

Graphene

©2012 by David A. Katz. All rights reserved.

Carbon occurs in a number of allotropic forms, coal, graphite, diamond, Buckminsterfullerene, carbon nanotubes, and graphene.

Coal is formed from organic matter that has decayed and been compressed under great pressure. It is an amorphous form of carbon that has no definite crystal structure.

Graphite consists of layers of carbon atoms in a hexagonal arrangement. There are only weak bonds between layers, allowing the layers to slide over one another. Graphite is used in the “lead” of lead pencils, as a dry lubricant, and in electroplating of substances.

Diamond has a framework structure where each carbon atom is bonded to 4 other carbons in a three-dimensional structure. Diamond is the

hardest naturally occurring mineral found in nature. Used for drills, cutting wheels, and polishing of many substances, as well as for jewelry.

Buckminsterfullerene, consisting of 60 carbon atoms in a spherical shape similar to a soccer ball, is formed by electrically evaporating graphite in an atmosphere of He gas. Note that the structure consists of both 5 and 6 member carbon rings. Because the shape is similar to that

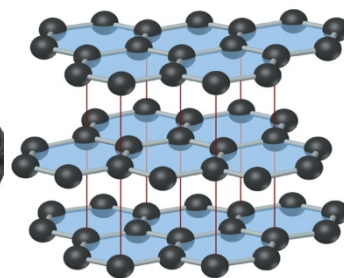
of a geodesic dome invented by R. Buckminster Fuller, it was named buckminsterfullerene or “Bucky Ball” for short. Fullerenes have been prepared with as few as 20 carbon atoms and more than 80 atoms. Applications include superconductors, along with compounds with interesting electrical, magnetic, and optical properties.

Carbon nanotubes, discovered in 1952, and again noted in subsequent years, were overlooked until about 1991. Carbon nanotubes are essentially a single sheet of graphite rolled into a seamless tube

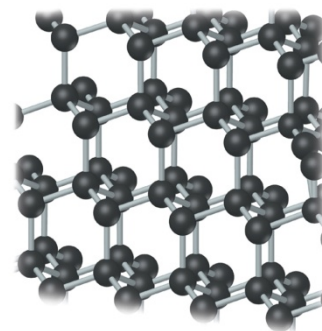
approximately 1 nm in diameter. They have very high strength and high electrical and heat conductivity. (Multi-wall carbon nanotubes have been synthesized.) Uses include wires or structural elements, special



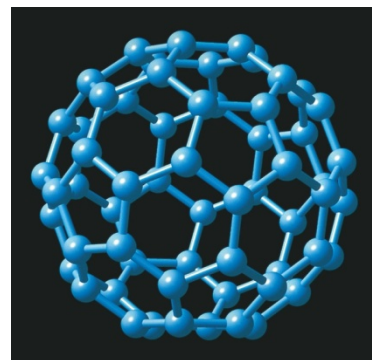
Coal



Graphite



Diamond

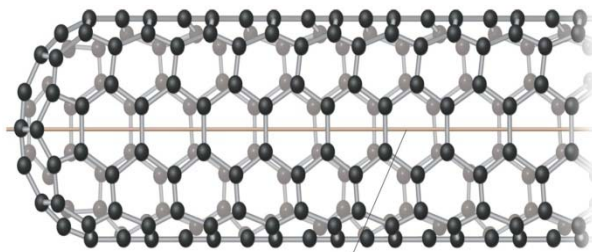


Buckminsterfullerene

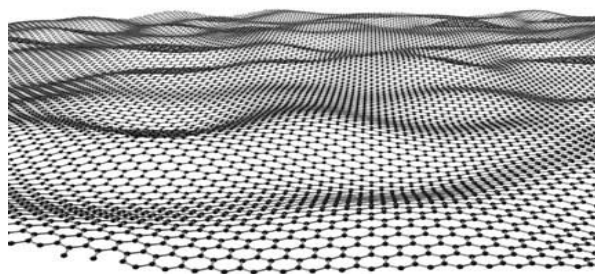
conductors, transistors, computer memory elements, nanoscale motors, and medical delivery systems.

Graphene is a single planar sheet of carbon atoms that are densely packed in a honeycomb crystal lattice. Graphene is the basic structural element for all other graphitic materials including graphite, carbon nanotubes and fullerenes. Made by high temperature reduction of SiC and also by microelectronic methods, it was made in 2004 when physicists from the University of Manchester and the Institute for Microelectronics Technology, Chernogolovka, Russia, found a way to isolate graphene by peeling it off from graphite with Scotch tape and optically identified it by transferring it to a silicon dioxide layer on Si.

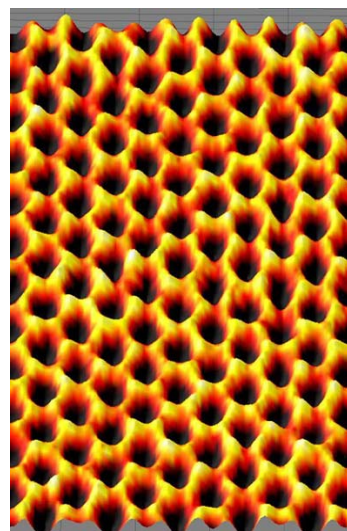
Graphene's high electrical conductivity and high optical transparency make it a candidate for transparent conducting electrodes, required for such applications as touchscreens, liquid crystal displays, organic photovoltaic cells, and Organic light-emitting diodes.



