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Teeny Tiny Wonders: Nanotechnology and Machines

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by Stephen J. Griffith

Overview

Nanotechnology is a new branch of science that deals with extremely small objects. As a new area of science it is important and imperative for students to find out about this field, which is quickly becoming a part of our everyday world with many products already having been released that uses nanotechnology. Although this field of science is exciting and expanding rapidly there are few references to nanotechnology in current middle school science textbooks; the creation of this unit plan is an important resource in teaching basic concepts about nanoscale and nanotechnology. To better acquaint oneself with nanotechnology, it is important to understand how many of the ideas of physics change as the size of the objects also change.

This unit is designed for students who have already been thoroughly exposed to Newton's three laws of motion, transfer of energy, properties of matter, and atomic theory. The unit will introduce students to some of the work currently being done in research facilities around the world involving nanotechnology, as well as some practical applications of this technology currently being used by industry.

This unit plan will develop three areas of nanotechnology for students; it is aligned with the state objectives for eighth grade students in Georgia. The three sections are: (1) The size of matter and how size determines the physical properties of objects; this will consist of a comparison of nanoparticles with objects in the macroscopic world. (2) The use of nanotechnology in delivery systems for medicines; this will consist of both practical uses and theoretical items still being explored. (3) The use of nanotechnology as building blocks for useful products in the macro-world; this will consist of a look at products already available for consumer consumption, and also potential products of the future that could change the landscape of Earth. It is designed to be taught over a three to four week period.

The GA state objectives that will be used as a correspondence to this unit will be: (S8P3) Students will investigate relationship between force, mass, and the motion of objects, (S8P5) Students will recognize characteristics of gravity, electricity, and magnetism as major kinds of forces acting in nature.

Why Nano? : A Brief History

Richard Feynman is considered the grandfather of nanotechnology. In 1959 he gave a lecture at Caltech to the American Physical Society titled "There's Plenty of Room at the Bottom." This speech highlighted the possibility available at the time of being able to write all of the volumes of the *Encyclopedia Britannica* onto the head of a pin. He further described that all of the information of all the books of the world could be written in a cube 1/200 th of an inch wide. [1]

Through this talk he laid out the theoretical ideas for how to work and develop things at such a small scale. Talking to a group of physicists he told them that this was old news to those in the science of biology. Biologists had been studying DNA for decades: although its structure had only been revealed a few years before his lecture, they already knew that this tiny elongated chain coded for everything that made a human, or any plant or animal for that matter. He suggested that biologists were simply waiting around for physicists to catch up with their thinking in order to create new machines needed to see below the visible light spectrum. This was eventually realized in the electron microscope. The remainder of the lecture went through various scenarios for miniaturizing and working with different materials at such small scale. [2]

The conclusion of Feynman's lecture was a set of challenges to prove some of the points of his lecture could become reality. One was the creation of a working electric rotary motor to be no larger than 1/64 inch cubed. This first challenge was completed successfully less than a year after this lecture. William McLellan created a working motor at the scale suggested by Feynman; McLellan was able to complete this task using convential machinery and not by the methods Feynman suggested in his lecture. This however proves to be at the "bottom" of what humans are capable of building using traditional means. The second challenge was to write one complete page of a text at the scale 1/25,000 of normal standard print size. This challenge was not met until 1985 by Tom Newman. Newman successfully used an electron beam to write a page from *A Tale of Two Cities* on the head of a pin; he later stated how hard it was to find the text on the vast emptiness of the head of the pin compared to the actual text demonstrating the extremely small scale in which nanoscience takes place. [3]

This beginning led the way for the nano-revolution currently going on around the world. As technology has increased more tools have become available, such as the electron microscope, more and more research has been conductred into this miniscule world. As scientists began to be able to observe this small "world" it became evident that the properties of matter change significantly when you get down to this size, making it essential to understand some of the physical attributes of objects at this scale in order to work and produce objects at this scale.

Strange Science at the Nanoscale

We live in our own world. We are used to seeing and comprehending things that are at our scale, or approximately our size. We can change that scale by looking down at the ants and other insects on the ground, or looking up into the night sky and looking at the stars and planets above us. Looking up or down, we are still very much occupied with the scale that is most present around us. We understand and comprehend fairly easily objects and their behaviors at this scale such as an apple falling from a tree due to gravity, or the effects of a collision between two cars on a highway.

Understanding Scale of Objects

It is hard for us to comperehend the incredible distances between planets in our solar system, and the distance to other stars. Once we begin to comprehend these vast spaces it becomes clear that physics has a lot of catching up to do if we ever wish to visit any of these places in person as opposed to with a telescope. Although it is possible to understand these distances our science and technology is still firmly grounded with the scale at which we live, forcing us to launch a vehicle to Pluto that will take 9 years of flight time to get there: and Pluto is an object still within in our own solar system.

If we look downward at an ant or other insects we find lots of things to be interested in, but we still have trouble comprehending what life is like at that size scale. Looking at a lone ant carrying a portion of a leaf or a cracker that is three to five times his size and likely 10 times or greater his weight perplexes us. In our world, we have trouble carrying large items as their size makes us unstable; even the greatest human body builders cannot carry 10 times their body weight as the structure of human bones would simply crush under these increased forces. [4]

Objects and matter behave differently as they get larger or smaller. Plenty of Sci-Fi has been written or filmed with either shrinking or incredibly large humans. Either change in size (larger or smaller) is usually shown as a perfectly scaled human, or insect, or animal, just at a larger or smaller scale, yet physics makes this impossible. Consider the largest and smallest humans that have lived: the changes in body shape of a human at these different scales helps to clarify this phenomena without even dealing with the gross proportions of movies or stories such as *Gulliver's Travels*.

A larger human has more body weight and thus more gravitational force acting upon the body: to counteract this force, the person's base (feet and legs) need to be disproportionately bigger to compensate for the increased weight, just as when a tree gets taller its trunk at the base also gets much larger creating a larger cross-sectional area at ground level. Likewise, in a smaller human, the size of legs and arms become disproportionate to the size of the chest, because the chest still must maintain all of the organs needed for the body to function.

Looking at how a human embryo grows into a fetus shows this transition of size as the body begins to become more proportionate, although even a newborn has a disproportionate head size, which is larger than the rest of the body, and it takes many years of human growth for a young child to become proportionately accurate. The larger head size is due to the importance of the functions of the brain: if you can visualize this large-headed baby and consider shrinking the body down, the head would continue to be disproportionately larger as its functions-which require a certain number of cells and, therefore, a certain volume-would still be needed.

