Lesson 2:
Scale of Objects

Student Materials

Contents

Visualizing the Nanoscale: Student Reading

How Small is a Nanometer?

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

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

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

Table 1. Common size units and examples.

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

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

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

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

So is That What Nanoscience is All About—Smallness?

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

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

How Can We Imagine the Nanoscale?

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

Imagine Zooming In on Your Hand

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

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

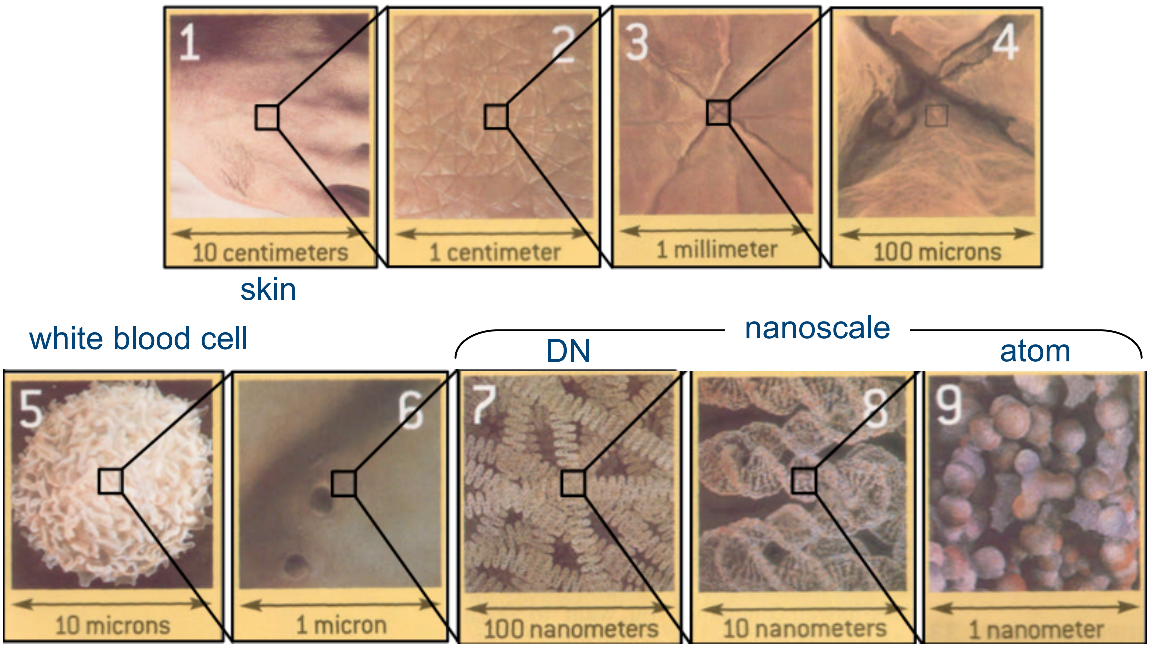


Figure 1. Zooming in on your hand by powers of 10 [1].

What is This Powers of 10 Stuff?

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

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

Another Shrinking Exercise

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

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

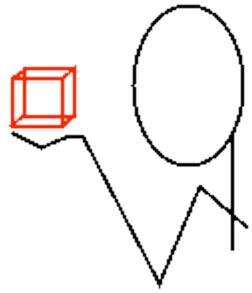
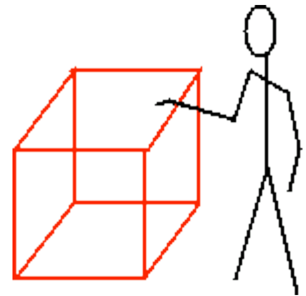
			
10^{-3} m (1 mm)	10^{-2} m (1 cm)	10^{-1} m (10 cm)	1 m
a grain of salt	a marble	a baseball	A box
			

Figure 2. The macroscale.

