Research Experience for Teachers
New Jersey Institute of Technology
CENTER FOR PRE-COLLEGE PROGRAMS

Module Topic
The Secret Life of Nano-Particles – Why Size Does Matter

Background:
The topic of nano-technology is in the news frequently, but, students may not have a grasp of what it means to be that small. The first part of this lesson gives students a sense of what it means to be as small as micro and nano size, with size comparisons to larger objects. The second part explores why ultra small size matters to scientists and engineers with examples of the applications making use of it. Most examples come from medical and pharmaceutical engineering applications. This part will also discuss some of the problems encountered with working with very small particles.

Learning Objectives: Students will be able to:
- Measure and compare the sizes of things in their environment.
- Make measurements with the SI units.
- Analyze the change in total surface area of a given volume of particles as the average size of the particles gets smaller.

Standards and Indicators
5.3.4.A2. Recognize and comprehend the orders of magnitude associated with large and small physical quantities.
5.3.4.B2. Use a variety of measuring instruments and record measured quantities using the appropriate units.

Materials
- Student handouts and worksheets, computers with Excel
- Hands-on activities or demos use meter sticks, micrometers, finely ground or powdered substances such as sugar, sand, flour, etc., or large models such a ping pong balls, tennis balls, koosh balls, and packing peanuts.

Approximate time required
1-5 days depending on the activities

Handouts: Worksheets

Classroom activity: Demo/Hands on activity comparing sizes of objects and flow rates of fine particles, worksheets with practice calculations, writing exercise/web site research, building an excel spreadsheet.

Homework: Worksheets/activities

Assessment: Rubric for grading essay with the module and activities worksheets

LESSON #1
The Secret Life of Nano-Particles, Why Size Does Matter

Background

The prefixes “micro” and “nano” respectively refer to anything that is a million or a billion times smaller than a base unit of measure. In this module the base unit is the meter, which is abbreviated to m, for example 10 meters is 10 m. One micrometer is one millionth, $1/10^{-6}$, of a meter, so there are one million micrometers in one meter. The abbreviation for the prefix micro is the Greek letter mu, μ, for example, 10 micrometers is 10 μm. One nanometer is one billionth, $1/10^{-9}$, of a meter, so there are one billion nanometers in a meter. The abbreviation for the prefix nano is n, for example, 10 nanometers is 10 nm.

When an object’s size is ten times smaller or larger than another object we say that the two objects are different in size by one “order of magnitude”, or one power of 10. The average human is about 1.5-1.8 m tall, (5-6 feet). Imagine you are holding a book which is about 0.15-0.18 meters (4-6 inches) long. This says that the book in your hand is an order of magnitude shorter than you. Likewise, the marble in your hand which measures 0.05 m, or 5 centimeters, is two orders of magnitude smaller than you are. The “metric mile”, or 1500 meters is 3 orders of magnitude, 1.5×10^3, longer than you.

