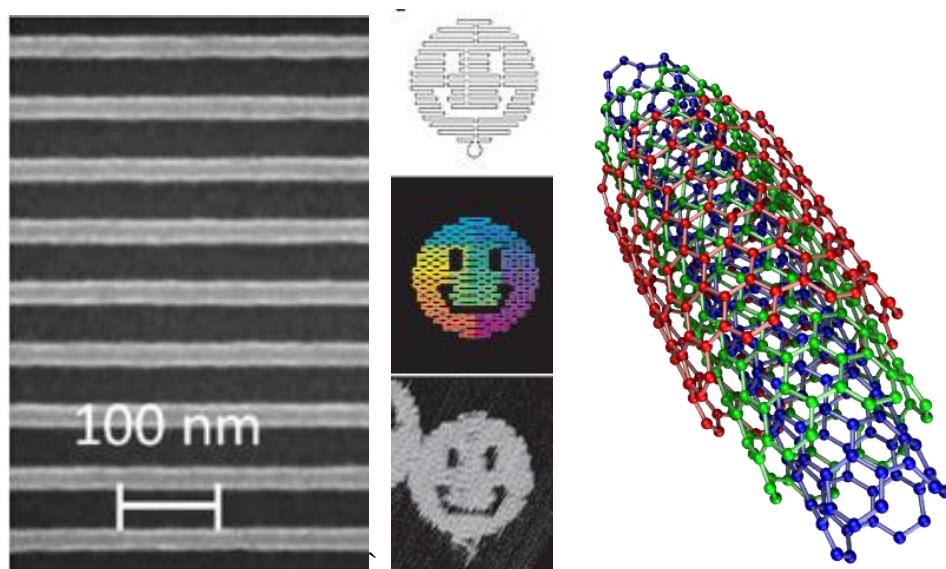


# Nanoscience and Nanotechnology!

## Thin Films, DNA, and Carbon Nanotubes

3/15/2013



Mad Duck Science Friday Laboratory Notebook

Name:

Team:

# Lab 1: Thin Films 3 Different Ways



A **thin film** is a layer of material ranging from less than a nanometer (one billionth of a meter) to several micrometers (millionths of a meter) thick. **Everyday examples of thin films** include soap bubbles, oil slicks on water, and anti-reflection coating on eyeglasses.

**Warmup: What do you think these words mean?**

**CONSTRUCTIVE**

**DESTRUCTIVE**

**IRIDESCENT**

**WAVELENGTH**

**UNIFORM**

**REPRODUCIBLE**

**SHADOW MASK**

**VACUUM**

The way a material behaves on the **macroscale** (big) is affected by its structure on the **nanoscale** (small).

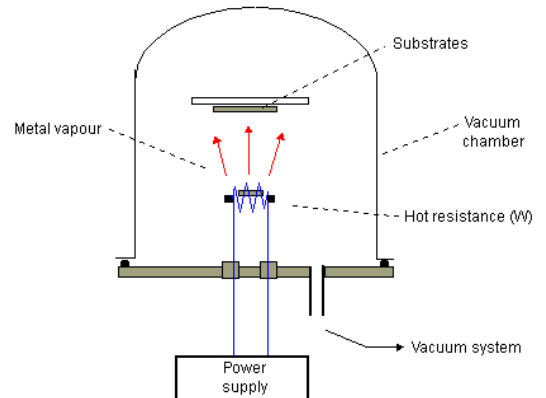
**Nanotechnology** takes advantage of special properties at the nanoscale to create new materials and devices.

**Q: Can you think of other examples of thin films?**

# GOAL: Determine the advantages and disadvantages of 3 different techniques for making thin films

## Experiment 1: Evaporating a Thin Film of Aluminum

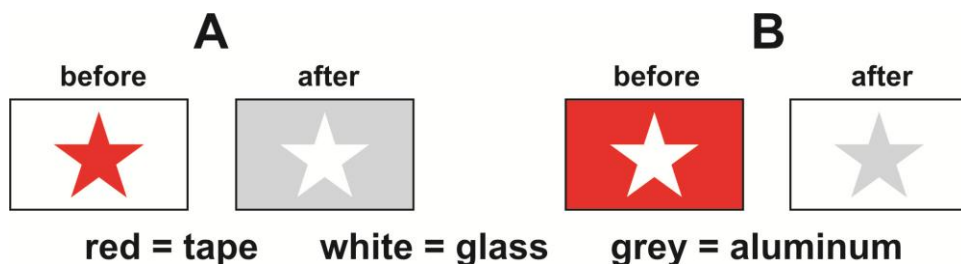
One way to make thin films is by thermal *evaporation*. This method requires high power and high-vacuum equipment to evaporate solid aluminum metal into a cloud of atoms. The atoms will then stick to whatever they run into. We can control where the atoms stick to make useful patterns.



You will make a *shadow mask* to make a pattern of aluminum metal on a glass *substrate*. A *substrate* is a material that supports your thin film sample.

A *shadow mask* is like a stencil. Once you make your shadow mask, the Mad Duck scientists will evaporate aluminum using a thermal evaporation system. Any exposed area will be coated with aluminum.

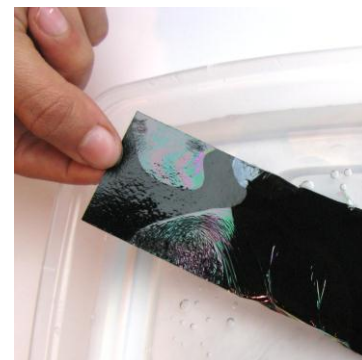
You will use tape to make your shadow mask. You can make designs by cutting out shapes in the tape (A) or using the tape to “outline” a shape (B). Think about where you want the aluminum to stick to the glass...



