Lesson 3:
Unique Properties at the Nanoscale

Student Materials

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Size-Dependant Properties: Student Reading

Overview

What is so special about nanotechnology that suddenly we have focused so much attention on this area? The new generation of scientific tools that operate on the nanoscale allow us to collect data and to manipulate atoms and molecules on a much smaller scale than we have ever been able to in the past. With these tools we are finding out that many familiar materials act differently and have different characteristics and properties when we have very small (nanoscale) quantities of them. As we study these materials in nanoscale quantities and generate theories to explain why they behave the way they do, we are learning new things about the nature of matter and developing the ability to manipulate these properties to create all sorts of new products and technologies, like the stain-repellant pants and solar power paint that we hear about in the media.

What Does it Mean to Talk About the Characteristics and Properties of a Substance?

Characteristics and properties are ways of describing different qualities of a substance and how it acts under normal conditions. Over centuries, scientists have accumulated a great deal of information about the properties of different substances (such as gold). For example we have information about gold's optical properties (such as color and transparency), electrical properties (such as conductivity), physical properties (such as density and boiling point) and chemical properties (such as reactivities and reaction rates). We can use this information to predict what gold will do under different conditions and to make decisions about whether or not it is good material to use when we are building or synthesizing new materials.

How Do We Know the Characteristics and Properties of Substances?

We have come to understand the characteristics and properties of atoms and molecules by studying a pure sample of the substance in quantities big enough to measure under normal laboratory conditions. Because atoms and molecules are so extremely small, we need a huge amount in order to see them, measure their mass on a typical laboratory scale and mix specific amounts together (remember just 18 grams of water (1 mole) contains 6.022×10^{23} molecules). So when scientists make measurements of the different properties of gold, they are actually measuring the average properties based on the behavior of billions and billions of particles and not looking at the behavior of individual atoms or molecules. We have always assumed that these properties are constant for a given substance (gold always acts the same no matter how much of it you have) and in our macro-scale world experiences they have been. This means that even though we measure these properties for large numbers of particles, we assume that the results should be true for any size group of particles.

What's Different at the Nanoscale?

Using new tools that allow us to see and manipulate small groups of molecules whose size in the nanoscale, scientists have now discovered that these tiny amounts of a given substance often exhibit different properties and behaviors than larger particles of the same substance! We've seen that when the number of atoms or molecules bonded together is so small that they only occupy between 1 and 100 nanometers of space, the properties are no longer predictably the same properties that are listed in tables of "physical properties" of a substance. Consider an analogy with sand on a beach. When looking at a sandy beach from afar, the sand appears to have a uniform color and texture. As you zoom in and examine fewer grains of sand at a time, you discover that the sand is actually made up of a variety of individual colors and textures of particles. As we develop better and better tools that allow us to look at and move these grains of sand (atoms and molecules), our understanding of the nature of matter changes.

How Do These Properties Change?

The color of gold is a classic example of how properties can change based on the size of the particles. When we have an **aggregation** of gold atoms bonded together in a solid with a diameter of about 12 nanometers, we can observe the color of the nanoparticles by looking at a bunch of them suspended in water. If the atoms are in the right bonding arrangement, we see that the gold nanoparticles appear red, not gold-colored. If we add a bunch more atoms in the right arrangement, we see the particles look purple. Why? Each of the different sized arrangement of gold atoms absorbs and reflects light differently based on its energy levels, which are determined by size and bonding arrangement. This is true for many materials when the particles have a size that is less than 100 nanometers in at least one dimension.

Reaction time is another phenomenon that changes at this scale. The greater the surface-to-volume ratio that reacting substances have, the faster the reaction time. Nanosized groups of particles are so small that they have a very high surface area to volume ratio, and thus react so quickly that precise measurements of time are difficult.

For nanosized objects, some familiar properties also become meaningless. Some physical properties of substances, for example, don't necessarily make sense at the nanoscale. How would you define, much less measure, boiling temperature for a substance that has only 50 atoms? Boiling temperature is based on the average **kinetic energy** of the molecules needed for the vapor pressure to equal the atmospheric pressure. Some molecules in a pot of water on the stove will be moving fast and some will be moving more slowly. The vapor pressure results from the average force per unit area exerted by the fast moving particles in the vapor bubbles in the water. When you only have 50 molecules of water, it is highly unlikely that a bubble would form so it doesn't make sense to talk about vapor pressure.

Why Do These Properties Change at the Nanoscale?

