

# **Educator's Guide**



# Introduction to Nanoscale Science and Engineering

Small, Smaller, Nano: The Structure of Matter

All matter is composed of atoms. Atoms interact with each other to form molecules. Thermal (heat) energy causes them to vibrate, so atoms and molecules are always moving—even in a solid.



Scientists holding a model of a molecule

The arrangement of molecules gives a material its properties. As the size of a material approaches the nanoscale, materials often exhibit different and unexpected properties. Nanotechnology takes advantage of these properties to create new materials and devices.

#### **Seeing Nano Structures**

Nanoscientists use special tools to see and make images of things at the nanoscale. Magnifying glasses and optical microscopes allow scientists to see things as small as 500 nanometers. Other tools can make images of things that are even smaller.

A Scanning Electron Microscope (SEM) uses electrons instead of light. SEMs allow scientists to see things at the microscale and approaching the nanoscale.

Probe microscopes like Atomic Force Microscopes (AFMs) and Scanning Tunneling Microscopes (STMs) can image on the nanoscale. They use special, tiny tips to "feel" rather than "see" on the nanoscale. They can detect individual atoms!



Scientist using an Atomic Force Microscope

#### **Making Nano Structures**

Nanotechnology involves making new materials and tiny devices smaller than 100 nanometers in size. Nanotechnology allows scientists to make things like smaller, faster computer chips and new medicines to treat diseases like cancer.

How Big is a Nanometer?				
Macroscale	10 <sup>-0</sup>	Child	A child is 1 meter tall	
	10 <sup>-1</sup>	Hand	A hand is 1 decimeter wide	
	10 <sup>-2</sup>	Pinky finger	A pinky is 1 centimeter wide	
	10 <sup>-3</sup>	Freckle	A freckle is 1 millimeter wide	
	10 <sup>-4</sup>	Hair	A strand of hair is 0.1 millimeters wide	
Microscale	10 <sup>-5</sup>	Red blood cell	red blood cell is 10 micrometers wide	
	10 <sup>-6</sup>	Bacterium	A bacterium is 1 micrometer wide	
	10 <sup>-7</sup>	Virus	A virus is 0.1 micrometers wide	
Nanoscale	10 <sup>-8</sup>	Cell wall	A cell wall is 10 nanometers thick	
	10 <sup>-9</sup>	Sugar molecule	A sugar molecule is 1 nanometer wide	
	<b>10</b> <sup>-10</sup>	Atoms	Atoms are 0.1 nanometers wide	

A nanometer is a billionth  $(10^{-9})$  of a meter.

There are three primary ways of manipulating matter on the nanoscale:

- Moving individual molecules one by one
- Patterning many molecules at a time
- Using self assembly to get molecules to create structures on their own

#### Moving Molecules One by One

Nanoscientists use special tools called probe microscopes to detect and move individual atoms. They have a very tiny, sharp needle that is controlled by a computer with nanometer precision.

The first scientists to move individual atoms were a team led by Don Eigler at IBM. In 1989, they created an image of their company name using thirteen xenon atoms. Each atom was picked up and moved into place.



IBM logo spelled out with xenon atoms

#### Making Patterns with Optics and Chemistry

The nano-sized features in many electronic components are made using a process called *photolithography*. Photolithography allows scientists to transfer a pattern onto a surface at a very fine resolution.

In this process, the first step is to create a *mask* (stencil). The mask allows light to pass through some areas but not others.

A strong ultraviolet light is shone through the mask onto a substrate (usually a silicon wafer) that is coated with *photoresist*, a chemical that is sensitive to light.

The light passing through the mask transfers the pattern. Lenses can be used to shrink the image from the mask.

When the light reaches the photoresist on the surface, it changes the solubility of the photoresist, making it easier or harder to wash away. The surface is washed and what is left over is the pattern that was originally on the mask.



Surface patterned using photolithography

#### Self Assembly

Under the right conditions, molecules can self assemble into organized structures. The process of self assembly occurs naturally and is a major area of research in nanotechnology.

Natural structures and materials—like cells, bone, snowflakes, or soap bubbles—are formed through *self assembly*. The macroscale structure (soap bubble) that we can see is based on the nanoscale self arrangement of atoms.



Soap bubble

Self assembly is possible because molecules are always moving and sticking to each other. At the nanoscale, thermal energy causes molecules to shake and bump into each other. The hotter the temperature, the more the molecules jostle around. As molecules bump into each other, they stick together by forming weak bonds. Most of the bonds that are created between molecules break apart again as the molecules move. The bonds that form ordered structures stay together, because the molecules fit together like pieces in a puzzle and hold each other in place.

