ABOUT THE NANOTECHNOLOGY DEMONSTRATION KIT

"If I were asked for an area of science and engineering that will most likely produce the breakthroughs of tomorrow, I would point to nanoscale science and engineering."

-Neal Lane,
Assistant to the President for Science and Technology
former Director of the National Science Foundation
April 1998.

Terms such as nanoscience, nanotechnology, nanoengineering, nanoscale materials and nanocomposites have become quite popular in recent years, often appearing on the evening news. Yet there seems to be little to connect this emerging field to fundamental secondary science education curriculum. A nanometer is one billionth of a meter, about the size of a few atoms lined up next to each other. Nanoscience and nanotechnology refer to things that occur on the nanometer scale (1 to 100 nanometers). In the same way that 100 yards is the relevant scale for a football game, the nanoscale is the playing field for molecules and their interactions.

"Nanotechnology has given us the tools…to play with the ultimate toy box of nature – atoms and molecules." -*Horst Stormer, Nobel Laureate*

Phenomenal examples of nanotechnology abound in nature (abalone shells, photosynthesis, the human body). The capability for humans to manufacture materials using similar principles, will change the way almost everything is designed and manufactured, including vaccines, computers, water filters, batteries, paint, and more fuel-efficient cars. Physicists, biologists, chemists, materials scientists, and engineers are working together in research laboratories across the country to build nanoscale materials to make lighter, faster, stronger and smarter products.

The purpose of this Nanotechnology Demonstration Kit is to allow secondary school students to learn about nanotechnology and next generation materials by making and testing nanostructured materials by themselves using a minimum of laboratory supplies and ordinary tap water. The transfer of nanoscience concepts is often significantly limited by the high cost and complexity of the required scientific instrumentation, such as scanning tunneling microscopy and molecular beam epitaxy. Electrostatic self-assembly (ESA) is a revolutionary processing technique that, unlike other state-of-the-art methods to synthesize nanostructured materials and microelectronic devices, involves only low-cost lab supplies and simple processing at room temperature and pressure, in an open environment.

The kit is divided into five units that will introduce students to the following concepts.

- Nanotechnology and nanostructured materials
- Chemical bonding
- Electrostatics
- Electrostatic self-assembly
- Fabrication of their own nanostructured film

The activities provide examples of the concepts introduced and relate them to everyday uses. A set of questions is included for each activity to encourage further thought. During the ESA fabrication experiment, layers that are one molecule (a few nanometers) thick are built up one at a time, and stacked on top of each other to form a film. The stacking is observed through the increase in the bright color (blue) of the film. This is related back to concepts introduced during previous units.

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UNIT ONE: INTRODUCTION TO NANOTECHNOLOGY

Introduction to Nanotechnology

Objective:
The objective of this module is to introduce the concept and definitions of Nanotechnology. This unit is intended as a lecture or discussion and should be used as a refresher on topics assumed to have been addressed in previous learning activities, such as:

- Electrostatics – the attraction and repulsion of like and opposite charges
- Chemical bonding – definition of atoms, molecules and polymers and a simple understanding of ionic and covalent bonds.
- Surface tension

What is Nanotechnology
Nano - one billionth of something. Derived from the Greek word for dwarf.

Technology – Systematic scientific and engineering knowledge related to manufacturing. Knowing how to make something and why it works.

Meter (m) - a length that is approximately 39 inches

Nanometer (nm) - one billionth of a meter
Nanotechnology – knowing how to manufacture things at the nanometer scale, the size of atoms.

Like all other technologies it relies on many branches of science, in particular chemistry and physics. Nanotechnology is similar to other technologies in that the better the science is understood, the better the technology can be used and the better the devices that can be made.

Nanotechnology differs from other low and high technologies in the premise. Nanotechnology is manufacturing things by extracting raw materials from the environment and assembling them an atom or molecule at a time.

This would compare to what we would call a low technology activity such as sculpting. A sculptor will extract the raw material in the form of a large rock. The parts of the rock that are not part of the sculpture are removed and discarded using chisels and files. The artistic skill of the sculptor determines how well any cracks or color variations in the stone are incorporated into the final artwork.

