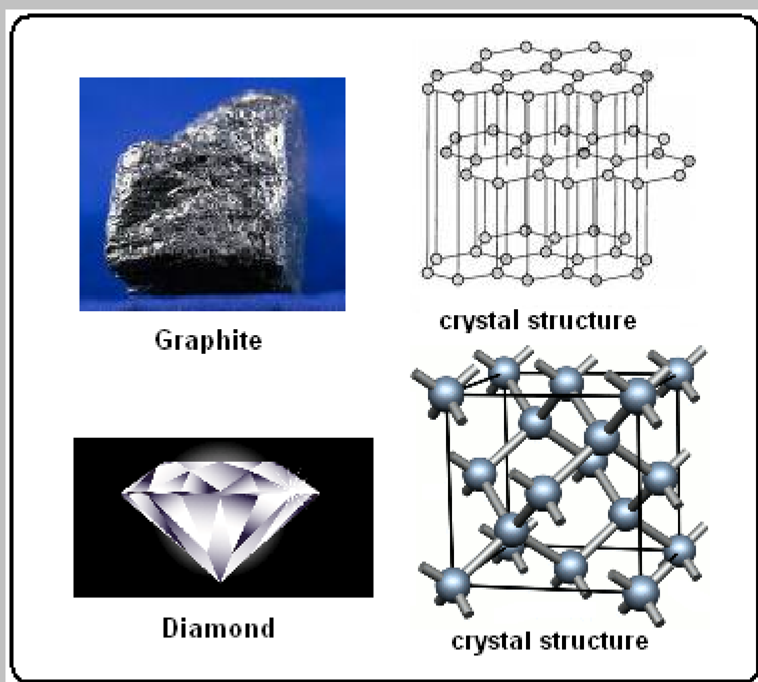
Graphene on the ironing board

Single atom sheets need to get a little wavy, says S.Ananthanarayanan.

Graphene, sheets of carbon, just one atom thick (or thin) is the latest wonder-material. Carbon itself is a special atom, which is able to form more compounds than any other and which is the basis of life, as known on the earth. Apart from combinations with atoms of other elements, carbon atoms even join with other carbon atoms in a number of ways and there are different forms of carbon in nature.



For example, there is the common lump of coal, which is amorphous carbon, or carbon which has not formed crystals. When it forms crystals, it creates an exceedingly robust structure, in form of diamond, which is known for its hardness and lustre. It can also form into sheets which slide over each other, in the form of graphite, which is a lubricant, and found in pencils, which leave traces on paper as the layers of graphite slide off and deposit as writing!

The carbon atom

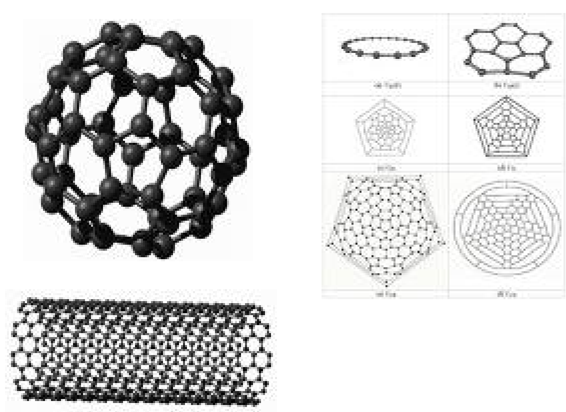
The remarkable discovery of the last few decades was 'geodesic structures' that carbon atoms form, in the form of 'buckyballs' and 'nanotubes'. Carbon owes its versatility in forging connection\s with other atoms to its atomic structure. All atoms consist of a heavy, positively charged centre, surrounded by shells of tiny, negatively charged particles called electrons, which neutralize the charge in the middle. The most stable form is for the shells, except the first one, to consist of eight electrons, and the electrons are distributed in this way. The outermost shell then has the remainder, from one to eight electrons. This ‘structure of eight’ is the most stable state (an outer shell of two is also stable) and atoms that have different numbers of outer electrons try to reach these numbers by exchange, in chemical combination.

Thus, atoms that have an electron to ‘give’ are the metals, like iron or copper and the atoms that can ‘accept’ an electron are the ‘non-metals’, like oxygen or chlorine. And hence, metals usually combine with non-metals to form oxides or chlorides and so on.

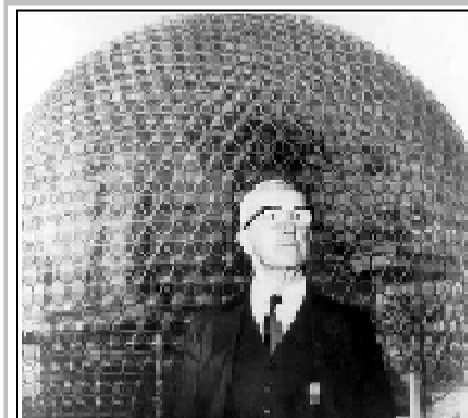
But carbon, which has four outer shell electrons, is exactly half-way from one the ‘eight electron state’, either by ‘giving’ or by accepting or even by ‘sharing’. The great variety of ‘organic’ chemicals, like plastics and ‘synthetics’ or as is seen in living things, is because carbon can form varied chains and rings, holding hands, as it were, with other carbon atoms and also with atoms of other elements. Carbon can also be the base of ‘components’ that are assembled into ‘polymers’, or chains that are thousands of units long.