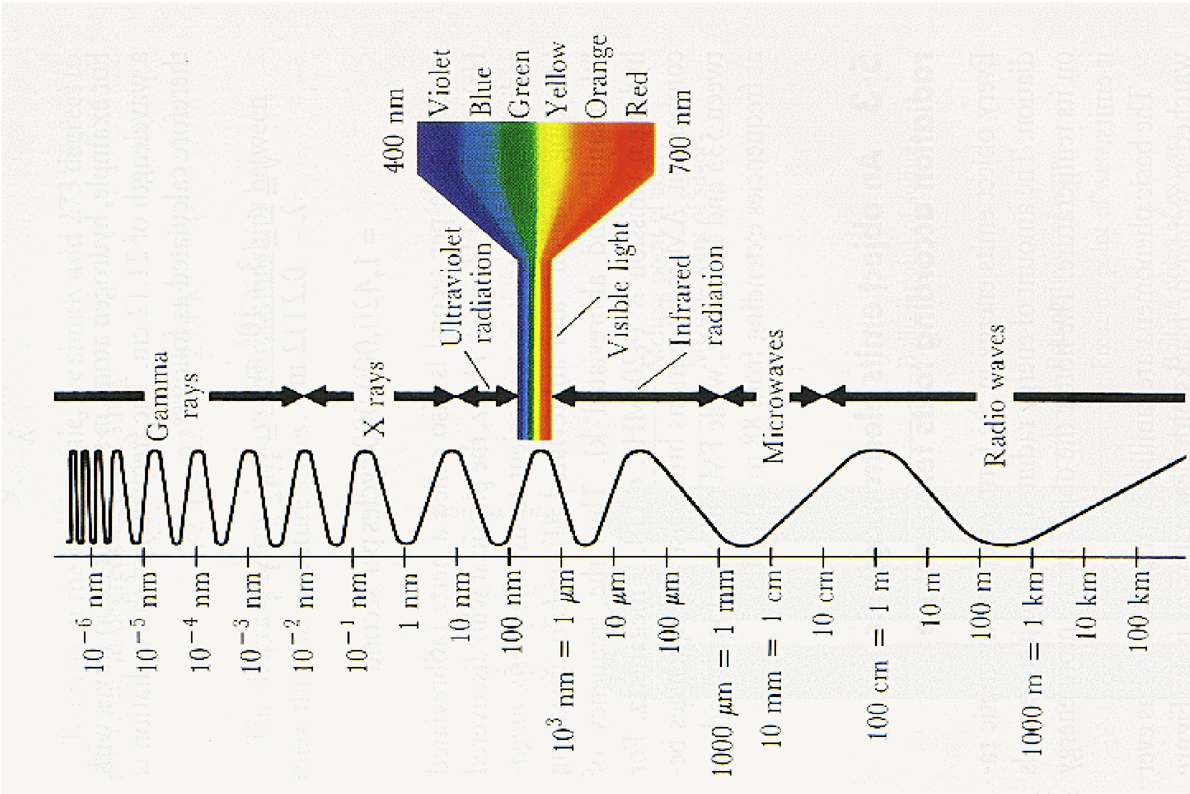
Part 1 – What it means to be very small … compared to humans

Table 1 compares the sizes of various objects relative to us as humans. In order to help students think about how different micro and nano sized particles are when compared to us, compare the objects in the table that are 6 and 9 orders of magnitude apart in size. Atoms and molecules are often measured with unit known as the Angstrom. This is 10^{-10} meters, only one order of magnitude smaller than nano-particles. The wavelength of light in the electromagnetic spectrum can be used as an example for all size comparisons. Low frequency radio waves can have wavelengths which are kilometers long. AM radio waves have wavelengths as big as a house, while FM radio wavelengths are as long as your arm. At the other end of the spectrum gamma ray wavelengths are smaller than atoms. See figure 1 for the electromagnetic spectrum.

Table exercise: Have students measure and compare the sizes of things in their environment. For example, compare the distance they travel to school to the size of their fingernails, or to the distance to the moon.

Units conversion exercise: The SI and metric systems are based on powers of 10 so you can convert numbers from one unit of measure to another simply moving the decimal. Try the exercise in Attachment 1 for practice.

Figure 1



http://stuff.mit.edu/people/rsmith80/spectrum.gif

Table 1

Objects and distances	Size in meters	Orders of magnitude different from the base unit
Average humans	1-2 meters	0 base unit
Baseball – diameter	About 1.0×10^{-1} m	1 smaller
Small finger nail	About 1.0×10^{-2} m	2 smaller
Diameter of a human hair	$0.17 – 1.8 \times 10^{-4}$ m	4 smaller
Wavelength of visible light	$4.0\text{-}7.5 \times 10^{-7}$ m	7 smaller
Length of a football field	Almost 1.0×10^{2} m	2 larger
Metric mile	1.5×10^{3} m	3 larger
Height of the empire state building	3.81×10^{2} m	2 larger
Height of Mt. Everest	8.848×10^{3} m	3 larger
Average distance to the moon	2.38857×10^{5} m	5 larger
Average distance to the sun	9.3×10^{7} m	7 larger

Try making your own table to compare sizes.
Find sizes of objects on the internet on websites such as:
http://geography.about.com/

