Balloon Nanotubes

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General Description

Visitor participation activity/display

“Nanotube Balloons” is a large display made of balloons that can be used to draw visitors to a program on nanotechnology. Visitors observe how the carbon atoms are arranged in a carbon nanotube. The suspended nanotube balloon model can be pre-constructed by museum staff, or visitors can help to build it. The balloon structure provides an intriguing hook for other programs, like “Forms of Carbon” or the “World of Carbon Nanotubes”. In the tabletop version, visitors help build a model of a carbon nanotube---out of balloons!

There are two versions of this activity: a small tabletop model or a giant hanging model.

Program Objectives

Big idea: Carbon nanotubes are a form of carbon with an interesting structure and unique properties.

Learning goals:
As a result of participating in this program, visitors will learn that:
1. Carbon nanotubes are a form of carbon
2. Carbon nanotubes are nanoscale molecules with a hexagonal structure.

NISE Network Main Messages:
[ ] 1. Nanoscale effects occur in many places. Some are natural, everyday occurrences; others are the result of cutting-edge research.
[ ] 2. Many materials exhibit startling properties at the nanoscale.
[x] 3. Nanotechnology means working at small size scales, manipulating materials to exhibit new properties.
[ ] 4. Nanoscale research is a people story.
[ ] 5. No one knows what nanoscale research may discover, or how it may be applied.
[ ] 6. How will nano affect you?

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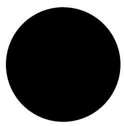
Time Required

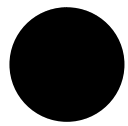
For giant activity

Set-up



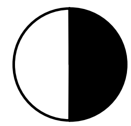
60 minutes

Program



60 minutes

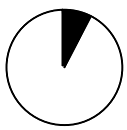
Clean Up



30 minutes

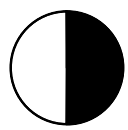
For tabletop activity

Set-up



5 minutes

Program



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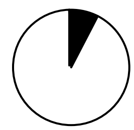
Clean Up



5 minutes

Background Information

Definition of terms

Nano is the scientific term meaning one-billionth (1/1,000,000,000). It comes from a Greek word meaning "dwarf."

A *nanometer* is one one-billionth of a meter. One inch equals 25.4 million nanometers. A sheet of paper is about 100,000 nanometers thick. A human hair measures roughly 50,000 to 100,000 nanometers across. Your fingernails grow one nanometer every second.

(Other units can also be divided by one billion. A single blink of an eye is about one-billionth of a year. An eyeblink is to a year what a nanometer is to a yardstick.)

Nanoscale refers to measurements of 1 – 100 nanometers. Some viruses are about 70 nm long. A cell membrane is about 9 nm thick. Ten hydrogen atoms strung together are about 1 nm long.

At the nanoscale, many common materials exhibit unusual properties, such as remarkably lower resistance to electricity, or faster chemical reactions.

Nanotechnology is the manipulation of material at the nanoscale to take advantage of these properties. This often means working with individual molecules.

Nanoscience, nanoengineering and other such terms refer to those activities applied to the nanoscale. “Nano,” by itself, is often used as short-hand to refer to any or all of these activities.

Program-specific background

Forms of Carbon

Carbon is found in all living things and is one of the most abundant elements on our planet.

- Carbon atoms can attach, or *bond*, to one another in several different ways to create different materials with varying properties.
- For example, diamond is one form of carbon. The graphite used in pencils is another.
- Carbon is also found in the spherical nanoscale forms called *fullerenes* (“buckyballs”) and *carbon nanotubes* (CNTs).
- Carbon is most stable when it has formed four bonds. Sometimes, to achieve this, it must form multiple bonds with another atom. If there are two bonds between a carbon atom and another atom, it is called a double bond. If there are three bonds between the two atoms, it is called a triple bond.
    - All of the bonds in diamond are single bonds.
    - Graphene sheets (that make up a CNT) contain a mix of single and double bonds.
    - Fullerenes, or “buckyballs”, contain a mix of single and double bonds.

Atomic Structure

The different arrangements of atoms in these four forms of carbon create materials with very different properties.

