Lesson 1: Introduction to Nanoscience

Student Materials

Contents

Introduction to Nanoscience: 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 nanoscale special 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 x 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 m x 0.5 m x 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.

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**!

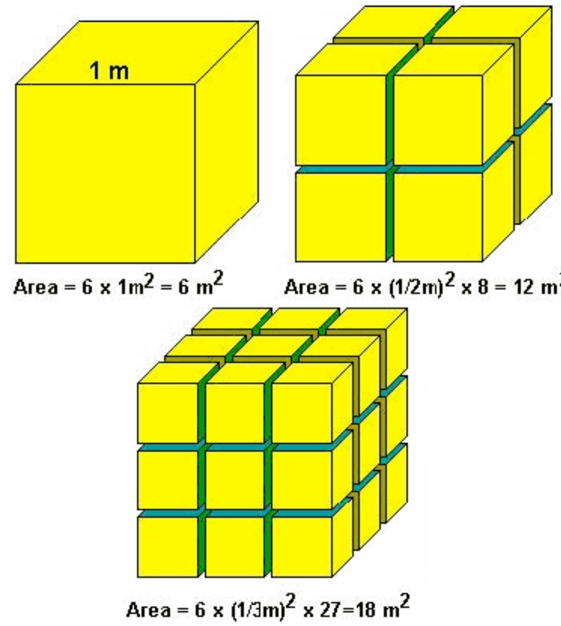

Figure 1. Total surface area increases as you cut the block into smaller pieces, but the total volume stays constant [2].

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]

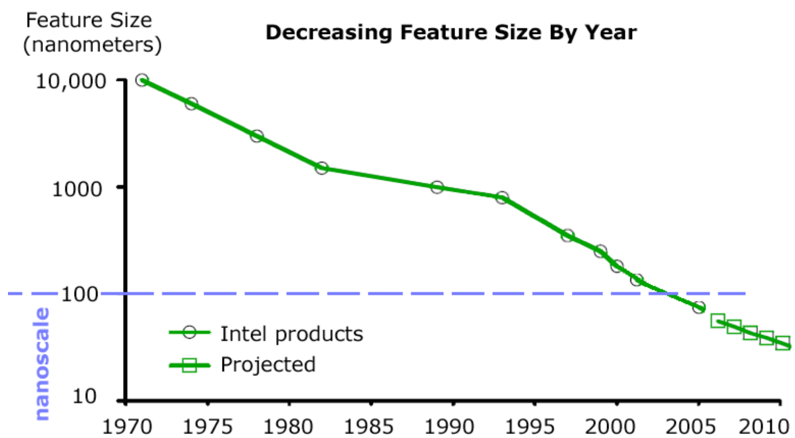

Figure 2. The decreasing minimum feature size of transistor components [3]. Note that size is graphed on a logarithmic scale, so the change is exponential.

Another group of devices that are considered small, but not quite at the nanoscale, are **MEMS (micro-electro-mechanical 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.

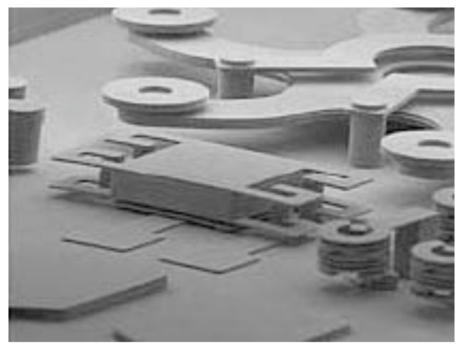

Figure 3. MEMS accelerometer [5].

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.

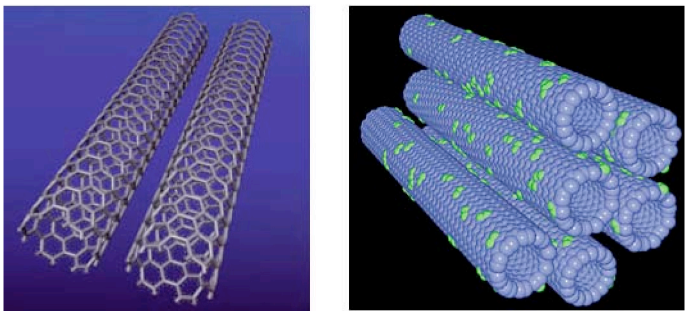

Figure 4. Computer-generated models of carbon nanotubes [6, 7].