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

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

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

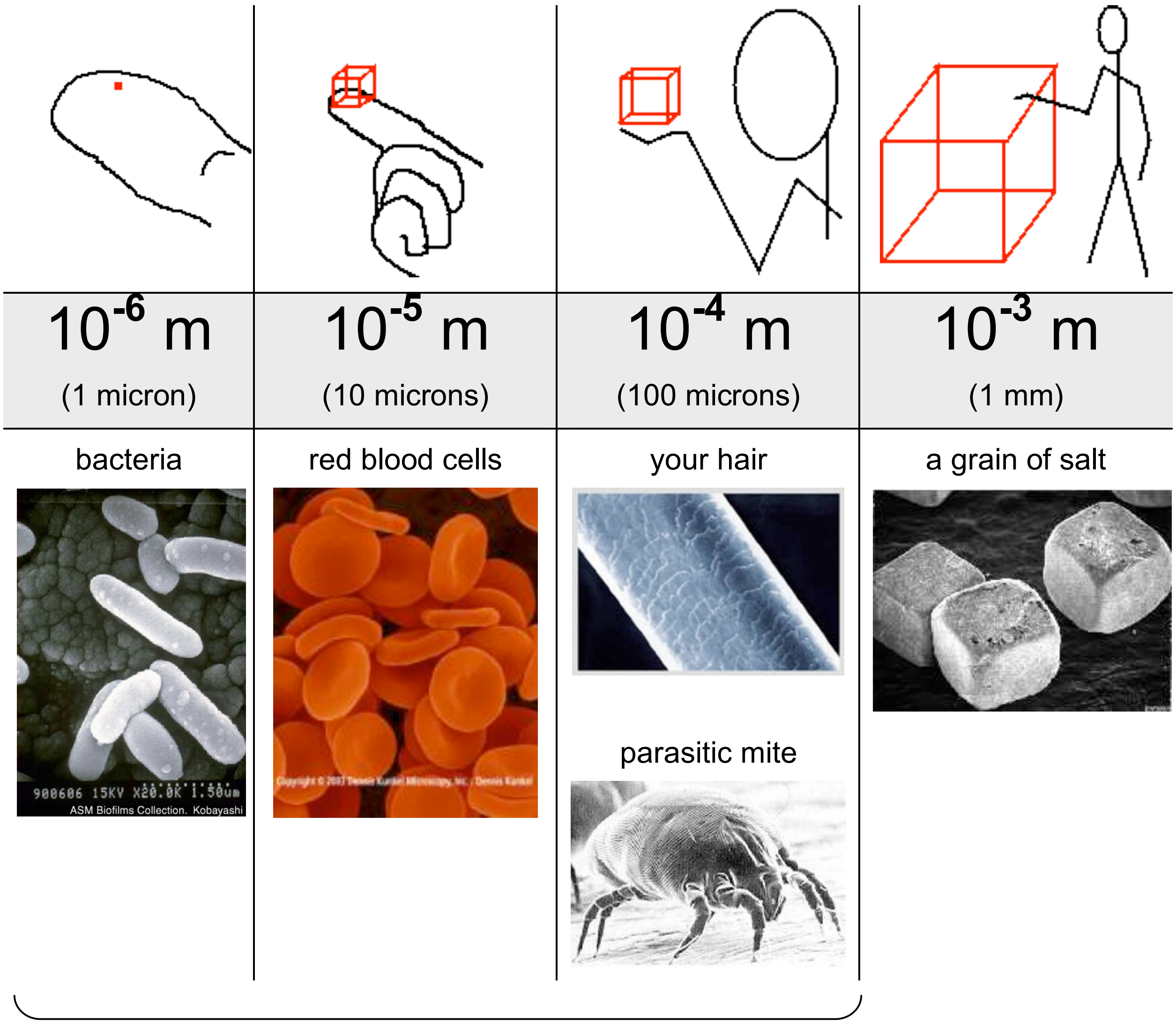


Figure 3. The microscale.

