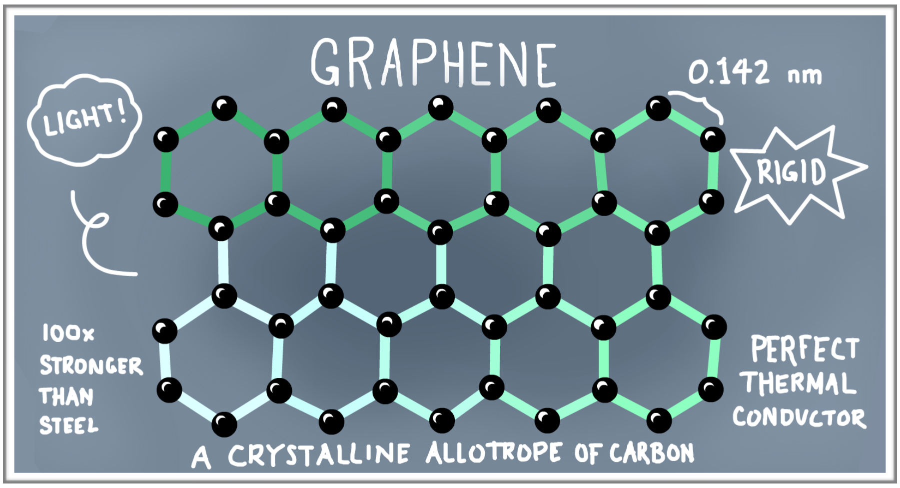
Graphene, the miraculous material that will change the world!

Protons, neutrons and electrons. During the first half of the 20th and ending of the 19th century occurred the discovery of most of the general knowledge of matter. Ernest Rutherford published in 1911 the gold foil experiment in which he pointed beam alpha particles at an extremely thin gold foil and he observed that most of the radiation could go through it without bouncing. Hence, he concluded that matter was mostly empty and the atom was divided into a small nucleus and orbiting electrons. Although this atomic model was left obsolete not long after, it's revolutionary idea would be maintained: most of the space inside an atom is empty!

Again, in the 70s a new hypothesis began to take shape: was it possible to obtain by-dimensional crystals at room temperature? Initially, it was discarded. Nonetheless, the discovery of carbon-made nanotubes, or the fullerenes, gave more hope to scientists to pursue for this quest. Finally, in 2004 the later Nobel Prize in physics (2010) managed to isolate a monolayer of carbon atoms at room temperature. Actually, this new material preserved the graphite carbon layers' structures: carbon atoms were located in the same hexagonal shape with a free electron each.

Graphene is a material so thin and with such peculiar characteristics that in the next decades we are going to see the development of more and more products made of it. It is as thin as an atom, and the surface of a gram of it would cover about 3000 m^2. It is transparent, tougher than the diamond, between 100 and 300 times harder than steel and it has an elasticity of 20%. And in addition, it is the best electric conductor known: it is a million times better working as a conductor than copper, and it gets less heated as its electrons move as if they did not have any mass at all (10). Some of these properties are so extraordinary that they can only be explained by Relativistic Quantum Mechanics.



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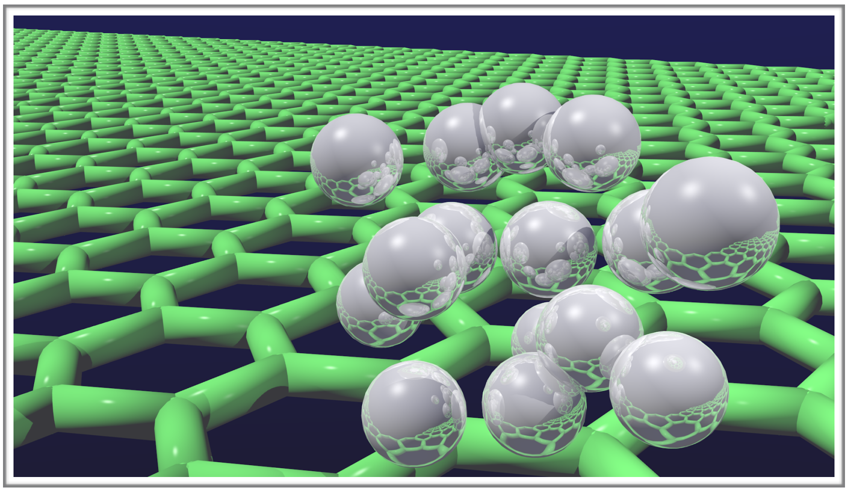
Furthermore, in 2005 the Hall effect, which is the generation of voltage difference in an electrical conductor, was observed in graphene. *This fact proved right the Berry phase theory about the fermions without mass by Dirac.* The fermions include some quantic sub-particles considered as the basic constituent of all matter. But, the graphene revolution in the field of physics does not stop here. In 2012 professor Mikhail Katsnelson even speculated that in the future a particle accelerator, like the one in Switzerland, could be reduced to the size of 1 cm^2 in a graphene layer, with no need for building megalithic structures (11).

