Teacher's Preparatory Guide

Seeing Nano I: Using Scanning Electron Microscopy (SEM) to View Nano-size Objects

Purpose: To learn how to visualize nano-size objects using scanning electron microscopy (SEM)

Time required: 50-120 min

Level: Middle and High School (General Science, Biology, Physical Science, Physics, and Chemistry)

Big Ideas in Nanoscale Science: Tools and Instrumentation

Teacher Background

Nanotechnology is the study of objects that are 1-100 nm in size in one direction. Nano means one billionth (10^{-9}) and one 1 nm is equal to 10^{-9} meters. Nano-size objects have many applications that range from titanium dioxide nanoparticles in sunscreen that protect against UV radiation to silver nanoparticles that kill bacteria. Nano-size objects are smaller than the wavelength of light and due to their size cannot be viewed with a light microscope. Light microscopes have a limit of about 1,500X.

One device that can be used to magnify nano-size objects is a scanning electron microscope (SEM). The SEM, shown in Figure 1A, uses electrons to image the surface of a material. To image the object, an electron gun supplies electrons that bombard the surface of the object. The electrons travel down the chamber and are focused by a series of condensing lenses. These electrons excite other electrons out of the specimen which are captured by detectors. Detectors near the object's surface use the electron scatter to form an image, which is projected in gray-scale on a computer screen. The image seen on the screen is a generated model based on the scanning of the electrons. Depending on the device model, the resolution of a SEM can range from 5 to 10 nanometers. SEMs are important tools for observing nanoscale objects and features and have been important in the advancement of nanoscale science and engineering. It can magnify objects, such as pollen, up to a million times their normal size[1]. A SEM picture of pollen is shown in Figure 1B. What are some of the features that you notice in the magnified pollen that is not observable with the unaided eye?

Before beginning this exercise, you may want to have students do a size and scale activity such as: http://www.nnin.org/education-training/k-12-teachers/nanotechnology-curriculum-materials/size-and-scale or http://nanosense.org/activities/sizematters/sizeandscale/SM_Lesson2Teacher.pdf.

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Alternatively, you could have them investigate size and scale using interactive scales available at: http://www.mcrel.org/nanoleap/multimedia/Nanosize_me.swf ; http://scaleofuniverse.com/ ; or http://www.powersof10.com/. These activities will lay the foundation of how small nanoscale objects are. You should also stress that when objects are greatly magnified, as with an SEM, you need to use smaller units of measurement such as microns and nanometers. Another activity you could do with students is "The Pinch Test" (http://www.nnin.org/education-training/k-12-teachers/nanotechnology-curriculum-materials/pinch-test) which has students select the right tool to see different objects or SI prefixes.