1. It is important to keep the glass clean so that the aluminum will stick well. Be sure to wear gloves while preparing your sample.
2. Use a marker to write your initials on one side of a glass slide so you can find your sample later.
3. Use scissors to cut the tape for your shadow mask.
4. Apply your shadow mask (the tape) to the **clean** side of the glass.
5. Once your shadow mask is done, put your sample on the tray at the front of the room.

## Experiment 2: Make an Iridescent Thin Film

1. Write your name or draw a picture on a strip of black paper.
2. Slide the paper into the pan. Make sure it's completely under water.
3. Use the brush to drip one drop of nail polish onto the surface of the water. The polish will spread out into a thin film.
4. Hold one end of the paper and lift it up out of the water. The film of nail polish will stick to the paper. Does the nail polish still look clear?



**Q: What does the film look like on the surface of the water?**

**Q: Why doesn't the nail polish mix with the water?**

### What's going on?

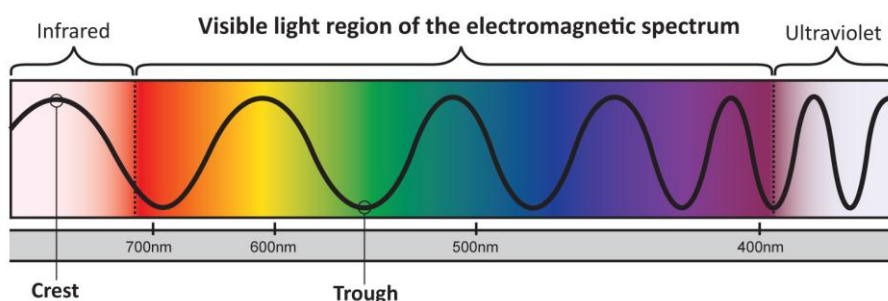
Thin films can reflect light in special ways, because they're only a few hundred nanometers thick—in the same size range as the wavelength of visible light. The nail polish spreads out into a super-thin film, which creates *iridescent*, rainbow colors on the paper. The thin film is only a few hundred nanometers thick, about as thick (or thin!) as a soap bubble. The film is slightly thicker in some places and thinner in others.

### Why do some thin films have beautiful colors?

Light travels in waves. Just like water waves, light waves have crests (high points) and troughs (low points). The distance between crests is a *wavelength*. Different colors of light have different wavelengths.

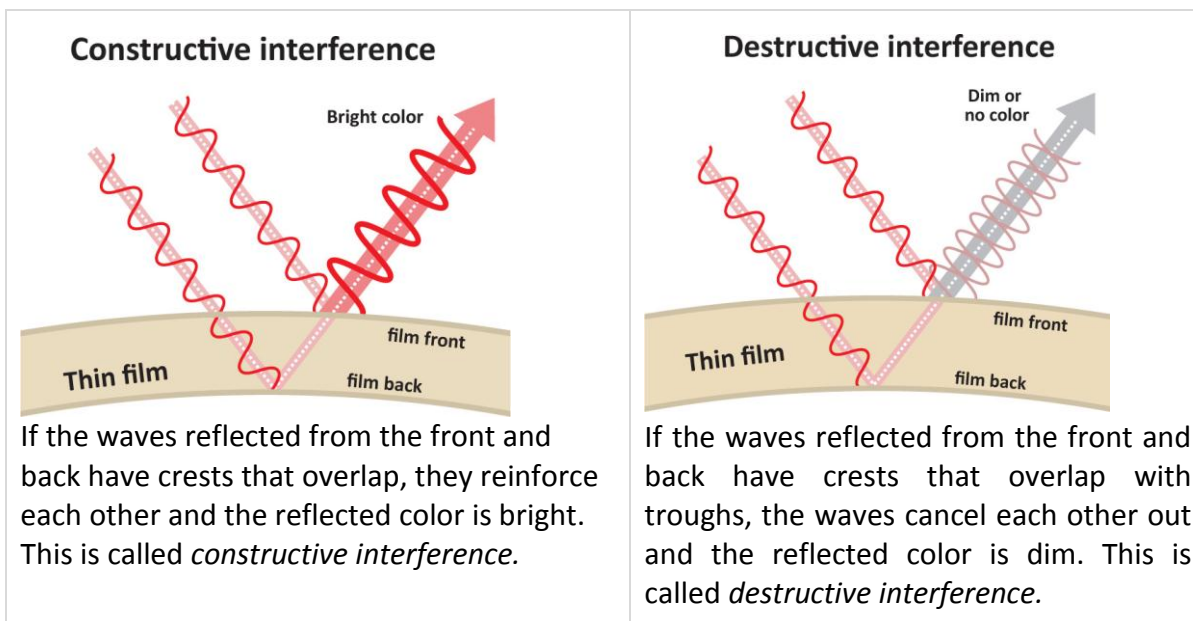
The wavelength of visible light ranges from about 400-700 nanometers.

The nanostructures of iridescent feathers, shells, and wings are in this same size range. So are thin films.



**Q: What colors do you see in your film? What are the wavelengths that match these colors? (Use the visible light chart above to determine the wavelengths)**

White light is made up of all wavelengths, or colors, of light. When white light hits a thin film, some of the light is reflected from the front surface of the film, and some travels through it and is reflected from the back surface.