When we look at nanosized particles of substances, there are four main things that change from macroscale objects. First, due to the small mass of the particles, gravitational forces are **negligible**. Instead **electromagnetic forces** are dominant in determining the behavior of atoms and molecules. Second, at nanoscale sizes, we need to use **quantum mechanical** descriptions of particle motion and energy transfer instead of the classical mechanical descriptions. Third, nanosized particles have a very large surface area to volume ratio. Fourth, at this size, the influences of random molecular motion play a much greater role than they do at the macroscale.

How Does the Dominance of Electromagnetic Forces Make a Difference?

As shown in Table 1, below, there are four basic forces known in nature: gravity, electromagnetism, the strong nuclear force, and the weak nuclear force. The gravitational force is the force of attraction between the masses of two objects. This force is directly proportional to the masses of the two objects and inversely proportional to the square of the distance between the objects. Because the mass of nanoscale objects is so small, the force of gravity has very little effect on the attraction between objects of this size. Electromagnetic forces are forces of attraction and repulsion between objects based on their charge and magnetic properties. These forces also increase with the charge or the magnetism of each object and decrease as the distance between the objects become greater, but they are not affected by the masses of objects. Since electromagnetic forces are not affected by mass, they can be very strong even with nanosized particles. The magnetic and electrostatic forces are very important forces that determine the behavior of substances chemically and physically at the particle level. The other two forces, the strong nuclear force and the weak nuclear force, are interactions between the particles that compose the nucleus. These forces are only significant at extremely short distances and therefore become negligible in the nanoscale range. Since electromagnetic, and not gravitational, forces are most influential at the nanoscale, nanoparticles do not behave like macrosized objects. For example, a nanosubmarine (if we could build such a thing) would behave very differently than its macroscopic counterpart. With weak gravitational, but strong electromagnetic forces, the nanosubmarine might just stick to the first surface it encountered or be repelled so that it couldn't get near another surface at all!

Table 1. The four basic forces in nature, and the scales at which these forces are influential. Note that all forces exist at all scales, but their size may be so small as to be negligible (also see the Scale Diagram).

	Gravitational Force	Electromagnetic Forces	Weak Nuclear Force	Strong Nuclear Force
Cosmic Scale 10^{7} m and bigger	X	X*		
Macroscale 10^{-2} m to 10^{6} m	X	X**		
Microscale 10^{-3} m to10^{-7} m	X	X		
Nanoscale 10^{-8} m to 10^{-9} m		X		
Sub-Atomic Scale 10^{-10} m and smaller			X	X

* In places like the sun, where matter is ionized and in rapid motion, electromagnetic forces are dominant.

** On a human scale, where matter is neither ionized nor moving rapidly, electromagnetism, though important, is not dominant.

How Does a Quantum Mechanical Model Make a Difference?

Classical mechanical models explain phenomena well at the macroscale level, but they break down when dealing with the very small (atomic size, where quantum mechanics is used) or the very fast (near the speed of light, where relativity takes over). For everyday objects, which are much larger than atoms and much slower than the speed of light, classical models do an excellent job. However, at the nanoscale there are many phenomena that cannot be explained by classical mechanics. The following are among the most important things that quantum mechanical models can describe (but classical models cannot):

- Discreteness of energy
- The wave-particle duality of light and matter
- Quantum tunneling
- Uncertainty of measurement

Discreteness of Energy

If you look at the spectrum of light emitted by energetic atoms (such as the orange-yellow light from sodium vapor street lights, or the blue-white light from mercury vapor lamps), you will notice that it is composed of individual lines of different colors. These lines echo the discrete energy levels of the electrons in those excited atoms. When an electron in a high-energy state falls down to a lower one, the atom emits a photon of light that corresponds to the exact energy difference of those two levels (because of the conservation of energy). The bigger the energy difference, the more energetic the photon will be, and the closer its color will be to the violet end of the spectrum. If electrons were not restricted to discrete energy levels, the spectrum from an excited atom would be a continuous spread of colors from red to violet with no individual lines.

It is the fact that electrons can only exist at discrete energy levels that prevents them from spiraling into the nucleus, as classical models predict. This quantization of energy, along with some other atomic properties that are quantized, give quantum mechanics its name.

The Wave-Particle Duality of Light and Matter

In 1690, Christiaan Huygens theorized that light was composed of waves, while in 1704, Isaac Newton theorized that light was made of tiny particles. Experiments supported each of their theories. However, neither a completely-particle theory nor a completely-wave theory could explain *all* of the phenomena associated with light!

