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# Welcome to Nanoscience

## INTERDISCIPLINARY ENVIRONMENTAL EXPLORATIONS

GRADES 9–12

NSTA press
National Science Teachers Association

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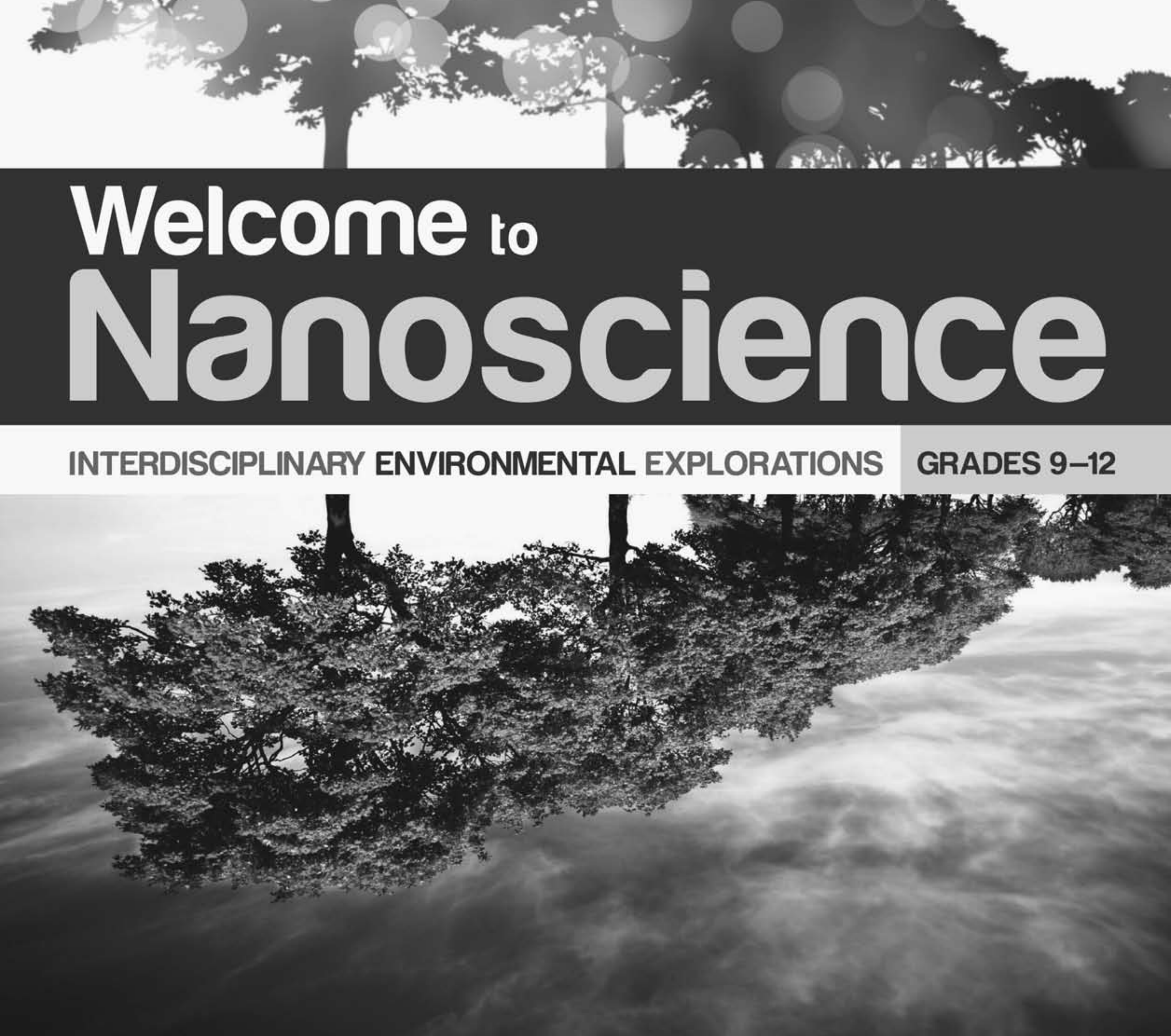

