The Quantum Magic of Graphene

Imagine sitting at a computer and instantly knowing every piece of data on your family genetics, or the stock market, or the size and shape of galaxies, or even the weather three years from now—in less than a fraction of a second. Welcome to the world of quantum computing.

The world's fastest traditional supercomputer can make 33.86 quadrillion calculations every second. This exceptional power is used to simulate astronomical phenomena, complex weather patterns, and even the functions and nerve activity of the human brain. Access to this computer is, unfortunately, restricted to just a handful of scientists. But what if this caliber of computer could be owned by you or me? What if it could be packed into a laptop or cell phone? Traditional computing is reaching its limits –sure, computers can be made even larger to achieve greater processing power, but modern supercomputers cost billions of dollars, fill vast facilities, and are weighed down by international politics. In short, they lack practicality. However, this may not prohibit the average consumer from owning their own supercomputer, thanks to a relatively new concept called quantum computing.

Traditional computers encode data as a binary digital signal –the "bit." Quantum computers use something much smaller: a "qubit," which is something as small as a single photon of light, but which still possesses the capacity to transmit data. Additionally, quantum computing does not need to rely on binary sets of data, because quantum bits take advantage of a funny little quirk of quantum mechanics called "superposition," wherein a very small object exists in two positions at once. All of these unique qualities allow for quantum computing to be many times faster and smaller than traditional electronic computing. Although this concept has been theoretically researched for many years, advancements in this field of quantum computation have been limited by the complicated physics present at the quantum level, and by insufficiently sophisticated materials. Now, however, a revolutionary substance known as graphene may hold the answers to new forms of transistors, circuitry, and displays, which could contribute to the realization of quantum computing.

Most forms of carbon, such as coal, graphite, and diamond, exist in three dimensions. Graphene, on the other hand, exists as a two-dimensional crystal –it is a single layer of bound carbon only one atom thick. It is flexible and transparent, but hundreds of times stronger than the most advanced steel. Most importantly, however, it transmits electrical current more effectively than almost any other material. The use of a flexible layer of carbon only one atom thick would revolutionize electronics by eliminating the need for heavy, expensive metals like copper and gold. Devices could be freed of cumbersome, brittle wiring, while transistors and integrated circuits could be improved massively. Although graphene has no current popular application, it is not as mysterious or complicated as it might seem. In fact, graphene is, essentially, the two-dimensional counterpart to the graphite core of most pencils.

Nobel Prize winning professor Konstantin Novoselov, of the University of Manchester, explains just how exceptional graphene is in a lecture at Imperial College London: "It's the thinnest possible material, the most conductive, the most thermoconductive, the most transparent, the most impermeable, and so on." With these unique properties, it is not difficult to imagine just how revolutionary graphene will be for electronics, and quantum computing in particular. The carbon from which it is made is abundant and lightweight, and the ability to transform it into strong sheets without electrical resistance eliminates the need for localized wiring and other burdensome components.

Because graphene propagates electrical signals much more efficiently than traditional semiconductors, one of its most promising uses is in transistors. Transistors amplify or alter electronic signals, but have been limited by technology for years. According to Novoselov, “If you make a transistor out of this material, it would work extremely fast, and at extremely high frequencies… orders of magnitude better than the best [silicon] transistors which are available to us at the moment.” The speed of electrical propagation through graphene makes it an ideal candidate to replace silicon in computers, perhaps even before quantum computing technology is realized.

Additionally, the practical applications of graphene are not limited merely to the internal components of computers. Because it is so thin, graphene is almost completely transparent, absorbing only a small fraction of the light that shines through it. Most devices with screens, as well as surfaces which are light and touch-sensitive, are covered with thin glass or plastic. These materials scratch, break, and lack the property of electrical conductivity. As professor Novoselov points out, graphene could soon replace materials not only in computer hardware, but also in displays and photovoltaic panels. In his lecture, he remarks, “If you [were] an electronic engineer, you would kill to have a material which is as conductive as graphene, and absorbs only a small fraction of light. It would be the central material for, say, touch screens, for liquid crystal displays, for solar cells…” Advancements in the efficiency and practicality of solar energy production based on durable, transparent layers of graphene crystal could accelerate the global transition from fossil fuels to renewable energy. Similarly, graphene’s flexibility and conductivity make it ideal for futuristic touch screens and displays which could be curved or even completely pliable, while still maintaining its structural integrity and durability.

So why isn’t this “material of the future” being broadly utilized already? Graphene, while exceptional, has been astoundingly difficult and expensive to manufacture, partially because low-dimensional objects are typically unstable. They do not exist in nature outside of very unique temperature and pressure conditions. Additionally, creating a single-layer sheet of carbon atoms requires complex chemistry that can make the finished product “dirty.” Finally, and perhaps most importantly, around the time of professor Novoselov’s work with graphene, lab-produced samples of the carbon crystal could only be measured in microns –they were simply too small to be used in practical applications. Displays and computer components must be millimeters, centimeters, or even meters long, and previous attempts could not create graphene sheets of sufficient length. In other words, graphene could be observed in a lab, but could not be justifiably mass-produced. New research from Germany, however, may have a solution to these problems.

A team of chemists led by Dr. Andreas Hirsch from the Friedrich-Alexander-Universität in Erlangen-Nürnberg are synthesizing graphene in a revolutionary new way. According to their work, published in *Nature Communications*, an open-source science journal, they have found a “mild, scalable and inexpensive method for graphene production surpassing previous wet-chemical approaches.” Hirsch’s team appears to have found a tentative solution to the three most serious issues facing common graphene synthesis and its use in devices such as quantum computers: cost, size, and purity. An inexpensive and reliable method of production could allow large-scale graphene to be applied to electronics and machinery more quickly. Although the point of quantum computing is to create exceptionally small machines with improved capabilities, graphene cannot be utilized effectively in the quantum world unless it has the ability to stretch across entire processors, circuits, and displays. Hirsch's team may be bringing us closer to that reality.

While the actual applications of graphene in technology remain to be seen, it is clear from its amazing qualities that the possibilities are practically limitless. In addition to its usefulness in electronics, its immense strength suggests that it could be used in the construction of revolutionary materials and structures. Whether it is quantum computing, flexible phones, or new spacecraft, graphene will be used to unlock the door to the future.

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