For most light phenomena—such as reflection, interference, and polarization—the wave model of light explains things quite well. However, there are several cases in which the wave model cannot explain the phenomena that are observed, but a particle model can! One such phenomenon is called the “photoelectric effect,” discovered by Albert Einstein. The photoelectric effect happens when you shine light on the surface of a metal and some of the electrons in the metal are knocked loose (similar to shooting pellets at sandpaper). With the photoelectric effect, scientists were unable to explain how this happens using the wave model of light. But when they thought of light as small particles, they could explain this effect. So scientists began to think of light as both a particle and a wave, and depending on what experiment you do, you will see light behave in one of these two ways. It is also important to note that the wave-particle duality extends to matter as well––it is not just limited to light—and the wave nature has been observed in experiments. It may be hard to imagine something like a “matter wave,” but when you are talking about small particles such as electrons, it is possible to observe wave-like behavior.

Quantum Tunneling

Quantum tunneling is one of the most interesting phenomena to be explained by quantum mechanics. As stated above, in quantum mechanics we talk about the probability of where a particle will be. The probably of finding a particle is explained by a probability wave. When that probability wave encounters an energy barrier, most of the wave will be reflected back, but a small portion of it will “leak” into the barrier. If the barrier is small enough, the wave that leaks through will continue on the other side of it. Even though the particle doesn't have enough energy to get over the barrier, there is still a small probability that it can “tunnel” through it! It would be like trying to drive over a river after part of the bridge has washed out. You couldn’t. But imagine that the gap in the bridge is really small—much smaller than the size of the tire on your car—and the situation changes. In a car, you can imagine jumping the small gap if you are going fast enough. Similarly, electrons can jump across small gaps.

Let's say you are throwing a rubber ball against a wall. You know you don't have enough energy to throw it through the wall, so you always expect it to bounce back. Quantum mechanics, however, says that there is a small probability that the ball could go right through the wall (without damaging the wall) and continue its flight on the other side! With something as large as a rubber ball, though, that probability is so small that you could throw the ball for billions of years and never see it go through the wall. But with something as tiny as an electron, tunneling is an everyday occurrence.

Uncertainty of Measurement

People are familiar with measuring things in the macroscopic world around them. Someone pulls out a tape measure and determines the length of a table. At the atomic scale of quantum mechanics, however, measurement becomes a very delicate process. Let's say you want to find out where an electron is and where it is going. How would you do it? Get a super high-powered magnifier and look for it? The very act of *looking* depends upon light, which is made of photons, and these photons could have enough momentum that once they hit the electron, they would change the electron’s course! So by looking at (trying to measure) the electron, you change where it is. Werner Heisenberg was the first to realize that certain pairs of measurements have an intrinsic uncertainty associated with them. In other words, there is a limit to how exact a measurement can be. This is usually not an issue at the macroscale, but it can be very important when dealing with small distances and high velocities at the nanoscale and smaller. For example, to know an electron’s position, you need to “freeze” it in a small space. In doing so, however, you get poor velocity data (since you had to make the velocity zero). If you are interested in knowing the exact velocity, you must let it move, but this gives you poor position data.

Why Do the Greater Surface Area to Volume Ratios Make a Difference?

Many of the observed properties of a substance are based on intermolecular forces. When we observe a large number of particles of that substance, the majority of the particles are in the interior of the material and subject to similar forces. But this is not true of the surface particles that experience forces not only from the substance but from the surrounding material as well.

For instance, suppose we have a liter of water at room temperature. Water molecules have a great deal of **polarity**, and as such, are attracted to each other via hydrogen bonds. These intermolecular hydrogen bonds cause water to be a liquid at room temperature. They also cause water to have a relatively high surface tension, resulting in the typical drop shape of water. What about at the water molecules at the edges of the container? Does the glass beaker have the same amount and type of attraction to the water as the water molecules have to each other? No, it is slightly different. The behavior of the water at the interface between the glass and water is different than within the interior of the water, where the water molecules are only surrounded by other water molecules. What about where the water molecules come into contact with the air? Does the air, composed of mostly nitrogen, have the same attraction to the water molecules as the water molecules have to each other? Again, no. In fact, the water molecules are not generally attracted to the molecules in the air very much at all. These examples highlight the fact that if you have a small (nano) amount of a substance, a greater proportion of the substance will have interactions with surrounding materials (e.g. container, air) than if you have a great (bulk) amount of the substance. This idea of greater surface area to volume ratio for small aggregations of substances can lead to different properties being displayed than for larger aggregations that have lower surface area to volume ratios.