Part 2 – The Advantages, and Problems, of Being Small

Why are micro and nano-particles cool? Google “nano” anything and thousands of references will return. Working with particles or objects that small means you are working at a level smaller than the size of cells in your body. Many new things are possible, for example:

1) Very small electric circuits are much more efficient because current can flow quickly over less distance with less friction. Think of your i-pod!
2) Very fine fibers of new materials improve texture, color, durability and other qualities of cloth for clothing, while constituting only a few percent of the total cloth. Check out “micro-fibers” in clothing.
3) Surfaces of new materials can be made super-absorbent or super-resistant to water, so they become self-cleaning. [1]
4) New compounds can be constructed at the molecular level.
5) Very fine particles of medicines can enter cells, and your bloodstream, directly through patches on your skin or melted in your mouth.
6) Medical treatments can be applied at the cellular level.
7) Construction and manufacturing flaws can be detected in materials at extremely precise levels.
8) Security systems can be tuned to detect single molecules.

When micro and nano sized particles are used in pharmaceuticals they give us new forms of drug delivery, with many advantages, and some disadvantages over conventional pills and capsules. Let’s look at some of these.

Advantages:

1) Very high ratio of surface area to total volume. (More surface area means more contact area with the places in your body that need the drug.)
2) Solubility problems are overcome with small size.
3) Just the right size to enter your bloodstream or cells directly.
4) Active ingredient particles are delivered in an easily handled thin film or jell
5) Patient specific dosages based on the area of the thin film
6) Lower dosages are required for the same effect
7) Fewer side effects as a result of lower dosage and direct application to area of the body affected.
8) Lower cost

Disadvantages and problems with powders and other fine particles

1) Hazardous to humans when dry (breathing hazard, fine irritants) [2]
2) Explosive! (typical of powders, even cake flour can do this!)
3) Difficult to store when dry
4) Particles agglomerate, so it’s difficult to keep them small
5) When handled dry, or sometimes even wet, fine powder particles don’t often flow or pour easily
6) They are light enough to be buoyant in air
7) Static charge can be a problem
8) The engineering needed to create and handle them properly is still being developed.

The increase in total surface area for a given volume of ultra small particles of material is often cited as a major advantage because it overcomes several of the problems and limitations of conventional drug delivery. The small size overcomes solubility and permeability problems. About 40% of current drugs are not water soluble, so they are not easily processed by the human body. Doctors must prescribe high dosages in so the body can get what it needs. Reducing the particle size overcomes the solubility and permeability problems leading to lower required dosages, less side effects, and lower cost.

Even though, mathematically, the sphere contains the maximum volume for its surface area, when the total volume is held constant, and the sphere is divided into smaller spheres, there is an increase in the total surface area of the new spheres. Initially this increase is small in comparison to the original surface area, but after the particles are divided about 24-28 times, when the diameter and the radius of the average particle are in the micro and nano meter range, the ratio of new surface area to original surface area increases exponentially.

Students can measure and analyze the change in total surface area of a given volume of particles as the average size of the particles gets smaller with the following exercise using Excel.

1) Create an Excel spread sheet with 9 columns, and enter the following headings: “number of particles”, “diameter, m”, “radius m”, “particle surface area m^2”, “total surface area, m^2”, “particle volume”, “total volume”, “ratio, total surface area to initial surface area”, “number of divisions”.
2) For the first row in the spreadsheet, imagine you have one particle, and the initial diameter is 0.01 m or 1cm. The data for the first row is:
    a. Number of particles = 1
    b. Diameter = 0.01 m
    c. Radius = diameter/2 (program the formulas into each cell)
    d. Particle surface area = 4 x π x $radius^2$ ($\pi = 3.14159$)
    e. Total surface area = number of particles x particle surface area
    f. Particle volume = (4/3 x π x $radius^3$) / number of particles
    g. Total volume = 4/3 x π x $(\text{radius of the first particle})^3$
    h. Ratio: total surface to initial surface area =
       (total surface area) / (surface area of the first particle)
    i. Number of divisions = first row = 0, second row = 1, third = 2, etc.
3) For the second row, and all rows thereafter, calculate the new number of particles first, divide the original volume among them, then solve for the new radius, diameter, and particle surface area.
    a. Number of particles = the previous row x 2 (since they are all divided in half)
    b. Diameter = radius x 2
    c. Radius = cube root ((3/4 new particle volume) / π)
    d. For d through i use the same formulas as for row 1.
4) Repeat the calculations in each row till the number of divisions is greater than 30 and the particle diameter is down to 10^{-7} meters.
5) Graph the ratio of total to initial volume on the y-axis, and on the x axis, particle radius and the number of divisions, to give the two graphs in figures 2 and 3. Notice how the total surface area changes when particles have micro and nano sized radii.

