NanoSense

Student Materials

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CK12 Editor

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CHAPTER 1 Size Matters-Student Materials

CHAPTER OUTLINE

1.1 Introduction to Nanoscience

Unit Overview

Contents

- (Optional) Size Matters: Pretest
- (Optional) Size Matters: Posttest

Name_______________

Date_______________

Period_______________

Size Matters: Pretest

1. How big is a nanometer compared to a meter? List one object that is nanosized, one that is smaller, and one that is larger but still not visible to the naked eye.

2. Name two properties that can differ for nanosized objects and much larger objects of the same substance. For each property, give a specific example.

3. Describe two reasons why properties of nanosized objects are sometimes different than those of the same substance at the bulk scale.

4. What do we mean when we talk about "seeing" at the nanoscale?

5. Choose one technology for seeing at the nanoscale and briefly explain how it works.

6. Describe one application (or potential application) of nanoscience and its possible effects on society.

Name_______________

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Introduction to Nanoscience

Contents

Student Reading

What is Nanoscience?

Way back in 1959, a physicist named Richard Feynman shared his vision of what very small things would look like and how they would behave. In a speech at the California Institute of Technology titled "There's Plenty of Room at the Bottom," Feynman gave the first hint about what we now know as **"nanoscience"**[1]:

"The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things **atom** by atom."

More generally, nanoscience is the study of the behavior of objects at a very small scale, roughly 1 to 100 nanometers (nm) . One nanometer is one billionth of a meter, or the length of 10 hydrogen atoms lined up. Nanosized structures include the smallest of human-made devices and the largest **molecules** of living systems.

What is the Big Deal About Nanoscience?

You might ask, "What is the big deal with nanoscience? Isn't it just a bunch of really small things?" It is, in fact, a bunch of small things. But it is a whole lot more. What makes the science at the nanoscales pecial is that at such a small scale, while all physical laws affect the behavior of matter, different laws dominate over those that we experience in our everyday lives. For example, the **element** gold (Au) as we are used to seeing it has a nice yellowish-brown color to it—the color we know as "gold." However, if you had only 100 gold atoms arranged in a cube, this block of gold would look very different—its color would be much more red. Color is just one property (optical) that is different at the nanoscale. Other properties, such a flexibility/strength (mechanical) and **conductivity** (electrical) are often very different at the nanoscale as well.

Surface Area is Big!

The smaller something is, the larger its surface area is compared to its volume. This high surface-to-volume ratio is a very important characteristic of **nanoparticles**.

For example, imagine that you have a big block of ice with one-meter sides (see Figure 1). This block has a surface area of 6 square meters (1 square meter on a side $\times 6$ sides) and a volume of 1 cubic meter . In this case, the surface area to volume ratio for the ice block is $6/1$ or 6 .

Suppose that cut the ice into 8 pieces that are one-half of a meter per side. The surface area of each piece of ice would be 1.5 square meters ($0.5 \text{ m} \times 0.5 \text{ m} \times 6$ sides). So the total surface area of all the pieces would be 12 square meters . However, the total volume of ice would stay the same: we haven't added or removed any ice. So in this case, the surface area to volume ratio is $12/1$, or 12 —twice the surface area to volume ratio of the block before it was cut. If you cut the ice into 27 pieces, the surface area increases to 18 square meters , and the surface area to volume ratio is $18/1$ or three times that of the uncut block. If you keep going, and cut the ice into 1000 small pieces, the surface area to volume ratio is $60/1$ or ten times that of the uncut block!

Imagine how big the surface area to volume ratio would be for something as small as a bunch of **nanoscale** particles.

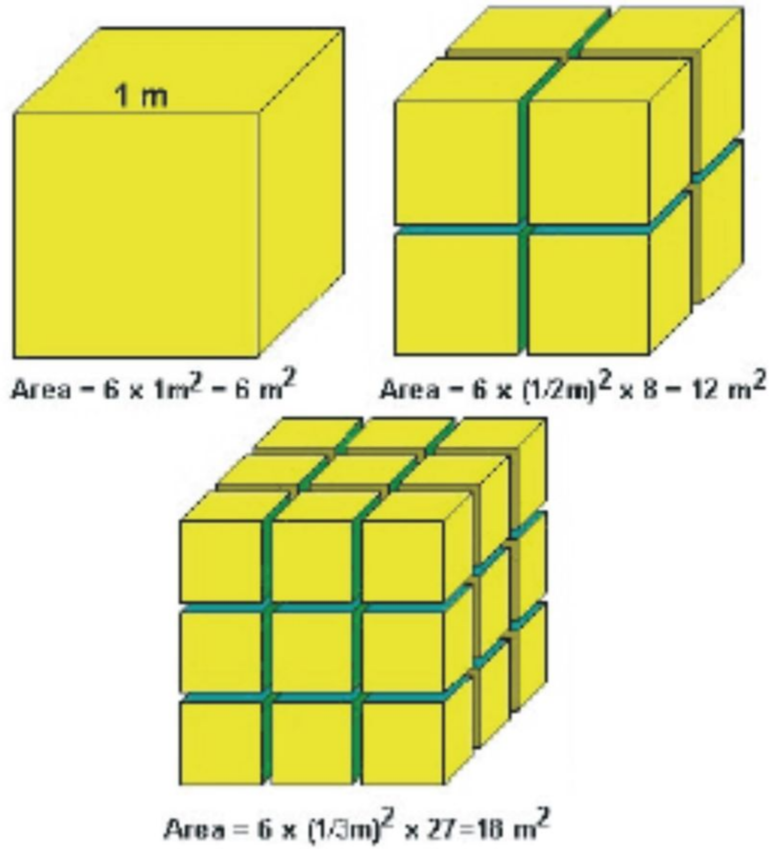

FIGURE 1.1

Total surface area increases as you cut the block into smaller pieces but the total volume stays constant

2

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The vastly increased ratio of surface area to volume makes interactions between the surfaces of particles very important. If something has more surface area, there are more places for other chemicals to bind or react with it. For example, fine powders offer greater reaction speed because of the increased surface area. Think about how much faster you can cool a glass of water if you put crushed ice in it rather than ice cubes.

Nanoscale particles maximize surface area, and therefore maximize possible **reactivity!**

Why is Large Surface Area Important?

The large surface area to volume ratio of nanoparticles opens many possibilities for creating new materials and facilitating chemical processes. In conventional materials, most of the atoms are not at a surface; they form the bulk of the material. In **nanomaterials**, this bulk does not exist. Indeed, **nanotechnology** is often concerned with single layers of atoms on surfaces. Materials with this property are unique. For example, they can serve as very potent **catalysts** or be applied in thin films to serve as thermal barriers or to improve wear resistance of materials.

Can We Make Small Devices?

Yes indeed. Over the past few decades, there have been many attempts to create devices at a small scale. If you look at the evolution of technology all around us, you'll notice that it's continually getting smaller.

Back in 1965, Gordon E. Moore (co-founder of Intel) observed that the number of **transistors** squeezed onto a computer chip roughly doubles every 18 months. This "rule" is known as "Moore's Law." The more transistors on a chip, the smaller their size and closer their spacing (see Figure 2). And as size decreases, speed and performance rise rapidly. This is why computers the size of a room in the 1950s now fit on your lap.

Indeed, many modern-day electronics already contain nanoscale-size components. For the **semiconductor** industry (Figure 2), nanotechnology has been the result of a continuous series of improvements in processing and materials over decades. Moore's Law won't last forever, though. At some point, the laws of physics will make it impossible to keep downsizing microelectronics at this exponential rate. Why? Because eventually, you get down to manipulating individual molecules, and at that level, a few atoms out of place could ruin an entire computer chip. The packed-in transistors also generate a lot of heat, which could melt the chip. Engineers are looking to nanoscience for tools and materials to enable computer chip manufacturing on an atomic scale. [4]

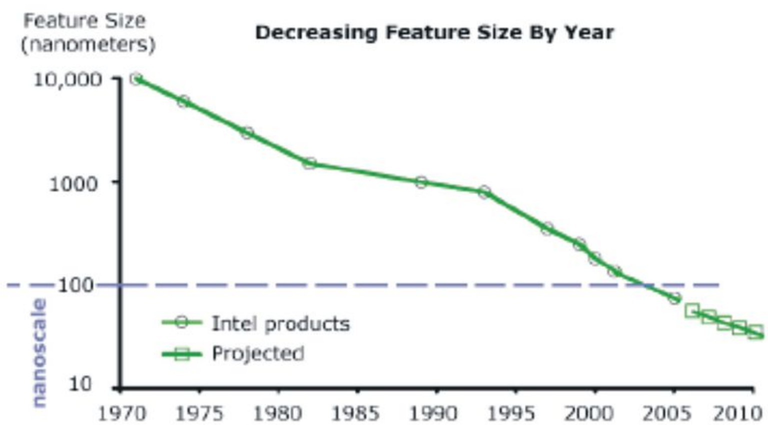

FIGURE 1.2
The decreasing minimum feature size of transistor components

3

. Note that size is graphed on a logarithmic scale so the change is exponential.

Another group of devices that are considered small, but not quite at the nanoscale, are **MEMS (micro-electromechanical systems)** devices. Imagine machines built to the scale of microns, with gears, motors, levers, and so on, which are capable of moving things. One useful application of MEMS devices is in tiny acceleration **sensors** that quickly deploy the airbags in your car during an accident.

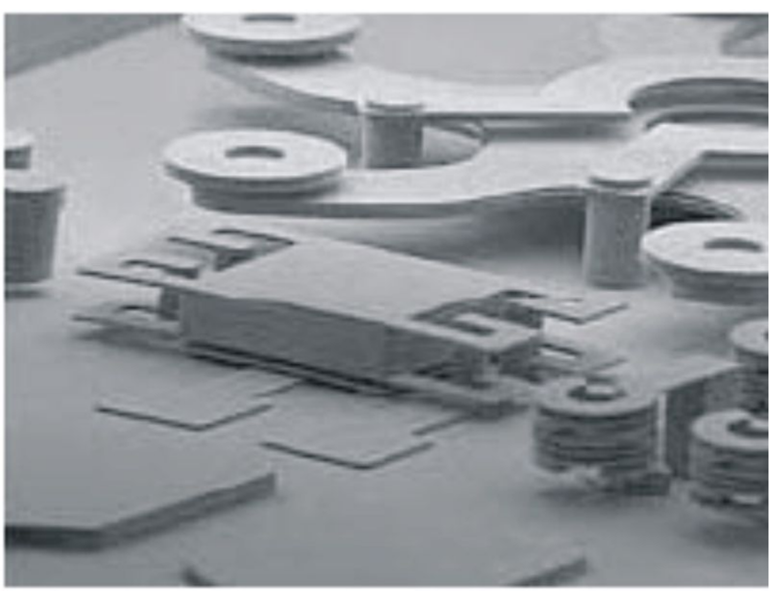

FIGURE 1.3
MEMS accelerometer

5

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What Kind of Nanostructures Can We Make?

Two interesting structures that have been constructed and fall into the nanoscale range are carbon nanotubes and buckyballs. You'll find these structures mentioned in almost any book or article on nanotechnology. Like diamond, carbon nanotubes and buckyballs are constructed solely out of carbon atoms. (Because carbon bonds so strongly to itself, it is a natural for use in nanotechnology.) What is most interesting about these two structures is that they possess some very unusual **chemical** and **physical properties**.

What is a Carbon Nanotube?

Carbon nanotubes are cylindrical carbon molecules with interesting properties. For example, they can be made to be excellent **electrical conductors** or **semiconductors** just by controlling how they are formed ("rolled"). With traditional materials, you have to add chemicals or elements to them to make them behave as conductors. With nanotubes, you just twist them! Another unique property of nanotubes is that they are very resilient and flexible, as well as extremely strong. We also know that nanotubes are very **"hydrophobic"**—they don't like water—and that they bind easily to proteins. Because of this last property, they can serve as chemical and biological sensors by being sensitive to certain molecules but not others by coating them in different ways. Nanotubes can also be made from elements other than carbon, such as gold and silver. Although they are not as strong as carbon nanotubes, they also have unique electrical and optical properties.

How Could Nanotubes be Used?

Carbon nanotubes have been used in a wide variety of products. For example, Toyota uses a carbon-nanotube-based composite in the bumpers and door panels of some of its cars, not only to make them stronger and lighter but also to make painting them easier since carbon nanotubes make the plastic electrically conductive so that the same electrically bonding paints that are used on metal parts can be applied.

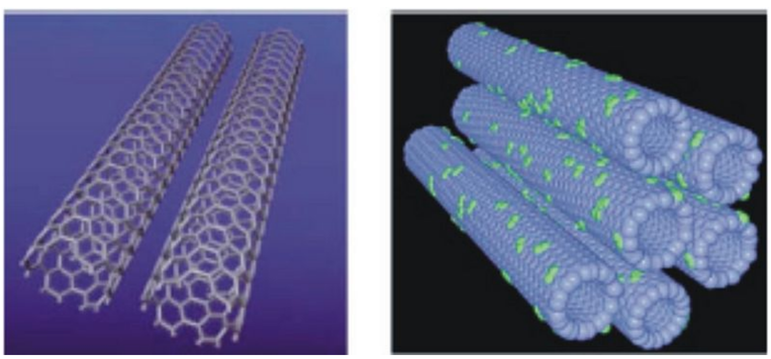

FIGURE 1.4
Computer-generated models of carbon nanotubes
6 7

What is a Buckyball?

Buckyballs also have a unique set of properties that are based on their structure. Notice how the molecular model of the buckyball looks like a soccer ball. The usual structure for this molecule is made of 60 carbon atoms arranged in a soccer ball-like shape that is less than one nanometer in diameter. Because of the "hollow-ball" shape of this structure, scientists are currently testing to see how effective buckyballs are as drug carriers in the body. The hollow structure can fit a molecule of a particular drug inside, while the outside of the buckyball is resistant to interaction with other molecules in the body. Even though much more research is needed in this area, buckyballs appear to be relatively safe functional drug "containers" that can enter cells, without reacting with them.

What Nanostructures Exist in Nature?

There are many natural nanoscale devices that exist in our biological world. Some examples are **ion pumps**, "molecular motors," and photosynthetic processes. Inside all cells, molecules and particles of various sizes have to move around. Some molecules can move by diffusion, but ions and other charged particles, such as **neurotransmitters**, have to be specifically transported around cells and across membranes. The classic example of an active ion pump

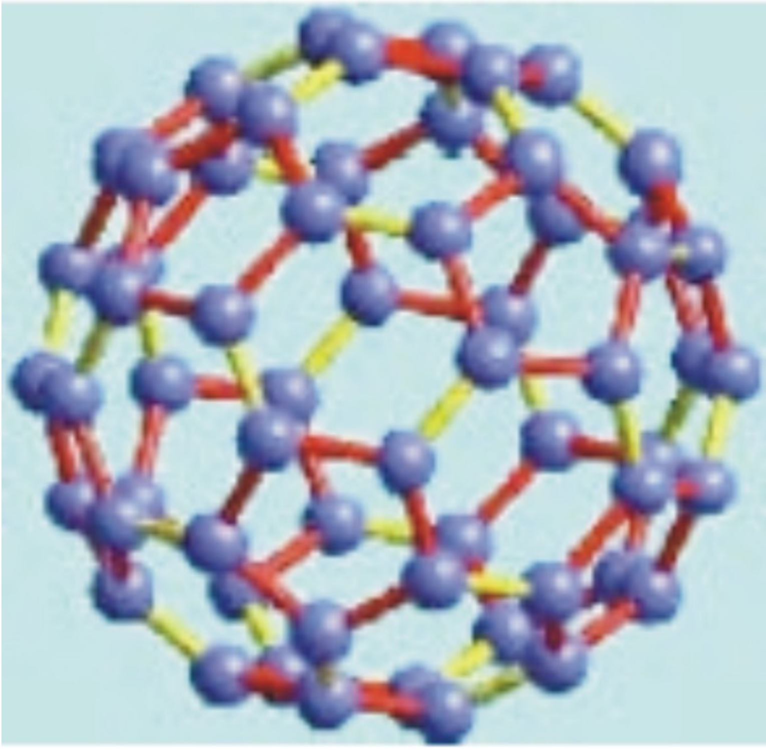

FIGURE 1.5
Model of a buckyball with single bonds *red* and double bonds *yellow* highlighted
8
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is in the **enzyme** ATP synthase. In this enzyme, the a central protein structure rotates as ATP is synthesized and ions are moved across a cellular membrane.

Another example is kinesin. Kinesin is a molecular motor that transports larger particles around cells on microtubules. The kinesin molecule acts like a train car on a microtubule nanosized track to carry **proteins** and larger particles to specific sites in cells. The **photosynthetic** machinery in plants (chloroplast) and bacteria is also a complex nanomachine. It includes a light-harvesting component, a reaction center, and an ion pump, all arranged in a specific layout within the cell membrane that allows for the conversion of light into energy that the plant can use.

So How Do We "See" These Small Things?

As the field of nanoscience has grown, new tools have made it easier for scientists to see, image, and manipulate atoms and molecules. One type of microscope that works at the nanoscale is the **scanning tunneling microscope (STM)** which was developed in 1981. The very end of the tip of this microscope is one atom in size. The "tunneling" of electrons (**quantum tunneling**) between the tip and the substance being viewed creates a current (flow of electrons). The strength of the current and how it changes over time can be used to create an image of the surface of the substance. Today's scanning microscopes can do much more than just see. Among other things, they can be used to move atoms around and arrange them in a preferred order.

A different type of microscope, the **atomic force microscope (AFM)**, uses a tiny tip that moves in response to the **electromagnetic forces** between the atoms of the surface and the tip. As the tip moves up and down, the motion is recorded and an electronic image of the atomic surface is formed.

How Do You Build Things That Are So Small?

Building nanoscale devices isn't quite as straightforward as simply making your tools smaller and using powerful microscopes. When you are dealing with objects at this scale, things literally start to become very "sticky." Nanoparticles are attracted to each other via electrostatic forces, and this effect makes it very hard to handle and move things that are very, very small.

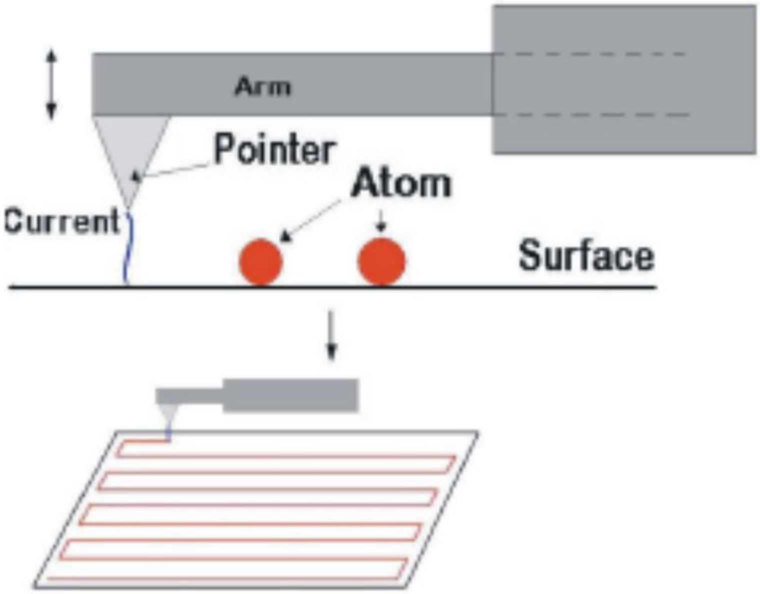

FIGURE 1.6
Schematic of a scanning tunneling microscope
9

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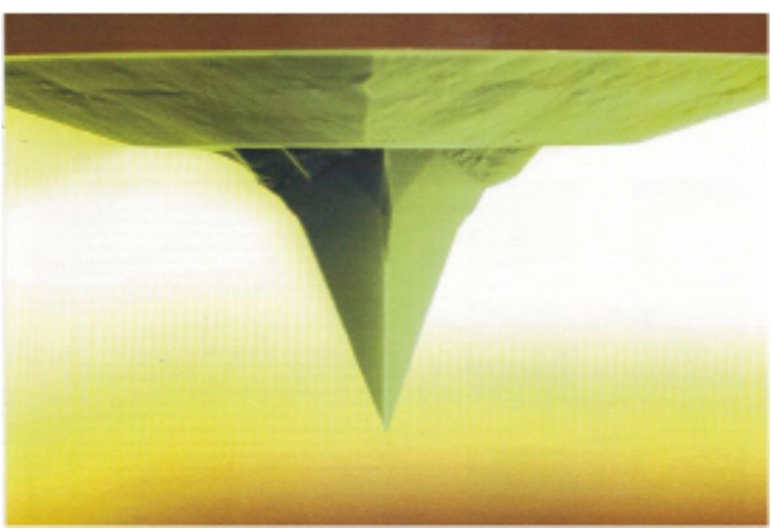

FIGURE 1.7
Tip of an atomic force microscope
10

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However, this difficulty hasn't stopped advances in how scientists and engineers build or fabricate nanomaterials. Here are the main nanofabrication techniques that are used to build small things:

1. Atom-by-Atom Assembly

Assembly atom-by-atom is similar to bricklaying in that atoms are moved into place one at a time using tools like the STM and AFM. Using this technique, scientists have, for example, positioned xenon atoms on nickel and buckyballs on copper to create nanoscale structures like the IBM logo and nanoscale abacus shown below. As you might guess, building structures one atom at a time is very time consuming. Examples of this type of assembly have typically been "proof of concept" to show that it can be done but don't necessarily have practical application because the process is expensive and slow.

FIGURE 1.8

IBM logo assembled from individual xenon atoms arranged on a nickel surface 11

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2. Chisel Away Atoms

Imagine taking a block of wood or stone and carving it away to create an object that you want. The smallest features you can create depend on the tools you use.

Like sculptors, scientists can also chisel out material from a surface until the desired structure emerges. The computer industry uses this approach when they create integrated circuits. They use a process called photolithography, in which patterned areas of material are etched away through physical or chemical processes.

3. Self-Assembly

Self-assembly means setting up an environment such that atoms assemble or grow automatically on prepared surfaces. In this approach, an environment is created in which structures assemble automatically. Examples include chemical vapor deposition and the patterned growth of nanotubes. Nature, of course, uses self-assembly mechanisms, such as the self-assembly of cell membranes. Our ability to create nanostructures improves as we gain understanding of biological self-assembly, develop new molecular structures, and construct new tools.

Summary

Although substances have existed for a long time that are composed of nanosized particles, it has been only after the invention of the new AFM and STM category of microscopes that we have been able to observe, gather data on, and even manipulate molecules and atoms. We are discovering that when molecules and atoms assemble into particles between 1 and 100 nanometers in size, different laws dominate at that scale than in our everyday experience of objects. Unique properties begin to emerge for substances at the nanoscale, including unique optical, mechanical, electrical, and thermal properties.

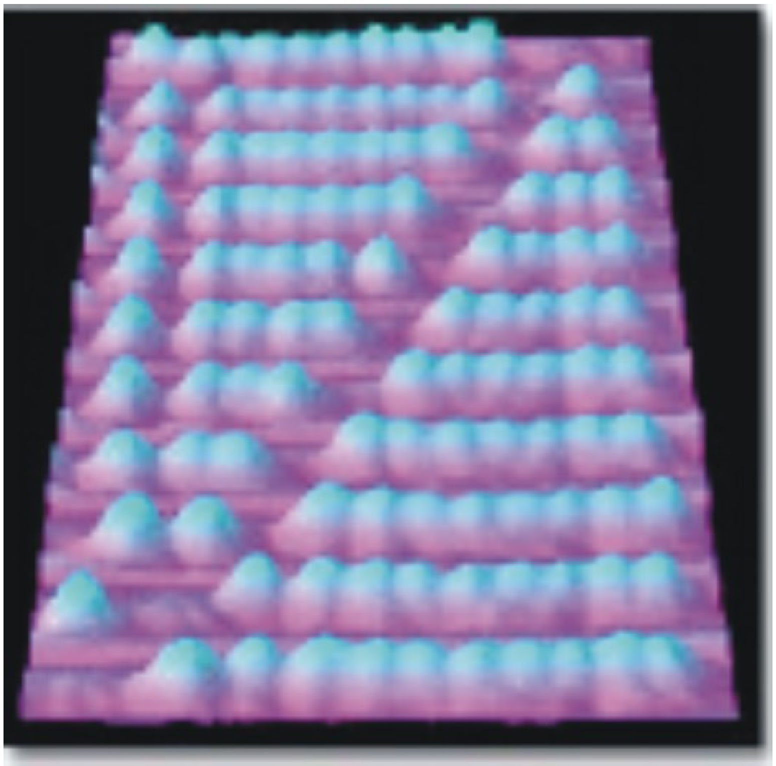

FIGURE 1.9
Nanoscale abacus buckyball &#8220 beads&#8221 placed on a copper surface

12

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Nanoscale science is an exciting area of current research. Applications in information technology, medicine, composite materials, and other fields, are now open for further exploration. Nanoscience is emerging as a way to describe the behavior of substances in biology, chemistry, physics, earth science, metrology, medicine, and engineering. It is a truly interdisciplinary field that can be the basis for the development of new, even revolutionary technologies of all kinds. These little particles and devices may soon have a huge impact on our daily lives.

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Glossary

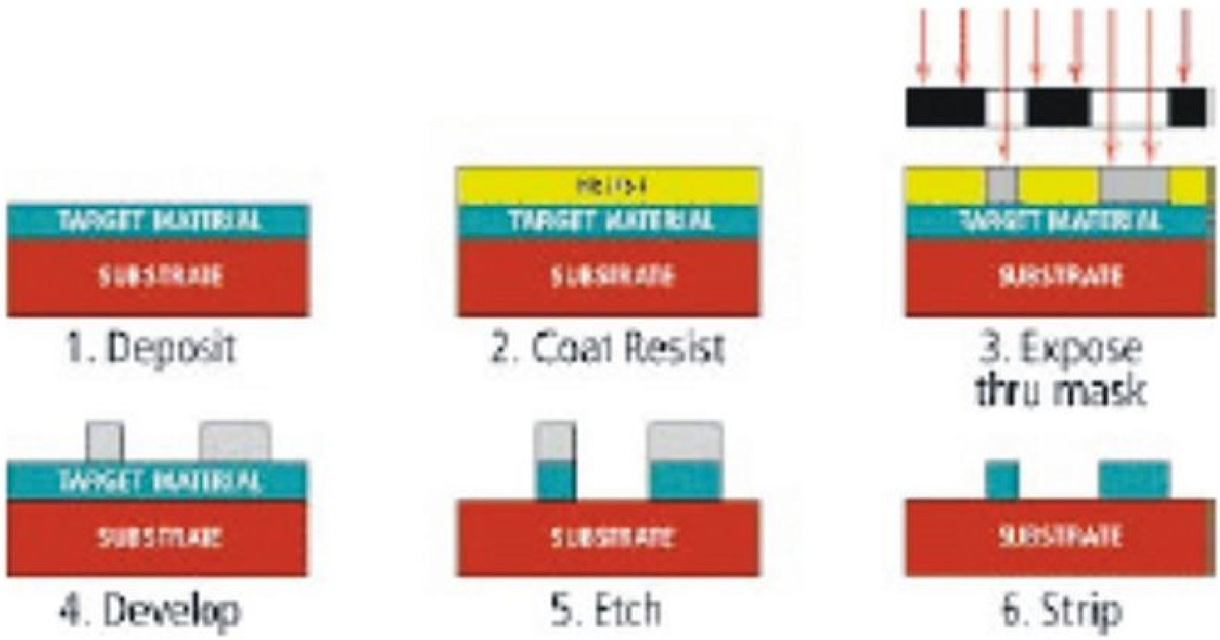

FIGURE 1.10
Photolithography a process of chiseling away material to make integrated circuits

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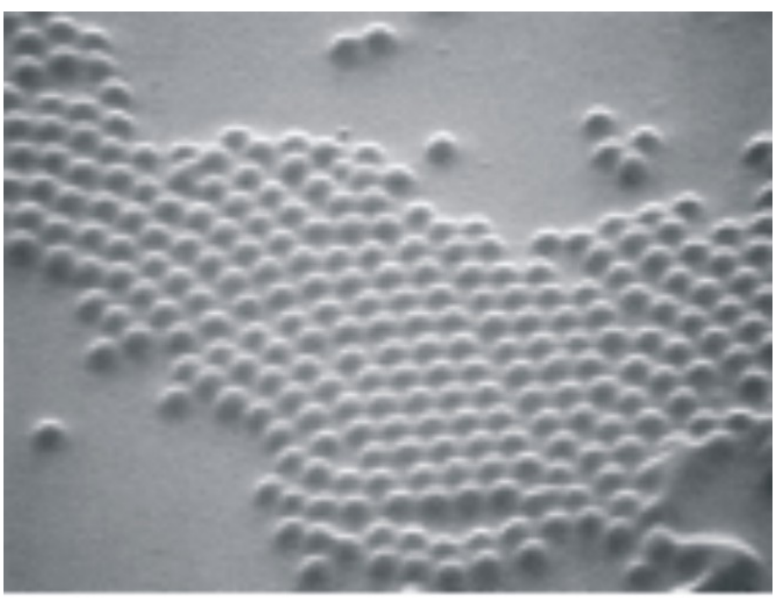

FIGURE 1.11
Polystyrene spheres self-assembling

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atom The smallest particle of an element that retains the chemical identity of the element; made up of negatively charged electrons, positively charged protons, and uncharged neutrons.

atomic force microscope (AFM) A high-powered instrument able to image surfaces to molecular accuracy by mechanically probing their surface contours.

catalyst A material that speeds up a chemical reaction without being used itself.

chemical property A characteristic of a substance that cannot be observed without altering the identity of the substance, only can be observed when substances interact with one another.

chemical bond A mutual attraction between different atoms that bonds the atoms together.

conductor A material that contains movable charges of electricity. When an electric potential difference is impressed across separate points on a conductor, the mobile charges within the conductor are forced to move, and an electric current between those points appears in accordance with Ohm's law.

electrical conductivity The current (movement of charged particles) through a material in response to electrical forces. The underlying mechanism for this movement depends on the type of material.

electrical conductor A material that contains charges that can move freely throughout the material. When these charges are forced to move in a regular pattern from one point towards another (due to an electrical force), this movement is called a current.

electrical insulator A material that does not allow electricity to flow through it.

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.

electrostatic force The attractive or repulsive force between two particles as a result of their charges. Like charges repel, unlike or different charges attract. The size of the force increases as the amount of charge on the particle increases, and the force rapidly decreases as the distance between the two particles increase.

element A substance that cannot be separated into simpler substances by a chemical change; simplest type of pure substance.

enzyme A protein that catalyzes a chemical reaction.

hydrophobic Water repelling.

ion pump A mechanism of active transport that moves potassium ions into and sodium ions out of a cell.

MEMS (micro-electro-mechanical systems) A technology that combines computers with tiny mechanical devices such as sensors, valves, gears, mirrors, and actuators embedded in semiconductor chips.

molecule The smallest particle of a substance that retains all of the properties of the substance and is composed of two or more atoms bonded by the sharing of electrons.

nanomaterial A material with an average grain size less than 100 nanometers .

nanometer One-billionth of a meter $(10 - 9 \text{ m})$. The prefix 'nano' is derived from the Greek word for dwarf because a nanometer is very small. Ten hydrogen atoms lined up side-by-side are about 1 nanometer long.

nanoparticle A microscopic particle whose size is measured in nanometers.

nanoscale Refers to objects with sizes in the range of 1 to 100 nanometers in at least one dimension.

nanoscience The study of phenomena at the nanoscale (e.g. atoms, molecules and macromolecular structures), where properties differ significantly from those at a larger scale.

nanotechnology The design, characterization, production and application of structures, devices and systems that take advantage of the special properties at the nanoscale by manipulating shape and size.

neurotransmitter A chemical substance responsible for communication among nerve cells. Typically reside in sacs at the end of an axon that carries nerve impulses across a synapse.

physical property Properties that can be measured without changing the composition of a substance, such as color and freezing point.

photosynthesis A biochemical process in which cells in plants, algae, and some bacteria use light energy to convert inorganic molecules into ATP, a source of energy for cellular reactions.

protein A compound whose structure is dictated by DNA. Proteins perform a wide variety of functions in the cell including serving as enzymes, structural components, or signaling molecules.

quantum tunneling A phenomenon in which a very small particle passes through an energy state that is "classically-forbidden" (meaning that it is not possible based on Newton's laws of physics). Another way of saying this is that the particles can pass through barriers that should be impenetrable and be found in places that Newton's laws would predict to be impossible. The classical analogy is for a car on a roller coaster to make it up and over a hill that it does not have enough kinetic energy (energy of motion) to surmount.

reactivity A substance's susceptibility to undergoing a chemical reaction or change that may result in side effects, such as an explosion, burning, and corrosion or toxic emissions.

scanning tunneling microscope (STM) A machine capable of revealing the atomic structure of particles. The microscope uses a needle-like probe to extend a single atom near the object under observation. When the probe is close enough, an electromagnetic current can be detected. The probe then sends a tiny voltage charge. This charge creates an effect known as tunneling current. The tunneling current is measured by scanning the surface of the object and mapping the distance at various points, generating a 3D image. Scanning tunneling microscopes have also been used to produce changes in the molecular composition of substances.

semiconductor A solid material whose electrical conductivity is greater than an **electrical insulator** but less than that of a good **electrical conductor**. The conductivity of semiconductors can also be manipulated by "doping" - adding certain impurities that change the ways electrons can travel through the material. This makes semiconductors a useful material for computer chips and other electronic devices

sensor A device, such as a photoelectric cell, that receives and responds to a signal or stimulus.

transistor A tiny device that turns the flow of electrons on and off to regulate electricity in a circuit. This on/off ability is used to represent binary digits, the digital data used for storing and transmitting information in a computer.

Name_______________

Date_______________

Period_______________

Student Worksheet

Below is a set of questions to answer during and/or following the introduction to nanoscience slide presentation.