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

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

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

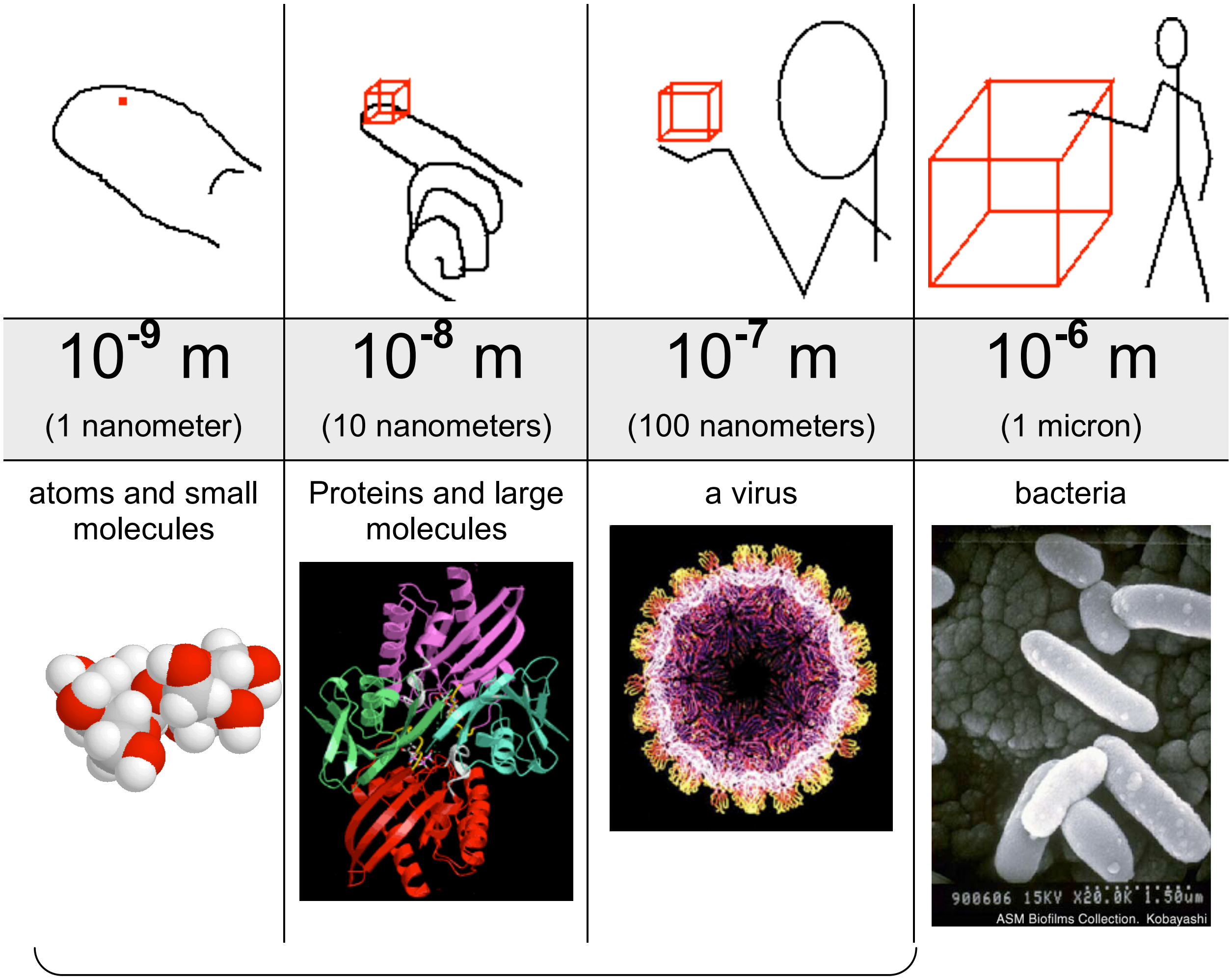


Figure 4. The nanoscale.

Summary

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

References

(Accessed August 2005.)