To better understand the concepts and nature at work at the nanoscale, it is important to look at some of the primary physical characteristics at work at the different sizes and how to calculate these differences as the scale diminishes. [5]

Surface to Volume Ratio

Surface to volume ratio is a concept taught in basic biology classes as a way to demonstrate the differences between multicellular and unicellular animals. This is done by showing that as an object shrinks in (a cell in this case) its surface to volume ratio increases. This concept is an important aspect of nanotechnology and should be explored further.

The surface area (S) to volume (V) ratio (S/V) is an important physical parameter. The surface area (S) is found from the formula $6(a)^2$, where a is the length and width of each side. The volume (V) is found from the formula $(a)^3$. The surface to volume ratio can be simplified to 6/*a*. For example, if you have a cell that is 1 unit in length, 1 unit in width, and 1 unit in height it will have a volume of also 1 unit cubed. The ratio of S:V is 6. With a large S/V ratio, there is sufficient surface area for the cell to obtain its required intake of oxygen or any matter needed by the cell. If the cell is 4 times larger in dimension, then the surface area becomes $6(4)^2$ or 96, and the volume is $(4)^3$ or 64. The ratio S/V is now 1.5:1. The larger cell has less surface area for the required intake of substances into the cell.

To illustrate this point using spherical objects (as nature tends to make spheres as opposed to nice neat cubes) the formulas are for surface of a sphere **$S= 4\prod r^2$** and the formula for volume is **$V= 4\prod r^3/3$ (divided by 3)**. This makes for a S/V ratio of 3/r for a spherical object. [6] Thus, S/V for a spherical object increases as r decreases. Figure 1 below illustrates the example for greater clarification.

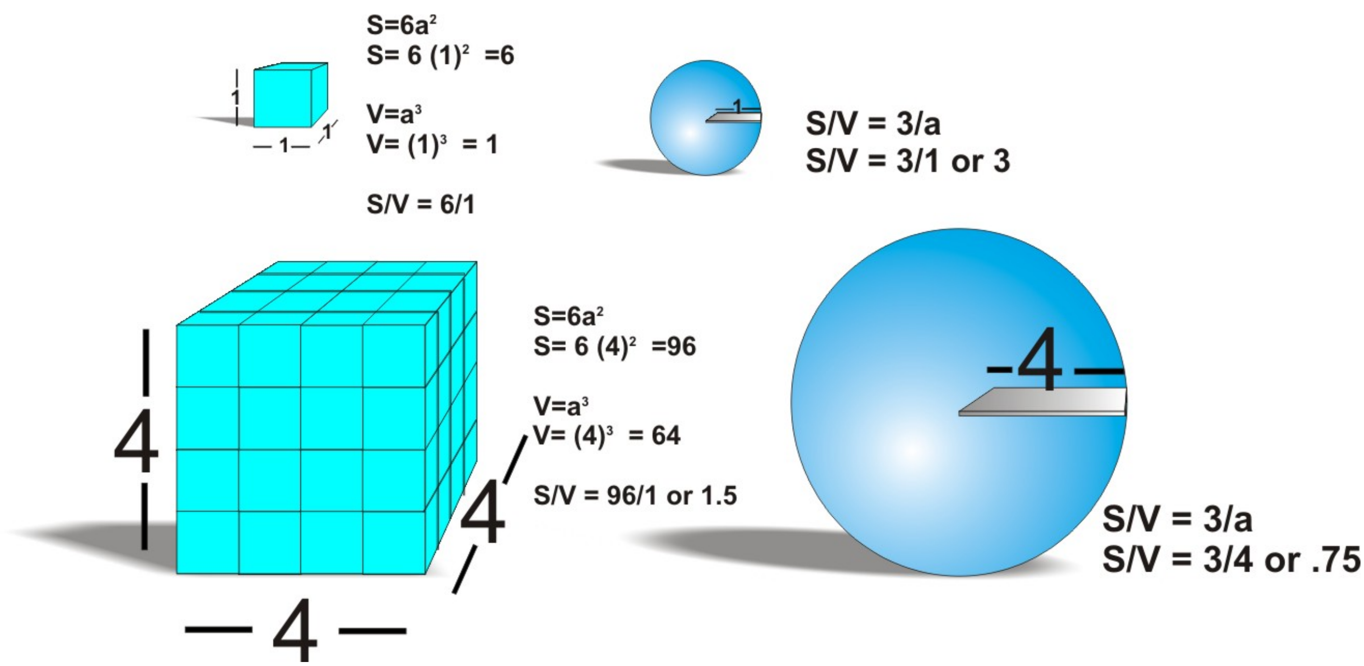


figure1

Just How Small Are We Talking About?

As previously stated it is difficult to comprehend the difference in scale from ours in working at the nanoscale. In a science class, student and teacher are generally working in a scale of centimeters, and may also employ the use of a meter or a millimeter. Rarely in the middle school will students be presented with the size of items smaller then this except for some brief examples in a book, such as wavelengths on the electromagnetic spectrum. In order to understand this scale it is important to look back at the units and prefixes associated with the metric system and the use of scientific notation. [7]

The nanoscale is 10^{-9} of the base unit of a meter. This means that in a meter there are 1 billion nanometers. A billion is already an astronomical number that is hard to comprehend, so to further illustrate the small scale at this level one can compare a nanometer to a millimeter. A millimeter still has one million nanometers in it. Suppose you asked a set of students to look at a millimeter on a ruler and asked them to place ten equidistant lines in the space between two millimeter marks. They could probably do that, but would they have the ability to scale down another ten and place 100 lines, or even 1000 lines, between the spaces of millimeter markings. The answer is an emphatic ***NO***. Yet, even this does not illustrate the problem with understanding scale at this level, because even with these 1000 divisions, the lines are not close to nanoscale.

There are many good sites available for use in understanding scale. A site from the University of Utah (http://learn.genetics.utah.edu/content/begin/cells/scale/) gives the ability to view objects in the macroscale, and continues to shrink down to objects at the nanoscale.

Scale and scientific notation are essential to teaching and understanding of objects at the nanoscale. Fig. 2 can be used to further develop the ideas of how to scale down in size for students so they can become more comfortable with the ideas. In the table the first column represents the size in meters using traditional numbering, followed by the same size using the base power of ten. Columns 2, 3, and 4 show the scale in centi, micro, and nanometers respectively. If not currently taught it is important to teach scientific notation.