Since the 1990s, it has been used in the form of nanotubes. Graphene nanotubes are three-dimensional structures made of only one carbon layer, forming a cylinder that helps to give stability to the molecule. Nowadays, it has been used to develop different types of products ranging from energy storage to biomedical uses. Nonetheless, the expectations for graphene are much greater and harder to achieve due to the material's complexity. In 2010, the first graphene transistor was developed by MIT professor Tomás Palacios, which was 10 times faster than the common silicon transistors. And by 2011, Samsung presented its first prototype for another graphene transistor as well as a touchscreen, that surprisingly enough, was flexible. Currently, some of the most revolutionary graphene-utilizing designs being tested are: batteries more optimized than the ones made of lithium, solar panels, batteries to transform calorific energy into electric energy, conductor inks, developing and coating of medical prosthesis, and other devices used in the fields of engineering and biotechnology.

More recently, new possible applications have been studied and a completely new field in biological sciences and biomedicine is being developed. Still, most of this nanotechnological developments are not yet completely stable, or have side effects that need further investigation. But for the moment, great progress has been achieved in the fields of tissue engineering, drugs and gene delivery, and bioimaging, which is a set of techniques aimed to observe biological processes in real time (1). In addition, it is also being studied as a new material for use in developing medical tools due to its antimicrobial properties, which are caused by a membrane disruption and an increase in oxidative stress in bacterial cells (2). For now, in the field of biological sciences, graphene family nanomaterials are being studied mainly in the form of hydrogels, films and composite materials (3).

For the bioimaging and biosensing purposes, graphene materials can be classified in three groups according to their structure: graphene nanocomposites, graphene quantum dots (GQDs), and graphene wrapped hybrids. GQDs are nano-sized dots formed by graphene's disintegration due to high pressure and temperature, and have interesting flexibility and electronic properties. Moreover, the graphene wrapped hybrids are structures designed to contain biological and chemical materials. In contrast to the graphene nanocomposites which usually serve as a support, graphene wrapped hybrids are more commonly used as biosensors for the quantification of substances (1).

However, other graphene chemical derivative compounds exist and have been used and studied for several applications, or as steps towards the obtention of pure graphene. They are like graphene but they contain functional groups bonded to certain carbon atoms, in this way, changing its properties quite substantially. One example can be graphene oxide (GO), which has been studied as a step for improving graphene obtention, and also because it is impermeable to most liquids and gases with the exception of water. Not even helium can cross this membrane (4).



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Even so, there is one large issue with graphene, that issue being that no-one has been able to develop an obtention process for producing it in large quantities yet. At the moment, it has only been obtained in small amounts in laboratories. Hence, as it is unsuitable for mass production, its high cost to obtain makes it impossible to use for common products. When it was discovered, it was first obtained by micromechanical cleavage of graphite via sticky tape. And although it is a very easy method to perform, it has quite a low output (5). Other procedures and methods can be used to obtain it in a laboratory, like the classic Hummers and Hoffman (1958) process for obtaining graphene oxide (GO) and later transforming it into graphene (6). Another example could be the obtention by heating of SiC, a crystalline structure, at 1100ºC (7).

In spite of these production problems, there are several companies in Spain dedicated to the production of graphene and its derivates i.e., *Graphenea* and *TheGrapheneBox*. Both companies sell it in its more common form of GO, allowing labs to reduce costs by obtaining the graphene themselves, as the graphene layers are very expensive. Although, they also sell graphene chips and films to use directly in all sort of products and as sensors. However, the costs are very high, resulting in prices like: 1 cm^2 graphene chip (350€), 400 mL solution 2,5% (p/p) GO (400€) or 1 g of GO powder (96€). Despite these inflated prices, whenever a mass production system has been successfully developed, graphene will become more affordable (9).

All these functions are mostly in the developmental stages, and graphene's potential is still being discussed. Nonetheless, graphene's particularities make it one of the biggest wonders of this century. It is not yet clear if it will be a success in every field, but it is bound to create competition in various industries. For example, for more than half a century silicon has been the material in which all transistors have been made, but in the long term graphene will threaten its predominant role (8). Still, it is undeniable that there is much to discover about graphene.

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