- In diamond, the hardest known natural material, each atom is tightly bonded to four other carbon atoms. This makes a tripod-like shape called a *tetrahedron*, which is very strong.
- In contrast, each carbon atom in graphite is strongly bonded to three carbon atoms in the same plane, but only weakly bonded to carbon atoms in other planes. The carbon atoms in each plane are arranged in hexagons, called *graphene sheets*. The weak bonding out of plane allows the sheets to slide easily past each other. Graphite can easily slide off a pencil and onto the paper because of the layered structure formed by these sheets of carbon atoms.
- Now, if you imagine taking one graphite sheet and rolling it up into a ball, you get a third form of carbon called a *fullerene*. Fullerenes are

nanometer-sized, soccer-ball-shaped molecules made of carbon atoms. They consist of hexagons and pentagons that form a sphere.
  - Fullerenes were named after the architect Buckminster Fuller, who designed the first geodomes. Spaceship Earth at Epcot Center in Disney World is a geodome you may recognize.
  - Some proposed applications of fullerenes include drug delivery tools, HIV inhibitors, and signal amplifiers for fiber optic communications.
- A fourth form of carbon is a *carbon nanotube*, or CNT, which looks like a single graphene sheet rolled into a cylinder.
  - If you roll the sheet up in different ways, you get different patterns around the circumference of the tube.
  - There are three different kinds of CNTs, which have different structures and, thus, different properties.
  - The three types of carbon nanotubes, determined by the orientation of the carbon hexagons, are called "armchair," "zig-zag," and "chiral."
  - CNTs can also be single-walled (SWNT), resembling a single graphene sheet rolled up, or multi-walled (MWNT), with several SWNTs nested inside each other.

Properties of CNTs

The structures of the nanotubes —armchair, zigzag, and chiral—determine their unique physical properties, such as:

- *Electrical conductivity*: One of the main things that distinguish CNTs from other nanomaterials is how they conduct electricity. They can act like semiconductors (some zigzag, chiral) or like metals (armchair, some zigzag), depending on their structure.
  - CNTs conduct electricity much more efficiently than copper nanowires because there is less scattering of electrons. In a copper nanowire, tens of thousands of electrons travel through the wire together. (Imagine many people rushing to get through a narrow door together—without lines to organize their movement.) The electrons travel in all three dimensions in the wire- moving forwards, sideways and even backwards. As they travel, the electrons "bang" into stationary atoms and get redirected, slowing them down because of the energy lost during the collisions (with the stationary atoms and with other electrons). This effect is called *scattering*. Scattering can generate a lot of heat and wastes energy. A carbon nanotube is hollow. Electrons can only travel in two dimensions in the graphene sheet. This limited pathway decreases the chance an electron has of "banging" into other atoms—therefore there is not as much scattering and loss of energy from the electron-atom collisions. Therefore, nanotubes do not generate as much heat and do not waste as much energy as conventional wires.

- *Mechanical properties (tensile strength)*: Based on small-scale experiments and some calculations, scientists predict a CNT rope 1 inch in length (~2.5 cm) may be up to 100 times stronger than steel but only 1/6 the mass.
- *Thermal conductivity:* CNTs conduct heat very well. Unlike metals, which conduct heat by moving electrons, CNTs conduct heat by wiggling the bonds between the carbon atoms themselves. Scientists predict a nanotube's thermal conductivity is 10 times higher than silver's.

Applications of CNTs

Engineers use carbon nanotubes in a number of significant applications.

- *Flat panel display screens:* An electrified nanotube will emit electrons from its end, like a small cannon. When electrons bombard a phosphor screen, such as a TV or computer monitor, it emits light. Several companies are exploiting this unusual electronic behavior to make thinner, lighter display screens.
- *Nanocomposite materials:* Mixing nylon with carbon fibers (100–200 nm diameter) creates a composite material that can be injected into the world's smallest gear mold. The excellent thermal conductivity of the carbon causes the nanocomposite material to cool more slowly and evenly, allowing for better molding. The tiny gears are currently being made for use in watches.
- *Chemical sensors:* In the presence of certain gases, semiconducting CNTs display a large change in their ability to conduct charge (e.g., NO_2 and NH_3). Researchers can use nanotubes as sensors, exposing them to gas and measuring the change in conductance. In the future, nanotube sensors could be used in security and environmental applications as a smaller, faster and more sensitive alternative to conventional sensors.
- *Nanoscale electronics:* Scientists have exploited the mechanical and electrical properties of CNTs to produce molecular electronic devices. One of the most significant applications is nanotube transistors. Transistors can act like an on/off switch or an amplifier for current and are used in nearly every piece of electronic equipment today. Scientists have been able to use semiconducting nanotubes as compact, highly efficient alternatives to conventional transistors.