Power of Ten in the Metric System

10 m	10^{1} m	1000 cm	10,000,000 um	10,000,000,000 nm	1	decameter
1 m	10^{0} m	100 cm	1,000,000 um	1,000,000,000 nm	1	meter
0.1 m	10^{-1} m	10 cm	100,000 um	100,000,000 nm	1	decimeter
0.01 m	10^{-2} m	1 cm	10,000 um	10,000,000 nm	1	centimeter
0.001 m	10^{-3} m	0.1 cm	1,000 um	1,000,000 nm	1	millimeter
0.0001 m	10^{-4} m	0.01 cm	100 um	100,000 nm		
0.00001 m	10^{-5} m	0.001 cm	10 um	10,000 nm		
0.000001 m	10^{-6} m	0.0001 cm	1 um	1,000 nm	1	micrometer
0.0000001 m	10^{-7} m	0.00001 cm	0.1 um	100 nm		
0.00000001 m	10^{-8} m	0.000001 cm	0.01 um	10 nm		
0.000000001 m	10^{-9} m	0.0000001 cm	0.001 um	1 nm	1	nanometer

figure 2 (Courtesy Mark Saltzman 2010)

Strength to Weight or I'm Stronger than You

Strength to weight comparisons can be seen on a scale that we are comfortable with. As stated earlier, ants are capable of carrying far more weight comparable to their size than a human, which is due to the limiting effects of gravity as objects get smaller. The smaller the object gets, the greater the strength to weight ratio for that object. In the text *Nanotechnology: Understanding Small Systems*, the authors use scaling laws, similar to what has already been discussed with the S/V ratio. These authors disregard the overall shape of the object to provide a general understanding of the importance of size. They let length, width, and height of an object all be titled D, or characteristic dimension, of the object. It is important to point out that this will only provide a general understanding of the principal as the shape of the object would also be a key characteristic to understanding physical effects. For the purpose of better understanding the effects of scale, the definition of "D" works well.

The formulas for determining the strength to weight ratio are *strength* $\approx D^2$, *weight* $\approx D^3$, so that *strength/weight* $\approx D^2/D^3 \approx 1/D$. In an example from the same text the authors compared a flea to an elephant giving a rough estimate of 1 m^{-1} for the elephant, versus about 1000 m^{-1} for a flea".[8] These numbers mean that a flea, for its size, is about 1000 times stronger than an elephant. This does not mean that the flea can lift 1,000 more weight than the elephant. Instead it means that the flea has much more strength per body mass than the elephant. To put it another way, if we were to look at a set of body builders in the Olympics and judge them by the strongest person would we look to see who lifts the most? To the general public they would probably say yes, but in the world of science and in accuracy this is not the case. The truth is that a smaller more dense body builder can lift more in ratio to his body weight then can a comparable larger and heavier body builder. True the larger body builder has lifted more overall weight, but in ratio of weight lifted to body mass, the smaller body builder is more successful, and thus should be considered the strongest.[9]

Understanding this concept it is easy; if you continue to reduce an object eventually getting down to the nanoscale you not only increase the surface to volume ratio, but you also increase the strength to weight ratio. Thus a nanoparticle of carbon is much stronger than a much larger particle of carbon. This is one of the reasons many industries are beginning to look into the use of nanoparticles in their products.

Minimizing Effects of Gravity

Have you ever looked at small insects walking up a wall and wonder how they are able to do this? It is partly due to stickiness between their feet and the wall, but also due to the size of the object and the force of gravity on it. Pollen grains rely on riding air currents and traveling through that fluid medium: they can do this for large distances due to their size, because gravity does not bring them down to the surface of the earth. If a bird decides it is tired it can lay out its wings and glide due to expanding surface area to volume; if the same bird forgets to spread its wings gravity will take over quickly and the bird will splatter on the ground. If a flea was pushed off a two-story building it would land and hop away: gravity would not cause it to crush as it landed due to its miniscule size. If an elephant was pushed off the same building, it would be crushed under its own weight.

Using the scale of meter as the base unit, and disregarding the overall shape of the object, one can use the formula for force of gravity $F_g = mg$ and relate it to D, defined previously. In this relationship $Fg \approx D^3$ as long as the units for two objects that are going to be compared remains constant.[10]

Compare a rock to a particle of dust. If one has a rock that is 10cm (10×10^{-2} m) in size and a dust particle that is 10Mm (microns) or (10×10^{-6} m) in size, the dust particle is 10,000 times smaller than the rock. Using the comparison formula gravity has $10{,}000^3$ (1 trillion) times less effect on the dust particle than the rock. These large numbers in the difference in size are pertinent as students are usually taught that all objects will fall at the same rate in a vacuum due to gravity. This concept is easy enough for students to grasp as they will be able to understand the large number and be able to understand why gravity would effect these particles with much less intensity than larger ones (especially since they can see the comparison by looking through disturbed particles either through a sunbeam, or other point source of light). If one disturbs this area you can see the dust particles flowing up and down; they do not instantly fall due to their small size, although the forces in the fluid (air pressure, and flow also come into play). This concept becomes more important for smaller objects. At the nanoscale objects are less dependent on the properties associated with gravity, instead they are more dependent on viscosity of the fluid they are in. [11]

Movement of Particles

Understanding the scale of objects and the effects of scale is only one implication to being able to work and understand objects at the nanoscale. The effects can also be seen in the movement of the particles and how the particles react to each other at the molecular level through cohesion, viscosity, and attractions between particles.

Brownian Motion

Brownian Motion, named after botanist Robert Brown, attempts to explain the physics at work in the nanoscale environment. Robert Brown upon observing pollen under a microscope in the early 19 th Century noticed the pollen particles were in a constant state of motion. People attempted to explain this observation for 100 years. Finally in the early 20 th century it was explained that the motion of extremely small objects (or for that matter any object on an extremely small scale) was due to the atoms in a constant state of motion. We do not see evidence of this in our universe as we are far from the scale of individual atoms; if one was to be able to look very closely at objects such as the pollen this constant state of motion would be evident as it was for Robert Brown. [12]

As the size of an object decreases its dependency and relationship to gravity also decreases. As the effects of gravity decrease the effects of viscosity on the object increases; viscosity affects the overall motion of the object and its ability to move. Viscosity is the measure of the resistance of a fluid to flow. In everyday terms one can define viscosity as how thick or thin a fluid is (meaning its overall rate of flow, thick moving slower and thin running faster). Thus in our macro-universe air and water which are the fluids we are in contact with the most are thin and thus have low viscosity (although water is much more viscous than air) making it fairly easy to move around in them, while honey or molasses are much thicker and thus have greater viscosity, making it harder to achieve the same movement through these fluids.

