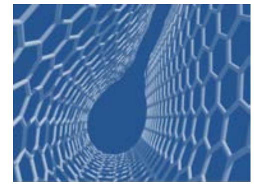
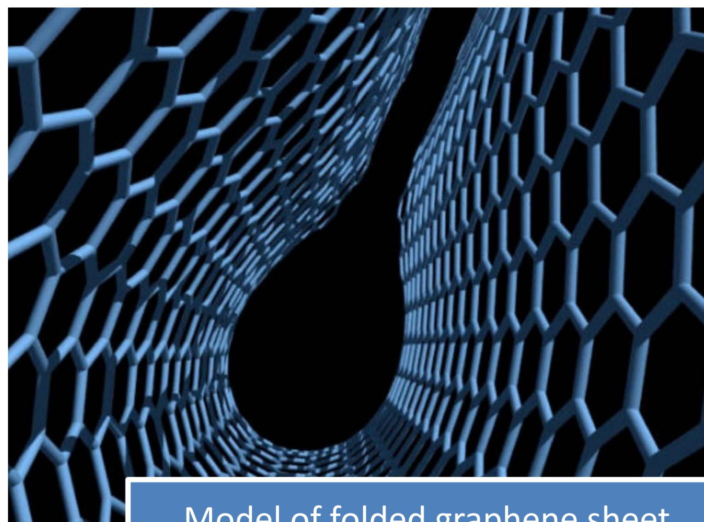
The Power of Graphene



Provided by TryEngineering - www.tryengineering.org

Lesson Focus
Lesson focuses on graphene and its electrical properties and applications. Students learn about nanotechnology and how engineers can harness the differences in how materials behave when small to address challenges in many industries. Students work in teams to hypothesize and then test whether graphene is an electrical conductor or insulator. They build a simple circuit using everyday items, and create a graphene sample using soft pencils on paper. They observe what they see, extrapolate to broader applications, present their ideas to the class, and reflect on the experience.

Lesson Synopsis
The "Power of Graphene" lesson explores graphene and its electrical properties and applications at the nano scale. Students work in teams to test graphene using a simple circuit set up and consider how this remarkable material is impacting many industries. Teams evaluate their test results, develop new theoretical applications for graphene, present their ideas to the class, and reflect on the experience.



Model of folded graphene sheet.
(Image Credit: Slava Rotkin and Yury Gogotsi, Drexel University)

Age Levels
8-18.

Objectives

- Learn about nanotechnology.
- Learn about graphene.
- Learn about circuits, insulators, and conductors.
- Learn how engineering can help solve society's challenges.
- Learn about teamwork and problem solving.

Anticipated Learner Outcomes
As a result of this activity, students should develop an understanding of:

- nanotechnology
- graphene
- circuits, insulators, and conductors
- teamwork

Lesson Activities

Students explore nanotechnology and the material graphene in terms of its ability to conduct electricity and its impact on many industries and products. Students test graphene to see if it will be an insulator or conductor in a simple circuit, and develop hypothetical applications for graphene that would revolutionize a product or system. Teams present their ideas to the class and reflect on the experience.

Resources/Materials

- Teacher Resource Documents (attached)
- Student Resource Sheet (attached)
- Student Worksheet (attached)

Alignment to Curriculum Frameworks

See curriculum alignment sheet at end of lesson.

Internet Connections

- TryEngineering (www.tryengineering.org)
- TryNano (www.trynano.org)
- National Science Education Standards (www.nsta.org/publications/nses.aspx)
- ITEA Standards for Technological Literacy (www.iteaconnect.org/TAA)

Recommended Reading

- Nanotechnology For Dummies (ISBN: 978-0470891919)
- Science at the Nanoscale: An Introductory Textbook (ISBN: 978-9814241038)
- Nanotechnology: Business Applications and Commercialization (ISBN: 978-1439845219)

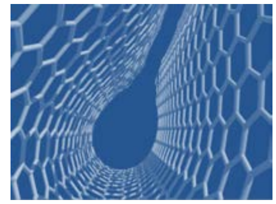
Optional Writing Activity

- Write an essay or a paragraph about how advances in nanotechnology have changed the field of electronics or medicine.

Safety Notice

- Students should NEVER attempt to run electric current through a pencil as this can cause the wood to catch on fire; this activity should be supervised by teachers at all times. Students should wear insulating gloves when handling the connector clips, and attach the battery last.