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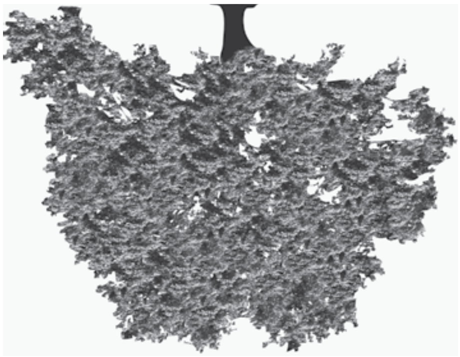
# CONTENTS

# The Nano2Earth Curriculum

Nano2Earth (pronounced "nano-to-Earth") is a secondary school science curriculum that brings nanoscale science and technology to life in the context of Earth and environmental sciences. Nanoscale science and technology, working together with environmental science issues, transcends traditional scientific knowledge and processes presented in high school chemistry, biology, geoscience, and environmental science classes today. Nevertheless, every aspect of the curriculum addresses one or more of the National Science Education Standards (NSES). Nano2Earth originated as an outreach project in the Department of Geosciences at Virginia Tech. *Welcome to Nanoscience* was a collaborative project four years in development. It was conceived, written, and classroom-tested by five high school science teachers from southwest Virginia, four professors from Virginia Tech, and several graduate students (see Working Group on Nano2Earth and the Nanobiogeochemistry Secondary Science and Math Curriculum Project, p. ix). This material is based on work originally supported by the National Science Foundation (NSF) Nanoscale Science and Engineering Program under contract EAR-0103053, and subsequently by NSF and the Environmental Protection Agency (EPA) under NSF Cooperative Agreement EF-0830093, Center for the Environmental Implications of NanoTechnology (CEINT). Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NSF or the EPA. This work has not been subjected to EPA review and no official endorsement should be inferred.



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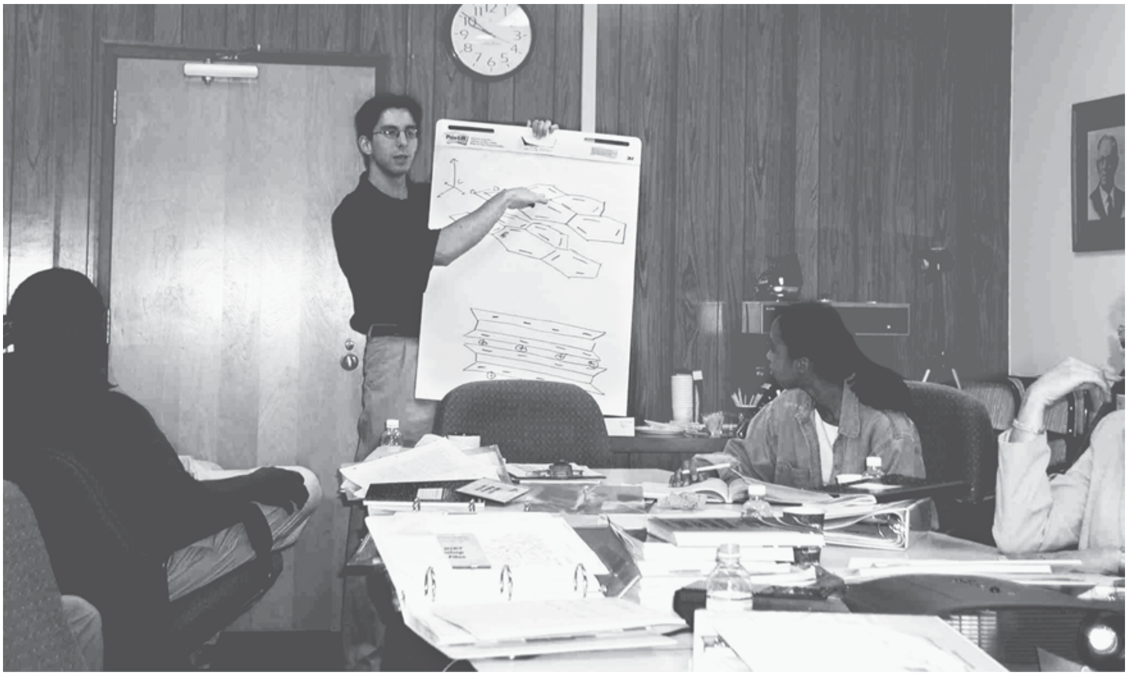
# Tips For Using This Book