The importance of surfaces is demonstrated by looking at a drop of water that is resting on a waxy surface such as wax paper (see Figure 1, below). We can see that the force of attraction of the water molecules to each other (cohesive forces) is far greater than the force of attraction of the water molecules to the surface of the wax paper (adhesive forces). This results in the drop shape of the collection of water molecules, which is evidence of a high surface tension. When the surface upon which the molecules rest is changed to one in which the molecules of water are more attracted such as plastic wrap, then the shape of water collapses, because the adhesive forces between the water and the plastic wrap are strong enough to overcome the cohesive forces (which we see as surface tension) between the water molecules. You can try this at home with drops of water on wax paper and plastic wrap. This example illustrates the impact of surface features on the behavior of a substance. Nanoscale objects have a far greater amount of surface area than volume, so surface effects are far more significant in general.

Another example of the importance of surfaces is rate of reaction. Since reactions occur at the interface of two substances, when a large percentage of the particles are located on the surface, we get maximum exposed surface area, which means maximum reactivity! So nanosized groups of particles can make great catalysts.

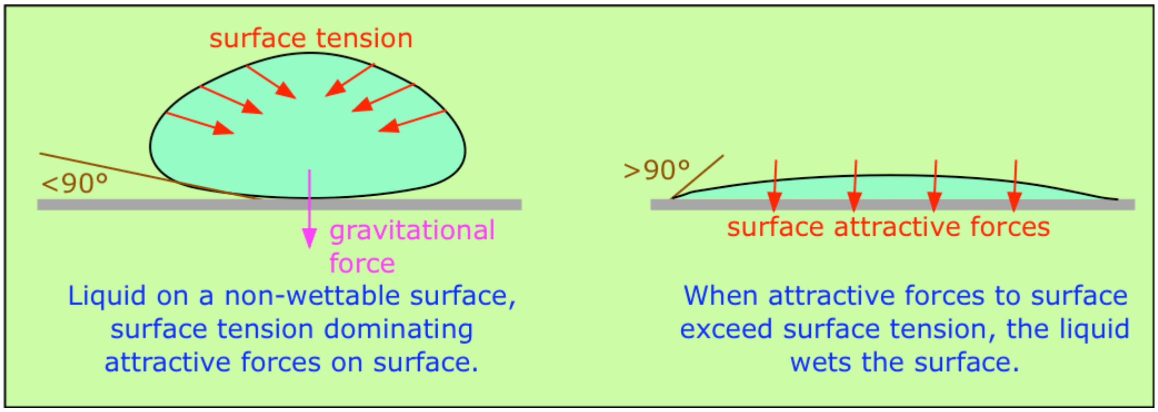

Figure 1. Surface tension and surface attractive forces for a drop of water on a non-wettable surface like glass (left), or a more attractive surface (right) [1].

Why Does Random Molecular Motion Make a Difference?

Random molecular motion is the movement that all molecules in a substance exhibit (assuming the sample is above **absolute zero**) due to their kinetic energy. This motion increases at higher temperatures (temperature is actually a macroscale measure of the average **kinetic energy** of all the particles in a substance). This motion can involve molecules moving around in space, rotating around their bonds, and vibrating along their bonds. While random kinetic motion is always present, at the macroscale this motion is very small compared to the sizes of the objects and thus is not very influential in how object behave. At the nanoscale however, these motions can be on the same scale as the size of the particles and thus have an important influence on how particles behave. For example, the imaginary nanosubmarine we talked about earlier would have its internal parts and mechanisms bending and flexing in all directions in constant random motion.

An example of how random kinetic motion can influence things is Brownian Motion [2]. Brownian Motion is the random movement of tiny particles suspended in a gas or a liquid resulting from bombardment by the fast moving particles of the gas or liquid. Think of a regular submarine in the ocean, even though it is constantly bombarded by the random kinetic motion of the water particles, it is so large that this does not significantly affect its motion through the water. Compare this to the imaginary nanosubmarine that would be constantly jostled around because the fluid molecules might be almost as big as it is!

So What Does This All Mean?

The dominance of electromagnetic force, the presence of quantum mechanical phenomena, the large surface area to volume ratio and the importance of random kinetic motion cause nanoscale sized particles to often have very different properties than their macroscale counterparts. The discovery that the properties of a substance can change with size (made possible by the new generation of scanning probe microscopes) has helped us to expand our understanding of the nature of matter and to develop new products that take advantage of the novel properties of materials at the nanoscale. As we continue to develop better tools and learn more about how and why these properties change, we will be better able to manipulate these properties to meet our needs and develop new materials and products that take advantage of these properties.