The Power of Graphene



For Teachers:
Teacher Resources

◆ Lesson Goal

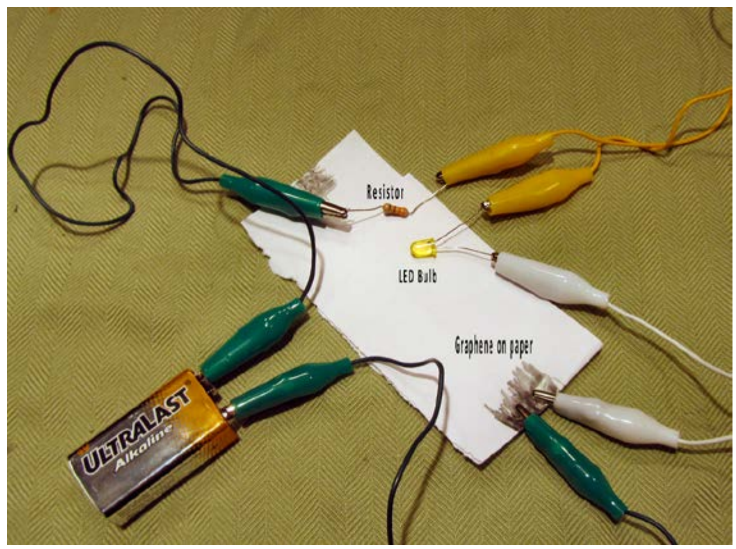
The "Power of Graphene" lesson explores graphene and its electrical properties and applications at the nano scale. Students work in teams to test graphene using a simple circuit set up and consider how this remarkable material is impacting many industries. Teams evaluate their test results, develop new theoretical applications for graphene, present their ideas to the class, and reflect on the experience.

◆ Lesson Objectives

- Learn about nanotechnology.
- Learn about graphene.
- Learn about circuits, insulators, and conductors.
- Learn how engineering can help solve society's challenges.
- Learn about teamwork and problem solving.

◆ Materials

- Student Resource Sheets
- Student Worksheets
- Student Team Materials: pencils, paper, LED light, 330 Ohm resistor (to prevent the LED light from burning out), insulated connectors, 9 volt battery.

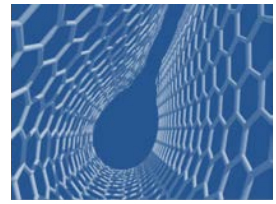


◆ Procedure

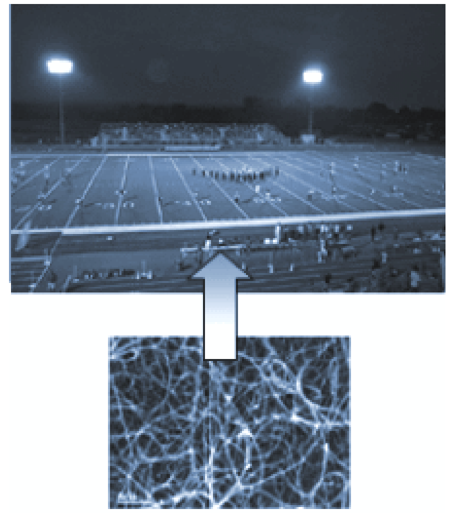
1. Show students the student reference sheets. These may be read in class or provided as reading material for the prior night's homework.
2. To introduce the lesson, consider asking the students what they know about insulators and conductors and whether they think graphene would behave in either way.
3. If internet access is available, have students review the resources at www.trynano.org. The site will provide additional background information about nanotechnology and the industries where it is having great impact.
4. Teams of 3-4 students will consider their challenge, and as a team theorize whether they think graphene would conduct or insulate electric current.
5. Teams next build a working circuit using an LED light, battery, and resistor, and then test graphene (and other materials if you would like to extend the activity) on a piece of paper to see if it completes the circuit.
6. Teams observe what happened, compare their hypotheses to the actual results, complete a reflection sheet, and present their experiences to the class.

◆ Time Needed

One to two 45 minute sessions.



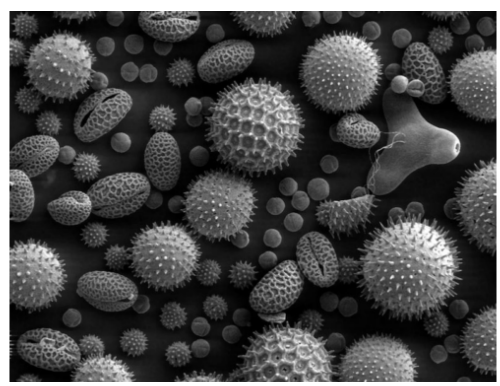
Student Resource:
What is Nanotechnology?