The thickness of the film determines which colors will be bright and which will be cancelled out. In a very thin film (less than 400 nanometers thick) all the colors cancel out, and the film appears black.

**Q: What other things are made of waves? How do you think interference affects these other things?**

### How are thin films used?

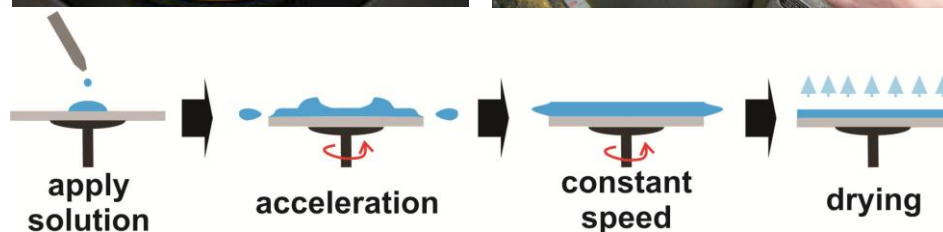
Scientists are developing thin films to use as computer memory and in solar cells. Flexible thin film batteries can be made by printing onto plastic, thin metal foil or paper. Using thin films can make the products they are in cheaper than they are now.



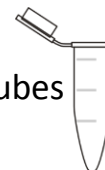
Thin film solar panels

**Q: Can you think of other everyday things that are made using thin films?**

## Experiment 3: Spin Coating Thin Films



1. **Wear gloves** to keep the glass slides clean during the experiment and to keep from getting paint on your hands.
2. Prepare different solutions (samples A-D) of paint and water in Eppendorf tubes according to the table below. **With the cap on**, shake tubes well to mix the solutions.



Sample →	A	B	C	D
drops of water	0	1	2	3
drops of paint	4	3	2	1

3. Place a piece of *double-stick tape* in the center of the spin coater fan. (The double-stick tape should be bigger than the slide.)
4. Firmly place the glass slide on the fan so that it is secured onto the double stick tape.
5. Use a pipette to put 2-3 drops of sample A on the center of the glass slide.
6. **COVER THE SPIN COATER WITH THE LID!**
7. Connect the cables to the battery pack to turn on the spin coater and let it run for 20 seconds. (The spin coater is spinning at about 2000 rpm!) When it's finished, disconnect the cables and remove the lid.
8. Take the glass slide off carefully, holding by its sides, and set it on a paper towel to dry. Write the sample letter from the table next to each slide so you can remember which sample is which.

Repeat steps 2-7 for each mixture of paint and water (samples B, C, and D).



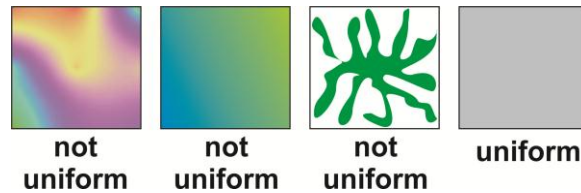
## Wrap Up: Sample Analysis

### Key Point: How do we know if we made good quality films?

For high-tech applications, it is important that we make films that are *uniform*.

Think about groups of people that wear uniforms... The uniform makes all the members of the group **look the same** so that they are easily recognizable.

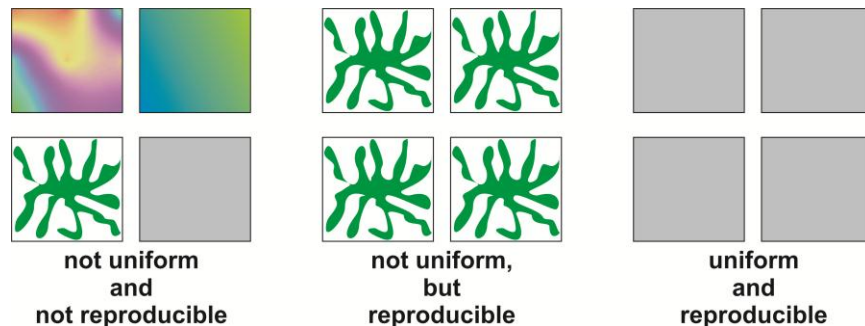
When we talk about films being *uniform*, it means that they **look the same** everywhere. Different parts of uniform films don't have different features. (Remember, the features of nanomaterials determine how they behave.)



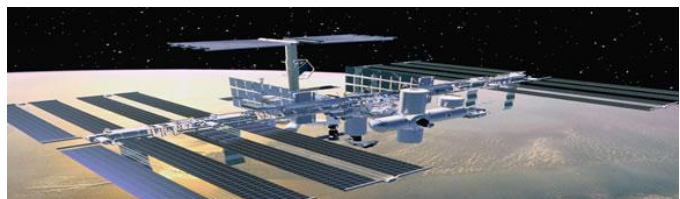
### Q: Why is it important for the thin films in smart phone screens to be uniform?

We also need our method for making films to be *reproducible*. Something is *reproducible* if it works the same way every time you do it.

With thin films, *reproducibility* means that every film you make with a certain method looks the same. Anyone who starts with the same supplies should be able to get the same film.



### Q: What would happen if the process for making thin film solar panels on satellites was not reproducible?



## Sample Analysis

Compare the 3 different methods for making thin films. Compare your samples to samples made by other members of your group to determine the reproducibility of each method. Fill in the Tables below.

**Table 1: Film appearance and reproducibility**

Deposition method	Uniform? (✓ or X)	Reproducible? (✓ or X)	Draw what the films look like

In Table 2, rate each deposition method, with “1” being the best in that category and “3” being the worst. Pick 2 other **positive film qualities** and fill them in to the 2 blank columns.