At the nanoscale the relative effects of viscosity in all fluids increase as the size of the object decreases. For example, if water has a viscosity of 1 to humans and a bacterium is 1/1000000 our size, then the effects of viscosity of water is 1 million or 10^6 to the bacterium compared to the human. Water is a very viscous fluid for the bacterium making it hard to move around in the fluid similar to what honey would be to us. Therefore, the bacterium in water has a similar experience to a person having to walk through fluid even thicker than honey or molasses. Although the viscosity of the water has not changed, the effects of the viscosity changes due to the size of the object. It requires a lot of energy to be able to function in a highly viscous world, thus the relationship of unicellular to multicellular is important when discussing the viscosity and energy consumption of objects at the nanoscale. [13]

Reynold's Number

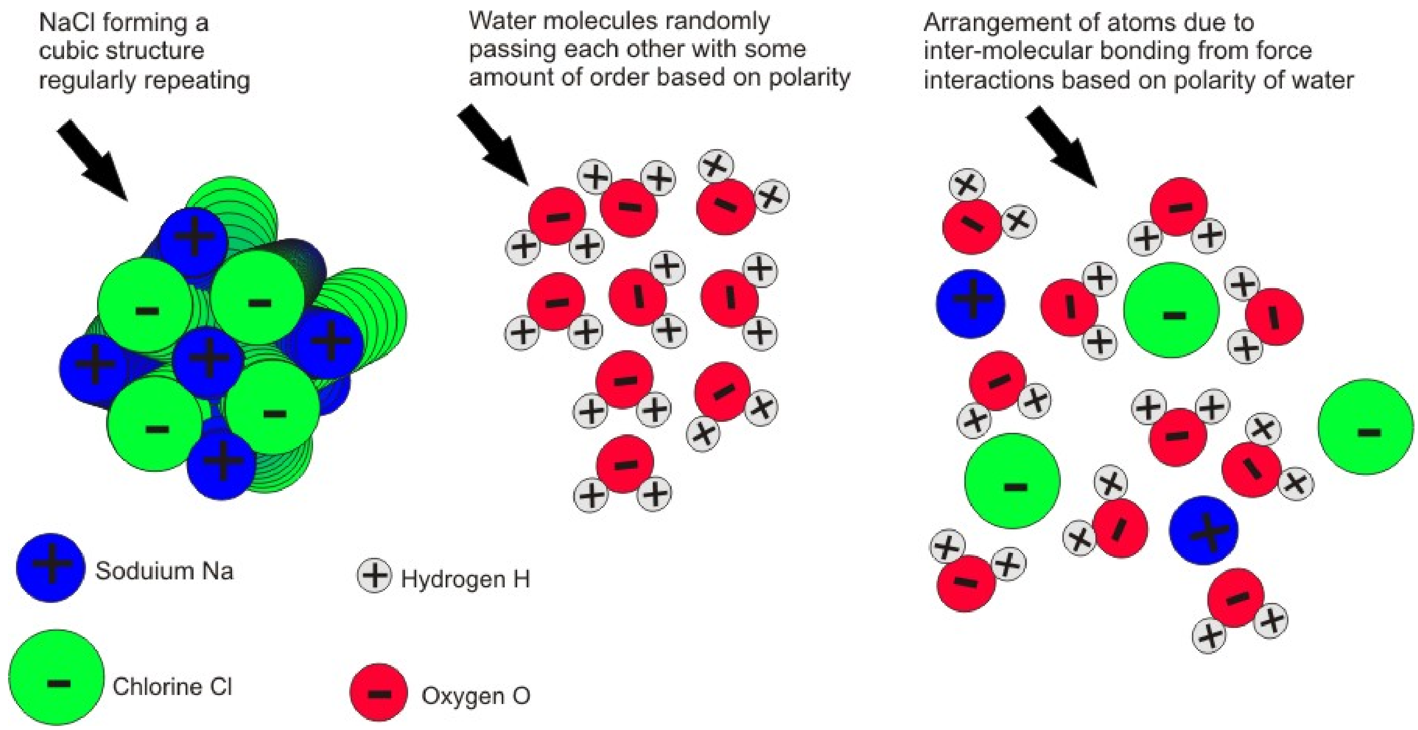
This relationship with small objects at this scale can be further illustrated with an explanation of the Reynold's number. This number deals with the ratio of an object's inertial forces to that of the viscous forces. As demonstrated earlier this can be done in general principal by comparison of two objects moving through the same fluid. The larger the Reynolds number of an object in motion, the greater the inertia, or the greater tendency of that object to continue moving (if no longer being propelled with energy). In contrast, the smaller the object the greater the effects of viscosity to that object, and thus that object will quickly stop moving (if the energy being used to propel the object ceases).

Consider a human swimmer in a pool. When the swimmer is completing full strokes, they move forward in the opposite direction of the force they are applying, obeying Newton's third law of motion. If this swimmer stops the strokes, they will continue moving forward or drifting forward through the fluid eventually coming to a stop due to frictional forces associated with the water; this is essentially showing a relationship to Newton's first law of motion. This swimmers Reynolds number can be calculated by taking the swimmers overall area multiplied to their velocity, and then multiplied to the fluid density, this product is then divided by the fluid viscosity number. Assume that 10^4 is the Reynold's number of the swimmer. We can compare this to a bacterium going through the same fluid, using the same rules and calculating a Reynold's number of around 10^{-4}. [14] In the case of the bacterium if it stopped moving its flagellum it would instantly stop moving as its inertial forces are far less than the viscosity of the fluid around it. The only motion the bacterium would continue with would be due to movements inside the fluid itself, or by being struck by another object.

Molecular Interactions

Intramolecular forces are the forces that hold compounds together. These are the cohesive bonds found in a compound either through the exchange of electrons or the sharing of electrons. Ionic or covalent bonds are strong and stable and require substantial energy to break.