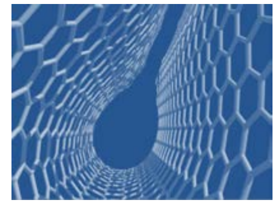
Four grams of carbon nanotubes has the same surface area of a football field.

Imagine being able to observe the motion of a red blood cell as it moves through your vein. What would it be like to observe the sodium and chlorine atoms as they get close enough to actually transfer electrons and form a salt crystal or observe the vibration of molecules as the temperature rises in a pan of water? Because of tools or 'scopes' that have been developed and improved over the last few decades we can now observe at a very small scale. This ability to observe, measure and even manipulate materials at the molecular or atomic scale is called nanotechnology or nanoscience. If we have a nano "something" we have one billionth of that something. Scientists and engineers apply the nano prefix to many "somethings" including meters (length), seconds (time), liters (volume) and grams (mass) to represent what is understandably a very small quantity. Most often nano is applied to the length scale and we measure and talk about nanometers (nm). Individual atoms are smaller than 1 nm in diameter, with it taking about 10 hydrogen atoms in a row to create a line 1 nm in length. Other atoms are larger than hydrogen but still have diameters less than a nanometer. A typical virus is about 100 nm in diameter and a bacterium is about 1000 nm head to tail. The tools or new "scopes" that have allowed us to observe the previously invisible world of the nanoscale are the Atomic Force Microscope and the Scanning Electron Microscope.

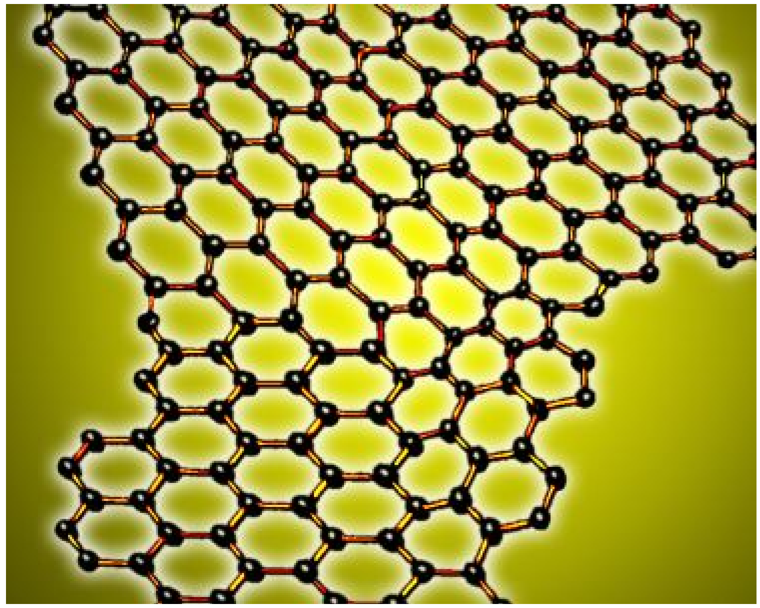
◆ **Scanning Electron Microscope**



The scanning electron microscope is a special type of electron microscope that creates images of a sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. In a raster scan, an image is cut up into a sequence of (usually horizontal) strips known as "scan lines." The electrons interact with the atoms that make up the sample and produce signals that provide data about the surface's shape, composition, and even whether it can conduct electricity. The image to the right is Pollen from a variety of common plants, magnified about 500 times. It was taken with a scanning electron microscope at the Dartmouth Electron Microscope Facility at Dartmouth College in New Hampshire, US. Other images are at www.dartmouth.edu/~emlab/gallery.



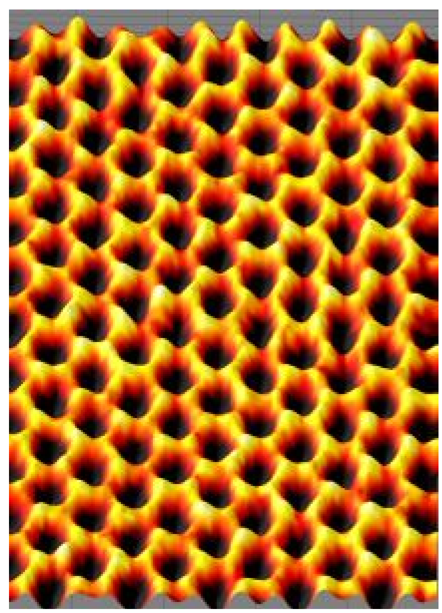
Student Worksheet: What is Graphene?