1. What is the range of the "nanoscale"?

2. What is the smallest size (in meters) that the human eye can see?

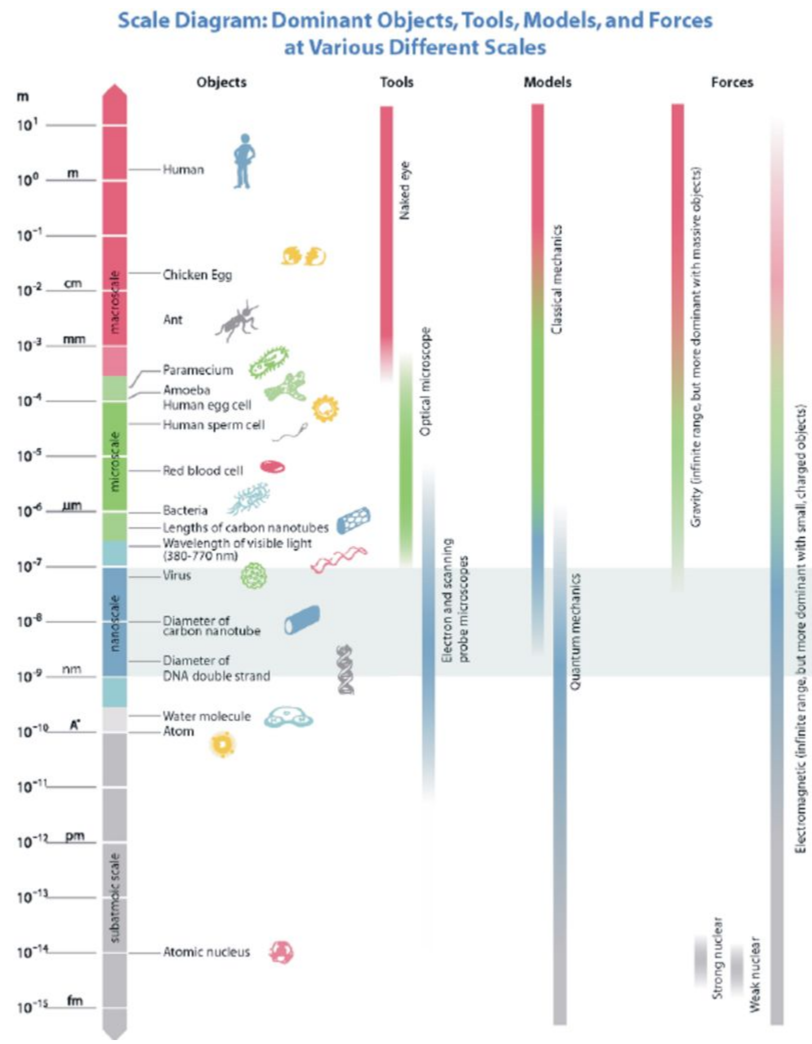
3. How much more "power" can a light microscope add to the unaided eye? In other words, what is the smallest resolution that a light microscope can show?

4. Briefly describe how light microscopes and electron microscopes work.

5. Name one of the new microscopes that scientists have used to view objects at the nanoscale and explain how that microscope allows you to view objects.

6. Give a short explanation of why the nanoscale is "special."

7. Name one example of a nanoscale structure and describe its interesting properties.



The Personal Touch (Prom Day, 2045 A.D.): Student Reading

"So, Aladdin, how'm I doin'?" Sandra asked the household artificial intelligence (AI) as she walked into the bathroom.

Recognizing her unique voiceprint, the system answered, "Sandra, if you place your hand on the wall panel, I'll do a quick checkup."[1]

[1] Although a voiceprint is a highly accurate identifier,the touch panel that reads both fingerprints and DNA in the skin is an extra insurance of privacy.

"OK," Sandra slapped her hand against the panel, "and you can start the shower for me."

"Sandra," the bathroom said, "you should take a "C" tablet after you finish your shower. You are starting to show signs of a cold. Otherwise all your physical functions appear to be fine. There is one exception; your pulse rate is slightly elevated." [2]

[2] Two approaches could be used for sensing Sandra's physical conditions: Chronic embedded nanosensors that emit signals to be picked up by nearby analytic equipment, or nanosensors that read the presence of substances in the body by contact with the skin or sampling breath.

"OK!" she replied, stepping into the stream of water. "Guess the pulse rate is just because I'm looking forward to the prom tonight." Sandra knew that the diagnostic intelligence built into the house AI didn't care if she answered or not, but somehow it seemed to have a personality.

As she adjusted the hot water, enjoying the play of the hot shower on her skin, the communication implant below her ear signaled for attention. [3]

[3] Communication devices will be built of components assembled at a molecular level and will be able to receive and transmit to local "WiFi" devices in the environment (e.g., house or car). Implants placed on bone tissue near the ear could generate sound that would be heard through bone conduction. The scale of memory devices will permit application specific computers to operate with minimal power, such as that generated from room lights or body heat.

"It's Victoria calling, do you wish to answer?" the implant said through bone conduction.

"Yes, put her on... Hi, Vicky! What's up?"

"Hi, Sandy. So, hey, did you end up renting that Lauren Sigali gown we were talking about?"

"Yeah, and it's awesome. I was playing with it today. It can even generate dynamic patterns," Sandy replied. [4]

[4] Quantum dots embedded in the fabric of clothing may be controlled to switch colors and create patterns based on electrical impulses from a device sold with the clothing.

"That is so cool. Mine isn't as good as that, but it has great shading and pretty good luminosity. So what color are you going to hue it? I think you should wear blue...it will go with your eyes."

"Yeah. A pale blue...I like that. And I could play a pattern when we start dancing. How about you, Vic?"

"I think I'll hue mine a bright red...make me stand out from the crowd. Maybe I'll flip to green when we dance."

"Sounds great, Vic. So did you hear that Munira got an ad gown? It was free."

"Ugh. I just hope it doesn't play one of those tacky logo collages."

"So, what kind of pattern could I make that's personal for this evening?"

They talked for another fifteen minutes before Sandra finally said, "Phone disconnect."

After toweling off and taking the "C' tablet, she turned her attention to makeup. [5] The oil in the cosmetics was broken down so finely that it felt like a second skin. In addition, it acted as a sunblock, which was important here in Nanocity, Arizona. [6]

[5] The "C" tablet contains nanobiological machines that attract and attach to viruses, preventing them from infiltrating cells.

[6] Nanobots are used to break the oil down into smaller molecular clusters than can be done with refining methods alone.

For the thousandth time Sandra wondered why Nanocity had to be built so far away from any other place. She understood that when the geostationary orbiting space platform had been tethered to the ground, more than half the country thought it would be dangerous. [7] Now, years later, with the "splatform" still up there, and being the key to space exploration and research, nobody worried.

[7] The tether, made of carbon nanotubes weaved into a huge cable, reaches from the ground station to the splatform about $36,000$ kilometers above the earth. Fibers of the cable are electrically conductive, permitting transmission of power to elevator motors, which lift items into space much more economically than rockets could.

Her dad—who managed the ground station, the tether, and the elevator up to the spatform—had mentioned that there were other political problems to deal with now. In fact, her boyfriend, Lenny had told her that his mother was up at the splatform doing some controversial experiments.

As Sandra took her leisurely time preparing for the evening, Len was finishing his last few laps at the high school track. Light filtered through the translucent concrete dome that covered the stadium, protecting it from the ravages of the sun and, right now, shielding the field from the thunderstorm encircling the valley. [8]

[8] The dome is made of sheets of concrete layered internally with carbon nanotubes and light conductive fiber so that it appears translucent.

Len felt good as he finished his laps. The leg he had broken in his clumsy attempt at pole vaulting had healed quickly after the doctor injected the nanofiber diamond-coated prosthesis to support the bone until it healed. [9]

[9] Diamondoid structures are a derivative of the carbon-based nanotubes, but are anatomically neutral, and thus cannot harbor infection.

Now it was straight to the gym for a shower and then home to get dressed for the prom.

Out of habit, he placed his hand on the wall panel signaling Mother to perform a physical check. The school's AI, nicknamed "Mother" by the kids, recognized him. A few moments after he stepped into the shower, it chirped, "Leonard Gonzales, all systems are go. You have not ingested any prohibited substances." The same message was recorded in the coach's log files. Any time the coach wanted to, he could get a view of the condition of every player from readings of their chronic sensor implants.

Len grinned,... "all systems are go," he laughed. Mother was an old AI system still using outdated phrases.

He dressed quickly, went out to his car in the parking lot, and pressed his thumb against the keyspot on the door to unlock it. [10] Len was proud of his first car. Like his dad's, it had a lightweight nanotube reinforced fiber body that was the same color all the way through, so even deep scratches didn't show. The main difference was that his car was electric and his Dad's car, built for longer distance driving, was hydrogen powered. The hydrogen, of course, was refilled at the solar fuel station on the highway. [11] Len's car captured some electricity from solar conversion and braking, and he fully recharged it by plugging into the grid, usually at home.

[10] The keyspot is similar to the wall panel identifier in note 2.

[11] Electricity from the national (or international) power grid is used locally at the filling station to power the nanomachine chemical conversion of water to hydrogen and oxygen. Burning the hydrogen in the car's engine results in a nonpolluting exhaust (the only exhaust product is water).

As he put his hands on the steering wheel, there was a slight pause as the car checked his breath (to make sure that he hadn't had anything that would impair his driving) and his prints, again, to make sure that he was the registered owner or a designated alternate driver. In less than a second, the green light came on and he shifted into "drive."

Before he pulled out of the school lot, his communication implant signaled a call from his mother, who was taking the elevator home from work. Len's mom had been up at the spaltform's isolation lab supervising the start of a new series of experimental nanocapsules for prescription drug delivery via the blood to specific cell types in the body. [12]

[12] Nano encapsulation technologies (using, for example, nanotubes and fullerines) can be treated to bond with cells of specific organs of the body and deliver their load of medication directly rather than spreading it throughout the body. (Kidney medication to kidney cells, etc.)

"Hello, Madre Mia! What's up?" Len answered the call.

"I can't seem to reach your father, Len, and I wanted him to know that the storm may slow us down a bit. You know... the risk of electrical interference."

"Mom, I don't understand why the isolation lab has to be on the splatform. I think you have the longest commute of anyone I know." [13]

[13] The splatform is far above Earth's atmosphere, where there are few air particles to provide friction. With less friction, the electrically powered elevator running on the tether can achieve speeds that would not be possible within Earth's atmosphere, making such a commute possible on a daily basis.

"Maybe you're right about the commute, Len. But tell your father that I'll be delayed a bit. He should go ahead with dinner without me."

"OK, but really, Mom, you don't need a weightless environment for the lab work. Everyone knows that nano particles are influenced more by inertia, friction, and Brownian motion than by gravity."

"That's true, Len. The reason for the isolation lab being on the splatform is political, not scientific. You know, for example, that nanotubes and buckyballs can be toxic if you're overexposed. Well, a lot of people are worried about the possible toxic effects of other nanoscale particles. Enough of them fear some strange new 'world plague' that they have passed laws prohibiting some research from being done on Earth, so we do it in space. If something goes wrong, we abandon the lab, thrust it, and have it burn up before it hits the Pacific."

"But why do you have to be there?" Len asked. "I thought the lab was automated."

"Well, Len, one thing that our best AI can't do is adapt to unforeseen circumstances...there's always a need for the personal touch."

"Yeah, I guess...but it's still a long commute." Len grumbled.

"Sorry, kiddo. Have a good time tonight and I'll see you in the morning."

Len signed off and signaled his implant to stream music from his favorite narrowband.

After driving home, he pulled into the garage and the charger moved out to plug into the car. The car was covered with solar converter paint that recharged the battery from sunlight, but this wasn't always enough to keep the car fully charged [14]. Electricity generated by solar converters placed in large areas throughout the world, such as these Arizona deserts, was fed into the national grid.

[14] The "paint' is composed of a medium in which molecular solar energy conversion cells are implanted. In the future, nano solar cells that could be rolled out, ink-jet printed, or painted onto surfaces.

He left a message for his father and started to prepare for the prom. As he laid out his clothes on the bed, his stomach growled, so he went to the kitchen for a snack. It might be late by the time the food was served at the prom, and a small sandwich couldn't hurt. Afterwards, he took a mouthful of Nanodent. The nanomachines in the mouthwash recognized particles of food, plaque, and tartar and lifted them from the teeth and gums to be rinsed away. [15]

[15] Being suspended in liquid and able to swim about, nanobots could reach surfaces beyond reach of toothbrush bristles or the fibers of floss. After a few minutes in the body, they would fall apart into harmless fiber. With such easy daily dental care from an early age, tooth decay and gum disease may never arise.

Within an hour, he was dressed and on his way across town to pick up Sandra.

At Sandra's house, Ms. Houston met him at the door. "Sandra will be ready in a few minutes. You know that girls going to a prom can't be ready on time. It would violate some rule of the universe," she laughed. "Have a seat, Lenny. Want something to drink while you wait?"

"That would be macro, thanks. Maybe some juice?" Len sat in the living room feeling a little awkward with his formal clothes and corsage box in hand.

Ms. Houston brought in some grape juice and handed it to Len. A bit nervous about these relatively rare meetings with Sandra's mother, he spilled some of the juice on his white shirt.

"Oh, sh. . . !" He stopped what he was about to say.

Ms. Houston laughed reassuringly. "No worries. Here, let me get a damp cloth, Lenny. These rented formal clothes reject anything that is non-fabric. It'll just wipe off." [16] She led Len to the kitchen and wiped off the stain.

[16] Nanofibers in cloth will not allow dirt or other objects to adhere. These "nanowhiskers" act like peach fuzz and create a cushion of air around the fabric so that liquids bead up and roll off.

"Thanks, Ms. Houston." Len grinned. "I guess I'd better just sit down and wait."

Finally, after a seemingly interminable dozen minutes, Sandra walked into the room in glimmering pale blue gown and asked breezily, "Have I kept you waiting, Len?"

Len grimaced and Sandra laughed.

He handed her the corsage box and she beamed when she opened it.

"Goodnight, Mom," Sandra called out.

"Goodnight, Ms. Houston," Len echoed.

"Don't forget to send me a few pictures of the prom." Ms. Houston waved as they walked away.

"I'll be too busy, Mom," Sandra replied. But they'll be taking class pics at the entrance. They'll go right onto the class net."

As they walked out to the car, Sandra looked at Len and touched his shoulder, turning him around to face her. With a smile, she grabbed his hand and placed it on her shoulder. He leaned in for a kiss.

"Hold on, sport, I'm just recording your hand's temperature gradient. I already recorded mine. My gown will use them to create a pattern of color gradients. You'll see when we dance." Sandy worked the gown's controller. [17]

[17] See note 4. Quantum dots can be tuned to emit different wavelengths of light. These small nanoscale crystalline structures will also be used as fluorescent labels in biological imaging and drug discovery research.

"Well I'm glad I'm good for something," he said.

"There's always a need for the personal touch," she quipped.

"Seems I've heard that somewhere else today," Len mumbled to himself.

Related Reading

(Accessed August 2005.)

- Top 10 future applications of nanotechnology.

http://www.utoronto.ca/jcb/home/documents/PLoS_nanotech.pdf#38;e=10431

- Nanotechnology predictions.

http://www.nanotech-now.com/predictions.htm

- Space elevator made with carbon nanotubes.

http://www.space.com/businesstechnology/technology/space_elevator_020327-1.html

- Dreaming about nano health care.

http://wiredvig.wired.com/news/technology/0,1282,40166,00.html?tw=wn_story_related

- Nanodentistry.

http://www.rfreitas.com/Nano/Nanodentistry.htm

- Quantum dot pigments and infrared paints.

http://www.evidenttech.com/applications/quantum-dot-pigments.php

- Meeting energy needs with nanotechnology.

http://www.foresight.org/challenges/energy001.html

- Nanotechnology in construction.

http://www.aggregateresearch.com/article.asp?id=6279

- Nanotechnology in clothing.

http://www.sciencentral.com/articles/view.php3?article_id=218391840#38;cat=3_5

Name________________

Date________________

Period________________

The Personal Touch: Student Worksheet

You will read a story that describes how nanotechnology might impact daily life in 2045. The story is fictional, but is based on current or proposed research, and in some cases, already existing technology.

1. BEFORE you read the story, predict, and write below, TWO ways that you think that nanoscience or nanotechnology might affect your life in the future.

Prediction 1:

Prediction 2:

2. READ THE STORY SILENTLY TO YOURSELF.

3. Summarize, and write below, FOUR applications of nanotechnology mentioned in the story.

Application 1:

Application 2:

Application 3:

Application 4:

4. What application mentioned in the story do you think is MOST believable, and why?

5. What application mentioned in the story do you think is LEAST believable, and why?

6. Write below at least TWO science-related questions that you have about this story.

Question 1:

Question 2:

Scale of Objects

Contents

Visualizing the Nanoscale: Student Reading

How Small is a Nanometer?

The meter (m) is the basic unit of length in the metric system, and a nanometer is one billionth of a meter. It's easy for us to visualize a meter; that's about 3 feet . But a billionth of that? It's a scale so different from what we're used to that it's difficult to imagine.

What Are Common Size Units, and Where is the Nanoscale Relative to Them?

Table 1 below shows some common size units and their various notations (exponential,number, English) and examples of objects that illustrate about how big each unit is.

TABLE 1.1: Common size units and examples

Unit	Magnitude as an exponent (m)	Magnitude as a number (m)	English Expression	About how big?
Meter	10^0	1	One	A bit bigger than a yardstick
Centimeter	10^{-2}	0.01	One Hundredth	Width of a fingernail
Millimeter	10^{-3}	0.001	One Thousandth	Thickness of a dime
Micrometer	10^{-6}	0.000001	One Millionth	A single cell
Nanometer	10^{-9}	0.000000001	One Billionth	10 hydrogen atoms lined up
Angstrom	10^{-10}	0.0000000001		A large atom

Nanoscience is the study and development of materials and structures in the range of 1 nm$(10^{-9}$ m$)$ to 100 nanometers $(100 \times 10^{-9} = 10^{-7}$ m$)$ and the unique properties that arise at that scale. That is small! At the nanoscale, we are manipulating objects that are more than one-millionth the size of the period at the end of this sentence.

What if We Measured the Size of Various Objects in Terms of Nanometers?

A typical atom is anywhere from 0.1 to 0.5 nanometers in diameter. **DNA** molecules are about 2.5 nanometers wide. Most **proteins** are about 10 nanometers wide, and a typical **virus** is about 100 nanometers wide. A **bacterium** is about 1000 nanometers . Human cells, such as red blood cells, are about $10,000$ nanometers across. At $100,000$ nanometers , the width of a human hair seems gigantic. The head of a pin is about a million nanometers wide. An adult man who is 2 meters tall (6 feet 5 inches) is about 2 billion nanometers tall!

So is That What Nanoscience is All About—Smallness?

No, smallness alone doesn't account for all the interest in the nanoscale. Nanoscale structures push the envelope of physics, moving into the strange world of **quantum mechanics**. For nanoparticles, gravity hardly matters due to their small mass. However, the **Brownian motion** of these particles now becomes important. Nanosized particles of any given substance exhibit different properties and behaviors than larger particles of the same substance.

For now, though, we'll focus just on the smallness of nanoscale, and ways to visualize how extremely tiny the nanoscale is.

How Can We Imagine the Nanoscale?

Another way to imagine the nanoscale is to think in terms of relative sizes. Consider yourself with respect to the size of an ant $(3-5$ millimeters$)$. An ant is roughly 1000 times smaller than you are. Now think of an ant with respect to the size of an **amoeba** (about 1 micron). An amoeba is about 1000 times smaller than an ant. Now,consider that a nanometer is roughly 1000 time smaller than an amoeba! You would have to shrink yourself down by a factor of 1000 three times in a row in order to get down too the level of the nanoscale.

Imagine Zooming In on Your Hand

Let's try to conceptualize the nanoscale yet another way. Look at your hand. Let's zoom into your hand by a factor of ten, several times in a row (see Figure 1, below).

In frame 1 , at the 10 centimeter scale $(10^{-1}$ m$)$, we can see fingers and skin clearly. As we zoom in by a factor of ten to the 1 centimeter scale $(10^{-2}$ m) , we can begin to see the structure of skin (frame 2). If we move in another factor of ten to the 1 millimeter scale $(10^{-3}$ m) , we can see cracks in the skin clearly (frame 3). Moving in again by another factor of ten to the 100 micron level $(10^{-4}$ m) , the cracks look like deep crevices (frame 4). Zooming in again, to 10 microns $(10^{-5}$ m) , we can see an individual cell (frame 5). At the next level, 1 micron $(10^{-6}$ m) we can see the membrane of the cell and some of the features that exist on it (frame 6). Moving in another factor of ten to the 100 nm scale $(10^{-7}$ m) , we begin to see the individual DNA strands that exist within nucleus of the cell. This is the scale at which computer technology is currently being fabricated (frame 7). Zooming in again to the 10 nm length scale $(10^{-8}$ m) , we see the double helix that make up DNA. Finally, zooming in one last time to the 1 nanometer scale $(10^{-9}$ m) , we can see the see individual atoms that make up DNA strands!

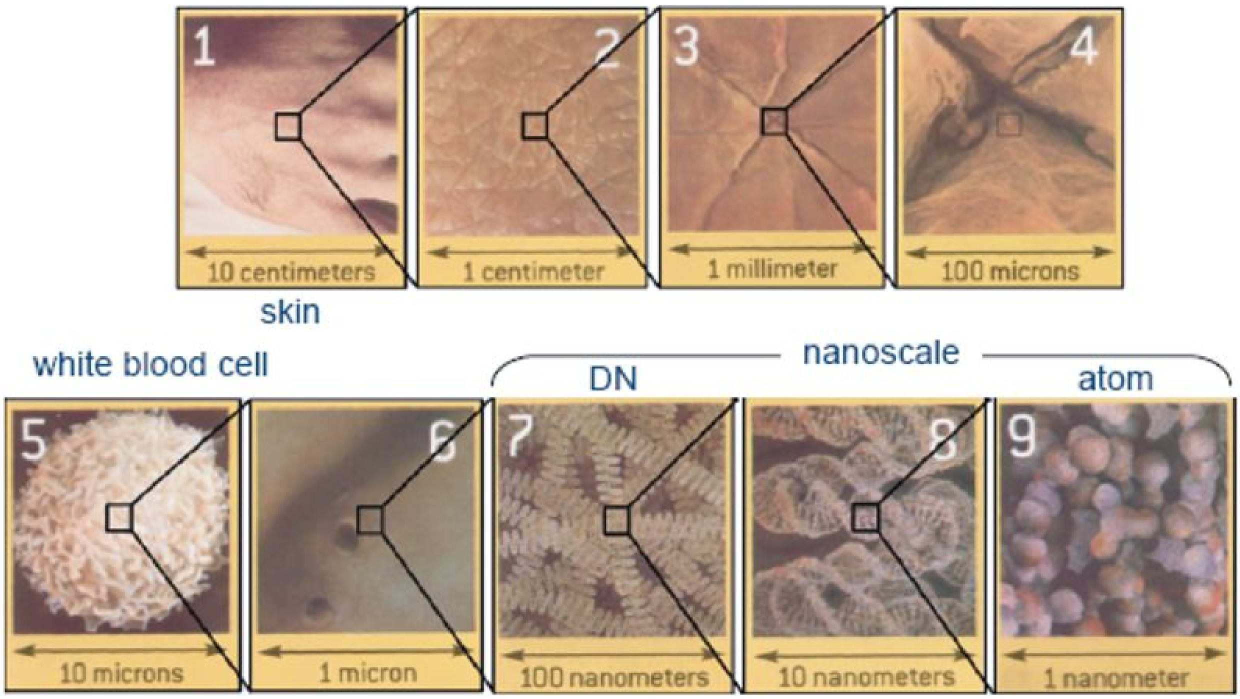


FIGURE 1.12

Zooming in on your hand by powers of 10

1

.

What is This Powers of 10 Stuff?

In the above example, each picture is an image of something that is 10 times bigger or smaller than the one preceding or following it. The number below each image is the scale of the object in the picture. In the text above, the scale is also written in powers of ten, or exponential notation (e.g., 10^{-2}) where the scale is mentioned. Since the ranges of magnitudes in our universe are immense, exponential notation is a convenient way to write such very large or very small numbers.

The Molecular Expressions Web site offers a nice interactive visualization of magnitudes in our universe; see http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/ The interactive Java applet on this site moves through space in successive orders of magnitude from the Milky Way galaxy $(10^{21}$ m) . our solar system $(10^{13}$ m) . towards the Earth $(10^{18}$ m) , to a city $(10^{4}$ m) , a tree $(10^{1}$ m) , a leaf $(10^{-1}$ m) , cells $(10^{-5}$ m) , strands if DNA $(10^{-7}$ m) , an atom $(10^{-10}$ m) , and eventually **quarks** $(10^{-16}$ m) . Check it out!

Another Shrinking Exercise

Recall that we said that you'd have to shrink yourself down by a factor of 1000 three times in a row to get to the nanoscale. Let's try that! [2]

Imagine you are sitting at your desk with the following items: A box, a baseball, a marble, and a grain of salt, as show below. These items represent a length spread of 3 orders of magnitude. Each item is 10 times longer than the item to its left. The box is 1000 times longer than the grain of salt. These objects are in the realm of what is often referred to as the macroscale.

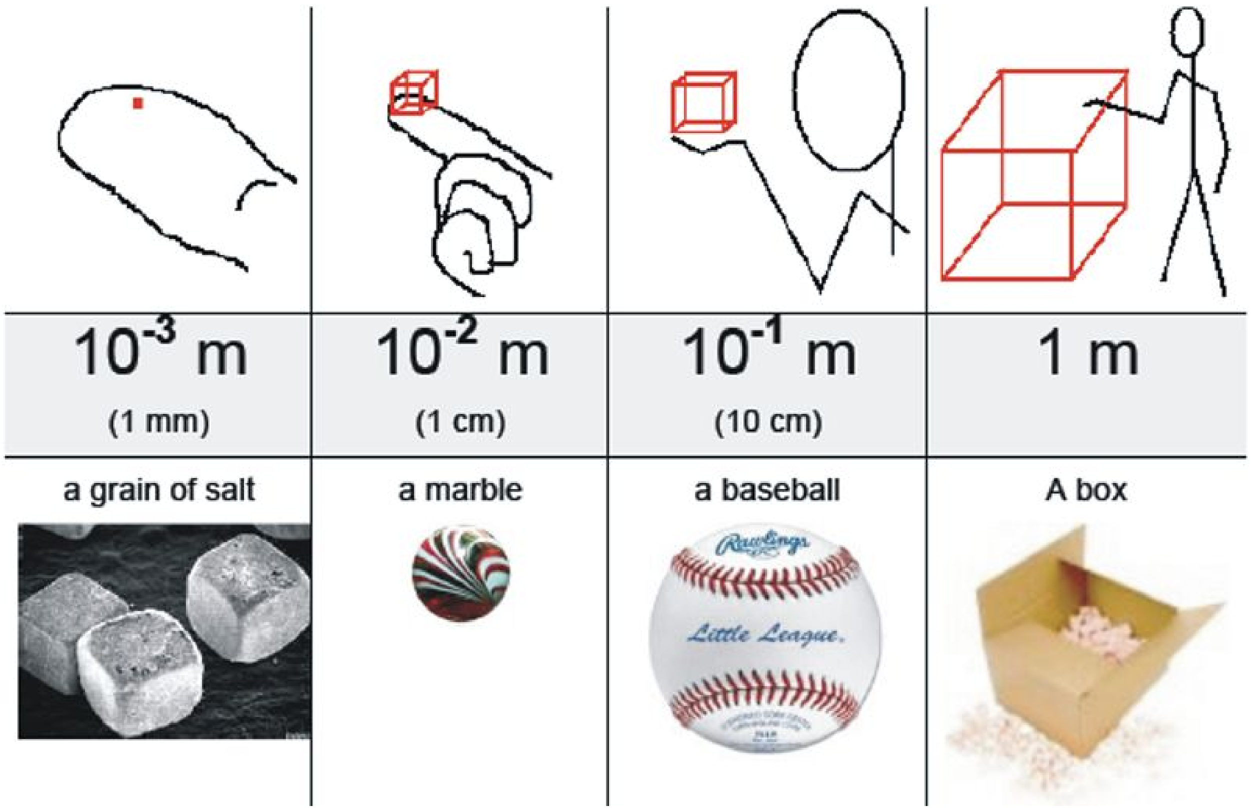


FIGURE 1.13

The macroscale.

What if we zoomed in 1000 times **, so that the grain of salt was as big as the box?**

- We could stand next to the grain of salt, and use it as a bed or a desk.
- Dust mites would look like hand-sized turtles, and your hair would look like giant ropes.
- Blood cells would be little red and white marbles.
- Bacteria on your skin would look like little grains of sand.

These objects, measured in microns, are in the realm of what is referred to as the microscale.

What if we zoomed in 1000 times **again, so that the bacteria were as big as the box?**

- We could sit on the bacteria like easy chairs.
- We could use viruses for batting practice.
- We could play marbles with proteins and large molecules.
- Atoms and small molecules would look like little grains of sand.

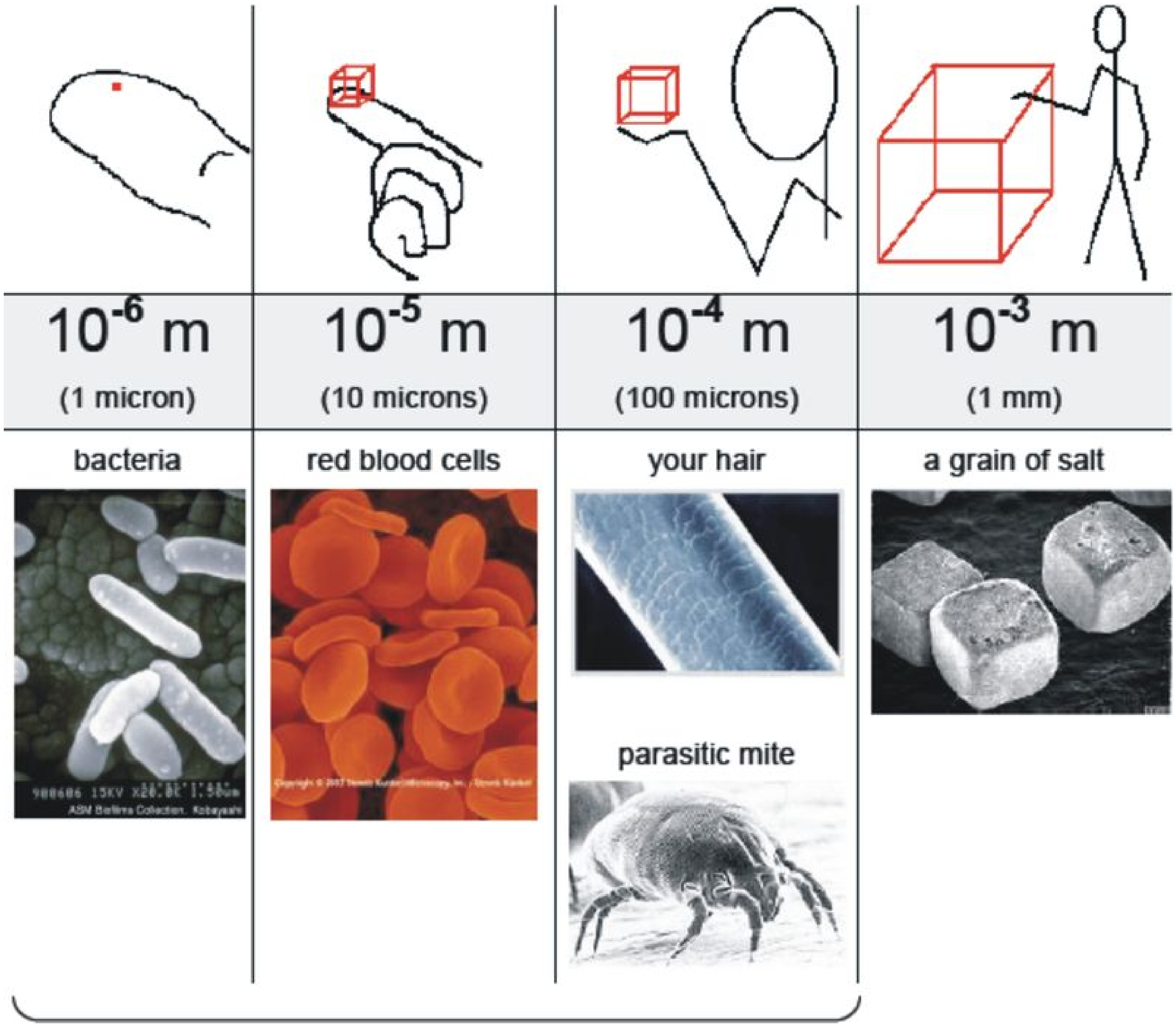


FIGURE 1.14

The microscale.

