Lesson 4:
Tools of the Nanosciences

Teacher Materials

Contents

Tools of the Nanosciences: Teacher Lesson Plan

Orientation

This lesson focuses on two of the most widely used new probe imaging tools: the Atomic Force Microscope (AFM) and the Scanning Probe Microscope (SPM).

- The Scanning Probe Microscopy PowerPoint explains how these two tools work, the difference between them, and what you can see and build with them.
- The Student Reading on Seeing and Building Small Things provides more details on scanning probe tools and describes self-assembly as another way to build things.
- The Black Box Activity gives students the opportunity to use probes to "see" the unknown surface of a mystery box and consider firsthand the challenges of using probes.
- The Seeing and Building Small Things Quiz tests students knowledge of scanning probes and self-assembly.

You may want to extend this lesson beyond one day to incorporate building a model of an AFM. Two different strategies are suggested in the Optional Extensions for Exploring Nanoscale Modeling Tools: Teacher Notes.

Essential Questions (EQ)

What essential questions will guide this unit and focus teaching and learning?

(Numbers correspond to learning goals overview document)

4. How do we see and move things that are very small?
5. Why do our scientific models change over time?

Enduring Understandings (EU)

Students will understand:

(Numbers correspond to learning goals overview document)

4. New tools for seeing and manipulating increase our ability to investigate and innovate.

Key Knowledge and Skills (KKS)

Students will be able to:

(Numbers correspond to learning goals overview document)

5. Explain how an AFM and a STM work, and give an example of their use.

Prerequisite Knowledge and Skills

- Familiarity with atoms and molecules.

Related Standards

- NSES Science and Technology: 12EST2.1, 12EST2.2
- NSES Science as Inquiry: 12ASI2.3
- AAAS Benchmarks: 11D Scale #1, 11D Scale #2

Day	Activity	Time	Materials
Prior to this lesson	*Homework*: Student reading: Seeing and Building Small Things	*30 min*	Photocopies of student reading
	Teacher Resource: Scanning Probe Microscopy: Teacher Reading	*30 min*	One copy for the teacher
Day 1 (50 min)	Show the Scanning Probe Microscopy: PowerPoint Slides, using teacher's notes as talking points. Highlight the AFM and STM, and the relationship between new tools and the ability to gather new data and to innovate using new technologies.	20 min	Introduction to Nanoscience: PowerPoint Slides Computer and projector
	Conduct Black Box Activity	20 min	Prepare black boxes according to teacher instructions Photocopies of the Black Box Activity: Student Instructions and Questions
	Discuss Black Box Activity and student reading: Seeing and Building Small Things	10 min	
Day 2 (50 min)	Optional: Extensions for Exploring Nanoscale Modeling	Will vary	Teacher notes
	Student Quiz: Seeing and Building Small Things	10 min	Photocopies of Student Quiz Teacher Key for correcting Student Quiz

Scanning Probe Microscopy: Teacher Reading

Introduction

In 1981, Gerd Binnig and Heinrich Rohrer, two IBM scientists working in Zurich, Switzerland, invented the first scanning tunneling microscope (STM). They were awarded the Nobel Prize in physics for this work, which gave birth to the development of a new family of microscopes known as scanning probe microscopes (SPM). All SPMs are based on scanning a probe just above a sample surface while monitoring the interaction between the probe and surface. The different types of interactions that are monitored are what characterize the different types of scanning probe microscopes. The STM monitors the electron tunneling current between a probe and a conducting sample surface, while the more recently developed atomic force microscope (AFM) monitors the Van der Waals forces of attraction or repulsion between a probe and a sample surface. The advantage of this new family of scanning probe microscopes is that we are able to image and manipulate matter as small as 0.1 Angstroms (.01 nm). So how do these probe microscopes work to obtain images down to the atomic level?

The Scanning Tunneling Microscope (STM)

The STM is based upon a quantum mechanical phenomenon known as electron tunneling. Tunneling is the movement of an electron through a classically forbidden potential energy state. A common analogy is that of a car of a roller coaster at the bottom of a large hill. Based on classical mechanics, one would predict that the car would not make it over the hill if it did not have enough kinetic energy. However, viewed from a quantum mechanical viewpoint, an electron is no longer just a particle having either enough or not enough energy to make it past a potential energy barrier. Rather, an electron also exhibits wave like properties, and as such, the electron is no longer confined to strict energy boundaries. As a wave, there is a small but finite probability that the electron can be found on the classically forbidden side of the potential energy barrier. When an electron behaves in such a manner, it is said to have tunneled.

Electron tunneling is the core concept behind the STM. In the STM, a probe, commonly referred to as the tip, is brought close to the surface of a sample being examined (see Figure 1). The energy barrier that is classically forbidden is the gap (air, vacuum) between the tip and the sample. When the tip and the sample are brought within a distance of around 1 nm of each other, tunneling occurs from the tip to the sample or vice versa, as long as the sample is an electrical conductor. A current can then be measured as result of electrons tunneling.

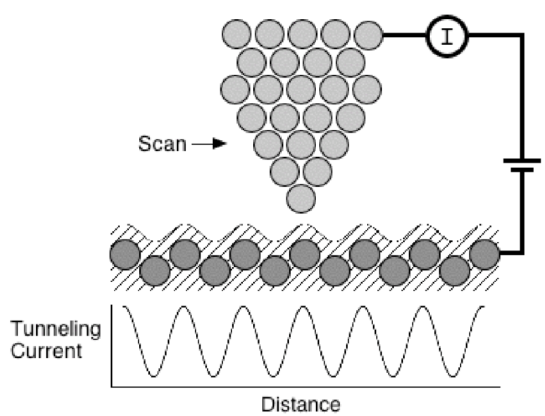


Figure 1. Tip and surface and electron tunneling [1]

The magnitude of the tunneling current is very sensitive to the gap distance between the tip and the sample. The tunneling current drops off exponentially with increased gap distance. If the distance is increased by as small as 1 Angstrom, the current flow is decreased by an order of magnitude.

Imaging of the surface of a sample based on electron tunneling current can be carried out in one of two ways:

1. Constant height mode: The tunneling current is monitored as the tip is scanned across a sample. The changes in current give rise to an image of the topography of the sample.
2. Constant current mode: The tip is moved up and down as the surface changes in order to keep the actual tip-to-sample height constant. This maintains a constant current, and the movement of the tip is monitored as it is scanned across a sample. The changes in tip height give rise to an image of the topography of the sample. This mode is more commonly used.

STM Tips

Because of the dependence of the tunneling current upon the tip to sample distance is exponential, it is then only the closest atom on the tip of the STM probe that will interact with the sample surface (see Figure 2). Tunneling occurs between the electrons of a single atom on the tip of an STM probe, and one atom at a time on the sample surface.

How are these tips made? It is actually not as difficult as one would think. STM tips can be made by etching a pit into a crystalline surface such as silicon to make a mold. Then a thin layer of the material to be used to make the tip, such as silicon nitride, is placed onto the silicon mold, filling the pit. When the silicon nitride layer is removed from the silicon that contained the etch pit, an STM tip is produced. Tungsten and platinum are also commonly used to make STM tips.

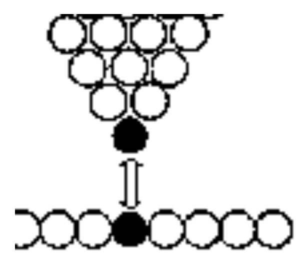


Figure 2. An STM tip [2]

But how do we make sure that the tip is one atom sharp? Actually, is not necessary to worry about placing one atom at the very tip. Looking closer at the tip, you will see that there is invariably a crystalline structure there (see Figure 3). And if you were to look even closer, at the atomic level, you would in fact see a truly atomic tip. Again, because electron-tunneling current changes so dramatically with distance (an increase in distance of one Angstrom causes a decrease in tunneling current by a power of ten), that one atom at the tip will produce a tunneling current. Interference from surrounding atoms is negligible due to their distance from the sample surface.

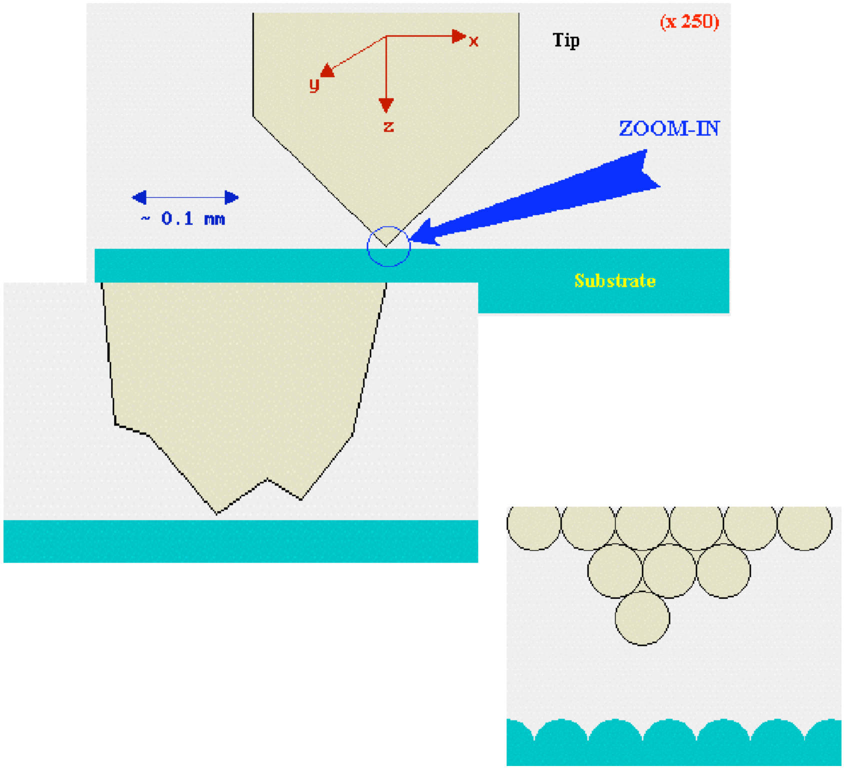


Figure 3. Zoom in of tip [3]

Moving the STM Tip

In order to get a precise picture of the topography of a sample, the STM tip must scan across the surface in increments as small as Angstroms. It is impossible for human manipulation to move a probe at such a small scale. To solve this problem, piezoelectric materials are used to move the STM tip in increments that the human hand cannot.

Piezoelectric materials are materials that change shape when a voltage is applied. Some examples of piezoelectric materials are ceramics, quartz, human bone, and lead zirconium titanate, which is typically used in STMs. The STM tip is connected to a tube containing piezoelectric material. Voltage can then be applied to the piezoelectric material, causing fine changes in dimension, which causes the tip to move Angstroms at a time.

Putting It All Together

The operation of an STM is based on electron tunneling, which occurs when a tip approaches a conducting surface at a very small distance (1nm). The tip is mounted onto a piezoelectric tube, which allows tiny, controlled movements of the tip by applying a voltage to the tube. As the tip is scanned along a sample in this way, the tip maintains a constant current or a constant tip-to-sample-surface distance. The resulting movement of the tip is recorded and displayed revealing a surface picture at the atomic level (see Figure 4).

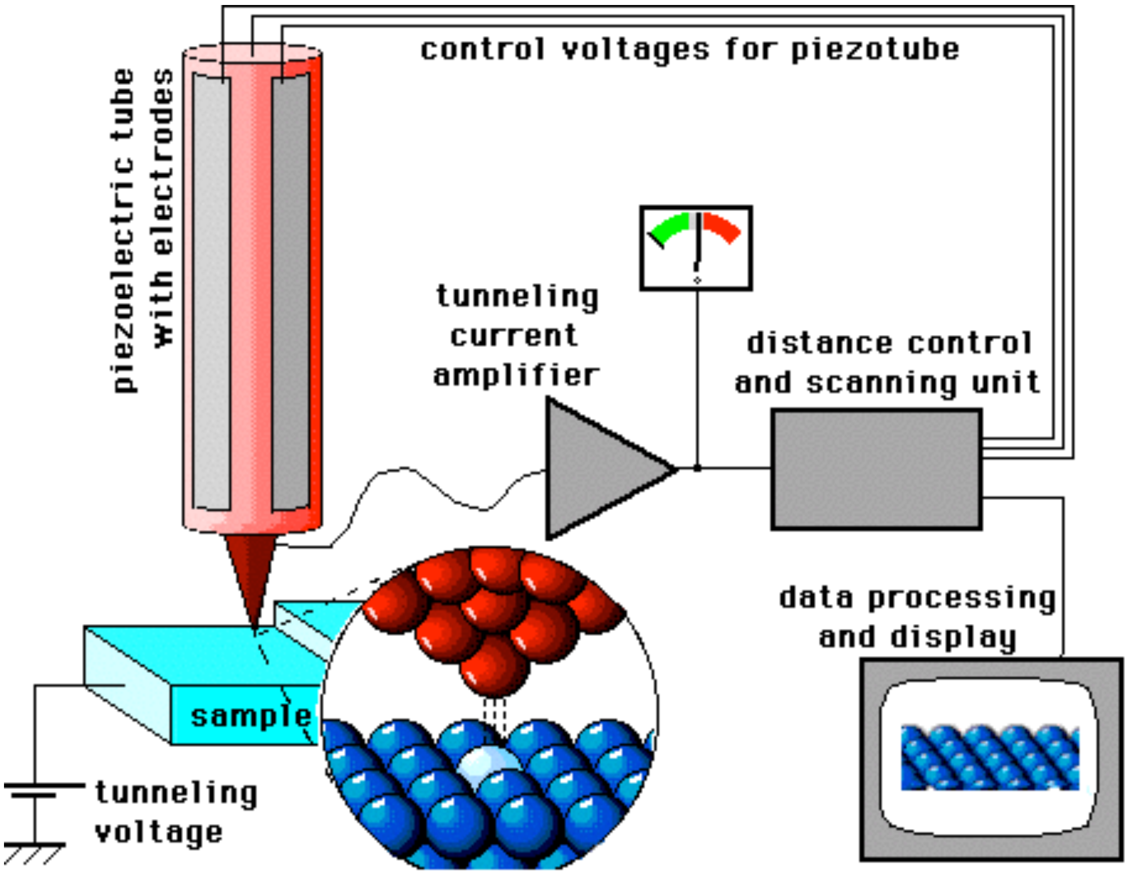


Figure 4. Diagram of an STM [4]

Challenges in using an STM

In practice, several challenges arise when using the scanning tunneling microscope. One is vibrational interference. Since the tip of an STM is only a nanometer or so from the surface of a sample, it is easy to crash the tip into the sample. Any minor cause for vibration, such as a sneeze or motion in the room, could result in damaging the tip.

Contamination from particles in the air such as dust can also be problematic. A small dust particle is made up of millions of atoms, and would certainly interfere with the microscope performance. For this reason, STMs are commonly run under vacuum. The chemical reactivity of particles in air with the tip or sample surface is another reason to scan samples under vacuum.

One other drawback of the STM is that it is only useful for producing images of conducting or semiconducting materials because it relies on the tunneling movement of electrons. It is not effective in producing images of nonconducting materials. Another scanning microscope, the atomic force microscope, allows us to see nonconducting materials at the atomic level.

The Atomic Force Microscope (AFM)

The atomic force microscope (AFM) is another type of scanning probe microscope in the same family as STMs. It's based on the same idea: a probe tip scanning a sample to create an image of a sample's topography. But rather than monitoring the electron tunneling current between a scanning tip and sample, the AFM monitors the forces of attraction and repulsion between a scanning tip and a sample.

In an AFM, the scanning tip is attached to a spring or cantilever that allows the tip to move as it responds to forces of attraction or repulsion it has for a sample surface. The cantilever is a beam around 0.1 mm long and a few microns thick. It is supported on one end and has the scanning tip hanging from it on the other. Parallel to how the STM works, as the AFM tip is scanned over the sample at constant force, the tip attached to a cantilever or spring moves up and down, producing an image of the topography. Piezoelectric materials are again used to control the small distances needed to see a sample at the atomic level.

A laser beam is used to measure the movement of the cantilever (see Figure 5). The laser beam is positioned so that it reflects off the backside of the cantilever, which usually has a gold coating, behaving like a mirror. The reflected beam hits a detector that magnifies and monitors the movement of the cantilever.

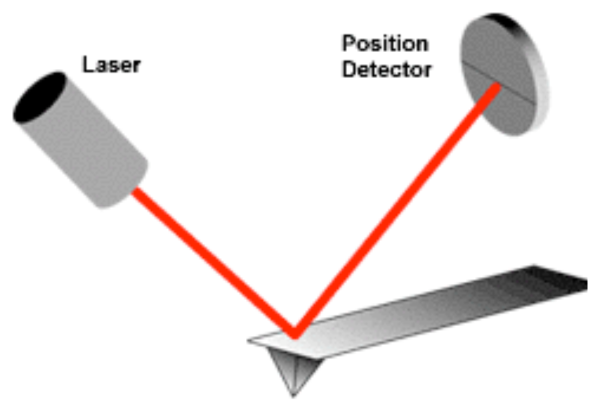


Figure 5. Laser used to measure cantilever movement [5]

Deciding on a tip to use requires careful consideration. Because it is the mechanical movement of the tip itself that ultimately produces the image, the size of the tip used must be chosen carefully. It must be small enough to get into all the "nooks and crannies" of a sample surface. The sharpness of a tip must be appropriately chosen.

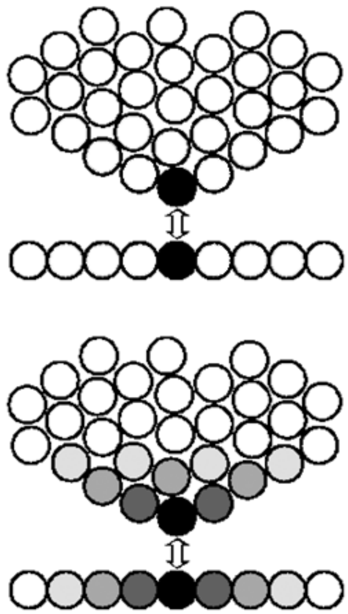


Figure 6. Interatomic interaction for STM (top) and AFM (bottom); shading shows interaction strength [6]

In addition, unlike the STM where only the one atom sharp tip registers surface topography due to electron tunneling occurring only over short distances, with the AFM, several atoms near the tip will play a role (see Figure 6). Forces of attraction and repulsion occur over longer distances. Several atoms near the tip of an AFM will be attracted or repulsed by several atoms on the sample surface.

The AFM is also more versatile than the STM. It can be adjusted to monitor different forces depending on the type of contact the tip has with a sample as well as the type of tip used to scan a sample. Depending on the force being monitored, different images of a sample surface can then be produced.

For example, an AFM can be in "contact mode," where the tip is in direct contact with a surface sample. This measures van der Waals forces. A drawback of contact mode is the lateral frictional force that would exist as a tip is "dragged" over a sample. To address this, some samples are scanned using the "tapping mode" which oscillates the cantilever tip, while tapping a sample. The benefit of this mode is that frictional forces are dramatically reduced.

Another mode, called the "lift" mode, allows one to image a surface by monitoring magnetic forces and electrostatic forces. In addition, because the tip is attached to a cantilever or spring, lateral movement and angled deflection can also be measure to produce an image.

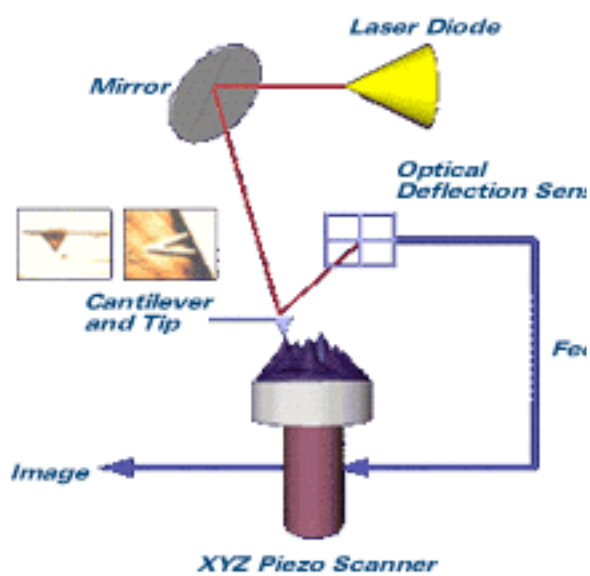


Figure 7. How the AFM works [7]

Using STMs and AFMs in Nanoscience

Not only do STMs and AFMs allow us to see images at the nanoscale level, they also enable us to manipulate matter at this level. By applying small voltages to an STM tip, atom-by-atom manipulation is possible. Being able to change the orientations of atoms (or clumps of atoms) as well as deposit or remove atoms (or clumps of atoms) is just the beginning of the development of many future applications.

References

(Accessed August 2005.)

[1] http://mrsec.wisc.edu/Edetc/modules/MiddleSchool/SPM/MappingtheUnknown.pdf

[2] http://mechmat.caltech.edu/~kaushik/park/3-3-0.htm

[3] http://www.chem.qmw.ac.uk/surfaces/scc/scat7_6.htm

[4] http://www.iap.tuwien.ac.at/www/surface/STM_Gallery/stm_animated.gif

[5] http://www.nanoscience.com/education/AFM.html

[6] http://mechmat.caltech.edu/~kaushik/park/3-3-0.htm

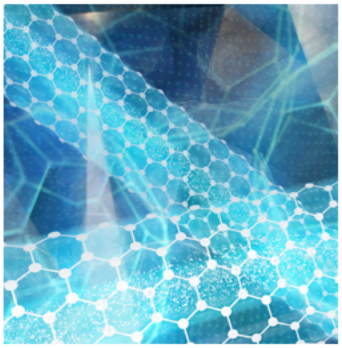
[7] http://physchem.ox.ac.uk/~rgc/research/afm/afm1.htm

Additional Resources

http://weizmann.ac.il/Chemical_Research_Support/surflab/peter/afmworks/

http://home.earthlink.net/~rpterra/nt/probes.html

http://www.lotoriel.de/pdf_uk/all/pni_tutorial_uk.pdf



Scanning Probe Microscopy

"Seeing" at the nanoscale

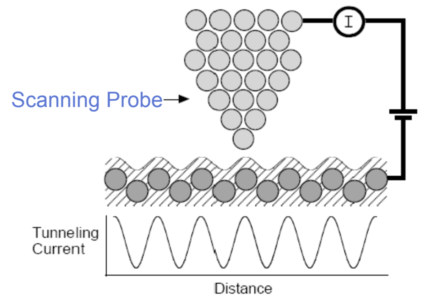
NanoSense
the basic sense behind nanoscience

Scanning Probe Microscopes (SPMs)

- **Monitor the interactions between a probe and a sample surface**
- **What we "see" is really an image**
- **Two types of microscopy we will look at:**
  - Scanning Tunneling Microscope (STM)
  - Atomic Force Microscope (AFM)

Scanning Tunneling Microscopes (STMs)

- **Monitors the *electron tunneling current* between a probe and a sample surface**
- **What is electron tunneling?**
  - Classical versus quantum mechanical model
  - Occurs over very short distances

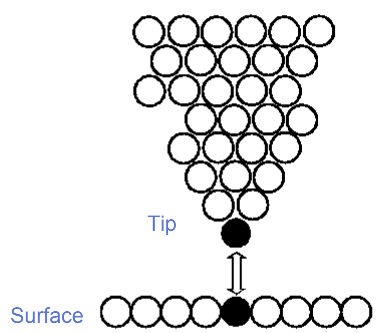


Tip and surface and electron tunneling

Source: http://mrsec.wisc.edu/Edetc/modules/MiddleSchool/SPM/MappingtheUnknown.pdf

STM Tips

- **Tunneling current depends on the distance between the STM probe and the sample**



Tunneling current depends on distance between tip and surface

Source: http://mechmat.caltech.edu/~kaushik/park/3-3-0.htm

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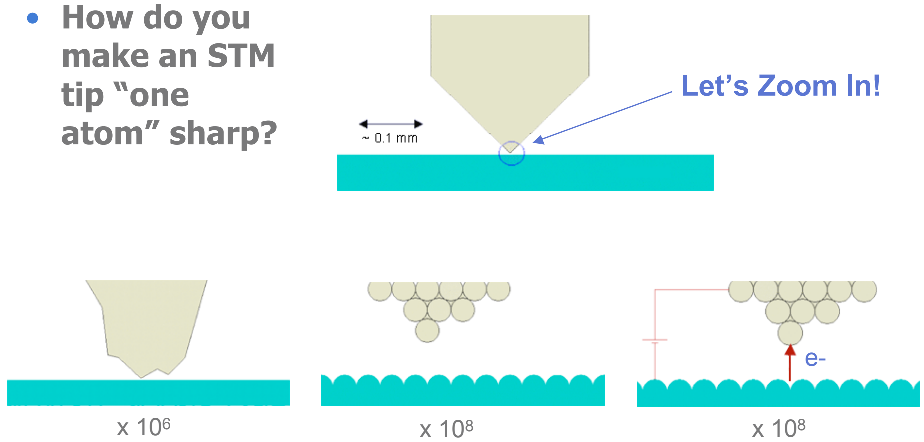
STM Tips II

- How do you make an STM tip "one atom" sharp?



Source: http://www.chem.qmw.ac.uk/surfaces/scc/scat7_6.htm

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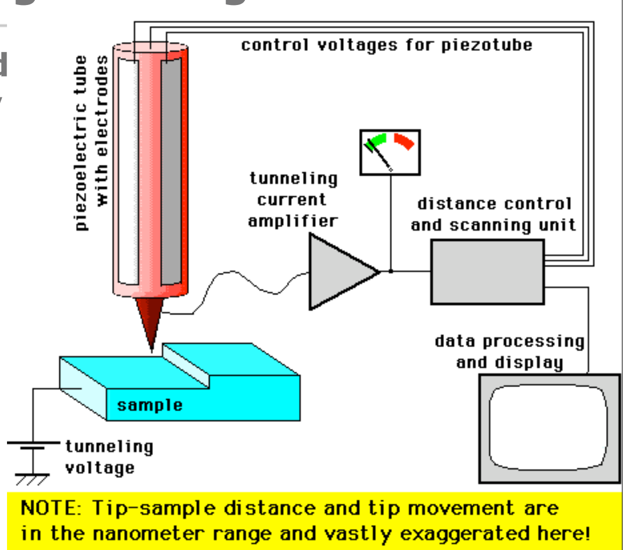
Putting It All Together

- The human hand cannot precisely manipulate at the nanoscale level
- Therefore, specialized materials are used to control the movement of the tip



How an STM works
(click to play or see URL below)

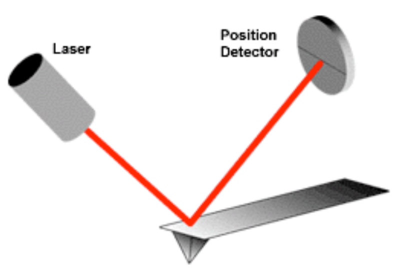
Source: http://www.iap.tuwien.ac.at/www/surface/STM_Gallery/stm_animated.gif

Challenges of the STM

- **Works primarily with conducting materials**
- **Vibrational interference**
- **Contamination**
  - Physical (dust and other pollutants in the air)
  - Chemical (chemical reactivity)

Atomic Force Microscopes (AFMs)

- **Monitors the forces of attraction and repulsion between a probe and a sample surface**
- **The tip is attached to a *cantilever* which moves up and down in response to forces of attraction or repulsion with the sample surface**
  - Movement of the cantilever is detected by a laser and photodetector

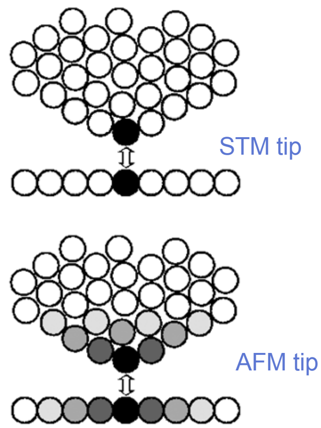


Laser and position detector used to measure cantiliver movement

Source: http://www.nanoscience.com/education/AFM.html

AFM Tips

- **The size of an AFM tip must be carefully chosen**

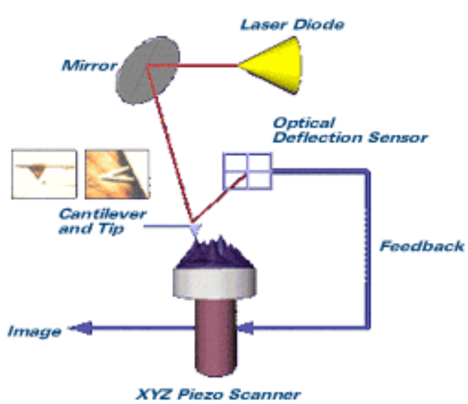


Interatomic interaction for STM (top) and AFM (bottom). Shading shows interaction strength.

Source: http://mechmat.caltech.edu/~kaushik/park/3-3-0.htm

The AFM

- **Specialized materials are again used to manipulate materials at the nanoscale level**



Source: http://physchem.ox.ac.uk/~rgc/research/afm/afm1.htm

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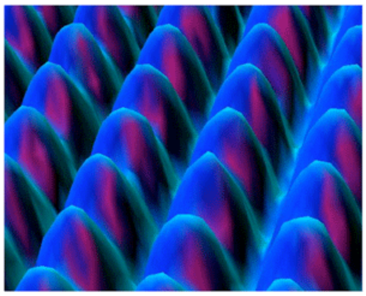
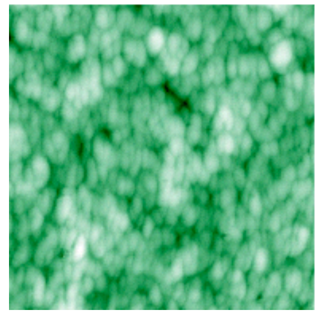
So What Do We See?



Nickel from an STM



ZnO from an AFM

Sources: http://www.almaden.ibm.com/vis/stm/blue.html
http://www.asylumresearch.com/ImageGallery/Mat/Mat.shtml#M7

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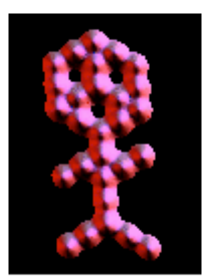
And What Can We Do?

- **Using STMs and AFMs in Nanoscience**
  - Allows atom by atom (or clumps of atoms by clumps of atoms) manipulation as shown by the images below

Xenon atoms



Carbon monoxide molecules

Source: http://www.almaden.ibm.com/vis/stm/atomo.html

Scanning Probe Microscopy Slides: Teacher Notes

Overview

This series of slides introduces students to two major types of scanning probe microscopy that are used to see and manipulate matter at the nanoscale level. It is recommended that you read the accompanying teacher background reading, as it provides more in-depth explanations of the ideas addressed in the PowerPoint slides.

Slide 1: Scanning Probe Microscopy

Explain to the students that we will cover how scanning probe microscopes can be used to help us "see" at the nanoscale level.

Slide 2: Two Types of Scanning Probe Microscopes (SPMs)

All SPMs monitor some type of interaction between a probe and a sample surface. The type of interaction that is monitored depends on the type of SPM you are using.

- STMs monitor an electrical current between a probe and a sample surface, meaning it is useful for seeing the surface of *conducting* materials.
- AFMs monitor the force of attraction or interaction between a probe and a sample surface, and can be used to see the surface of all types of materials.

You may also want to discuss that what we are "seeing" is really an image and how this image may be similar or different to what we can see with other tools, such as light microscopes.

Slide 3: Scanning Tunneling Microscopes (STMs)

In the classical view of the electron, an electron is a particle that will be found in locations where it has enough energy to exist.

In the quantum mechanical view of the electron, an electron is a wave that primarily exists in areas of high probability. However, due to its wave nature, there is a finite possibility that the electron may exist in a location beyond high probability energy states, thus allowing for tunneling. Tunneling occurs at very short distances, around 1 nm.

You may talk about the two different microscopy modes: constant height vs. constant current. You may also address the fact that the double-headed arrow signifies that electron tunneling can occur tip to probe or probe to tip, depending on how the instrument is biased. But electrons do not tunnel in both directions at the same time.

Slide 4: STM Tips

Only the atom at the very tip of an STM tip will experience electron tunneling with a sample surface, because electron tunneling is exponentially dependent upon distance.

Slide 5: STM Tips II

A series of pictures zooming in on an STM tip shows that a one atom sharp tip will almost inevitably be naturally occurring.

Slide 6: Putting it All together

The animation runs a little slow; you might want to talk over it.

http://www.iap.tuwien.ac.at/www/surface/STM_Gallery/stm_animated.gif

The specialized material is referencing piezoelectric materials. You may choose to go into this or skip it depending on your class level.

Slide 7: Challenges of the STM

Vibrational interference might include sneezing or other air movement in the room that could cause crashing of the tip into the sample surface. Running the STM in a vacuum addresses some of the challenges.

Slide 8: Atomic Force Microscopes (AFMs)

You might want to start by defining what a cantilever is. AFMs monitor the forces of attraction between a scanning probe tip and a sample surface. Because movement of the tip occurs at the nanoscale level—which the human eye cannot detect without aid—the movement of a laser beam detects movement in the cantilever.

Slide 9: AFM Tips

Unlike STM tips where the electron tunneling will selectively occur between the closest atom on the tip and a sample surface, the AFM tip measures interactions between several atoms at the tip. For this reason, the size of the tip must be carefully chosen. Smaller and sharper tips yield finer resolution and vice versa. You might want to refer back to the Black Box activity and some of the follow-up questions that were addressed or discussed there.

Slide 10: The AFM

The AFM is a bit more versatile than the STM. Technology has found new ways to monitor different force interaction between a tip and a sample surface, leading to their respective images at the atomic level.

Slide 11: So What Do We See?

These images of nickel and ZnO are taken from IBM research labs.

Slide 12: And What Can We Do?

In general, manipulation is done by applying voltages and charges to an STM tip.

Black Box Lab Activity: Teacher Instructions & Key

Purpose

To use different probes to determine the layout of objects on the bottom surface of a closed box, and to consider the limitations and challenges in using probes to "see." The idea is to get students thinking about how the scanning probe microscopes give us a picture of the surface of atoms, and to consider some of the basic challenges in scanning probe microscopy.

Materials

- One black box
- One pencil and magnet probe
- One cotton swab probe
- One skewer probe

How to Make a Black Box

1. Glue different objects to the bottom of each box. Use a variety of objects in various arrangements to make this as challenging an activity as appropriate. The class as a whole can have the same surface, or each pair can have their own unique surface. Use objects of different compositions and shapes—such as pastas, magnets, macaroni noodles, and Q-tips—and glue them in pattern such as a square, circle, or triangle. Do not use cotton balls, since they come apart after many jabs with probes. Also, use a strong super glue or rubber cement to keep the objects (especially the magnets) in place. When arranging, keep in mind that we want the students to be able to deduce the bottom surface more accurately when using the smaller barbecue skewer probe. An arrangement that would allow this differentiation (such as macaroni noodles 1/4 cm apart instead of 2 ping pong balls 5 inches apart) is favorable.
2. Cut a small (e.g., 1/2 inch) hole in the top of the box, through which students will insert the probes. A square box will work best, since it will allow students to reach all parts of the bottom surface from a center top hole. If shoeboxes are used, cut more than one hole in the top so that all areas of the bottom surface can be reached.
3. For the pencil and magnet probe, glue an eraser-size magnet onto the eraser end of the pencil. With this probe, students will find strong pulls and repulsions by the magnets that are at the bottom of your black box.
4. Prepare enough black boxes and probes for each pair to work with their own set.