Graphene is a two dimensional crystal consisting of a single layer of carbon atoms arranged hexagonally. (Image Source: Lawrence Berkley National Lab)

Graphene is a one atom thick, two dimensional material which consists of carbon atoms densely packed into a honeycomb-like crystal lattice.

This is known as a single layer graphene. Bi-layer and multi-layer graphenes have also been synthesized in the laboratory. Graphene exhibits very interesting electrical, optical, mechanical, thermal and other properties. Electrically, it is a semimetal or a semiconductor with zero bandgap. Graphene shows a very low resistivity, for example, only 10-6Wcm at room temperature. A single later graphene film is highly opaque, it absorbs only 2% of the white light. The mechanical properties are exceptional.



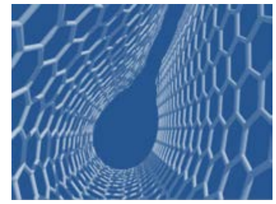
This image of a single suspended sheet of graphene taken with Transmission Electron Aberration-corrected Microscope shows individual carbon atoms (yellow) on the honeycomb lattice. *(Image Source: Lawrence Berkley National Lab)*

The interesting properties of graphene have led to an explosion of research recently in their synthesis, characterization of their properties, and development of applications. Promising applications include electronic devices, transparent electrodes for solar cells and plasma displays, composites, energy storage devices, and chemical and biological sensors.

Currently researchers are able to produce graphene by reducing graphene oxide. This chemical synthesis approach can now yield gram quantities of the material. It is also possible to deposit single layer of graphene on a silicon wafer. A technique called chemical vapor deposition allows growth of single or multilayer graphene at 900-1000º C.

◆ Nobel Prize for Graphene Research

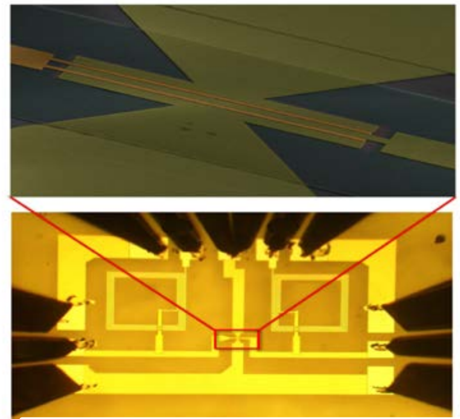
Two researchers recently received the Nobel Prize in physics for their work on graphene! In 2010 Andre Geim and Konstantin Novoselov jointly shared the award "for groundbreaking experiments regarding the two-dimensional material graphene." The researchers, along with several collaborators, were the first to isolate the layers of carbon from the material graphite, which is used in pencil "lead."



Student Worksheet: Graphene Applications

Graphene Circuits

Graphene has the ideal properties to be an excellent component of integrated circuits. In 2011, IBM researchers announced that they had succeeded in creating the first graphene-based integrated circuit, a broadband radio mixer. Designed for wireless communications, this graphene-based analog integrated circuit could improve today's wireless devices. This is because graphene is the thinnest electronic material -- consisting of a single layer of carbon atoms packed in a honeycomb structure -- and it possesses outstanding electrical, optical, mechanical and thermal properties that when used as a circuit could be less expensive and use less energy inside portable electronics like smart phones.*



Optical image of a completed graphene integrated circuit (IC) including contact pads.
Photo Credit: IBM

Potential Applications

Graphene is stronger than diamond, but also lightweight and flexible, and it enables electrons to flow much faster than silicon. So its applications will impact most industries. Many researchers around the globe are exploring potential applications for graphene. For example, research suggests that graphene filters could outperform other techniques of desalination by a significant margin. And, graphene may help improve solar power too! Graphene/polymer sheets have been produced that can be used to create dense arrays of flexible organic photovoltaic cells. It may eventually be possible to run printing presses laying extensive areas covered with inexpensive solar cells, much like newspaper presses print newspapers.

The Chinese Academy of Sciences recently found that sheets of graphene oxide are highly effective at killing bacteria such as Escherichia coli. This means graphene could potentially be useful in applications such as hygiene products or in packaging that will help keep food fresh for longer periods of time.