References

(Accessed August 2005.)

[1] http://www.chem1.com/acad/sci/aboutwater.html

[2] A nice animation of Brownian Motion is available through the Molecular Workbench software at http://mw.concord.org/modeler1.3/mirror/thermodynamics/brown.html

Glossary

Term	Definition
absolute zero	0 Kelvin (-273.15°C) is the coldest temperature theoretically possible at which all atomic motion stops.
aggregation	A group of something (in chemistry usually atoms or molecules).
classical mechanics	Scientific model useful for describing the behavior of macro and micro sized objects based on Newton's laws of force and motion.
electromagnetic forces	Particles with charge (or areas of charge) exert attractive or repulsive forces on each other due to this charge. Particles with magnetic properties exert attractive or repulsive forces on each other due to these magnetic properties. Since magnetism is caused by charged particles accelerating (for example by the electron "spin" in materials such as iron), these forces are considered to be two aspects of the same phenomenon and are collectively called electromagnetic forces.
kinetic energy	Energy of motion.
negligible	So small that it can be ignored.
polarity	The degree to which a molecule has a charge separation leading to one part of the molecule being partially positively charged and another part being partially negatively charged.
quantized	Something that is said to exist only in specific units and not all values along a continuum.
quantum mechanics	Scientific model useful for describing the behavior of very small particles (such as atoms and small molecules). Motion is described by probabilistic wave functions and energy can only exist in discrete (quantized) amounts.
wave function	A mathematical equation used in quantum mechanics to describe the wave characteristics of a particle. The value of the wave function of a particle at a given point of space and time is related to the likelihood of the particle's being there at the time.

Unique Properties Lab Activities: Student Directions

Lab Station A:
Serial Dilution

Purpose

The purpose of this lab is to investigate the effects of decreasing the concentration of a solution of the dual properties of color and odor. Nanosized materials, (from 1 to 100nm), often appear to have different colors and scents than they do at larger sizes.

Safety Precautions

- Wear goggles while conducting this lab.
- Do not eat or drink any solutions or chemicals.

Materials

- A stock solution "assigned" the value of 1.0 Molar
- Five test tubes that can hold 10-mL each
- One 25-mL graduated cylinder
- A test tube holder
- Grease marker
- Tap water
- One 1.0-mL graduated pipette, plastic or glass
- A sheet of white paper for background, to help students judge color

Procedures

Concentration

1. Label each of your test tubes from 1 to 5.
2. Use a pipette to place 10.0 mL of 1.0 Molar of colored solution into test tube #1.
3. Remove 1.0 mL from test tube #1 and inject this into test tube #2. Then add 9.0 mL of water into test tube #2.
4. Remove 1.0 mL from test tube #2 and inject this into test tube #3. Then add 9.0 mL of water into test tube #3.
5. Continue in this fashion until you have completed test tube #5.
6. Note that each subsequent test tube has the concentration of the previous test tube divided by 10.
7. **On your lab sheet,** record the concentration of the solution in each test tube.

Color

1. Hold the white paper behind your test tubes to determine the color change.
2. Use test tube #1 as the strongest color.
3. Continue from test tube #2 to #5 using the gauge below.

1	2	3	4	5
full strength of solution A	→ increasing lighter color			no visible color

4. **Record on your lab sheet** the strength of each test tube according to the scale above. At what strength are you no longer able to detect color? Explain why this has happened.

Odor

1. Waft, with your hand, the air over the top of the test tube towards your nose. Sniff. Record the strength of odor according to the scale below on you lab worksheet.
2. Use test tube #1 as the strongest odor.
3. Continue with test tube #2 to #5 in the same manner.

1	2	3	4	5
Odor in test tube #1	→ decreasing strength of odor			no odor

4. **Record on your lab sheet** the concentration at which the odor of your solution is no longer detectable. Record other observations and questions as asked on the lab sheet. Explain why you think this happened.

Lab Station B:
Ferrofluid Display Cell Lab

Purpose

The purpose of this lab is to design a series of activities that investigate and compare the force of magnetism in ferrofluid (small pieces of iron suspended in fluid) and in a solid piece of iron.

Safety Precautions

- **Do not shake or open the bottle of ferrofluid!**
- Use care when handling glass.