An example of high technology is the manufacture of computer microchips. A large rod of silicon passes through multiple purification steps to remove the impurities that present the challenge to the sculptor. Once this is refined to satisfaction the large rod is cut into wafers. Piles of various chemicals called photoresists are layered on the wafer. These piles are then etched or modified with lasers, the chisels and files of the high technologists. These tools are able to etch with a resolution at 250 nanometers. The goal in this industry is to improve the tools to reduce this resolution to 100 nanometers by the year 2006.

In nanotechnology the required atoms are extracted from a chemical soup and assembled into the desired material or device. This is similar to constructing a word from letters floating in a bowl of alphabet soup, with the letters analogous to atoms.

A second concept that is central to nanotechnology is self-assembly. The atoms are too small for a person to direct, find, and place each atom individually. A template needs to be developed that stores the plans, like DNA in our body. A process needs to be developed that finds the correct atoms and places them according to the template.

Nanotechnology Science

There are many laws and principles that have been around since the start of the universe. These laws have not changed or been modified. Our classification and understanding of these laws is constantly being improved and revised. This is the work of the scientist whether the field is astronomy, physics, chemistry or biology. The science required for nanotechnology development and applications will draw from all scientific disciplines but most heavily chemistry, physics and biology.

Nanotechnology will not change or append any scientific laws. It will force us to expand and modify our understanding of these laws and how we can use them. The uses for the new materials and devices can be for beneficial purposes as well as for malicious purposes and can have unintended effects. The ethical and legal aspects of nanotechnology are a serious discussion in the nanotechnology community but we will not pursue that discussion any further.

Examples of Nanotechnology

Our physical bodies are amazing Nanotechnology machines. We feed our bodies food, water and air. The body converts these raw materials into a variety of amino acids, sugars and minerals. From these materials DNA, cells, blood, muscle, bones etc are all created. Other processes convert these inputs into energy that is used to power our bodies.

One example biologists are studying is how the abalone forms its shell. The shells are 98% calcium carbonate and are 3000 times tougher than rocks made from the same material. The mollusk forms the shell by alternating very thin layers, 50 to 200 nanometers, of calcium carbonate and proteins. Biologists have attempted to manufacture a new material by mimicking the materials and structure of the abalone shell. They have succeeded in making a material with good toughness characteristics, but not nearly as good as the abalone's, which is still at least 10 times tougher. The hypothesis is that thinner layers than the biologists could make are needed. To truly succeed the biologists will need to be able to control their manufacturing at a molecular level, nanotechnology. (Biomimetics is a relatively new branch of biology that is attempting to create new materials by mimicking biological processes like the abalone.)

Photosynthesis is an example of a process that extracts carbon dioxide from air and water from the plant to rearrange the atoms to form oxygen and carbohydrates using sunlight for energy.

There are many more examples in nature. The important attributes are that the starting materials are rearranged and recombined to give products with completely different properties. In the example of photosynthesis chemical reactions are involved, in the example of abalone shells a physical structure was modified.

Manufacturing Methods

Nanotechnology is an emerging technology. This means that we can imagine more fantastic things than we can accomplish today. Some people have achieved control over the placement of individual atoms. Others have generated computer simulations of 3 dimensional atomic scale pumps and motors that follow the laws of chemistry and physics. Others have created processes that accomplish part of the total objective.

Today, Scanning Tunneling Microscopy can accomplish true atomic position control. This is a device used to look at atoms and take a picture of atoms. It is also able to pick up and place one atom at a time. The first demonstration of this was to write IBM by placing Xenon atoms on a Nickel substrate. This device is used for research and for high technology art. If it were automated it could self assemble. However it is too slow to build any significant quantity of material. Remember it would take 2 billion years to make 0.6 ounces of water at 10 million molecules a second.

Today Electro-static self-assembly accomplishes partial self-assembly and molecular control in one dimension. We will investigate this process further in later sections of this module.

Future Applications:

Many creative people are working hard to develop the vision, the science, the technology and the tools required for nanotechnology. The visions they have for devices to be made by nanotechnology affect all aspects of our lives. Some examples include

- Information on a thousand CDs could fit into a wristwatch
- Many medical procedures could be handled by nano-machines that scour and rebuild arteries, rebuild bones, reinforce bones with diamond thread.
- Nanostructured vaccines that are more precisely manufactured to eliminate the hazards of today's vaccines, nano-machines that build an independent immune system that is not disabled by AIDs.
- Manufacturing will use less material, will reuse more garbage, will require fewer toxic molecules for manufacture and create no pollution.
- Planes, trains and automobiles will be lighter, faster, and more fuel-efficient; constructed of lighter, stronger materials.
- Inexpensive solar cell sheets that can be handled like fabric. Smart fabric that opens microscopic windows when the inside temperature reaches a certain degree and humidity could be self-powered by lights or the sun.