Graphene's high electrical conductivity and high optical transparency also 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 (LEDs). There will be few industries not impacted by graphene in the next decade. It may serve as an alternative to batteries, help generate strong yet lightweight car parts which can save on fuel consumption, and will have broad impacts on electronics and communications devices.

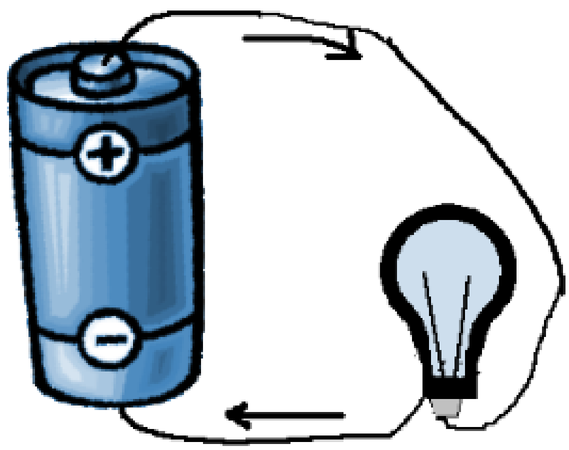
(*Source of some content in this paragraph provided by IBM)

Student Resource: What is a Simple Circuit?

◆ Simple Circuit

A simple circuit consists of three minimum elements that are required to complete a functioning electric circuit: a source of electricity (battery), a path or conductor on which electricity flows (wire) and an electrical resistor (lamp) which is any device that requires electricity to operate. The illustration below shows a simple circuit containing, one battery, two wires, and a bulb. The flow of electricity is from the high potential (+) terminal of the battery through the bulb (lighting it up), and back to the negative (-) terminal, in a continual flow.

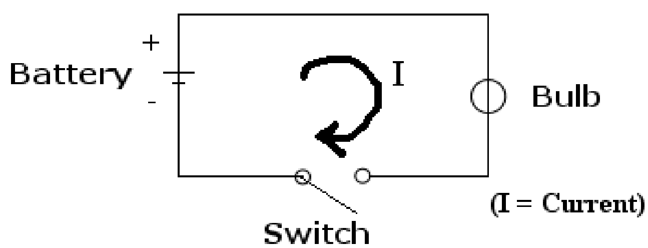
Simple Circuit



◆ Schematic Diagram of a Simple Circuit

The following is a schematic diagram of the simple circuit showing the electronic symbols for the battery, switch, and bulb.

Schematic Diagram of a Simple Circuit



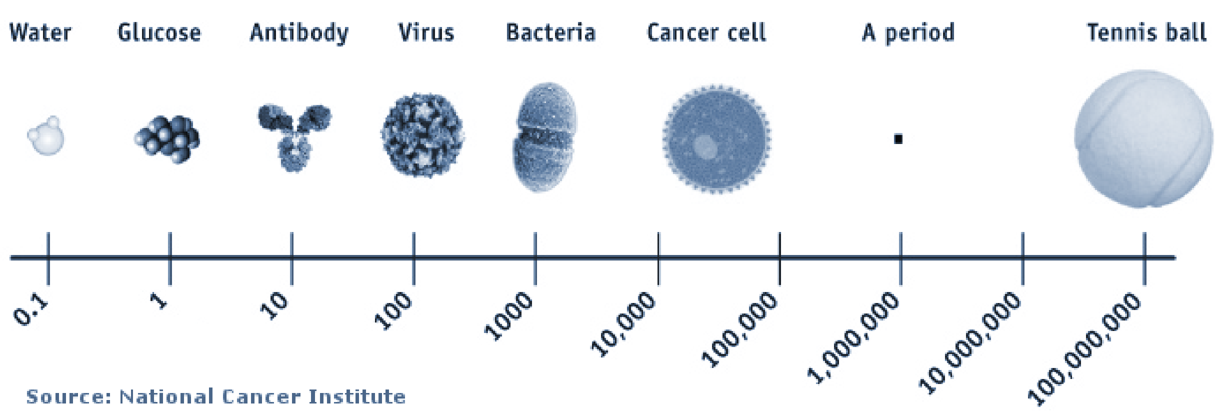
The Power of Graphene

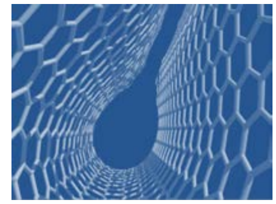
Student Resource: How Big is Small?

