**World of Carbon Nanotubes**

**Lesson Plan**

Organization: Museum of Science, Boston

Contact person: Tim Miller

Contact information: tmiller@mos.org

General Description

Public Presentation

**This program introduces the carbon nanotube, its discovery and applications.**

**Program Objectives**

**Big idea:**

Carbon nanotubes are a new, cool material that will affect your life.

**Learning goals:**

As a result of participating in this program, visitors will be:

familiar with carbon nanotubes

understand applications of this material

know some of its properties

**NISE Network Main Messages:**

[ X ] 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 and create new devices.

[ X ] 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?

**Time Required**

**Set-up** **Program** **Clean Up**

5 minutes 20 minutes 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 ñ 100 nanometers.

A virus is about 70 nm long. A cell membrane is about 9 nm thick. Ten hydrogen atoms are about 1 nm.

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

There is a TON of good material out there, and quite a bit thatís lousy. Start with wikipedia, but don’t stop there:

HYPERLINK "http://en.wikipedia.org/wiki/Carbon\_nanotube" http://en.wikipedia.org/wiki/Carbon\_nanotube

You should also skim through basically any undergraduate Chemistry book, and get an idea for what an sp2 and sp3 bond is, and what allotrope means.

**Materials**

Digital slide presentation

1 soccer ball

1 other ball of similar size

2 chicken wire models

1 large (36î x 36î) sheet full of a hexagon pattern

1 plastic model of a carbon nanotube, which you can buy here:

HYPERLINK "http://www.indigo.com/models/gphmodel/carbon-nanotube-model-W.html" http://www.indigo.com/models/gphmodel/carbon-nanotube-model-W.html

You may also want a sample of actual nanotubes. A good supplier is:

HYPERLINK "http://www.nano-lab.com" www.nano-lab.com

**Set Up**

Time: 5 minutes

Step 1:

Turn on your slide projector. Take out your materials.

**Program Delivery**

Time: 20 minutes

**Safety:**

If you are using REAL carbon nanotubes, safety is CRITICAL. They will likely be shipped without effective safety measures. You want to transfer them to a SEALED, durable glass container. This should be done inside a chemical hood. (Consult your local lab or university if necessary.)

**Procedure and Discussion:**

[Slide 1 Title slide]

[Slide 2 blank]

<Greet and welcome the audience.>

[Slide 3]

One of the most important technological advances in human history happened 5,000 years ago, in the valleys of Mesopotamia, when people started making axe heads and other tools out of a new material called bronze. Until that point, we only knew how to make tools out of stone--we would start with a big block of stone, and chip away the pieces until we had the tool we wanted. Bronze tools could be made faster, lasted longer and were better at their jobs. This made a big change in the way human beings lived their lives. It was the first time we gave up hunting and gathering, and built cities, and learned to write. It was the end of the Stone Age, and the beginning of the Bronze Age. In the last couple of centuries, the same thing happened. Our ability to make things out of different types of stuff changed the way we live. Because of steel, we built ships that sailed the sea. And because of plastic and aluminum, we went to outer space. Today in the world there is another revolution going on, one that promises to change our lives as much as any of these. And once again, it is caused by a new type of material, called

[Slide 4]

The carbon nanotube, which is what I am here to tell you about today. It’s a story in three parts. I am going to tell you

[Slide 5]

How we found them, why they're cool, and why you should care. We will start with some fundamentals. You’ve probably heard before that all the world is made of atoms, these tiny building blocks of all the stuff in the universe. (If that's news to you, I am telling you now: all the stuff in the world is made of atoms.)

[Slide 7]

There are about 100 different kinds of atoms, and we list them on this chart we call the periodic table. Atoms get together with one another and form these bigger things we call molecules. A molecule is just a regular geometric arrangement of atoms. This is a picture of the salt molecule, sodium chloride. Some molecules, like salt, are simple. Others, like this biological protein, are very complicated. The interesting thing about molecules is that it's not what atoms you put in them that matters so much, but how those atoms are arranged.