The secondary school curriculum presented in this book is designed to introduce the new, revolutionary fields of nanoscience and nanotechnology to high school students. This curriculum is the first in the country (as far as we know) to introduce these two subjects using an environmental science approach, which makes the curriculum appropriate for biology, chemistry, and Earth science courses.

This book is divided into two parts. Part I is made up of chapters 1–5. Chapters 1–3 provide background material for the teacher, answering questions such as the following: What is nanoscience and technology? What are the important historical and societal aspects of nanotechnology? How is nanoscience related to environmental science? Chapter 4 describes how education in nanoscience and nanotechnology addresses the National Science Education Standards. Chapter 5 describes the curriculum.

Part II is the Nano2Earth curriculum itself, consisting of five lessons. Teachers may use the entire curriculum or pick and choose among its several parts depending on their preferred emphasis, the course level, and available time. The curriculum is meant to be flexible, with numerous entry and exit points. Teachers



Andrew Madden explains to the Nano2Earth team how nanoscale forces of interaction are related to the properties of mineral surfaces.

can use aspects of the curriculum for as little as one day, explore the entire package for a few weeks, or choose an in-between length of time. For example, Lesson 5, "Nanoforces in Nature" includes two scenarios. The choice of scenario would depend on whether Lesson 3 or Lesson 4 was done beforehand.

While most required materials are readily available or inexpensive, two lessons include technology or supplies that the teacher should consider before starting:

1. Activities in both Lesson 3 and Lesson 4 require probeware or a dissolved oxygen (D.O.) probe (Lesson 3) or a light-sensing probe (Lesson 4).
2. Activities in Lesson 4 require fluorescent microbeads that must be purchased—no substitutes have been identified (see the lesson description on pp. 81–84 for details).

Appendixes include excerpts from the NSES, a correlation chart relating AP Environmental Science Themes with Nano2Earth lesson content, and a glossary of key terms.

We encourage comments and suggestions. Please send them to Ms. Ellen Mathena (*mathena@vt.edu*). These will help us produce the next edition of Nano2Earth. In addition, questions concerning the use of this curriculum should also be sent to Ellen for distribution to the appropriate team member.

Lesson 5 in this book uses a computer simulation program. This program can be downloaded at *www.nsta.org/download/nanosim.exe.*

Full color versions of the figures in this book can be downloaded at *www.nsta.org/dowload/WelcometoNanoscienceimages.pdf.*

# Lesson 1

## Introduction to Nanotechnology

### Purpose

Students identify and compare the scale of different objects, and define *nanoscale* and *nanoscience*. The teacher introduces the history and applications of nanoscience.

### Background Information and Lesson Overview

Imagining differences in scale can be very easy (a softball is bigger than a baseball) or very difficult (how can we imagine the size of a galaxy?). It is perhaps most challenging to build conceptual frameworks for objects that are too small to see. In fact, the world of inner space is more vast and daunting to the imagination than the entire world visible to us on Earth and the nearby solar system. Nanoscience is the field of science that measures and explains the changes of the properties of substances as a function of size; these changes occur in the range of approximately 1–100 nm. Nanotechnology simply takes advantage of this phenomenon by applying property modifications of this nature to some