One Nanotechnology Process - Electrostatic Self Assembly
There are many different processes being investigated to make devices using nanotechnology. We will explore in more detail one of these processes, Electrostatic Self-Assembly (ESA).

ESA is a process that applies a coating exactly one molecule thick on a surface. By building a coating one molecule thick at a time absolute control of the composition can be achieved.

The ESA process in a nutshell is the creation of a charged surface and the bonding of oppositely charged ions to the surface. The electrostatic forces on the ions drive and control the layer to one molecular thickness while creating the next charged surface. The devices that can be made are limited by the imagination and the ability to identify suitable ions for deposition.

Following is some of the science background needed to understand this corner of nanotechnology.

Background Science for Nanotechnology and ESA

Units and measures

Just how small is the nanotechnology world?

Distance Dimension visualization

Distance to sun = 150 billion m	1 meter = 1 billion nm
Distance to moon = 380 million m	1 Pinhead = 1 million nm
Height of Mt Everest = 8.8 thousand m	1 Red blood cell = 5 thousand nm
Height of Michael Jordan = 2 m	1 DNA molecule = 2.5 nm
1 Foot = 0.3 m	1 Sodium atom = 0.2 nm

Just how many atoms have to be handled to build a device one atom at a time?

Avogadro number visualization

1 gram-mole = Number of atoms in 18 grams (0.6 ounce) of water = $6.02*10^{23}$ (Avogadro number)	Avogadro number of unpopped popcorn kernels = a pile that covers the entire United States 9 miles deep
	Time to count every atom in a gram-mole = 2 billion years at a rate of 10 million atoms per second
	Time for a 1 gigahertz computer to count every atom in a gram-mole at one atom per cycle (Hz) = 20 million years

Electrostatics review

(Note it is assumed that previous investigations into electrostatics have been performed. If not there is a section in Appendix 3 that addresses electrostatics in more than summary form.)

Like charges repel and unlike charges attract

When a balloon is rubbed on a wool sweater it will be attracted enough to a wall to stick. When two balloons are rubbed on a wool sweater they will be repelled by each other enough to move away if hung on a string.

The force that pushes the balloons away is an electrical repulsion. The act of rubbing transfers loose electrons from the wool sweater to the balloon by friction, giving the balloon a net negative charge. When two balloons are rubbed together they both pick up extra electrons to create a negative charge on both balloons. The negative charges try to get away from each other and the balloons will push away from each other.

The force that holds the balloon to the wall is an electrical attraction. The act of rubbing transfers loose electrons from the wool sweater to the balloon by friction, giving the balloon a net negative charge. The wall has a net positive charge. As long as the balloon holds enough electrons it will hang on the wall.

The physical response of two oppositely charged materials is always an attraction of the two charges. In some cases the attraction is strong enough to move or make objects stick, like balloons, hair and static cling socks . In other cases the attraction is strong enough to cause electrons to jump, like lightning or static shock when touching a doorknob.

Atoms, Molecules and Chemical Bonds

Atoms

All materials are made of atoms. All atoms are composed of protons, neutrons and electrons. Protons have a positive electrical charge, neutrons have a neutral electrical charge and electrons have a negative electrical charge. The number of protons and electrons in an atom are equal making atoms electrically neutral.

Molecules

Molecules are atoms that are held together by chemical bonds. The number and location of the protons and electrons in the molecule are equal making them electrically neutral.

Polymers are a special kind of molecule made by bonding repeating smaller molecules (monomers). For example, bonding in a long chain made of ethylene molecules makes polyethylene.

Polar molecules occur when the electrons and protons are not always evenly distributed around the molecule. Water is a "polar" molecule; this means that even though there is the same number of protons and electrons in the whole molecule there is a partial negative charge on the oxygen and partial positive charges on the hydrogen.

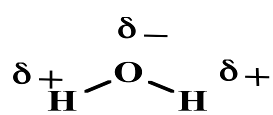

Illustration of the polar character of water

The polar character of water causes the waters molecules to be attracted to each other. The partial negative charge on the oxygen is attracted to the partial positive charge on the hydrogen.

