A Model of a Scanning Tunneling Microscope

IISME Education Transfer Plan by Jon Rockman, Castilleja School, Palo Alto CA
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Conceived for use in 9th grade physics class, but could easily be used in any middle or high school science class that addresses atomic theory.

Standards: This activity addresses the following items from the NBPTS/AYA SCIENCE standards:

Accomplished teachers understand the similarities and differences of basic properties of matter and the principles governing their interactions…; the nature of atoms and molecules …; and the forces that exist between and within objects and atoms.

Objectives:

- Teacher will demonstrate an atomic model of how an STM works.

- Teacher will assist students in working atomic model manipulative so students better understand electrostatic forces holding atoms together in a crystal.

Abstract Invented in the 1980s, the scanning tunneling microscope (STM) provides a way to examine the surfaces of materials with atomic-scale precision. The microscope consists of a very fine needle-like tip that scans across the surface at close range. A bias voltage between the tip and the surface causes a tunneling current to pass between the two; this current is extremely sensitive to the distance between tip and surface. In one operation mode, as the tip scans across the surface (in the *X/Y* plane), a feedback loop moves the tip in the *Z* direction in order to maintain a constant tunneling current. These small changes in *Z* position are recorded and evaluated, giving an image that (in one sense) can be interpreted as a topographic map of the surface.

In the early 1990s, researches at IBM found that they could move atoms across surfaces, building atomic-sized structures. Images of such structures can be found, for example, at http://www.almaden.ibm.com/vis/stm/stm.html or http://mota.stanford.edu/. Current research in the Manoharan Lab at Stanford University involves extending this work, examining surfaces and placing atoms and molecules on those surfaces with increasingly finer precision.

This model helps to bring that research into the classroom by aiding an explanation of the atom-manipulation capabilities of the modern STM. Inexpensive, easily-obtainable materials are used to build a simple model of this complex task.

Materials The choice of materials is flexible and somewhat arbitrary. Substitutions for the listed materials could be easily made.

Round wooden balls, 1” dia. The ones I used were made by “Lara’s Crafts” (www.larascrafts.com) and purchased at a local craft store.

Round wooden balls, 1 1/2” dia. Same manufacturer.

Disc-shaped neodymium magnets. Assembling the model is something of a trial-and-error process. For that reason, it’s best to obtain an assortment of sizes of magnets. Relatively inexpensive assortments are available from many online retailers. The two magnets I used were a disc 1/2” dia. x 3/16” high, and a cylinder 1/2” dia. x 1/2” high.

A small box. I used a cardboard box approx. 2” x 4” x 6”.
A short piece of wooden dowel.
Wood glue.
A bandsaw or hacksaw.
Drill.
Paint.

Constructing the model: Arrange a single, regular layer of the 1” balls in the box (see Fig. 1). This forms the “surface” that the STM will examine.

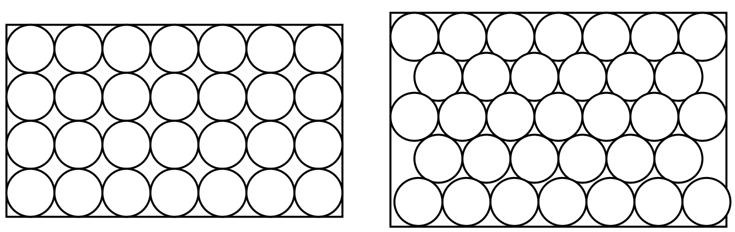

Fig 1. Two possible arrangements of the “surface atoms.” In the real system, these differences would be attributable to different crystal structures.

A 1” ball will be used for the “adatom,” the atom that is moved across the surface. Saw the ball in half, and drill a 1/2” hole into one of the hemispheres; this will hold the cylinder magnet. Insert the magnet into the hole, and glue the two halves back together.

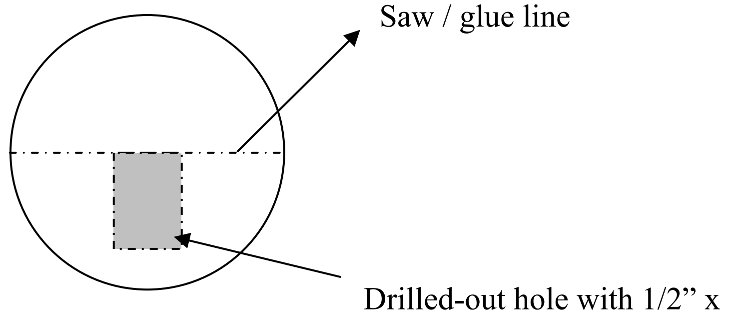

Fig. 2 The movable “adatom.” An alternative approach would be to drill all the way in from one end, insert the magnet, then plug the hole.

