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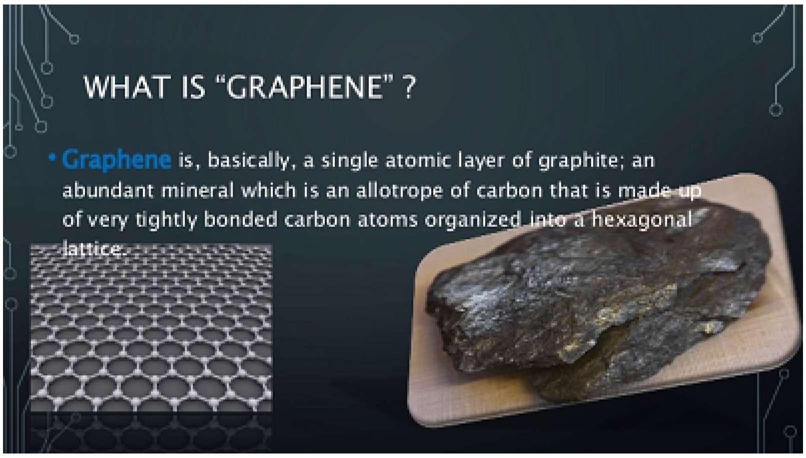
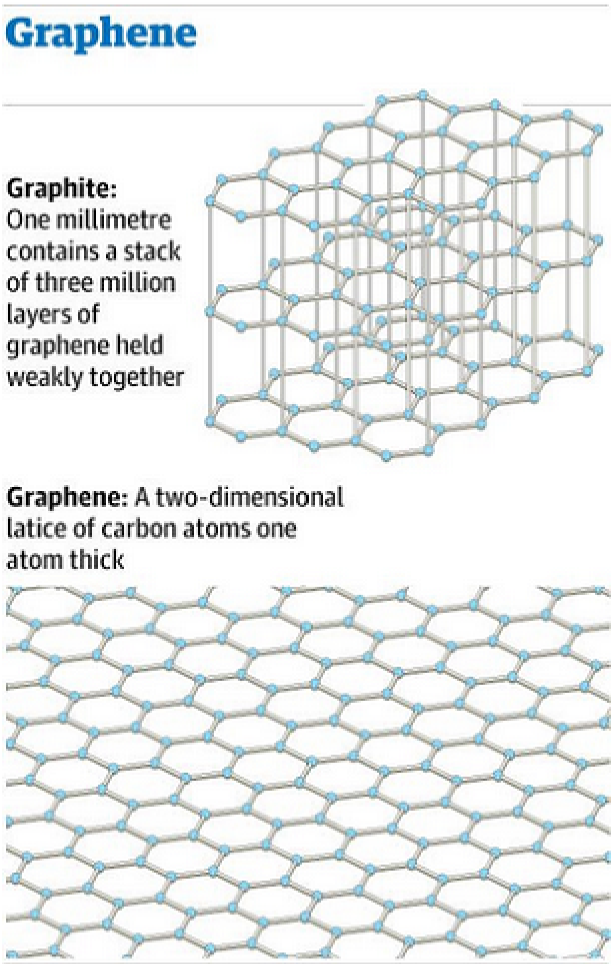
A miracle material that is more solid than steel and a better conductor than copper



According to David Larousserie of The Guardian, scientific interest is rolling in for a miracle material more solid than steel and a better conductor than copper. The pricelessness of this molecule is not measured in cost (few hundred per kilo) but in the value that lies in its potential. The molecule is called graphene. The European Union is prepared to devote over a billion dollars to find out if it can transform a range of sectors such as electronics, energy, health and construction.

Since 2005, according to Scopus (a bibliographic database), more than 8,000 papers have been written about graphene.



Graphene is extracted from graphite, material used in pencils. Not much unlike graphite, graphene is entirely composed of carbon atoms. 1mm of graphite contains some 3 million layers of graphene. Graphite is a three-dimensional crystalline arrangement. Graphene is a two-dimensional crystal only an atom thick. The carbons are perfectly distributed in a hexagonal honeycomb formation only 0.3 nanometres thick, with just 0.1 nanometres between each atom. This 100% pure carbon simplicity confers some remarkable properties on graphene, very close to the calculated theoretical ones, as observed by the authors of A Roadmap for Graphene that Nature published in 2012.