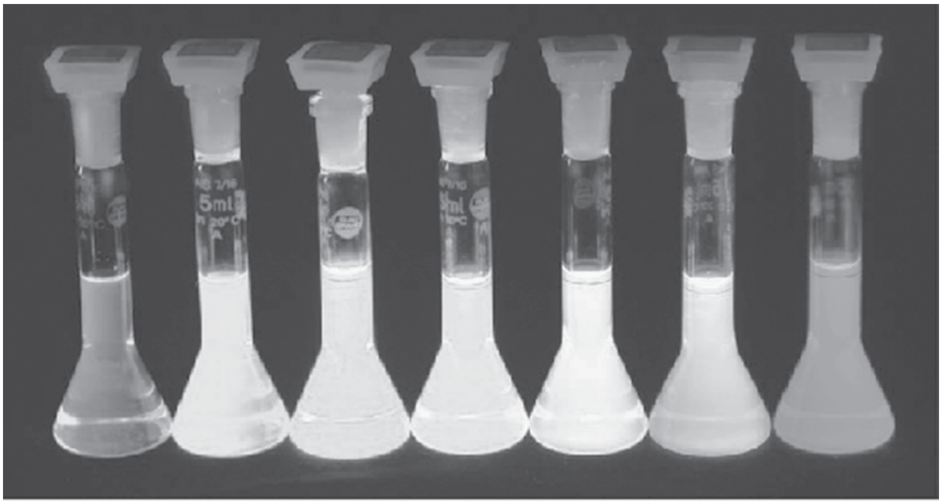


**FIGURE 1:** These flasks contain suspensions of nanosize CdSe particles known as “quantum dots.” The color arises after UV illumination. The only difference between the flasks are the size of the particles, ranging from 2 nm (left) to approximately 5 nm (right).

beneficial endeavor. Chapters 1–3 provide a descriptive background for teachers of nanoscience, nanotechnology, and the roles of both in Earth and environmental science.

In this lesson, the engagement brainstorming activity will help bring out any preconceived notions students may have regarding the scale of objects. Then, the scaling activity provides an opportunity to compare and plot the scale of objects ranging from atoms to galaxies. The explain activity introduces Richard Feynman's 1959 visionary speech, demonstrating that what was then science fiction is now being realized. The current events webquest provides opportunities for students to investigate if we have come as far as Richard Feynmann had imagined. Finally, for assessment, current events information is shared through an in-class presentation.

## For Further Information

- National Nanotechnology Initiative: *www.nano.gov*
- Nanotechnology Center for Learning and Teaching: *http://community.nsee.us*
- Nanotechnology: Big Things From a Tiny World: *www.nano.gov/Nanotechnology_BigThingsfromaTinyWorld-print.pdf*

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Ratner, M. A., and D. Ratner. 2003. *Nanotechnology: A gentle introduction to the next big idea.* Upper Saddle River, NJ: Pearson Education.

Stevens, S. Y., L. M. Sutherland, and J. Krajcik. 2009. *The big ideas of nanoscale science and engineering: A guidebook for secondary teachers.* Arlington, VA: NSTA Press.

## National Science Education Standards (NSES)

| Nano2Earth Lesson | NSES Addressed |
|---|---|
| **Introduction to Nanotechnology**<br>**Engage:** Brainstorming<br>**Explore:** Scaling Activity<br>**Explain:** Why Is the Nanoscale important?<br>**Elaborate:** Current Events Webquest<br>**Evaluate:** Current Events Presentations | Unifying Concept<br>• Measurement<br>Science as Inquiry<br>• Using Technology and Mathematics to Improve Communications<br>Science and Technology<br>• Understanding about Science and Technology Science in Personal and Social Perspectives<br>• Science and Technology in Local, National, and Global Challenges<br>History and Nature of Science<br>• Historical Perspectives |

## Engage: Brainstorming

The class will brainstorm to identify and compare the scale of different objects. On a piece of paper or chalkboard, make a list of the largest and smallest objects students mention. Rank the objects according to estimated size. Ask students to add objects to the list that can be seen only with scientific instruments, such as telescopes and microscopes. Discuss how they would compare the size of these objects.