Figure 2

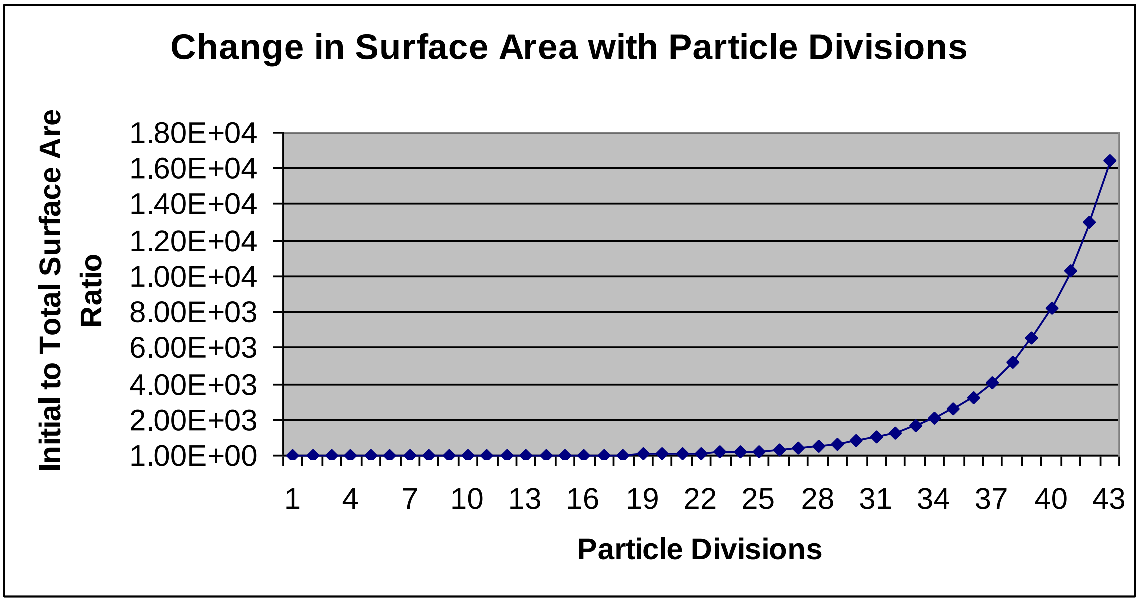
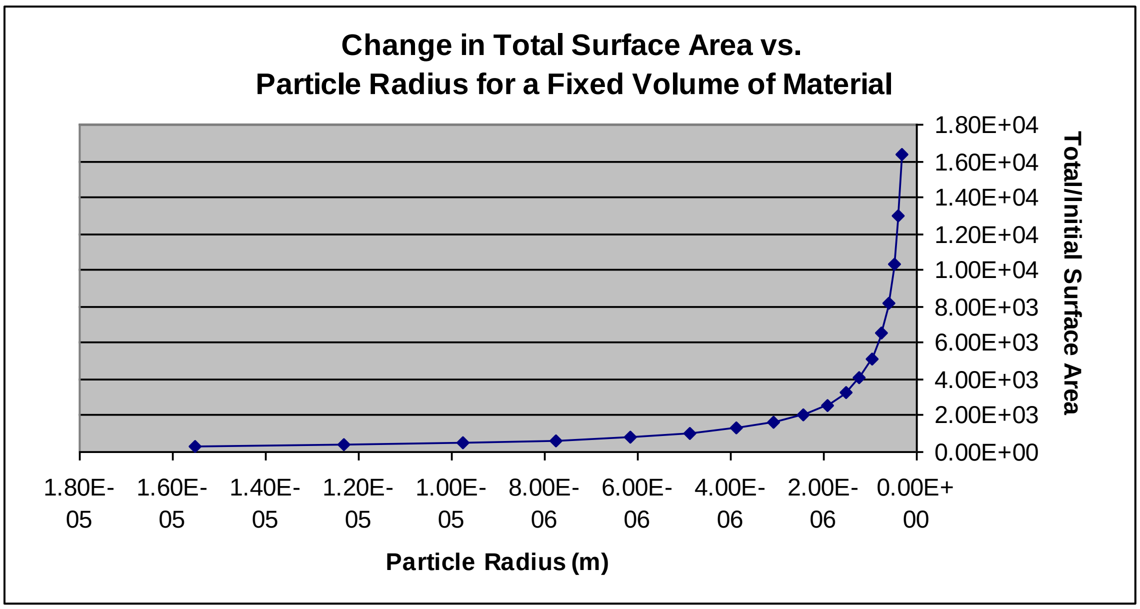