Carbon nanotube



Graphene



An atomic force microscope image of graphene

Materials Needed:

- Graphite
- Scotch tape
- White index cards
- Pencil
- Conductivity tester
- Silicon wafers (Look for silicon wafers on eBay for the best price. Used silicon wafers will work for this procedure.) Note: The silicon wafer should be clean and free of organic matter. To clean the silicon wafers, heat in warm acetone, on a hot plate, for several minutes.
- Plastic forceps
- Microscope (polarizing preferred)
- Light for illuminating sample on microscope



Safety Precautions

Wear goggles for this procedure.

Wear gloves for this procedure. Do not handle silicon wafers with your bare hands.

Procedure:

Using a pencil, draw a dark rectangle, approximately 3 cm x 1 cm on a white index card. Make sure it is uniformly black.

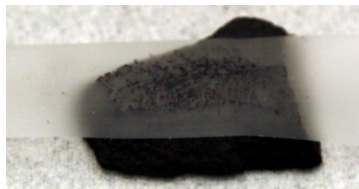
Rub your finger over the dark rectangle. Record your observations.

Test the dark rectangle for conductivity. (Press the electrodes of the conductivity device against the dark rectangle.)



Obtain a sample of graphite. Test the graphite for conductivity.

Take a piece of scotch tape about 4 inches long (10 cm). Fold over about ¼ inch of each end of the tape to make “handles” for holding the tape.



Place approximately half of the tape onto the graphite sample.



Smooth the tape with your finger or your forceps. Slowly, lift the tape from the graphite.



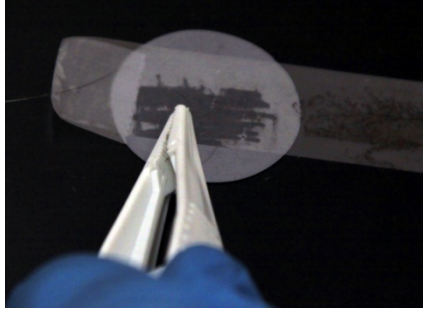
Fold the tape in half, sticky sides together, then slowly peel it apart.



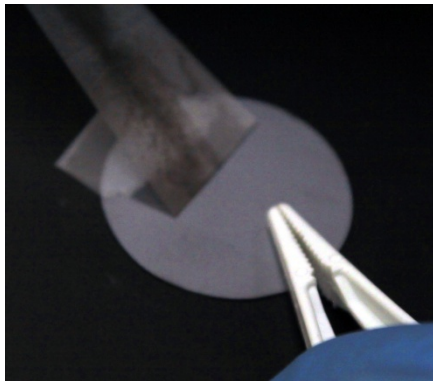
Fold the tape in half over the graphite area again and peel it apart again. Do this several more times.



Place the tape with the last graphite layer onto a silicon disk. Take care as the silicon wafers are fragile and break easily.



Gently rub the tape with your forceps for about 10 minutes to transfer the graphite/graphene to the silicon wafer. **Do not press hard.**



Using your forceps to hold the silicon wafer in place, **SLOWLY** peel off the tape. This may take about one minute. Do not pull hard as it will cause the silicon wafer to break.

If you have been successful, there will be thin layers of graphite/graphene on the surface of the silicon wafer.

To observe the graphite/graphene, use the forceps to place the silicon wafer on a microscope stage. Illuminate the wafer from above. Focus using the 10x objective. The graphite/graphene material may look like red or pink spots on the silicon surface.

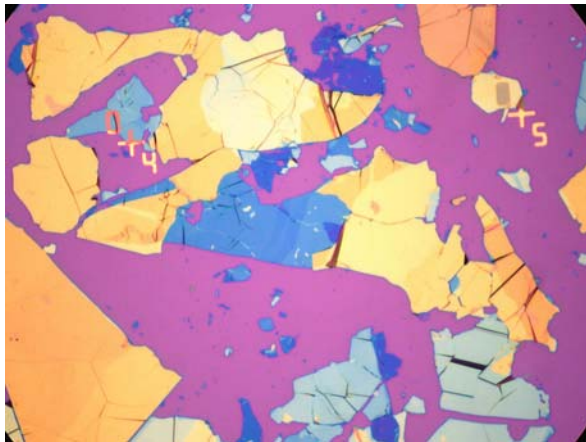
Once you have located the graphite/graphene debris, rotate the 40x objective into place. Focus using the fine focusing knob only. If your microscope is equipped with a 50x, 60x, or 75x objective, you can try to use them to view the graphite/graphene. **Note:** The stronger the objective, the closer it will be to the silicon wafer surface and less light will be available to illuminate sample. **DO NOT USE** a 100x objective, this is an oil immersion objective and will not work in this experiment.

Explanation:

You have made some very thin layers of graphite—and maybe even some graphene. The graphite sample you started with was most likely foliated or layered, that is, it consists of many layers of graphene stacked on top of each other. Since the layers are only loosely bonded together, they can slide over one another making the surface feel slippery. Loosely held electrons are responsible for the conductivity of the graphite.

The “lead” in a pencil is made of graphite mixed with a mineral clay and baked into a rod. Pencil leads composed of graphite will conduct electricity. The dark layer you made on a piece of paper should be continuous enough to show conductivity. Any graphene you made, although it is conductive, is most likely not continuous enough to demonstrate conductivity with our measuring device.

Below are two photographs from an article in **Scientific American** by JR Minkel titled *D.I.Y. Graphene: How to Make One-Atom-Thick Carbon Layers With Sticky Tape*, March 20, 2008 | 11. This photo shows graphite debris that can be produced from this procedure.



If you were lucky, you may have obtained graphene: highly transparent, crystalline shapes with little color compared with the material on the rest of the wafer. That steplike pattern, in the photograph below, is a pile of graphene sheets layered on top of one another.