Nanoscientists are researching ways to create conditions under which molecules will self assemble into useful structures, such as electronic components and medicine-delivery devices.

#### Nano and Me

The products of nanotechnology may affect our lives in both positive and negative ways. Nanoscale objects are small enough to permeate the biological barriers that protect living organisms. This means that nanoscale materials present different health risks than the same materials do at a larger scale.

As a result, nanotechnology applications could be harmful in ways that we cannot predict. It is important that scientists, government agencies, and concerned citizens research and consider the potential risks and benefits of nanotechnology.

#### **Image Credits**

- Scientist holding a model of a molecule: iStockphoto
- Scientist using an Atomic Force Microscope: Cornell Photography, Cornell University
- IBM logo spelled out with xenon atoms: IBM/Dan Eigler
- Surface patterned using photolithography: Nanobiotechnology Center, Cornell University
- Soap bubble: Microsoft Clip Art



# **Exhibition Overview**

Zoom Into Nano introduces fundamental concepts in nanoscale science and engineering, focusing on the processes by which materials are manipulated on the molecular scale to generate very small structures and devices. The exhibition and accompanying educational materials are designed for families and school groups with children ages 8-13.

Zoom Into Nano features four exhibit clusters:

- Small, Smaller, Nano
- Making Nano Structures
- Seeing Nano Structures
- Nano and Me

## Small, Smaller, Nano

Get oriented to three size scales in this exhibit cluster:

- small (greater than 100 micrometers);
- smaller (1 to 100 micrometers);
- nano (less than 100 nanometers).

#### There are 1,000,000,000 (one billion) nanometers in a meter!

#### Entry panels

Watch a video introducing key exhibition concepts. Two additional panels without audiovisuals are provided for use in lobbies or at other entries.

#### Magnification Station & Small, Smaller, Nano

View different magnifications of familiar objects (such as a butterfly wing, an oyster shell, and a salt crystal) to see that all matter is made of atoms. Visitors can use hand-held magnifiers, then experience three size scales as they move to the right: small (greater than 100 micrometers), smaller (1 to 100 micrometers), and nano (less than 100 nanometers).

#### Zoom into Nano

Turn a wheel to zoom in and out from the macroscopic world to the nanoscopic world and back again. Go at your own speed to explore these fascinating objects (four stations):

- butterfly wing
- oyster shell
- computer chip
- dragonfly wing

#### Particle Progression

Use your senses to lead you on a nano journey from

- small (sand) to
- smaller (dust)
  - to
- nano (smell)

Discover that molecules are too small to see but not too small to smell.

## **Making Nano Structures**

This exhibit cluster introduces two ways scientists make tiny structures and devices:

- Moving lots of atoms at once (Shrink a Pattern)
- Moving atoms one-by-one (Atom Transporter)

#### Shrink a Pattern

Design patterns of translucent colored discs. The light and lenses will shrink the pattern to make it many times smaller.

#### Atom Transporter

Arrange individual atoms into a pattern while the atoms are in motion. Are you up to the challenge?

## **Seeing Nano Structures**

Models of atoms and molecules are enlarged to 100 million times their actual size within this courtyard of exhibits. View, build, and stretch molecules while exploring their shape and structure. Experience the constant motion of atoms and molecules.

#### **Shaking Solids**

See that atoms and molecules are always moving - even in solid objects.

#### **Infinity Crystal**

Immerse yourself in a crystal's repeating patterns of atoms that seem to go on forever.

#### **Carbon Nanotubes**

Feel the atoms as you move among the carbon nanotubes. Learn about their potential uses.

#### Stretch a Molecule

Use your hands to grab and pull apart the ends of a virtual RNA molecule. When you let go, the molecule folds back up into its favorite shape. (Full-body interactive video installation)

#### **Dissolve a Crystal**

Dissolve a virtual crystal of salt using your body's movement to generate "heat." (Full-body interactive video installation)

#### **Build A Molecule**

Have fun creating your own molecular models against a background of compelling imagery showing the beauty and complexity of the molecular world.

#### **Build a Carbon Nanotube**

How high can you go? Work in a group to build up gigantic carbon nanotube models.

#### **Banners and Video Projections**

Enhance and expand vertical spaces with eight 3'x8' double-sided banners, and optional video projection of up to 9'x12'.

### Nano and Me

Learn about some highlights of the implications of current and future developments in nanoscale science and engineering.

#### **Delving into Nanotechnology (4)**

At four video kiosks, learn how scientists are using nanotechnology to develop new tools and materials that may affect our lives. Topics include cancer treatment, solar cells, magnets, and carbon nanotubes.

