Life at Small Scale

Lesson Objectives: Students will be able to do the following:

- Explain the steps in micromachine fabrication
- Define nanotechnology
- Name two reasons why scientists developed the scanning tunneling microscope

Key concepts: MEMS, sensors, actuators, nanotechnology, scanning tunneling microscope (STM), atom

Micromachines

Machines made from **microscopic** components are known as **MEMS**. These machines have both electrical and **mechanical** parts, so they are also called microelectromechanical systems. MEMS have advantages over their larger counterparts, because they are less invasive and can do very precise **work** in very small spaces. Currently, MEMS are divided into two categories, either **sensors** or **actuators**.

Sensors are used to take measurements in many different environments, both natural and artificial. Their small size allows them to do this without interfering with the environment itself. Sensors are widely used in the automobile industry to detect minute pressure changes in engine oil, transmission fluid, tire pressure, and vacuum pressure. Sensors are also used to measure minute changes in ocean water chemistry, because their small size makes the equipment easy to handle and portable while still providing accurate measurements. They use less power than large sensors, so they can operate for longer periods of time without replacing batteries.

Actuators interact with the environment to perform some type of work. The motion they deliver is exact due to their small size. These devices are used in such places as automobiles to trigger the release of air bags. They can also be used to position computer disk drives and make micromeasurements for the manufacture of other machines.

The first **micromachines** were fabricated in ways similar to the integrated circuit or **microchip**. This is an **etching** process that builds up layers of material on the surface of the base, and then the material is eaten away to create the parts of the machine. The layered materials have either mechanical or electrical properties. By using this technology, scientists are able to mass-produce these machines at low cost for a variety of uses. Today scientists still use this technique, but even as you are reading this information it is becoming obsolete. MEMS technology is advancing at such a fast rate that new **fabrication** techniques are invented as new types of micromachines are developed.

Nanotechnology

Through the years researchers have built upon the knowledge of those before them to design smaller, better, and more reliable machines. Scientists have focused on the **electronics** and **mechanization** sciences to miniaturize and develop new machines usable in the microenvironment. With technological advances in fabrication, scientists also realized that they were simply following nature's lead to overcome problems at the **micro** level. For instance the use of **silicon** as a building material is widespread in nature, as we see in the **diatoms** with their two-part crystalline shells. Silicon is also the base that researchers use for their micromachine fabrication. Looking again to nature we see the simple **flagella** found in microscopic organisms is actually a motor, and the **cellulose** that gives plants support represents the struts and beams produced in our macro world.

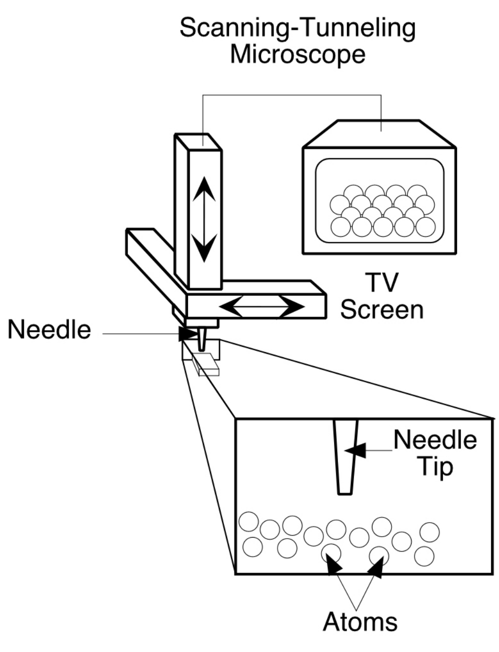
Scientists became intrigued with nature. Could they build things as nature did from the bottom up one **element** or **atom** at a time? Would they be able to create machines as complex as those found in living organisms? If they could do this, what kinds of machines would be possible? Could they create micro robots to do hazardous work or clean the environment of pollutants? Could they make food to feed the hungry? Out of this curiosity **nanotechnology** was born. This is the science of building electronic circuits and devices from single atoms and **molecules**.

The Scanning Tunneling Microscope

If scientists were going to manipulate atoms and molecules, they had to have an instrument that would help them do this. They had to find a way to see something microscopic in size and move it around without being able to hold it in their hands. The instrument that would allow scientists to do this was developed in 1981. It was called the **scanning tunneling microscope (STM)**.

The STM helps researchers to "see" atoms by detecting the **electron** cloud that surrounds each one. As the electrons move around the atomic **nucleus**, they form hills and valleys that look like waves. The STM can detect these patterns by applying **voltage** to a probe made from a single atom. When the probe is charged, the electrons jump from the sample to the probe. This creates an electric **current** that is translated into a picture on a television screen. In this way, scientists can "see" where the atoms are located. If the voltage is increased, the atoms can actually be picked up and moved.