Intermolecular forces are the forces found between different objects, or compounds. These can be found between compounds of an alike substance such as a teaspoon of water (H_2O), and can also be the interaction of different compounds such as a teaspoon of water with salt (NaCl) to it. The interaction of these forces is relatively weak compared to the intramolecular forces that hold a single compound together. But the forces are noticeable and important, and contribute to why we get structures on the macroscale, including ourselves. When NaCl is dissolved in H_2O the ionic bonds break down and allow the Na+ and Cl- to rearrange themselves based on the polarity of the H_2O (note: in this state the H_2O bonds remain firm and undisturbed). Although this is a general example of these interactions, it provides an excellent example as the relationship between salt and water is almost always used in teaching basic concepts of chemistry to students. For further clarification look at Figure 3. In the picture to the right you can see NaCl dissolved in H_2O; in looking at the picture note the arrangement of the molecules of water to the structures of Na+ and Cl-. This occurs due to the inter-molecular bonds between the hydrogens in water and the Cl-, and the oxygen in water and the Na+, as they have electrical bonding properties due to polarity.



(figure 3)

Understanding these properties, and that these properties exist and can be manipulated, is the cornerstone to nanotechnology and the ability to self-assemble objects.

Self Assembly

Self assembly is the ability to order objects that may not generally have order. This occurs due to the interactions between different molecules through hydrogen bonding, or use of attractive and repulsive forces. Self assembly may not always result in the correct arrangement of molecules that one is looking for, especially when attempting to generate them in a lab or industrial setting, but the relative ease at which the process works makes it cost efficient.

Self-assembly works by utilizing the fact that collections of molecules will always seek out the lowest energy level available to them. This may be in creating a bond with an adjacent molecule, or it may be a reorientation of the molecule itself to better establish intermolecular bonds such as Na+ and Cl- ions in the water. Think of a compass with its needle pointing north. If you shake the compass the needle no longer is pointing north, but once it reorients itself it again begins to point in its predestined location. This action of self assembly can even be seen at the macroscale in which we live. If you place cheerios in water or milk and give them some time to rearrange, they will begin to self assemble into a pattern of repeating hexagons. This can be done with many other products as well, bubbles for example will be attracted to each other through cohesion and thus reduce the surface area which has contact instead creating a larger structure made form these individual smaller items. For many other ideas on this look at John Pelesko's book **Self Assembly**.

Molecules self assemble all the time in living things. Phospholipids are molecules with two domains. One of these domains is a hydrophilic (attracted to water) and water-soluble and the other is hydrophobic (repelled from water). The hydrophilic structures are attracted to the polar water molecules found in the body while the hydrophobic sections are repelled by the water. These forces cause phospholipids to self-assemble into bilayer membranes. Phospholipids form a bilayer with the two hydrophilic sides facing opposite directions one facing outward into a water rich environment, and the other facing inward again into a water rich environment. The lipid (fat) layer represents the middle part of this membrane. This is a product of self assembly, as the individual molecules are attracted to one another through this intramolecular attraction between the hydrophilic end of the molecule and the water.

The principle of self assembly is one of the primary reasons people involved with nanotechnology have been successful at building things at such a small scale. Once it is understood how molecules will behave in different environments it is easy to use this as a method of getting molecules to join and form desired structures through this process.

Nanotechnology at Work

Now that we have introduced topics concerning structure and properties of matter at the nanoscale we can discuss some of the ideas that are either being used currently in industry and also some of the theoretical work that is being done.

Medicine Uses: Practical and Theoretical

This section reviews ideas already in practice and theoretical research still being developed. Medical research in nanotechnology is a burgeoning field due to the major implications it could have on diseases such as cancer, cystic fibrosis, and genetic disorders. This technology is useful as it gives scientists the ability to create and generate medicines that are small enough to penetrate the cells where they are most needed (while not being detected by the body as foreign objects due to their small size) as opposed to being diluted throughout the body, or accumulating in the liver as a waste products. In order to develop these medicines, scientists must be concerned with the overall physical properties of the structure they are creating (what will it be attracted to, will it be absorbed, how well will it flow through the body). Although this section barely scratches the surface of nano applications in medicine it is enough to help understand the difficulties and benefits in working at this scale.

Medicine Creation in Nanoscale

A liposome for drug delivery is made from a lipid layer with the drug on the inside. The lipid layer is made from molecules similar to the phospholipids in the cell membrane. They are arranged with the hydrophilic head facing outwards and the hydrophobic tail facing inwards. This spherical lipid object now has a cavity into which a drug can be placed for drug delivery onto the body. The nature of the liposome prevents the drug from being diluted into the body prematurely and thus creates a stable platform for the delivery. "Liposomal drug delivery has achieved success in the past decade as Ambisome (lipid-based delivery of amphotreicin...) was approved for treatment in ... meningitis and HIV infected patients". [15]

Drugs can be encapsulated into polymers in a similar way. To begin with you take a container full of oil such as methyl chloride $MeCl_2$ and in that you place a polymer that is oil soluble and also a medicine that is oil soluble. This solution should be mixed vigorously with the $MeCl_2$ acting as the solvent for the solution. Then this gets emulsified by adding it to an agitated solution of water with a surfactant or stabilizer in it. This surfactant will be integral in the final stage of the process. As the new emulsified solution continues to be agitated the oil will quickly form very small "bubbles" in the water through properties of self assembly with bits of the polymer and medicine in it. In this state it has more surface area which helps the $MeCl_2$ to evaporate out of the water. As it evaporates the polymer forms a hard shell encasing the medicine in it. Once all of the oil has evaporated the remaining substance can be filtered out it can be placed in a centrifuge and then lyophilized (freeze dried). In this state they are nanoparticles that would appear to the macroscale a very fine white powder. Under electron microscopy, the image would show many small spherical units each with medicine in it. Thanks to the surfactant that was in the solution there is now an ability to add a molecule to the surface of each of these. This molecule will also have hydrophobic and hydrophilic properties. The purpose of this is to act as a receptor site so that these nanoparticles can gain access to cells readily as they slowly dissolve in the body releasing a steady stream of medicine. This is far superior to traditional methods as the medicine is at such a small scale and can gain access to areas where it is most needed. This process is being used currently in labs and should have a promising future. For further clarification of this process see figure 4. [16]