#### Listen to a Nano Story (2)

Sit back and listen to stories about nanotechnology from the popular Earth and Sky radio series. (2 coffee table stations surrounded by benches; flexible layout.)



# **Key Concepts and Learning Standards**

*Zoom Into Nano* introduces fundamental concepts in nanoscale science and engineering, focusing on the processes by which materials are manipulated on the molecular scale to generate very small structures and devices. The exhibition and accompanying educational materials are designed for families and school groups with children ages 8-13.

#### **Key Concepts**

- All things are made of atoms.
- Atoms bond together and form molecules.
- Atoms and molecules are always moving.
- There are one billion nanometers in a meter.
- Nanotechnology is making new materials and tiny devices smaller than 100 nanometers in size.
- Nanotechnology allows scientists to make new things like smaller, faster computer chips and new medicines for diseases, such as cancer.

#### National Science Education Standards

*Zoom Into Nano* addresses a number of National Science Education Standards (NSES). NSES Content Standards for Grades K-4, Grades 5-8, and Grades 9-12 are provided below.

To cross-reference with local standards, you can access the NSES standards online, or order a print publication:

- National Resource Council, 1995. *National Science Education Standards.* Washington, DC: National Academy Press.
- http://books.nap.edu/readingroom/books/nses/overview.html#content

#### Zoom Into Nano: NSES Content Standards, Grades K-4

Unifying concepts and processes

- Systems, order, and organization
- Evidence, models, and explanation
- Change, constancy, and measurement
- Form and function

Science as inquiry

- Understandings about scientific inquiry
- Physical science
  - Properties of objects and materials
- Earth and space science
  - Properties of earth materials
- Science and technology
  - Understandings about science and technology

Science in personal and social perspectives

- Science and technology in local challenges History and nature of science
  - Science as a human endeavor

#### Zoom Into Nano: NSES Content Standards, Grades 5-8 Unifying concepts and processes

- Systems, order, and organization
- Evidence, models, and explanation
- Change, constancy, and measurement
- Form and function

Science as inquiry

• Understandings about scientific inquiry Physical science

• Properties and changes of properties in matter Science and technology

• Understandings about science and technology Science in personal and social perspectives

- Science and technology in society
- History and nature of science
  - Science as a human endeavor
  - Nature of science
  - History of science

#### Zoom Into Nano: NSES Content Standards, Grades 9-12

Unifying concepts and processes

- Systems, order, and organization
- Evidence, models, and explanation
- Change, constancy, and measurement

Science as inquiry

• Understandings about scientific inquiry Physical science

- Structure of atoms
- Structure and properties of matter

Science and technology

• Understandings about science and technology

Science in personal and social perspectives

Science and technology in local, national, and global challenges

#### History and nature of science

- Science as a human endeavor
- Nature of scientific knowledge
- Historical perspectives

#### Zoom Into Nano

NSES Content Standards	Grades K-4	Grades 5-8	Grades 9-12
Unifying concepts and processes	<ul> <li>Systems, order, and organization</li> <li>Evidence, models, and explanation</li> <li>Change, constancy, and measurement</li> <li>Form and function</li> </ul>	<ul> <li>Systems, order, and organization</li> <li>Evidence, models, and explanation</li> <li>Change, constancy, and measurement</li> <li>Form and function</li> </ul>	<ul> <li>Systems, order, and organization</li> <li>Evidence, models, and explanation</li> <li>Change, constancy, and measurement</li> </ul>
Science as inquiry	<ul> <li>Understandings about scientific inquiry</li> </ul>	<ul> <li>Understandings about scientific inquiry</li> </ul>	<ul> <li>Understandings about scientific inquiry</li> </ul>
Physical science	<ul> <li>Properties of objects and materials</li> </ul>	<ul> <li>Properties and changes of properties in matter</li> </ul>	<ul><li>Structure of atoms</li><li>Structure and properties of matter</li></ul>
Earth and space science	<ul> <li>Properties of earth materials</li> </ul>		
Science and technology	Understandings about science and technology	Understandings about science and technology	Understandings about science and technology
Science in personal and social perspectives	Science and technology in local challenges	<ul> <li>Science and technology in society</li> </ul>	<ul> <li>Science and technology in local, national, and global challenges</li> </ul>
History and nature of science	<ul> <li>Science as a human endeavor</li> </ul>	<ul> <li>Science as a human endeavor</li> <li>Nature of science</li> <li>History of science</li> </ul>	<ul> <li>Science as a human endeavor</li> <li>Nature of scientific knowledge</li> <li>Historical perspectives</li> </ul>