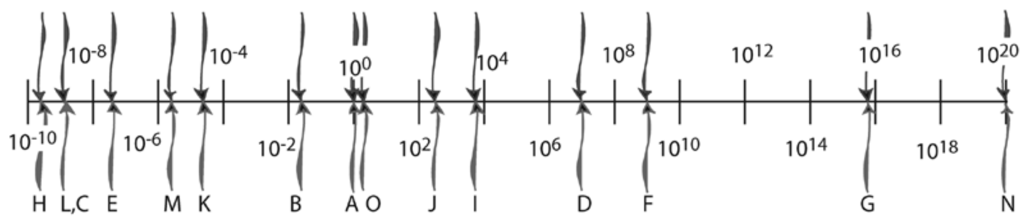
## Explore: Scaling Activity

1. Key points to review: units and scientific notation
    - 1 meter (m) = the International System (SI) standard unit of length. All length scales are referenced to this length.
    - Scientific notation is related to "orders of magnitude," or numbers multiplied by powers of 10.
    - Multiplying 1 m by 10 equals a decameter, or $1 \times 10^1$ m. Multiplying 1 m by 1,000 equals 1 km, or $1 \times 10^3$ m (1 m × 10 × 10 × 10 = 1,000 m).
    - Multiply 1 m by 0.001 = 0.001 mm or $1 \times 10^{-3}$ m

2. Introduce the term *nanometer (nm)* or $1 \times 10^{-9}$ or a billionth of a meter. The nanoscale is considered 1–100 nm.

3. Instruct students to complete "The Scale of the Earth Sciences" student activity sheet (p. 38) by placing the letter corresponding to each object on the scale above the appropriate arrow. The upper set of arrows (Scale A) is for the students' estimations, while the lower set of arrows (Scale B) is for the students to write down the answers given by the teacher.

4. When students are finished, provide the correct answers from the list below and have them complete the scale of the actual size of the objects by writing the correct letter underneath the lower set of arrows). Note that both L and C are associated with the same arrow.




| | | |
|---|---|---|
| H. | Diameter of an atom | $1 \times 10^{-10}$ to $5 \times 10^{-10}$ m |
| L. | A nanometer | $1 \times 10^{-9}$ m |
| C. | Diameter of a DNA molecule | $1 \times 10^{-9}$ m |
| E. | Diameter of a typical virus | $1.5 \times 10^{-8}$ to $5 \times 10^{-7}$ m |
| M. | Diameter of typical bacteria | $0.2 \times 10^{-6}$ to $2 \times 10^{-6}$ m |
| K. | The width of a human hair | $6 \times 10^{-5}$ m |
| B. | The length of your thumbnail | $2 \times 10^{-2}$ m |
| A. | A meter | 1 m |
| O. | Your height | 1.7 m |
| J. | Height of the Empire State Building | $4.48 \times 10^{2}$ m |
| I. | Height of Mount Everest | $8.848 \times 10^{3}$ m |
| D. | Diameter of the Earth | $1.27 \times 10^{7}$ m |
| F. | Diameter of the Sun | $1.39 \times 10^{9}$ m |
| G. | A light year | $9.5 \times 10^{15}$ m |
| N. | Distance across the Milky Way Galaxy | $10^{20}$ m |

5. Instruct the students to answer the summary questions (p. 39) and then review the correct answers.

   - Which part of the scale is considered the nanoscale?

     *1–100 nm*

   - What is the smallest part of the scale that your eye can see?

     *About $10^{-5}$ m*

   - What is the smallest part of the scale that a classroom microscope can see?

     *About $10^{-6}$ m*

   - On the scale, is your height closer to Mount Everest or to a nanometer?

     *Mount Everest*

- What distance separates $10^0$ and $10^2$? What distance separates $10^2$ and $10^4$? (Your answers should not be the same.)