Figure 3



For Figure 3, limit the data to show just the area of the curve where the slope changes the most so it's easier to see. While the number of particles has been increasing exponentially, the total surface area increases slowly, then dramatically, when the radius is down to micrometers. Examine the two plots to evaluate this rate of change. .

Another activity allows students to explore some of the disadvantages of being small. Very fine particles are usually powders and may be hydrophobic, or hydrophilic to the point of being hydroscopic, or some combination. Whether they are hydrophobic or hydrophilic, a major engineering problem that must be addressed is how well the particles “flow”, given the opportunity to flow. The ability flow, and flow without compromising particle size, is important to the engineering needed to create commercial products with fine particles. To simulate this have the students make a list of typical powdered or fine particulate substances, such as flour, sugar, cinnamon, talcum, or sand. Which ones pour easily out of their packages? If the powder pours well, the particles will not stick together, or agglomerate, and the resulting pile of powder will be flat or nearly flat. If the particles stick easily, and therefore don’t pour well, the resulting “pile” of power will be a tall cone.

Some small particles can actually be coated lubricants or surfactants in order to make them behave better when flowing. One surfactant, used for the drug griseofulvin, is called sodium dodecyl sulfate, which you might find in shampoo. It has a long carbon chain of 12 carbons, which is hydrophobic, but it also forms a polyatomic ion where the sodium is bonded. When added to a solution of griseofulvin and water the hydrophobic side of the molecule covers the surface of the particle and the hydrophilic side stretches out into the water forming what is known as a micelle. A micelle looks like a molecular sized koosh ball, and some can be less than a micron in diameter. Try pouring a container of koosh balls! They don’t agglomerate. Compare them to fine sand or gravel. Compare them to packing peanuts. This is a good way to observe all the problems on a macro scale that engineers encounter on a micro scale.

Follow-up Activities:

Now that you know about nano-particles here are some things you can try:

1) Write a short essay describing the advantages and problems micro and nano particles. Your essay should include examples of each, applications of things which use the advantages and

2) Design an experiment to compare how powders and fine particles flow. Make sure you include a control variable, a hypothesis, a procedure and a description of how you will evaluate your results. You might want to use a liquid as a standard or control to rank the pour-ability of the solids.

Bibliography and Additional References

1) Forbes, Peter "Self Cleaning Materials", *Scientific American*, August 2008, Volume 299, Number 2, pp88-95.

2) "How Safe Are Nanoparticles?", Associated Press 12/11/05, http://www.wired,com/print/science/discoveries/news/2005/12/69808 , accessed 8/3/2008

3) http://www.bbc.co.uk/schools/gcsebitesize/science/edexcel/designerproducts/nanotechnologyrev3.shtml, BBC Home, "GCSE ScienceSmart Materials" Retrieved 8/1/2008.