Materials

- One capped bottle of ferrofluid (nanoscopic iron particles suspended in a liquid)
- A 100-mL graduated cyclinder
- A large empty test tube, clear plastic if possible, and stopper
- A piece of iron rod, nail or washer
- Two circle magnets

Procedures

1. Make observations and record your observations of the ferrofluid and the iron object separately.
2. Predict how the magnet will influence the ferrofluid and the iron object.
3. Use the magnets to observe how the force of magnetism influences the ferrofluid and the iron object.
4. Record on your lab sheet your conclusions in the designated place on your lab sheet.

Lab Station C:
Bubbles Self-Assembly

Purpose

One of the methods proposed to mass manufacture nanosized objects is use nature's own natural tendency to self-assemble. Fluid or flexible objects will automatically fill the space of the container, taking the most efficient shape. The purpose of this lab is to demonstrate how bubbles self-assemble.

Safety Precautions

- Do not eat or drink anything in lab.
- Use caution when handling glassware.

Materials

- A bubble solution
- Small shallow dish
- Toothpicks
- Paper towels
- Straw

Procedures

1. Stir the solution with the straw to create bubbles, as needed.
2. Pour about 10.0 mL of bubble solution into the shallow dish.
3. **Caution: Be careful not to spill the solution or to drop the dish!**
4. Draw what you see in your worksheet. This is your "before" diagram.
5. Take the toothpick and pop one of the bubbles. Notice how the arrangement of bubbles changed. Draw what has happened. This is your "after" diagram. Repeat this procedure several times (you do not need to illustrate after the first "before" and "after" observations).

Lab Station D:
Surface Area to Volume Effects…
Which Shape Can Dissolve the Fastest?

Purpose

One of the characteristics of nanosized objects is that the surface area to volume ratio is much greater than bulk sized objects. The purpose of this lab investigation is to compare the effects of varying the surface area to volume ratio for two samples of the same substance and mass, but different particle size, on the rate of dissolving in water.

Safety Precautions

- Do not eat or drink anything in lab.
- Use caution when handling glassware.
- Wear safety goggles.

Materials

- Two sugar cubes
- Granulated sugar
- A digital balance or scale, with readout to 0.1 gram, or a triple beam balance
- Two 250-mL Erlenmeyer flasks
- A 100-mL graduated cylinder
- A grease marker
- Tap water, about 50-mL
- A clock or watch with a second hand

Procedures

1. Using a grease marker, label one Erlenmeyer flask #1 and the other #2**.** (These may have already been marked. No need to mark twice.)
2. Set the scale to zero, after placing a square of paper on top of the scale (this is called “taring”).
3. Measure and record the mass of two cubes of sugar. Put the sugar cubes into flask #1.
4. Measure and record a mass of granulated sugar equal to the mass of the two sugar cubes.
5. Put the granulated sugar into flask #2.
6. Using your graduated cylinder, add 100.0 mL of tap water to each flask.
7. Gently swirl each flask exactly 60 seconds.

8. Record the relative amount of sugar that has dissolved in each flask on your lab sheet.
9. Swirl each flask for another 60 seconds.
10. Record the relative amount of sugar that has dissolved in each flask on your lab sheet. Answer the questions asked about the rates of dissolving.

Lab Station E:
More Surface Effects… Faster Explosion?

Purpose

The purpose of the following activities is to give you more experience with examining the effects of changing surface area to volume ratios. **Faster explosion** looks at the effect of different surface area to volume ratios on the speed of reaction.

Safety Precautions

- Do not eat or drink anything in the lab.

Materials

- Two empty film canisters and their lids
- One tablet of Alka Seltzer®
- One small mortar and pestle
- One timer or watch with seconds hand

Procedures

1. Break the Alka Seltzer® tablet in half as exactly as you can.
2. Put one of the halves of the Alka Seltzer® tablet into the mortar and crush it with the pestle until it is finely granulated.
3. Place the uncrushed Alka Seltzer® and the crushed Alka Seltzer® each into a different film canister. Each canister should contain Alka Seltzer® before you proceed to the next step.
4. Simultaneously fill each film canister halfway with tap water. Quickly put their lids on.
5. On your lab sheet, record how much time it takes for each canister to blow its lid off.
6. Rinse the film canisters with water when finished.

Lab Station F:
More Surface Effects… Is All Water the Same?

Purpose

The purpose of the following activities is to provide students with more experience at examining the effects of changing surface area to volume ratios. This lab investigates different surface areas for the same volume of water on the speed of boiling.

Safety Precautions

- Wear safety goggles while conducting this investigation.
- Be careful when handling glass.
- Use extra caution when trying to move hot glassware. Either handle with tongs or wait until glassware is fully cooled.
- Be certain to turn off heat source when you have completed this investigation.