  *99 m / 9900 m*

- Nanoparticles with diameters of 10 nm are common in the soil, air, and water around you. How many of these nanoparticles could you line up in a row along the width of a human hair? How many would fit lined up along the length of your thumbnail?

  *Along a hair: 6,000; along a thumbnail: 2,000,000*

- Assume that the size of one atom is $10^{-10}$ m. How many atoms fit in one nanometer? How about a cube with all dimensions 1 nm (1 $nm^3$ volume)? How many atoms would you expect in a cubic nanoparticle with all sides 10 nm?

  *If one atom was $10^{-10}$ nm, then 10 atoms would fit in one nm, 1,000 atoms would fit in 1 $nm^3$, and 1,000,000 atoms would fit in 10 $nm^3$.*

An additional opportunity for inquiry involves having the students develop their own similar questions.

## Explain: Why Is the Nanoscale Important?

Have the students read "There's Plenty of Room at the Bottom" (p. 40). It contains excerpts from the lecture of the same name given by the physicist Richard Feynman at CalTech in 1959. It was first published in the February 1960 issue of Caltech's *Engineering and Science*, and at the time of this writing, the entire speech could be found online at *www.its.caltech.edu/%7Efeynman*.

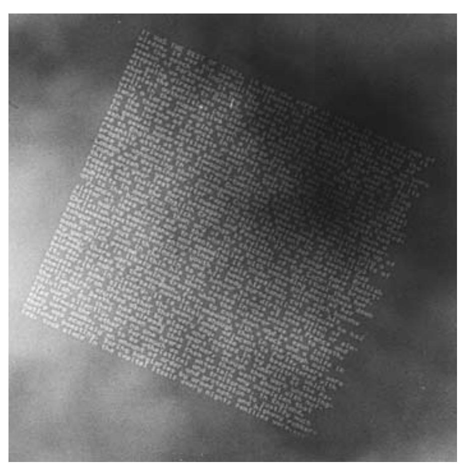


**FIGURE 2:** The first page of *A Tale of Two Cities* by Charles Dickens minimized to 1/25,000th scale.

1. Tell the students that at the end of the lecture, Dr. Feynman announced a $1,000 prize for the first people to make an electric motor only 1/64th inch cube and another $1,000 prize for the first person to write a passage from a book at a 1/25,000 smaller scale than the original text. Do the students think these feats have been accomplished, and if so, when?

*The two Feynman Prizes mentioned in the lecture were awarded in 1960 (making a 1/64th inch operating electric motor) and in 1985 (minimizing a page of a book at 1/25,000th scale so it could be clearly interpreted by an electron microscope). The prize-winning transmission electron micrograph, taken by Drs. Pease and Newman from Stanford University in 1985, is shown in Figure 2, p. 35.* (*The text is the opening of* A Tale of Two Cities *by Charles Dickens.*)

2. Ask the students if they think it is currently possible to image and manipulate atoms.

   *The answer is yes! Using a tool called the scanning tunneling microscope (STM), which the students will learn more about in Lesson 5, it is possible to both image and manipulate individual atoms of certain types (see Figure 3).*

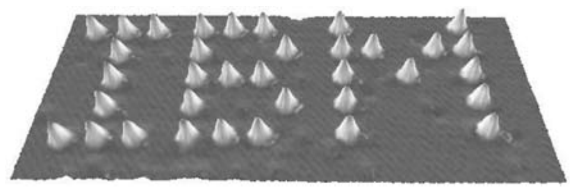


**FIGURE 3:** This image from Donald Eigler at IBM (1988) shows individual Xe atoms arranged with a scanning tunneling microscope, predecessor of the atomic force microscope, to form perhaps the world's smallest logo.