4) http://nanoparticles.org/ retrieved August 4, 2008

5) http://www.moleculeoftheday.com/2006/05/04/sodium-dodecyl-sulfate-for-that-fresh-no-scum-feeling/ retrieved July 30 2008

This material is based upon work supported by the National Science Foundation under Grant Nos. EEC-0552587 & EEC-0540855

Supporting Program: Center for Pre-College Programs, at the New Jersey Institute of Technology
Contributors
Marie Aloia (Bayonne High School, Bayonne, NJ), Primary Author
Howard Kimmel, Levelle Burr-Alexander, John Carpinelli - Center for pre-College Programs, NJIT.
Sara Marzouk, Qurratulann Khokhar, Sameer Dalvi, Raj Dave – C-SOPS, NJIT

Appendix

Worksheets

1) "SI Units Conversion"

Writing Rubrics

Grade = 3	Grade = 2	Grade = 1
Shows a complete understanding of the scientific concept	Shows an adequate understanding of the scientific concept	Shows limited understanding of the scientific concept
Scientific Concepts are well developed, clearly explained and organized	Scientific Concepts are adequately developed explained and organized	Scientific Concepts are not well developed, and/or poorly explained and organized.
Answers are correctly formatted	Answers are mostly in correct format	Answers are incorrectly formatted.
No spelling or grammatical errors	Minor grammar errors	Many spelling or grammatical errors

Practice with Units Conversion

Name:______________________ Date ___________Period_______

Reference table: Above the base unit the prefixes make the new unit smaller, below the base unit the prefixes make the unit larger.

Prefix	Symbol	Exponent
Femto	F	10^{-15}
Pico-	P	10^{-12}
Nano	N	10^{-9}
Micro	μ	10^{-6}
Milli	M	10^{-3}
Centi	C	10^{-2}
Deci	D	10^{-1}
(base unit)		10^{0}
Deka	D	10^{1}
Hecto	H	10^{2}
Kilo	K	10^{3}
Mega	M	10^{6}
Giga	G	10^{9}
Tera	T	10^{12}

Convert units using the reference table.

Step 1: Look at the units you have. If the new unit is smaller that the current one, the number will get larger. If the new unit is larger than the current one the number will get smaller.

Step 2: Look at the number of places exponents for the current and new units are apart. Make the number bigger or smaller by moving the decimal point the number of places the two exponents are apart.

Step 2a: If the number is in Scientific notation, make the exponent smaller or larger by number of places the two exponents are apart.

For example: m is for meters, the base unit

Convert: 60.0 cm to mm ➔ 60.0 cm = 600. mm
The exponent for millimeters in the table is smaller than centimeters by one place, so make the number larger by moving the decimal point one place.

Convert: 30,000 cm to km ➔ 30,000 cm = 0.3 km
The exponent for kilometers in the table above is 5 places larger than the exponent for centimeters so move the decimal to make the number smaller by 5 places.

Convert 4.5×10^{2} km to m ➔ 4.5×10^{5} m
The exponent for kilometers in the table above is 3 places larger than the base unit meters so add 3 to the exponent of the number in scientific notation to convert the unit to meters

Convert 7.3×10^{8} cm to m ➔ 7.3×10^{6} m
The exponent for centimeters in the table above is 2 places smaller than the base unit meters so subtract 3 from the exponent of the number in scientific notation to convert the unit to meters

Practice with Units Conversion – page 2

Name:____________________________ Date __________Period______

Convert the units using the table:

1) 7.2 km to m ___________________ 95 m to km _________________

2) 5300 m to km ___________________ 720 km to m _________________

3) 42 cm to m ___________________ 0.52m to cm __________________

4) 360 mm to cm _________________ 45 cm to mm __________________

5) 230000 cm to km ______________ 12 km to cm ___________________

6) 5.72×10^{4} m to km _______________ 1.3×10^{2} km to m _______________

7) 8.72×10^{6} m to Gm _______________ 5.5×10^{-3} Gm to m _______________

8) 3×10^{7} mm to m ________________ 4.52×10^{-2} m to mm ______________

9) 1.46×10^{12} μm to m _______________ 6.7×10^{3} m to μm _________________

10) 28 km to m ___________________ 95 m to km _____________________

11) 567 cm to km _________________ 24 km to cm ____________________

12) 500 cm to mm __________________ 970 mm to cm ___________________