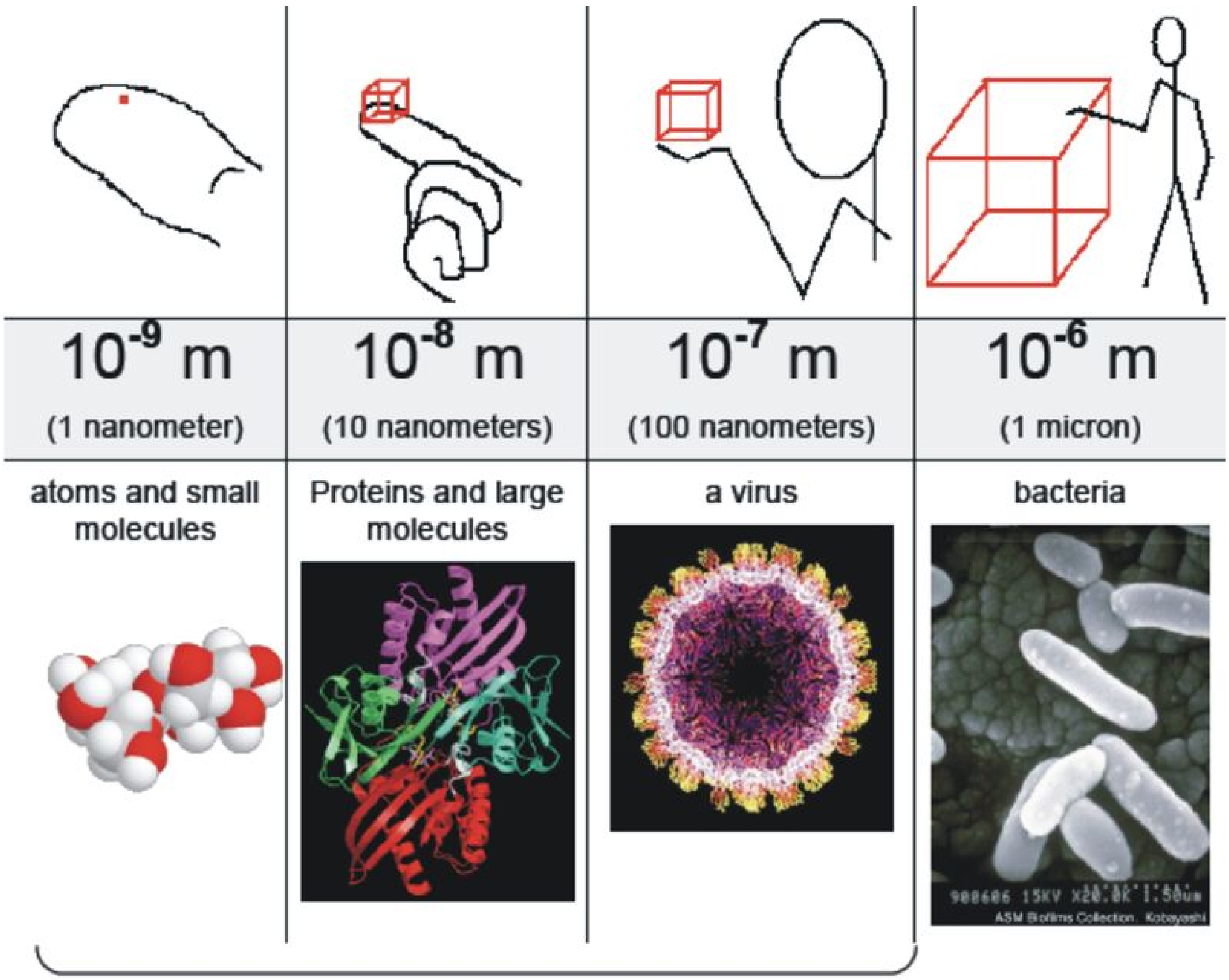


FIGURE 1.15
The nanoscale.

These objects, measured in nanometers, are in the realm of what is referred to as the nanoscale.

Summary

Although many sizes in the universe—including the nanoscale—are hard for us to comprehend because they are far removed from our experience, we can represent such sizes in mathematical notation and through relationships and analogies. Hopefully the examples and analogies used here help you better comprehend the size and scale of the nanoworld.

References

(Accessed August 2005.)

- From M. Hersam's Introduction to Nanometer Scale Science #38; Technology at http://www.materialsworld.net/nclt/docs/Introduction%20to%20Nano%201-18-05.pdf
- Adapted from "A view from the back of the envelope" at http://www.vendian.org/envelope/

Glossary

amoeba A single-celled organism with a nucleus, found in fresh or salt water environments.

bacterium A structurally simple single cell with no nucleus. Bacteria occur naturally almost everywhere on Earth including soil, skin, on plants and many foods.

Brownian motion The random motion of microscopic particles suspended in a liquid or gas, caused by collision with surrounding molecules.

DNA The genetic material of almost every organism. It is a long, double-stranded, helical molecule that contains genetic instructions for growth, development, and replication.

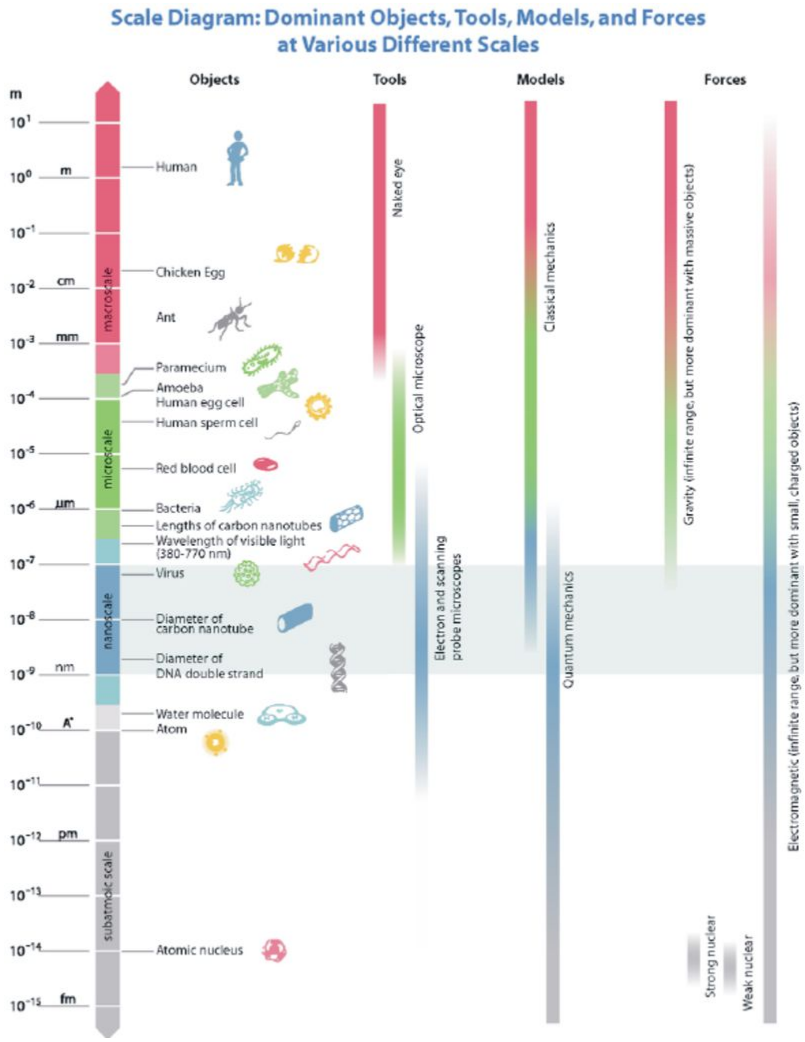
protein An organic compound whose structure is dictated by DNA. Proteins perform a wide variety of functions in the cell including serving as enzymes, structural components, or signaling molecules.

quantum mechanics A 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.

quark The basic building block of matter. Quarks combine with gluons to make the protons and neutrons that make up every atom in the universe.

virus A structure containing proteins and nucleic acid. Viruses can infect cells and reproduce only by using their cellular machinery.

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.



Name________________

Date________________

Period________________

Number Line/Card Sort Activity: Student Instructions #38; Worksheet

In this activity, you will explore your perception of the size of different items. Your task is to create a "powers of 10 " number line and place items appropriately on the number line.

Materials

- Cards for the objects
- Cards for the units, in powers of 10 meters

Instructions

On a surface like a lab table, order the cards for powers of 10 in a vertical column, with the largest at the top and the smallest at the bottom. Space the cards equidistant from each other, leaving a gap between the cards for 10^{-10} and 10^{-15} . This is your number line.

Next, place each object next to the closest power of 10 in the number line that represents the size of that object in meters. Some objects may lie between two powers of 10 .

When you are done placing all of the cards, record your results in the table on the next page and answer the questions that follow.

TABLE 1.2:

Size (meters)	Objects
10^{0}	
10^{-1}	
10^{-2}	
10^{-3}	
10^{-4}	
10^{-5}	
10^{-6}	
10^{-7}	
10^{-8}	
10^{-9}	
10^{-10}	
(large gap)	
10^{-15}	

1. Which objects were the hardest for you to estimate size for? Why?
2. Why are we using powers of 10 for the number line instead of a regular linear scale (like a meter stick)?

Cards for Number Line Activity: Objects

(Printing on card stock paper is recommended; then cut to separate.)

TABLE 1.3:

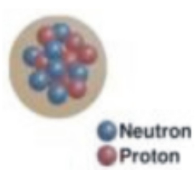
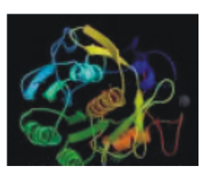
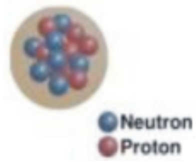
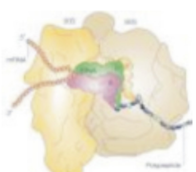
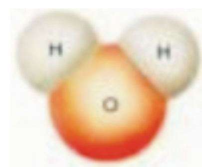
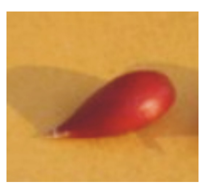
		
		

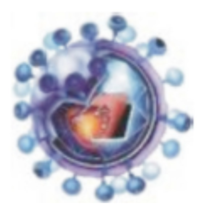
TABLE 1.3: (continued)

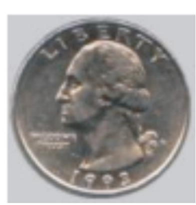












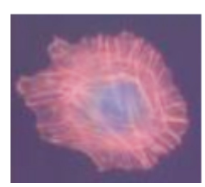


TABLE 1.3: (continued)

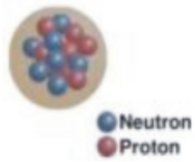
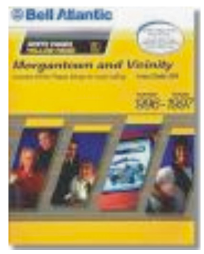
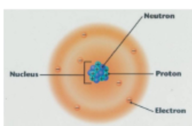
		
		
		 Visible Light Spectrum

TABLE 1.4: **(Uses a base**

	Cards for Number Line Activity: Units	
10^{-15} m (1 femtometer) On $\log_{10}$ scale: -15	10^{-10} m (1 angstrom) On $\log_{10}$ scale: -10	10^{-9} m (1 nanometer) On $\log_{10}$ scale: -9
10^{-8} m (10 nanometers) On $\log_{10}$ scale: -8	10^{-7} m (100 nanometers) On $\log_{10}$ scale: -7	10^{-6} m (1 micron) On $\log_{10}$ scale: -6

TABLE 1.4: (continued)

Cards for Number Line Activity: Units		
10^{-5} m (10 microns) On $\log_{10}$ scale: -5	10^{-4} m (100 microns) On $\log_{10}$ scale: -4	10^{-3} m (1 millimeter) On $\log_{10}$ scale: -3
10^{-2} m (10 millimeters) On $\log_{10}$ scale: -2	10^{-1} m (100 millimeters) On $\log_{10}$ scale: -1	10^{0} m (1 meter) On $\log_{10}$ scale: 0

Image Sources for Object Cards

Accessed September 2007 through Google images (http://images.google.com).

a. Thickness of a penny: http://www.poly.edu/admissions/undergrad/images/photos/coin.jpg
b. Nucleus of an oxygen atom: http://scienzapertutti.lnf.infn.it/P2/nucle.jpg
c. Diameter of a red blood cell: http://www.biopal.com/images/Red_Bl1.jpg
d. Height of a typical 5-year-old child: http://www.lowerallen.pa.us/Parks/ParksImages/soccer%20kid%20cartoon.gif
e. Width of a proteinase enzyme: http://aiims.aiims.ac.in/ragu/aiims/departments/biophy/enzyme5.jpg
f. Length of a dust mite: http://www.owlnet.rice.edu/ psyc351/Images/DustMite.jpg
g. Width of a typical wedding ring: http://www.goldringsplus.com/GRP_img/half/RS.jpg
h. Length of an amoeba: http://gladstone.uoregon.edu/ awickert/ceramics/amoeba.jpg
i. Width of an electrical outlet cover: http://www.punchstock.com/image/comstock/4550022/large/ks2793.jpg
j. Diameter of a ribosome: http://histo.ipfw.edu/images/ribosome.gif
k. Thickness of sewing thread: http://www.techsewing.com/image/left/company-needle.gif
l. Water molecule: http://www.lenntech.com/images/Water%20molecule.jpg
m. Width of a bacterium: http://www.scientific-art.com/GIF%20files/Zoological/microbea.gif
n. Length of an apple seed: http://www.thebestlinks.com/images/thumb/5/5c/250px-Old-appleseed-d402.jpg
o. Diameter of a virus: http://www.xtec.es/ imarias/virus.gif
p. Length of a business envelope: http://www.superfineprinting.com/images/business_envs.gif
q. Diameter of a quarter: http://www.pipebombnews.com/readerimages/quarter.gif
r. Length of a human muscle cell: http://dept.kent.edu/projects/cell/tm1.jpg
s. Diameter of a carbon nanotube: http://www.csiro.au/images/activities/carbon_nanotube.jpg
t. Length of a phone book: http://www.rickleephoto.com/phone97.jpg
u. Height of a typical NBA basketball player: http://sports.tjhsst.edu/boosters/merchandise/images/basketball-player-3.gif
v. Diameter of an atom: http://web.buddyproject.org/web017/web017/ae.html
w. Thickness of a staple: http://www.unisa.edu.au/printing/images/binding/staple%20icon.jpg
x. Wavelength of visible light: http://esp.cr.usgs.gov/info/sw/climmet/anatomy/index_nojava.html

Name________________

Date________________

Period________________

Cutting it Down Activity: Student Instructions and Worksheet

How many times do you think you would need to cut a strip of paper in half in order to make it between zero and 10 nanometers long? In this activity, you'll cut a strip of paper in half as many times as you can, and think about the process.

BEFORE you begin cutting the strip of paper, answer the following questions (take a guess):

1. How many times do you need to cut the paper in half to obtain a 10 nanometer **long piece?**

2. How many times do you think you can cut the paper before it becomes impossible to cut?

Now cut the strip of paper in half as many times as you can. Remember to keep track of how many cuts you make.

AFTER completing the activity, answer the following questions.

3. Were your predictions to the above two questions accurate?

4. How many times were you able to cut the paper?

5. How close was your smallest piece to the nanoscale?

6. Why did you have to stop cutting?

7. Can macroscale objects, like scissors, be used at the nanoscale?

8. Can you think of a way to cut the paper any smaller?

Name_______________

Date_______________

Period_______________

Activity: Student Instructions and Worksheet

In this activity, you will explore your perceptions of different sizes. For each of the following items, indicate its size by placing an " *X* " in the box that is closest to your guess.

Key:

A. Less than 1 nanometer (1 nm) [Less than 10^{-9} meter]

B. Between 1 nanometer (nm) and 100 nanometers (100 nm) [Between 10^{-9} and 10^{-7} meters]

C. Between 100 nanometers (100 nm) and 1 micrometer ($1\mu m$) [Between 10^{-7} and 10^{-6} meters]

D. Between 1 micrometer ($1\mu m$) and 1 millimeter (1 mm) [Between 10^{-6} and 10^{-3} meters]

E. Between 1 millimeter (1 mm) and 1 centimeter (1 cm) [Between 10^{-3} and 10^{-2} meters]

F. Between 1 centimeter (1 cm) and 1 meter (m) [Between 10^{-2} and 10^{0} meters]

G. Between 1 meter and 10 meters [Between 10^{0} and 10^{1} meters]

H. More than 10 meters [More than 10^{1} meters]

TABLE 1.5:

	Less than 1 nm	1 nm to 100 nm	100 nm to 1 ¯m	1 ¯m to 1 mm	1 mm to 1 cm	1 cm to 1 m	1 m to 10 m	More than 10 m
Object	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
1. Width of a human hair								

TABLE 1.5: (continued)

	Less than 1 nm	1 nm to 100 nm	100 nm to 1 ¯m	1 ¯m to 1 mm	1 mm to 1 cm	1 cm to 1 m	1 m to 10 m	More than 10 m
2. Length of a football field								
3. Diameter of a virus								
4. Diameter of a hollow ball made of 60 carbon atoms (a "buckyball")								
5. Diameter of a molecule of hemoglobin								
6. Diameter of a hydrogen atom								
7. Length of a molecule of sucrose								
8. Diameter of a human blood cell								
9. Length of an ant								
10. Height of an elephant								
11. Diameter of a ribosome								
12. Wavelength of visible light								

TABLE 1.5: (continued)

	Less than 1 nm	1 nm to 100 nm	100 nm to 1 ¯m	1 ¯m to 1 mm	1 mm to 1 cm	1 cm to 1 m	1 m to 10 m	More than 10 m
13. Height of a typical adult person								
14. Length of a new pencil								
15. Length of a school bus								
16. Diameter of the nucleus of a carbon atom								
17. Length of a grain of white rice								
18. Length of a postage stamp								
19. Length of a typical science textbook								
20. Length of an adult's little finger								

Adapted from Tretter, T. R., Jones, M. G., Andre, T., Negishi, A., #38; Minogue, J. (2005). Conceptual Boundaries and Distances: Students' and Experts' Concepts of the Scale of Scientific Phenomena. *Journal of Research in Science Teaching*.

Name_______________

Date_______________

Period_______________

Scale of Small Objects: Student Quiz

1. Indicate the size of each item below by placing an “ X ” the appropriate box.

Key:

A. Less than 1 nanometer (1 nm) [Less than 10^{-9} meter]

B. Between 1 nanometer (nm) and 100 nanometers 100 nm) [Between 10^{-9} and 10^{-7} meters]

C. Between 100 nanometers (100 nm) and 1 micrometer ($1\mu m$) [Between 10^{-7} and 10^{-6} meters]

D. Between 1 micrometer ($1\mu m$) and 1 millimeter (1 mm) [Between 10^{-6} and 10^{-3} meters]

E. Between 1 millimeter (1 mm) and 1 centimeter (1 cm) [Between 10^{-3} and 10^{-2} meters]

TABLE 1.6:

Object	Less than 1 nm **A**	1 nm to 100 nm **B**	100 nm to 1 ¯m **C**	1 ¯m to 1 mm **D**	1 mm to 1 cm **E**
1. Width of a human hair					
2. Diameter of a hollow ball made of 60 carbon atoms (a “buckyball”)					
3. Diameter of a hydrogen atom					
4. Diameter of a human blood cell					
5. Wavelength of visible light					

2. Order the following items in order of their size, from smallest to largest.

a. Width of a water molecule

b. Diameter of a gold atom

c. Thickness of a staple

d. Diameter of a virus

e. Length of an amoeba

f. Diameter of a carbon nanotube

Smallest:

________ ________ ________ ________ ________

Largest:

____

Unique Properties at the Nanoscale

Contents

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 surfaceto-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 1.7:

	Gravitational Force	Electromagnetic Forces	Weak Nuclear Force	Strong Force	Nuclear
Cosmic Scale 10^7 m and bigger	X	$X*$			
Macroscale 10^{-2} m to 10^6 m	X	$X**$			
Microscale 10^{-3} m to 10^{-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.

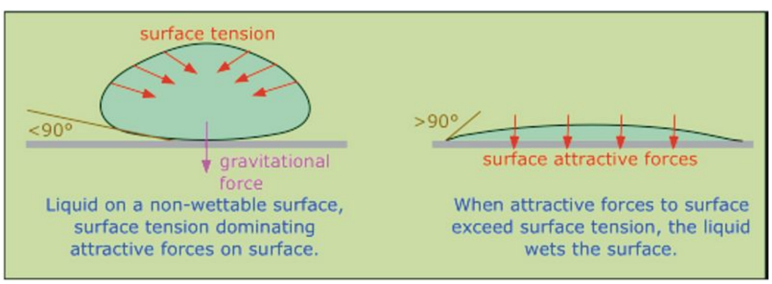


FIGURE 1.16

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

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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

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.

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 100 nm), 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

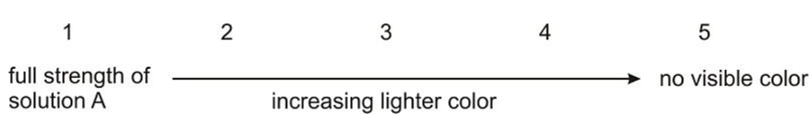
a. Label each of your test tubes from 1 to 5.
b. Use a pipette to place 10.0 mL of 1.0 Molar of colored solution into test tube #1.
c. Remove 1.0 mL from test tube #1 and inject this into test tube #2. Then add 9.0 mL of water into test tube #2.
d. Remove 1.0 mL from test tube #2 and inject this into test tube #3. Then add 9.0 mL of water into test tube #3.
e. Continue in this fashion until you have completed test tube #5.
f. Note that each subsequent test tube has the concentration of the previous test tube divided by 10 .
g. **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.

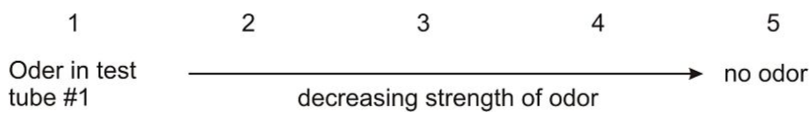
3. Continue from test tube #2 to #5 using the gauge below.



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

a. 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.
b. Use test tube #1 as the strongest odor.
c. Continue with test tube #2 to #5 in the same manner.



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

a. Make observations and record your observations of the ferrofluid and the iron object separately.
b. Predict how the magnet will influence the ferrofluid and the iron object.
c. Use the magnets to observe how the force of magnetism influences the ferrofluid and the iron object.
d. 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

a. Stir the solution with the straw to create bubbles, as needed.
b. Pour about 10.0 mL of bubble solution into the shallow dish.
c. **Caution: Be careful not to spill the solution or to drop the dish!**
d. Draw what you see in your worksheet. This is your "before" diagram.
e. 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

a. Using a grease marker, label one Erlenmeyer flask #1 and the other #2. (These may have already been marked. No need to mark twice.)
b. Set the scale to zero, after placing a square of paper on top of the scale (this is called "taring").
c. Measure and record the mass of two cubes of sugar. Put the sugar cubes into flask #1.
d. Measure and record a mass of granulated sugar equal to the mass of the two sugar cubes.
e. Put the granulated sugar into flask #2.
f. Using your graduated cylinder, add 100.0 mL of tap water to each flask.
g. Gently swirl each flask exactly 60 seconds .
h. Record the relative amount of sugar that has dissolved in each flask on your lab sheet.
i. Swirl each flask for another 60 seconds .
j. 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

a. Break the Alka Seltzer® tablet in half as exactly as you can.
b. Put one of the halves of the Alka Seltzer® tablet into the mortar and crush it with the pestle until it is finely granulated.
c. 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.
d. Simultaneously fill each film canister halfway with tap water. Quickly put their lids on.
e. On your lab sheet, record how much time it takes for each canister to blow its lid off.
f. 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

a. Fill in the chart on your lab sheet with the size and type of beaker or flask.
b. Fill each of the beakers with 100.0 mL of tap water.
c. 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.
d. 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.
e. 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.
f. 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

a. Light the two Bunsen burners to the same level of flame.
b. 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.

c. 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.
d. Once the objects are cooled, deposit any waste into the trash.
e. 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

- $\text{CuCl}_2 \bullet 2H_2O$ crystals

Materials

- One teaspoon
- One glass stirring rod
- Two 100 mL beakers
- Two squares, 2 inches $\times$ 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

a. Fill each of the 100 mL beakers about half full with tap water.
b. Add 1 teaspoon of $\text{CuCl}_2 \bullet 2H_2O$ crystals to each of the beakers of tap water and mix well with the stirring rod.
c. Form 1 piece of aluminum foil into a loose ball; leave the other piece as is.
d. Put each of the aluminum foil pieces into their own beaker.
e. On your lab sheet, record the time that it takes for each reaction to be complete.
f. Dispose of solution and waste according to your teacher's instructions.

Name_______________

Date_______________

Period_______________

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

TABLE 1.8: 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.

TABLE 1.9:

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:

TABLE 1.10:

	Mass Record to the nearest 0.1 gram	Observations of sugar remaining after 1^{st} 60 – seconds of stirring	Observation of sugar remaining after 2^{nd} 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:

TABLE 1.11:

	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.

TABLE 1.12:

A Type of container for the water	B Diameter of surface of water (cm)	C Radius of surface of water (cm)	D Surface area of water (cm^2)	E Surface area to volume ratio	F Initial time heat is applied	G Time when water boils	H 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 $\pi = \text{pi} = 3.14$ and $r = \text{radius}$.
- 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.

TABLE 1.13:

	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_______________

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)*

Tools of the Nanosciences

Contents

Name_______________

Date_______________

Period_______________

Black Box Lab Activity: Student Instructions and Worksheet

Purpose

To use different probes to determine the layout of objects on the bottom surface of a closed box, and to consider the limitations and challenges in using probes to "see."

Materials

- One black box
- One pencil and magnet probe
- One cotton swab probe
- One skewer probe

Instructions

1. Obtain from your teacher a box, pencil and magnet probe, a cotton swab probe, and a barbecue skewer probe.

2. Place the pencil and magnet probe into the center hole, and determine as best you can what the surface of the bottom of the box looks like. Draw your best guess below.

3. Replace the pencil and magnet probe with the cotton swab probe, using the swab end as the probe. Is there any additional information you are able to conclude about the surface of the bottom of the box? Draw your best guess below.

4. Replace the cotton swab probe with the barbecue skewer probe, using the pointed end of the skewer as the probe. Is there any additional information you are able to conclude about the surface of the bottom of the box? Draw your best guess below.

Questions

1. Describe the technique you used to investigate the surface of the bottom of the box.

2. What kinds of information about the bottom surface were you able to deduce?

3. How accurate do you think your drawing is?

4. What could you do to get a better idea of what the bottom surface looks like, besides opening the box?

5. What if a ping-pong ball was attached to the probing end of the skewer? How might this have affected your interpretations?

6. What difficulties did you encounter in using this probing technique to "see" the unknown? Or what challenges could there be in using such a technique?

Seeing and Building Small Things: Student Reading

How Do You See and Build Things That Are So Small?

Although **Richard Feynman** launched the idea of **nanotechnology** way back in his 1958 speech, it wasn't until decades later that we were actually able to create things at the **nanoscale**. Why did it take so long? Because we didn't have the right tools until then. We had lots of tools to make small devices, but these tools didn't operate at a small enough scale—until now!

Scanning Probe Instruments

In recent years, new tools have been developed that make it easier for scientists to measure and manipulate atoms and molecules. Some of the first tools were scanning probe instruments, developed in the early 1980s. The idea behind these instruments is simple: If you close your eyes and slide the tip of your finger across a surface, you can tell tree bark from satin from peanut butter. The tip of your finger acts like a probe that measures the force that it takes to move across the surface. It's easier to slide your finger across satin than across peanut butter because the peanut butter exerts a drag force that pulls the finger back. You can even rearrange the peanut butter by dragging it this way.

Scanning probe instruments are like your finger, but reduced to the nanoscale. They have probes that slide across surfaces and measure properties like force—but the very tip of such probes are often only a single atom in size! With this tiny tip, these instruments can "feel" the force of one atom on the surface and from that, be able to tell what kind of atom it is. They can even be used to move atoms around and arrange them in a preferred order, just as you can move peanut butter with your finger.

What Are Some Types of Scanning Probe Instruments?

One type of scanning probe instrument is the atomic force microscope (AFM). The AFM uses a tiny tip that moves in response to the **electromagnetic forces** between the atoms of the surface and the tip. Tips are usually made of silicon, though sometimes carbon nanotubes are used for the tip. As the tip is scanned across a surface, the AFM measures the tiny upward and downward deflections of the tip necessary to remain in close contact with the surface. Alternately, the tip can be made to vibrate and intermittently "tap" the surface. In this case, the AFM senses when the tip (briefly) contacts the surface and uses this information to generate a topographical images.

Another type of scanning probe instrument is the scanning tunneling microscope (STM). With this instrument, the "tunneling" of electrons between the tip and the atoms of the surface being viewed creates a flow of electrons (a current). Tungsten is often used for STM tips because it is strong, electrically conductive, and easy to electrochemically etch to a fine point. Carbon nanotubes may also prove to be suitable for use as STM tips, given their remarkable electrical and mechanical properties.

The AFM was invented to overcome the STM's basic drawback: it can only be used to sense the nature of materials that conduct electricity, since it relies on the creation of a current between the tip and the surface. The AFM relies on actual contact rather than current flow, so it can be used to probe almost any type of material, including **polymers**,glass, and biological samples.

The signals (forces or currents) from these instruments are used to infer an image of the atoms. The tip's fluctuations are recorded and fed into computer models that generate images based on the data. These images give us a rough picture of the atomic landscape.

You Mean I Can *Move* Things Too?

But these microscopes can do much more than just "see": their tips can form bonds with the atoms of the material

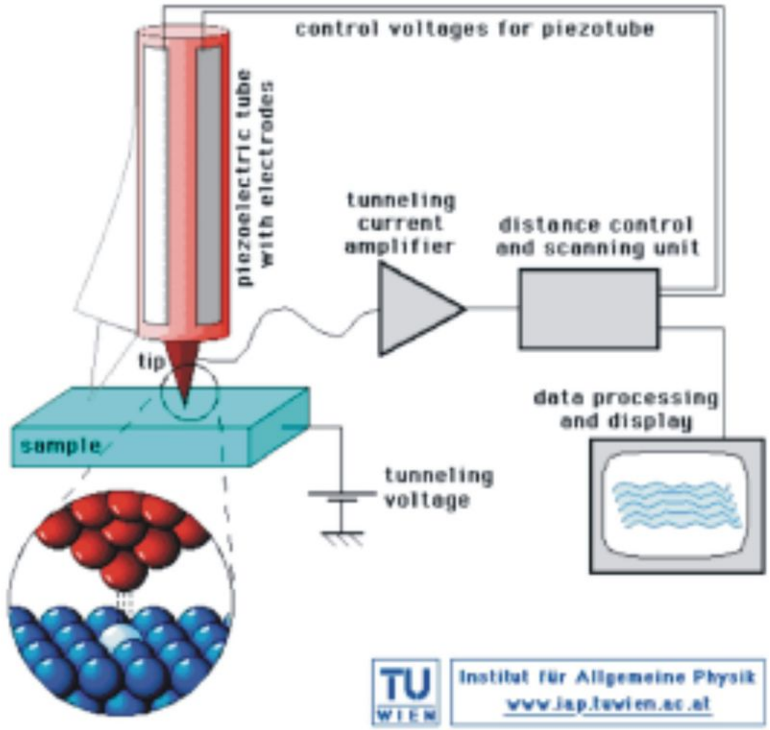


FIGURE 1.17
Scanning tunneling microscope STM

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they are scanning, and *move* the atoms. Manipulation of atoms by an STM is done by applying a tiny pulse of charge through the tip of the instrument. For example, hydrogen can be removed from hydrogen-silicon bonds by scanning a STM tip over the surface while applying rapid pulses, which pulls the bonds apart.

Once an atom has been lifted, it can be deposited elsewhere. Using this method with xenon atoms, IBM created the tiniest logo ever in 1990. In 1996, the tiniest abacus was also created by arranging **buckyballs** on a copper surface.

Is This a Good Way to Make Things?

Creating devices and materials atom-by-atom is more than an academic exercise; it paves the way for the next wave of nanotechnology research. But producing a material one atom at a time is not great for satisfying mass demand, because it's expensive and slow. For example, using the fastest techniques we have today, it would still take over 60 million years to assemble one aspirin table atom-by atom, because there are a lot of aspirin molecules (about 3.5×10^{20} to be precise) in one aspirin tablet that would need to be assembled! So how else can we manipulate atoms?

What is Self Assembly?

Self assembly is the process by which molecular building blocks "assemble" naturally to form useful products. Molecules try to minimize their energy levels by aligning themselves in particular positions. If bonding to an adjacent molecule allows for a lower energy state, then the bonding will occur. We see this happening in many places in nature. For example, the spherical shape of a bubble or the shape of snowflake are a result of molecules minimizing their energy levels. In cells, DNA is self-assembled from the atomic particles available to the cell. **Photosynthesis** is a process of self assembly. In fact, all the functions of the cell are variations of self assembly.

Is Self Assembly a Good Way to Build Things?