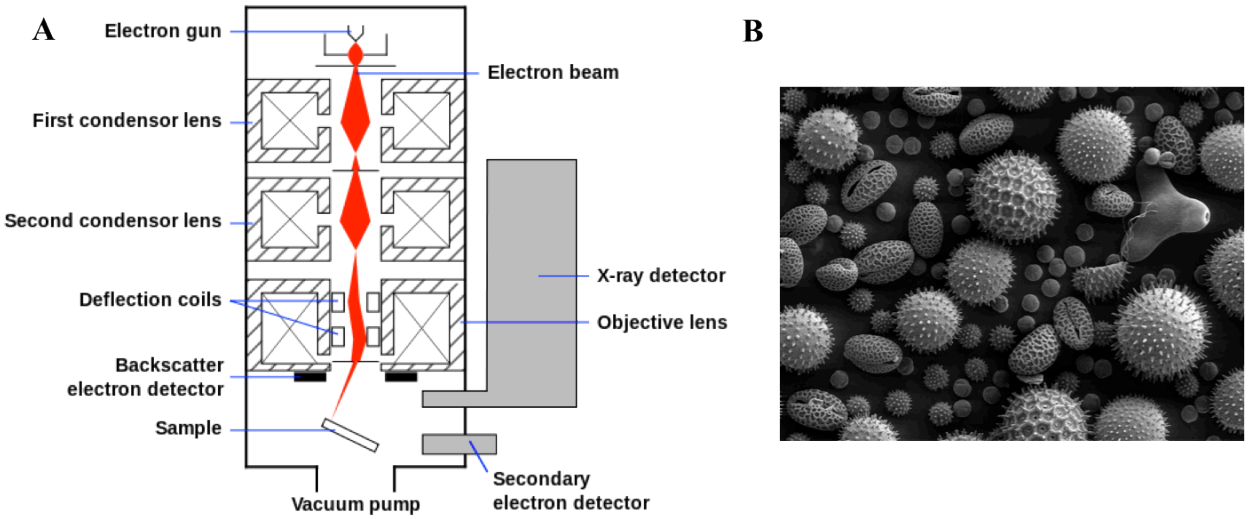

Figure 1: Schematic of a SEM (A) and a SEM image of pollen (B)[1,2].

Materials:

- Magnifying glass
- USB digital microscope (**optional**) such as ProScope, Dino-Lite, Motic® Ecoline
- Hitachi TM3000 Tabletop SEM (recommended but not required)
- SEM images of common objects (recommended objects include feathers, Styrofoam, seashells)
- Actual objects used for the SEM images for students to match to the images

Advanced Preparation: The teacher should review the background on nanotechnology, light microscopes, and scanning electron microscopy. General resources can be found on the Internet. If the teacher has access to a SEM, provide the students with a tutorial on how to use it and explain the types of samples that are appropriate for imaging. For Part 2 of the activity, the teacher can use the provided SEM images or find images online. The object to be magnified should be prepared in advance and provided to the student, if possible, so they can examine it with a magnifying glass (USB digital scope) to match it with its corresponding SEM picture. For example, place a feather in a petri dish, small box, or plastic bag for students to examine with a magnifying glass or USB digital scope.

Safety Information: Students should carefully handle all the objects with gloves. Live or very wet objects should not be used for imaging.

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Directions for the Activity: Part I will allow students to prepare and image objects using the SEM. For Part II, students will match an object with its SEM image.

Procedure:
If you have access to a SEM start with Part I, if not start with Part II.

Part I: Using the SEM

The recommended SEM for this activity is the TM3000 Tabletop SEM (Hitachi, Tokyo, Japan). Directions to operate the device can be found at http://www.hht-eu.com/hht-eu/nte/TM3000%20brochure.pdf. Other tabletop or standard SEMs can also be used to scan materials used in the activity. Some universities provide remote access to their SEMs for educational purposes such as these facilities:

- http://nano4me.org/remoteaccess.php
- http://www.nanotech.ucsb.edu/index.php?option=com_content&view=article&id=506&Itemid=15
- http://www.sci.sdsu.edu/emfacility/CUCMEoutreach.html
- http://www.ndsu.edu/em_lab/instrumentation/jeoljsm_6490lv/remote_sem_use/
- http://itg.beckman.illinois.edu/technology_development/remote_microscopy/
- http://www.sci.sdsu.edu/emfacility/CUCMEoutreach.html
- http://www.hssemgroup.com/students-enjoying-their-sems/web-sem

Student Worksheet
(answers in red)

Make a Prediction: How does a scanning electron microscope (SEM) image nano-size objects?

Materials Needed:

- Magnifying glass or USB digital scope (optional) such as Motic®Ecoline, ProScope, DinoLite
- Hitachi TM3000 Tabletop SEM (recommended but not required)
- SEM images of common objects (recommended objects include feathers, Styrofoam, seashells)
- Actual objects used for the SEM images for you match to the images

Procedure:

1. Prepare an appropriate specimen to image by adhering it to a specimen holder using carbon tape which allows for conduction. Ask your teacher about the type of specimens that can be imaged in the SEM. They need to be conductive. The preparation for the specimen will be dependent on the type of device that is used.

   The type of specimen that can be used for the SEM is dependent on the device. For the Hitachi TM3000 SEM the specimen information is found in the brochure link cited above. Typically, wet objects and live specimens cannot be imaged because samples are under vacuum.

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2. After loading your specimen into the SEM. Look at the projected SEM image at three magnifications (suggested magnifications 40X, 400X, and 4000X) and draw the images below. Label the magnification and the scale bar.