It can be hard to visualize how small things are at the nanoscale. The following exercise can help you visualize how big small can be!

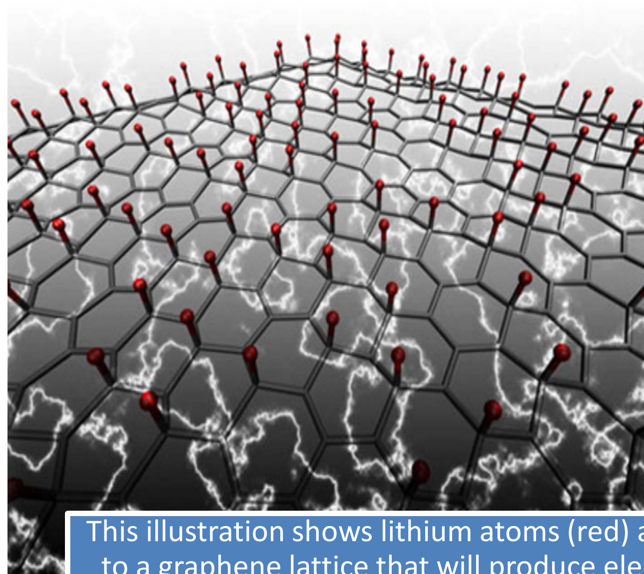
The following are drawings of items you may recognize…. a bowling ball, a billiard ball, a tennis ball, a golf ball, a marble, and a pea. Think about the relative size of these items.

Now take a look at the chart below that was developed by the National Cancer Institute (U.S.) and think about how much smaller the various items are…moving down from the familiar tennis ball. The "." on this page is 1,000,000 microns -- quite gigantic compared to a virus or a single molecule of water (H_20).





Student Worksheet: Graphene Research Press Release



This illustration shows lithium atoms (red) adhered to a graphene lattice that will produce electricity when bent, squeezed or twisted. Conversely, the graphene will deform when an electric field is applied, opening new possibilities in nanotechnology.
Photo Credit: Mitchell Ong / Stanford School of Engineering

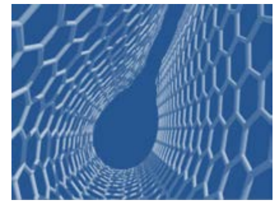
To the long list of exceptional physical properties of graphene, Stanford University engineers have added yet another: piezoelectricity, the property of some materials to produce an electric charge when bent, squeezed or twisted.

In what became known as the "Scotch tape technique," researchers first extracted graphene with a piece of adhesive in 2004. Graphene is a single layer of carbon atoms arranged in a honeycomb, hexagonal pattern. Under a microscope, it looks like chicken wire. In 2010, the researchers who first isolated it shared the Nobel Prize.

Graphene is a wonder material. It is a hundred times better at conducting electricity than silicon. It is stronger than diamond. And, at just one atom thick, it is so thin as to be essentially a two-dimensional material. Such promising physics have made graphene the most studied substance of the last decade, particularly in nanotechnology.

Yet, while graphene is many things, it is not piezoelectric. Perhaps most valuably, piezoelectricity is reversible. When an electric field is applied, piezoelectric materials change shape, yielding a remarkable level of engineering control. Piezoelectrics have found application in countless devices from watches, radios and ultrasound to the push-button starters on propane grills, but these uses all require relatively large, three-dimensional quantities of piezoelectric materials. The Stanford team's engineered graphene has, for the first time, extended such fine physical control to the nanoscale.

Using a sophisticated modeling application running on high-performance supercomputers, the engineers simulated the deposition of atoms on one side of a graphene lattice – a process known as doping – and measured the piezoelectric effect. They modeled graphene doped with lithium, hydrogen, potassium and fluorine, as well as combinations of hydrogen and fluorine and lithium and fluorine, on either side of the lattice. Doping just one side of the graphene, or doping both sides with different atoms, is key to the process as it breaks graphene's perfect physical symmetry, which otherwise cancels the piezoelectric effect. While the results in creating piezoelectric graphene are encouraging, the researchers believe that their technique might further be used to engineer piezoelectricity in nanotubes and other nanomaterials with applications ranging from electronics, photonics and energy harvesting to chemical sensing and high-frequency acoustics.
(Source: 2012 Press Release, Stanford University)