3. If it is possible to view and move individual atoms, why can't we build anything we want? If sources of the necessary atoms were available, could they just be organized in the arrangement of any material? These very questions are at the heart of current debate in nanotechnology. One of the original proponents of these ideas, Eric Drexler, considers these questions to be the future of nanotechnology. Known by Dr. Drexler as "molecular manufacturing" or "molecular nanotechnology," the possibility of creating nearly anything from constituent atoms may revolutionize human society. However, many scientists, including Dr. Richard Smalley, suggest that such synthesis is not possible. Dr. Smalley was awarded a Nobel Prize in Chemistry for his work in the discovery of carbon nanostructures. He (and others) suggests that bringing atoms in proximity to one another is not enough to cause the necessary bonding arrangements to occur in the resulting molecules. Present students with the idea of building materials "from scratch." What thoughts do they have for and against the possibility of building anything we want to?

## Elaborate: Current Events Webquest

Assign students to find a current event on nanoscience. This can be done as a homework assignment or in the computer lab over the internet. Instruct students to seek recent articles in the newspaper, magazines, or on the web dealing with new technologies, applications, or products that are developed using nanotechnology. Links to nanoscale science and technology websites include:

- National Nanotechnology Initiative: *www.nano.gov*
- *http://dir.yahoo.com/Science/Nanotechnology*

## Evaluate: Current Events Presentations

Students can summarize and present current events so you can assess their understanding of nanoscale sizes and potential applications of nanotechnology. Students should be able to describe the new technology, application, or products; identify the size or scale of the objects or products; and discuss the potential use of the new technologies, applications, or products to society.

## Nano2Earth Student Activity Sheet

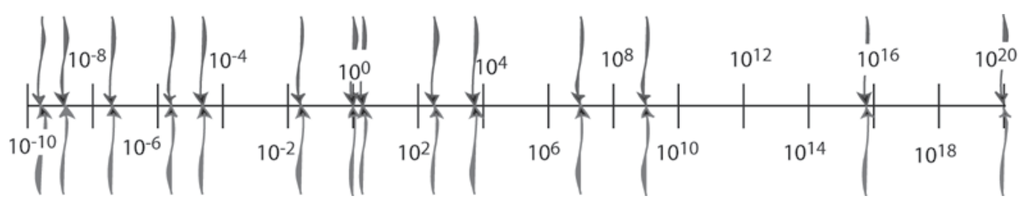
# The Scale of the Earth Sciences

Below is a list of objects from all areas of the scale. Below that are two scales showing a wide range of measurements, from extremely small to extremely large. Estimate the size of each object, and place the corresponding letter on Scale A. Afterward, your teacher will provide the answers for you to write on Scale B. The scales are in meters.

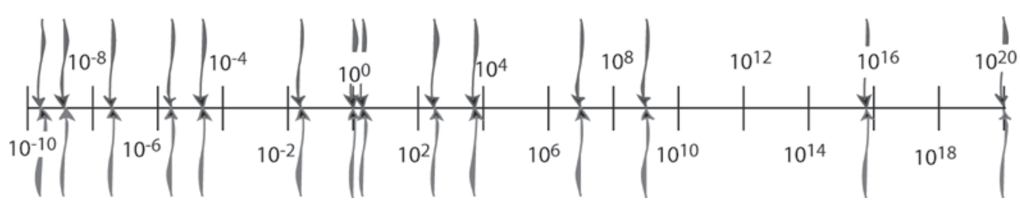
A. A meter
B. The length of your thumbnail
C. Diameter of a DNA molecule
D. Diameter of the Earth
E. Diameter of a typical virus
F. Diameter of the Sun
G. A light year
H. Diameter of an atom

I. Height of Mount Everest
J. Height of the Empire State Building
K. The width of a human hair
L. A nanometer
M. Diameter of a typical bacteria
N. Distance across the Milky Way Galaxy
O. Your height

## Scale A: Estimated size (meters)




## Scale B: Actual size (meters)



# Introduction to Nanotechnology



## Summary Questions:

1. Which part of the scale is considered the nanoscale?

2. What is the smallest part of the scale that your eye can see?

3. What is the smallest part of the scale that a classroom microscope can see?

4. On the scale, is your height closer to Mount Everest or to a nanometer?

5. What distance separates $10^0$ and $10^2$? What distance separates $10^2$ and $10^4$? (Your answers should not be the same.)