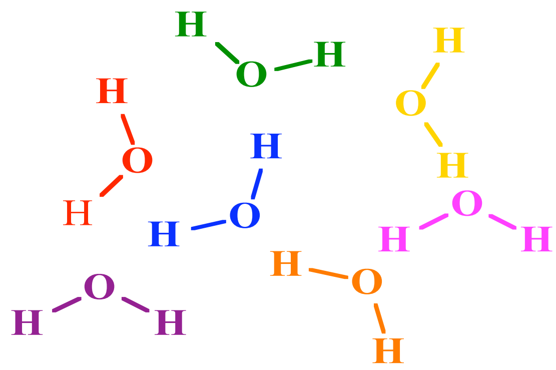

Illustration of the polar cohesion between individual water molecules

Ions

An ion is an atom or molecule that has a net positive or negative charge.

An anion is an atom or molecule with a negative charge, more electrons than protons

A cation is an atom or molecule with a positive charge, more protons than electrons.

Ionic bonds

Ionic bonds are when one atom or molecule donates one or more electrons to another atom or molecule. This creates one positive ion and one negative ion. The attraction of the two charges holds the atoms or molecules together.

Electrostatic forces hold ionic bonds together.

UNIT TWO: INTRODUCTION TO ELECTROSTATIC SELF-ASSEMBLY

Introduction to Electrostatic Self-Assembly

Introduction

ESA is a process that applies a coating exactly one molecule thick on a surface. By building a coating one molecule thick at a time, absolute control of the composition can be achieved. Since we are completely coating a surface we are creating a film.

The ESA process in a nutshell is the creation of a charged surface and the bonding of oppositely charged ions to the surface. The electrostatic forces on the ions drive and control the layer to one molecular thickness while creating the next charged surface. The devices that can be made are limited by the imagination and the ability to identify suitable ions for deposition.

Process

The ESA process occurs in 4 basic steps:

- Device Design
- Substrate Preparation
- Solution Preparation
- Self Assembly - Monolayer formation

Device Design

The first step in ESA is to plan. We need to plan what is the function of the final material or device we intend to manufacture. Knowing this we can select the exact materials and methods we will use to manufacture the product. Remember technology is about manufacturing materials or devices.

For ESA we must first select a substrate. This is a form we will apply our molecular layer films on. If we need a transparent device we might select glass. If the device must be shatterproof and transparent we might select a polycarbonate safety glass. If the device must move like Piezo-electric (electric voltage causes movement, or movement causes an electric voltage) we might select a very thin sheet of polymer.

Next we must select an anion solution (negative charges) and a cation solution (positive charges). The ions must have properties consistent with the function of our final material. The types of properties could be transparency, index of refraction, Piezo-electric response (mechanical movement in an electric field), conductivity, electro-chromic (changes color in an electric field), electro-optic (makes electricity in the presence of light).

Substrate Preparation

Once selected the substrate must be prepared for ESA. ESA films are held together by ionic bond electrostatic attractions. To start the process the substrate must be modified so the surface has a permanent charge. These permanent charges are made by either breaking existing bonds at the surface that leave charged sites, or by bonding chemicals to the surface that have charged sites. Most substrate preparation methods create a negative charge.

Solution Preparation

The materials used to build the films are dissolved in water. In water the materials carry positive or negative charges. This is necessary for the electrostatic attraction to occur. The water used to make solutions is purified to remove all contaminants from the water. In particular we are removing charged contaminants that may compete or interact with our desirable ions.

The anion solutions are made of water and negatively charge ions. The cation solutions are made of water and positively charged ions. When the anions and cations interact they form ionic bonds with each other. We only want the anions and cations to interact at the surface of the film we are creating. To do this we keep the anion and the cation solutions separate.

Self Assembly - Monolayer formation

A monolayer is a layer of material one molecule thick. That's only a nanometer or so! ESA coatings are formed one monolayer at a time. Positive and negative monolayers are alternated when building a film that is many monolayers thick.

The layers are drawn together and bonded together by electrostatic attraction. Cations (positive) will be attracted to a negative surface. Anions (negative) will be attracted to a positive surface. The electrostatic attractions drive the self-assembly of a monolayer.