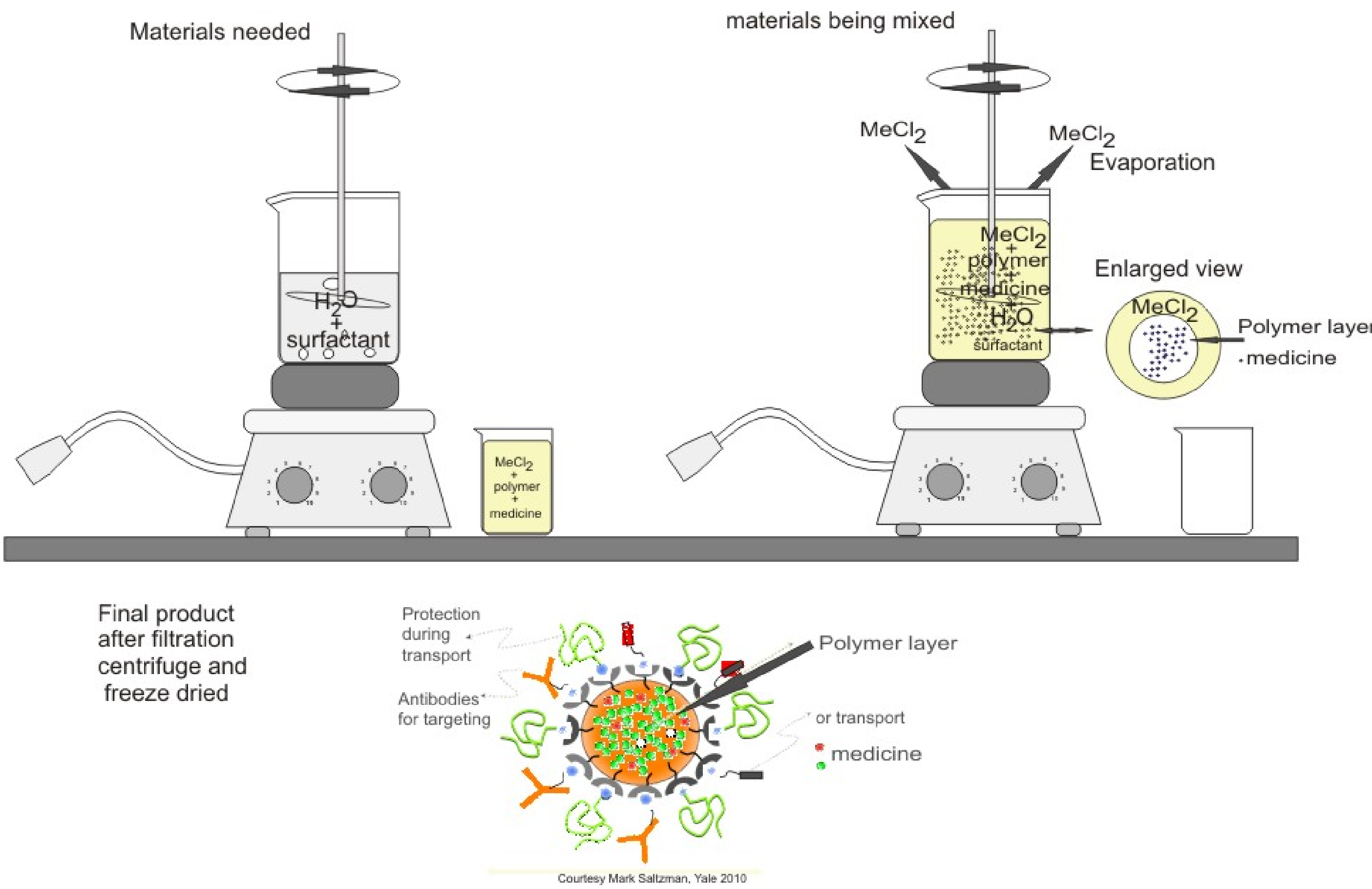


figure4

Plasmids and Viruses

A form of nanotechnology at work in research facilities, which holds future promise is the use of objects that are already occurring in nature and adapting them to our needs. The use of plasmids for the generation of insulin for diabetes patients has already been done for some time. The newest forms of this research is looking at placing the plasmid into cells for other forms of gene therapy. The process is as follows.

Plasmids are circular DNA that already naturally occurs in bacteria. The main difference is its size (it is very small compared to a full strand of human DNA) and its circular closed shape. One aspect of this plasmid that make it beneficial is the discovery of enzymes that work as a pair of scissors enabling scientists to cut a section of the DNA apart. Once this section of DNA is apart another section of DNA can be attached. This new section of DNA encodes for the production of a desired protein. The plasmid can be placed back inside a bacterium for reproduction and expression.

Viruses are fascinating objects that scientists are harvesting for use in gene therapy and research. A virus has the ability to penetrate a cells membrane due to its structure and properties. Once inside a cell, it is normally successful at implanting its DNA into the host cell, so when the host cell replicates the new viral DNA replicates with it. Now suppose, similar to the plasmids, that you replace DNA in a virus with signals to stop certain actions of a cell, or replace the DNA with a gene that correctes a certain disease. This is being researched, but one problem that scientists need to overcome is the bodies response to viral infections.

Design of Nanoscale Products for the Macroworld

The use nanoparticles is a growing phenomenon. As of July 2010 it was reported that there are three new products that come out for consumer use each week that use some form of nanoparticle. To design and utilize these particles scientists must still hurdle all of the previous physical properties of dealing with objects at this scale and then use the techniques of self assembly to make larger products.

Some of the products that are out now are fabrics that are stain resistant due to particles at the nanoscale that repel dirt and stains. It is hoped that this technology will continue growing so that one day in the future we may not need washing machines as we will be able to simply air clean our clothes (just imagine the water conservation from that). Another larger area of development is in the use of nano-silver for making water purification systems for the home and also on the industrial scale. These nanoparticles have the ability to prevent impurities from entering the water making the water that we drink much cleaner and healthier for us (chalk two up for nano in helping us with water).

Along with water purification there is also a lot of research and development into air purification systems using the same technology as the water systems.

Cosmetics and lotions are the third largest area of development in nanotechnology and also the one that is most scrutinized. Sunscreen lotions use nano zinc-oxide which has helped make sunscreen lotions that are now clear as opposed to the glaring white lotion of old. It has fantastic properties for deflecting the suns UV rays making it much better for our skin; on the downside, nano-sized particles of zinc oxide may be toxic to humans if ingested into the lungs. Cosmetics that have nano particles are falling under the same scrutiny for the same reasons. One result of this is the EPA decision in June of 2010 to rewrite their policies to include detection of nanoparticles and conduct studies for levels of toxicity for nanoparticles. The FDA is also interested in finding more information about the toxicity of certain particles before allowing them to be used for foods and drugs.