Through self assembly, large structures can be prepared without the individual tailoring that is required in the methods mentioned above. Just toss atoms or molecules onto a surface, and stand back. Of course it's not quite that simple—they don't always go in the places that you want them to! But because of the large number of structures

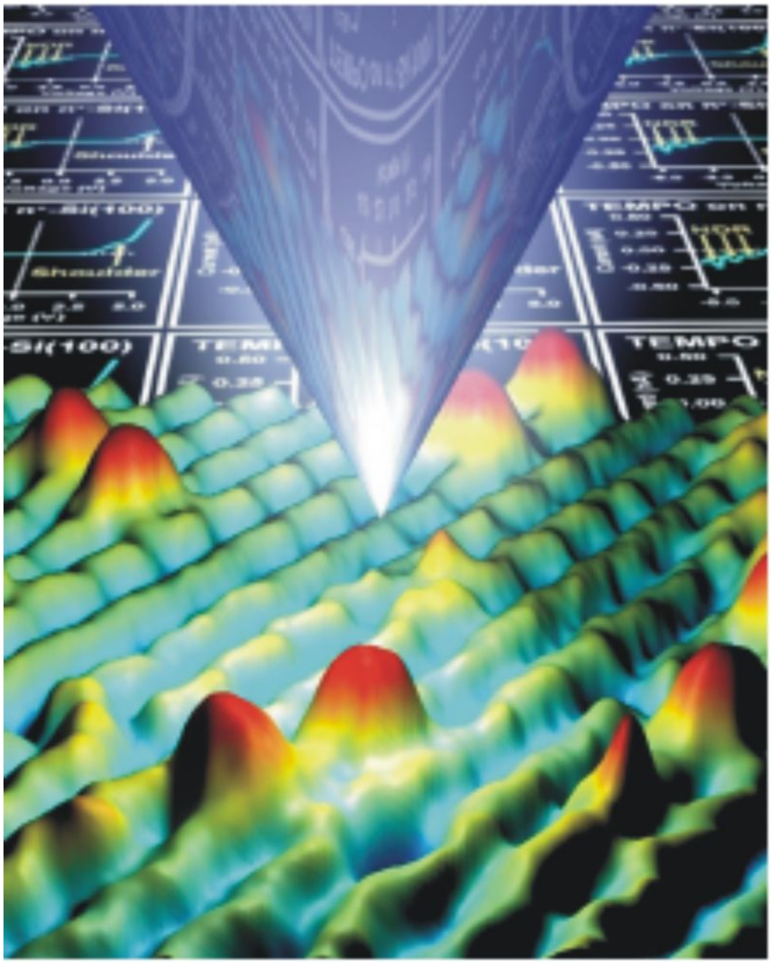

FIGURE 1.18
Tip of a scanning probe instrument

2

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FIGURE 1.19
Nano logo

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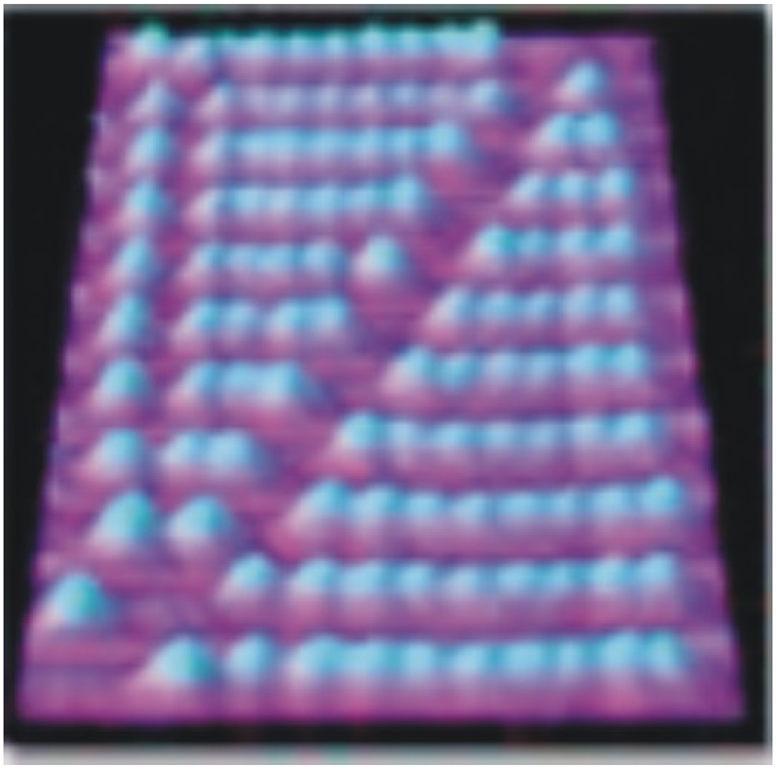

FIGURE 1.20
Nano abacus
4
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one could create quickly with this method, it will probably become the most important nanofabrication technique.

One particular type of self-assembly is crystal growth. This technique is used to "grow" **nanotubes** and **nanowires**. In this approach, "seed" crystals are placed on some surface, some other atoms or molecules are introduced, and these particles mimic the pattern of the small seed crystal. For example, one way to make nanotubes is to create an array of iron **nanopowder** particles on some material like silicon, put this array in a chamber, and add some natural gas with carbon to the chamber. The carbon reacts with the iron and **supersaturates** it, forming a precipitate of carbon that then grows up and out. In this manner, you can grow nanotubes like trees!

Summary

The size limit of the smallest features you can create depends on the tools that you use. We've seen that STM and AFM's can be used to measure and manipulate atoms, either in a one-by-one fashion, or through nanolithography methods like DPN. In contrast to this "positional" approach, self-assembly is carried out largely by nature, usually through a chemical reaction. We can use self-assembly to create new structures if we set up the conditions just right. Although there are many examples of self-assembly around us in nature (including ourselves!), the rules that govern these assemblies are not fully understood. Our ability to create nanostructures improves as we gain understanding of biological self-assembly, the chemical development of new molecular structures, and the physical development of new tools.

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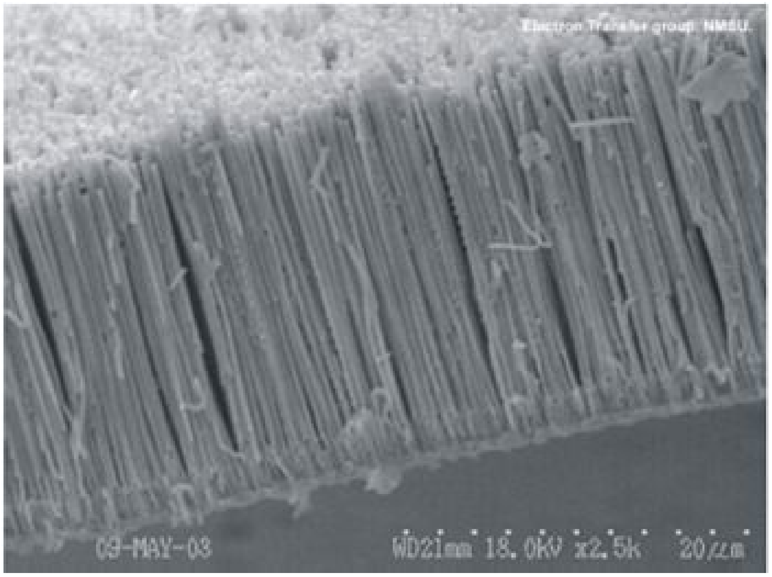


FIGURE 1.21

Growing nanotubes like trees

6

- http://www.chemistry.nmsu.edu/ etrnsfer/nanowires/

Glossary

buckyball A soccerball-shaped molecule made up of 60 carbon atoms. Also known as Buckminsterfullerene.

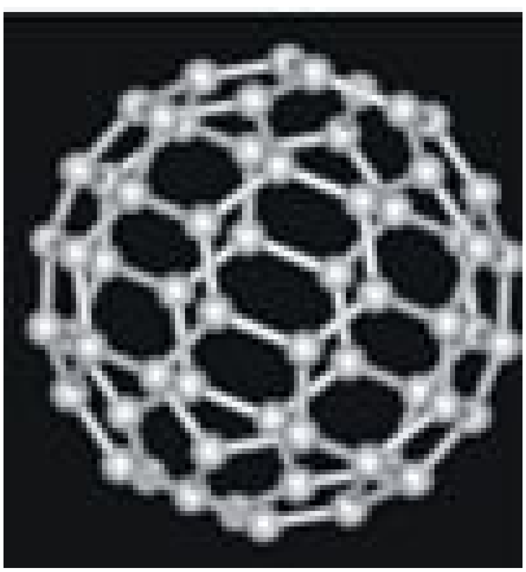


FIGURE 1.22

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.

Feynman, Richard (1918-1988) One of the most influential American physicists of the 20th century, Richard Feynman greatly expanded the theory of quantum physics and received the Nobel Prize for his work in 1965. He also helped in the development of the atomic bomb and was an inspiring lecturer and amateur musician.

FIGURE 1.23

nanometer One-billionth of a meter $(10-9m)$. The prefix 'nano' is derived from the Greek word for dwarf because a nanometer is very small. Ten hydrogen atoms lined up side-by-side are about 1 nanometer long.

nanopowder A dry collection of nanoparticles.

nanoscale Refers to objects with sizes in the range of 1 to 100 nanometers in at least one dimension.

nanotechnology The design, characterization, production and application of structures, devices and systems that take advantage of the special properties at the nanoscale by manipulating shape and size.

nanotubes Carbon nanotubes are cylindrical molecules made up of carbon bonded in a hexagonal formation. They are unusually strong, efficient conductors of heat and exhibit unique electrical properties. These characteristics make them potentially useful in extremely small scale electronic and mechanical applications.

nanowires A "nanowire" is a wire of dimensions of the order of a nanometer $(10-9 \text{ meters})$. At these scales, quantum mechanical effects are important - hence such wires are also known as "quantum wires".

photosynthesis A biochemical process in which cells in plants, algae, and some bacteria use light energy to convert inorganic molecules into ATP (a high energy storage molecule) which they can use for energy later.

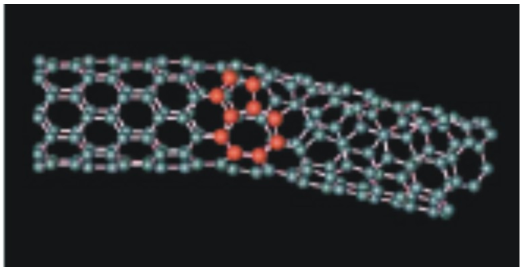


FIGURE 1.24

polymer A generic term used to describe a substantially long molecule. This long molecule consists of structural units and repeating units strung together through chemical bonds.

supersaturation Supersaturation (or oversaturation) refers to a solution that due to special conditions contains more of the dissolved material than could be dissolved by the solvent under normal circumstances.

Name_______________

Date_______________

Period_______________

Seeing and Building Small Things: Student Quiz

1. Name the scanning probe instrument that uses electrical current to infer an image of atoms. Briefly describe how it works.

2. Name the scanning probe instrument that reacts to forces inherent in atoms and molecules to infer an image of atoms. Briefly describe how it works.

3. Scanning probe instruments can also be used to create things atom by atom. Briefly summarize the down-side of using such tools to create an aspirin tablet.

4. How does dip pen nanolithography (DPN) work? Using a drawing in your explanation.

5. Name two things in nature that are created by self-assembly processes.

1: 2:

6. Circle true or false for each of the following.

E-beam lithography is a type of self assembly. True False

One type of self-assembly is crystal growth. True False

Nanotubes can be grown like trees from seed crystals. True False

The rules governing self-assembly are fully understood. True False

Applications of Nanoscience

Contents

- What's New Nanocat? Poster Session: Student Topic List
- What's New Nanocat? Poster Session: Peer Feedback Form

What's New Nanocat? Poster Session: Student Directions

Overview

When scientists want to share their findings and proposals with other scientists, they often do it at a national meeting with scientists who have the same interests. They often share ideas at what is called a *poster session*. The scientists come to the meeting with a poster that explains in *text and graphics* what their findings or proposal is all about. The poster is usually either a rolled up paper about 4 feet long and 2.5 feet wide, or a set of 8 – 12 normal (letter size) printed pages that they tack up on a board. They stand near the poster and as others walk by, they discuss their work with the other scientists and answer questions.

Your Assignment

You will assume the role of a prominent nanoscientist working on a new nanotechnology application, and explain the proposed usage of the new technology to replace a current technology in a poster session. You will be given a list of nanotechnology applications (based on what we have discussed in class) from which you can choose, or you can prepare a poster on an application that is not on the list if your teacher approves it. The posters will be displayed in class and you will explain the technology by explaining the poster. Your classmates will assess your poster, and you will assess their posters, using the Poster Feedback Sheet.

Your poster must include the following:

a. A written description of the current technology and how it is used, and how it works.
b. At least one picture or diagram that helps illustrate how the current technology works.
c. A written description of the new, related nanotechnology, how it is proposed to be used, and how it works.
d. At least one picture or diagram that helps illustrate how the new nanotechnology works.
e. A written description of the implications of the new nanotechnology: how it will help improve understanding, solve a problem, and possible ethical or societal issues.

At the poster session, be prepared to discuss the applications and answer questions, so that someone visiting the poster will walk away with a good understanding of the science.

Grading

To receive full credit,

a. Your poster must include all of the elements mentioned above.
b. Your written descriptions and diagrams must have a sound scientific basis.
c. Your design should be neat and have an attractive layout.
d. All text and borrowed diagrams must have source citations.
e. Your oral explanation must be clear and understandable, all team members must participate, and you should be able to answer questions about the poster and how you created it.

What's New Nanocat? Poster Session: Student Topic List

Stain Resistant Clothes

Manufacturers are embedding fine-spun fibers into fabric to confer stain resistance on khaki pants and other products. These "nanowhiskers" act like peach fuzz and create a cushion of air around the fabric so that liquids bead up and roll off. Each nanowhisker is only ten nanometers long, made of a few atoms of carbon. To attach these whiskers to cotton, the cotton is immersed in a tank of water full of billions of nanowhiskers. Next, as the fabric is heated and water evaporates, the nanowhiskers form a chemical bond with cotton fibers, attaching themselves permanently. The whiskers are so tiny that if a cotton fiber were the size of a tree trunk, the whiskers would look like fuzz on its bark. Nanoresistant fabric created by NanoTex is already available in clothing available at stores like Eddie Bauer, The Gap, and Old Navy. This innovation will impact not only khaki wearers, but also dry cleaners who will find their business declining, and detergent makers who will find less of their project moving off the shelf. Nanoparticles (e.g., of silver) could also be introduced to destroy microbes and create odor-resistant cloths.

More information:

- Fancy pants: http://www.sciencentral.com/articles/view.php3?article_id=218391840#38;cat=3_5
- Nano fiber finishing: http://www.textileinfo.com/en/tech/nanotex/page02.html
- Odor-resistant products: http://www.physorg.com/news1373.html

Paint That Resists Chipping

On cars, special nanopaints that hold up better to weathering, are more resistant to chipping and have richer and brighter colors than traditional pigments. The paints contain tiny ceramic particles added to a liquid clearcoat. The particles link and create a very dense and smoothly structured network that provides a protective layer.

More information:

- Mercedes-Benz Nano Paint (3 page article on benefits, material, and paint process): http://www.auto123.com/en/info/news/news,view.spy?artid=21942#38;pg=1
- Nanotechnology improves paint gloss: http://www.canadiandriver.com/articles/jk/040407.htm
- Mercedes tougher, shinier nanopaint: http://www.supanet.com/motoring/testdrives/news/40923/

Paint That Cleans the Air

Chinese scientists have announced that they have even invented nanotech-based coating material that acts as a permanent air purifier. If the coating proves to be effective at air cleaning, it will be gradually used on buildings across Shanghai in order to improve the city's air quality. The core of the material is a titanic-oxide-based compound that comprises particles at nanoscale achieved by advanced nanotechnology. Exposed under sunlight, the substance can automatically decompose the major ingredients that cause air pollution such as formaldehyde and nitride.

More information:

- Paint to help clean and purify the air: http://english.eastday.com/eastday/englishedition/metro/userobject1ai710823.html
- New pollution paint will clean the air: http://www.edie.net/news/news_story.asp?id=8025#38;channel=0
- Smog-busting paint: http://www.ananova.com/news/story/sm_862568.html?menu=news.latestheadlines

Painting On Solar Cells

Enough energy from the sun hits the earth every day to completely meet all energy needs on the planet, if only it could be harnessed. Doing so could wean us off of fossil fuels like oil and provide a clean energy alternative. But currently, solar-power technologies cost as much as 10 times the price of fossil fuel generation. Chemists at U.C. Berkeley are developing nanotechnology to produce a photovoltaic material that can be spread like plastic wrap or paint. These nano solar cells could be integrated with other building materials, and offer the promise of cheap production costs that could finally make solar power a widely used electricity alternative. Current approaches embed nanorods (barshaped semiconducting inorganic crystals) in a thin sheet (200 nanometers deep) of electrically conductive polymer. Thin layers of an electrode sandwich these nanorodpolymer composite sheets. When sunlight hits the sheets, they absorb photons, exciting electrons in the polymer and the nanorods, which make up 90 percent of the composite. The result is a useful current that is carried away by the electrodes. Eventually, nanorod solar cells could be rolled out, ink-jet printed, or even painted onto surfaces, so that even a billboard on a bus could be a solar collector.

More information:

- Painting on solar cells: http://www.californiasolarcenter.org/solareclips/2003.01/20030128-6.html
- Cheap, plastic solar cells may be on the horizon: http://www.berkeley.edu/news/media/releases/2002/03/28_solar.html
- New nano solar cells to power portable electronics: http://www.californiasolarcenter.org/solareclips/2002.04/20020416-7.html
- Our energy challenge: http://smalley.rice.edu/

High Density Storage Media

New nanomedia could have a storage density that is a million times higher that current CDs and DVDs. Nano storage applications currently in development use a variety of methods, including self-assembly.

More information:

- Franz J. Himpsel's web site: http://uw.physics.wisc.edu/ himpsel/nano.html
- Nanoscale memory: http://uw.physics.wisc.edu/ himpsel/memory.html
- Nanoscale memory developed at ASU: http://www.asu.edu/feature/nanoscale.html
- IBM's Millipede project demonstrates trillion-bit data storage density: http://domino.research.ibm.com/comm/pr.nsf/pages/news.20020611_millipede.html
- IBM puts new spin on nano-storage: http://news.zdnet.com/2100-9584_22-934825.html
- Nanoscale memory builds itself: http://www.betterhumans.com/News/news.aspx?articleID=2003-12-09-5

Smaller Devices and Chips

A technique called nanolithography enables us to create much smaller devices than current approaches. For example, dip pen nanolithography is a 'direct write' technique that uses an AFM to create patterns and to duplicate images. "Ink" is laid down atom by atom on a surface, through a solvent—often water.

More information:

- AFM Oxidation nanolithography http://www.ntmdt.ru/SPMTechniques/Principles/Lithographies/AFM_Oxidation_Lithography_mode37.html
- Dip pen nanolithography (DPN): http://www.chem.northwestern.edu/ mkngrp/dpn.htm
- Improved DPN through thermal dip pen nanolithography: http://www.voyle.net/Nano%20Research%20200/research00110%20.htm

Hybrid Neuro-Electronic Networks

Researchers are studying the electrical interfacing of semiconductors with living cells—in particular, neurons—to build hybrid neuro-electronic networks. Cellular processes are coupled to microelectronic devices through the direct contact of cell membranes and semiconductor chips. For example, electrical interfacing of individual nerve cells and semiconductor microstructures allow nerve tissue to directly communicate their impulses to computer chips. This research is directed (1) to reveal the structure and dynamics of the cell-semiconductor interface and (2) to build up hybrid neuro-electronic networks. Other researchers have built a cyborg, a half-living, half-robot creature that connects the brain of an eel-like fish to a computer and is capable of moving towards lights. Such research explores the new world at the interface of the electronics in inorganic solids and the ionics in living cells, providing the basis for future applications in medical prosthetics, biosensorics, brain research and neurocomputation. For example, neuro-electronic networks could lead implants that can restore sight.

More information:

- Nanopicture of the day from Peter Fromherz: http://www.nanopicoftheday.org/2003Pics/Neuroelectronic%20Interface.htm
- Max Planck research: http://www.biochem.mpg.de/mnphys/
- Lamprey cyborg: http://www.sciencenews.org/articles/20001111/fob4.asp

Detecting Disease with Quantum Dots

Quantum dots are small devices that contain a tiny droplet of free electrons, and emit photons when submitted to ultraviolet (UV) light. Quantum dots are considered to have greater flexibility than other fluorescent materials, which makes them suited for use in building nano-scale applications where light is used to process information. Quantum dots can, for example, be made from semiconductor crystals of cadmium selenide encased in a zinc sulfide shell as small as 1 nanometer (one-billionth of a meter). In UV light, each dot radiates a brilliant color.

Because exposure to cadmium could be hazardous, quantum dots have not found their way into clinical use. But they have been used as markers to tag particles of interest in the laboratory. Scientists at Georgia Institute of Technology have developed a new design that protects the body from exposure to the cadmium by sealing quantum dots in a polymer capsule. The surface of each capsule can attach to different molecules. In this case, they attached monoclonal antibodies directed against prostate-specific surface antigen, which is found on prostate cancer cells. The researchers injected these quantum dots into live mice that had human prostate cancers. The dots collected in the tumors in numbers large enough to be visible in ultraviolet light under a microscope. Because the dots are so small, they can be used to locate individual molecules, making them extremely sensitive as detectors. Quantum dots could improve tumor imaging sensitivity tenfold with the ability to locate as few as 10 to 100 cancer cells. Using this technology, we could detect cancer much earlier, which means more successful, easier treatment.

More information:

- Quantum dots introduction: http://vortex.tn.tudelft.nl/grkouwen/qdotsite.html
- Lawrence Livermore Labs work in quantum dots: http://www.llnl.gov/str/Lee.html
- Quantum dots light up prostate cancer: http://www.whitaker.org/news/nie2.html
- Quantum Dots. Cientifica White Paper. http://nanotechweb.org/dl/wp/quantum_dots_WP.pdf

Growing Tissue to Repair Hearts

Cardiac muscle tissue can be grown in the lab, but the fibers grow in random directions. Researchers at the University of Washington are investigating what type of spatial cues they might give heart-muscle cells so that they order themselves into something like the original heart-muscle tissue. Working with one type of heart muscle cell, they have been able build a two-dimensional structure that resembles native tissue. They use nanofibers to "instruct" muscle cells to orient themselves in a certain way. They have even able to build a tissue-like structure in which cells pulse or 'beat' similar to a living heart.

More information:

- University of Washington cardiac muscle work: http://www.washington.edu/admin/finmgmt/annrpt/mcdevitt.htm
- The heart of tissue engineering: http://www.coe.berkeley.edu/labnotes/1202/healy.html

Preventing Viruses from Infecting Us

If we could cover the proteins that exist on the influenza virus, we could prevent the virus from recognizing and binding to our body cells. We would never get the flu! A protein recognition system has already been developed. More generally, this work suggests that assembled virus particles can be treated as chemically reactive surfaces that are potentially available to a broad range of organic and inorganic modification.

More information:

- Virus nanoblocks http://pubs.acs.org/cen/topstory/8005/8005notw2.html
- Nanotechnology could block viruses from entering cells: http://www.betterhumans.com/Errors/index.aspx?aspxerrorpath=/Nanotechnology_ http://www.betterhumans.com/Errors/index.aspx?aspxerrorpath=/Nanotechnology_ Could_Block_Viruses_from_Entering_Cells.Article.2003-03-20-1.aspx

Nanobots Making Repairs to the Body

Nanobots are decades off, but if they are developed someday, they could be used to maintain and protect the human body against pathogens. For example, they could (1) be used to cure skin diseases (embedded in a cream, they could remove dead skin and excess oils, apply missing oils), (2) be added to mouthwash to destroy bacteria and lift plaque or tartar from the teeth to be rinsed away, (3) augment the immune system by finding and disabling unwanted bacteria and viruses, or (4) nibble away at plaque deposits in blood vessels, widening them to prevent heart attacks.

More information:

- Nanorobots: medicine of the future: http://www.ewh.ieee.org/r10/bombay/news3/page4.html
- Robots in the body: http://www.genomenewsnetwork.org/articles/2004/08/19/nanorobots.php
- Drexler and Smalley make the case for and against molecular assemblers http://pubs.acs.org/cen/coverstory/8148/8148counterpoint.html

Drug Delivery Systems

Nanotubes and buckyballs could serve as drug delivery systems. Researchers have attached florescent markers and proteins to nanotubes and mixed them with living cells. They can see (from the florescent marker) that the nanotubes enter the cell, and could "deliver" the protein inside the cell. The nanotubes don't seem toxic to the cell, so far, but lots more research to be done. Similarly, investigators anticipated that buckyball or fullerene-related structures could serve as "cages" for small drug molecules.

More information

- Tiny weapons with giant potential: http://www.multsclerosis.org/news/Jul2002/NanobombsDeliveringDrugs.html
- Amino groups link up with carbon nanotubes: http://nanotechweb.org/articles/news/2/3/1/1
- Buckymedicine: http://www.sciencenews.org/articles/20020713/bob10.asp

Self-Cleaning Surfaces

Self-cleaning surfaces (e.g., windows, mirrors, toilets) could be made with bioactive coatings. Researchers have already developed water-repellent surfaces that could lead to self-cleaning glass. This surface mimics the surface of the water lily, which is waxy and covered with tiny bumps, so water rolls off. There are spray coatings that currently exist that make glass self-cleaning, but these coatings wear off. Nanotechnology would build this new surface into the surface of the window, so it would work for the lifetime of the window.

More information:

- Bumpy glass could lead to self-cleaning windows: http://www.voyle.net/Future%20Technology%202005/Future%202005-0006.htm
- Yes, it's true: Windows that clean themselves: http://www.clarkpublicutilities.com/Residential/TheEnergyAdviser/Archives2004/04_10_17
- ABC News: Scientists develop self-cleaning windows: http://abcnews.go.com/Technology/DyeHard/story?id=440893#38;page=1

Food Storage and Manufacturing

Nanocomposites for plastic film coatings used in food packaging could detect or even prevent contamination in food or food packaging. This could enable wider distribution of food products to remote areas in less industrialized countries.

More information:

- Food manufacture: A mini revolution: http://www.foodmanufacture.co.uk/news/fullstory.php/aid/472/A_mini_revolution.html

- Coating process could revolutionize food packaging: http://www.bakeryandsnacks.com/news/news-NG.asp?id=50325
- Hungry for nano: The fruits of nanotechnology could transform the food industry: http://www.findarticles.com/p/articles/mi_m1200/is_13_166/ai_n6366589

Water Treatment

Nanotechnology could lead to advanced water-filtering membranes that could purify even the worst of wastewater. Only about 1 percent of the water in the world is usable (97 percent is saltwater, and two-thirds of the remaining fresh water rest is ice). With the world population expected to double in 40 years, over half the world population could face a very serious water shortage in that time. Even now, $10,000$ to $60,000$ people die every day because of diseases caused by bad water. Advanced nanomembranes could be used for water purification, desalination, and detoxification, nanosensors could detect contaminants and pathogens, and nanoparticles could degrade water pollutants and make salt water and even sewage water easily converted into usable, drinkable water.

More information:

- Nano world: Water, water everywhere nano: http://www.wpherald.com/storyview.php?StoryID=20050318-112217-1110r
- Nanowater: http://www.nanowater.org/nano.htm
- Wired News: Water filters rely on nanotech: http://www.wired.com/news/technology/0,1282,65287,00.html

Health Monitoring

Several nano-devices are being developed to keep track of daily changes in patients' glucose and cholesterol levels, aiding in the monitoring and management of diabetes and high cholesterol for better health. For example, some researchers have created coated nanotubes in a way that will fluoresce in the presence of glucose. Inserted into human tissue, these nanotubes can be excited with a laser pointer and provide real-time monitoring of blood glucose level. No more discomfort from needles, pricking, or drawing blood!

More information:

- Selective coatings create biological sensors from carbon nanotubes: http://www.voyle.net/Nano%20Research%20200/research00176.htm
- Nano-sensor to monitor glucose levels in diabetics: http://www.123bharath.com/health-indianews/index.php?action=fullnews#38;id=44390
- Encapsulated Carbon Nanotubes for Implantable Biological Sensors to Monitor Blood Glucose Levels: http://www.azonano.com/news.asp?newsID=439
- Glowing sensor may allow artificial pancreas: http://www.betterhumans.com/News/news.aspx?articleID=2004-03-17-3

Clean Energy

Cars of the future may use nonpolluting hydrogen fuel cells. Today, hydrogen fuel is expensive to make, but with catalysts made from nanoclusters, it may be possible to generate hydrogen from water by photocatalytic reactions. Novel hydrogen storage systems could be based on carbon nanotubes and other lightweight nanomaterials, nanocatalysts could be used for hydrogen generation, and nanotubes could be used for energy transport.

More information:

- Sun and hydrogen to fuel future: http://news.bbc.co.uk/2/hi/science/nature/3536156.stm
- Nanotechnology could promote hydrogen economy: http://www.eurekalert.org/pub_releases/2005-03/rtsu-ncp032805.php
- USF working hard to make alternative fuels a reality: http://www.voyle.net/Nano%20Research/research00092%20.htm

- Our energy challenge: http://smalley.rice.edu/

Name________________

Date________________

Period________________

What's New Nanocat? Poster Session: Peer Feedback Form

1. What is the topic of the poster you are evaluating?

2. What are the names of the students who developed the poster you are evaluating?

3. The poster contained the following items:

A text description of a current technology and how it works. True False

A picture that helps illustrate how the current technology works. True False

A text description of a new, related nanotechnology and how it works. True False

A picture that helps illustrate how the new nanotechnology works. True False

A text description of the implications of the nanotechnology: how it will help improve understanding, solve a problem, and any possible societal issues. True False

4. How strongly do you agree with the following statements?

TABLE 1.14:

	Strongly Agree	Agree	Unsure	Disagree	Strongly Disagree
The poster is visually appealing.	1	2	3	4	5
The poster has a solid scientific basis.	1	2	3	4	5
The poster presenters communicated clearly and answered questions effectively.	1	2	3	4	5
Borrowed text and pictures have citations.	1	2	3	4	5

5. What was your favorite part of the poster?

6. Any additional comments or suggestions for the poster or poster presenters?

Chapter 2 Clear Sunscreen-Student Materials

Chapter Outline

2.1 How Light Interacts with Matter

Unit Overview

Contents

- (Optional) Clear Sunscreen: Pretest
- (Optional) Clear Sunscreen: Posttest

Name_______________

Date_______________

period_______________

Clear Sunscreen: Pretest

1. In what ways are "nano" sunscreen ingredients similar and different from other ingredients currently used in sunscreens? For each of the four categories below, indicate whether "nano" sunscreen ingredients are "similar" or "different" to organic and inorganic ingredients and explain how.

TABLE 2.1:

	Organic Ingredients (e.g. PABA)	Inorganic Ingredients (e.g. Classic Zinc Oxide used by lifeguards)
Chemical Structure	Similar or Different How:	Similar or Different How:
Kinds of Light Blocked	Similar or Different How:	Similar or Different How:
Way Light is Blocked	Similar or Different How:	Similar or Different How:
Appearance on the Skin	Similar or Different How:	Similar or Different How:

2. Briefly describe one benefit and one drawback of using a sunscreen that contains "nano" ingredients.

3. What determines if a sunscreen appears white or clear on your skin?

4. How do you know if a sunscreen has "nano" ingredients?

Name_______________

Date_______________

period_______________

Clear Sunscreen: Posttest

1. In what ways are "nano" sunscreen ingredients similar and different from other ingredients currently used in sunscreens? For each of the four categories below, indicate whether "nano" sunscreen ingredients are "similar" or "different" to organic and inorganic ingredients and explain how.

TABLE 2.2:

	Organic Ingredients (e.g. PABA)	Inorganic Ingredients (e.g. Classic Zinc Oxide used by lifeguards)
Chemical Structure	Similar or Different How:	Similar or Different How:
Kinds of Light Blocked	Similar or Different How:	Similar or Different How:
Way Light is Blocked	Similar or Different How:	Similar or Different How:
Appearance on the Skin	Similar or Different How:	Similar or Different How:

2. Briefly describe one benefit and one drawback of using a sunscreen that contains "nano" ingredients.

3. What determines if a sunscreen appears white or clear on your skin?

4. How do you know if a sunscreen has "nano" ingredients?

Introduction to Sun Protection

Contents

- Summary of Radiation Emitted by the Sun: Student Handout
- Clear Sunscreen Initial Ideas: Student Worksheet
- Ultra-Violet (UV) Protection Lab Activity: Student Instructions #38; Worksheet

Summary of Radiation Emitted by the Sun: Student Handout

TABLE 2.3: Chart of Different Kinds of Solar Radiation

Radiation Type	Characteristic Wavelength (λ)	Energy per Photon	% of Total Radiation Emitted by Sun	Effects on Human Skin	Visible to Human Eye?
UVC	$\sim 200-290$ nm (Short-wave UV)	High Energy	$\sim 0\%$ ($< 1\%$ of all UV)	DNA Damage	No
UVB	$\sim 290-320$ nm (Mid-range UV)	Medium Energy	$\sim .35\%$ (5% of all UV)	Sunburn DNA Damage Skin Cancer	No
UVA	$\sim 320-400$ nm (Long-wave UV)	Low Energy	$\sim 6.5\%$ (95% of all UV)	Tanning Skin Aging DNA Damage Skin Cancer	No

TABLE 2.3: (continued)

Radiation Type	Characteristic Wavelength (λ)	Energy per Photon	% of Total Radiation Emitted by Sun	Effects on Human Skin	Visible to Human Eye?
Visible	∼ 400 – 800 nm	Lower Energy	∼ 43%	None Currently Known	Yes
IR	∼ 800 – 120,000 nm	Lowest Energy	∼ 49%	Heat Sensation (high λ IR)	No

Graph of Radiation Emitted by the Sun by Wavelength

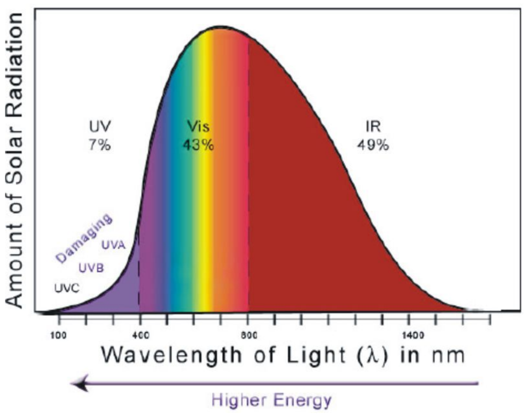


FIGURE 2.1

Name_______________

Date_______________

period_______________

Clear Sunscreen Initial Ideas: Student Worksheet

Write down your initial ideas about each question below and then evaluate how confident you feel that each idea is true. At the end of the unit, we'll revisit this sheet and you'll get a chance to see if and how your ideas have changed.

TABLE 2.4:

1. What are the most important factors to consider in choosing a sunscreen?	**How sure are you that this is true?** Not sure	**How sure are you that this is true?** Kind-of-Sure	**How sure are you that this is true?** Very Sure	**End of Unit Evaluation**
2. How do you know if a sunscreen has "nano" ingredients?	**How sure are you that this is true?** Not sure	**How sure are you that this is true?** Kind-of-Sure	**How sure are you that this is true?** Very Sure	**End of Unit Evaluation**

TABLE 2.4: (continued)

1. What are the most important factors to consider in choosing a sunscreen?	**How sure are you that this is true?** Not sure	**How sure are you that this is true?** Kind-of-Sure	**How sure are you that this is true?** Very Sure	**End of Unit Evaluation**
3. How do "nano" sunscreen ingredients differ from most other ingredients currently used in sunscreens?	**How sure are you that this is true?** Not sure	**How sure are you that this is true?** Kind-of-Sure	**How sure are you that this is true?** Very Sure	**End of Unit Evaluation**

Name_______________

Date_______________

period_______________

Ultra-Violet (UV) Protection Lab Activity: Student Instructions #38; Worksheet

Introduction

It is important to protect our skin from damaging UV radiation, but how do we know how well we are protecting ourselves? Is wearing a light shirt at the beach as effective as wearing sunscreen? Is it better protection? Do thicker, whiter sunscreens protect us better than transparent sprays? Can we tell how well something will block UV by looking at its appearance?