Materials

For giant balloon display:

Balloon pump or source of compressed air
12.5 feet Dura PEX tubing, 3/4" OD, 1/2" ID
1/2" male/male joint, plastic or copper
2 screws

2 wing nuts, to fit on screws
Phillips head screwdriver
100 feet climbing / poly rope
20 feet medium thickness rope (we use 3/8" diameter nylon rope)
Duct tape
Fishing line
Scissors
2 bags of Qualatex 350 balloons in Onyx Black, 100 ct (available from http://www.tmeyers.com) **the balloons used are the long, sausage like balloons used by balloon artists**

For tabletop balloon display:

Balloon pump or source of compressed air
1-2 bags of Qualatex 260 balloons in Onyx Black, 100 ct (available from http://www.tmeyers.com) **the balloons used are the long, sausage like balloons used by balloon artists** (the tabletop version uses ~10-15 balloons for a 4 ft tube.)

Set Up

Time: 60 minutes

Step 1: Constructing the frame

1. Dura PEX tubing usually comes in 25 ft spools. Cut the tubing into two 12.5 ft pieces; this will be enough for two 4-foot diameter frames. Insert the 1/2" male/male joint into one end of the tubing and drill a hole through both pieces with a power drill about 0.5" from the end of the tube. Insert the other end of the joint into the opposite end of the tube and repeat.

2. Secure the hoop for the frame with screws and wing nuts. Insert a screw into the hole you just drilled to attach the joint to one end of the tubing. Fasten in place with a wing nut.

3. Attach the other end of the tubing to the joint with the second screw and wing nut.

4. Mark out quadrants on the circle using tape or pen. Put a mark directly across from the joint, and then put marks halfway between that mark and the joint on each side.

[Alternatively, a hula hoop can be purchased at a local toy store for use as the frame once the water or sand inside the hoop has been drained out. Balloon Nanotubes made with a hula hoop will have a smaller diameter than the ones featured in this guide.]

Step 2: Preparing the frame for hanging

1. Take a segment of medium rope about 10 ft long. Fold it in half and tie it across the circle at two of the marked points opposite each other. Repeat for the other two marks with another length of rope. [Optional: the ropes can be duct taped where they meet the frame to prevent sliding during construction.]

Step 3: Hanging the frame

1. Tie one end of the climbing rope to the point where the medium ropes cross. A hangman's knot works well for this.
    a. You should consult your building manager about the best way to hang and tie off the sculpture. Note that the frame will have to be raised several times during construction and the final sculpture will weigh about 10 lb.
    b. Initially, the frame should be suspended about shoulder height from the floor.
2. Once you've hung the frame, adjust it by sliding the medium ropes through the center knot until the frame is balanced and even with the floor.

Program Delivery

Time: 1 hour (max) for giant nanotube / 30 minutes for tabletop activity

Safety:

Use proper ladder techniques when suspending the large sculpture. The structure itself is very lightweight and poses little hazard.

People with latex allergies shouldn't handle the balloons, or stand too close to the balloons while they are being inflated.

Small children should be supervised when around balloons to avoid accidental ingestion/choking.

Procedure and Discussion:

This program is often used as a hook to draw visitors to a program. It can be supplemented with the NISE demo, "World of Carbon Nanotubes," which explores the history and uses of carbon nanotubes or the NISE program "Forms of Carbon".

Educators can also engage visitors during the construction of the nanotube to examine this balloon structure as a model. Ask the visitor the following questions:

- what are the strengths of using balloons as a model for a CNT?
- what are the drawbacks of using balloons as a model for a CNT?
- where else do people encounter models in everyday life? What are the strengths and weaknesses of these models?

If you do the Giant Balloon Nanotube activity with a captive audience, you can turn its construction into a contest, with two groups racing to build the largest tube in a set amount of time. In this case, the materials list would be doubled.

Giant nanotube

Step 1: Adding the first ring

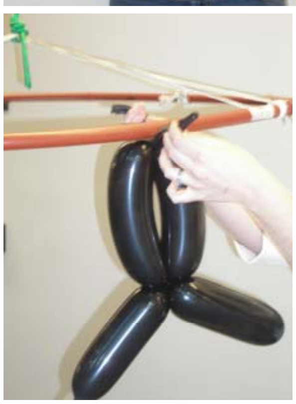
1. Hang the frame with the climbing rope and adjust inner ropes to make the frame level.