Large potential changes may occur in nanotechnology in the future. Consider the case of carbon nanotubes. Carbon nanotubes are only 2-3nm wide, but theoretically can be as long as you want. Think of a chicken wire rolled into a tube formation and this is the basic structure of a carbon nanotube. For its size and shape, these nanotubes are much stronger than steel. It is hoped that one day scientists will be able to make thousands of these at incredible lengths and twist them together like a rope or steel cable. The difference is this material will be lighter and stronger than steel. One implication of this is that humans might be able to build a suspension bridge over the strait of Gibraltar from Spain to Morocco. There is even greater hope that this technology will be able to be used to build a space elevator (search space elevator for more clarification) as a cheaper means of transport of both people and materials into space. Unfortunately the largest carbon nanotube created thus far is just a few centimeters long. Carbon nanotube research also centers on their ability to conduct electricity making it feasible that they can be used for nanowires in incredibly small and efficient circuitry for future computers and other electronic components. This research is just beginning but it presents an exciting new world for us to look forward to.

Conclusion

Nanotechnology is in its infancy and looks to be the pioneering science of the 21 st century. The reality is that education reform for science and math must include advanced classes in calculus and an exposure to quantum physics at the high school level, as these are the areas scientists need to understand to be able to fully manipulate the properties of these small objects. Richard Feynman started a revolution into the small fifty years ago but we are still just beginning to build useful products at this scale.

As the years go by more research and products will be produced in medicine and perhaps finally some cures for some diseases like cancer. In the manufacturing industry these products will continue to be developed due to their strength and ability to repel other objects. I challenge you to look deeper into this and take this unit even further to changing the course of middle school science.

Strategies

This unit was written to provide background information about nanotechnology to help educate an educator, but also to provide the reasoning and methods for the teaching of a unit on this subject.

As stated in the introduction my students will already have been exposed to Newton's three lays of motion as well as conservation of energy, and a unit on chemistry which they will have done earlier in the year. The goal is to take those principles and then apply them to this scaling down of objects.

My first step will actually be to teach some of the history about this and why we have been able to develop objects at such a small scale. This will involve a look at Richard Feynman and his lecture that inspired scientists to begin looking down in scale. Although not in this paper, but readily available, I will expose the students to the instruments that are used (such as the different forms of electron microscopes and tools that enable scientists to move particles around) and how that technology actually helped further this research.

The first step in functional science education for this is to make sure students can understand the numbers that are involved with nanotechnology as an introduction to the subject matter. They will look at everyday objects and use them to determine how large or small the objects are on different scales of measurement. The items for this may include their desk, a book, a pencil, a piece of hair, and other small objects. This will expose students to the reasons scientists work with different levels of measurement. They will continue this exploration by looking at the surface to volume ratio of these different objects based on their total size. This will then be related to coursework they have previously completed on S/V ratio and the need for energy in cells of living things. They will conclude this by looking at how many nanometers each of their objects are. This will give them a sense of how small objects in the nanoscale really are. A discussion of how much more advantageous it is to be at nanoscale with particles should follow.

The next section will look into is the physics of size change. They will look at strength to weight ratio by performing a lab. In this lab they will have dowel rods of various diameters. They will take the smallest one and determine a length (short length 5cm) and calculate the volume of the object. With this number they will need to make an accurate scale of the remaining objects so that each larger diameter will have exponential growth in their length. Once completed they will then test each object for strength by hanging weights from the rods until failure occurs and keep track of in a data table. The conclusion of the lab should show them that the smallest rod had the greatest strength to weight ratio (the greatest ratio of weight to its surface area). For more detail of this please see lab in activities section of document. A discussion of the strength of nanoparticles can follow this lab.

A discussion of Brownian Motion and Reynolds number is the next logical step. This can be done in discussion with demonstration or a lab can be developed. Viscosity should be discussed in detail for students to understand viscous flow. Students can be shown different objects and have them placed in different fluids to sense the effects of more or less viscous fluids using the same objects. This demonstration or lab should also use particles of different sizes so students can actually see the effects of the Reynolds's number as the smaller particles will fall more slowly in the fluid or even become trapped in the fluid. An extension of this can be to have students look at pond scum under a microscope with a discussion that the movement of the microscopic organisms is also magnified (they are not moving as fast as you think they are because of the magnification factor). They can see that when objects stop using their flagella they quickly stop moving. This can then be used to discuss the swimmer in the pool as discussed earlier. This is an area where the discussion should also include ideas about gravity and the diminishing effects of gravity with objects of this size. This can generate an interesting discussion on knowing the objects may be stronger at this size, but they are also harder to propel if you need them to move.

A reminder of how elements react and bond with each other would be an important discussion to ensure they can understand the difference between inter, and intra-molecular bonds and forces. This may require a worksheet or short lecture to remind them of these things (it will have been 3 months since my students discussed these principles in class). Once students are reacquainted with this they can move into a discussion of self-assembly of products, and the need for people in industry to use self-assembly. This discussion can be about certain objects in nature that go through self-assembly and then lead students into the need for using nature's mechanisms to create objects in the nanoscale. This will conclude with a look at how objects even in the macroscale will self assemble. For more on this please look at section on activities.

Once students have completed a background secton on how physics effects objects of different size, this should generate a discussion of how and why we even build things at this scale. The class can develop a list of pros and cons for nanotechnology. This is a good time to share with them different ideas about the uses and applications of nanotechnology in medicines, in industry, and in consumer products. This will lead students to their culminating project and activity. Students will research one product of medical use of these materials and report about how it was developed and why, what its use and application is, and if there are any harmful or potentially harmful properties about these applications. The conclusion of their project should be a short piece of persuasion either for or against further research into nanotechnology.

Student Activities

Strength VS Weight Lab

Purpose: To demonstrate the effects the reduction of size has on the strength of the objects.

Materials: Wooden dowel rods of different diameters cut to differing lengths so that all objects keep the same diameter to length ratio using a factor of 3. Also needed is string and a bucket and sand to use as mass.

Procedures:

So for example:

- d_1=1mm and l_1 = 50mm
- d_2=3mm and l_2= 150mm
- d_3=9mm and l_3= 450mm

Continue for five total dowel rods and create a data table including diameter, length, volume, and mass held. To determine the volume of a cylinder use the formula $V_c= \Pi r^2 h$. Take each dowel rod and tie string to the center part of the length and pace rod suspended between two tables. Tie bucket to other end of string. Begin slowly placing sand in the bucket continuing until dowel rod snaps in two. Place bucket on balance and record total mass. Continue for all dowel rods.