   The image will vary depending on the microscope, but more details should be visible as the magnification is increased.

3. How does the magnified image differ than the macro-size object (i.e. the whole object)?

   Details such as pores and patterns should be visible.

4. What are some unique features of the item that you can see with SEM that is not visible with the unaided eye?

   This will depend on the object but typically increased magnification provides greater detail of the object's surface.

Optional: Create a "Powers of Ten" poster showing our images with a description of what can be seen at each magnification used. Share this with the class.

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Part II: Identifying SEM Images

For this activity you will identify objects that have been magnified using a SEM. Use the magnifying glass and objects provided by your teacher to match the object to the correct SEM image.

1.

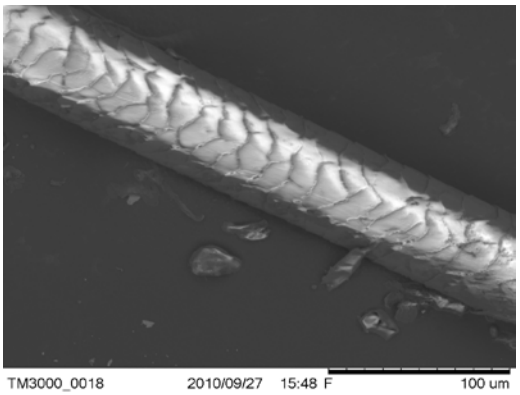

Image Name_____hair_____

2.

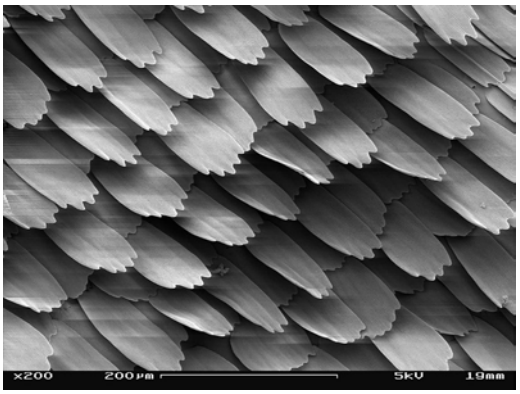

Image Name_____Butterfly wing_____

3.

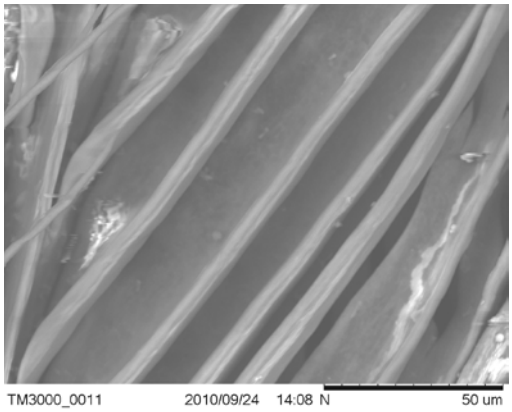

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Image Name_____feather_____

4.

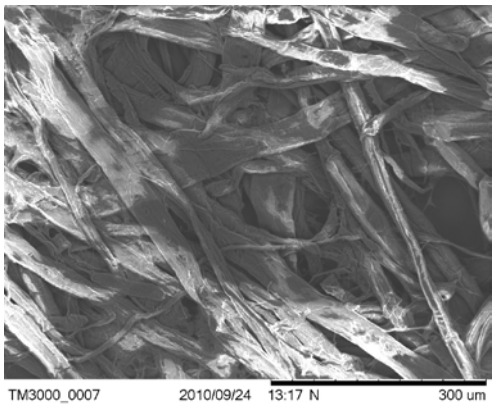

Image Name_____coffee filter_____

5.

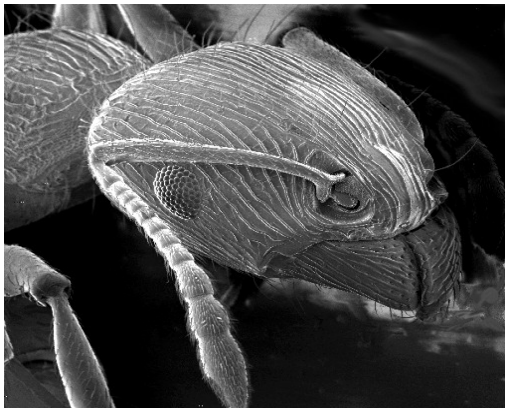

Image Name_____ant_____

6.