[Slide 8]

Here we see two very different materials. The one on the left, graphite--the stuff inside the pencil--is dark gray, and so soft you can crumble it with your fingertips. The material on the right, diamond, is perfectly transparent, and the hardest stuff on earth. The interesting thing about diamond and graphite is that they are both made up of just one type of atom. They are both 100 percent carbon atoms, and nothing but carbon atoms. But it is the arrangement of those atoms, the geometry of the molecule, that determines the properties of the material.

[Slide 9]

Now, molecules are very small, smaller than you can see with the naked eye, or most types of microscopes. The scale of molecules is what we call the nanoscale. Now, nano is just a prefix. It comes from the Greek word for dwarf, and scientists use it to signify one one-billionth of something. You could write it one of several different ways. Other prefixes you might be more familiar with include mega, kilo, centi, milli, or micro. These are all multipliers. A megabyte is one million bytes. A milligram is one one-thousandth of a gram. Thus, a nano-something is one one-billionth of that thing. And the word nanoscale comes from the nanometer, which is one one-billionth of a meter. To get an idea of how small that is, let's go back to salt.

[Slide 10]

Think of the smallest thing you can see with the naked eye say, one tiny grain of salt for example. If you could shrink yourself down, so that a salt grain seemed like it was getting bigger and bigger, how far would you have to go before you could just barely see the molecules? The answer is that when you got to that point, the salt grain would seem to be the size of a baseball park. We could express that as a ratio: The ratio in size between a salt grain and a ballpark is the same as the ratio between a salt molecule a and a salt grain. We could also say it like this: The number of molecules in a grain of salt is the same as the number of salt grains it would take to fill a ballpark. That’s how small a molecule is.

So what is this new molecule called the carbon nanotube, how did we find it, and why is it cool?

[Slide 11]

It was found primarily be these five scientists. The guy on the lower right, Harold Kroto, was an interstellar chemist. That means his job is to look into space and try and figure out what the things he sees are made of. He thought maybe he was seeing some long chains of carbon compounds. So he got together with the other guys, who had a machine they'd been using to make long chains of things, and convinced them to put some carbon in it. But they got something they didn't expect. Instead of chains of varying length, they kept getting clusters of exactly sixty atoms of carbon. Nobody had ever seen anything like that before. They didn't know what it was. But they did know some other things about it, including its architecture.

[Slide 12]

This picture shows something called a geodesic dome. That's a sphere made of a series of straight lines. It was designed and made popular by the architect Buckminster Fuller. And what the scientists realized is that they might have made a molecule with the same shape as a geodesic dome. It turns out it would have exactly this shape [Hold up soccer ball.] If you imagine putting an atom at each place where two lines meet--what we call a vertex--there would be exactly sixty atoms on the surface of the soccer ball.

[Slide13]

The scientists realized they had made a molecule like this, a perfectly spherical molecule, a cage of carbon atoms. They decided to call it the buckminster fullerene, after the architect. Today we more commonly refer to it as a buckyball. And its discovery was a big deal.

[Slide 14]

Such a big deal, in fact, that a few years later the scientists won the Nobel Prize. (Notice that 5 scientists did the experiment, and 3 won a prize. If any of you are gunning for the Nobel Prize, I recommend standing in the center of the photograph.)

[Slide 15]

A few years after that, scientists in Japan discovered that you could have more than 60 atoms in the structure. You could have 70, or 80, or 100, or 100,000. [Hold up plastic model] If you imagine cutting the soccer ball in half, and adding in another ring of atoms, you eventually start to form a long tube. We started calling the tubes buckytubes, but we more commonly refer to them today as

[Slide 16]

Carbon nanotubes. Here we see a group of them under a special kind of microscope. So, what's the big deal? Why are they so cool?

[Slide 17]

To know why they are cool, you need to know something about your friend and mine, the carbon atom.

[Slide 18]

Now carbon is a very important little atom. For reasons I won't go into, it really likes to get together with other atoms. That's a good thing, because with the exception of water, you and I are made mostly out of carbon. One of things that carbon likes to get together with most is other carbon atoms. Sometimes a group of atoms get together and form a special structure called an aromatic ring.

[Slide 19]

This is a group of carbon atoms that forms a hexagon, or a six-sided shape. It is very important in organic chemistry. Sometimes, a whole bunch of these rings get together, forming what we call a graphene sheet.