Where cations cover a negatively charged surface, the new surface has a positive charge. Where anions cover a positive surface, the new surface has a negative charge. Electrostatic repulsion will push away other ions from that newly formed part of the surface. Electrostatic repulsions limit the self-assembly to one layer.

Participatory Demonstration of ESA

Concepts to Investigate:
ESA components, ESA procedures, ESA film structures

This set of exercises will involve multiple students in the demonstration of the steps involved in ESA processing, and how they produce the necessary films structures, using simple Velcro buttons. The molecules used for ESA are of two types: anionic and cationic. For this exercise the positive charges of the cation and the negative charges of the anion are represented by the hooks and loops of the Velcro buttons. The loops form mechanical bonds with the hooks as anions will form ionic bonds with the cations. The hooks will not form mechanical bonds with other hooks and the loops will not form mechanical bonds with other hooks, as the anions will not form ionic bonds with the other anions and the cations will not form ionic bonds with the other cations. It is therefore simple to demonstrate the alternating cationic/anionic structure of ESA.

Five exercises follow

Exercise 2 simulates a proper assembly of an ESA film.
Exercise 3 demonstrates the self-limiting nature of ESA.
Exercises 4 & 5 illustrate a major concern for ESA film assembly

EXERCISE 2.1: Preparing 'Solutions'

1 - Have the groups separate and identify the pieces.
They should have three separate piles.
- The Anions are the white Velcro loop buttons.
- The Cations are the black Velcro hook buttons.
- The Substrate with a negatively charged (anionic) surface is the tongue depressor with the white Velcro strip.

EXERCISE 2.2: Formation of a simple ESA film

1 - Place the substrate with the Velcro strip facing up.

The Velcro strip simulates negative charges. Most substrates we use do not have a negative charge in their normal state. We create these charged surfaces chemically. This is normally accomplished by either chemically bonding a molecule with a negative charge or by immersion in an acid to break a bond on the surface thus leaving behind negatively charged sites.

2 - Build a Cationic monolayer. Try to place all the Cation buttons on the substrate.

This simulates immersion of the substrate in a Cationic solution. In solution the opposite charges will attract each other and the cations will migrate through solution to the surface. Once near the surface the positive charges (cations) will form an ionic bond with the negative charges on the surface.

3 - Rinse the monolayer. Remove all Cation buttons that are not fully adhered to the substrate. Place these ions back in the Cation pile.

This simulates a rinse step. In the rinse step all ions that are not ionically bonded to the surface are removed. By using a pure water rinse any ions not firmly bonded to the surface will migrate by diffusion away from the surface and will be removed by the rinse.

4 - Build and Rinse an Anionic Monolayer. Repeat steps 2 and 3 using Anions instead of Cations. You now have one bilayer.

5 - Build and Rinse a second Bilayer by repeating steps 2-4

6 - Inspect the film; it should be 4 layers of alternating colors

EXERCISE 2.3: Using only anion molecules

1 - Separate the last film into the 3 separate piles.
  - The Anions will be the white Velcro buttons.
  - The Cations will be the black Velcro buttons.
  - The Substrate with a negative charged (anionic) surface will be the tongue depressor with the white Velcro strip.

2 - Place the substrate with the Velcro strip facing up.

3 - Build an Anionic monolayer. Try to place all the Anion buttons on the substrate.

4 - Rinse the monolayer. Remove all Anion buttons that are not completely adhered to the substrate. Place these ions back in the Anion pile.

5 - Repeat steps 3 and 4 two more times.

6 - Inspect the film; it should have no layers built up.

This simulates the "self limiting" nature of the ESA process. Self-limiting means that no more than one monolayer will form at any time. In ESA the ionic bond is formed only when the surface of the film and the solution are of opposite charge.

There are other mechanisms by which a film can be built. These other mechanisms do not form ionic bonds and the final properties of the film will be different from what is intended.

EXERCISE 2.4: Substrate contamination

1 - Separate the last film into the 3 separate piles.
   - The Anions will be the white Velcro buttons.
   - The Cations will be the black Velcro buttons.
   - The Substrate with a negatively charged (anionic) surface will be the tongue depressor with the white Velcro strip.

2 - Place the substrate with the Velcro strip facing up.

3 - Place the fingerprint smudge Velcro Hook strip in the middle of the substrate.

   This simulates an oil smudge or fingerprint. This is one of the most common causes of poor films. The smudge is an uncharged high surface tension surface. The high surface tension prevents the water-based solutions from properly interacting with the surface and the lack of charge prevents bonding if there was adequate interaction.