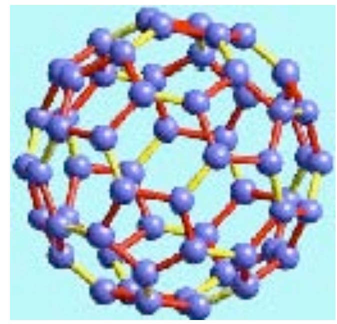

Figure 5. Model of a buckyball with single bonds (red) and double bonds (yellow) highlighted [8].

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 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.

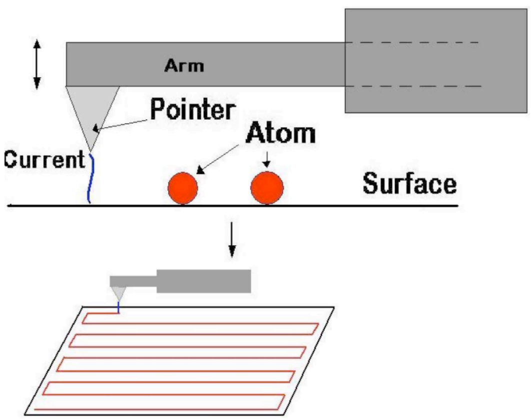

Figure 6. Schematic of a scanning tunneling microscope [9].

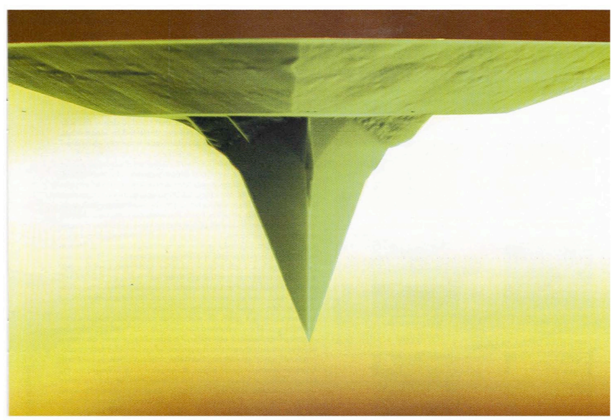

Figure 7. Tip of an atomic force microscope [10].

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.

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 8. IBM logo assembled from individual xenon atoms arranged on a nickel surface [11].

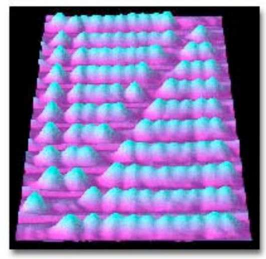

Figure 9. Nanoscale abacus buckyball “beads” placed on a copper surface [12].

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.

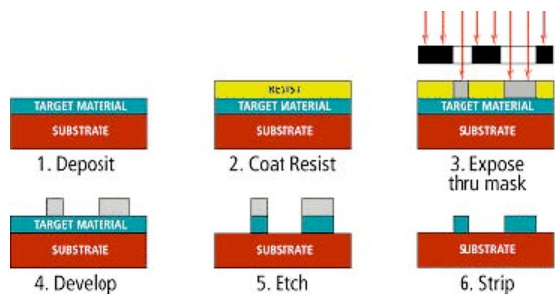

Figure 10. Photolithography, a process of chiseling away material to make integrated circuits [13].

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.

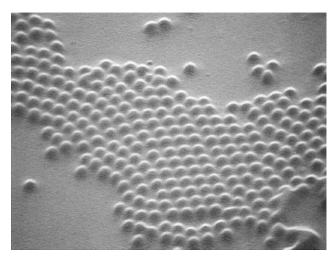

Figure 11. Polystyrene spheres self-assembling [14].

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.

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.

References

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[5] http://www.microfabrica.com

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[7] http://pubs.acs.org/cen/coverstory/7851/figures/7851sci14x.ce.gif

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Glossary

Term	Definition
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 (10-9m). 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.
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 ______

Introduction to Nanoscience: 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?