Research Question

In this lab you will be investigating the following research question:

- Does the appearance of a substance (its opacity) relate to its ability to block UV light?

Opacity

The *opacity* of a substance is one way to describe its appearance. Opacity is the opposite of how transparent or "see-through" something is; for a completely opaque substance you can not see through it at all. Opacity is a separate property than the color of a substance –for example you can have something that is yellow and transparent like apple juice or something that is yellow and opaque like cake frosting.

Hypothesis

Do you think that UV blocking ability relates to a substance's opacity? Would you expect transparent or opaque substances to be better UV blockers? If you are right, what implications does this have for how you will protect yourself the next time you go to the beach? Write down your best guesses to answer these questions and explain why you think what you think.

Materials

- Assorted white substances varying in opacity (for example: different sunblocks, sunscreens, sungels, glass pieces, white tee-shirts of varying thickness, white tissue paper, white paper of varying thickness, laundry detergent, white paint, white face makeup)
- Eight paper cups

- One micro spoon
- Sunscreen Smear Sheet
- Black construction paper (for judging opacity of white substances)
- UV light source
- UV sensitive bead testers
- UV bead color guide
- Cotton swabs (for apply sunscreen to the Sunscreen Smear Sheet)
- Alcohol wipes (for cleaning sunscreen off the Sunscreen Smear Sheet)

Procedure

Part I: Choose Your Samples

Goal: Choose a group of substances from the ones provided by your teacher that you think will best help you determine if opacity is related to UV blocking.

- Obtain eight small paper cups. Obtain a small sample of each of the substances you have chosen. Label each cup with the name of the substance.

  Tip: Try to choose substances that vary in their opacity and that you would expect to vary in their blocking ability.

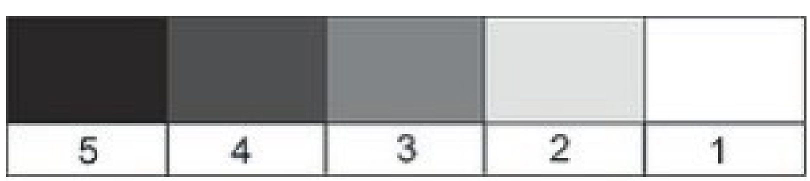
Part II: Judge the Opacity

Goal: To make observations about the appearance (opacity) of the substances you chose,using your eyes as the instruments.

- Obtain a Sunscreen Smear Sheet. Place it on top of a black sheet of paper.
- Label one square with the name of each substance you are going to test.
- Use the micro spoon to measure out the first substance (make sure to use an equal amount of all the other substances).
- Then use the cotton swab to smear the substance onto the Sunscreen Smear Sheet,evenly covering a whole square with a thin layer. (For solid substances, just place them on top of the sheet).
- How well can you see through the substance to the black sheet of paper?
- Use the Opacity Guide on the next page to rank each sample on a 1 to 5 scale.

  Use 5 to represent no opacity (you cannot see the substance at all). Use 1 to represent complete opacity (you can't see any black through the sample).

- Record your observations into the Data Chart in this packet.
- Repeat for each of your substances.



Opacity Guide

Part III: Test the UV Blocking

Goal: Use UV-sensitive beads to determine how effective your chosen substances are in blocking UV-light.

- Obtain 3 UV bead testers:

- Bead Tester "C1" for Control 1. This bead will always be kept out of the UV light and will show you the lightest color that the bead can be. Keep this in the envelope until you need it.
- Bead Tester "C2" for Control 2. This bead will always be exposed to the UV light and should always change color to let you know that the UV light is reaching the bead. This bead will show you the darkest color that the bead can reach.
- Bead Tester "E" for Experimental. Keep this in its envelope so that it is not exposed to any UV light while you are not using it.

Checking Bead Tester C1 and C2

- Use UV bead color guide to record the initial bead color number $(2-10)$ of C1 on your data chart.
- Expose C2 to the UV light for 30 sec . and quickly compare it to the UV bead color guide. Record the bead color number $(2-10)$ on your data chart.

Using Bead Tester E with Your Substances

- To test the UV blocking of a substance, hold Bead Tester E under the square for that substance on the Sunscreen Smear Sheet. (For solid substances, just hold Bead Tester E directly behind them).
- Expose Bead Tester E (covered by the substance) and Bead Tester C2 (uncovered) to your UV lamp (or direct sunlight) for 30 secs .
- Take both Bead Testers out of the light, uncover Bead Tester E, and observe any changes to the color of the beads using the UV bead color guide. Record the bead color number $(2-10)$ for both E and C2 on your data chart.
- Repeat for each of your substances.

Data Chart

Initial C1 Bead Color Number________

Initial C2 Bead Color Number_________

TABLE 2.5:

Substance Name(Include SPF if applicable)	Appearance (Describe)	Opacity (1 to 5 rating)	Color of UV bead "E" (2 to 10 rating)	Color of UV bead "C2" (2 to 10 rating)	Observations and Notes

Analysis

Now you need to analyze your data to see if it helps to answer the research question:Does the appearance of a substance (opacity) relate to its ability to block UV light? One of the ways that scientists organize data to help them see patterns is by creating a visual representation. Below you will see a chart that you can use to help you analyze your data.

To fill in the chart, do the following for each substance that you tested:

a. Find the row that corresponds to its opacity.
b. Find the column that corresponds to its UV blocking ability.
c. Draw a large dot • in the box where this row and column intersect.
d. Label the dot with the name or initials of the substance.

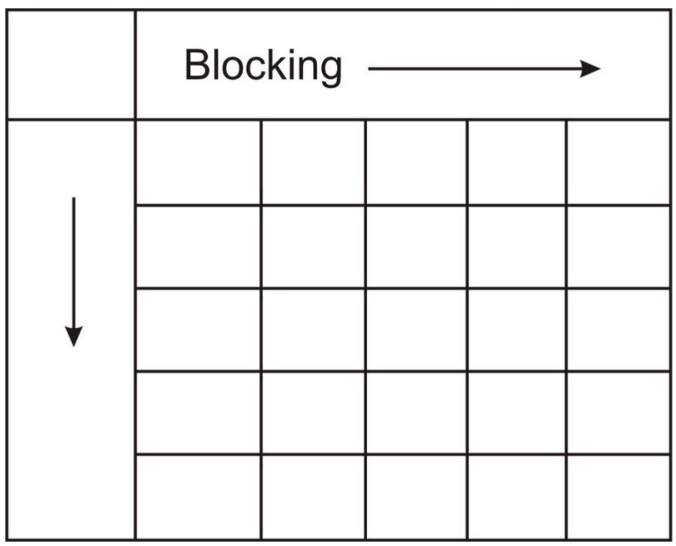
After you have filled in the chart, answer the analysis questions that follow.

TABLE 2.6:

UV Blocking Ability → Opacity ↓	No Blocking (10)	Low Blocking (8)	Medium Blocking (6)	High Blocking (4)	Total Blocking (2)
5 Fully Transparent					
4					
3					
2					
1 Fully Opaque					

1. Look at the visual representation of your data that you have created and describe it. Note any patterns that you see. Remember that seeing no pattern can also give you important information.

2. What pattern would you expect to see if there is a relationship between the appearance of a substance (opacity) and its ability to block UV light? Draw the pattern by coloring in the grid below.



3. Does your chart match the pattern you would expect to see if there is a relationship between opacity and UV blocking ability?

□ Yes

□ No

□ I'm not sure

4. What does this answer mean in practical terms? What does it tell you about how well you can judge the effectiveness of sun protection by looking at its appearance? How might this affect your sun protection activities?

5. Do you think that increasing the number of substances you tested would change your answer? Why or why not?

6. How confident are you that the answer you came up with is correct? Do you think that increasing the number of substances you tested would change *how sure you are* of your answer? Why or why not?

Conclusions

1. Answer the research question:

□ Yes, there is a relationship.

□ No, there is not a relationship.

□ I'm not sure if there is a relationship.

2. This is how the evidence from the experiment supports my answer: (Make sure to be specific and discuss any patterns you do or do not see in the data.)

3. Identify any extra variables that may have affected your experiment:

4. How could you control for these variables in future experiments?

5. What changes would you make to this experiment so that you could answer the research question better?

6. All experiments raise new questions. Sometime these come directly from the experiment and others are related ideas that you become curious about. What is a new research question that you would want to investigate after completing this experiment?

All About Sunscreens

Contents

Overview of Sunscreen Ingredients: Student Handout

TABLE 2.7:

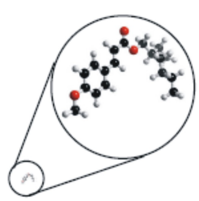
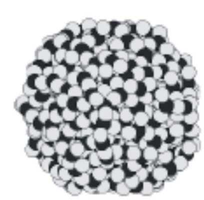
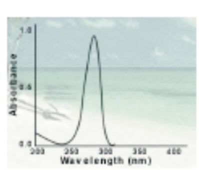
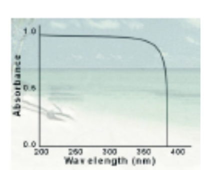
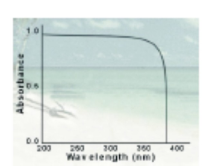
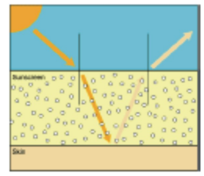
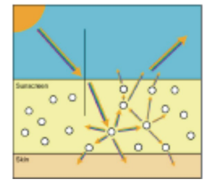
	Organic Ingredients	Inorganic Ingredients (Nano)	Inorganic Ingredients (Large)
Atoms Involved	Carbon, Hydrogen, Oxygen, Nitrogen	Zinc, Titanium, Oxygen	Zinc, Titanium,Oxygen
Structure (not drawn to scale)	Individual molecule 	Cluster $\sim$ 100 nm in diameter 	Cluster $>$ 200 nm in diameter 
Interaction with UV light	Absorb specific λ 	Absorb all UV $<$ critical λ 	Absorb all UV $<$ critical λ 
Absorption Range	Parts of UVA or UVB spectrum	Broad spectrum UVA and UVB	Broad spectrum UVA and UVB

TABLE 2.7: (continued)

	Organic Ingredients	Inorganic Ingredients (Nano)	Inorganic Ingredients (Large)
Interaction with Visible light	None	Minimal Scattering 	Much Scattering 
Appearance	Clear	Clear	White

Name________________

Date________________

period________________

Light Reflection by Three Sunscreens: Student Worksheet

Introduction

Three sunscreens were tested for reflection (back-scattering) with different wavelengths of light:

- One contains nanosized inorganic ingredients
- One contains traditional inorganic ingredients
- One contains organic ingredients

A graph was created to show the percent of light reflected by each sunscreen at different wavelengths and is included in this packet.

Instructions

Use the graph to answer the following questions for each sunscreen in the chart on the next page:

a. Will it appear white or clear on your skin? How do you know?
b. What size (approximately) are the molecules / clusters?
c. Can we tell how good a UV blocker it is from this graph? Why/ why not?
d. Which one of the sunscreens is it? How do you know?

TABLE 2.8: Light Reflection by Three Sunscreens Chart

	Appearance	Size	UV Blocking	Identity (w/ reason)
# 1				
# 2				
# 3				

Light Reflected by Three Sunscreens

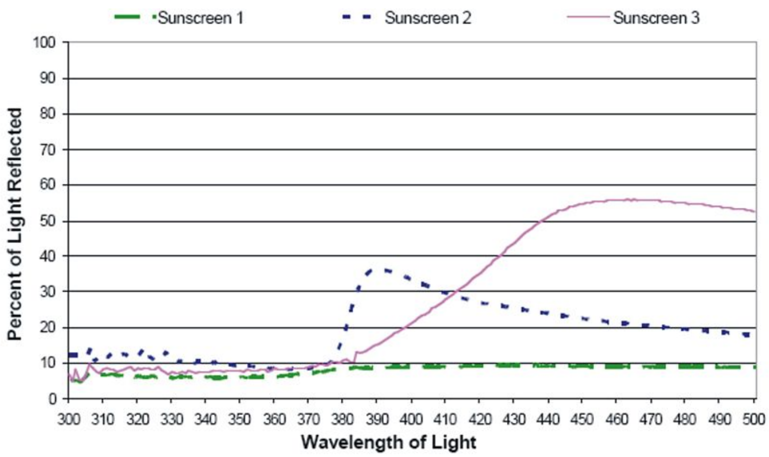


FIGURE 2.2

Sunscreen Ingredients Activity: Student Instructions #38; Worksheet

Most of us (hopefully) apply sunscreen to protect us from the sun when we are going to be outside for a long time. But how many of us have ever stopped to read the bottle to see what we are putting on our bodies? What kinds of chemicals are used to block the sun rays? Do different sunscreens use different ingredients to block the sun? How might the different ingredients used affect us? In this activity you'll take a look at several sunscreens to see what we are putting on our bodies when we use these products.

Materials

- Five different bottles of sunscreen.

To get a diverse group of sunscreens try to use more than one brand. Also see if you can find the following:

- One sunscreen with a high SPF (30-50).
- One sunscreen with a low SPF (5-15).
- One sunscreen designed for skiers or surfers.
- One sunscreen for sensitive skin or babies.
- One sunscreen that has zinc oxide (ZnO) or titanium dioxide (TiO_2) as an ingredient.

Note: the proper scientific name for TiO_2 is "titanium (IV) oxide", but the older name "titanium dioxide" is more commonly used.

Instructions

Look at the back of one of the bottles. You should see a list of the "active ingredients" in the sunscreen. These are the ingredients that prevent sunlight from reaching your skin ("inactive ingredients" are added to influence the appearance, scent, texture and chemical stability of the sunscreen.) Also look to see what kind of protection the sunscreen claims to provide. Does it provide UVB protection? UVA protection? Does it claim to have "broad spectrum" protection? What is its SPF number? Does it make any other claims about its protection? Record your observations for each sunscreen in the data chart and then answer the questions that follow.

TABLE 2.9: Data Chart

	Brand	Active Ingredients	SPF	UVB?	UVA?	Broad Spectrum?	Price
#1							

TABLE 2.9: (continued)

	Brand	Active Ingredients	SPF	UVB?	UVA?	Broad Spectrum?	Price
#2							
#3							
#4							
#5							

Questions

1. How many different active ingredients did most of the sunscreens have?

2. What were the most common active sunscreen ingredients you saw? Are these organic or inorganic ingredients?

3. Did any of the sunscreens you looked at have active ingredients that were very different from the rest? If so, what were they?

4. Were you able to find a sunscreen with inorganic ingredients in it? If so, which one(s) contained them?

5. How many of your sunscreens claimed to have UVA protection? UVB protection? Broadband protection?

6. Why do you think that many sunscreens have more than one active ingredient? Why can't they just put in more of the "best" one?

7. You have just looked at a sample of the different chemicals you are putting on your skin when you use sunscreen. Does this raise any health concerns for you? If so, what are some of the things you might be concerned about and why?

8. Where could you go to find out more information about possible health concerns?

Summary of FDA Approved Sunscreen Ingredients: Student Handout

TABLE 2.10:

	λ range (nm)	Protection Against UVB 280 – 320 nm	Protection Against UVA 320 – 400 nm	Possible Allergies	Other Issues
Organic Ingredients					
PABA derivatives					
Padimate O (Octyl dimethyl PABA)	295 – 340	Good	Little	Yes	-
PABA (p-aminobenzoic acid)	200 – 320	Good	Little	Yes	Greasy,Stains
Cinnamates					
Octinoxate (Octyl methoxycinnamate) (OMC) (Parasol MCX)	295 – 350	Good	Little	Yes	-
Cinoxate	280 – 310	Good	Little	Yes	-

TABLE 2.10: (continued)

	λ range (nm)	Protection Against	Protection Against	Possible Allergies	Other Issues
Salicylates					
Homosalate	295 – 340	Good	Little	Yes	-
Octisalate (Octyl salicylate)	295 – 330	Good	Little	Yes	-
Trolamin salicylate	260 – 355	Good	Little	Yes	-
Benzophenones					
Oxybenzone(Benzophenone-3)	295 – 375	Good	Some	Yes	-
Sulisobenzone(Benzophenone-4)	260 – 375	Good	Some	Yes	Hard to solubilize
Dioxybenzone (Benzophenone-8)	250 – 390	Good	Some	Yes	Hard to solubilize
Other Organics					
Ensulizole	290 – 340	Good	Little	Yes	-
Octocrylene	295 – 375	Good	Little	Yes	-
Menthyl anthranilate (Meradimate)	295 – 380	Good	Some	Yes	-
Avobezone (Parsol 1789)(Butyl methoxydibenzoyl methane)	295 – 395	Good	Good	Yes	If not well formulated, loses potency
*****NEW***** Ecamsule (Mexoryl SX)	310 – 370	Some	Good	Yes	Water-soluble
Inorganic Ingredients					
Titanium Dioxide	upto 365	Good	Good	No	-
Zinc Oxide	upto 380	Good	Good	No	-

Name________________

Date________________

period________________

Reflecting on the Guiding Questions: Student Worksheet

Think about the activities you just completed. What did you learn that will help you answer the guiding questions? Jot down your notes in the spaces below.

1. What are the most important factors to consider in choosing a sunscreen?

What I learned in this activity:

What I still want to know:

2. How do you know if a sunscreen has "nano" ingredients?

What I learned in this activity:

What I still want to know:

3. How do "nano" sunscreen ingredients differ from most other ingredients currently used in sunscreens?

What I learned in this activity:

What I still want to know:

How Sunscreens Block: The Absorption of UV Light

Contents

Absorption of Light by Matter: Student Reading

Absorption is one of the ways in which light can interact with matter. In absorption, the energy of the light shining on an object (or a gas or liquid) is captured by the substance's molecules and used to move them from a ground (low energy) state to higher (excited) energy states.

Absorption by a Single Atom

Absorption can only occur when the energy packet carried by one photon of light is equal to the energy required to bring about transition between states. Since the energy of a photon is directly related to its frequency (by the formula $E = hf$ where E is the photon's energy, f is its frequency, and h is Plancks' constant: 6.26×10^{-34} J s), then a given transition can only be caused by one specific frequency of light.

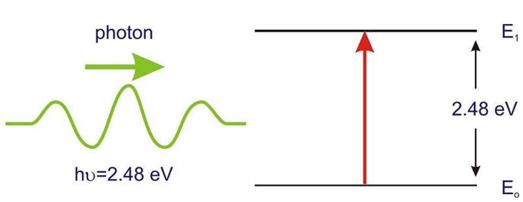


FIGURE 2.3

The energy of a photon must be exactly the same as the energy difference between levels for it to be absorbed

1

The frequency of a photon is inversely related to its wavelength (by the formula $\lambda = c/f$ where λ is the wavelength, f is the frequency and c is the speed of light in a vacuum). This means that the energy of the energy transition determines what frequency and hence what wavelength of light can be absorbed. The greater the energy of transition, the smaller the wavelength of light that can be absorbed.

What exactly are these different energy states that the atom can be in? Well, in atoms they correspond to the types of electron configurations in orbitals that are allowed by the rules of quantum mechanics. You may be familiar with transitions between electronic states if you've studied light emission by gasses. The main difference between the emission and the absorption of light is that in one case the light energy is being given off and in the other it is being captured, but in both cases the light energy of the photon absorbed or emitted corresponds to the energy difference between the two electronic states.

For example, Figure 2 shows several different energy levels and one possible transition for a hydrogen atom (in a gas). Each of the horizontal lines is an electronic state that the atom can be in and each the vertical line shows a possible "jump" or transition that could occur. Each possible transition (like the one shown) has a characteristic energy, and thus a specific wavelength of light that must be absorbed for it to occur. If we shine a flashlight at a sample of hydrogen atoms in a gas and measure the wavelengths of light that get through at the end, we would see an absorption spectrum like the one shown in the bottom of Figure 3. What you see is the full color spectrum, except for the "absorption lines", the specific wavelengths of light whose energy was absorbed because it corresponds to the energy difference between states for helium atoms. Similarly, if we stimulate a hydrogen atom to emit light, it will do so only at these same characteristic wavelengths whose energy (which is proportional to its frequency given by $E = hf$) corresponds to the energy between possible electron states for the hydrogen atom.

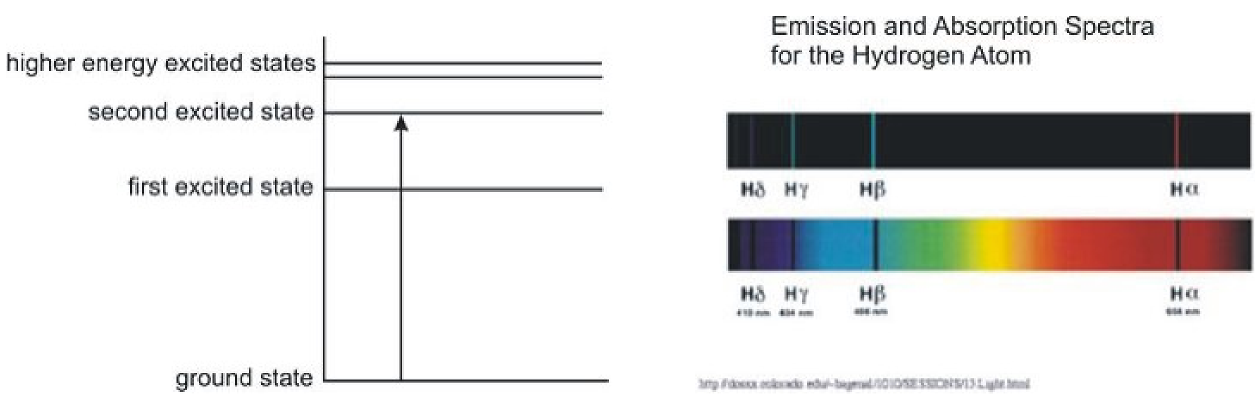


FIGURE 2.4

Energy states and one transition for the hydrogen atom*Left* Emission *top* and absorption *bottom* spectra for the hydrogen atom

2

Each line corresponds to a single transition*Right*

Absorption by Molecules

When we start dealing with molecules instead of atoms, the situation gets more complicated. When we talk about atoms being bonded together, it is not as if they are solidly glued to one another. The "glue" that hold the atoms together in a molecule is the attractive forces between the electrons and the different nuclei (intramolecular forces.) As electrons are constantly in motion, the strength of these attractive forces fluctuates over time allowing the nuclei to move back and forth and giving rise to molecular vibrations. As with electronic states, there are only certain vibrational modes which are possible. One simple example of molecular vibration can be seen in formate $(COOH^-)$, a moleculararanion. The six possible vibration modes for formate are shown in Figure 4.

Within each vibrational state, there are also multiple ways that the atoms in the molecule can rotate. These are called rotational states and again there are a limited number of possible rotational states that the molecule can be in. When we consider vibrational and rotational states, we realize that even without exciting any electrons (ground state), there are a bunch of different energy states that a molecule can be in. Not surprisingly, this is also true for the excited state. So now we have a situation in which the molecule can transfer from any of the ground states to any of the excited states and instead of a single energy of transition, we have a large group of energy gaps able to absorb light energy.

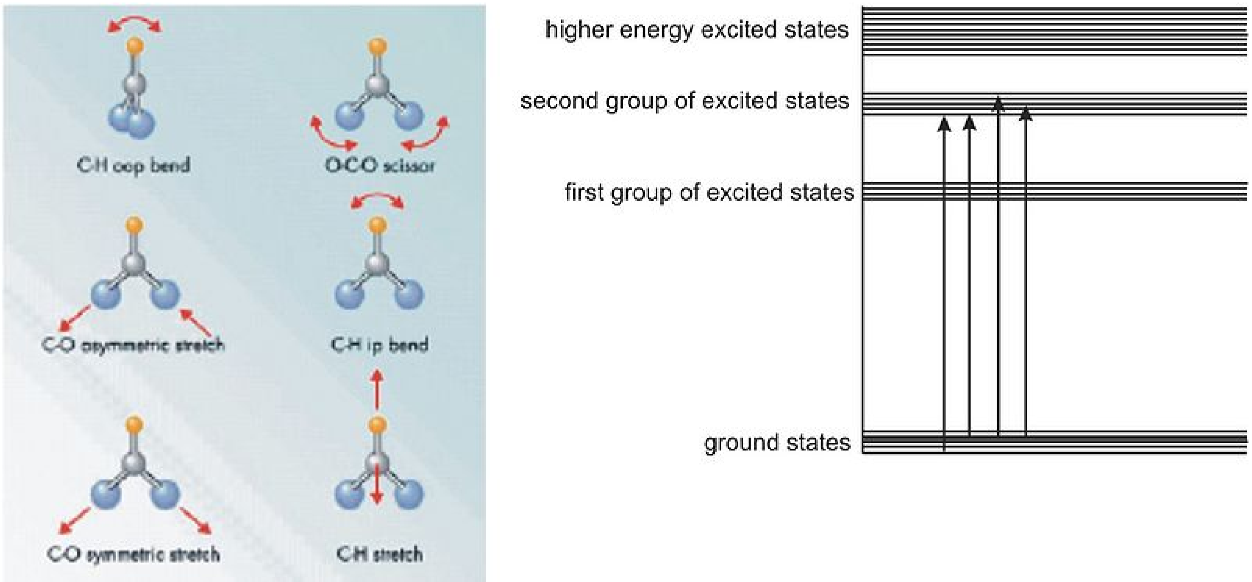


FIGURE 2.5

6 Vibrational modes for formate ion

3

Left Multiple Transition Energies for Electrons in Molecules*Right*

The multiple energy transitions possible correspond to a range of photon energies and thus frequencies of light that can be absorbed. Comparing Figure 5 with Figure 2 we can see that where there was a single transition for an atom, there are multiple ones for a molecule. Each arrow corresponds to one transition. Since we now have clusters of energy levels (due to the different variations in rotational and vibrational energies possible), we have a cluster of multiple transitions with similar energies.

Thus light absorbing molecules produces multiple, closely spaced absorption lines which combine to form an absorption curve. Absorption curves can be described both by their absorption range and peak absorption wavelength as shown in Figure 6. Not that absorption is not uniform across the range; it is greatest at the peak and drops off rapidly. So absorption at the edges of the range is not very good.

Absorption by Ionic Compounds

In inorganic compounds, there is no discrete atom or molecule to talk about. Instead the electrons belong to the positive nuclei as a collective group. Because so many atoms are close together and involved, there are a very large number of possible energy levels for electrons in both the ground and excited states as shown in Figure 7. Because there are so many possible energy states packed so closely together, we assume that electrons can have virtually any energy within each state and change between them very easily. Thus we call the group of possible energies for the ground states the "valence band" and the group of possible energies for the excited state the "conduction band".

Electrons can transition from any energy value in the valence band to any energy value in the conduction band. The energy spacing between the two bands is called the "band gap" and is the minimum amount of energy that the substance can absorb. This corresponds to the minimum frequency (and maximum wavelength) of light that the substance can absorb as shown in Figure 8. Now instead of seeing an absorption peak, we see almost complete absorption up to a cut-off wavelength (which corresponds to the energy of the band gap). For example, zinc oxide (ZnO) has a particular band gap (minimum energy that can be absorbed). Using $E = hf$ and $c = \lambda f$ (where h

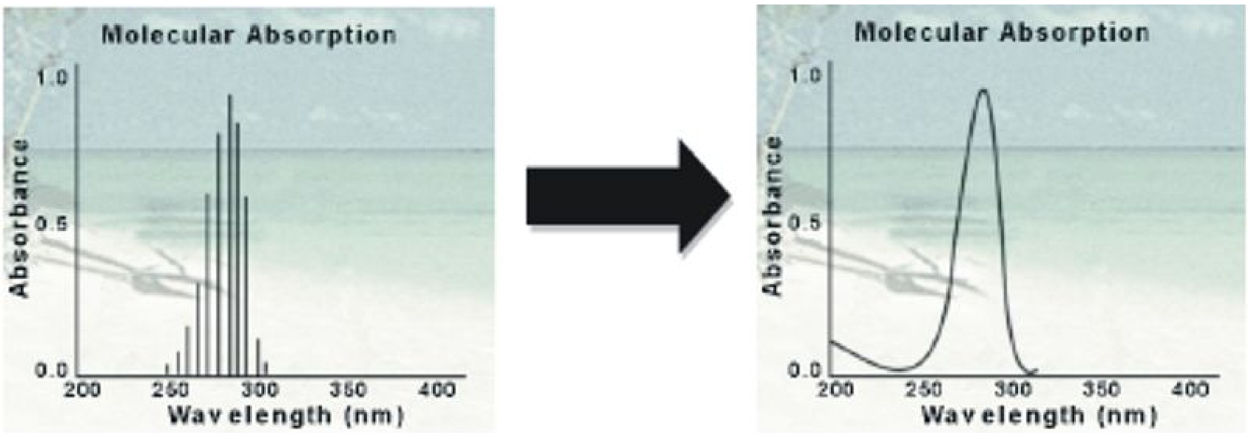


FIGURE 2.6
Absorption lines and curve spectrum for an organic molecule $Range\Psi Peak\Psi$

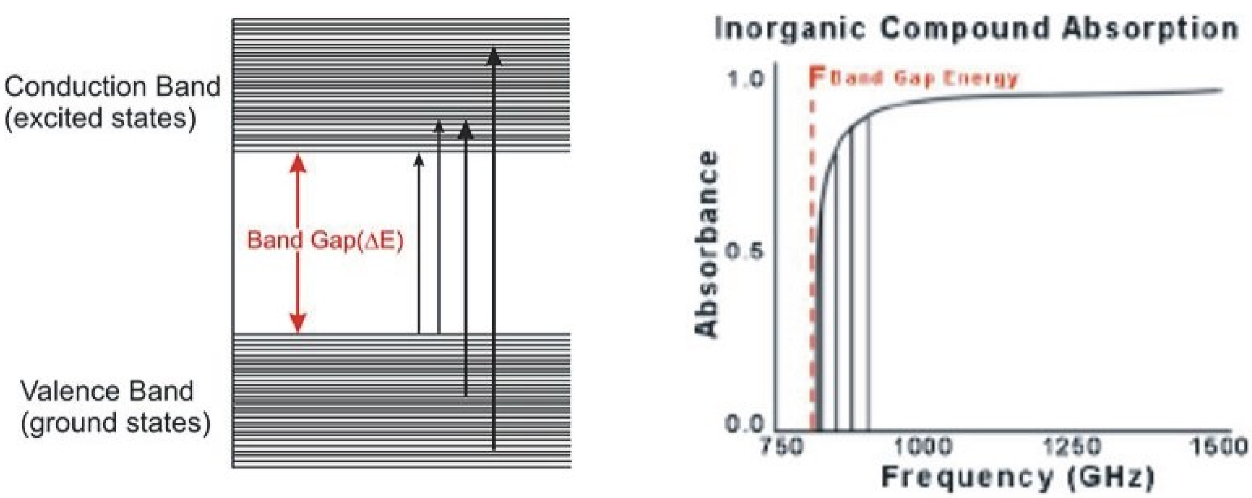


FIGURE 2.7
The large number of tightly packed energy levels possible for ground and excited electron states and possible transitions$Left$ Absorption versus frequency graph for an inorganic compound. The smallest of light that can be absorbed corresponds has an energy equal to the band gap energy$Right$

is Planck's constant and c is the speed of light) we can calculate that this corresponds to light with a wavelength of 380 nm . Thus light with higher frequencies and energies is almost completely absorbed and light with lower frequencies and energies is not absorbed. If we think about absorption in relation to the wavelength of light (instead of the frequency) our graph gets reversed (remember that wavelength and frequency are inversely related by $c = \lambda f$). This leads to an absorption spectra with the characteristic sharp drop shown in Figure 9. Thus the *minimum frequency* corresponds to a *maximum wavelength* up to which the inorganic sunscreen ingredients can absorb.

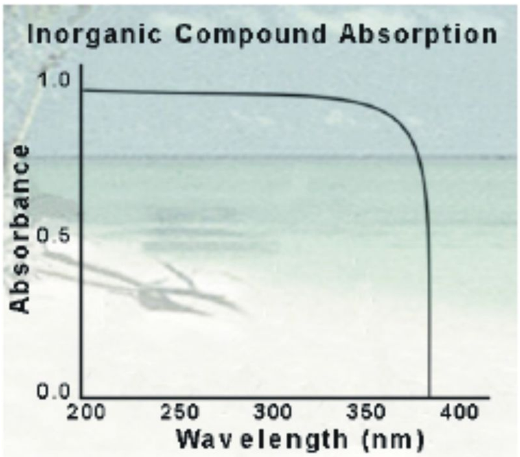


FIGURE 2.8
Absorption Spectrum for an Inorganic Compound . Light with wavelengths less than is almost completely absorbed. Light with wavelengths greater than is not absorbed at all.

References

(Internet resources accessed December 2005)

- http://members.aol.com/WSRNet/tut/absorbu.htm
- http://staff.imsa.edu/science/astro/astrometry/spectra/sld010.htm
- http://www.isis.rl.ac.uk/ISIS97/feature14.htm
- http://www.nptel.iitm.ernet.in/courses/IITMadras/CY101/lecture16new/lecture16.htm

Absorption Summary: Student Handout

TABLE 2.11:

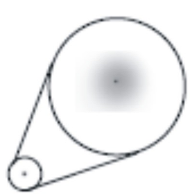
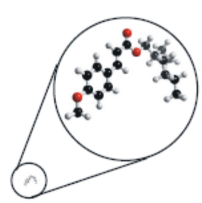
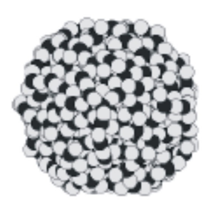
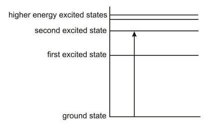
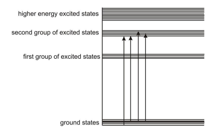
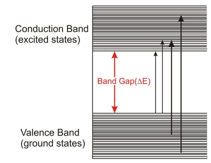
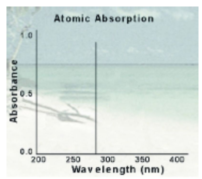
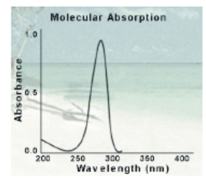
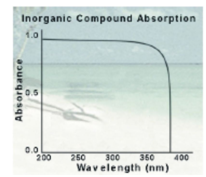
	Atoms	Organic Molecules	Inorganic Compounds
Structure (not drawn to scale)	Nucleus with electron cloud 	Individual molecule 	Cluster of ions 

TABLE 2.11: (continued)

	Atoms	Organic Molecules	Inorganic Compounds
Energy Levels			
Absorption Spectrum	Absorbs specific λ 	Absorbs specific λ range 	Absorbs all UV < critical λ 
UV Protection	Minimal	Parts of UVA or UVB spectrum	Broad spectrum UVA and UVB

Name_______________

Date_______________

period_______________

Reflecting on the Guiding Questions: Student Worksheet

Think about the activity you just completed. What did you learn that will help you answer the guiding questions? Jot down notes in the spaces below.