In 1990 two researchers at IBM sprayed atoms of the gas **xenon** onto a clean nickel surface that had been cooled to a minus 269 degrees **Celsius**. At this temperature, the atoms were almost motionless, so researchers could locate them and rearrange them. They spelled the letters IBM using 35 xenon atoms. The following year the same team built CO Man (carbon monoxide man) from 28 molecules of the gas **carbon monoxide**. As each day passes, researchers are able to refine their techniques creating new possibilities for nanotechnology. The future potential for developing smaller and more sophisticated MEMS could open the door for such things as atomic scale data storage. With the development of such technology, all the information in the world's libraries could be held in the palm of your hand.



Adapted from
"Beyond 2000 Micromachines and Nanotechnology"
by David Darling

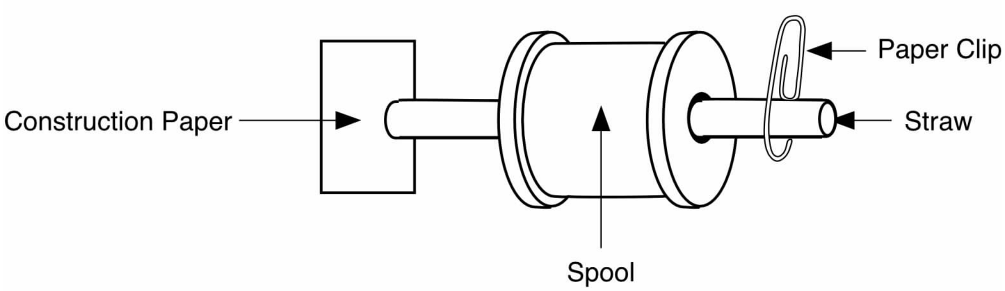
Activity: Building a Miniature Machine

As machines became smaller, scientists had new problems to overcome while they were fabricating these tiny devices. They had to develop instruments to help them see some of the microscopic machine pieces. The work they had to complete was very precise. They also had to develop instruments to manipulate the small parts, because these items were too little to hold.

Objectives: Students will be able to do the following:
1. Construct a mini machine.
2. Use tools to recreate this machine.
3. Evaluate the construction process.

Materials:
Each student needs the following items:
- Spool
- Paper clip
- Four inch length of straw with two slits cut in one end
- Approximately two inch square piece of construction paper
- Two pair of tweezers
- Two round ended toothpicks
- Tape (small piece to secure construction paper to straw)

Miniature Machine



Hand Driven Windmill

Procedure:
1. Give each student materials from the list above.
2. Provide students with a picture of the machine to be constructed. (See diagram above.)
3. Have students construct the machine making sure the paper clip handle turns the straw.
4. Have students disassemble their machine.
5. Have students use the tweezers instead of their hands to try to assemble their machine.

6. Have students use the toothpicks as tools to try to assemble their machine.
7. Have the students use one pair of tweezers and one toothpick to assemble their machine.
8. Have students discuss the advantages and disadvantages of each assembly process and relate it to real world fabrication issues.

Possible Extensions:

1. Students try to reconstruct the machine without being able to see.
2. Students work in groups and share ideas about how to overcome construction problems.
3. Students design a machine of their own choosing using additional materials. Then students come together in groups to create a machine that has a prescribed function. Discuss how different groups solved the same problem.
4. Work together in groups to construct the best machine. Explain why it is the best.

Student Information: MEMS and Nanotechnology

Scientists used information they learned while making **microchips** to create **micromachines** with electrical and **mechanical** parts. These machines are called **MEMS** or microelectromechanical systems. They have moving parts that are **microscopic** in size. Some of them are no bigger than the width of a human hair. These tiny machines do lots of useful tasks such as positioning satellites in space or tracking migration of salmon populations. They're even found in the latest **electronic** toys and moving dolls.

Scientists also realized that they could use **nanotechnology** to make even smaller machines. Nanotechnology is the science of building micromachines from single **atoms** and **molecules**. Atoms are the building blocks of all substances. They contain a **nucleus** and an **electron** cloud. As the electrons swirl around the nucleus, scientists are able to record their position using a **scanning tunneling microscope** (STM).

The STM uses a probe made up of only one atom. The electrons in this atom probe are attracted to the electrons in the sample when a **voltage** is applied. This causes the electrons in the sample to hop up to the probe. This hopping is then recorded and projected on a television screen. This way reserarchers can see where the atoms are located. If the sample is cooled, the electrons stop moving and the atom becomes almost motionless. Then the scientists can use the probe to move the atoms around in the surface of the sample.

By doing this, scientists have been able to make tiny motors with propellers, that are small enough to fit into human cells. Perhaps in the future these machines could float through the bloodstream administering medicine or fighting off disease.