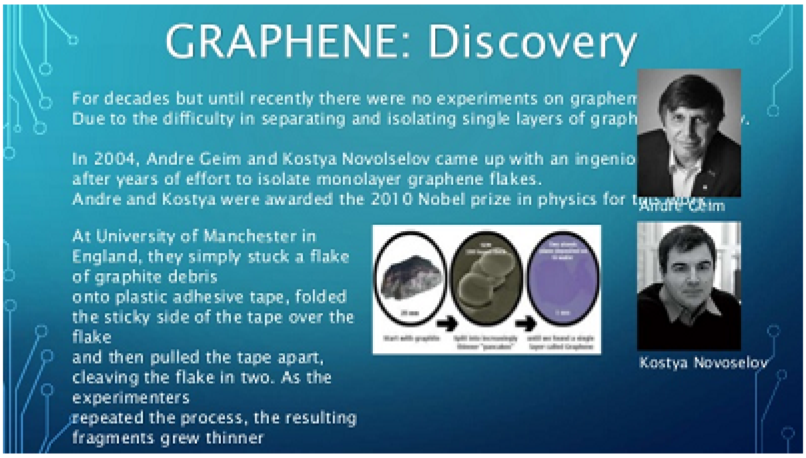
Graphene conducts electricity better than copper. It is 200 times stronger than steel but six times lighter. It is almost perfectly transparent since it only absorbs 2% of light. It impermeable to gases, even those as light as hydrogen or helium. If that were not enough to impress, chemical components can be added to its surface to alter its properties.

GRAPHENE FLAGSHIP

"Graphene is a platform, like a chessboard, on to which one can place the pawns you want. The subtlety lies in finding the right positions. There is a real beauty in its simplicity," explained Vincent Bouchiat, from the Institut Néel in Grenoble, part of the National Center for Scientific Research (CNRS).

"*The future lies in pencil graphite!*" according to Annick Loiseau, from the National Office for Aerospace Studies and Research (ONERA), coining a slogan. She is the French representative to the executive office of Graphene

Flagship, a research consortium funded by the EU for the next 10 years. The project was officially launched in 2013. "We have already learnt a great deal but new results could emerge in certain situations – only we don't yet know which ones," said Mark Goerbig, another CNRS researcher, who works in the solid physics department at Paris-Sud Orsay University.



This miracle material has come a long way. In theory, such a two-dimensional structure was believed to be unstable and therefore better rolled up, as observed in the 1990s with carbon nanotubes. In 2004 two Russian-born scientists, Andre Geim and Konstantin Novoselov, along with others, published the first electronic measurements proving they had isolated graphene. They had removed carbon flakes from graphite using bits of sticky tape – which ultimately led to them winning a Nobel prize for physics in 2010.

"The theory only really held true for two dimensions, but in actual fact the crystal grows in a three-dimensional space and the small surface fluctuations, like waves, stabilise the crystal," said Goerbig. Experiments rapidly confirmed the marvellous behaviour of this new material, which can be explained by a kind of sea of electrons on the surface that nothing can stop and that do not interact with each other. It's as though the electrons have no mass and move at a speed 300 times slower than light. The mathematical equation to describe them is closer to that for high-energy particles than for solid matter, hence this outstanding performance that suggests so many potential uses.

Being transparent as well as a good conductor, graphene could replace the electrodes in the indium used in touchscreens. Since it is light, graphene could be integrated into composite materials to eliminate the impact of lightning on aircraft fuselages. It is also waterproof and would be perfect to use in hydrogen reservoirs. Since nothing can stop the electrons, graphene cannot be "switched off" so in theory it is of little use in transistors, which are the key components of modern electronic goods. However, research is being carried out into ways of creating an artificial band gap that would enable it to be switched off and therefore used for that purpose.

The European consortium has decided to focus on a number of applications. "Our goal is to support innovation in Europe but also to create a network of specialists in contact with companies for long-term R&D projects," said Stephan Roche, in charge of one section of the project, and a researcher at the Catalan Institute of Nanoscience and Nanotechnologies in Barcelona.