6. Nanoparticles with diameters of 10 nm are common in the soil, air, and water around you. How many of these nanoparticles could you line up in a row along the width of a human hair? How many would fit lined up along the length of your thumbnail?

7. Assume that the size of one atom is $10^{-10}$ m. How many atoms fit in one nanometer? How about in a cube with all dimensions 1 nm (1 $nm^3$ volume)? How many atoms would you expect in a cubic nanoparticle with all sides 10 nm?

## Nano2Earth Student Reading Section

# "There´s Plenty of Room at the Bottom"

*(Excerpts from "There's Plenty of Room at the Bottom," a December 1959 lecture by Richard P. Feynman at the annual meeting of the American Physical Society at the California Institute of Technology)*

I would like to describe a field, in which little has been done, but in which an enormous amount can be done in principle … a point that is most important is that it would have an enormous number of technical applications.

What I want to talk about is the problem of manipulating and controlling things on a small scale. As soon as I mention this, people tell me about miniaturization, and how far it has progressed today. They tell me about electric motors that are the size of the nail on your small finger. And there is a device on the market, they tell me, by which you can write the Lord's Prayer on the head of a pin. But that's nothing; that's the most primitive, halting step in the direction I intend to discuss. It is a staggeringly small world that is below. In the year 2000, when they look back at this age, they will wonder why it was not until the year 1960 that anybody began seriously to move in this direction.

Why cannot we write the entire 24 volumes of the Encyclopedia Britannica on the head of a pin?

Let's see what would be involved. The head of a pin is a sixteenth of an inch across. If you magnify it by 25,000 diameters, the area of the head of the pin is then equal to the area of all the pages of the Encyclopedia Britannica. Therefore, all it is necessary to do is to reduce in size all the writing in the Encyclopedia by 25,000 times. Is that possible? The resolving power of the eye is about 1/120 of an inch—that is roughly the diameter of one of the little dots on the fine half-tone reproductions in the Encyclopedia. This, when you demagnify it by 25,000 times, is still 80 angstroms in diameter—32 atoms across, in an ordinary metal. In other words, one of those dots still would contain in its area 1,000 atoms. So, each dot can easily be adjusted in size as required by the photoengraving, and there is no question that there is enough room on the head of a pin to put all of the Encyclopedia Britannica.…

That's the Encyclopedia Britannica on the head of a pin, but let's consider all the books in the world. The Library of Congress has approximately 9 million volumes; the British Museum Library has 5 million volumes; there are also 5 million volumes in the National Library in France. Undoubtedly there are duplications, so let us say that there are some 24 million volumes of interest in the world.

Nano2Earth Student Reading Selection

# "There´s Plenty of Room at the Bottom"

What would happen if I print all this down at the scale we have been discussing? How much space would it take? It would take, of course, the area of about a million pinheads because, instead of there being just the 24 volumes of the Encyclopedia, there are 24 million volumes. The million pinheads can be put in a square of a thousand pins on a side, or an area of about 3 square yards.… All of the information which all of mankind has every recorded in books can be carried around in a pamphlet in your hand—and not written in code, but a simple reproduction of the original pictures, engravings, and everything else on a small scale without loss of resolution.

What would our librarian at Caltech say, as she runs all over from one building to another, if I tell her that, ten years from now, all of the information that she is struggling to keep track of—120,000 volumes, stacked from the floor to the ceiling, drawers full of cards, storage rooms full of the older books—can be kept on just one library card! When the University of Brazil, for example, finds that their library is burned, we can send them a copy of every book in our library by striking off a copy from the master plate in a few hours and mailing it in an envelope no bigger or heavier than any other ordinary air mail letter.

*Source:* Feynman, R. P. 1960. There's plenty of room at the bottom: An invitation to enter a new field of physics. *Engineering and Science* (Feb). *www.zyvex.com/nanotech/feynman.html.*

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