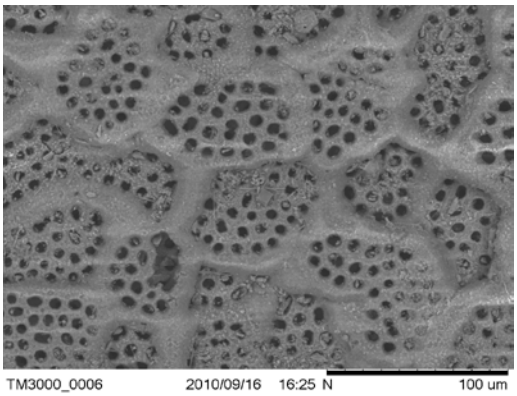

Image Name_____seashell_____

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7.

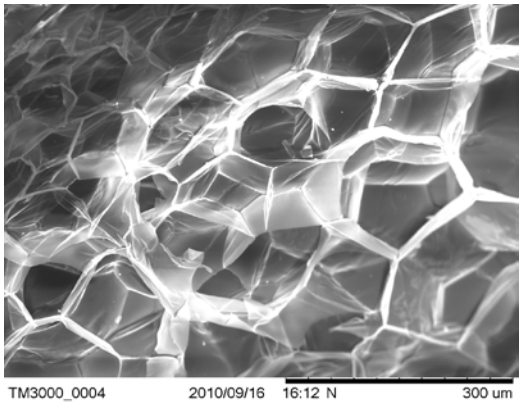

Image Name_____Styrofoam pellet_____

8.

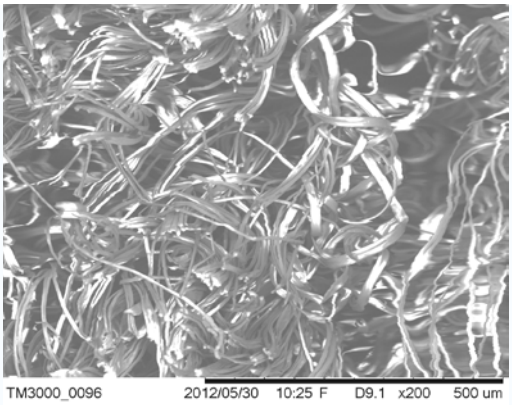

Image Name _____towel_____

9.

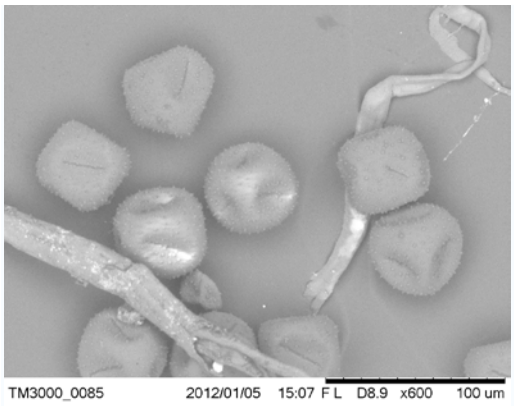

Image Name _____Christmas Cactus Pollen_____

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10.

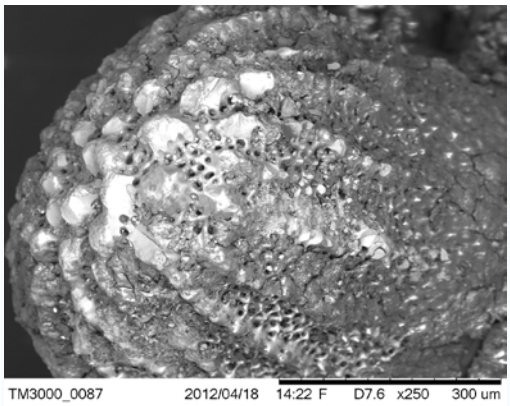

Image Name _____Starfish Spine (dried)_____

11.