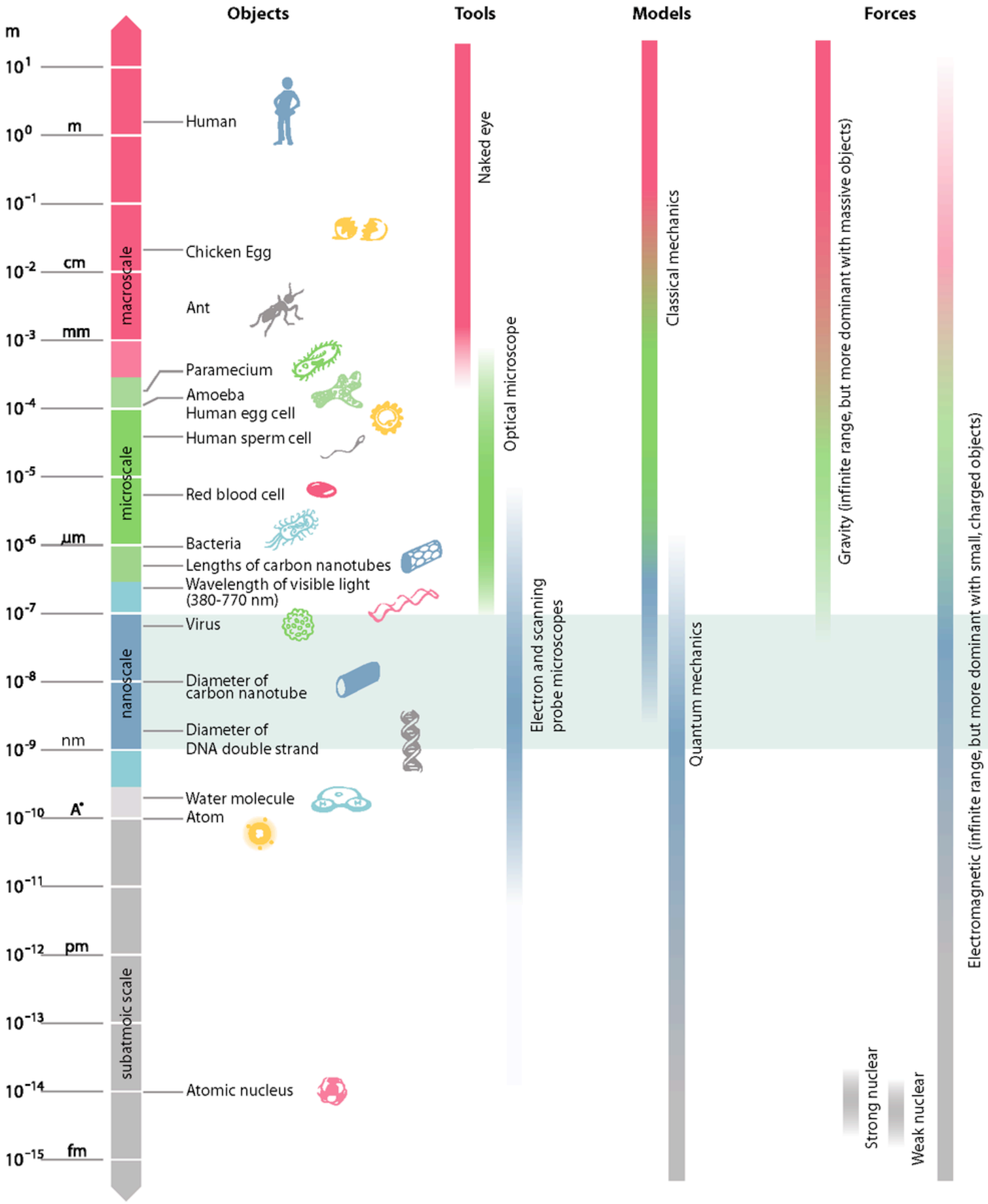
[1] From M. Hersam's Introduction to Nanometer Scale Science & Technology at http://www.materialsworld.net/nclt/docs/Introduction%20to%20Nano%201-18-05.pdf

[2] Adapted from "A view from the back of the envelope" at http://www.vendian.org/envelope/