Materials

- Three different size beakers or flasks
- Hot plate(s) or 3 Bunsen burners
- One 100-mL graduated cylinder
- A centimeter ruler
- Tongs designed to use with glassware
- Clock or watch

Procedure

1. Fill in the chart on your lab sheet with the size and type of beaker or flask.
2. Fill each of the beakers with 100.0 mL of tap water.
3. Measure the diameter of each of your beakers and record to the nearest mm. For the Erlenmeyer flask, if you are using one, measure the diameter of the water when it is in the flask.
4. Turn on hotplate(s) or Bunsen burners to an equal flame or setting (if using more than one hotplate) **at the same time.** Record the start time on your lab sheet.
5. Record the time that the water begins to boil in each of the beakers/flasks. Record this time in the appropriate column on your lab sheet in the table provided.
6. Fill out the rest of the lab worksheet for this investigation.

Lab Station G:
Surface Area to Volume Effects… Burn Baby Burn!

Purpose

These activities demonstrate the effects of an increased surface area to volume ratio on the rate of combustion (burning).

Safety Precautions

- **Do not pick up any hot items with your fingers or with paper towels. Let cool first.**
- Wear safety goggles.
- Tie back any long hair.

Materials

- One solid rod of steel (or a nail)
- Two sets of tongs
- Two Bunsen burners and starters
- A 2” section of steel wool

Procedures

1. Light the two Bunsen burners to the same level of flame.
2. Pick up the steel rod or nail with the tongs and heat in the hottest part of the flame for 2 minutes, then remove from flame and let cool. Record your observations on your lab sheet.
3. Pick up the section of steel wool with the tongs and place in the hottest part of the flame for 2 minutes, then remove from flame and let cool. Record your observations on your lab sheet.
4. Once the objects are cooled, deposit any waste into the trash.
5. Answer questions on your lab sheet.

Lab Station H:
Surface Area to Volume Effects… Bet I Can Beat'cha!

Purpose

The purpose of this lab activity is to demonstrate the effect of varying surface area to volume ratios of the same materials on the rate of reaction.

Safety Precautions

- Wear goggles during this lab investigation.
- Don't eat or drink anything at your lab station.
- Deposit chemical waste according to the instructions of your teacher. Do not flush solution into the drain.
- Use caution when handling glassware.

Reagent

- $CuCl_2{\bullet}2H_2O$ crystals

Materials

- One teaspoon
- One glass stirring rod
- Two 100 mL beakers
- Two squares, 2 inches x 2 inches, of aluminum foil
- A pair of tongs
- Paper towels and a solid waste disposal
- A clock or watch with a second hand display

Procedures

1. Fill each of the 100 mL beakers about half full with tap water.
2. Add 1 teaspoon of $CuCl_2{\bullet}2H_2O$ crystals to each of the beakers of tap water and mix well with the stirring rod.
3. Form 1 piece of aluminum foil into a loose ball; leave the other piece as is.
4. Put each of the aluminum foil pieces into their own beaker.
5. On your lab sheet, record the time that it takes for each reaction to be complete.
6. Dispose of solution and waste according to your teacher's instructions.

Name___________________________________ Date______________________ Period ______

Unique Properties Lab Activities: Student Worksheet

Directions: Go to the lab stations assigned by your teacher. Follow the directions for the lab that are taped to each of the lab stations. Conduct the lab activity and record your data on this lab write up sheet. Answer the questions asked on this lab sheet. Be sure to pay special attention to the purpose of each lab.

Lab Station A: Serial Dilution

Record your data in the following chart:

Characteristics of Solution	Test tube #1 Initial	Test tube #2	Test tube #3	Test tube #4	Test tube #5 Final
Concentration/ Molarity					
Color					
Smell					

Questions

1. At what molarity of your solution was the color undetectable?

2. What pattern did you notice about the color of the solution as it decreased in strength?

3. At what molarity of your solution was the scent of your solution undetectable?

4. What pattern did you notice about the smell of the solution as it decreased in strength?

5. How does this phenomenon relate to the idea of properties of matter at the nanoscale?

Lab Station B:
Ferrofluid Display Cell Lab

Follow the directions posted at your lab station. Experiment with the ferrofluid, solid iron and magnets to discover the differences and the similarities of the two iron objects. Record your procedures (what you did), your observations (what you saw) and your discussion/conclusions (what you think about what you did and saw). Write down any questions that occurred to you regarding the objects.