Carbon frameworks

Even without the need to form chemical links, carbon atoms themselves can form into frameworks that are stable, strong and light-weight. Carbon atoms were found to take the Buckminster Fuller’s geodesic dome structure, to form into stable football shapes or even tubes and cylinders built out of hexagons (the structures are known as ‘fullerenes’). Being one-atom thick surfaces, these forms have very special mechanical and electrical properties and they were at the start of nanotechnology or the science of very small structures.



Fullerene shapes and varieties



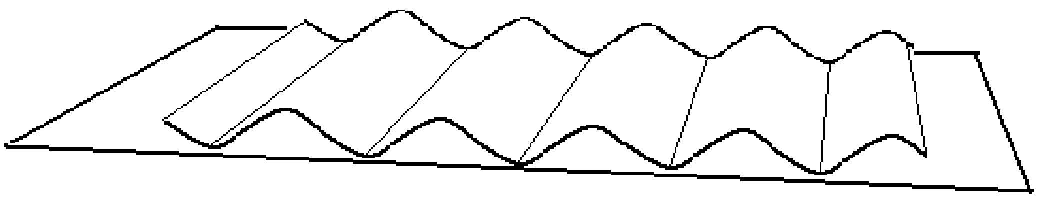
Buckminster Fuller and dome

While the carbon nano-cylinder, just a few atom dimensions in diameter, can be exceedingly long, in comparison to its girth, an interesting variant was the single atom sheet, which could stretch to reasonable lengths in 2 dimensions. But the trouble with this kind of carbon surface is that it cannot be stable, unlike the football or the cylinder.

But when this form of carbon, in single atom sheets, which is called grapheme, was realized in reasonable sizes, it was found that for stability, the sheets developed a ‘ripple’, which enabled them to resist deformation.

Corrugated sheets

Civil engineers have long used the curved surface for supporting loads, as in the arches that support bridges. The same idea is used to give strength to ordinary paper sheets, by sticking together a plane sheet and a wavy or ‘rippled’ sheet. The thickness that the waviness creates gives strength along the length of the ripples and the plane sheet gives strength in the perpendicular direction. Hence the use of corrugated paper sheets for packaging, with strength, insulation and lightness. It is the same principle in the corrugated iron or asbestos sheets used for roofing.



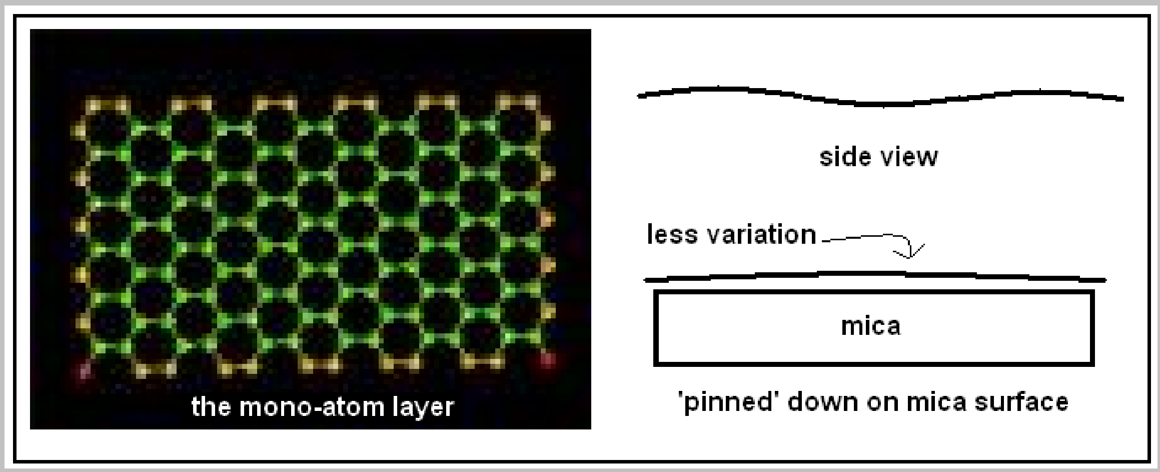
Corrugated board

Well, the carbon one-atom-sheet makes use of the idea to gain stability. When the surface takes on a wavy shape, the result is that deformation of the surface would result in unequal stretching and compression of the ripples, leading tensions and restoring forces. The appearance of the ripple then enables the sheet to be formed in reasonable dimensions without being destroyed by the lightest disturbance.

The plane surface

For all the stability of the wavy surface, there is still interest in the truly plane carbon one-atom layer, because such a layer would have remarkable electric properties and show features of marked quantum-mechanical nature, or in the counter-intuitive way that matter in very small dimensions behaves. Study of the plane one-atom layer would then help understand more intimately the practically feasible, wavy layer and also the nature of such layers, generally.

The journal, ***Nature*** has carried a report by a team at the Dept of Physics and Electrical Engineering, Columbia University, New York, of their work in ‘pinning’ a carbon one-atom layer down on “the atomically flat terraces of cleaved mica surfaces’.



The extent of corrugation that is intrinsic to the mono-atom layers is about 1 nanometer over 25 nanometers, which is like the undulation of 1 cm over the length just under one foot. On the plane mica surface, however, the variation of height was less than 25 picometres over a micrometer length, which comes to a variation of only in millionths!

This kind of flat layer of grapheme will help understand the properties added, or properties to be looked for, or properties suppressed, by the appearance of ripples in the practically realized mono-atom layers.