1. What are the most important factors to consider in choosing a sunscreen?

What I learned in this activity:

What I still want to know:

2. How do you know if a sunscreen has "nano" ingredients?

What I learned in this activity:

What I still want to know:

3. How do "nano" sunscreen ingredients differ from most other ingredients currently used in sunscreens?

What I learned in this activity:

What I still want to know:

How Sunscreens Appear: Interactions with Visible Light

Contents

- Ad Campaign Project (ChemSense Activity): Student Instructions
- Sunscreens #38; Sunlight Animations: Student Instructions #38; Worksheet
- Reflecting on the Guiding Questions: Student Worksheet

Scattering of Light by Suspended Clusters: Student Reading

FIGURE 2.9
Dust clusters from a passing car scatter sunlight*Left* Without the dust clusters we can not see the sun rays *right*

What is Scattering?

Scattering is a phenomenon in which light is redirected in different directions by small clusters of atoms suspended in some other substance. A common example of scattering is when you shake out a dusty object in a sunny room - the dust seems to sparkle in the air. This effect occurs because the dust is scattering the sunlight, which then reaches your eyes. Scattering also explains why snow and salt are white, and why the sky is blue. In each of these situations, the light is being redirected many times before it reaches our eyes. This is why the process is called multiple scattering.

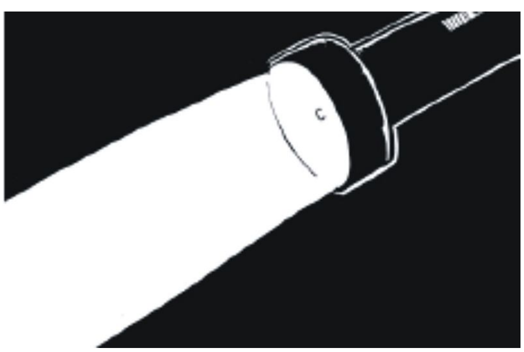


FIGURE 2.10
What is wrong with this picture

1

In many cartoons we often see the "light" from a flashlight in the dark, but this is a false image because we can not see this light unless there are clusters there to scatter it towards our eyes. Try shining a flashlight at a wall in a dark room. Can you see the beam of light between the wall and the flashlight (like in the picture above)? Now sprinkle some baby powder in the air while you shine the beam. Can you see the beam now?

How Does Scattering Occur?

When lots of clusters of one material are suspended in another material (for example drops of water in the air, or active sunscreen ingredients in the lotion) light has a chance to interact with these many clusters. The interaction bends the light in many different directions. After this, it will then continue traveling in the suspension medium until it reaches another cluster. If the light is bent multiple times in multiple directions, we call this multiple scattering.

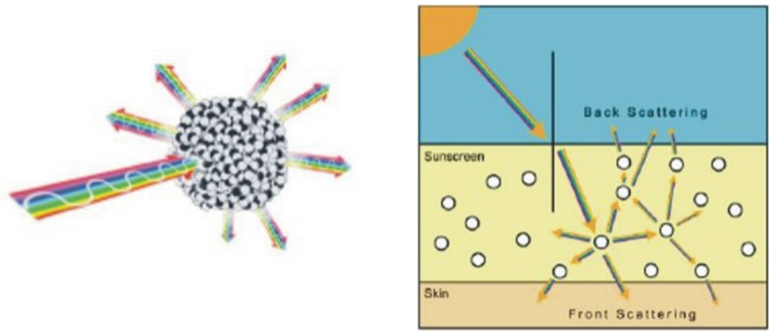


FIGURE 2.11
Scattering of light by a suspended cluster*Left* Multiple scattering of light by suspended cluster*Right*

While on the micro-level scattering redirects the light in many different directions, on the macro-level this combines to produce one of two results: the light is sent back in the general direction from which it came at various angles (back scattering) or the light continues in the same general direction it was moving, but at various angles (front scattering).

Does Scattering Always Happen?

Whether or not scattering will occur depends on many factors. For clusters suspended in a medium some of the most important factors are: the identity of the clusters, the identity of the suspending medium and the cluster size. Scattering happens most when the clusters have a diameter that is half as big as the wavelength of light involved. So a 200 nm cluster would scatter 400 nm light the most and it would scatter $300-500$ nm light quite a bit as well. The amount of scattering continues to decrease as wavelengths become much bigger or much smaller than 400 nm , as shown in figure 5.

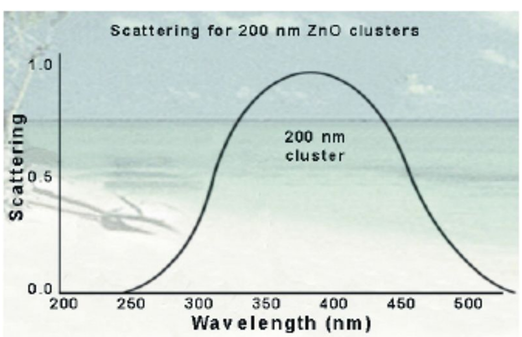


FIGURE 2.12
Graph of Scattering for a Cluster in Sunscreen

References

(Accessed December 2005)

- http://www.liberty-news.com/showCartoons.php?artist=Lalo+Alcaraz#38;src=h2856

Ad Campaign Project: Student Instructions

Overview

Sunsol, the prominent sunscreen maker, has just decided to launch a new product into the market. The sunscreen will use a zinc oxide (ZnO) nanopowder as its only active ingredient, and will be formulated to go on clear and non-greasy. Sunsol is very excited about its new product, and wants to launch a full ad campaign to promote it to consumers who may not be familiar with the idea of a clear sunscreen that offers full spectrum protection.

Sunsol feels that it is very important for their potential customers to understand both how *ZnO* interacts with light to protect people's skin and how the size of the particles affects the sunscreen's appearance. For this reason, they have decided that the ad campaign should center on an animated commercial that shows how traditional *ZnO* and *ZnO* nanopowders interact with UV and visible light.

Sunsol has invited several creative teams—including yours—to use the ChemSense Animator to create animations showing how the different sized *ZnO* particles suspended in the sunscreen will scatter visible light differently.

The Request

Sunsol is requesting a total of 4 animations:

a. Sunscreen with $\sim$ 50 nm *ZnO* particles interacting with UV light.
b. Sunscreen with $\sim$ 50 nm *ZnO* particles interacting with visible light.
c. Sunscreen with $\sim$ 300 nm *ZnO* particles interacting with UV light.
d. Sunscreen with $\sim$ 300 nm *ZnO* particles interacting with visible light.

Your teacher will put you in teams and let you know which of the animations you should work on.

Animation Matrix

TABLE 2.12:

	UV light	Visible Light
50 nm*ZnO* particles	1	2
300 nm*ZnO* particles	3	4

Requirements

All animations should contain the following elements:

- A light source (the sun)
- A skin surface with sunscreen lotion applied
- *ZnO* particles of the required size suspended in the lotion
- A minimum of 10 frames

The UV light animations should also include:

- At least 2 UVA and 2 UVB light rays interacting with the *ZnO* particles (and skin when appropriate)
- All relevant blocking mechanisms for the *ZnO* particles in the sunscreen

The visible light animations should also include:

- At least 5 visible light rays interacting with the *ZnO* particles (and skin when appropriate)
- A human observer and an indication of what the they see

Things to consider in your animation

- How thick will the sunscreen be applied?
- What concentration of particles will the sunscreen have?
- How will you show the different blocking mechanisms?
- How will you indicate what the human observer sees?

Evaluation

Sunsol will evaluate the animations based on the following criteria:

- All required elements are present and accurately depicted
- Animations show correct interaction of light rays with *ZnO* particles (and skin)
- All relevant blocking mechanisms shown (UV light only)
- Animations clearly indicate what the observer sees and why (Visible light only)
- All team member contributed and worked together to produce the animations

Discussion

Questions to answer about each model:

- How does this model show absorption / scattering?
- How does this model show what the observer sees?
- What are its strengths? (What aspects of scattering does it show particularly well?)
- What are its limitations? (What aspects of scattering are not shown well?)
- Is there anything that seems inaccurately depicted?
- What could be done (within the structure of the animation) to address some of these limitations?

Questions to answer about the group of models as a whole:

- What do the different animations have in common? How do they show things in similar ways?
- What things do the animations show in different ways? Are different animations better at showing different aspects of the phenomenon?
- If different models can be used to represent a phenomenon, how do we know which one is "better"? (Models which best align with or represent the empirical data we have are better.)

TABLE 2.13: **Rubric for Ad Campaign Evaluation – UV Light Animations**

Category	**Novice (1)** Absent, missing or confused	**Apprentice (2)** Partially developed	**Skilled (3)** Adequately developed	**Masterful (4)** Fully developed
Required Elements • Light source • Skin surface • Sunscreen lotion • Suspended *ZnO* particles • 2+ UVA rays • 2+ UVB rays • 10+ frames	$0-2$ of the required elements are present.	$3-4$ of the required elements are present.	$5-6$ of the required elements are present.	All 7 required elements are present.
	Few of the required elements are accurately depicted.	Some of the required elements are accurately depicted.	Most of the required elements are accurately depicted.	All of the required elements are accurately depicted.
Interactions of light rays with *ZnO* particles (and skin where appropriate) correctly shown	Few or no key aspects of the interaction are correctly shown.	Some aspects of the interaction are correctly shown.	Most key aspects of the interaction are correctly shown.	All keyaspects of the interaction are correctly shown.

TABLE 2.13: (continued)

Category	Novice (1) Absent, missing or confused	Apprentice (2) Partially developed	Skilled (3) Adequately developed	Masterful (4) Fully developed
All relevant blocking mechanisms correctly shown	Few or no key aspects of the blocking mechanism are correctly shown.	Some key aspects of the blocking mechanism are correctly shown.	Most key aspects of the blocking mechanism are correctly shown.	All key aspects of the blocking mechanism are correctly shown.
Teamwork • All team members contributed significantly to the project • Group worked together to manage problems as a team	Few team members contributed to the project.	Some team members contributed to the project.	Most team members contributed to the project.	All team members contributed to the project.
	Group did not address the problems encountered.	Group did not manage problems effectively.	Problems in the group managed by one or two individuals.	Group worked together to solve problems.

TABLE 2.14: **Rubric for Ad Campaign Evaluation – Visible Light Animations**

Category	Novice (1) Absent,missing or confused	Apprentice (2) Partially developed	Skilled (3) Adequately developed	Masterful (4) Fully developed
Required Elements • Light source • Human observer • Skin surface • Sunscreen lotion • Suspended *ZnO* particles • 5+ visible light rays • 10+ frames	0 – 2 of the required elements are present.	3 – 4 of the required elements are present.	5 – 6 of the required elements are present.	All 7 required elements are present.
	Few of the required elements are accurately depicted.	Some of the required elements are accurately depicted.	Most of the required elements are accurately depicted.	All of the required elements are accurately depicted.

TABLE 2.14: (continued)

Category	**Novice (1)** Absent,missing or confused	**Apprentice (2)** Partially developed	**Skilled (3)** Adequately developed	**Masterful (4)** Fully developed
Interactions of light rays with *ZnO* particles (and skin when appropriate) correctly shown	Few or no key aspects of the interaction are correctly shown.	Some aspects of the interaction are correctly shown.	Most key aspects of the interaction are correctly shown.	All key aspects of the interaction are correctly shown.
What the observer sees and why they see is correctly shown	Few or no key aspects of the observer's view are correctly shown.	Some key aspects of the observer's view are correctly shown.	Most key aspects of the observer's view are correctly shown.	All key aspects of the observer's view are correctly shown.
Teamwork • All team members contributed significantly to the project • Group worked together to manage problems as a team	Few team members contributed to the project.	Some team members contributed to the project.	Most team members contributed to the project.	All team members contributed to the project.
	Group did not address the problems encountered.	Group did not manage problems effectively.	Problems in the group managed by one or two individuals.	Group worked together to solve problems.

Name_______________

Date_______________

period_______________

Sunscreens #38; Sunlight Animations: Student Instructions #38; Worksheet

Introduction

There are many factors that people take into account when choosing which sunscreen to use and how much to apply. Two of the most important factors that people consider ate the ability to block UV and the visual appearance of the sunscreen (due to the interaction with *visible* light). You are about to see three animations that are models of what happens when sunlight (both UV and visible rays) shine on:

- Skin without any sunscreen
- Skin protected by 200 nm *ZnO* particle sunscreen
- Skin protected by 30 nm *ZnO* particle sunscreen

Open the animation file as instructed by your teacher and explore the animations for different sunscreen and light ray options. Then choose the sunscreen option and wavelength(s) of light as indicated to answer the following questions.

Questions

1. Select the UVA and UVB wavelengths of light with no sunscreen and click the play button.

a. What happens to the skin when the UV light reaches it?

b. How is the damage caused by the UVA rays different from the damage caused by the UVB rays? (You may want to play the animation with just UVA or UVB selected to answer this question)

c. Based on what you know about the different energies of UVA and UVB light why do you think this might happen?

2. Now leave UVA and UVB light selected and try playing the animation first with the 30 nm ZnO sunscreen and then with the 200 nm ZnO sunscreen.

a. What kind of sunscreen ingredients are shown in each animations?

b. What happens to the UV light in the animation of 30 nm ZnO particle sunscreen?

c. What happens to the UV light in the animation of 200 nm ZnO particle sunscreen?

d. Is there any difference in how the UV light interacts with the 30 nm ZnO particles versus the 200 nm ZnO particles? Explain why this is so based on your understanding of how the sunscreens work to block UV light.

e. Is there any difference in how the two kinds of UV light interact with the sunscreens? Explain why this is so based on your understanding of how the sunscreens work to block UV light

3. Select the visible light option and play the animation for each of the sunscreen conditions. What happens to the visible light in each animation and what does the observer see?

a. Skin without any sunscreen

b. Skin with 200 nm ZnO particles sunscreen

c. Skin with 30 nm ZnO particle sunscreen

4. What determines what the observer sees? (Do they see the skin or the sunscreen? What color do they see?)

5. How does scattering affect what the observer sees?

6. What variables don't change between the two animations with sunscreens?

7. What variable determines if the visible light scatters or not?

8. What would happen if we applied the large particle sunscreen in a layer only half as thick as the one shown? How would this affect its appearance? How would it affect its UV blocking ability?

9. What would happen if the observer (eye) moved 3 steps to the left to look at the skin?

10. When we make a model (such as these animations) we make tradeoffs between depicting the phenomenon as accurately as possible and simplifying it to show the key principles involved.

a. Are the different elements of the animation drawn on the same size scale? If not, which ones aren't? How do these affect the animation's ability to depict the scattering mechanism? Which elements in the animation are really on or close to the nanoscale? Which are on the macroscale? Which are on the cosmic scale?

b. What are some other ways these animations have simplified the model of the real world situation they describe?

c. What are some of the benefits of making a simplified model? What are some of the drawbacks?

Name________________

Date________________

period________________

Reflecting on the Guiding Questions: Student Worksheet

Think about the activity you just completed. What did you learn that will help you answer the guiding questions? Jot down notes in the spaces below.

1. What are the most important factors to consider in choosing a sunscreen?

what I learned in this activity:

What I still want to know:

2. How do you know if a sunscreen has "nano" ingredients?

What I learned in this activity:

What I still want to know:

3. How do "nano" sunscreen ingredients differ from most other ingredients currently used in sunscreens?

What I learned in this activity:

What I still want to know:

Culminating Activities

Contents

Consumer Choice Project: Student Instructions

Introduction

SmartShopper, the consumer advocacy group, has heard a lot in the media about the new clear sunscreens with nanoparticulate ingredients coming out on the market. Consumers have been contacting them lately to ask them if these new products are better than traditional sunscreens, if they are safe to use, and how to know if a sunscreen uses nanoparticulate ingredients. To help consumers decide whether these products are right for them, SmartShopper has decided to produce a pamphlet that tells consumers all they need to know about these new products. SmartShopper also will need to take a position on whether or not they endorse the use of the sunscreens and justify this position based on a comparison of the benefits and risks backed up with science. They turn to you and your team to create this pamphlet.

Requirements

SmartShopper asks that your pamphlet makes full use of both sides of an 8.5×11 piece of paper folded into thirds for easy distribution (see "How to Make a Pamphlet") and contains:

- A brief overview of what nanoparticulate sunscreen ingredients are and how they are similar and how they are different from other active sunscreen ingredients.
- A list of common nanoparticulate active sunscreen ingredients and how to know if your sunscreen contains them.
- An explanation of how sunscreens with nanoparticulate ingredients work to block UV light from reaching the skin and the benefits of using them (including advantages over other sunscreen ingredients).

- An explanation of why nanoparticulate sunscreen ingredients are clear and a diagram that illustrates the science principles involved.
- A transmission versus wavelength graph that supports this explanation.
- An explanation of the possible downsides / dangers of using sunscreens with nanoparticulate ingredients.
- SmartShopper's position on the use of sunscreens nanoparticulate ingredients (do you endorse their use?) with justification of this position based on a comparison of the benefits and risks involved.

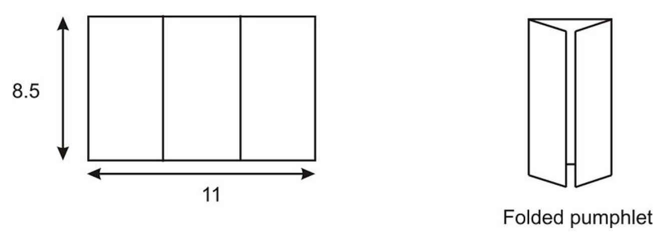
How to Make a Pamphlet

By Hand:

Take a regular piece of 8.5×11 paper turn it sideways. Fold the paper into thirds and crease it firmly. This is what the pamphlet will look like when it's done. When you unfold the paper, you can use the creases as column guides. It is good to make the front and back of your pamphlet on different pieces of paper and use a copying machine to make the pamphlet double sided in case you decide to make changes along the way.

With a Computer:

Open a new document in Microsoft Word. Go to File#62;Page Setup to choose a Landscape Orientation and make all of the margins 0.5 inches . Go to Format#62;Columns to choose 3 columns and click the check box for Line Between. You will need to either use a printer that will print double-sided or print the two sides of your pamphlet separately and use a copying machine to make them double sided.



Evaluation

SmartShopper will evaluate the pamphlets based on the following criteria:

- All required information is present and correct
- Scientific explanations are used to back up pamphlets claims
- Effective use of diagram and graph to enhance explanation of why nanoparticulate sunscreen ingredients are clear
- Convincing argument weighing all the relevant information for position taken on nanoparticulate sunscreen use
- All team member contributed and worked together to produce the animations

Name_______________

Date_______________

period_______________

Consumer Choice Project: Peer Feedback Form

1. What are the name(s) of the student team who developed the pamphlet you are evaluating?

2. Is all of the required information present and correct?

TABLE 2.15:

	Not at all	____	____	____	Completely
Overview of nanoparticulate sunscreen ingredients and similarities/differencesfrom other active ingredients.	1	2	3	4	5
List of common nanoparticulate active sunscreen ingredients and how to know if your sunscreen contains them.	1	2	3	4	5
Explanation of how nanoparticulate sunscreens block UV light from reaching the skin and benefits of using them.	1	2	3	4	5
Scientific explanation and diagram of why nanoparticulate sunscreen ingredients are clear.	1	2	3	4	5
Transmission versus wavelength graph that supports the explanation.	1	2	3	4	5
Explanation of possible downsides / dangers of using sunscreens with nanoparticulate ingredients.	1	2	3	4	5

TABLE 2.15: (continued)

	Not at all	____	____	____	Completely
SmartShopper's position on the use of sunscreens nanoparticulate ingredients with justification.	1	2	3	4	5

3. List any information that you think is missing or incorrect here:

4. Was the information in the pamphlet presented clearly and communicated in an appropriate way?

Not at all	A little	Somewhat	A lot	Completely
1	2	3	4	5

5. If not, please identify the area(s) of confusion here:

6. To what degree are scientific explanations used to back up pamphlets claims?

Not at all	A little	Somewhat	A lot	Completely
1	2	3	4	5

7. To what degree do the diagram and graph enhance the explanation of why nanoparticulate sunscreen ingredients are clear?

Not at all	A little	Somewhat	A lot	Completely
1	2	3	4	5

8. To what degree is a convincing argument made—one that weighs all of the relevant information for the position taken on nanoparticulate sunscreen use?

Not at all	A little	Somewhat	A lot	Completely
1	2	3	4	5

9. Describe one thing that you think the pamphlet did very well:

10. Give at least one suggestion for improving the pamphlet:

Name_______________

Date_______________

period_______________

The Science Behind the Sunscreen: Student Quiz

30 points total

1. Why is UV light a source of health concern when visible and infrared light are not? (2 *points*)

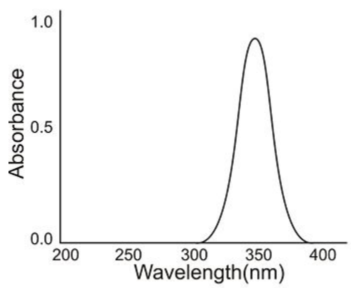
2. List 2 kinds of damage to the body caused by UV radiation. (2 *points*)

3. Explain in your own words why it is important to block UVA light.(2 *points*)

4. How do you know if a sunscreen protects against UVA light (now and future)? (2 *points*)

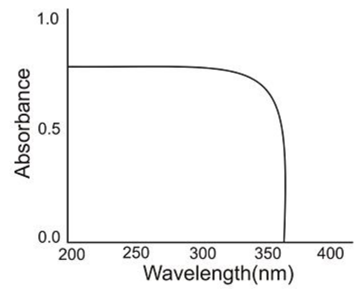
5. How do you know if a sunscreen protects against UVB light? (1 *point*)

6. For each of the following absorption graphs, circle the correct answers for a) what kind(s) of light are strongly absorbed and b) whether it is an organic or inorganic sunscreen. (4 *points*)



a) UVA UVB

b) Organic Inorganic



a) UVA UVB

b) Organic Inorganic

7. Why do sunscreens that use nano-sized TiO_2 clusters appear clear on our skin while sunscreens that use traditional sized TiO_2 clusters appear white? (5 *points*)

8. How do you know if a sunscreen has "nano" ingredients? (2 *points*)

9. Briefly describe one benefit and one drawback of using a sunscreen that contains "nano" ingredients: (1*point each, a total of* 2 *points*)

10. In what ways are "nano" sunscreen ingredients similar and different from other ingredients currently used in sunscreens? For each of the four categories below, indicate whether "nano" sunscreen ingredients are "similar" or "different" to organic and inorganic ingredients and explain how. (1 *point each, total of* 8 *points*)

TABLE 2.16:

	Organic Ingredients (e.g. PABA)	Inorganic Ingredients (e.g. Classic Zinc Oxide used by lifeguards)
Chemical Structure	Similar or Different How: Nano ingredients are small ionic clusters while organic ingredients are molecules.	Similar or Different How: Nano ingredients are a kind of inorganic ingredients. Bother are ionic clusters but the nano clusters are smaller.
Kinds of Light Blocked	Similar or Different How: Organic ingredients each block a small part of the UV spectrum (generally UVB) while nano ingredients block almost the whole thing,	Similar or Different How: Both nano ingredients and traditional inorganic ingredients block almost the whole UV spectrum.

TABLE 2.16: (continued)

	Organic Ingredients (e.g. PABA)	Inorganic Ingredients (e.g. Classic Zinc Oxide used by lifeguards)
Way Light is Blocked	Similar or Different How: Both nano and organic ingredients block UV light via absorption. (The specific absorption mechanism is different, but students are not expected to report this)	Similar or Different How: Both nano and inorganic ingredients block UV light via absorption.
Appearance on the Skin	Similar or Different How: Both nano and organic ingredients appear clear on the skin.	Similar or Different How: Traditional inorganic ingredients appear white on the skin while nano ingredients appear clear.

Clear Sunscreen Final Reflections: Student Worksheet

Now that you have come to the end of the unit, go back and look at the reflection forms you filled out after each activity and try to answer the guiding questions below. Write down answers each question below and then evaluate how confident you feel that each idea is true.

TABLE 2.17:

1. What are the most important factors to consider in choosing a sunscreen?	**How sure are you that this is true?** Not So Sure	**How sure are you that this is true?** Kind-of Sure	**How sure are you that this is true?** Very Sure
2. How do you know if a sunscreen has "nano" ingredients?	**How sure are you that this is true?** Not So Sure	**How sure are you that this is true?** Kind-of Sure	**How sure are you that this is true?** Very Sure
3. How do "nano" sunscreen ingredients differ from most other ingredients currently used in sunscreens?	**How sure are you that this is true?** Not So Sure	**How sure are you that this is true?** Kind-of Sure	**How sure are you that this is true?** Very Sure

Now go back to the worksheet you filled out with your initial ideas at the beginning of the unit and mark each idea with a $\surd$ if you still believe it is true, an X if you don't think that it is true and a ? if you are still unsure. Then answer the following questions.

1. What ideas do you have now that are the same as when you started?
2. What ideas are different and how?
3. What things are you still unsure about?

One-Day Version of Clear Sunscreen

Contents

Summary of Radiation Emitted by the Sun: Student Handout

TABLE 2.18: Chart of Different Kinds of Solar Radiation

Radiation Type	Characteristic Wavelength (λ)	Energy per Photon	% of Total Radiation Emitted by Sun	Effects on Human Skin	Visible to Human Eye?
UVC	$\sim 200-290$ nm (Short-wave UV)	High Energy	$\sim 0\%$ ($< 1\%$ of all UV)	DNA Damage	No
UVB	$\sim 290-320$ nm (Mid-range UV)	Medium Energy	$\sim .35\%$ (5% of all UV)	Sunburn DNA Damage Skin Cancer	No
UVA	$\sim 320-400$ nm (Long-wave UV)	Low Energy	$\sim 6.5\%$ (95% of all UV)	Tanning Skin Aging DNA Damage Skin Cancer	No
Visible	$\sim 400-800$ nm	Lower Energy	$\sim 43\%$	None Currently Known	Yes
IR	$\sim 800-120,000$ nm	Lowest Energy	$\sim 49\%$	Heat Sensation (high λ IR)	No

Graph of Radiation Emitted by the Sun by Wavelength

Summary of FDA Approved Sunscreen Ingredients: Student Handout

TABLE 2.19:

	λ range (nm)	**Protection Against** UVB $280-320$ nm	**Protection Against** UVA $320-400$ nm	**Possible Allergies**	**Other Issues**
Organic Ingredients **PABA derivatives**					
Padimate O (Octyl dimethyl PABA)	$295-340$	Good	Little	Yes	-

TABLE 2.19: (continued)

	λ range (nm)	Protection Against	Protection Against	Possible Allergies	Other Issues
PABA (p-aminobenzoic acid)	200 – 320	Good	Little	Yes	Greasy,Stains
Cinnamates					
Octinoxate (Octyl methoxycinnamate) (OMC) (Parasol MCX)	295 – 350	Good	Little	Yes	-
Cinoxate	280 – 310	Good	Little	Yes	-
Salicylates					
Homosalate	295 – 340	Good	Little	Yes	-
Octisalate (Octyl salicylate)	295 – 330	Good	Little	Yes	-
Trolamin salicylate	260 – 355	Good	Little	Yes	-
Benzophenones					
Oxybenzone(Benzophenone-3)	295 – 375	Good	Some	Yes	-
Sulisobenzone(Benzophenone-4)	260 – 375	Good	Some	Yes	Hard to solubilize
Dioxybenzone (Benzophenone-8)	250 – 390	Good	Some	Yes	Hard to solubilize
Other Organics					
Ensulizole	290 – 340	Good	Little	Yes	-
Octocrylene	295 – 375	Good	Little	Yes	-
Menthyl anthranilate (Meradimate)	295 – 380	Good	Some	Yes	-
Avobezone (Parsol 1789)(Butyl methoxydibenzoyl methane)	295 – 395	Good	Good	Yes	If not well formulated, loses potency
NEW Ecamsule (Mexoryl SX)	310 – 370	Some	Good	Yes	Water-soluble
Inorganic Ingredients					
Titanium Dioxide	upto 365	Good	Good	No	-
Zinc Oxide	upto 380	Good	Good	No	-

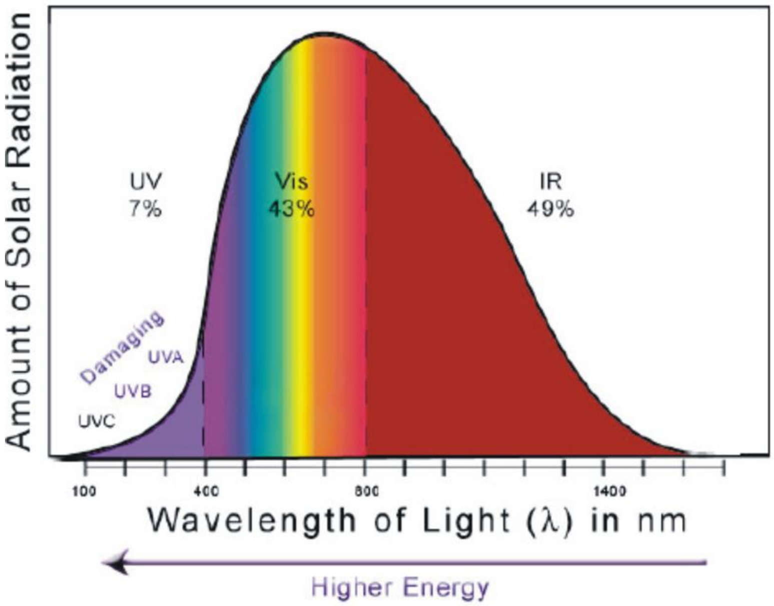


FIGURE 2.13

Overview of Sunscreen Ingredients: Student Handout

TABLE 2.20:

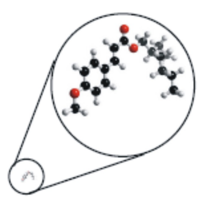
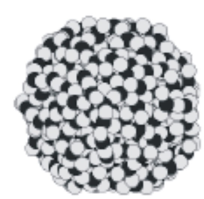
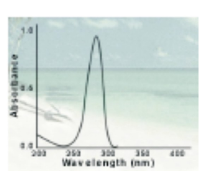
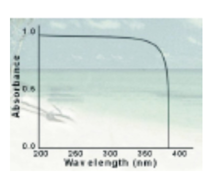
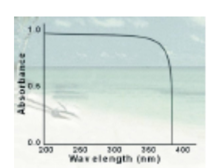
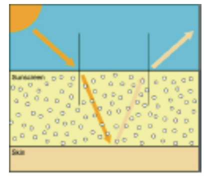
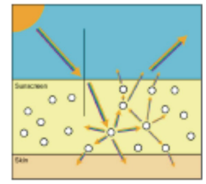
	Organic Ingredients	Inorganic Ingredients (Nano)	Inorganic Ingredients (Large)
Atoms Involved	Carbon, Hydrogen, Oxygen, Nitrogen	Zinc, Titanium, Oxygen	Zinc, Titanium,Oxygen
Structure (not drawn to scale)	Individual molecule 	Cluster $\sim$ 100 nm in diameter 	Cluster $>$ 200 nm in diameter 
Interaction with UV light	Absorb specific λ 	Absorb all UV $<$ critical λ 	Absorb all UV $<$ critical λ 
Absorption Range	Parts of UVA or UVB spectrum	Broad spectrum UVA and UVB	Broad spectrum UVA and UVB

TABLE 2.20: (continued)

	Organic Ingredients	Inorganic Ingredients (Nano)	Inorganic Ingredients (Large)
Interaction with Visible light	None	Minimal Scattering 	Much Scattering 
Appearance	Clear	Clear	White

CHAPTER 3 Fine Filters-Student Materials

CHAPTER OUTLINE

3.1 Filtering Solutions for Clean Water

Unit Overview

Contents

- (Optional) Fine Filters: Pretest
- (Optional) Fine Filters: Posttest

Name________________

Date________________

Period________________

Fine Filters: Pretest

1. Which of the following types of contaminants can nanomembranes filter out of water? For which of these, would you typically use a nanomembrane for removal? Explain why or why not. (1 point each, total of 12 points)

TABLE 3.1:

	Can a nanomembrane filter it out?	Is a nanomembrane the best way to filter it out?
Bacteria	Yes or No Why/why not:	Yes or No
Lead (Pb^{2+})	Yes or No Why/why not:	Yes or No
Salt (Na^+ and Cl^-)	Yes or No Why/why not:	Yes or No
Sand	Yes or No Why/why not:	Yes or No

2. Name two benefits that nanomembranes bring to the filtration of water that help to address the world's problem of a scarcity of clean drinking water. (1 point each, 2 points total)

3. Describe three ways in which nanofilters can operate differently than traditional filters to purify water: (2 points each, 6 points total)

Name________________

Date________________

Period________________

Fine Filters: Posttest

1. Which of the following types of contaminants can nanomembranes filter out of water? For which of these, would you typically use a nanomembrane for removal? Explain why or why not. (1 point each, total of 12 points)

TABLE 3.2:

	Can a nanomembrane filter it out?	Is a nanomembrane the best way to filter it out?
Bacteria	Yes or No Why/why not:	Yes or No
Lead (Pb^{2+})	Yes or No Why/why not:	Yes or No
Salt (Na^+ and Cl^-)	Yes or No Why/why not:	Yes or No
Sand	Yes or No Why/why not:	Yes or No

2. Name two benefits that nanomembranes bring to the filtration of water that help to address the world's problem of a scarcity of clean drinking water. (1 point each, 2 points total)

3. Describe three ways in which nanofilters can operate differently than traditional filters to purify water: (2 points each, 6 points total)

The Water Crisis

Contents

Name________________

Date________________

Period________________

Student Data Worksheet

Directions

Using the graphs and maps, answer the following questions. This activity will give you the opportunity to interpret some of the graphs and maps that you'll see during the Water Crisis slide presentation during class.