Glossary

Term	Definition
amoeba	A single-celled organism with a nucleus, found in fresh or salt water environments.
bacterium	A structurally simple single cell with no nucleus. Bacteria occur naturally almost everywhere on Earth including soil, skin, on plants and many foods.
Brownian motion	The random motion of microscopic particles suspended in a liquid or gas, caused by collision with surrounding molecules.
DNA	The genetic material of almost every organism. It is a long, double-stranded, helical molecule that contains genetic instructions for growth, development, and replication.
protein	An organic compound whose structure is dictated by DNA. Proteins perform a wide variety of functions in the cell including serving as enzymes, structural components, or signaling molecules.
quantum mechanics	A scientific model useful for describing the behavior of very small particles (such as atoms and small molecules). Motion is described by probabilistic wave functions and energy can only exist in discrete (quantized) amounts.
quark	The basic building block of matter. Quarks combine with gluons to make the protons and neutrons that make up every atom in the universe.
virus	A structure containing proteins and nucleic acid. Viruses can infect cells and reproduce only by using their cellular machinery.
wave function	A mathematical equation used in quantum mechanics to describe the wave characteristics of a particle. The value of the wave function of a particle at a given point of space and time is related to the likelihood of the particle's being there at the time.

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



Name___________________________________ Date______________________ Period ______

Number Line/Card Sort Activity: Student Instructions & Worksheet

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

Materials

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

Instructions

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

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

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

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

1. Which objects were the hardest for you to estimate size for? Why?

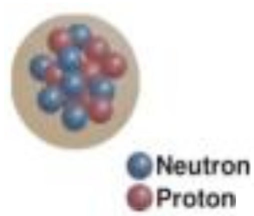
2. Why are we using powers of 10 for the number line instead of a regular linear scale (like a meter stick)?