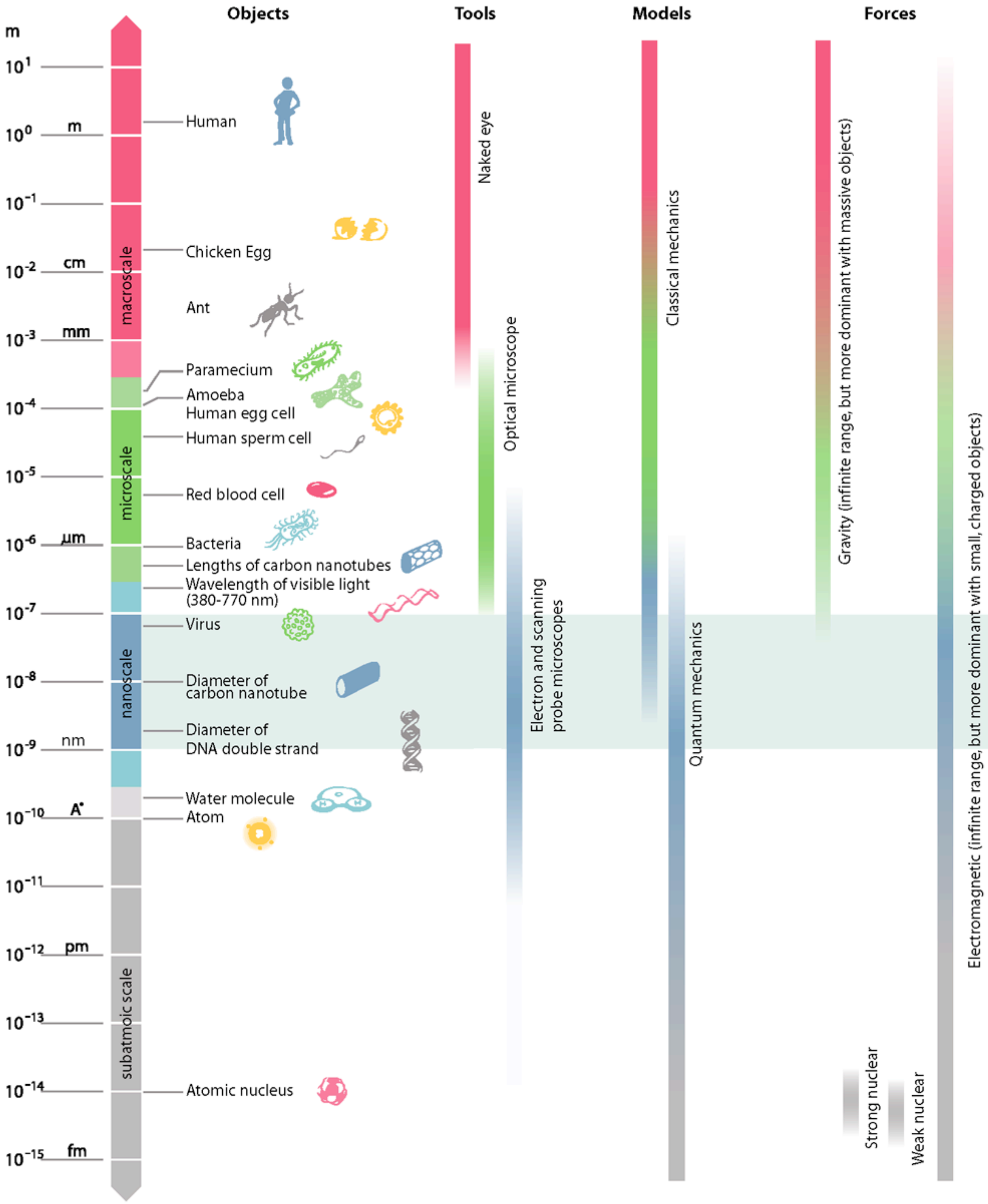
4. Briefly describe how light microscopes and electron microscopes work.

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.

Scale Diagram: Dominant Objects, Tools, Models, and Forces at Various Different Scales



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]

"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]

"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]

"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]

"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."

[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.

[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.

[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.

[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.

"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]

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.

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]

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]

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,

[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.

[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.

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

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

"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.

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]

"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]

"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."

[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).

[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.)

[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.

"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.

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]

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

[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.

[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.

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.

"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]

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

[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.

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

"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&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://wired-vig.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&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: