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Teacher's Guide

Modeling Scanning Probe Microscopes (SPM)

Grade Level: High school

Subject area(s): Physics

Time required: 50 minutes

Learning Objectives: through exploration, understand interactions at the nanoscale; analyze and interpret data; communicate results and information

Summary: The *Modeling Scanning Probe Microscopes (SPM)* lab is designed to show students the principles of how a Scanning Probe Microscope works and how mapping on a smaller scale provides a more detailed view of a surface. Students will use a conductivity apparatus to model the mapping behavior of an SPM. This lab is intended to simulate the tunneling current that is used to image very small objects—on the order of 10 nm or less (at the nanoscale).

Lesson Background Information: Scanning probe microscopes (SPM) map the shape of a surface using a tiny needle (probe tip) that is manufactured to a few atoms in width. The needle is mounted on a cantilever, similar to a record player. A simple SPM works by having the needle touch the surface of a sample. A laser beam reflects off the top of the cantilever and this beam moves up and down as it measures the topography of the sample. Trouble was, the SPM tip would rip and tear soft material and scientists needed another method of learning about a surface without actually touching the surface.

The Scanning Tunneling Microscope (STM) was invented in 1981 by G. Binnig and H. Rohrer who later shared the 1986 Nobel Prize in Physics. Development of the STM furthered the advancement of nanoscale science. The STM lets researchers to "see" and manipulate atoms and molecules. While we cannot really see atomic structures, the STM uses electric current (atomic charge) to obtain images of the sample's topography. STM works by maintaining a constant voltage across the tip and the surface. If the tip is close enough to the surface, electrons will jump across the gap (called *tunneling*). When electrons jump across, a current is measured. The lower the tunneling current the more detailed the picture that is produced. However, STM is limited to imaging only conducting surfaces. The development of the STM led to the invention of another type of powerful microscope called the Atomic Force Microscopes (AFM), which allows any surface to be imaged (even non-conducting materials). At the completion of the activity, it is recommended to show students a graphical representation of an SPM or STM to compare to the model they used.

Further information about STMs as well as images can be found at these websites:

- IBM's Scanning Tunneling Microscopy page with images -- http://www.almaden.ibm.com/vis/stm/stm.html

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- A general description of how STMs woris on Wikipedia - http://en.wikipedia.org/wiki/Scanning_tunneling_microscope

- Nobel prize description showing the inventors -- http://nobelprize.org/educational_games/physics/microscopes/scanning/index.html
- The National Nanotechology Inititative's page on Microscopes and nanotechnology – https://www.nano.gov/nanotech-101/what/seeing-nano
- You Tube has videos on SPM, STM, and AFM for further background
- Scanning probe microscope:
    - https://en.wikipedia.org/wiki/Scanning_probe_microscopy
    - https://teachers.stanford.edu/activities/SPMReference/SPMReference.pdf (for teachers)

Pre-requisite Knowledge: recording, graphing, and interpreting data; metric units

Materials: (groups of 3-4)

- aluminum foil (about 60.0 cm for an entire class)
- metric ruler
- sharp tipped permanent marker
- empty egg carton, with the lid cut off
- ring stand
- test tube clamp
- uncoated nail
- conductivity apparatus, which includes:
    - LED light
    - 9 V battery
    - 2 wire leads with insulated alligator clips, 1 black and 1 red
    - 37kΩ resistor
    - film canister
    - electrical tape
    - 9V battery connector with 6 inches of red and black wires/leads

To make the conductivity apparatus you will need:

- Soldering gun
- Solder
- Safety glasses
- Wire strippers

Safety Information: Do not use the conductivity meter near water.

Advance Preparation:

There should only be 3–4 students per group, since larger groups may become unconcerned bystanders. A few weeks before the activity, collect enough egg cartons for each student group. You can request free film canisters from your local film lab (if they are still processing film). Canisters can be purchased online at:

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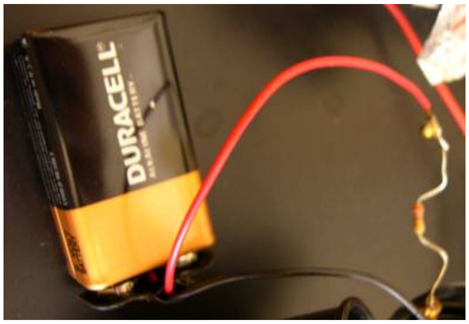
- Educational Innovations: www.teachersource.com (12 for $7.95)
- Amazon: amazon.com (pack of 60 ~$15.00)
- Google for numerous other sources

Acquire a soldering iron (15W–30 W range), solder, and a pair of wire strippers from a hardware store for the conductivity apparatus.

Assemble the conductivity apparatus: (teacher)

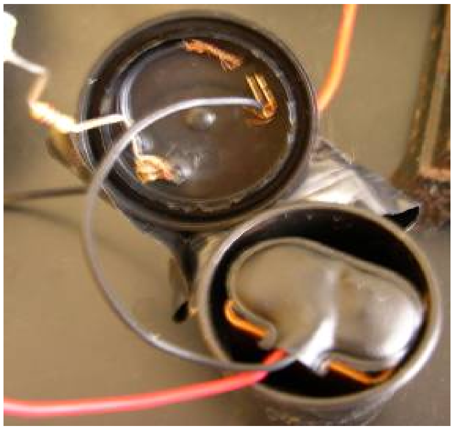


1. Attach the 9 V battery to the connector with red and black wires.
2. Strip the red and black wires so that they are only 2–3 inches long.
3. Lay the red wire down so that the exposed wire end touches one wire end of the resistor. If it doesn't stay in place, an alligator clip can clamp them together.
4. Plug in the soldering iron and wait until the tip is hot.

Safety tip!
The rosin in the solder releases fumes that are harmful to your eyes and lungs, so be sure to work in a well-ventilated area.

5. Wearing eye protection, solder one end of the resistor to the red wire by touching the pen to the solder until it melts, and then touching the melted drop of solder to the wire/resistor connection. If you used an alligator clip to clamp the wires, remove it. (Make sure that it does not become soldered to the other wires!)

6. Use a ballpoint pen or other sharp object to puncture 3 holes in the plastic lid of the film canister so that the holes form a triangle. The holes should be far enough apart so that the wires do not cross.
7. Insert the red wire that is attached to the insulated alligator clip through one of the holes in the film canister lid so that wire-exposed end is on the underside of the lid.
8. Repeat steps 3–5 to solder this wire to the resistor.
9. Push the wire ends of the LED through a hole in the film canister lid so that the LED bulb is on the outside of the lid, and the prongs are on the underside of the lid. Bend the LED wire ends away from each other to hold the LED in place (and to avoid the wire terminals from crossing).



10. Insert the black wire that is attached to the insulated alligator clip through the last open hole in the film canister lid so that wire-exposed end is on the underside of the lid. Pull the wire through so that this wire touches the LED wire.

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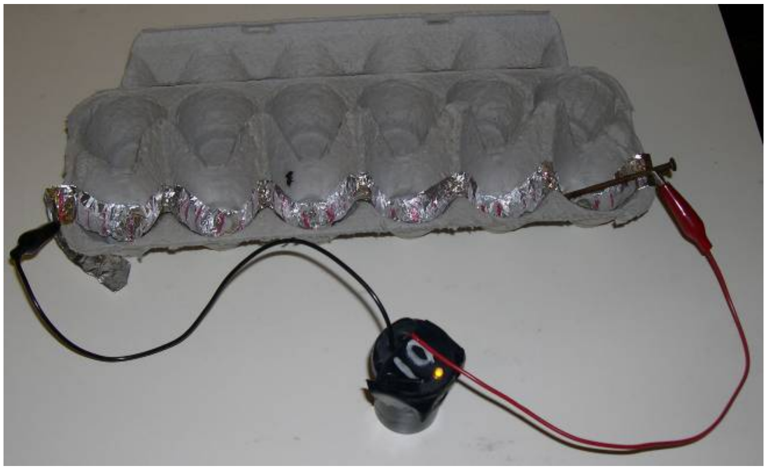
11. Wrap the black wire (leading to the alligator clip) around the LED wire terminal. Repeat steps 3–5 to solder this wire to the LED.
12. Wrap the black wire (leading to the 9V battery) around the other LED terminal. Repeat steps 3–5 to solder this wire to the LED.
13. Put the 9V battery into the film canister. Insert the red and black wires that go to the battery and the resistor (bend it if necessary) into the film canister and close the lid.
14. Seal the lid to the canister with electrical tape, leaving the LED bulb exposed. You have finished a conductivity meter!
15. Test your conductivity meter before the activity by clamping the red alligator clip to the nail and clamp the black alligator clip to the aluminum foil. Touch the nail to the foil. The LED should light.

16. If LED bulb does not light, open the container and check to make sure no connections are loose and that parts of the circuit that shouldn't touch are not touching. You may use electrical tape to help keep the inside wiring in place.



Directions for the Activity:
An introduction to STM and SPM should be done perform the activity. This can be either teacher led (using resources in this Teacher Guide) or you can assign this as homework for the groups to investigate these instruments and prepare a short PowerPoint or paper. The directions for the activity are in the Student Worksheet below. Begin with the sandpaper activity as an analogy to the SPM.

Assessment:
Students should be assessed on their answers to the questions found in the Student Worksheet. If they are assigned investigating the instruments as homework use a rubric to score the accuracy of their information.

Next Generation Science Standards:
HS-PS1.A Structure and Properties of Matter
HS-PS2.B Types of Interactions

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Science and Engineering Practices:
Planning and Carrying Out Investigations
Obtaining, Evaluating and Communicating Information
Analyzing and Interpreting Data

Optional activity extension:
While this lab only focuses on SPM and STM, a good extension to this activity would be to have students explore the various methods of creating a model AFM and testing its accuracy. They could write a short paper on their model AFM and its applications to nanoscience research.

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Student Worksheet (with answer key in red)

Understanding Scanning Probe Microscopes (SPM)

A start-up company called ElectraMap has hired your team of consultants to use electric current to map a surface. This company would eventually like to be able to make images of very small surfaces that cannot be seen through an optical microscope. These surfaces are most likely at the nanoscale which is below the visible light range (380nm-740nm) which is why an optical (light) microscope is not an option to examine the surfaces. ElectraMap would like your ideas on how this might be done. Your team must advise this company how to increase the detail of the map to get the best image of the surface.

Pre lab: Sandpaper is measured by the number of abrasive particles per square inch, called *grit.* You will given 3 types of sandpaper that will feel significantly different in texture (see table at right). Use your fingertips to feel across the sandpaper. Answer these questions:

1. What does sandpaper feel like? *rough; it varies on the grit of sandpaper*
2. Describe the textures *(Answers depend on grit. See table, right)*
3. What tool are you using to measure the grit? *Fingertips*
4. What do your fingers represent? *Tip of the SPM*
5. Why does the grit with the highest number feel the smoothest? *Example answer: your fingers are not sensitive enough to feel the differences between the pieces of grit.*
6. How would this same sandpaper feel if your fingertip was as small as a needle? *Example answer: you would get a more detailed picture of the object as a very small tip is more sensitive to small objects.*

Grit	Feel
40–60	*Coarse*
80–120	*Medium*
150–180	*Fine*
220–240	*Very fine*
280–320	*Extra fine*
360–600	*Super fine*

Materials per group:

- egg carton
- 60.0 cm of aluminum foil
- permanent ink marker
- conductivity apparatus
- nail
- meter stick
- ring stand
- small ruler (inches/cm ~1 foot long)

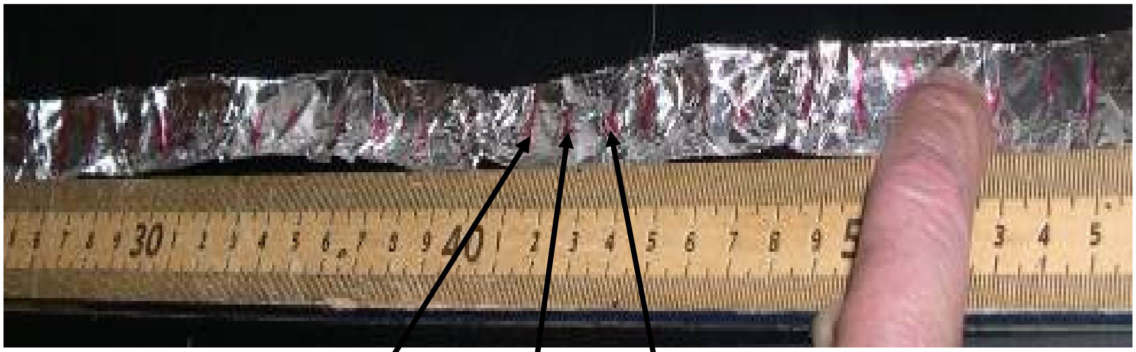
Directions for the Activity:

Question: How can you make a detailed map of a surface using an electric current?

Make a Prediction: *Sample Prediction: First, the surface must be able to conduct electricity. I think taking more measurements over a small space will give me the best image of the surface.*

Procedure:

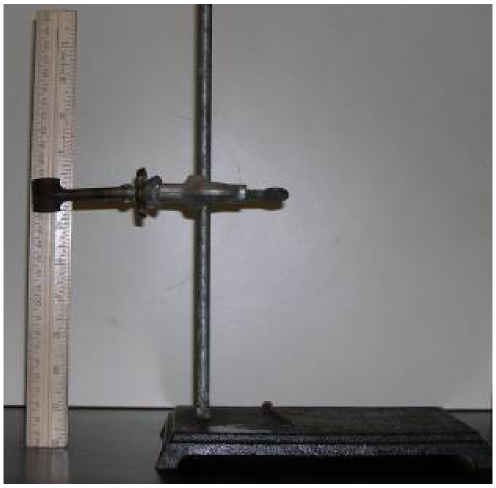
1. Cut the 60.0 cm-long aluminum foil into 4.0 cm-wide strips. Fold each strip over about 3 times so that it is about 1.5 cm wide. (This makes the foil less likely to rip unless you use heavy-duty foil.)
2. Mark each strip of aluminum foil with a permanent marker every 1.0 cm as shown below.



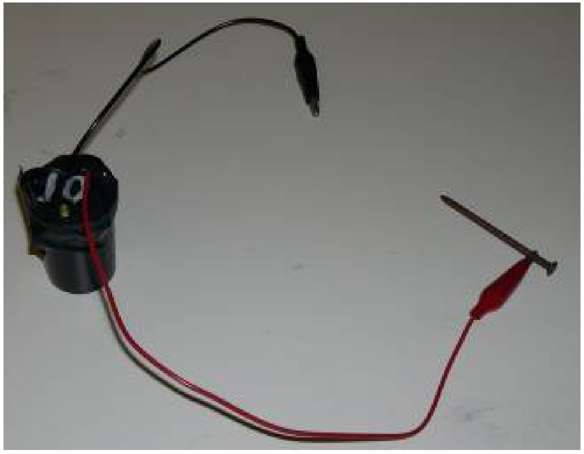
Markings on foil every 1 cm

3. Press the strip into the egg carton so that it follows the bumps in the carton as shown below. This will be your first surface to map.

4. Clamp the ruler to the ring stand so that the ruler is perpendicular with the table (and touching the table). Make sure that the 0 cm/0 in mark touches the table.