Cards for Number Line Activity: Objects

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

1. thickness of a penny

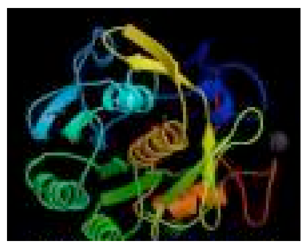
2. nucleus of an oxygen atom



3. diameter of a red blood cell

4. height of a typical 5-year-old child

5. width of a proteinase enzyme



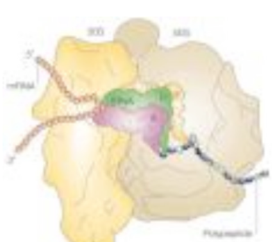
6. length of a dust mite

7. width of a typical wedding ring

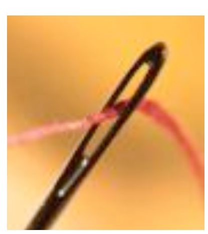
8. length of an amoeba

9. width of an electrical outlet cover

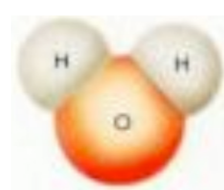
10. diameter of a ribosome



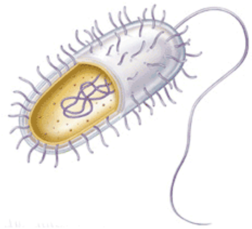
11. thickness of sewing thread



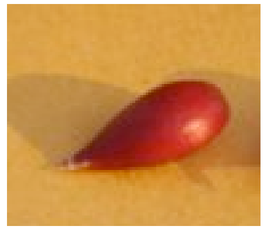
12. width of a water molecule



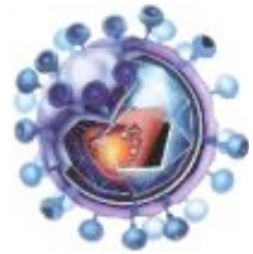
13. width of a bacterium



14. length of an apple seed

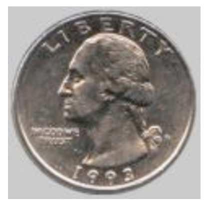


15. diameter of a virus



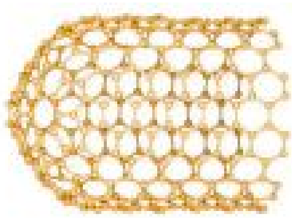
16. length of a business envelope

17. diameter of a quarter

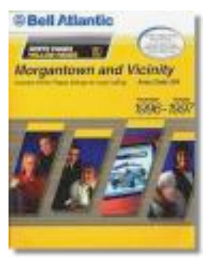


18. length of a human muscle cell

19. diameter of a carbon nanotube

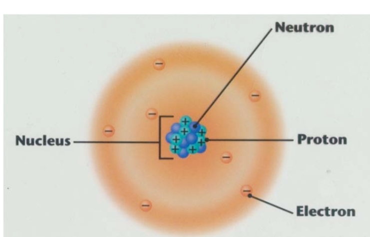


20. length of a phone book



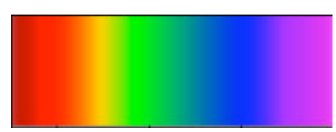
21. height of a typical NBA basketball player

22. diameter of a nitrogen atom



23. thickness of a staple

24. wavelength of visible light



Visible Light Spectrum

Cards for Number Line Activity: Units

(Uses a base 10 logorithmic scale so they can be equally spaced, except gap from 10^{-15} to 10^{-10})

10^{-15} m (1 femtometer) On $\log_{10}$ scale: -15	10^{-10} m (1 angstrom) On $\log_{10}$ scale: -10	10^{-9} m (1 nanometer) On $\log_{10}$ scale: -9
10^{-8} m (10 nanometers) On $\log_{10}$ scale: -8	10^{-7} m (100 nanometers) On $\log_{10}$ scale: -7	10^{-6} m (1 micron) On $\log_{10}$ scale: -6
10^{-5} m (10 microns) On $\log_{10}$ scale: -5	10^{-4} m (100 microns) On $\log_{10}$ scale: -4	10^{-3} m (1 millimeter) On $\log_{10}$ scale: -3
10^{-2} m (10 millimeters) On $\log_{10}$ scale: -2	10^{-1} m (100 millimeters) On $\log_{10}$ scale: -1	10^{0} m (1 meter) On $\log_{10}$ scale: 0

Image Sources for Object Cards

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

1. Thickness of a penny: http://www.poly.edu/admissions/undergrad/images/photos/coin.jpg
2. Nucleus of an oxygen atom: http://scienzapertutti.lnf.infn.it/P2/nucle.jpg
3. Diameter of a red blood cell: http://www.biopal.com/images/Red_Bl1.jpg
4. Height of a typical 5-year-old child: http://www.lower-allen.pa.us/Parks/ParksImages/soccer%20kid%20cartoon.gif
5. Width of a proteinase enzyme: http://aiims.aiims.ac.in/ragu/aiims/departments/biophy/enzyme5.jpg
6. Length of a dust mite: http://www.owlnet.rice.edu/~psyc351/Images/DustMite.jpg
7. Width of a typical wedding ring: http://www.goldringsplus.com/GRP_img/half/RS.jpg
8. Length of an amoeba: http://gladstone.uoregon.edu/~awickert/ceramics/amoeba.jpg
9. Width of an electrical outlet cover: http://www.punchstock.com/image/comstock/4550022/large/ks2793.jpg
10. Diameter of a ribosome: http://histo.ipfw.edu/images/ribosome.gif
11. Thickness of sewing thread: http://www.techsewing.com/image/left/company-needle.gif
12. Water molecule: http://www.lenntech.com/images/Water%20molecule.jpg
13. Width of a bacterium: http://www.scientific-art.com/GIF%20files/Zoological/microbea.gif
14. Length of an apple seed: http://www.thebestlinks.com/images/thumb/5/5c/250px-Old-appleseed-d402.jpg
15. Diameter of a virus: http://www.xtec.es/~imarias/virus.gif
16. Length of a business envelope: http://www.superfineprinting.com/images/business_envs.gif
17. Diameter of a quarter: http://www.pipebombnews.com/readerimages/quarter.gif
18. Length of a human muscle cell: http://dept.kent.edu/projects/cell/tm1.jpg
19. Diameter of a carbon nanotube: http://www.csiro.au/images/activities/carbon_nanotube.jpg
20. Length of a phone book: http://www.rickleephoto.com/phone97.jpg
21. Height of a typical NBA basketball player: http://sports.tjhsst.edu/boosters/merchandise/images/basketball-player-3.gif
22. Diameter of an atom: http://web.buddyproject.org/web017/web017/ae.html
23. Thickness of a staple: http://www.unisa.edu.au/printing/images/binding/staple%20icon.jpg
24. Wavelength of visible light: http://esp.cr.usgs.gov/info/sw/clim-met/anatomy/index_nojava.html