2. Inflate Qualatex 350 balloons to 22", leaving a 2" to 3" tail. The sculpture looks best when the balloons are relatively uniform in length, so you may want to inflate one balloon to the desired length and then use this as a template. You will need about 90 balloons for every 10 ft of sculpture.

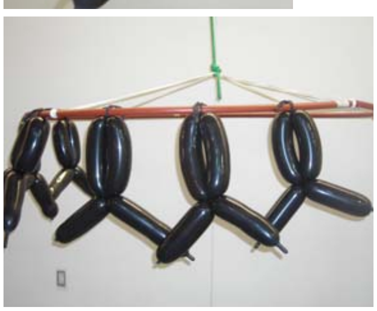
3. To start the first ring, pinch and twist a balloon at its midpoint, forming two links.

4. Pinch and twist the midpoints of the newly formed links, quartering the balloon.

5. Twist the newly-made midpoints together, forming an upside-down “Y” shape.



6. Using a piece of an unused balloon (or a piece of string), tie the twisted joint onto the frame. The upside-down “Y” shape should now be attached to the frame.



7. Repeat Steps 3-6 to add another upside-down “Y” shape to the frame. Make sure the un-inflated tail of the new “Y” points toward the knot end of the first “Y.” Continue to repeat Steps 3 through 6 until the upside down “Y” shapes fill the frame.

8. Tie the un-inflated tail of one “Y” point to the knot end of the “Y” next to it.

9. Continue to tie tails to knots until all upside-down “Y” shapes are connected. (The joints created by these knots are “downward-facing” and will be the sites for adding to the structure.)

Step 2: Adding to the structure

1. Pinch and twist a new balloon at its midpoint. Drape this balloon by its midpoint over a downward-facing joint.

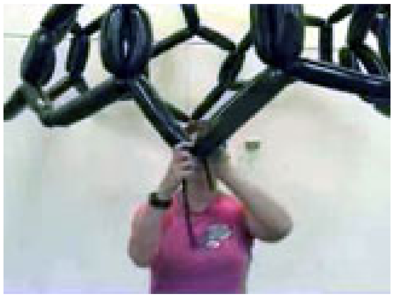
2. Fold the two halves of the hanging balloon downward over the joint. Twist each half at its midpoint, again quartering the balloon. Finally, twist the halves together at these newly made midpoints, forming an upside-down “Y” shape.

3. Repeat steps 1 and 2 on the next downward facing joint, so that two upside-down Y-shaped balloons are hanging next to each other.

4. Knot adjacent ends of the Y-shaped balloons together, forming a hexagon.

5. Repeat steps 1, 2 and 4 to complete the row. Continue repeating them to add more rows to the sculpture. Raise the structure periodically so that it’s at a comfortable working height. Add as many rows as you wish without letting the sculpture touch the floor. (Grit on the floor can cause balloons to pop.)

Step 3: Finishing the structure



1. For the final row, follow steps 1 to 4 above, then stop.

2. The bottom row may need some weight added to look like hexagons. Fill a balloon with a small amount of water and drape over two or three of the downward facing joints to add weight.

The complete assembly process, with videos of each step, can be seen at:

http://www.mrsec.wisc.edu/Edetc/cineplex/balloons/index2.html

Tabletop nanotube

Step One: Starting the structure

1. Inflate the Qualatex 260 balloons to ~22". Make sure to leave a 2" to 3" "tail" of un-inflated balloon at the end. Also, the sculpture looks best when the balloon lengths are relatively uniform. You may want to inflate one balloon to the desired length and then use it as a template.

2. For the initial ring, pinch and twist the balloon into segments that are approximately the width of your hand, making all segments as close to the same length as possible. The segments represent bonds in the carbon nanotube, and the joints represent the carbon atoms. Be sure to twist all joints in the same directions. The first ring must have an EVEN number of bonds. Eight bonds seems to be ideal and most manageable.

3. Tie the "tail" to the knot to complete the ring. Some segments may come untwisted during the process. Just re-twist them before tying off.

Step Two: Making the first row

1. Tie the end of another balloon onto the ring you just created at any of the joints. You will make your first hexagon with this new balloon. Pinch and twist off four equal hand-width segments from the balloon you just attached (leaving a long fifth segment with all the excess air). On the top ring, count off two segments to the right of the joint attached to your balloon. Tie the balloon to this spot – twist the joint between the fourth and fifth segments of the balloon over the joint of the top ring.