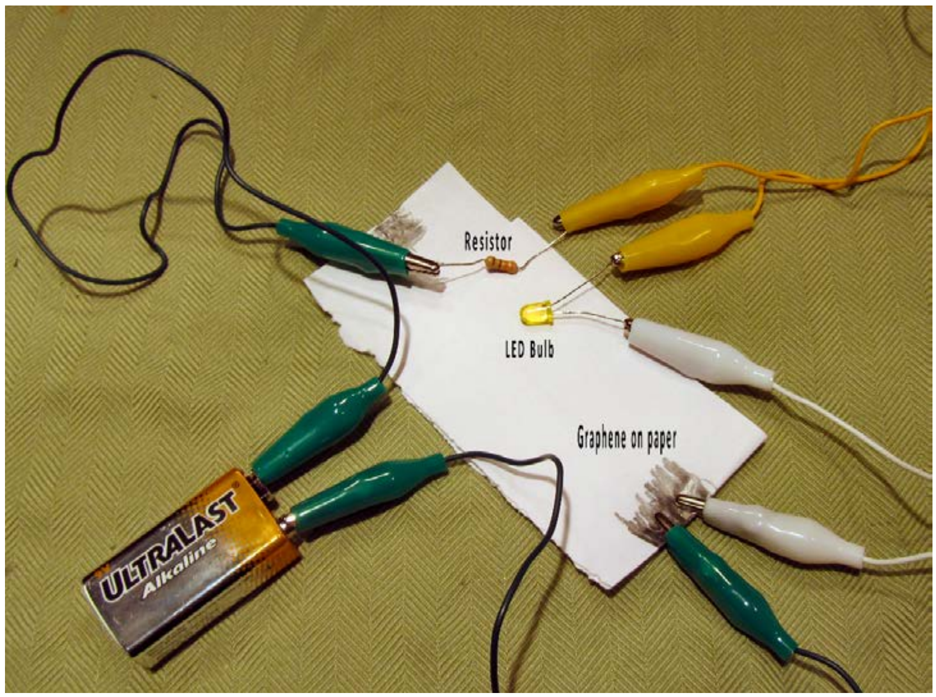


Student Worksheet:
Surface Area Challenge

◆ Research Phase
Read the materials provided to you by your teacher. If you have access to the internet, also explore resources at www.trynano.org to learn more about nanotechnology and graphene.

◆ Hypothesis
As a team, decide whether you think graphene (in ordinary pencil "lead") would be an electrical conductor or an insulator. Write a supporting paragraph for your hypothesis on the other side of this paper.

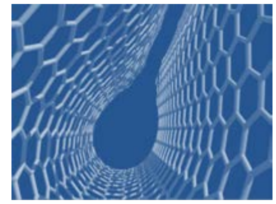
◆ Test
Now, test your hypothesis! Set up a simple circuit using connectors, an LED bulb, a battery, and other materials provided by your teacher. You'll create a working circuit first -- see if you can light the bulb! Then, adjust your circuit so that the current must flow through a paper that you have rubbed lots of pencil onto. (Do NOT attach the connectors to pencil lead that is still in a pencil.) If you like, you can test other items provided by your teacher to see if they are conductors or insulators.



◆ Observation and Results
Observe and discuss what happened -- if anything -- and compare the results with your team's hypothesis.

◆ Application Development
Based on the result of your experiment, as a team brainstorm on how graphene might be used to revolutionize a product. Consider how lightweight and flexible the material is and prepare a brief presentation to your class about how graphene might either improve a product or allow the product to be made smaller.

◆ Presentation and Reflection Phase
Present your original hypothesis and experiment observations to the class along with your team's product application. Listen to the presentations of the other teams and then complete the reflection sheet.



Student Worksheet:

◆ Reflection

Complete the reflection questions below:

1. How accurate was your hypothesis compared to what happened?

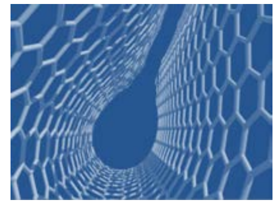
2. What surprised you about what you saw?

3. What new application for graphene that was presented by a team in your classroom was the most interesting to you? Why?

4. Do you think that engineers have to keep track of what is happening in research in order to improve on existing products or methods?

5. When a product is improved based on new research or materials, who do you think should be credited or compensated for the enhanced product?