4 - Build a Cationic monolayer. Try to place all the Cation buttons on the substrate.

   This simulates immersion of the substrate in a Cationic solution. In solution the opposite charges will attract each other and the cations will migrate through solution to the surface. Once near the surface the positive charges (cations) will form an ionic bond with the negative charges on the surface.

5 - Rinse the monolayer. Remove all Cation buttons that are not completely adhered to the substrate. Place these ions back in the Cation pile.

   This simulates a rinse step. In the rinse step all ions that are not ionically bonded to the surface are removed. By using a pure water rinse any ions not firmly bonded to the surface will migrate by diffusion away from the surface and will be removed by the rinse.

6 - Build and Rinse an Anionic Monolayer. Repeat steps 4 and 5 for using Anions instead of Cations. You now have one bilayer.

7 - Build and Rinse a second bilayer by repeating steps 4-6

8 - Inspect the film; it should be 4 layers of alternating colors.

9 - Write down any observations

EXERCISE 2.5: Mixing the anion and cation solutions together

1 - Separate the last film into the 3 separate piles.
   - The Anions are the white Velcro buttons.
   - The Cations are black Velcro buttons.
   - The Substrate with a negative charged (anionic) surface is the tongue depressor with the white Velcro strip.

2 - Place the substrate with the Velcro strip facing up.

3 - Combine the Anion and Cation solutions.

4 - Have one student knead the two piles of buttons together.

5 - Build and Rinse a monolayer. Use same procedure as steps 2 and 3 from first exercise.

6 - Inspect the film. The buttons should all be in one single jumbled pile attached to the substrate.

   This illustrates what happens when we see a haze in our films. One of the unique characteristics of our films is transparency. Particles become visible when they affect visible light. For this to happen particles need to be larger than about 500 nanometers (1/2 micron). When we do not perform adequate rinsing and leave too much of the opposite charged ions near the surface they form larger agglomerate particles like this one just created. Too many particles like this create a haze and hurt other characteristics of the films we try to create

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UNIT THREE: MAKE YOUR OWN NANOSTRUCTURED MATERIAL

Manufacture an ESA film on a Microscope slide

In this section, the electrostatic self-assembly process, which was investigated theoretically in Unit Two, will be used to fabricate an optical thin film. Enough solution for the entire class will be divided up for film fabrication by each student group. The exercises are designed in a manner that accommodates four students in rotating roles. Suggested roles are equipment manager, dipping specialist, timekeeper and recorder. The recorder should also keep a tally of the number of dips performed.

Concepts to Investigate: polymer solution preparation, anionic and cationic polymer roles

EXERCISE 3.1: Preparing solutions

A minimum of two solutions are necessary to perform ESA: one cationic and one anionic.

Materials:
Bottle labeled "Anion"
Bottle labeled "Cation"
Graduated Snap Seal Container (2)

Procedure:

Put on a pair of gloves
Mark the snap-seal container to hold the "Anion" solution with a '—'
Mark the snap-seal container to hold the "Cation" solution with a '+'

Mixing the solutions

- Add 10 mL of each the anion and cation to their respective vials
- Fill to the line marked 60 mL with water. Shake briefly.

The solutions should now be ready to use to build ESA films on microscope slides.

EXERCISE 3.2: Manufacture an Electrostatic Self-Assembled Film

Materials:
Anion - Polymer dye (-) solution mixed in Exercise 3.1
Cation – Clear solution (+) solution mixed in Exercise 3.1
Prepared microscope slide
Graduated Snap-Seal container
Gloves
Plastic beaker

Procedure:

1 - Make sure you are still wearing gloves.
The gloves will prevent oil from your hands getting on to your microscope slide.
2 - Open the graduated Snap-Seal container containing the Polymer dye (-) solution
3 - Open the graduated Snap-Seal container containing the Cation (+)
4 - Label the two plastic beakers, one with a '—' and one with a '+'
5 - Fill the cation and anion rinse beakers ½ full with water

Build a bilayer

Cationic Monolayer

6 - Dip the slide into the cation rinse beaker filled with just water.
What happens to the water on the slide when you take it out of the beaker?
7 - Place one of the prepared microscope slides upright in the Cation solution. Leave it there for 30 seconds to allow the cations in solution to interact with the microscope slide surface.
8 - Remove the slide from the solution and gently shake off any excess solution back into the container.
9 - Rinse the slide off by moving it back and forth in the beaker. Be sure not to set the wet slide down on a flat surface, as this will damage the film. What happens to the water on the slide when you take it out of the beaker?
10 - Write down any observations.