1. According to the bar graphs in Figure 1, **what percentage** of the world's water is **fresh water**?

2. What do these three divided bar graphs tell you about **where** the Earth's fresh water resides?

Physical water scarcity refers to the lack of water to meet domestic, industrial, and agricultural needs. Areas of physical water scarcity are shown in red on the map in Figure 2 below. Economic water scarcity means that an area or country has insufficient financial resources to deliver safe, clean water to those areas that need it for drinking or agriculture. Areas of economic water scarcity are shown in orange in Figure 2.

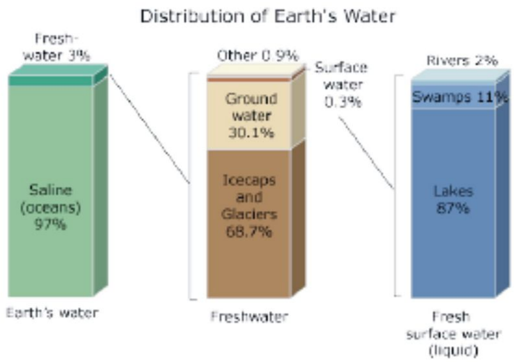


FIGURE 3.1
Distribution of earth&#8217 s water.

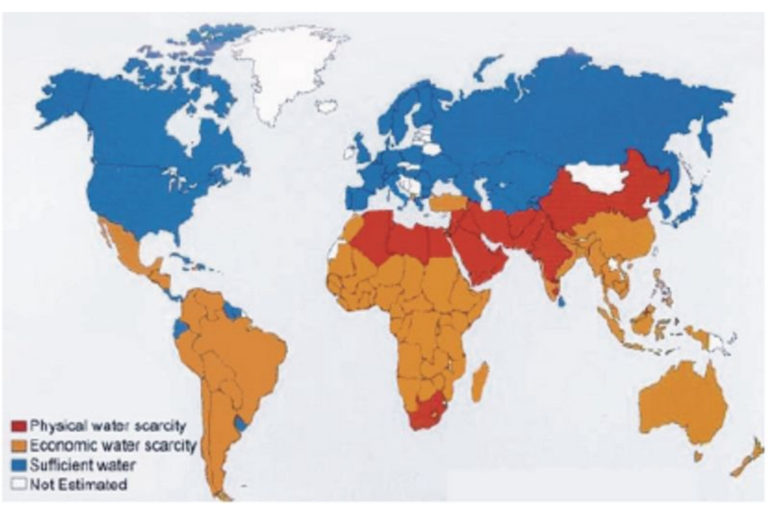


FIGURE 3.2
Global map of water scarcity in 2006.

Answer questions 3-8 based on information from the map in Figure 2.

2. Name the countries or global areas that are experiencing **physical water scarcity**.

3. What would you predict the climate to be in these areas and why?

4. Name the countries or global areas that are experiencing **economic water scarcity**.

5. Name the countries or global areas that are **not** experiencing any water scarcity.

6. What do you predict the difference in per capita income (average income per person) would be between regions with plenty of water and regions with economic water scarcity?

7. The southwestern United States is typically characterized as having a dry, arid climate. Why might this region be shown as having plenty of water even if it is dry and arid?

When water is taken from a natural source for human use, it is called "water withdrawal." However, a country can never withdraw all of the fresh water that is theoretically available within its borders. Much of it is seasonal, or part of flood runoff, or rain that cannot possibly all be captured. Countries that withdraw a high percentage of their available fresh water are said to be under "freshwater stress" and are in danger of becoming considered "water scarce." In the map in Figure 3, the light orange represents mild freshwater stress and the darker orange represents extreme fresh water stress. Blue areas are considered to be free from freshwater stress.

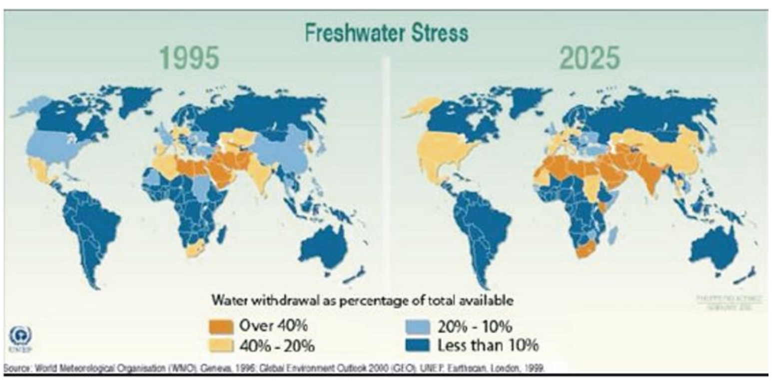


FIGURE 3.3

Global map of freshwater stress 1995 and 2025 *predicted*.

8. Compare the two maps above, showing freshwater stress from the year 1995 and projected to the year 2025. What are the changes that you see happening in which areas?

9. In Figure 4, what trend do you see in for the global population?

10. What would you predict the global population to be in 2060? Justify your prediction.

11. According to the graph in Figure 5, which sector uses the most water?

12. Which sector uses the least amount of water?

13. How does the trend in water consumption (Figure 5) compare to the trend in population (Figure 4) for the time period 1950-2000?

14. According to Figure 6, which countries consume the most water?

15. Which countries consume the least water?

Answer questions 16-19 based on information from the graph in Figure 7.

16. How many countries have an average per person purchasing power of less than $10,000?

17. How many countries have an average per person purchasing power of more than $25,000?

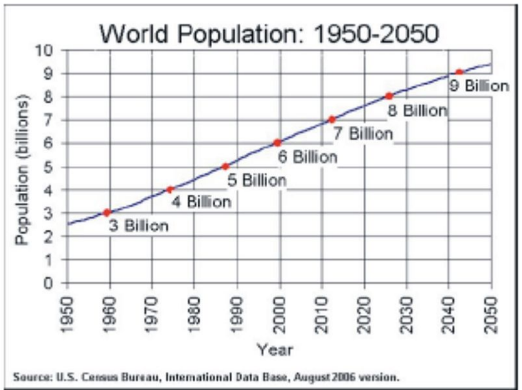


FIGURE 3.4

World population from 1950 to 2050 *predicted*.

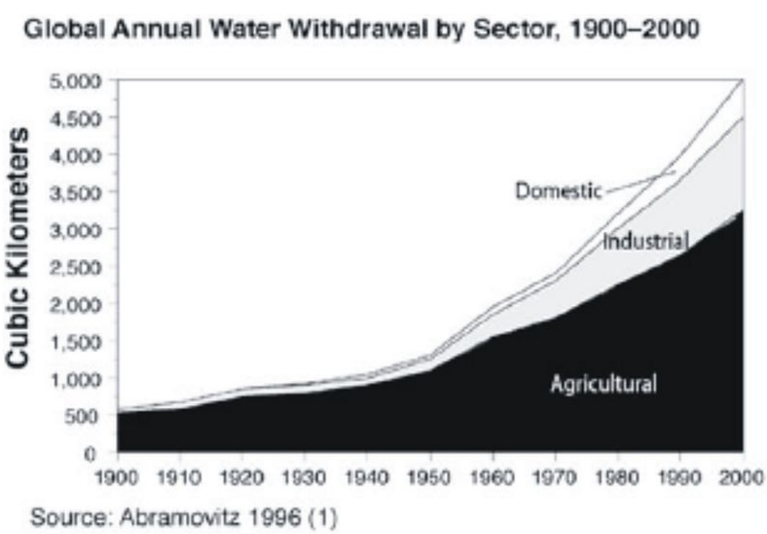


FIGURE 3.5

Global annual water withdrawal by sector 1900-2000.

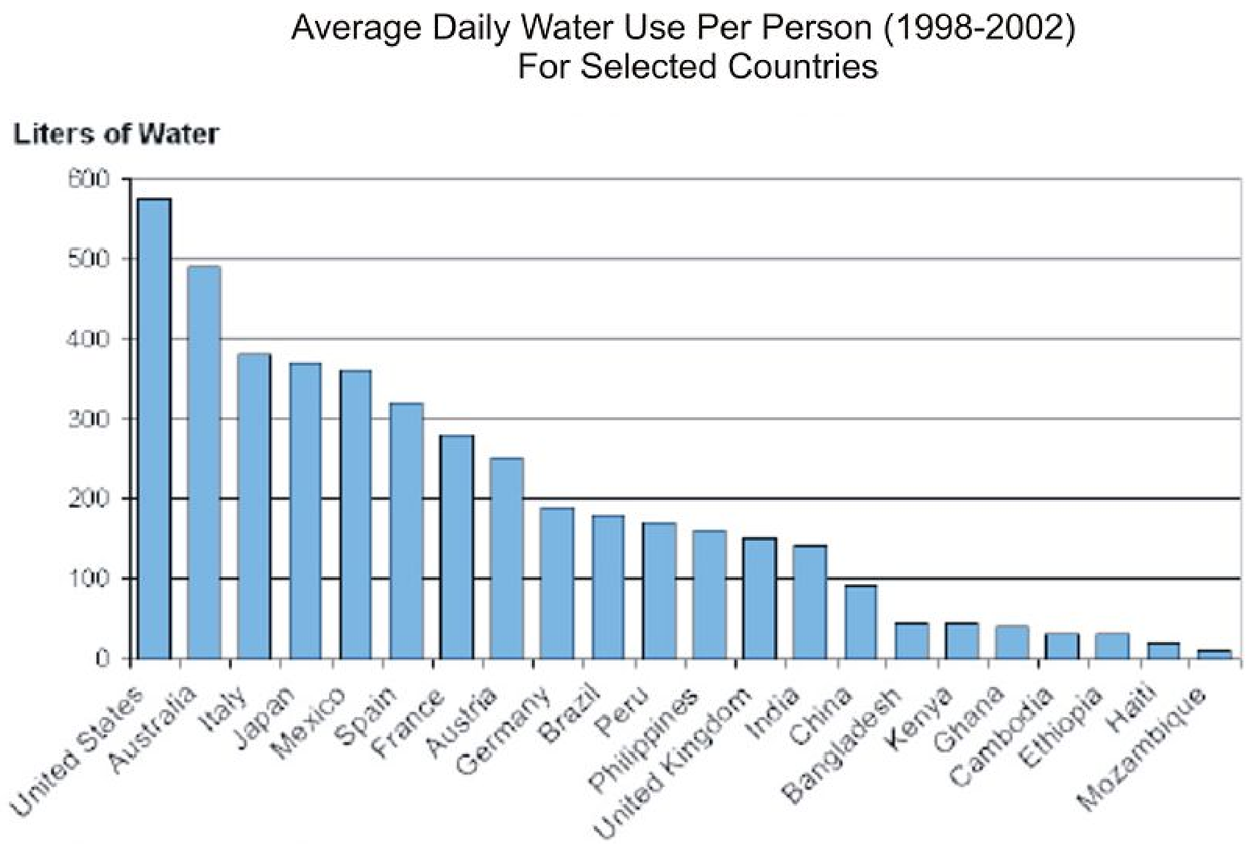


FIGURE 3.6
Average daily water use per person for selected countries from 1998 to 2002.

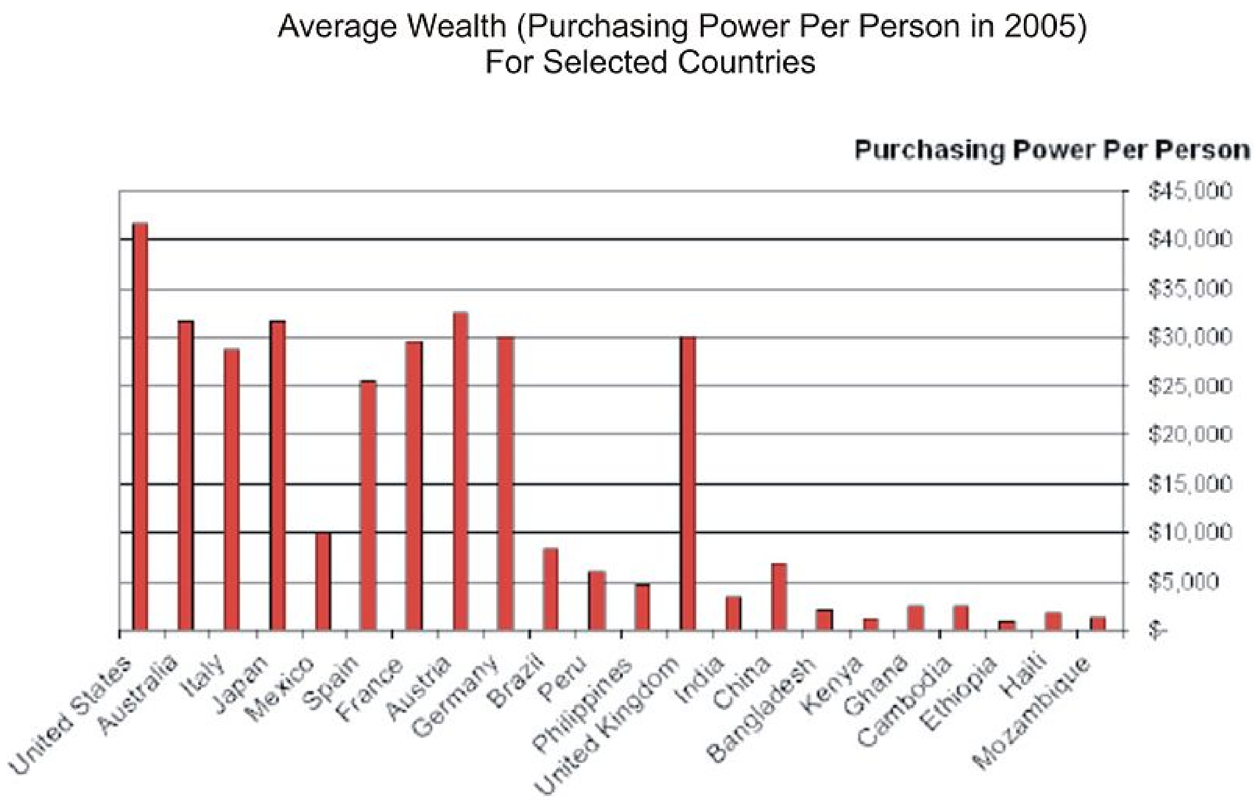


FIGURE 3.7

Average wealth for selected countries *purchasing power by person in* 2005.

18. How many countries have an average per person purchasing power of $\$10,000-\$25,000$?

19. What is the difference between the average per person purchasing power in the highest wealth country and the lowest wealth country?

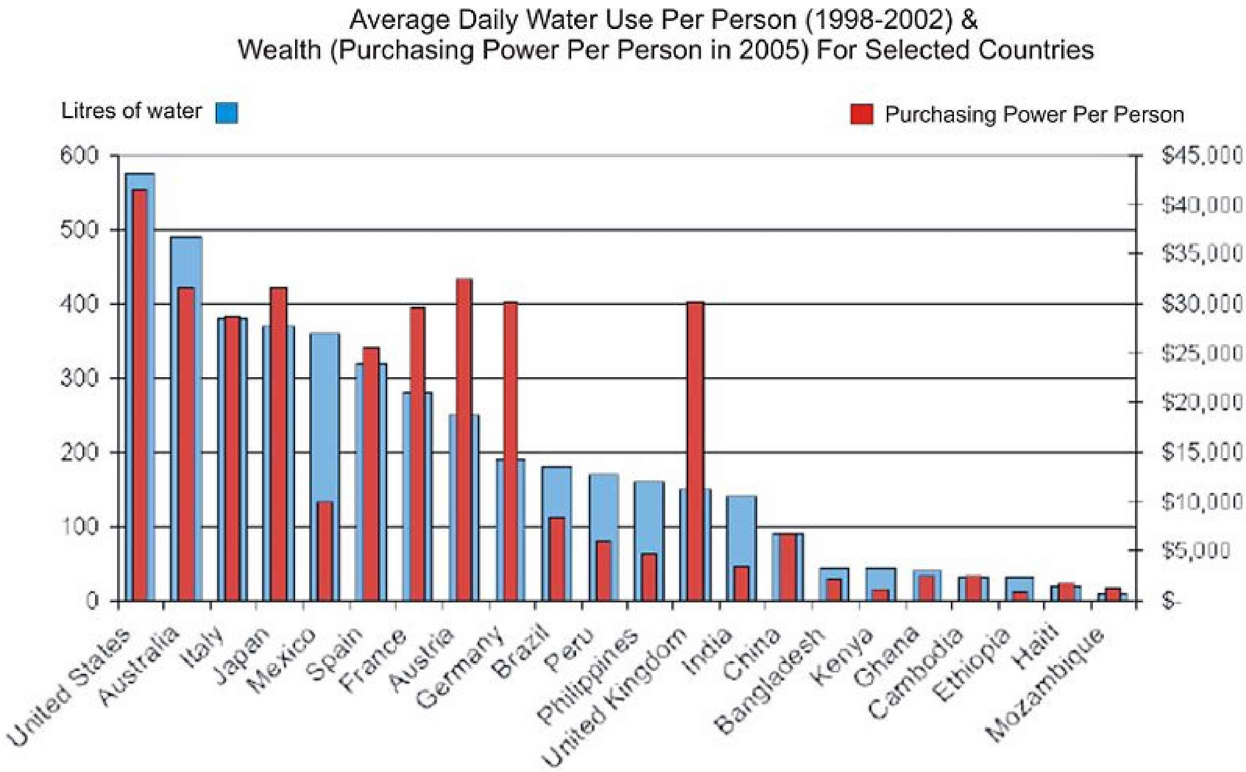


FIGURE 3.8

Average daily water use per person and wealth.

20. According to Figure 8, does there seem to be a relationship between a country's wealth and their average daily water consumption? If so, what is the relationship?

Name_______________

Date_______________

Period_______________

Fine Filters Initial Ideas: Student Worksheet

Write down your initial ideas about each question below and then evaluate how confident you feel that each idea is true. At the end of the unit, we'll revisit this sheet and you'll get a chance to see if and how your ideas have changed.

Table 3.3:

1. Why are water's unique properties so important for life as we know it?	**How sure are you that this is true?** Not Sure	**How sure are you that this is true?** kind-of Sure	**How sure are you that this is true?** Very Sure	**End of Unit Evaluation**
2. How do we make water safe to drink?	**How sure are you that this is true?** Not Sure	**How sure are you that this is true?** kind-of Sure	**How sure are you that this is true?** Very Sure	**End of Unit Evaluation**
3. How can nanotechnology help provide unique solutions to the water shortage?	**How sure are you that this is true?** Not Sure	**How sure are you that this is true?** kind-of Sure	**How sure are you that this is true?** Very Sure	**End of Unit Evaluation**
4. Can we solve our global water shortage problems? Why or why not?	**How sure are you that this is true?** Not Sure	**How sure are you that this is true?** kind-of Sure	**How sure are you that this is true?** Very Sure	**End of Unit Evaluation**

Name________________

Date________________

Period________________

Student Quiz

Write down your ideas about each question below.

1. What does it mean to have "clean fresh drinking water"?

2. Explain the term "water scarcity."

3. Does water scarcity have an impact on human health? If so, what are some of the consequences?

4. Describe three reasons why some nations are experiencing a scarcity of clean drinking water.

5. Why is the water scarcity problem projected to increase?

6. Which sector—domestic, industrial, or agriculture—consumes the most water?

The Science of Water

Contents

- The Science of Water Lab Activities: Student Worksheets
- The Science of Water: Student Quiz
- Reflecting on the Guiding Questions: Student Worksheet

Lab Activities: Student Directions

Lab Station A: Surface Tension Lab

Purpose

The purpose of this lab is to investigate the property of the surface tension of water. This lab will look at the way that water sticks to itself to make a rounded shape, the way that water behaves as a "skin" at the surface, and a comparison of water's surface tension with two other liquids, oil and soapy water.

Safety Precautions

- Wearing goggles is dependent on your school's safety criteria.
- Caution needs to be exercised around hot plates and the alcohol burner.
- Caution needs to be exercised around hot water and hot glassware.
- Do not eat or drink anything in the lab.
- Do not wear open-toed sandals in the lab.
- Wear long hair tied back to prevent touching the substances at the lab stations.

Materials

- 3 pennies
- Available water
- Small containers of water, oil, and soapy water
- A dropper for each of the containers
- A square, about $4'' \times 4''$, of wax paper

Procedures

Counting Drops on a Penny

1. Check to make sure all of the materials needed are at your lab station.

2. Using a dropper bottle containing only water, count the number of drops of water that you can balance on top of a penny. When the water falls off of the penny, record the number of drops. Wipe the water off of the penny.

3. Repeat this procedure of counting and recording drops with oil and then with the soapy water.

Comparing the Shape of a Drop

4. Drop a small sample of each of the liquids—water, oil, and soapy water—on the wax paper. Draw the shape and label the shape of the drops made by each of the liquids on your worksheet. Wipe off the wax paper.

5. Answer the questions on your worksheet.

Lab Station B: Adhesion/Cohesion Lab

Purpose

The purpose of this lab is to investigate the property of **cohesion** and **adhesion** of water.

- **Cohesion** is the molecular attraction exerted between molecules that are the same, such as water molecules.
- **Adhesion** is the molecular attraction exerted between unlike substances in contact.

Cohesion causes water to form drops, surface tension causes them to be nearly spherical, and adhesion keeps the drops in place (http://en.wikipedia.org/wiki/Adhesion).

This lab will work with capillary tubing of various diameters to see the rate at which water is able to "climb" up the tubes. This is very similar to the way that water enters a plant and travels upward in the small tubes throughout the plant's body. The "stickiness" of the water molecule allows the water to cling to the surface of the inside of the tubes.

You will see how the diameter of the tube correlates with the rate of traveling up the tube by measuring how high the dye-colored water column is at the end of the time intervals.

Safety Precautions

- COOL GLASSWARE FOR A FEW MINUTES BEFORE PUTTING INTO THE COOLING BATH OR THE GLASSWARE WILL BREAK.
- Wearing goggles is dependent on your school's safety criterion.
- Do not eat or drink anything in the lab.
- Do not wear open-toed sandals in the lab.
- Wear long hair tied back.

Materials

- 4 pieces of capillary tubing of varying small sized diameters (no greater than 7 mm in diameter), $8-24$ inches in length
- Metric ruler
- Pan of dyed (with food coloring) water into which to set the capillary tubing
- Clamps on ring stands to stabilize the tubing so that it remains upright in a straight position

Procedures

a. Check to make sure all of the materials needed are at your lab station.
b. Set the capillary tubing into the dye-colored water from the largest diameter tubing to the smallest. Make certain they are all upright and secure.
c. Record the height of each of the tubes in the table on your worksheet every 2 minutes.
d. After 10 minutes, release the capillary tubing, wrap the tubing in paper towels, and deposit them in an area designated by your teacher.
e. Answer the questions about this experiment on your lab sheet.

Lab Station C: Can You Take the Heat?

Purpose

The purpose of this lab is to investigate the heat capacity of water. You will measure the temperature of water (specific heat of water is 4.19 kJ/kg.K) and vegetable oil (specific heat of vegetable oil is 1.67 kJ/kg.K) over equal intervals of time, and will record your data and findings on your lab sheet.

Specific heat is the amount of energy required to raise 1.0 gram of a substance $1.0°C$.

Safety Precautions

- Cool hot glassware slowly. Wait a few minutes before placing in cold water or the glass will break.
- Wearing goggles is dependent on your school's safety criterion.
- Do not eat or drink anything in the lab.
- Do not wear open-toed sandals in the lab.
- Wear long hair tied back.

- Use caution when working with fire or heat. Do not touch hot glassware.

Materials

Assemble two Erlenmeyer flasks or beakers, each containing one of the liquids,with a thermometer suspended into each liquid, from a clasp attached to a stand, inserted about midway into the liquid.

- 2 equal amounts, about 100 mL , of water and vegetable oil
- 2 250 – mL Erlenmeyer flasks or 2 250 – mL beakers
- 2 thermometers
- 2 Bunsen burners or 1-2 hot plates
- 2 ring stands: each ring stand will have a clamp to hold the thermometer. Use a screen if using a Bunsen burner rather than hot plate(s).
- Cold water bath for cooling the Erlenmeyer flasks or beakers

Procedures

1. Set the cooled flasks containing their solutions on the ring stands or hot plate.

2. Take the initial temperature reading of each of the liquids.

3. Turn on the hot plate to a medium temperature, or, if using Bunsen burners instead, light them, adjusting the flame of each to the same level.

4. Record the temperature of the liquid in each flask every 2 minutes until 4 minutes after each liquid boils. Record the temperature in the table on your lab sheet.

5. After recording the final temperatures, move the Erlenmeyer flasks or beakers with tongs or a heat-resistant set of gloves into the cooling bath. Add small amounts of ice as needed to keep the water temperature cold.

DO NOT THRUST HOT GLASSWARE DIRECTLY INTO ICY WATER BEFORE COOLING BECAUSE THE GLASS WILL BREAK!

6. Answer the questions about this experiment on your lab sheet.

Lab Station D: Liquid at Room Temperature Data Activity

Purpose

The purpose of this activity is to discover how unusual it is, based on a substance's molecular weight, that water is a liquid at room temperature.

Safety Precautions

None are needed, since this is a paper and pencil activity.

Materials

- Water is Weird! Data Table
- Lab worksheet for recording trends

Procedures

Data table 1 shows the physical properties of a variety of substances. This table is typical of one that a chemist would examine to look for trends in the data. For instance, is there any correlation with the color of the substance and its state of matter? Is there any correlation between the state-of-matter of a substance and its density? How does water compare to other substances?

a. Examine the data table. Look for relationships between the physical properties of some of these substances. What do you notice that fits into any patterns? What is the opposite or is unusual to the most common pattern?

b. Discuss the trends with your lab partner. Record your thoughts on your lab worksheet.
c. Answer the questions about this experiment on your lab worksheet.

Water is Weird!

Data Analysis Activity

Water is Weird! How Do We Know?

We have been discussing the many ways that water is weird. Water seems pretty common to us. How do we know that it is unusual? Let's compare water to some other substances and see what we can find, using the data table below.

Record the trends that you notice on your lab worksheet.

TABLE 3.4: Physical Properties of Some Substances

Substance	Formula	Molar, mass, grams	State of matter at normal room conditions	Color	Specific Heat J/g K	Density of gas, liquid, or solid	Boiling Temperature, °C
Water	H_2O	18.0	liquid	colorless	4.19	0.997 g/cm^3	100
Methane	CH_4	16.0	gas	colorless		0.423^{-162} g/cm^3	−161.5
Ammonia	NH_3	17.0	gas	colorless		0.70 g/L	−33
Propane	C_3H_8	44.1	gas	colorless		0.493^{25} g/cm^3	−42.1
Oxygen	O_2	32.0	gas	colorless	0.92	1.308 g/L	−182.9
Carbon dioxide	CO_2	44.0	gas	colorless		1.799 g/L	−78.5
Bromine	Br_2	159.8	liquid	red	0.47	4.04	58.8
Lithium	Li	6.94	solid	silvery, white metal	3.58	0.534 g/cm^3	1342
Magnesium	Mg	24.3	solid	silvery, white metal	1.02	1.74 g/cm^3	1090

Lab Station E: Now You See It, Now You Don't A Dissolving Lab

Purpose

The purpose of this activity is to introduce the idea that different types of liquids may dissolve different substances.

Safety Precautions

- Wearing goggles is dependent on your school's safety criterion.
- Do not eat or drink anything in the lab.
- Do not wear open-toed shoes.
- Tie long hair back.

Materials

- 6 plastic cups
- 6 plastic spoons
- Water
- Oil
- Granulated salt

- Granulated sugar
- Iodine crystals

Procedures

a. Fill 3 plastic cups 1/3 to 1/2 full with water.
b. Fill 3 plastic cups 1/3 to 1/2 full with oil.
c. Put about a half-teaspoon of salt into the water in one cup and another half-teaspoon of salt into the oil in one cup.
d. Stir each for about 20 seconds or until dissolved.
e. Record your observations in the table on your lab sheet.
f. Repeat this procedure with sugar.
g. Repeat this procedure using iodine crystals BUT only drop 2 or 3 crystals into the water and into the oil.
h. Record your observations and answer the questions about this experiment on your lab sheet.

Lab Station F: Predict a New World! Inquiry Activity

Purpose

We all know that ice floats; we take it for granted. However, in nature, the solid form of a substance being less dense than the liquid form is extraordinary. What we don't know or think about much is how our world would be affected if ice did not float in water. This "thought" activity is explores the worldly implications if ice had a greater density than water.

Safety Precautions

None are required because this is a paper and pencil activity.

Materials

- A fish bowl with some fish and live plants

Procedures

1. Read the following. Look at the fish bowl. Think. Write your thoughts on your lab worksheet.

Assume that there will be one change in the way that nature behaves: On the day after tomorrow, worldwide, ice (the solid form of water) will now become denser than water, rather than its current state, which is less dense.

What will be the impact of this change?

2. Discuss this with your lab partner.

3. Answer the questions about this experiment on your lab worksheet.

Reference

- http://snow.reports.co.nz/snow_ida_800.jpg

Name_______________

Date_______________

Period_______________

Lab Activities: Student Worksheets

Directions: Go to the lab stations assigned by your teacher. Follow the directions for each lab that are posted at each of the lab stations. Conduct the lab activity and record your data on the lab write-up sheet. Answer the questions

FIGURE 3.9
Beautiful lake in early winter.

[1]

asked on the lab sheet. Be sure to pay special attention to the purpose of each lab before beginning the lab. You are encouraged to talk to your lab partners about the lab and to ask your teacher questions.

Lab Station A: Surface Tension Lab

Drops of Water

Fill in the table below with the number of drops you added to the penny of each substance before the liquid spilled over.

TABLE 3.5:

	Water	Oil	Soapy Water
Number of Drops			

Questions

1. What does a high surface tension do to the number of liquid molecules that can stay together?

2. Based on your evidence, compare the surface tension of these four substances.

3. After placing a few drops of each of the liquids on the wax paper, draw what the drops look like from the side view. Be sure to capture the relative height/flatness of the drop

Water

Oil

Soapy Water

Name_______________

Date_______________

Period_______________

Lab Station B: Adhesion/Cohesion Lab

Questions

1. Define adhesion

2. Define cohesion

3. Ask your teacher to provide you with the diameter of the capillary tubes if they are not labeled. In the table below,

Date________________

Period________________

Lab Station C: Can You Take the Heat? Student Lab Sheet

Specific heat is the amount of energy that it takes to raise 1.0 gram of a substance 1.0°C .

Fill out the table as you conduct your experiment.

TABLE 3.7:

Liquids	Water Temperature	Vegetable Oil Temperature
2 minutes		
4 minutes		
6 minutes		
8 minutes		
10 minutes		
14 minutes		

Questions

1. Based on your evidence, which substance has the highest specific heat? The lowest?

2. Think about and explain the relationship between high specific heat of a liquid and hydrogen bonding.

3. Compare the boiling temperatures of water and of oil. What is the relationship between hydrogen bonding and boiling temperature?

4. What happened to the temperature of the water and the oil after boiling? Explain why.

Name________________

Date________________

Period________________

Lab Station D: Liquid at Room Temperature Data Activity

Questions

1. What trends do you notice in the data table? Explain.

2. What is unusual about the most common pattern? Explain.

3. How does water compare to other substances?

Name________________

Date________________

Period________________

Lab Station E: Now You See It, Now You Don't A Dissolving Lab

A **solvent** is the liquid that is doing the dissolving. A **solute** is the substance that will be dissolved in the liquid.

Record your observations about how quickly and thoroughly each of the solutes dissolves in water and oil in the table below.

TABLE 3.8:

SOLVENT	SOLUTES	SOLUTES	SOLUTES
	Salt	**Sugar**	**Iodine Crystals**
Water			

TABLE 3.8: (continued)

SOLVENT	SOLUTES	SOLUTES	SOLUTES
Oil			

Questions

1. Summarize what you found in your experiment, based on your recorded observations.

2. Why do you think that some substances dissolve easier in one type of liquid than in another?

Name_______________

Date_______________

Period_______________

Lab Station F: Predict a New World! Inquiry Activity

Questions

1. Summarize your thoughts about the impact on the world if ice were denser than water.

Name_______________

Date_______________

Period_______________

Student Quiz

Write down your ideas about each question below.

1. Why does all bonding occur between atoms, ions, and molecules?

2. Draw a water molecule. Label the atoms that make up the water molecule with their chemical symbol. If there is an electrical charge or a partial electrical charge on any of the atoms, indicate that by writing the symbols on the atoms:

$+ =$ positive charge

$- =$ negative charge

$\delta^+ =$ partial positive charge

$\delta^- =$ partial negative charge

3. Explain the term "polar" molecule.

4. Why does water have an increased surface tension compared to most other liquids?

5. What is "hydrogen bonding"? What makes these bonds unique?

6. a. Define or describe "specific heat."

b. How does water's specific heat have an impact on our climate?

7. Is water's specific heat, compared to other liquids:

High □ or Average □ or Low □ ?

8. Are water's melting and boiling temperatures, compared to other liquids:

High □ or Average □ or Low □ ?

9. a. What happens to the temperature of the water in a pot on a heated stove as it continues to boil?

b. Explain what the energy is being used for that is heating the water at the boiling temperature.

10. Explain how a spider can walk on water.

11. Fill out the following table: Name and explain five of water's unique properties, and provide an example of the phenomenon in nature caused by each of these properties.

TABLE 3.9:

Property of Water	Explanation of Property	Phenomenon Property Causes

Name_______________

Date_______________

Period_______________

Reflecting on the Guiding Questions: Student Worksheet

Think about the activity you just completed. What did you learn that will help you answer the guiding questions? Jot down notes in the spaces below.