The major steps in this process have already begun. Several start-up companies are already manufacturing graphene, mainly for laboratories, using a variety of techniques. The "historical" one with sticky tape has been replaced by chemical exfoliation. An alternative is to use a carbon and silicon substrate, which is heated to remove the silicon atoms, leaving a layer of graphene on the surface. Yet another method is to place carbon on the surface of copper which, after heating, catalyses the graphene formation reaction. A team from Rice University in the US has even used a cockroach leg as a source of carbon.

In Europe, Applied Graphene Materials (AGM) in the UK and Avanzare and Graphenea in Spain are the spearheads. "If we want graphene to become the equivalent of silicon in microelectronics today, it is important to control the material and its quality," said Etienne Quesnel of the French Alternative Energies and Atomic Energy Commission, in charge of the energy aspect of Graphene Flagship, which also works with manufacturing specialists.

Industry giants are in the running too. IBM has produced several electronic component prototypes, while Samsung has produced a flat screen (70cm in the diagonal) with graphene electrodes. The tennis racket maker Head used tennis champions Novak Djokovic and Maria Sharapova to promote rackets made with graphene. BASF and Daimler-Benz have designed a concept electric car called Smart Forvision that incorporates graphene in a conductive e-textile. In 2012, BASF produced a report on the future of graphene, forecasting a market worth $1.5bn in 2015 and $7.5bn in 2025.

It goes without saying that China is also in the race, with 2,600 articles published in Europe. And with more than 2,200 patents it has surpassed Europe and the US. Last summer one start-up, Bluestone Global Tech, announced a partnership with a mobile phone manufacturer for the first graphene-based touchscreens to be launched on the Chinese market in the coming months. Nevertheless, mass applications are not yet in the pipeline.

"People are being sold graphene that is really graphite only more expensive," said Marc Monthioux, from the CEMES research centre in Toulouse at a conference on graphene-based composite materials held in Paris earlier this year. Strictly speaking, graphene is single-layered, but manufacturing processes may create stacks of several layers. When more than 10 layers are created, the properties change enormously and resemble graphite more than graphene. "To date graphene is not absolutely superior to carbon nanotubes," said Monthioux. According to Loiseau, "In composites it is necessary for the carbon, graphene or nanotube molecules to 'touch' each other to be conductive. That is easier for elongated nanotubes than for flake-shaped graphene, which explains the difference." It takes a long time to develop a composite material and nanotubes have the advantage of being the more mature material. Nanotube researchers were not happy to see graphene arrive and grab both attention and funding.

Nevertheless, accumulated nanotube experience is very useful to speed up work on graphene. "It took six years to produce the first transistors with nanotubes," said Loiseau. "With graphene, we had the first electric measurements in a year." As far as its medical use is concerned, knowledge of one material serves for the other. A crucial aspect of the European project is devoted to how to protect the people working with graphene as well as end users, in addition to researching possible medial applications. "At present we have studies showing no effect while others indicate a potential risk," said Alberto Bianco, CNRS head of research at the Institute of Molecular and Cellular Biology in Strasbourg, who co-heads the health and environmental aspects of the European project.

In fact, as with carbon nanotubes, the considerable diversity of types of graphene need to be taken into account. Size certainly matters, but so does the chemical state. The molecule may be oxidised to a greater or lesser extent, or contain different amounts of residual impurities as a result of how the graphene is synthesised, or how its layers are built up. There is no definitive answer. In an article published in April in Angewandte Chemie, scientific journal of the German Chemical Society, Bianco quoted several contradictory studies, some of which found toxic effects on micro-organisms where others did not. Nor has any light been shed on the way graphene could cause damage to cells. Does the graphene cut through the cell wall perpendicularly or does it coat the cell?

"One optimistic note is that chemistry may enable us to modulate the biological activity of this nanomaterial," said Bianco. For instance, by binding different chemical groups one might make the graphene more or less soluble, or guide it towards a given therapeutic target. Additional work is therefore required. The consortium will study the effects on different types of cells (cancerous, neuronal, related to the immune system etc)as well as on amphibians.