Anionic Monolayer

11 - Place the rinsed slide upright in the Anion solution and leave it there for 30 seconds.
12 - Remove the slide from the solution and gently shake off any excess solution back into the container.
13 - Rinse the slide off by moving it back and forth in the beaker. Be sure not to set the wet slide down on a flat surface, as this will damage the film
14 - Write down any observations.

Build the rest of the film (Bilayers 2 – 10):

15 - Repeat Steps 7 – 14, nine more times to build 10 total bilayers.
16 - Air-dry the slide before laying it down to avoid damaging the film

After each monolayer, observe the microscope slide to see if there is any change in the film, particularly the color.

Compare your 10-layer sample with the 10-layer ESA sample provided with the kit. Is it darker or lighter? What does this tell you about the amount of film material built up during this experiment? Which film is absorbing more light, the one on your slide or the reference slide? What type of mater is the solution (solid, liquid, or gas...mixture or compound)? What type of bonding is occurring in your film?

EXERCISE 3.3: Using only the anion

As you can see, the anionic solution is blue, while the cationic solution is clear, any color buildup on the slide will be due to layers of the anion. This exercise demonstrates that the anion will not accumulate if the cation is not used. This is analogous to Exercise 2.2, in which colored balls were used to represent the different types of molecules. In this exercise we will try to make a 5-layer film using only the anion.

Materials:
Polymer dye (-) solution used in Exercise 3.1
Prepared microscope slide
Graduated Snap-Seal container
Gloves
Plastic beaker

Procedure:

1 - Make sure you are still wearing gloves.
The gloves will prevent oil from your hands getting on to your microscope slide.
2 - Use the polymer dye solution (—) prepared for exercise 3.2
3 - Use the anionic rinse beaker (—) from exercise 3.2
4 - Fill the anion rinse beaker ½ full with clean water

Build a film

Anionic Monolayer

5 - Place one of the prepared microscope slides upright in the Anion solution and leave it there for 30 seconds.
6 - Remove the slide from the solution and gently shake off any excess solution back into the container.
7 - Rinse the slide off by moving it back and forth in the beaker. Be sure not to set the wet slide down on a flat surface, as this will damage the film. What happens to the water on the slide when you take it out of the beaker?
8 - Write down any observations.

Build the rest of the film (Bilayers 2 – 10):

9 - Repeat Steps 5 – 8, four more times to build a total of 5 bilayers.
10 - Air-dry the slide before laying it down to avoid damaging the film

Compare your 5-layer sample with the 10-layer ESA sample you fabricated in 3.2 and with the ESA sample provided with the kit. Is it darker or lighter? What does this tell you about the amount of film material built up during this experiment? Why does this slide have a different amount of material on it than the slide you made in exercise 3.2?

EXERCISE 3.4: Substrate Contamination

Materials:
Anion - Polymer dye (-) solution mixed in Exercise 3.1
Cation – Clear solution (+) solution mixed in Exercise 3.1
Prepared microscope slide
Graduated Snap-Seal container
Gloves
Plastic beaker

Principles and Procedures:

1 - Make sure you are still wearing gloves.
The gloves will prevent oil from your hands getting on to your microscope slide.
2 - Open the graduated Snap-Seal container containing the Polymer dye (-) solution
3 - Open the graduated Snap-Seal container containing the Cation (+)
4 - Fill the cation and anion rinse beakers ½ full with fresh water

Build a bilayer

Cationic Monolayer

5 - Make a fingerprint in the middle of one of the prepared microscope slides
6 - Place the slide upright in the Cation solution. Leave it there for 30 seconds to allow the cations in solution to interact with the microscope slide surface.
7 - Remove the slide from the solution and gently shake off any excess solution back into the container.
8 - Rinse the slide off by moving it back and forth in the beaker. Be sure not to set the wet slide down on a flat surface, as this will damage the film
9 - Write down any observations.