5. Clamp the red alligator clip of your conductivity meter to a nail.



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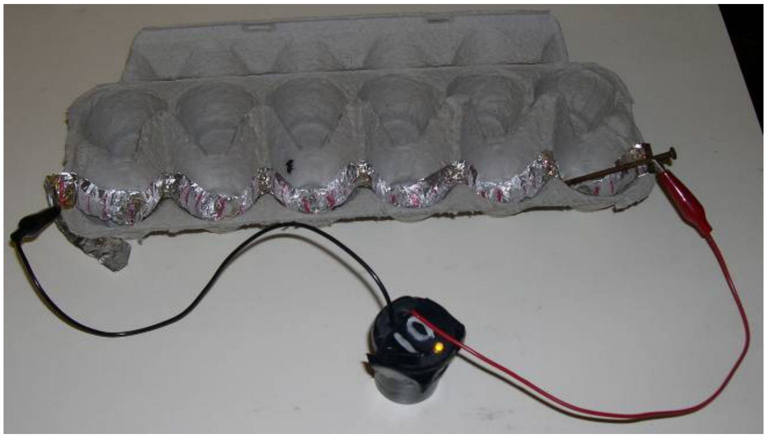
6. Clamp the black alligator clip to the left end of the aluminum foil.
7. Touch the nail to the foil. The LED should light. You are ready to take your first measurement.



8. Touch the tip of the nail to the foil so that the nail is perpendicular to the surface. The LED bulb should light.
9. Move the ruler near the nail so the flat edge of the nail is level with the marks on the ruler.
10. Record the height of the top of the nail in the chart on the next page.
11. Repeat steps 8–10 for the next mark. Continue to repeat this process until measurements have been taken across the entire surface. You may need to move the ring stand and ruler in front of the egg carton to get a more accurate measurement. Make sure that the nail is perpendicular to the surface for each measurement.
12. Repeat steps 8–11, but this time, measure every 4th mark.

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Analysis: Record the height and position in the table below. Graph both data sets with the position as the *x*-axis and the height as the *y*-axis.

Measurement set *A*		**Measurement set *B***	
Position (cm)	**Height (cm)**	**Position (cm)**	**Height (cm)**

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Questions

1. Compare the graphs of measurement sets *A* and *B*. Which measurement set more closely resembled the surface? Why? *Measurement set A more closely resembled the egg carton because more measurements were taken across the surface. They were taken at 1cm intervals versus 4 cam intervals.*
2. What happened to the accuracy when you gathered the data at every 4th mark? *Students should notice the accuracy decreases with fewer data points.*

3. Notice the first data point on your graph. This is not the actual height of the surface. Explain what you would need to do to make a graph using the actual heights of the surface. *Students should recognize that the height of the nail should be taken into consideration. To graph the actual height of the surface, the height of the nail should be measured and then subtracted from all data points.*

4. How would the accuracy of your data change if you had more data points for the position? *More data points should give a more precise picture of the substance.*

5. How would tip size affect your results if you were using more data points as in question 4? Can you draw examples? *If the tip were narrower (sharper) then the data should more closely resemble the substance and if wider then it would be less accurate because it measures a broader area. Drawing should show fine tip capturing the shape of the objet more fully while the broad tip misses the details of the shape.*

6. What could you image if you kept making the tip smaller? Give examples. *Students should suggest other materials that have much smaller relief than egg cartons.*

7. If you were looking for a certain feature, might less accuracy be better? Explain. *If the feature you are looking for is large, then you can cover much more area more quickly.*

8. What would happen to the image if you were looking at really small things and loud music was playing nearby? *Students should realize that vibrations from the stereo will interfere with collecting good data.*

Conclusion: Create a written report on your recommendations to the ElectraMap Company. Remember they want to be able to image very small surfaces that cannot be seen with an optical microscope. These surfaces are most likely at the nanoscale and therefore below the visible light range. Include how to use electricity to get the most detailed image of a surface using your recommended techniques (s). Be specific and include measurements and drawings when possible.
Students should recognize that a conductive surface must be used to use electrical current as a technique to map a surface using this technique*. Students should explain that the detail of the surface increases with more data points and a finer tip.*

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