Student Instructions

1. Obtain from your teacher a box, pencil and magnet probe, a cotton swab probe, and a barbeque skewer probe.

2. Place the pencil and magnet probe into the center hole, and determine as best you can what the surface of the bottom of the box looks like. Draw your best guess below.

A rough sketch of the surface, highlighting any magnets.

3. Replace the pencil and magnet probe with the cotton swab probe, using the swab end as the probe. Is there any additional information you are able to conclude about the surface of the bottom of the box? Draw your best guess below.

   A more specific sketch, perhaps identifying some general shapes of the objects.

4. Replace the cotton swab probe with the barbecue skewer probe, using the pointed end of the skewer as the probe. Is there any additional information you are able to conclude about the surface of the bottom of the box? Draw your best guess below.

   A more specific drawing, identifying the layout and composition of the surface.

Questions

1. Describe the technique you used to investigate the surface of the bottom of the box.

   A systematic survey of the bottom surface, scanning back and forth, row by row.

2. What kinds of information about the bottom surface were you able to deduce?

   The layout of the bottom of the box, as well as the composition of the various materials on the bottom surface of the box.

3. How accurate do you think your drawing is?

   The basic layout and the general composition of the different objects are pretty accurate. The specific shapes and the texture of the surfaces are some properties that could not accurately be interpreted.

4. What could you do to get a better idea of what the bottom surface looks like, besides opening the box?

   Use a finer probe, use your fingers as a probe to increase sensitivity, scan the bottom surfaces in smaller increments.

5. What if a ping-pong ball was attached to the probing end of the skewer? How might this have affected your interpretations?

   A ping-pong ball would have revealed general information, such as the general layout. The resolution would have been less specific and less accurate compared with what the barbecue skewer told us.

6. What difficulties did you encounter in using this probing technique to "see" the unknown? Or what challenges could there be in using such a technique?

   The tip of the probe could be damaged, or the bottom surface could be damaged during probing. The size of the probe must be appropriately small.

Activity adapted from: http://mrsec.wisc.edu/Edetc/modules/MiddleSchool/SPM/MappingtheUnknown.pdf

Seeing and Building Small Things Quiz: Teacher Key

1. Name the scanning probe instrument that uses electrical current to infer an image of atoms. Briefly describe how it works.

Scanning tunneling microscope (STM): As the STM tip is scanned across a surface, the STM measures the flow of electron tunneling current between the tip and the surface. This tunneling current depends strongly on the distance between the probe tip and the sample, and thus is sensitive to peaks and valleys of the surface. The changes in the strength of this current can be used to create an image of the surface.

2. Name the scanning probe instrument that reacts to forces inherent in atoms and molecules to infer an image of atoms. Briefly describe how it works.

Atomic force microscope (AFM): As the AFM tip is scanned across a surface, the AFM measures the tiny up and down movements of the tip that occur due to the electromagnetic forces of attraction and repulsion between the tip and the sample. This movement can be used to create an image of the surface.

3. Scanning probe instruments can also be used to create things atom by atom. Briefly summarize the downside of using such tools to create an aspirin tablet.

Creating an aspirin table one atom at a time would be very expensive and slow; it would take millions of years just to create one tablet because there are a huge number (more than one trillion billion) of aspirin molecules in an aspirin tablet.

4. How does dip pen nanolithography (DPN) work? Using a drawing in your explanation.

DPN writes structures to a surface the same way that we write ink using a pen. A reservoir of atoms or molecules (the "ink") is stored in the tip of an AFM. The tip is then moved across a surface, leaving the molecules behind on the surface in specific positions. (Drawing should show the transfer of molecules from the AFM tip to the surface.)

5. Name two things in nature that are created by self-assembly processes.

Many answers are possible here; for example, a bubble, snowflake, crystal growth, DNA, cell walls and functions, etc.

6. Circle true or false for each of the following.

E-beam lithography is a type of self assembly.	True	**False**
One type of self-assembly is crystal growth.	**True**	False
Nanotubes can be grown like trees from seed crystals.	**True**	False
The rules governing self-assembly are fully understood.	True	**False**

Optional Extensions for Exploring Nanoscale Modeling Tools: Teacher Notes

Exploring AFM Models

Wooden AFM

Mr. Victor Brandalaise and Dr. Maureen Scharberg at San Jose State University have developed a large-scale wood model of an atomic force microscope (AFM). The cost for the materials for this model is approximately $30. The wood cantilever has a sewing needle tip, and on top of the cantilever near the tip is a mirror. A laser pointer is positioned to beam light from above the cantilever. As the tip skims along a surface, such as copper pellets, a piece of textured plastic, or popcorn kernels, the laser beam reflects the surface onto a piece of paper. From behind the piece of paper, which is attached to a piece of transparent plastic, students can easily trace the amplified surface. For more information, contact Dr. Scharberg at (408) 924-4966 or email scharbrg@pacbell.net

LEGO AFM

As part of their “Exploring the Nanoworld” program, the Materials Research Science and Engineering Center on Nanostructured Materials and Interfaces (MRSEC) at the University of Wisconsin offers materials showing how to assemble a large-scale AFM with LEGO bricks; see http://mrsec.wisc.edu/Edetc/LEGO/PDFfiles/2-1app.PDF.

To learn more about exploring the nanoworld with LEGO bricks, or how to order LEGO kits for this purpose for your classroom, see http://mrsec.wisc.edu/Edetc/LEGO/index.html

How Such Models Could Be Used

Using such models, your students could examine a range of surfaces composed of pure or mixed materials. Students could compare traces from the different instruments and, given unidentified traces made by other students, try to infer the surface type. These activities could lead to discussions of measurement error, identification of impurities in samples, and the advantages and appropriateness of different imaging techniques for different surface types. These activities would provide a revealing view of the instruments and principles behind them.