Observations (ferrofluid and iron object separately):

Predictions:

Observations (interactions between magnets and: 1) ferrofluid and 2) iron object):

Discussion/Conclusions/Questions:

What difference do you think the size of the particles of iron made on their behavior?

Lab Station C:
Bubbles Self-Assembly

Conduct the lab activity according to directions posted at your lab station. Select a few instances to record in writing and sketch "before" and "after" pictures.

Drawings:

Before	**After**
Describe what you saw.	**Describe what happened.**

Questions

1. What do you conclude about bubbles ability to self-assemble?

2. What possible implications could the idea of self-assembly of objects have on the manufacturing of nanosized objects? You may refer back to your notes about self-assembly.

Lab Station D:
Surface Area to Volume Effects…
Which Shape Can Dissolve the Fastest?

Conduct this lab activity according to the directions on the lab station. Record your measurements here:

	Mass Record to the nearest 0.1 gram	Observations of sugar remaining after 1st 60-seconds of stirring	Observation of sugar remaining after 2nd 60-seconds of stirring
Sugar cube			
Granulated sugar			

Questions

1. What do you conclude about the relationship between the volume and surface area on the rate of dissolving?

2. Can you think of additional experiments to conduct?

Lab Station E:
More Surface Effects… Faster Explosion?

Record the time it takes to blow the lid off of each film canister:

	Time it takes for lid to blow off
Film canister with 1/2 Alka Selzer tablet *not* crushed:	
Film canister with 1/2 Alka Selzer tablet crushed:	

What do you conclude about the surface-to-volume effects on the speed of reaction based on this experiment?

Lab Station F:
More Surface Effects… Is All Water the Same?

Record the size of each beaker and the time it takes for the water in each beaker to boil.

A	B	C	D	E	F	G	H
Type of container for the water	Diameter of surface of water (cm)	Radius of surface of water (cm)	Surface area of water (cm^2)	Surface area to volume ratio	Initial time heat is applied	Time when water boils	Total time taken for water to boil

Hints to fill out the chart:

- A is name of the type of container and the capacity, i.e. 100-mL beaker.
- B is the diameter of the surface of the water in each beaker, in centimeters; measure across the surface of the water in each container.
- C is the radius of the surface of the water in each beaker; divide the diameter (column B) by 2.
- D is the surface area of the water in each beaker (cm^2); calculate using πr^2 where π= ***pi* = 3.14** and r = radius.
- E is the surface area to volume ratio of water in each beaker, that is, the surface of the water (column D) divided by the volume of the water. Use the smallest whole number ratio; e.g., 2:1 means the surface area is twice the volume of the water.
- F, G, and H are times in minutes and seconds. H is column G minus column F.

Question

What do you conclude about the surface-to-volume ratio and the time it takes to boil?

Lab Station G:
Surface Area to Volume Effects… Burn Baby Burn!

Compare and contrast your observations between when the steel sample was heated and when the steel wool was heated.

What do you conclude about surface-to-volume ratios and the speed of combustion (burning)?

Speculate based on evidence: What effect(s) do you think that the increased surface area of nanosized objects make compared to bigger objects? What evidence do you have that supports your thinking?

Lab Station H:
Surface Area to Volume Effects… Bet I Can Beat'cha!

Record the time that it takes for the aluminum foil to come within an estimated 80% of a completed reaction.

	Time for foil to come within 80% of completed reaction, in seconds
Flat square of aluminum foil	
Balled-up piece of aluminum foil	

What do you conclude about the effects of surface-to-volume ratio and reaction rates?

Name_________________________________ Date_____________________ Period ______

Unique Properties at the Nanoscale: Student Quiz

For questions 1-4, choose which force best matches the statement. *(1 point each)*

a. gravitational force b. electromagnetic forces

_____ 1. Describe(s) the attraction of the masses of two particles to each other.

_____ 2. Dominate(s) for nanosized objects.

_____ 3. Do/does not vary with mass.

_____ 4. Stronger for objects with greater mass.

5. Identify a property that doesn't have meaning when you only have a few nanosized particles, and explain why. *(2 points)*

6. Compare the surface-to-volume ratios of a large piece of gold with a nanosized piece of gold. *(1 point)*

7. Explain in your own words why surface-to-volume ratios are important in determining the properties of a substance. You may use a drawing or example to help clarify your explanation. *(3 points)*

8. Name and explain three properties that are likely to change as when an object is nanosized. You may give examples to help clarify your explanation. *(3 points)*

9. Explain the concept of electron tunneling and address why this may be a problem for nanosized objects. *(2 points)*