[Slide 20]

That's a big honeycomb pattern of carbon atoms. This is the structure that the atoms have in graphite, which is just a big stack of these sheets. And with nanotubes, instead of being stacks of sheets, are sheets rolled up into tubes.

[Slide 21]

Now, there is more than one way to roll up a sheet. [Take paper and demonstrate.] You can roll from top to bottom, or from left to right. Remember how I said in the beginning that the geometry of the molecule determines the properties of the material? Well, since nanotubes can have many different geometries, they can also have many different properties. I want to share with you just a few important examples.

[Slide 22]

First and foremost, nanotubes have some amazing electrical properties. If you roll the sheet up a certain way, you get a material that is an extremely good conductor of electricity. Carbon nanotubes have the lowest room-temperature electrical resistance of any material we have ever measured. That could be very important for the way we move electricity from one place to another.

If you roll the sheet up a different way, you get a sometimes-good conductor, called semiconductor. Semiconductors are materials that sometimes conduct electricity, and sometimes they don't. But you can predict when they will and when they won't, so you can use them to make all sorts of interesting things, like computer chips and solar cells.

[Slide23]

In addition to having cool electrical properties, nanotubes also have some cool mechanical properties. Remember I said that carbon atoms can form strong bonds? Well the tube is just a whole bunch of bonds, all lined up in the same direction, making carbon nanotubes the strongest material we have ever seen. They can be 50 times stronger than steel. That's so strong that if you could weave a rope of pure carbon nanotubes the thickness of one human hair, that rope could hoist your car straight up into the air. But they are also very light, because they’re mostly empty space. They are much lighter than aluminum, the metal we use for soda cans and spacecraft. They are also very elastic, meaning that you can bend them a lot, and they will return to their original shape.

[Slide24]

Carbon nanotubes also have some fascinating thermal properties. In particular, they conduct heat very well along their long axis, but very poorly perpendicular to it. That might prove to be a very big deal indeed, because one of the biggest problems in making tiny and fast devices is figuring out how to get rid of all the heat.

[Slide25]

And this is why you should care. Because that list of properties is very likely to enable us to make some things we have never been able to make before. Let me show you just a few of the many examples.

[Slide26]

One place where nanotubes might prove very important is in the production of energy. It would be great to be able to make most of our energy from sunlight without having to burn coal or gas or anything. We have panels today that turn sunlight into electricity, but they are very expensive. I don't have panels like these on the roof of my house, and most of you don't have them on yours, because of the cost. But there’s a group of engineers trying to use nanotubes (as well as a number of other interesting materials) to try and make the next generation of solar panels, which we hope will be more durable, and less expensive.

Nanotubes might also have a big impact on another major resource question: water. There are lots of places on Earth that don't have enough fresh water. There is plenty of water in the oceans, but we can't drink it because of the salt. There's a group of engineers who believes they might be able to use nanotubes to make a simple filter to take the salt out of water for people to drink, and that would be a very big deal.

Nanotubes might also change the way we build great big things, like buildings and bridges, or aircraft and automobiles. The design of these systems is always based on the strength of a material relative to its weight, and nanotubes offer a much better ratio than anything we have ever seen before.

[Slide27]

Another place where we think you are likely to see nanotubes in the future is in consumer electronics. Old tube televisions worked by firing a stream of electrons at the screen, with magnets bending the beam to draw the picture. Nanotubes also make good electron guns, so you might be able to make screens with thousands of tiny, highly accurate tubes, instead of just one as in a conventional TV. Some people even think you might be able to make them so thin that they'd be flexible, so someday you might have a screen on your parka that shows the weather channel, or a TV in your house that unrolls like a window-shade when you want to watch it, and rolls up out of the way when you want to look out the window.