6. Did you think that working as a team made this project easier or harder? Why?



For Teachers:
Alignment to Curriculum Frameworks

Note: Lesson plans in this series are aligned to one or more of the following sets of standards:

- U.S. Science Education Standards (http://www.nap.edu/catalog.php?record_id=4962)
- U.S. Next Generation Science Standards (http://www.nextgenscience.org/)
- International Technology Education Association's Standards for Technological Literacy (http://www.iteea.org/TAA/PDFs/xstnd.pdf)
- U.S. National Council of Teachers of Mathematics' Principles and Standards for School Mathematics (http://www.nctm.org/standards/content.aspx?id=16909)
- U.S. Common Core State Standards for Mathematics (http://www.corestandards.org/Math)
- Computer Science Teachers Association K-12 Computer Science Standards (http://csta.acm.org/Curriculum/sub/K12Standards.html)

◆National Science Education Standards Grades K-4 (ages 4-9)

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop

- ✦ Abilities necessary to do scientific inquiry
- ✦ Understanding about scientific inquiry

CONTENT STANDARD B: Physical Science

As a result of the activities, all students should develop an understanding of

- ✦ Properties of objects and materials

CONTENT STANDARD E: Science and Technology

As a result of activities, all students should develop

- ✦ Understanding about science and technology

CONTENT STANDARD F: Science in Personal and Social Perspectives

As a result of activities, all students should develop understanding of

- ✦ Science and technology in local challenges

CONTENT STANDARD G: History and Nature of Science

As a result of activities, all students should develop understanding of

- ✦ Science as a human endeavor

◆National Science Education Standards Grades 5-8 (ages 10-14)

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop

- ✦ Abilities necessary to do scientific inquiry
- ✦ Understandings about scientific inquiry

CONTENT STANDARD B: Physical Science

As a result of their activities, all students should develop an understanding of

- ✦ Properties and changes of properties in matter

CONTENT STANDARD E: Science and Technology

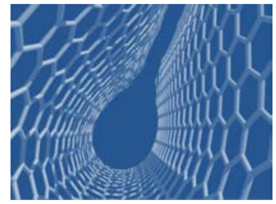
As a result of activities in grades 5-8, all students should develop

- ✦ Understandings about science and technology

CONTENT STANDARD F: Science in Personal and Social Perspectives

As a result of activities, all students should develop understanding of

- ✦ Personal health
- ✦ Risks and benefits
- ✦ Science and technology in society



For Teachers:
Alignment to Curriculum Frameworks (cont.)

◆National Science Education Standards Grades 5-8 (ages 10-14)

CONTENT STANDARD G: History and Nature of Science

As a result of activities, all students should develop understanding of

- Science as a human endeavor
- Nature of science
- History of science

◆National Science Education Standards Grades 9-12 (ages 14-18)

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

CONTENT STANDARD B: Physical Science

As a result of their activities, all students should develop understanding of

- Structure and properties of matter

CONTENT STANDARD E: Science and Technology

As a result of activities, all students should develop

- Understandings about science and technology

CONTENT STANDARD F: Science in Personal and Social Perspectives

As a result of activities, all students should develop understanding of

- Science and technology in local, national, and global challenges

CONTENT STANDARD G: History and Nature of Science

As a result of activities, all students should develop understanding of

- Science as a human endeavor
- Nature of scientific knowledge
- Historical perspectives

◆Next Generation Science Standards Grades 2-5 (Ages 7-11)

Matter and its Interactions

Students who demonstrate understanding can:

- 2-PS1-2. Analyze data obtained from testing different materials to determine which materials have the properties that are best suited for an intended purpose.
- 5-PS1-1. Develop a model to describe that matter is made of particles too small to be seen.
- 5-PS1-3. Make observations and measurements to identify materials based on their properties.

Engineering Design

Students who demonstrate understanding can:

- 3-5-ETS1-2.Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
- 3-5-ETS1-3.Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

For Teachers:
Alignment to Curriculum Frameworks (cont.)

◆**Standards for Technological Literacy - All Ages**

The Nature of Technology

- Standard 1: Students will develop an understanding of the characteristics and scope of technology.
- Standard 2: Students will develop an understanding of the core concepts of technology.
- Standard 3: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

Technology and Society

- Standard 5: Students will develop an understanding of the effects of technology on the environment.
- Standard 6: Students will develop an understanding of the role of society in the development and use of technology.

Design

- Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

Abilities for a Technological World

- Standard 13: Students will develop abilities to assess the impact of products and systems.