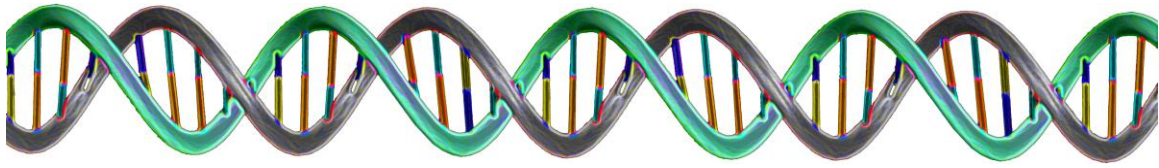
**Table 2: Comparison of film deposition methods**

Deposition method	Low power input	Inexpensive equipment	Reproducible	Uniform			Total score

**Q: Is a low score or a high score better? Which method did you rate the best?**



## Lab 2: DNA Nanotechnology – Decoding Life



**DNA** stands for “**d**eoxyribo**n**ucleic **a**cid”. DNA is present inside the cells of **every living thing**. It contains the chemical instructions and genetic information to help organisms develop and function.

DNA is so tiny that you usually can't see it. A nanometer is a billionth of a meter. (Your fingernails grow one nanometer every second!) **DNA is only two nanometers across**, but if you could unravel all the strands from just one cell and line them up end to end, you'd have a thread two meters long!

Most of our DNA—99.5%—is the same as every other person's, but a small amount is unique. **Only identical twins** have exactly the same DNA as another person.

**Warmup: What do you think these words mean?**

**PROTEIN**

**CODON**

**MUTATION**

**BASE PAIR**

**HELIX**

**AMINO ACID**

**PRECIPITATE**

**GENOME**

# GOAL: Extract DNA and learn about how DNA can be used as a code by nature *and* by scientists

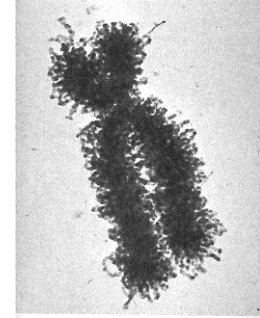
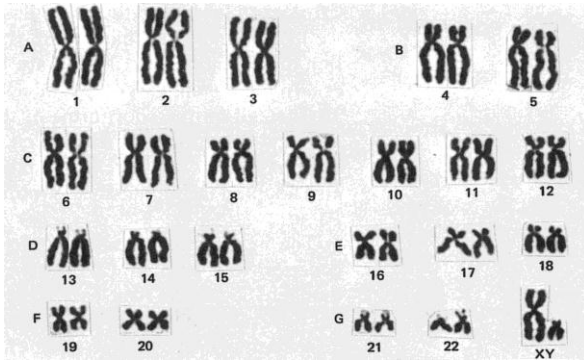
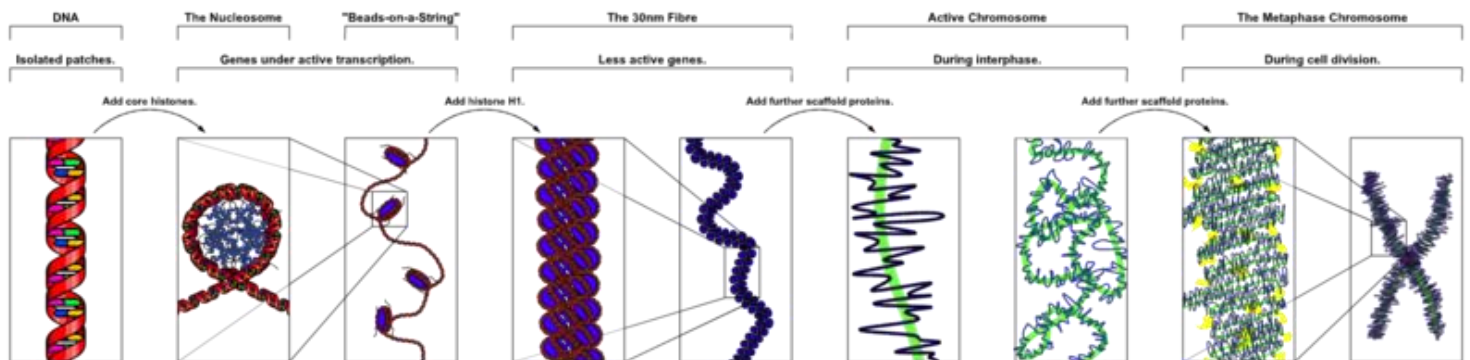


FIGURE 3-14  
An electron micrograph of a human chromosome.  
Chromosome XII from a HeLa cell culture. (Courtesy  
of Dr. E. Du Praw.)

The human *genome* (all of our genetic material) is contained in 46 long, thin “threads” called *chromosomes*. Each person inherits 23 chromosomes from each of their parents, for a total of 46 chromosomes. A chromosome is an organized structure of DNA and *protein*.

**Q: Why do you think it is important for DNA to fold into chromosomes?**



Human DNA is made of two long strands that are twisted together, in a structure called a *double helix*. It looks like a long, spiral ladder. The rungs are made of pairs of chemicals (called *bases*) known by the letters A, T, G, and C. **They always pair up together in the same way: A with T and G with C.** The order of these *base pairs* in the ladder is what contains the genetic information that helps your body to grow and live.