For assessment, students could be asked to depict the functionality of an AFM using the ChemSense Animator tool available for free download at http://chemsense.org. Using ChemSense, students could draw the components of the AFM and create an animation that predicts what will happen as the cantilever scans across a surface of a sample. In tandem, they could be asked to draw an associated graph that illustrates the changes in force over the surface as the tip moves in their animation. Students would describe the output of the instrument terms of magnetic repulsion or energy distribution.

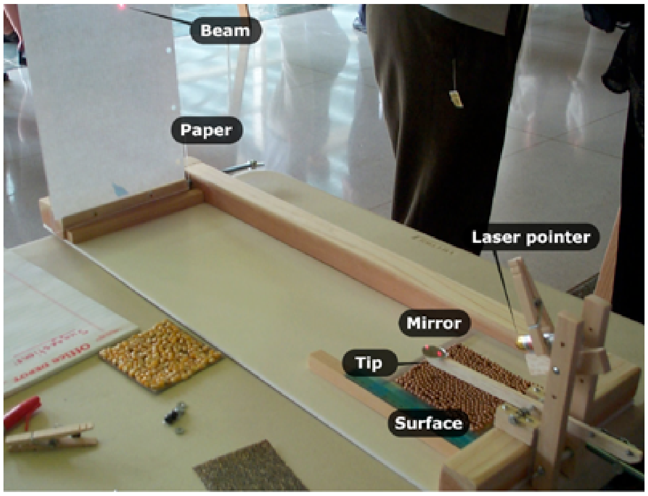


Figure 1. Wood AFM model.

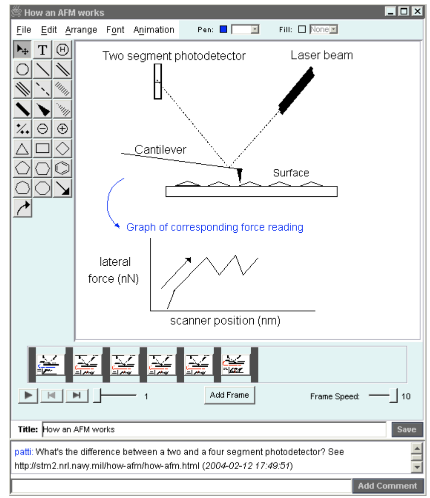


Figure 2. Screen shot of a ChemSense assessment activity.

Exploring Self Assembly

(Source: White paper by Bob Tinker, The Concord Consortium)

The Molecular Workbench (MW) software, available at http://molo.concord.org/software for both Macintosh and Windows platforms, can be used to model nano-engineering concepts such as self assembly. Self-assembly is a nano-engineering concept borrowed from biological systems. The underlying mechanisms for self-assembly are the general van der Waals mutual attraction of all atoms, Coulomb forces due to charged regions of molecules, and shape.

Shape and Smart Surfaces

To build in the impact of shape, MW has “Smart Surfaces” that can be drawn by the user. These surfaces are actually chains of MW atoms linked together with elastic bonds and covered by a flexible surface that hides the atoms. Charge can be added to the periphery of a Smart Surface. The result is a good approximation to a large molecule. It can hold its general shape, but it does vibrate, respond to temperature, and have both long-range Coulomb forces as well as short-range van der Waals forces.

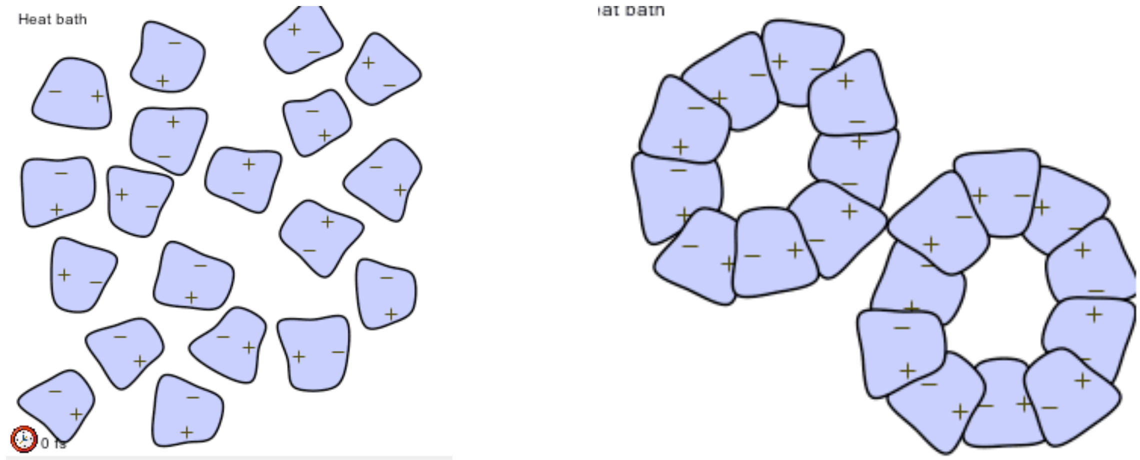


Figure 3. Smart surfaces can be made to self-assemble. Above is an example of a particularly interesting kind of self-assembling object based on nine identical sub-units.

To run the “Smart Surfaces” model, launch MW from http://molo.concord.org/software and then look for “self assembly” under “Recent models and activities.”

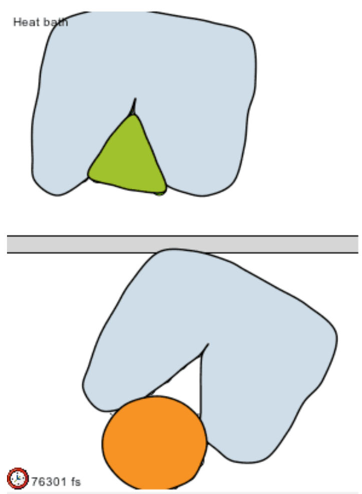


Figure 4. The importance of shape in docking.

The model at the left demonstrates the importance of shape in docking, something similar to self-assembly. This model can be heated to separate the two molecules and then both the ball and triangle bounce around. On cooling, the triangle eventually finds its way back to the complementary surface through a random walk that takes quite a long time. This gives one an appreciation for the time-scale of molecular events of this type.