Analyze: Looking at data produced generate ideas on how to determine which rod was the strongest. This should develop into a formula for determining the strength to weight ratio for each dowel rod, not which rod held the most mass. Once you determine a procedure write the procedure down and calculate the S/W ratio of each dowel rod creating a new data table to display answers.

Conclusions: When complete check your answers with a neighboring group and see if you have similar results. Which dowel rod did you determine to be the strongest? (the smallest one or the largest one? Describe your conclusion in an explanatory paragraph of what effects strength to weight ratio. Applying your conclusions: determine which is stronger, and ant, human, or elephant and describe why you know this to be true based on our previous observations.

What do you think happens to strength of objects as you minimize its surface area? How does strength to weight ratio compare to surface to volume ratio. Create a new data table determining the surface to volume ratio for each dowel rod and relate it to conclusions from experiment. Describe and comparisons or contrasts that become evident when looking at these two sets of numbers.

Self Assembly Lab

Self Assembly 1

Purpose: To demonstrate the how objects of similar size and/or shape tend to self assemble when placed in a fluid system.

Materials: Plastic Straws, Cheerios, or other uniform cereal, a bowl or container with water in it.

Procedures:

Pt1. Take several straws (at least 10) and cut them to the same length (say 10cm) and place them in a container of water. Observe for two minutes and write observations down. Disturb water by giving gentle shaking to side of container and observe straws for two more minutes. Write observations down. Next take straws and cut them at different lengths and cut tips of several straws to a "V" shape. Repeat original steps and write observations down.

Pt. 2 Take cheerios or other cereal and place them in container of water. Observe for a period of two minutes and write observations down. Using same gentle shaking of container repeats for two minutes and write observations down. (note: you may need fresh cereal for second part as soaking may effect outcome of observations).

Pt.3 Repeat all procedures with a dry container and determine similarities and differences evident between the two types of fluid (air and water).

Analyze: Looking at data from observations generate ideas on what is happening in the fluid, and what is happening to the objects placed in the fluid. Draw conclusions based on observations about why the objects behaved the way they did in the container of water, and in the air.

Conclusions: What do you think self assembly is? Determine your own definition for the process of self assembly based on the observations made in this lab. What practical applications might there be for self assembly in the world of nanoscience?

Self Assembly 2

Purpose: To demonstrate the how objects of dissimilar size, and or shape can be used to self assemble when placed in a fluid system.

Materials: Lego's four each that are 2X8 long and flat, and 8 each that are 2x2 flat. Magnetic mat material used for refrigerator magnets.

Procedures:

Take each piece of Lego and in different areas glue a small piece of magnetic material making sure that the N side of magnet is facing outward for the 2x8 pieces and the S side is facing outward for the 2x2 pieces. Take Lego's and place them in a shallow container like a shoe box. Does anything happen?

Now gently shake the container for 30 seconds (which represents an increase in thermal energy) and observe the inside of the container. Did the pieces self assemble? If yes, what shape did they make? If not try applying more thermal energy or less thermal energy to box (shaking action) until you successfully get some form of self assembly. What shape did you get? Compare your shape to that of a neighboring group. Now determine what shape you want to get and sketch it on lab report. How can you increase your probability of getting this shape each time? Experiment methods to determine how to reproduce your findings. Right down your procedures and share with a neighboring group to see if they can also get the same findings and same shape.

Analyze: Looking at data from observations generate ideas on what is happening in the fluid (the box), and what is happening to the objects placed in the fluid. Draw conclusions based on observations about why the objects behaved the way they did in the container.

Conclusions: What do you think self assembly is? Reflect on your own definition for the process of self assembly based on the observations made in this lab. Would you change your original definition? Is this a process that is easy to replicate? What practical applications might there be for self assembly in the world of nanoscience?

Nano-Project

Purpose: To become better acquainted with nanotechnology and the applications of this field of science.

Procedures:

Students in groups of two to three students will decide what area of nanotechnology they want to study further (medicine, consumer products, building materials).

Students will (either in computer lab or at home) study the broad topic area for a period of two days and determine an area that they want to concentrate on (one medicine, or one product).

Students will report to teacher the desired topic choice. They will then have a period of two weeks to study this topic in depth to learn the following: what is the product or idea, who is working on it and where, why is it being created (purpose), what type of nano-particles are being used, what processes are being used to make these particles, is there any toxicity problems for humans associated with this product, and any other relevant information pertaining to this product or idea.

Students will then create either a PowerPoint presentation based on their research, an infomercial about it, or a sketch using puppets or themselves as actors to teach the rest of the class about there findings. Length of presentation should be more than 10 minutes, but less than 15 minutes, with five minutes of additional time for questions from either students or the teacher. Each group should also create an assessment of their presentation ideas which should be a worksheet, quiz, crossword puzzle or some other individualized work that students can complete for home work.

Grading will be done with a rubric generated for presentations and projects and will be determined on amount of and accuracy of information, and quality of presentation. Project should be worth a minimum of 300 points and a maximum of 500 points. The high point value should generate enough interest in project to get good results.

Create your own rubric using:

http://www.teach-nology.com/ web_tools/rubrics/sciences/

Teacher and Student Resources

This is a brief set or URL's to connect to sites for more information on nanotechnology and product use and also other activities that can be used in class with this unit. This also includes information from the EPA and their need to increase regulations in the nano-fields of industry.

The University of Wisconsin hosts a web site with many excellent videos of self-assembling systems.

mresc.wisc.edu

Nanosense is a sight with many activities and curriculum already prepared for further explanation into some of the ideas about nanotechnology.

http://nanosense.org/activities/sizematters/index.html

While not comprehensive, this inventory gives the public the best available look at the 800+ manufacturer-identified nanotechnology-based consumer products.

http://www.nanotechproject.org/inventories/consumer/

Wikipedia Definition

http://en.wikipedia.org/wiki/Nanotechnology

Nanotechnology taking it to the people ... Provides a series of 13 teaching resources on nanotechnology

http://www.science.org.au/nova/089/089act.htm

Teacher Introduction for Nanotechnology Activities

http://www.nsec.ohio-state.edu/teacher_workshop/Ferrofluids.pdf

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