**Q: Why do you think DNA forms a “double helix” shape?**

# Experiment: Extract DNA from Split Peas

Split peas are a plant seed, so they have DNA in them. In this experiment, you will extract (remove) DNA from split pea cells. The Mad Duck scientists will start the process by putting the peas in a blender. The blender separates the cells.

You will add a “buffer solution” that breaks down the cell walls and pulls out the DNA. The buffer solution is made of water, dishwashing liquid, and a little bit of salt.

## Break down the cell membrane

1. Squirt about a teaspoon or so of pea mixture into a vial.
2. Squeeze about 10 drops of buffer solution into the vial.
3. Swirl or rock the vial to combine the buffer solution and pea mixture.



4. Let the vial sit for about 3 minutes to give the buffer solution time to work. The outside of the cell is called the *cell membrane*. The buffer solution breaks down the cell membrane and pulls out the DNA.

- The dishwashing liquid in buffer solution breaks down the fatty parts of the cell membrane. (When you wash dishes, it helps to break down the grease on your plates!).
- The salt in the buffer solution causes the contents of the cell—including the DNA—to come out.

Now the DNA is accessible inside the pea mixture, but it’s still too small to see. You will add some isopropyl alcohol which will make the DNA *precipitate*, or clump together.

## Precipitate the DNA

5. Tilt the vial and squirt about a half teaspoon of isopropyl alcohol down the inside.
6. The alcohol will form a clear layer on top of the pea mixture.
7. DNA will gradually rise out of the pea layer into the alcohol. It’s white and looks like mucus.
8. **Very gently** swirl or rock the tube to help the DNA rise and clump together.



Now you should have layer of pea mixture at the bottom and a clear layer of alcohol at the top.

9. Look closely: you should see DNA rising from the pea layer into the alcohol layer. There are millions of strands of DNA in the glob you see.

10. Let the vial sit for at least 10 minutes.

You can put your DNA into a tube to take home. If you like, you can put the tube on a piece of string and wear it as a necklace or a bracelet.

#### Put the DNA in a tube

11. Carefully pour the top layer (alcohol and DNA) from the vial into an Eppendorf tube.

12. Slip a length of string over the connector between the cap and tube.

13. Snap the cap shut. Remember to look at it later. The DNA will continue precipitating so it will be even easier to see later on.



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## Activity 1: DNA Origami

In this activity, you will fold your own double helix of DNA. Ask one of the Mad Duck scientists if you need help!

1. Cut out a blank DNA origami template.
2. Follow the instructions to fill in the template with a base sequence.
3. Color in your DNA template. Use different colors for A, T, C, and G.
4. Fold your DNA origami according to the instructions.

## Activity 2: Function Finders – Decoding DNA

A series of three bases (A,T,C,G) is called a *codon* which translates into an *amino acid*. **A series of amino acids make a protein.**

The codon wheel is central to this activity as it translates the DNA sequence into amino acids. To use the wheel you must work **from the inside circle out to the outer circle**. (For example if the first triplet of the sequence is CAT, the amino acid it codes for is Histidine (H).)

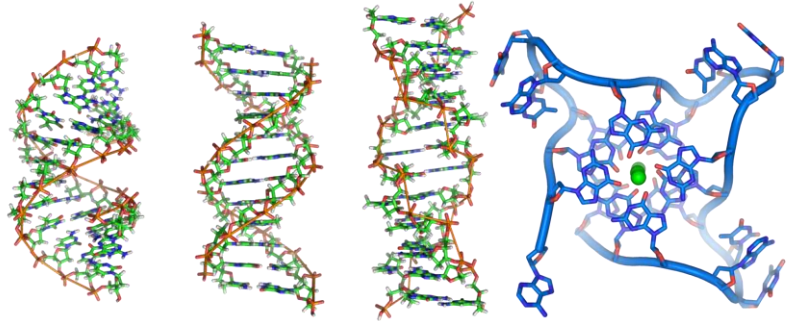
Work with a partner to use the Codon Wheel and the Protein Profile booklet to complete the Function Finders activity sheet.



## Activity 3: Using DNA as a Code - More Than Just Proteins

Your cells don't have to fold DNA into a helix like you did with the paper, it just happens on its own! This process is called *self-assembly*. The shape that DNA has depends on many factors, **including the amino acid**

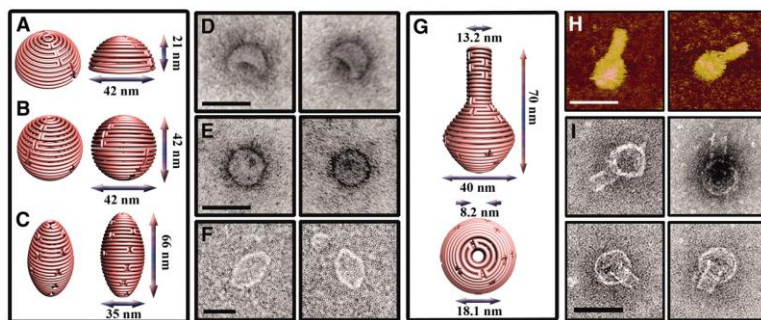
**sequence**, modifications to the bases, and how much water is around. DNA can take other shapes in nature than the double helix. Some examples of these are shown above.



**Q: Can you think of other examples of “self-assembly”?**

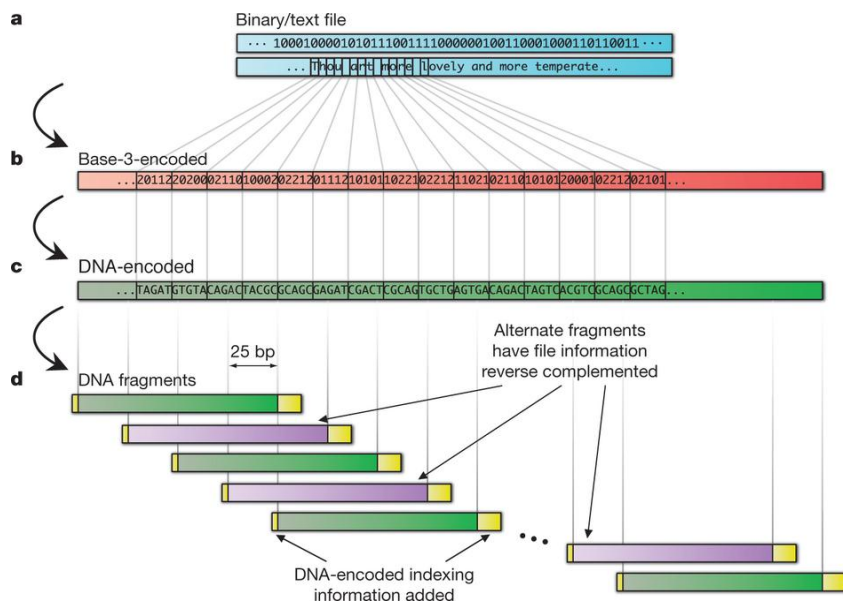
**Q: What are some things that you wish could self-assemble?**

Scientists have learned how to change the structure of DNA to do special jobs. DNA nanotechnology uses DNA and other nucleic acids as structural materials that can self-assemble to create new, nanoscale structures (like the smiley faces on your lab notebook cover). Applications of DNA nanotechnology include **DNA**



**computing** where DNA performs computation as it assembles, **nanoarchitecture** where DNA is used as a template to assemble other molecules, and in medicine where **DNA capsules** (like the ones to the left) can deliver a drug to a specific place in the body.

**Q: What are some other things that DNA nanotechnology could be used for?**



In DNA, we see that **the chemical sequence of amino acids controls how the structure looks**. But remember that the DNA sequence can also be used as a code. And not just a code for proteins! Just last month (Feb. 2013), scientists from England and California announced that **they had stored computer files of text** (Shakespeare's sonnets),

**photographs, and even audio** (MLK's "I have a dream" speech) **using a DNA code**. Computers use a code (of ones and zeros) to store information, the scientists translated the computer code into DNA code, just like you can translate something from English into Spanish. DNA has many advantages over written and electronic data storage: DNA doesn't need a power supply, it is stable for long periods of time with minimal care, and it is tiny! (The scientists estimate that **100,000,000 hours of high-def video could be stored in about 1 cup of DNA!**)

**You can use a DNA sequence to code and decode secret messages!**

The Codon Wheel doesn't have codons for 6 letters, but has multiple codons for other letters. For the missing 6 letters, use the following "duplicate" codons:

<b>B: G C T</b>	<b>J: A C G</b>	<b>O: C G G</b>
<b>U: C T T</b>	<b>X: C C G</b>	<b>Z: T C T</b>

Decode a "STOP" codon as the end of a sentence and "G G G" as a space between words. Look for these "duplicate" codons first, and then use the codon wheel to decode the rest of the secret messages below.

CACCTTATGGCCAATGGGGATAACGCAGGGGCACGCGAGC

GGGCGGGTTGAGAGGGGGACACATAGAGAAGAGGGGGGCT

ATTCTGTTGATCCGGAACGGGGCTGCCAGTGAAGGG

CCCGCCATCCGAAGTTAA



Now try this one:

ACCCACGAAGGGACTCGGACAGCCTTGGGGTTAGAGAATGGT

ACCCATGGGCGGTTTGGGGATAACGCAGGGATCAATGGG

CGGAACGAAGGGGCACCTTATGGCCAATGGGGGAACAACCTTGCG

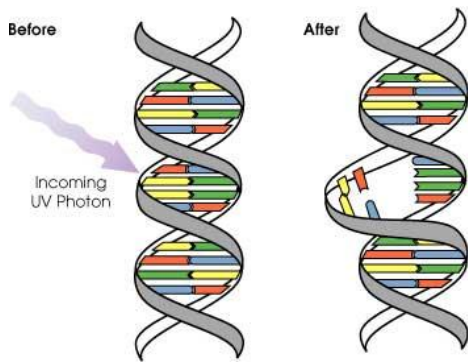
TTAAGCGGGAGCGAAGTTGAAAACACCTATGGGAGGGCGGCTT

AACGACGGGACCAGGATTCCCAGTGGGGTTTAGACGGATG

GGGGAAGCCAGAACCCACGGGACTCGGGGGACACATGAA

GGGAGTCTTAATTGA

Now write your own secret message using DNA! Use the space below and trade with a friend to decode each other's messages.



Being able to change the DNA code is a big responsibility. If you make a mistake, your message could get lost. But what if there is a “mistake” in the DNA in your body? When the amino acid sequence of DNA changes, it is called a *mutation*. *Mutations* play an important part in normal and abnormal biological processes. Not all DNA mutations will have an observable effect. In evolution, some mutations can be *beneficial* (good

for) an organism. But some mutations can have negative effects, and your body has ways to repair DNA that is damaged. **However, not all damages are repairable.** Sometimes we can do things to protect our DNA. (Wearing sunscreen is important to protect your DNA from damage by the UV radiation from the sun.) The damages that can’t be fixed build up with time and are the reason why our bodies change as we age.

**Q: Can you think of an example of a beneficial mutation?**

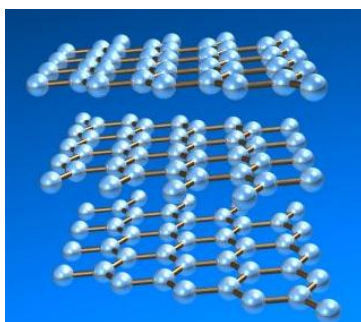
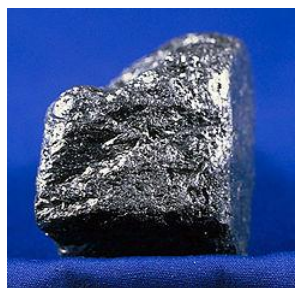
**Q: What are some other things we can do to protect our DNA?**

# Lab 3: Different Forms of Carbon – Nanotubes and Buckyballs

## **GOAL: Learn about the different forms of pure carbon and that nanostructure determines their properties**

Carbon atoms can arrange themselves in several different ways. Materials only made of one element are called *allotropes*. Two familiar allotropes of pure carbon are graphite and diamond. **Different allotropes of carbon have different properties because their structure on the nanoscale is different.**

Diamond and graphite are very different materials. **Graphite is very soft and slippery.** For this reason, it is used in pencils and as a lubricant in industrial machinery. **Diamonds are the hardest material found in nature.** A diamond ring can scratch glass easily, and the teeth of some saw blades contain tiny diamonds to help them better cut through concrete, bricks and wood.



**Graphite** is made of sheets of carbon atoms arranged in hexagons. Bonds between carbons and their 3 neighbors in the same sheet are strong, but bonds between sheets are weak.

Carbon atoms in **diamond** are strongly bonded to their 4 neighbor atoms in a 3-D arrangement called a *tetrahedron*. This structure is very rigid.

### **Try this!**

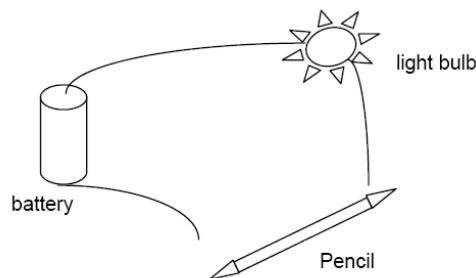
1. Write your name on paper using a pencil.
2. Try to write your initials on glass using a pencil.
3. Try to write your name on paper using a diamond scribe.
4. Try to write your initials on glass using a diamond scribe.

**Q: How do graphite pencils leave marks on your paper? Why does diamond scratch glass and graphite doesn't?**

Graphite conducts electricity, but diamond does not. Something that does not conduct electricity is called an *insulator*. Electrodes in some common batteries are made of graphite.

### Try this!

1. Connect two alligator wires (one to each terminal) to a battery pack.
2. Connect the alligator wires (one to each terminal) to the lightbulb. It should light up.
3. Disconnect one wire from the light bulb and connect it to one end of a pencil that has been sharpened on both ends.
4. Use a third alligator wire to connect the other sharp end of the pencil to the lightbulb.

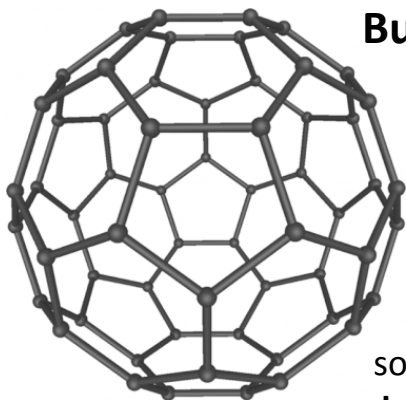


**Q: What happened when you completed the circuit by connecting the pencil to the lightbulb? Why? What other materials could be used to complete the circuit?**

**Q: Would the same thing happen if you used a giant diamond instead of a pencil? Why or why not?**

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Scientists have discovered new forms of pure carbon called buckyballs and carbon nanotubes.



### Buckyballs

A *buckminsterfullerene* molecule, also known as a fullerene or “buckyball,” contains **60 carbon atoms** arranged to form a hollow sphere. Each carbon atom in the sphere is bonded to its three neighboring carbons. The atoms are arranged to form a mix of hexagons and pentagons. (This is the same pattern as a soccer ball.) Buckyballs are naturally found in soot, and synthetic ones could one day be used for **solar cells, to combat HIV reproduction, or to store hydrogen fuel.**

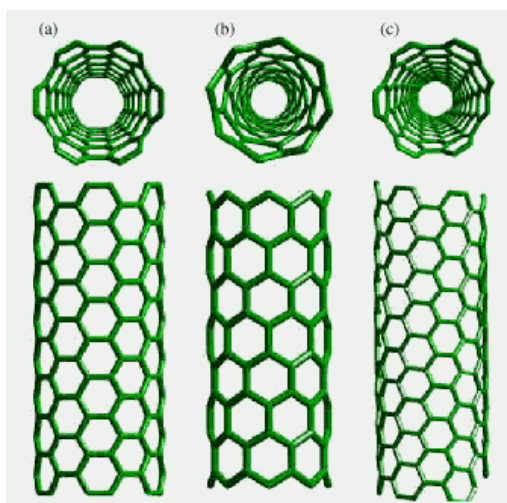
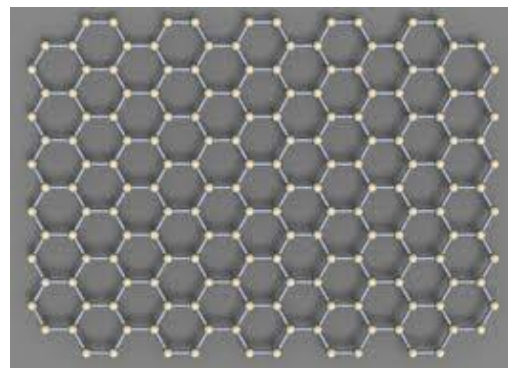
**Try this! Using mini marshmallows as carbon atoms and toothpicks as bonds, build your own model of a buckyball.**