Anionic Monolayer

10 - Place the rinsed slide upright in the Anion solution and leave it there for 30 seconds.
11 - Remove the slide from the solution and gently shake off any excess solution back into the container.
12 - Rinse the slide off by moving it back and forth in the beaker. Be sure not to set the wet slide down on a flat surface, as this will damage the film
13 - Write down any observations.

Build the rest of the film (Bilayers 2 – 5):

14 - Repeat Steps 6 – 13, four more times to build a total of 5 bilayers.

Air-dry the slide before laying it down to avoid damaging the film

What happened to the fingerprint? Why did this happen?

EXERCISE 3.5: Mixing the anion and cation together

If adequate buildup was not achieved by using the anion alone, it is obvious that you will need both the anion and the cation to produce the electrostatic attraction necessary to form ionically bonded.

This is analogous to Exercise 2.5, in which Velcro buttons were used to represent the different types of molecules.

In this exercise, we will try to make a 5-layer film by mixing the anion and cation together.

Materials:

Polymer dye (-) solution used in Exercise 3.3
PDDA (+) solution mixed in Exercise 3.2
Prepared microscope slide
Graduated Snap-Seal container
Gloves
Plastic beaker

Principles and Procedures:

1 - Make sure you are still wearing gloves.
The gloves will prevent oil from your hands getting on to your microscope slide.
2 - Use the polymer dye solution (—) prepared for exercise 3.2
3 - Pour the PDDA solution (+) used in Exercise 3.2 into the Polymer dye (—). Pour out some of the mixed solution so that approximately 60 mL remain. What happens to the mixed solution?
4 - Use the anionic rinse beaker (—) from exercise 3.2
5 - Fill the anion rinse beaker ½ full with clean water

Build a film

Mixed Bilayer

6 - Place one of the prepared microscope slides upright in the Anion solution and leave it there for 30 seconds.
7 - Remove the slide from the solution and gently shake off any excess solution back into the container.
8 - Rinse the slide off by moving it back and forth in the beaker. Be sure not to set the wet slide down on a flat surface, as this will damage the film. What happens to the water on the slide when you take it out of the beaker? What happened to the water in the rinse beaker?
9 - Write down any observations.

Build the rest of the film (Bilayers 2 – 10):

10 - Repeat Steps 6 – 9, four more times to build a total of 5 bilayers.
11 - Air-dry the slide before laying it down to avoid damaging the film

Write down any observations.

NOTES FOR THE TEACHER

Solutions can be stored overnight in the Nalgene bottles or the Snap-Seal containers.

Exercise 3.3
A light film may appear, however it should be much lighter than the one that will be obtained in Exercise 3.2. Because only negative charges were used, a film could not continue to build-up, producing only a very light color change. This is not ESA- no electrostatic attraction because there are no opposite charges.

The materials used in this film are currently in a product development stage. For this class the material was selected for the color that allows for visual observation of only a few bilayers. For our products there are two applications being considered. The anion responds to electrical voltage. One application is piezoelectric. The molecule can make a small movement with a small force when an electric voltage is applied. This could potentially by used to open and close small shutters for temperature or power control on solar cells used in outer space. The material also changes optical properties with and electric voltage is applied. This is being investigated for use as an optical switch. A beam of laser light is passed into the material and is split into two paths. If one path has the proper voltage applied the light waveform is shifted 180 degrees. When recombined the two light beams will cancel each other and turn off if the one beam has been phase shifted. ESA fabricated switches are being investigated for potential improvements over current technology for the fiber optic communications systems.

Exercise 3.5
The blue dots floating in the rinse beaker are similar to the Velcro clump in exercise 2.5.

Investigate other applications for Nanotechnology

Nanotechnology is still so new that novel applications and new methods to manufacture have yet to be imagined and created.

Investigate some of the following websites to see what people are imagining now and see if you can think of a novel idea. The more the idea sounds like science fiction the better.

Nanozine- This site is a NanoTechnology Magazine with many definitions and links to other nanoscience sites.

Foresight- This is a non-profit organization focusing their efforts on molecular nanotechnology

NASA NAS- The site for the NAS group of NASA, with researchers skilled in High performance computing and networking; distributed computing; parallel programming tools; nanotechnology and device modeling; applications for high-end computing; computational chemistry

Nanotechnology- This site contains many external links to sites with a wide range of information on various areas of nanotechnology

Nanospot- A search engine dedicated to nanotechnology on the world wide web

Small Times- A scientific journal dedicated to nanotechnology