Name________________________________ Date_____________________ Period ______

Cutting it Down Activity: Student Instructions and Worksheet

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

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

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

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

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

AFTER completing the activity, answer the following questions.

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

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

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

6. Why did you have to stop cutting?

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

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

Name__________________________________ Date______________________ Period ______

Scale of Objects Activity: Student Instructions and Worksheet

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

Key:

A. Less than 1 nanometer (1 nm) [Less than 10^{-9} meter]
B. Between 1 nanometer (nm) and 100 nanometers (100 nm) [Between 10^{-9} and 10^{-7} meters]
C. Between 100 nanometers (100 nm) and 1 micrometer (1 µm) [Between 10^{-7} and 10^{-6} meters]
D. Between 1 micrometer (1 µm) and 1 millimeter (1 mm) [Between 10^{-6} and 10^{-3} meters]
E. Between 1 millimeter (1mm) and 1 centimeter (1 cm) [Between 10^{-3} and 10^{-2} meters]
F. Between 1 centimeter (1 cm) and 1 meter (m) [Between 10^{-2} and 10^{0} meters]
G. Between 1 meter and 10 meters [Between 10^{0} and 10^{1} meters]
H. More than 10 meters [More than 10^{1} meters]

	Less than 1 nm	1 nm to 100 nm	100 nm to 1 µm	1 µm to 1 mm	1 mm to 1 cm	1 cm to 1 m	1 m to 10 m	More than 10 m
Object	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
1. Width of a human hair								
2. Length of a football field								
3. Diameter of a virus								
4. Diameter of a hollow ball made of 60 carbon atoms (a "buckyball")								
5. Diameter of a molecule of hemoglobin								
6. Diameter of a hydrogen atom								
7. Length of a molecule of sucrose								
8. Diameter of a human blood cell								
9. Length of an ant								
10. Height of an elephant								
11. Diameter of a ribosome								
12. Wavelength of visible light								
13. Height of a typical adult person								
14. Length of a new pencil								
15. Length of a school bus								
16. Diameter of the nucleus of a carbon atom								
17. Length of a grain of white rice								
18. Length of a postage stamp								
19. Length of a typical science textbook								
20. Length of an adult's little finger								

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

Name________________________________ Date_____________________ Period ______

Scale of Small Objects: Student Quiz

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

Key:

A. Less than 1 nanometer (1nm) [Less than 10^{-9} meter]
B. Between 1 nanometer (nm) and 100 nanometers (100 nm) [Between 10^{-9} and 10^{-7} meters]
C. Between 100 nanometers (100 nm) and 1 micrometer (1 μm) [Between 10^{-7} and 10^{-6} meters]
D. Between 1 micrometer (1 μm) and 1 millimeter (1 mm) [Between 10^{-6} and 10^{-3} meters]
E. Between 1 millimeter (1 mm) and 1 centimeter (1 cm) [Between 10^{-3} and 10^{-2} meters]

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

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

a. Width of a water molecule
d. Diameter of a gold atom
c. Thickness of a staple
d. Diameter of a virus
e. Length of an amoeba
f. Diameter of a carbon nanotube

Smallest: _________

____

____

____

____

Largest: _________