1. Why are water's unique properties so important for life as we know it?

What I learned in these activities:

What I still want to know:

2. How do we make water safe to drink?

What I learned in these activities:

What I still want to know:

3. How can nanotechnology help provide unique solutions to the water shortage?

What I learned in these activities:

What I still want to know:

4. Can we solve our global water shortage problems? Why or why not?

What I learned in these activities:

What I still want to know:

Nanofiltration

Contents

- The Filtration Spectrum: Student Handout
- Types of Filtration Systems and Their Traits: Student Handout
- Which Method is Best? Student Worksheet
- Comparing Nanofilters to Conventional Filters Lab Activity:

  Student Instructions #38; Worksheet

- Cleaning Jarny's Water: Student Instructions #38; Report
- New Nanomembranes: Student Reading
- Reflecting on the Guiding Questions: Student Worksheet

The Filtration Spectrum: Student Handout

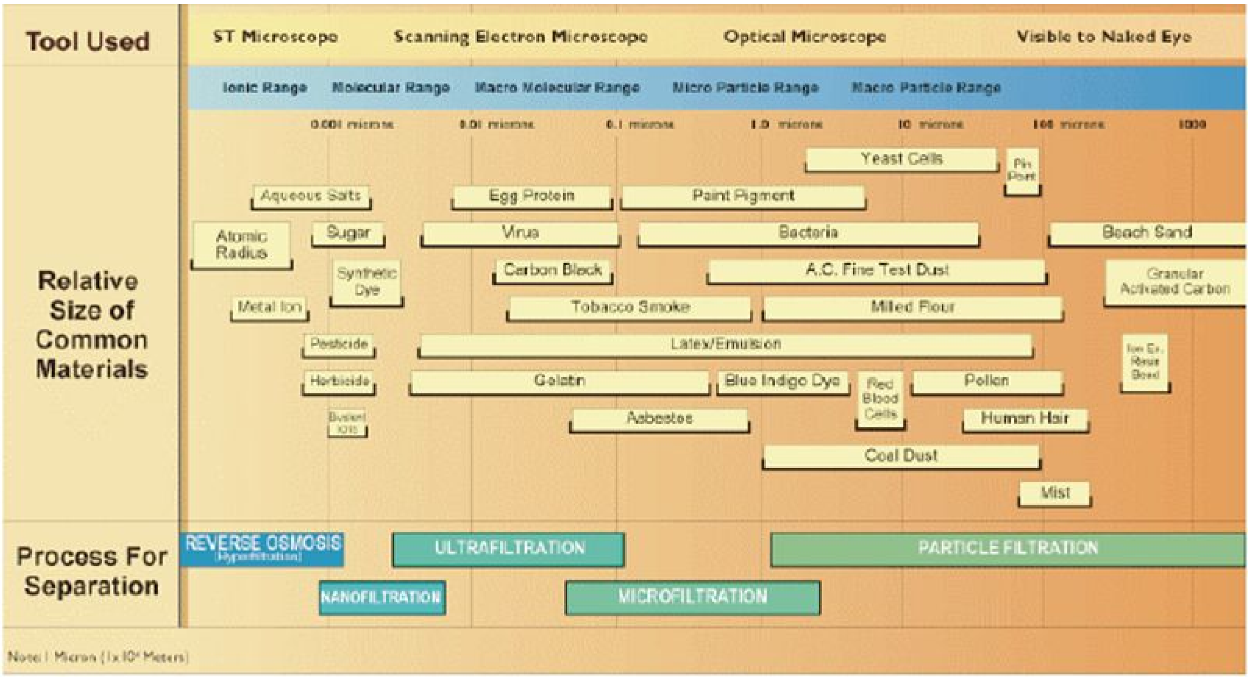


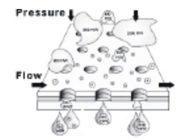
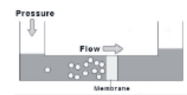
FIGURE 3.10
Osmonics Filtration Spectrum

Types of Filtration Systems and Their Traits: Student Handout

TABLE 3.10:

Types of Filtration	Max Particle Size (meters)	Characterization	Example Particles	Disadvantages	Diagram
Microfiltration(MF)	10^{-5} to 10^{-7}	Removal based on relatively large pore size, retains contaminants on surface. Very low water pressure needed. Often used as a pre-filter.	Sand, silt, clays, *Giardia lamblia, Cryptospoidium,* cysts, algae and some bacteria	Removes little or no organic matter.Does not remove viruses.	
Ultrafiltration (UF)	10^{-7} to 10^{-8}	Removal based on smaller pore size, retains contaminants on surface. Low water pressure needed.	Suspended organic solids Partial removal of bacteria Most viruses removed	Most problems are with fouling. Cannot remove iron or manganese ions (multivalentions).	 [1]

TABLE 3.10: (continued)

Types of Filtration	Max Particle Size (meters)	Characterization	Example Particles	Disadvantages	Diagram
Nanofiltration (NF)	10^{-8} to 10^{-10}	Removal based on very small pore size and shape and charge characteristics of membrane. Moderate pressure needed.	Suspended solids Bacteria Viruses Some multivalent ions	Currently most are susceptible to high fouling. Cost is relatively high (currently).	 [2]
Reverse Osmosis (RO)	10^{-9} to 10^{-11}	High pressure process that pushes water against the concentration gradient Different membranes have different pore sizes and different characteristics.	Suspended solids Bacteria Viruses Most multivalent ions Monovalent ions	Membranes are prone to fouling. Cost is high.	 [3]

Note: Relative Pressure needed for operation: $RO > NF > UF > MF$ **Relative Cost:** $RO > NF > UF > MF$ [4]

References

(Accessed December 2007.)

- http://www.freedrinkingwater.com/water-education/quality-water-filtration-method.htm
- Adapted from http://www.homecents.com/images/h2o-imgs/nano_f_l.gif
- Adapted from http://www.zenon.com/image/resources/glossary/reverse_osmosis/reverse_osmosis.jpg
- http://www.nesc.wvu.edu/ndwc/

Name_______________

Date_______________

Period_______________

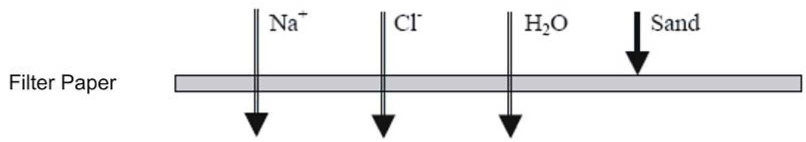
Which Method is Best? Student Worksheet

Purpose

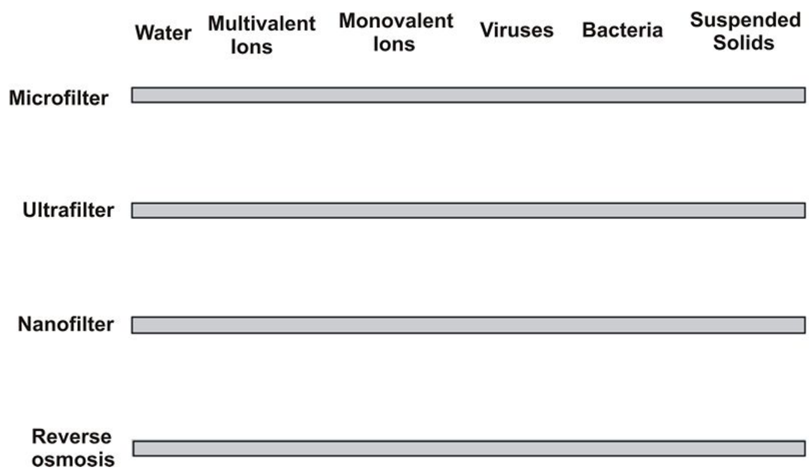
Use the Filtration Spectrum: Student Handout to determine which filtration method is best suited to filter a variety of particles.

Introduction and Example

If you had a filter that was made of paper, it would not let sand pass through but would allow water and dissolved sodium chloride pass through. To demonstrate this, you would draw the following arrows:



Refer to the Filtration Spectrum handout. Based on what you see in the handout, draw arrows that show which particles will pass through each membrane and which will not.



Comparing Nanofilters to Conventional Filters Lab Activity: Student Instructions

Overview

You are on a backpacking trip in the mountains with a friend. Each of you has brought 2 liters of water with you and you are running very low. You had planned to stay at least for another day, but realize that if you don't find a source of clean drinking water, you will need to turn back and end your trip early. You brought with you some water testing strips and a nanofilter that fits inside of a syringe, just in case you needed to drink the water from the river. Your job is to use your testing strips to find out what else, besides what you can see (such as leaves) is in the water. Once you find what is in the water, you will have to filter out any of the unwanted substances.

The pores of your nanofilter are so small that they will easily plug with large substances. You want to filter as much as you can using the gravel and the sand by the river in a funnel. You have also brought activated charcoal with you.

Can you make the river water clean enough to drink, or do you have to turn around and go home?

Materials: Filtration (Part I)

- 1/2 cup sand
- 1/2 cup gravel
- About 50 mL of activated charcoal
- 1 25 mm NanoCeram® nanofilter disc
- 1 Luer-Loc ceramic filter housing (to hold the nanofilter)
- 2 250 mL beakers
- 1 funnel
- Paper towels
- Syringe
- Test strips for nitrate and nitrite ions
- Test strips for chloride ions
- Test strips for copper
- Test strips or drops for iron(II) and iron(III) ions

- 1/2 liter of “river water” in a bottle

Materials: Comparing Ultrafiltration with Nanofiltration (Part II)

- 1 25 mm NanoCeram® nanofilter disc
- 1 25 mm Millipore VS ultrafilter disc
- 1 Luer-Loc ceramic filter housing (to hold the nanofilter and the ultrafilter)
- Syringe
- Bottle of water containing dissolved dye
- (2) small effluent collectors
- Paper towels

Procedures: Filtration (Part I)

Setup

a. Put the charcoal in water to soak for at least 10 minutes, and proceed with the next step. After 10 minutes, take the charcoal out and rinse it thoroughly to prevent coloring the water.
b. Arrange the ring on the ring stand and put the empty funnel inside of the ring, as shown in Figure 1. Put the 250 ml beaker underneath the funnel so it will catch the effluent.
c. Look at the river water in the bottle. Record your observations of the river water on your lab sheet. Be sure to notice texture, colors, and anything else that stands out.
d. Follow the instructions in the Ion Testing box below to test the river water for the presence of the ions.

FIGURE 3.11
Funnel supported by ring with beaker underneath to catch effluent

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Ion Testing

1. Label a paper towel with each of the symbols of the ions you will test:

Fe^{2+} Fe^{3+} CI^{-} $NO_3{}^{-}$ $NO_2{}^{-}$ Cu^{2+}

2. Dip the appropriate strips in the river water to test for these ions.

3. Put the wet strips on a paper towel under their appropriate symbols so you don't forget which strip represents a test for which ion.

4. Match the color of your strip with the color chart on the side of the relevant test strip bottle. The amount of the ion in your river water sample will be listed underneath the matching color square on the bottle.

5. Record on your lab sheet the color of the strip and the amount of each ion indicated by the test strip.

You will repeat this "ion testing" step after each filtration to find out if the ions are still present in the water.

Table 1 summarizes the consequences of the presence of these ions in drinking water.

TABLE 3.11: Ions and Consequences in Drinking Water

Ions	Consequences in Drinking Water
Fe^{2+} and Fe^{3+}	These ions indicate that rust from pipes has gotten into the water. While rust is not dangerous, it makes the water taste bad and leaves mineral deposits in sinks and bathtubs.
$NO_3{}^-$ and $NO_2{}^-$	These ions are an indication that pesticides from agriculture have gotten into the water.
Cl^-	This ion indicates that salt has intruded into the water. People cannot use salty water for drinking. Salty water usually cannot be used for agriculture either, although there are a few exceptions.
Cu^{2+}	Copper is normally found in water from natural sources as well as from corrosion of the copper pipes used for water. Copper is not harmful in quantities less than $1000 - \mu$m .

Gravel Filtration

1. Put 1/2 cup of **gravel** into the funnel.

2. Put a clean 250 mL beaker underneath the funnel.

3. Pour the river water supplied by your teacher over the gravel. Notice if the gravel stopped any of the substances that you saw in the water from going into the beaker below.

4. Record your observations on your lab sheets.

Gravel and Sand Filtration

5. Put 1/2 cup of **sand** on top of the gravel in the funnel.

6. Put a clean 250 mL beaker under the funnel.

7. Pour the contents of the first beaker, the effluent, into the funnel on top of the sand. Notice if the sand and gravel stop any of the substances in the water from going into the beaker below.

8. Record your observations on your lab sheet.

9. Rinse the empty 250 mL beaker and place it underneath the funnel.

Gravel, Sand, and Activated Charcoal Filtration

10. Put the **activated charcoal** into the funnel on top of the sand and the gravel.

11. Pour the remaining water (the effluent) left from the sand filtration step into the funnel on top of the charcoal. Notice if the charcoal removes anything else.

12. Record your observations on your lab sheet.

Conduct Ion Test

13. Using the test strips, test for the presence of the ions in the filtered water by following the instructions in the Ion Testing box above.

14. Record the results of your ion tests on your lab sheet and answer the questions.

Nanofiltration

15. Get a 25 mm NanoCeram® nanofilter disc and a Luer-Loc ceramic filter housing.

16. Open the filter housing and carefully place the disc into the filter housing, place the O-ring on top of the disc, and close securely, making sure the disc is centered in the housing to prevent leakage around the edges of the disc.

17. Rinse the empty 250 mL beaker and place it underneath the filter.

18. Fill the syringe with the effluent collected after filtering with the charcoal, sand, and gravel.

19. Screw the filter housing onto the syringe, taking care not to depress the plunger of the syringe during this operation.

20. Push the effluent through the nanofilter using even, steady pressure.

21. Record your observations of the solution after it has gone through the nanofilter on your lab sheet.

Conduct Ion Test

22. Using the test strips, test for the presence of the ions in the filtered water by following the instructions in the Ion Testing box above.

23. Record the results of your ion tests on your lab sheet and answer the questions.

Procedures: Comparing Ultrafiltration with Nanofiltration (Part II)

You have just used a new nanofilter (the NanoCeram filter) that has recently come to market. An older ultrafilter, called the Millipore VS filter is also available. The NanoCeram® filter is a multilevel woven membrane with various nanoparticles embedded into the layers of membranes. The Millipore VS membrane is a nonwoven, matte-like paper.

The purpose of this part of the lab activity is to compare the nanofilter with the ultrafilter based upon the following two criteria:

- Completeness of filtration
- The relative amount of pressure needed to push the water through each filter

The completeness of filtration will be measured by filtering dissolved dye through each of the filters and looking at the color of the filter and the effluent. The relative pressure needed for filtration will be measured by how hard you have to push the syringe to get the water to pass through the filters.

Compare Millipore VS and NanoCeram® Filtration

a. Open the bottle containing the dissolved dye and draw $2-3$ mL into the syringe.
b. Open the Luer-Loc filter housing and carefully place a single 25 mm disc of **Millipore VS** membrane material into it. Place the O-ring on top of the disc and close securely, making sure the disc is centered in the housing to prevent leakage around the edges of the disc.
c. Screw the filter housing onto the syringe, taking care not to depress the plunger of the syringe during this operation.
d. Depress plunger of the syringe while holding the syringe over an effluent collector to capture the fluid as it exits the syringe through the filter housing.
e. Apply enough pressure to ensure that the dissolved dye is passing through the filter media. *Typical results for this stage using the Millipore VS membrane material show only several drops coming out of the syringe due to the extreme amount of pressure required to force the dissolved dye through the filter*.

f. Once this is completed, carefully remove and open the filter housing, and remove the filter membrane.
g. Place the membrane aside, next to the effluent collector containing the effluent from this test.
h. Rinse the syringe and repeat the sequence of steps 1-7 above, but with the **NanoCeram®** filter. Push the dissolved dye through gently and steadily; avoid pushing fast.
i. Compare the color of the effluent from the two filters, the color of the filters, and how easy or hard it was to push the dissolved dye through the filters with the syringe.
j. Record your observations on your lab sheet.
k. Answer the questions on your lab sheet.
l. Clean your lab station.

References

(Accessed January 2008.)

- http://icn2.umeche.maine.edu/newnav/newnavigator/images/P7280072.JPG

Name_______________

Date_______________

Period_______________

Comparing Nanofilters to Conventional Filters Lab Activity: Student Worksheet

Part 1: Filtration

1. DRAW and DESCRIBE the contents and appearance of your river water. After looking carefully, write down everything that you see that is in the river water. Be sure to include any identifiable substances, and any colors.

2. Record the color of the test strip and amount of each ion indicated by the test strip.

TABLE 3.12:

Substance Tested	Color	Presence or Absence
Fe^{2+} and Fe^{3}		
$NO_3{}^-$ and $NO_2{}^-$		
Cl^-		
Cu^{2+}		

Gravel Filtration

3. Describe the appearance of the effluent after it was poured through the gravel.

4. Based on your observations, what was removed from the river water after filtering with the gravel?

5. Based on your observations, what remained in the river water after filtering with the gravel?

Gravel and Sand FIltration

6. Describe the appearance of the effluent after it was poured through the gravel and sand.

7. Based on your observations, what was removed from the river water after filtering with the gravel and sand?

8. Based on your observations, what remained in the river water after filtering with the gravel and sand?

Gravel, Sand, and Activated Charcoal Filtration

9. Describe the appearance of the effluent after it was poured through the gravel, sand, and charcoal.

10. Record the color of the test strip and amount of each ion indicated by the test strip.

TABLE 3.13:

Substance Tested	Color	Presence or Absence
Fe^{2+} and Fe^{3}		
$NO_3{}^-$ and $NO_2{}^-$		
Cl	[U+0080][U+0093]	
Cu^{2+}		

11. Based on your evidence (observations and strip tests), what was removed from the river water after filtering with the gravel, sand, and charcoal?

12. Based on your evidence (observations and strip tests), what remained in the river water after filtering with the gravel, sand, and charcoal?

Nanofiltration

13. Describe the appearance of the effluent after it was pushed through the NanoCeram® nanofilter.

14. Record the color of the test strip and amount of each ion indicated by the test strip.

TABLE 3.14:

Substance Tested	Color	Presence or Absence
Fe^{2+} and Fe^{3}		
$NO_3{}^-$ and $NO_2{}^-$		
Cl^-		
Cu^{2+}		

15. Based on your evidence (observations and strip tests), what was removed from the river water after filtering through the nanofilter?

16. Based on your evidence (observations and strip tests), what remained in the river water after filtering through the nanofilter?

Part II: Comparing Ultrafiltration with Nanofiltration

After following the lab directions for putting the effluent through the two filters, fill out the following table.

TABLE 3.15:

Filter Type	Color of Effluent	Color of Filter	Relative Pressure Required to Push the Solution Through the Filter
Millipore VS ultrafilter			
NanoCeram® nanofilter			

17. Which filter removed the dye the best? How do you know?

18. Which filter required less pressure to push the water through?

19. Based on your results about pressure, which filter would cost less overall?

20. Based on the evidence from your experiments, can you stay and camp another day or do you have to go home to get clean, drinkable water?

21. What do you think might have been the sources of the pollutants in your river water?

Cleaning Jarny's Water: Student Instructions #38; Report

There's a Problem with Our Water...

In the Eastern part of France, in the city of Jarny (see Figure 1), the local people have a serious problem with their drinking water. Their main source of drinking water comes from the ground water table located near an old iron mine. (See Figure 2 for an explanation of ground water.)

The water has always been pumped out of the mine and filtered before being used for drinking water. When the mine was active, this system worked fine. But since closing, the water has flooded up into the mine, creating a pool of standing water that seeps into the ground water used for drinking.

FIGURE 3.12

Jarny France *green arrow*

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Over time, the water sitting in the mine reacted with the debris left in the abandoned mine, leaving much of the water contaminated. A local water-monitoring agency has watched the rising contamination levels and determined that the current water cleaning system is not good enough to make the water safe to drink. Even before the water flooded up into the mine, a few substances were slightly above safety limits, but now their levels are even higher.

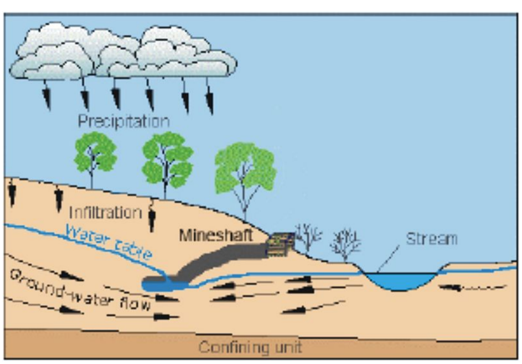

FIGURE 3.13

Ground water

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Water that comes from rain (precipitation) trickles through the ground (infiltration) until it flows to an area that it can't pass through, such as bedrock. Fresh water accumulates in these places and is referred to as *ground water*. The top of the ground water is the water table. When this underground water is large enough, it is called an aquifer. Aquifers are a commonly used source of fresh drinking water for people all over the world.

Now that you have some background on the water problem facing Jarny, your team's job is to design a system to clean the water to make it drinkable by the local residents. To do this you will need to do the following:

1. Analyze the data in Table 1 to identify what harmful substances are present in the water. This table provides raw water measurements on a set of substances, selected due to their change in concentration before and after the flooding.

2. Complete question 1 in the Student Report. Record the following information for each substance:

- The name of the substance identified to be filtered out of the water
- The amount the substance is over the acceptable limit
- The ranking of substances by size (1 = largest)
- The least expensive filter needed to filter the substance identified

3. Analyze the data on the current water cleaning system (Table 2), your reading handouts, and relevant charts to help inform your design of a system to clean the water to make it drinkable. Assume that your design will be added on to the system currently in place: a flocculation procedure, a sand filter, and a 1.0 micron microfilter. Remember that the town is poor and your design needs to provide a cost-effective solution. Your design may involve single-step or multiple-step methods.

4. Complete questions 2 and 3 in the Student Report.

TABLE 3.16: Water Measurements Before and After Flooding

Substance	Before flooding (mg/L)	After flooding (mg/L)	"Safe" levels (mg/L)	Health hazard or water-taste quality
Ca^{2+}	168	296	160	Contributes to water "hardness"
Mg^{2+}	31	185	15	Contributes to water "hardness"
Na^{+}	50	260	350	Dehydration
$CO_3{}^{2-}$	367	500	100	Taste or alkalinity
$SO_4{}^{2-}$	192	1794	300	Water taste
Cd^{2+}	.002	.018	.005	Kidney damage
Bacteria (*E. coli*)	0	24	0	Diarrhea, cramps, nausea, or headaches
Asbestos (million fibers/L) from rotting pipes	2	12	7	Increased risk of developing intestinal polyps
Human hair (million hairs/L)	16	48	3	None known, just disgusting

Jarny's Current Water Cleaning System

Jarny's current water cleaning system involves treating the water with a flocculent (a material that combines with large-sized particles in the water) and then letting the flocculent (with the large particle combinations) sink to the bottom so it can be removed. The remaining water is filtered through two filters: 1) sand, and then 2) a membrane with 1.0 micrometer diameter holes.

References

- http://maps.google.com
- Adapted from http://ga.water.usgs.gov/edu/earthgwdecline.html

Student Report

1. Use the water quality information in Table 1 to fill in Table 3 below.

TABLE 3.17: Substances Present at Unacceptable Levels

Substance	Amount over acceptable limit	Rank substances by size (1 = largest) If there is a range, choose the size at the smallest end of the range Particles of similar size can have the same ranking	Least expensive filter necessary
Ca^{2+}			
Mg^{2+}			
${CO_3}^{2-}$			
${SO_4}^{2-}$			
Cd^{2+}			
Bacteria (*E coli*)			
Asbestos			
Human hair			

2. The best filter or combination of filters to add to Jarny's water system are the following, in order:

3. Draw your design showing the water and its contents before and after passing through each filter in your design.

New Nanomembranes: Student Reading

The Desalination Problem

In the early1960's, the United States government challenged the scientific community to discover an inexpensive yet effective method for removing salt from water (**desalination**) on a large scale. Desalination offered the potential to make water from the oceans drinkable, but at the time, desalination methods tended to be expensive and inefficient.

Accepting this challenge, Samuel Yuster and two of his graduate students at the University of California, Los Angeles created a porous material that simulated the movement of water through a living cell's membrane. This material, a type of cellulose **polymer**, was called a **reverse osmosis** (RO) membrane.

Within a living cell, water travels across the cell membrane from an area of higher concentration of **solute** to an area of lower concentration. This natural process, called **osmosis**, continues until the concentration of solute on the inside and outside of the cell are equal. In *reverse* osmosis, water is transported through an artificial membrane from an area of lower concentration to one of higher concentration—the opposite of osmosis. The water goes against the "concentration gradient."

Because this does not happen naturally, pressure (e.g. from a pump) is required to push the water through the membrane. By pushing water through this membrane, which salt and other ions can't pass through, the water is filtered, leaving it pure and safe to drink. Reverse osmosis is the most expensive type of water filtration due to the constant energy required to pump water through the membrane at high pressure. Thus, even though we have a technique to make ocean water drinkable, the cost still prevents wide scale use.

Desalination technology has not changed much over the last fifty years... until now. Currently, there is a considerable amount of active research going into the creation of a variety of nanotechnology membranes, all with the goal of finding an inexpensive, but highly efficient method of removing salt from water.

Meet Eric Hoek

Eric Hoek, a researcher at the University of California, Los Angeles, has been making the news lately. Dr. Hoek is an assistant professor of civil and environmental engineering and is working with a company to patent a nanofiltration membrane that shows promise as an efficient and costeffective way to remove salt from water.

Dr. Hoek is working to create membranes with pore sizes of one nanometer. Because of the small pore size, the membrane blocks substances that are only a few nanometers in size.

FIGURE 3.14

Dr. Eric Hoek Assistant Professor at the University of California in Los Angeles *UCLA*

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However, the membrane not only filters based on *size* but also based on *charge*. In other words, the membrane can stop particles of a particular size and of a particular electrostatic charge while allowing water through. He explains that one-nanometer pores are an optimal size because an electric field is generated that covers the entire pore. This electric field is adjustable in strength so that it can be "tuned" to reject charged items in solutes.

In addition, Dr. Hoek has figured out how to embed noxious substances in his nanomembranes—substances that will kill bacteria on contact! Dr. Hoek explains that at the nanoscale level, you can build substances into the membrane to give it certain properties. For example, by implanting into the membrane substances that are toxic to bacteria, you can effectively kill bacteria in water.

Dr. Hoek's nanomembranes provide all of these new filtration benefits, but equally importantly, they filter water at much less pressure and cost than traditional reverse osmosis techniques. How does this happen? Dr. Hoek explains that channels can be built into the membranes that are surprisingly hydrophilic (attractive to water molecules). The hydrophilic channels *attract* water to pass it through the membrane, thus reducing the pressure needed to *push* the water through it.

Dr. Hoek plans to continue working on the development of smaller, "adaptive" membranes that can be adjusted through the combination of pressure-driven and electric/charge driven filtration. In other words, the membrane will allow you to have much greater control over the types of particles that can be filtered out. He also envisions creating membranes that are self-cleaning, which would reduce both maintenance and operating expenses. As Dr. Hoek tells his students, "Work on important problems, and your work will be appreciated. You'll do incremental work along the way to the goal, but you need the important problem to steer your work."

Fred Tepper and His Company Argonide

Fred Tepper, founder of the company Argonide, invented a new type of water filtering membrane with pores containing nanosized ceramic fibers. What is the advantage of this type of filter?

Because the filter has such a large quantity of **nanofibers**, it contains a tremendous surface area. The larger the surface area in a filter, the greater amount of "dirt" the filter can trap and remove from the water. This type of filter can hold many times more dirt than an **ultrafiltration** (UF) membrane can. And it is highly efficient in capturing very small particles in a water stream. Ultrafilters are often used as **prefilters** for reverse osmosis (RO) membrane systems, taking out particles that can clog, or **foul**, RO membranes.

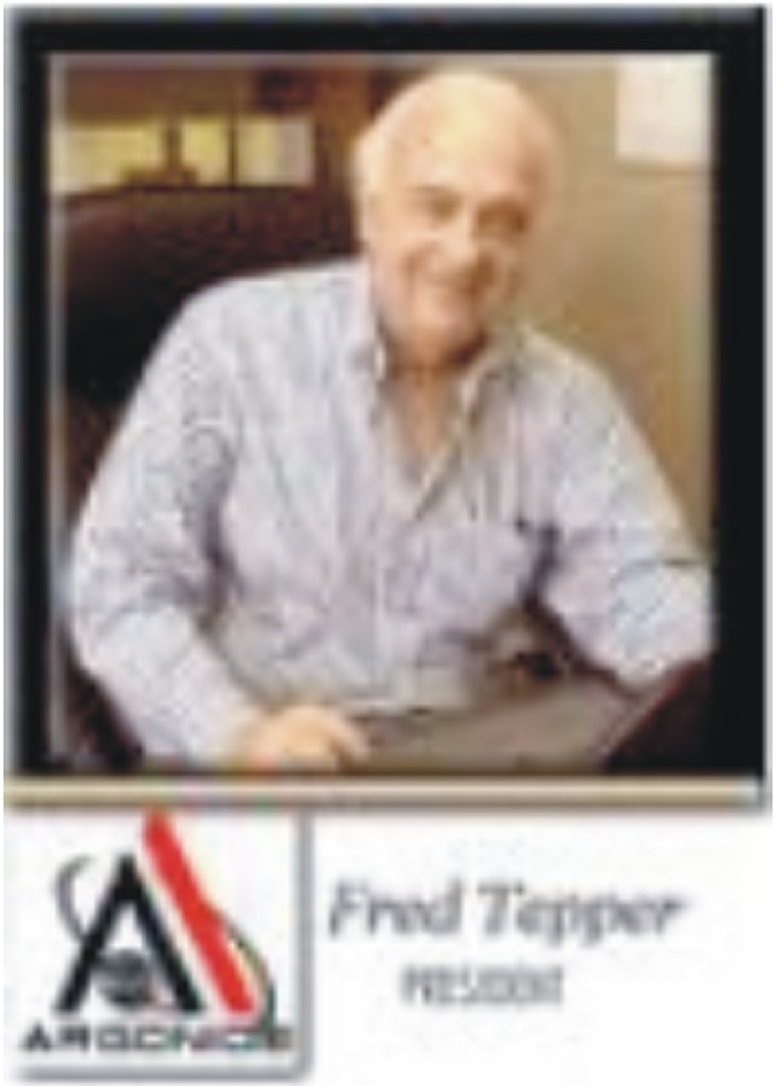

FIGURE 3.15

Fred Tepper founder of Argonide

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How Does Argonide's Nanofiltration Membrane Work?

The **nanoceramic** filter is composed of several different filter materials. In effect, each filter contains multiple layers of pores, which makes it very efficient at trapping a wide variety of particle sizes through a nanoscale adhesion process (**nanoadhesion**). The filter is completely lined with an **alumina**-based material which, when reduced to nano-sized fibers, gives the fiber surfaces a very strong positive charge. Negatively-charged particles, like salts or ions that need to be removed from water, are attracted to the positively-charged fiber surfaces and are effectively removed from the water.

Nanoceramic filters can sustain high water-flow rates, and are very good at capturing small particles. In traditional filtration, to capture smaller particles, you need smaller pores in the filter. However, with the **electroadhesive** properties of nanoceramic filters, particles are attracted to and captured by the positive charges on the filter surfaces.

For standard filters to approach the efficiency of nanoceramic filters, they must typically use a smaller pore size. This smaller pore size leads to increased clogging (fouling) of the pores and a lower flow rate of water compared to the nanoceramic filters.

Nanoceramic filters act as prefilters to reverse osmosis membranes since they are able to filter out particles that would typically harm or foul RO membranes. This allows the RO membrane to do what it does best: remove salt ions from water. The RO membrane will last much longer if it doesn't have to trap bigger particles, and it will need fewer maintenance/cleaning cycles, which can extend its lifetime. Thus even though the nanoceramic filter does not perform reverse osmosis, it contributes to a larger technology solution that makes RO less expensive.

References

- http://www.cnsi.ucla.edu/institution/personnel?personnel_id=124316
- http://www.argonide.com/company.html

Glossary

alumina A synthetically produced aluminum oxide (Al_2O_3)

desalination The process by which salt is removed from salt water (e.g. sea water) to make it drinkable.

electroadhesive Two substances adhere to each other by the attraction of opposite charges.

electroconductor A material that conducts electricity.

foul (fouling) The process in which the substance(s) being filtered out block the pores of a filter, making that filter unable to transport water.

nanoadhesion A process in which charged particles are (electrostatically) attracted to nanofibers that have been coated with a thin metallic film.

nanoceramic A ceramic (inorganic, nonmetallic material) that is synthesized from nano-sized powders.

nanofibers Fibers with diameters less than 100 nanometers.

osmosis The passage of water through a semi-permeable membrane from a region of low solute concentration to a region of high solute concentration until equilibrium is reached.

polymer A long molecule that is made up of a chain of many small repeated units.

prefilter A filter that cleans small particles out of the water, thereby increasing the efficiency of the next, smaller filter.

reverse osmosis A method of producing pure water by forcing saline or impure water through a semi-permeable (selectively permeable) membrane across which salts or impurities cannot pass.

solute A substance that is dissolved in another substance (called the solvent) in a homogeneous mixture. For example in salt water the salt ions are the solute and the water is the solvent.

ultrafiltration Method for removing particles from water via a membrane filter. By applying pressure, water passes through this membrane.

Name_______________

Date_______________

Period_______________

Reflecting on the Guiding Questions: Student Worksheet

Think about the activities you just completed. What did you learn that will help you answer the guiding questions? Jot down notes in the spaces below.

1. Why are water's unique properties so important for life as we know it?

What I learned in these activities:

What I still want to know:

2. How do we make water safe to drink?

What I learned in these activities:

What I still want to know:

3. How can nanotechnology help provide unique solutions to the water shortage?

What I learned in these activities:

What I still want to know:

4. Can we solve our global water shortage problems? Why or why not?

What I learned in these activities:

What I still want to know: