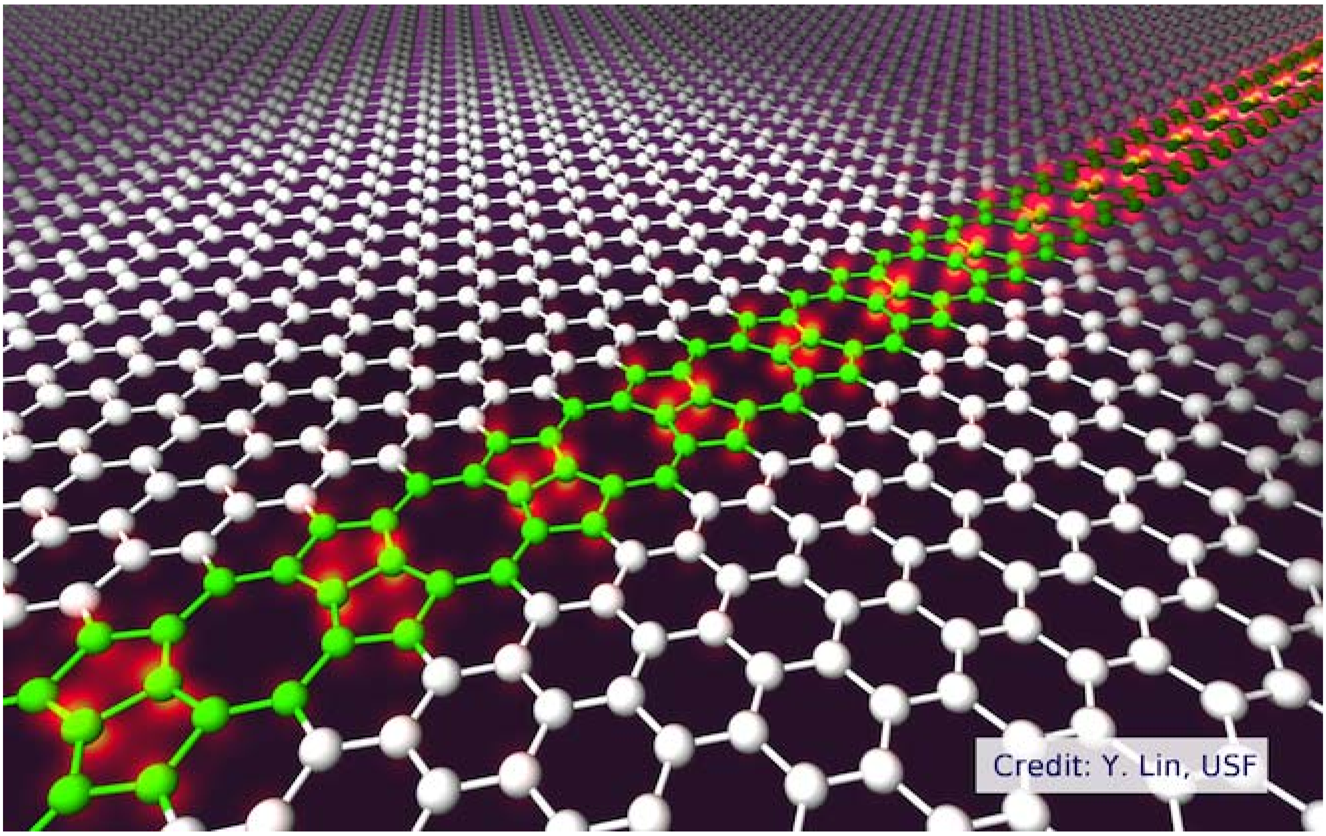
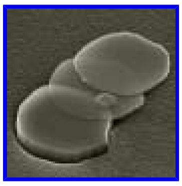
Why Graphene Won Scientists the Nobel Prize

By Tim Carmody October 5, 2010 | 4:53 pm | Categories: R&D and Inventions



Two University of Manchester scientists were awarded the 2010 Nobel Prize in physics Tuesday for their pioneering research on graphene, a one-atom-thick film of carbon whose strength, flexibility and electrical conductivity have opened up new horizons for pure physics research as well as high-tech applications.

Graphene Close-Ups



Graphene is one of the strongest, lightest and most conductive materials known to humankind. It's also 97.3 percent transparent, but looks really cool under powerful microscopes. See our gallery of graphene images.

It's a worthy Nobel, for the simple reason that graphene may be one of the most promising and versatile materials ever discovered. It could hold the key to everything from supersmall computers to high-capacity batteries.

Graphene's properties are attractive to materials scientists and electrical engineers for a whole host of reasons, not least of which is the fact that it might be possible to build circuits that are smaller and faster than what you can build in silicon.

But first: What is it, exactly?

Imagine "crystals one atom or molecule thick, essentially two-dimensional planes of atoms shaved from conventional crystals," said Nobel winner Andre Geim in *New Scientist*. "Graphene is stronger and stiffer than diamond, yet can be stretched by a quarter of its length, like rubber. Its surface area is the largest known for its weight."

Geim and his colleague (and former postdoctoral assistant) Konstantin Novoselov first produced graphene in 2004 by repeatedly peeling away graphite strips with adhesive tape to isolate a single atomic plane. They analyzed its strength, transparency, and conductive properties in a paper for *Science* the same year.

Super-Small Transistors

The Manchester team in 2008 created a 1-nanometer graphene transistor, only one atom thick and 10 atoms across. This is not only smaller than the smallest possible silicon transistor; Novoselov claimed that it could very well represent the absolute physical limit of Moore's Law governing the shrinking size and growing speed of computer processors.

"It's about the smallest you can get," Novoselov told Wired Science. "From the point of view of physics, graphene is a goldmine. You can study it for ages."

Super-Dense Data Storage

Researchers around the world have already put graphene to work. A Rice University team In 2008 created a new type of graphene-based, flash-like storage memory, more dense and less lossy than any existing storage technology. Two University of South Florida researchers earlier this year reported techniques to enhance and direct its conductivity by creating wire-like defects to send current flowing through graphene strips.

Energy Storage

The energy applications of graphene are also extraordinarily rich. Texas's Graphene Energy is using the film to create new ultracapacitators to store and transmit electrical power. Companies currently using carbon nanotubes to create wearable electronics — clothes that can power and charge electrical devices — are beginning to switch to graphene, which is thinner and potentially less expensive to produce. Much of the emerging research is devoted to devising more ways to produce graphene quickly, cheaply and in high quantities.

Optical Devices: Solar Cells and Flexible Touchscreens

A Cambridge University team argues in a paper in September's *Nature Photonics*that the true potential of graphene lies in its ability to conduct light as well as electricity. Strong, flexible, light-sensitive graphene could improve the efficiency of solar cells and LEDs, as well as aiding in the production of next-generation devices like flexible touch screens, photodetectors and ultrafast lasers. In particular, graphene could replace rare and expensive metals like platinum and indium, performing the same tasks with greater efficiency at a fraction of the cost.

High-Energy Particle Physics

In pure science, according to Geim, graphene "makes possible experiments with high-speed quantum particles that researchers at CERN near Geneva, Switzerland, can only dream of." Because graphene is effectively only two-dimensional, electrons can move through its lattice structure with virtually no resistance. In fact, they behave like Heisenberg's relative particles, with an effective resting mass of zero.

It's slightly more complicated than this, but here's a quick and dirty explanation. To have mass in the traditional sense, objects need to have volume; electrons squeezed through two-dimensional graphene have neither. In other words, the same properties that makes graphene such an efficient medium for storing and transmitting energy also demonstrate something fundamental about the nature of the subatomic universe.

In 2008, Geim and Novoselov handily won a Wired Science poll of that year's Nobel Prize candidates. In 2010, Wired.com's graphene fans finally got their wish.

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Tags: carbon, graphene, nanotech, nobel prize, science
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Comments (15)

Posted by: Shreenath | 10/5/10 | 9:59 pm |

Great article and extremely well laid out for the casual wired reader with the bite sized information and lead in. Thanks!

Posted by: sixwings | 10/5/10 | 10:52 pm |

Nice article except for this bit: "To have mass in the traditional sense, objects need to have volume." This is BS, of course. There is no law in physics that says that mass requires volume. And what is "mass in the traditional sense"? Mass is the property of a particle that causes it to resist changes in its rest or movement, as Newton proposed century ago. It has nothing to do with volume.