For the STM “tip,” make another magnetized ball similar to the movable atom. I used the smaller 1” ball with the thinner disc magnet. A piece of wooden dowel is attached to the ball for a handle. Additional balls are glued around the single magnetized tip, indicating that the tip is just a single atom at the end of a needle-like point.

The tip and the atom should attract each other enough so that the tip can drag the atom across the surface, but not so much that the atom will stick to the tip. This may take trial and error, varying the sizes of the magnets used and their precise placement within the wooden balls.

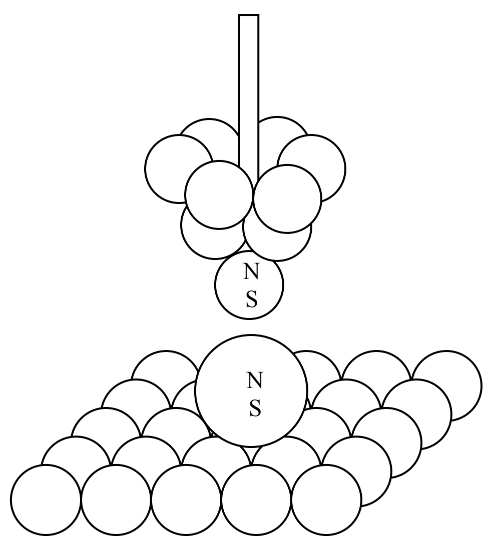

Fig. 3. Completed model. Magnetic interaction between the tip and the adatom causes the latter to move across the surface.

There is no intended physical significance to the movable atom being larger than the others. I used the larger ball because that increased the weight, allowing the atom to be moved without sticking to the tip. It should be possible to recreate the model using only the larger size balls, if desired. However, there is also no particular reason why they can't be different sizes, as atomic species do vary in size. This would be a good source for class discussion about the limits of any such model.

The wood balls may be painted to make them more uniform in appearance, and to conceal the seams from sawing and gluing.

Lesson: When discussing the atomic model of matter, students may reasonably ask, "If atoms are so small, how do we know they exist?" This would be an excellent time to introduce this model and associated images.

Begin by showing some STM images of atomic-scale structures, such as those referenced in the abstract. Begin a discussion with students of how such images could be made. Such a discussion should probably include some very basic background into the operation of an STM; other than the abstract here, such information can be readily found on the www. The discussion will also include questions about how the structures shown can be built in the first place, and that is the point of this demonstration.

Students should be invited to manipulate the "atom" using the "probe." The goal is to drag the atom across the surface, placing it wherever desired. Note that the atom will only rest in certain locations within the crystal structure of the surface, which is consistent with the physical system.

Note also that the atom makes a distinctive "click" as it drops into each allowed location in the crystal. Researchers in the Manoharan lab have interpreted their atom-moving data into such sound files, available on the lab's website.

Limitations of the model: In STM atom manipulation, there are two forces that must be precisely balanced: the electrical attraction between the adatom and the surface, and the weak electrical bond between the adatom and the tip. In our model, the first force is modeled by the weight of the ball, and the second force is modeled by a magnetic interaction. In the STM, the weight of the atom is irrelevant when compared with the electrical interactions; in fact, the surface is typically vertical rather than horizontal, and yet the atoms are in no danger of "sliding off."

As discussed earlier, the different sizes of the wooden balls used is not necessarily indicative of the atomic radii.

Although this model gives a good feel for how atoms can be moved on a surface, it does not do a good job of modeling how the STM can then be used to create an image of the surface, as shown in the images referenced earlier.

Evaluation: Because this is a demonstration to be part of a larger unit, and because it is intended to be enrichment rather than core content, I have not planned specific evaluation. The teacher is encouraged to check for verbal understanding among the students. Pay particular attention to misconceptions such as those listed below:

- Atoms are spherical and “solid”
- The attraction between atoms is magnetic
- Scientists can “see” the atoms directly

Bibliography:

General description of the design and function of the STM:

Gerd Binnig, Heinrich Rohrer, "The Scanning Tunneling Microscope," Scientific American 253(August 1985):50-56.

Description of atomic manipulation using STM:

Joseph A. Stroscio, D.M. Eigler, "Atomic and Molecular Manipulation with the Scanning Tunneling Microscope," Science 254(29 November 1991):1319-1326

STM images and background information can be found at:

http://www.almaden.ibm.com/vis/stm/stm.html
http://mota.stanford.edu/

Wooden balls:

www.larascrafts.com

Neodymium magnets:

www.teachersource.com