[Slide28]

There's even a group of engineers that believes nanotubes might be strong enough to make this thing called the space elevator. This is an idea that's been around in science fiction for a long time, but people are talking about it for real now. It works like this: [hold up a small ball, or your fist.] Imagine that this is the Earth. And you shoot a satellite high up into orbit above the Earth. And inside that satellite you have this giant spool of wire, a really long rope. Now put the satellite in orbit and unwind the spool, so that the end of the rope comes down from the satellite back to Earth, and bolt it to the ground. Now, since the Earth is rotating on its axis, and since the satellite is in orbit around the Earth, if you put it at the right distance the satellite gets flung outward, and the cable stays taut, standing straight up over one fixed point on the surface of the Earth. What this means is that you don't need rockets to send things to orbit anymore. You can just built a climbing car like an elevator that clamps onto the cable, climbs up as high as it wants to go, and lets go, releasing its cargo into orbit. The engineers working on this project claim that if they can get it built, it will lower the cost of sending things to orbit from $10,000 a pound today to $10 a pound. That's what you pay for FedEx. So if you could FedEx things to outer space, that would fundamentally change the way we use space as a resource--for energy, information, transportation, and ultimately tourism. Ten dollar a pound is less than what you pay now for an airline ticket to Europe. At that price, there are probably lots of people who would pay to go to space. There is still much debate in the engineering community about how practical this is, and how much it might cost, but this is the first time we have seen a material that has the strength necessary to make it real, and that's why people are talking about it.

[Slide 29]

You are probably thinking: "All this stuff sounds great! How come it hasn't happened yet?" There are still a few barriers, and one of them is cost. Until recently, nanotubes were only made in small batches in labs. They were hard to get, and really expensive. That price has come down, but is still too high for some of the applications I mentioned.

Another concern is the question of manipulation. If you wanted to make something like a computer chip, you'd need to carefully arrange several hundred thousand of these things. And that's not easy, because they are so small. Much of the current work being done on nanotubes is based on this question of fabrication.

Another concern is toxicity. If you look at carbon nanotubes under the microscope, they are long and skinny. They look a lot like another long, skinny material called asbestos. Asbestos was once the next big thing, but it turned out if you got it in your lungs it caused some bad business. There is some evidence that nanotubes might cause the same problems, so people are trying to make sure they aren't used in ways that can cause a threat to human health.

[Slide30]

So far, we have seen the first commercial devices made out of nanotubes. There’s a company in Massachusetts that’s making a type of digital memory similar to flash memory using nanotubes. The first nanotube materials are being used now, mostly in sporting goods like tennis rackets and baseball bats. Most importantly, the first factories that manufacture carbon nanotubes on an industrial scale have opened here and around the world. That is the most important advance, because it makes the tubes more abundant, more available, and easier for researchers to get hold of. As you might imagine, with a material that does so much, there are many other applications I have not mentioned here. I just wanted to give you the tip of the iceberg, and convince you of my main points:

[Slide31]

We found them, they're cool, and you should care. Because they will soon be in the things you own, and they are likely to change the world. That' all I have today, I'd now be happy to take your questions.

[Slide32]

**Tips and Troubleshooting:**

NOTICE:† Feel free to alter this program to suit your needs.† If you find something that works, share it with the rest of the community by posting your revisions on www.nisenet.org.

This program is targeted at teens and older. If you get much younger audiences, there isn’t much you can do to adjust the content, so be smart about how you advertise the show.

**Common Visitor Questions**

Common questions include:

Are there medical applications? Yes. Examples include scaffolding for re-growing of damaged nerve cells, and contrast agents for MRI scans.

Is this the same as carbon fiber? No. the molecular structure is completely different, and the two materials have much different electrical and thermal properties. They do have similarities, including that both materials are very light and very strong.

Is this what nanotechnology is all about? No. This is just one small section of the larger field known as nanoscale science and engineering.

**Going Further**

Here are some resources you can share with your visitors:

Start with wikipedia, but don’t stop there.

**Clean Up**

Time: 5 minutes

Pack up and go home.

**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:

[ x] 1. Repeat and reinforce main ideas and concepts

Repetition of main points at opening and conclusion; signposting.

[ x ] 2. Provide multiple entry points and multiple ways of engagement

Visually and aurally, through properties, history or applications.

[ x ] 3. Provide physical and sensory access to all aspects of the   
program

Visitors have opportunity to explore tactile models, paint mental picture of shape.

To give an inclusive presentation of this program:

If you have people who are low vision, be sure to try and describe objects you show, especially models, or allow them to hold models after the show. Be sure not to obstruct your face or mouth, to allow hearing impaired visitors to see your lips.

This project was supported by the

National Science Foundation under Grant No. ESI-0532536.