Posted by: Mujokan | 10/5/10 | 11:06 pm |

Buy stock in Scotch Tape.

Posted by: gnurph69@hotmail.com | 10/5/10 | 11:32 pm |

Density is mass per unit volume. If you are correct, then the density of the substance you hypothesize would be zero – an impossibility, I think. To say that mass and volume having nothing to do with each other is incorrect, or density as a property would not exist.

Posted by: sixwings | 10/5/10 | 11:39 pm |

Certainly, mass density is proportional to mass and inversely proportional to volume. However, reducing the volume of an object does not change its mass as the article seems to imply.

By the way, density is not restricted to mass. One can also speak of charge density.

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Posted by: vexatious | 10/5/10 | 11:41 pm |

I agree with sixwings. All of the leptons (electrons included) are seen as point like (no volume). They still have mass. String theory may confound this a little, but in the “traditional sense,” this isn’t true.

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Posted by: Anonymous | 10/6/10 | 1:13 am |

In addition to more efficient solar electricity graphine would help make the next generation of wind blades for 20 MW wind turbines at a cost less than coal. You can kiss the dirty and dangerous fossil fuel economy goodbye.

Posted by: Anonymous | 10/6/10 | 1:15 am |

In addition to more efficient solar graphene will enable much bigger wind blades for 20 MW wind turbines that will make electricity less expensively than coal. Kiss dirty and dangerous fossil fuels goodbye!

Posted by: Tim Carmody | 10/6/10 | 1:39 am |

I will definitely agree that this is not exactly the best way to explain what’s happening here. I tried to hang a lantern on its insufficiencies by calling it a “quick and dirty” explanation. I wrote about two paragraphs just trying to give sufficient background on quantum physics, and it did not work at all. Every time I rewrote it, it was more and more abstract. It doesn’t help that this is still emerging research.

The biggest issue is that electrons moving through graphene act as if they have no mass. It’s not that they don’t have mass, but they exist in a very particular kind of quantum configuration that gives them an effective mass of zero. In order to even visualize these configurations, you need to work with high levels of magnetism at extremely low temperatures.

Here's a pretty good write-up of some of the quantum implications of graphene. Choice bits:

Measuring and understanding how electrons carry current through the sheet is important to realizing its technological promise in wide-ranging applications, including high speed electronics and sensors. For example, the electrons in graphene act as if they have no mass and are almost 100 times more mobile than in silicon. Moreover, the speed with which electrons move through graphene is not related to their energy, unlike materials such as silicon where more voltage must be applied to increase their speed, which creates heat that is detrimental to most applications…

Because of the geometry and electromagnetic properties of graphene's structure, an electron in any given energy level populates four possible sublevels, called a "quartet." Theorists have predicted that this quartet of levels would split into different energies when immersed in a magnetic field, but until recently there had not been an instrument sensitive enough to resolve these differences.

What is happening, according to Stroscio, appears to be a "many-body effect" in which electrons interact strongly with one another in ways that affect their energy levels.

One possible explanation for this behavior is that the electrons have formed a "condensate" in which they cease moving independently of one another and act as a single coordinated unit.

Posted by: China Electronics Wholesale | 10/6/10 | 2:25 am |

dirty and dangerous fossil fuels goodbye!

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Posted by: Anonymous | 10/6/10 | 5:59 am |

wrong wrong wrong wrong wrong
The number of dimensions has nothing to do with the effective mass–scientists have been working with 2-dimensional electron gases (2DEGs) in the inversion layers of semiconductor heterostructures for decades, and in those structures the electrons have a non-zero effective mass. Graphene's zero effective mass is just a fancy way of saying that the band structure is linear instead of parabolic near the charge neutrality point. It falls out of a simple calculation based only on the hexagonal crystal structure.

Also the zero-mass thing is far from emerging, people did the calculations for graphite layers in the sixties, they just didn't know that single layers could be isolated and measured.

Posted by: Tim Carmody | 10/7/10 | 12:05 am |

Then I have fallen victim to my misreading of the scientific literature (and particularly scholars presenting the idea that the zero-mass thing had something to do with the quantum state of the lattice). Let me try to back this up and present a better explanation.