2. You now have four bonds coming off this joint. Fold the remaining segment back down toward the first half of the balloon. Pinch and twist the balloon back onto itself at the joint just before the ring – creating a "double bond".

3. Pinch and twist off three more hand-width segments and complete the next hexagon. Tie the balloon tail to the top ring, two segments to the right of the double bond you just created.

4. Start the next hexagon. Attach another balloon to the joint you just tied off to. Create a double bond as in step 2 above. Pinch and twist off three additional hand-width segments and attach balloon to the starting ring. Create another double bond. Pinch and twist the last three segments. The last segment will make a double bond with the very first segment you created and will tie to the top ring in the same place. (If you have excess balloon after joining to the starter ring, you can pop the remaining balloon and twist the deflated tail into the joint. The remaining segments should not deflate.)

Step Three: Adding additional rows

1. Attach a new balloon to a "downward" facing joint – the joint that is the bottom point of the hexagons in the first row.

2. Pinch and twist off four hand-width segments and attach the balloon to bottom joint of the next hexagon in the first row. Again, you will have four bonds coming out of one joint. Create a double bond, and pull the remaining segment of the balloon through the hexagon to get it in position to create the adjacent hexagon.

3. Add another balloon. Repeat Step 2 to complete the second row.

4. Repeat until the carbon nanotube is the desired length.

Tips and Troubleshooting:

Complete videos of the giant balloon are at:
http://mrsec.wisc.edu/Edetc/nanolab/balloons/

A full instructional video of the tabletop balloon can be seen at:
http://www.mrsec.wisc.edu/Edetc/cineplex/balloons/small_scale.html

Use fresh balloons - order no more than a few weeks in advance. Balloons deteriorate quickly when exposed to heat or UV light. Minimizing exposure to sunlight and heat sources will increase the lifetime of the sculpture.

Inflating balloons to the same size each time results in a more uniform nanotube. To achieve this easily, inflate one balloon to the ideal length and use as a template for subsequent balloons.

Using the above method will cause the first ring to have incomplete hexagons. If full hexagons in the first ring are desired, see the online tutorial. (http://mrsec.wisc.edu/Edetc/nanolab/balloons/) The method used to start the ring in this guide is simple enough that visitors can assist with these steps. If the online method for starting the ring is preferred, it is suggested that staff start the ring prior to engaging visitors, as the online method is trickier.

When building the structure with children (ages 6-10), smaller diameter balloons (like Qualatex 260 or Qualatex 160 balloons) are easier for smaller hands to manipulate. (For the diameter of the balloons: 160 < 260 < 360)

Common Visitor Questions

(To be added)

Going Further…

Here are some resources you can share with your visitors:

(To be added)

Clean Up

Time: 30 minutes for giant display / 5 minutes for tabletop activity

For the Giant Nanotube:
When you are ready to take down the sculpture, lower the frame to the floor. Cut the balloons that are holding the structure to the frame. Take the sculpture outside to pop, as it can be noisy. To deflate a balloon without popping, cut where the balloon is stretched at the ends. Be sure to clean up all the pieces of popped balloon.

For the Tabletop Nanotube:

Pop balloons and clean up pieces.

Universal Design

This program has been designed to be inclusive of visitors, including visitors of different ages, backgrounds, and different physical and cognitive abilities.

The following features of the program's design make it accessible:

[ ] 1. Repeat and reinforce main ideas and concepts
- The overarching main idea is communicated visually and reinforced verbally and tactilely.

[ ] 2. Provide multiple entry points and multiple ways of engagement
- The program allows for multiple entry points and ways of engagement through guided discussion and a hands-on activity.
    - The presenter verbally explains the different aspects of the CNT's structure.
    - Visitors visually observe and feel the hexagonal structure and different types of bonds.
    - Visitors can physically assist in the building of the structure.
    - Visitors can read about CNTs on the accompanying poster (available for download)

[ ] 3. Provide physical and sensory access to all aspects of the program
- The presenter builds the first two or three hexagons while verbally explaining the process to visitors. This allows for visitors to both hear and see the building process.

To give an inclusive presentation of this program:
1. For visitors with limited dexterity, models or previously built balloon structures can be passed around in the audience.
2. Diameter of the balloons can be selected to best fit intended audience.

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