## Carbon Nanotubes

A single sheet of graphite is called *graphene*. If you could roll up a sheet of graphene, you would make a **carbon nanotube (CNT)**. CNTs are very strong; a one-inch thick rope made of CNTs is predicted to be **100 times stronger than steel** with only  $1/6^{\text{th}}$  the weight! CNTs are currently used to make lightweight sports equipment, flat panel display screens, bicycles, and even boats!



Work with a partner or in a small group to make a graphene sheet with the marshmallows and toothpicks. Make your sheet have at least 11 columns of carbon hexagons (like the one to the right) so it will be easy to roll into a tube.



There are three types of nanotubes: armchair (a), zig-zag (b), and chiral (c). You can think about the different types as just graphene sheets that are rolled up differently.

See if you can roll your graphene sheet into a tube. Use extra toothpicks to connect the rolled ends of your sheet together. Which type of nanotube did you make?

Though the structures of the three types of CNTs are very similar, they behave very differently. Armchair CNTs are electrical conductors. Chiral CNTs are **semiconductors**, which conduct electricity better than an **insulator** (like diamond), but not as well as a **conductor** (like graphite).

**Q: Do you think zig-zag nanotubes are conductors, insulators, or semiconductors? Why?**

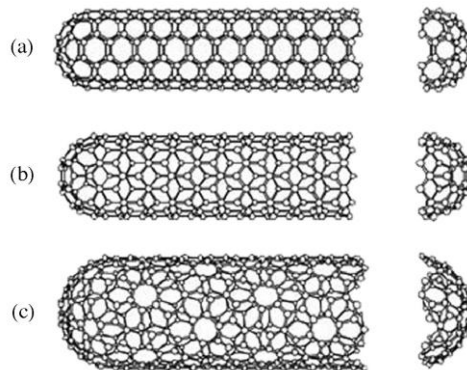
**Q: Can you roll your graphene sheet to make all three kinds of nanotubes? Which one is the easiest? Which one is the most difficult?**

**Q: Try to build a nanotube one atom at a time instead of rolling up a graphene sheet. Is this easier or more difficult?**



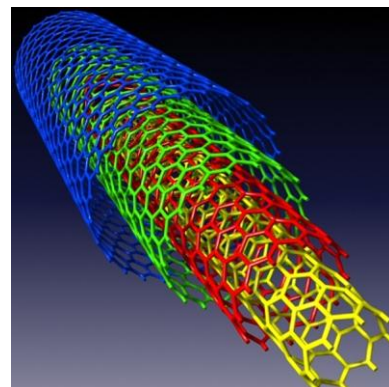
CNTs are actually capped at the ends with buckyball halves.

**Try to build a cap for your nanotube!**

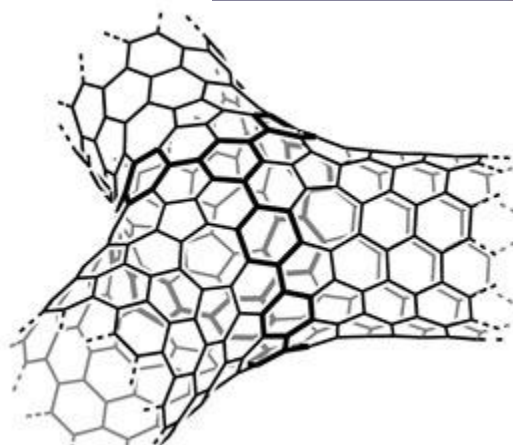


## More Complex Structures

CNTs can be classified as single-walled (SWNT) or multi-walled (MWNT). SWNTs resemble a single graphene sheet rolled up, while MWNT are made up of several SWNTs nested inside each other.

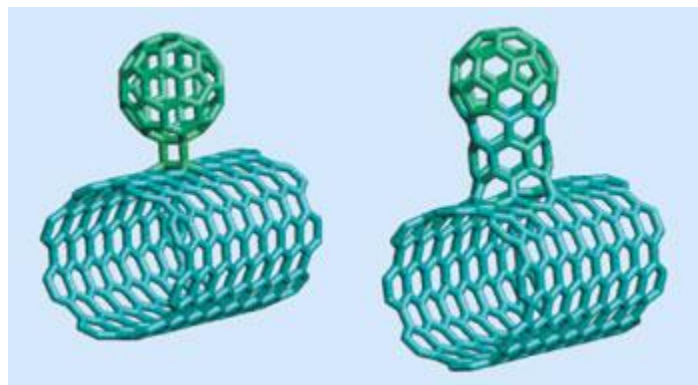


Some nanotubes have multiple branches.



When a buckyball grows off of a nanotube, it's called a "nanobud".

**Try to make some of these more complicated models!**



**Q: How do you think the properties of the nanotubes change as you make these more complicated structures? Be specific!**