Another advantage of graphene is that is opens up paths to other two-dimensional materials as small as atoms. Boron nitride, molybdenum sulphate and tungsten or even 100% silicon sillicene are some of the peculiar sounding names that could become more common. Some isolate, others conduct. Piling up these molecules layer-by-layer would create new materials with new properties. The game is on.

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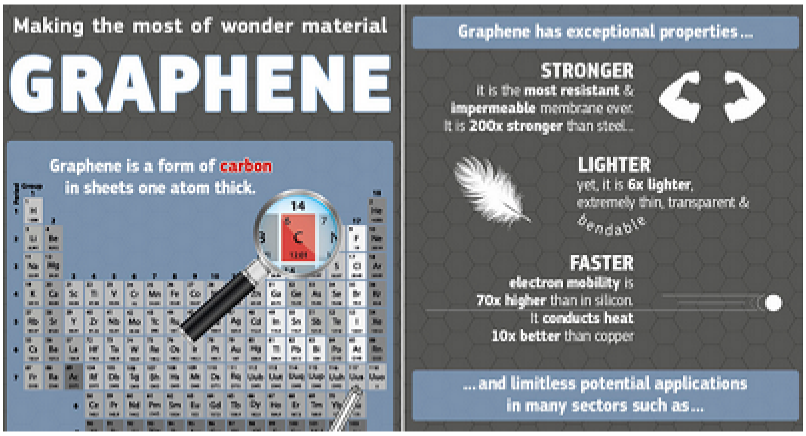

Graphene is a transparent and flexible conductor that holds great promise for various material/device applications, including solar cells, light-emitting diodes (LED), touch panels, and smart windows or phones. According to information from Changzhou, China-based 2D Carbon Graphene Material Co.,Ltd, graphene-based touch panel modules have been sold in volume to cell phone, wearable device, and home appliance manufacturers.

For example, there are actually some smart phone products with graphene touch screens that are already on the market. In 2013, the year Larousserie wrote the Guardan article, Head announced their new range of graphene tennis racquets. As of 2015, there is one product available for commercial use: a graphene-infused printer powder. Many other uses for graphene have been proposed or are under development, in areas including electronics, biological engineering, filtration, lightweight/strong composite materials, photovoltaics and energy storage.

Graphene is often produced as a powder and as a dispersion in a polymer matrix. This dispersion is supposedly suitable for advanced composites, paints and coatings, lubricants, oils and functional fluids, capacitors and batteries, thermal management applications, display materials and packaging, solar cells, inks and 3D-printers' materials, and barriers and films.

In 2016, researchers have been able to make a graphene film that can absorb 95% of light incident on it. It is also getting cheaper; recently scientists at the University of Glasgow have produced graphene at a cost that is 100 times less than the previous methods. In August 2, 2016, BAC's new Mono model is said to be made out of graphene as a first of both a street-legal track car and a production car.

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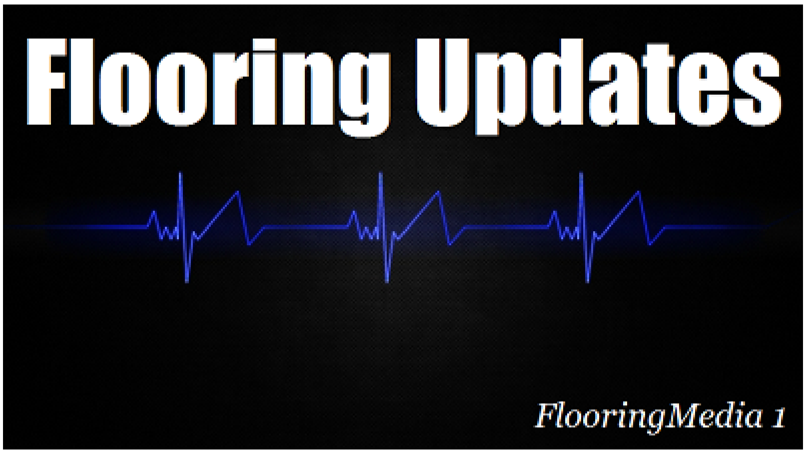

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