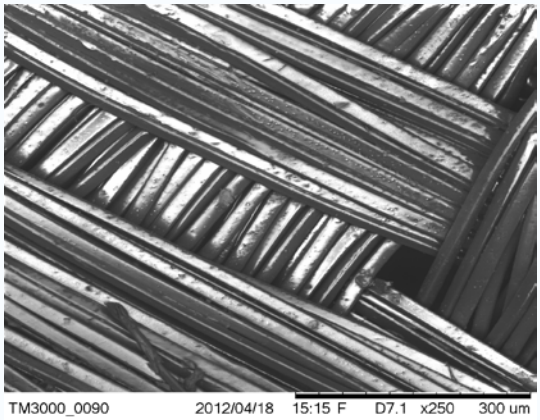

Image Name ____Carpet_____

12.

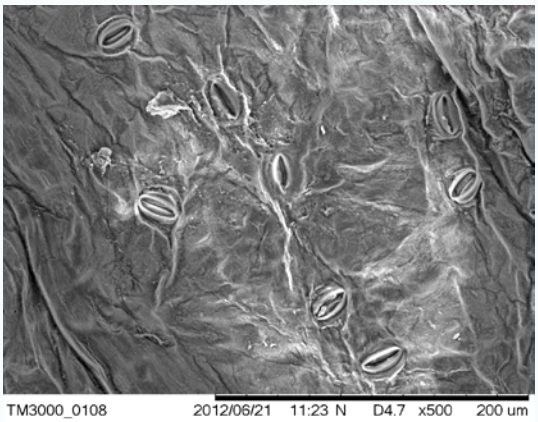

Image Name _____Rose petal (with stomata)_____

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Cleanup Collect all SEM specimens, objects, and magnifying glasses from the students at the conclusion of the activity. Students should discard the gloves and wash their hands.

Assessment

1. What does SEM stand for and what does it use to image objects?
   SEM stands for scanning electron microscope and it uses electrons to image objects.
2. How does SEM compare to the light microscope?
   Light microscopes use light and can image objects up to 1500x magnification. The images are in color. Light microscopes can be used to image living objects and wet samples. The scanning electron microscope uses electrons and can image items smaller than the wavelength of light including nanoscale obejcts. The pictures are not in color because light is not used. SEM cannot image living objects and wet samples.
3. In a typical SEM, samples must be coated with carbon or metal, why is this?
   Samples are coated to make the sample conductive (attracts electrons).
4. What are some of the limitations of using SEM for imaging?
   SEM cannot be used to image living organisms or wet samples because the samples are under vacuum. Non-conductive samples require a conductive coating which permanently alters the object. Size is also a limitation - small samples are required. Images must be artificially colored since they are not in color. A SEM is expensive and often requires expertise to operate it.
5. What features are visible on objects when viewed under SEM as compared in their macroscopic state (ex: pollen)? Patterns, pores, and other surface features can be seen with SEM. For the pollen, the different size and shapes are distinguishable with the SEM, but cannot be observed with the unaided eye.

Resources:

1. Williams, Linda, Adams, Wade. Nanotechnology Demystified. New York: McGraw-Hill, 2007.
2. http://en.wikipedia.org/wiki/File:Schema_MEB_(en).svg*
3. http://en.wikipedia.org/wiki/File:Misc_pollen.jpg
4. http://bayblab.blogspot.com/2008/07/sem-pics.html
5. http://en.wikipedia.org/wiki/File:Ant_SEM.jpg
6. How an SEM Works: http://science.howstuffworks.com/scanning-electron-microscope3.htm
7. Nanotechnology 101 http://nano.gov/nanotech-101

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National Science Education Standards (Grades 5-8)

Content Standard A: Science as Inquiry
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science
- Properties and changes of properties

Content Standard C: Life Science
- Structure and function in living systems

Content Standard E: Science and Technology
- Abilities of technological design

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- Understanding about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Science and technology in society

National Science Education Standards (Grades 9-12)

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science

- Structure of atoms
- Structure and properties of matter

Content Standard E: Science and Technology

- Abilities of technological design
- Understanding about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Science and technology in local, national, and global challenges

Next Generation Science Standards

MS-LS1-1

- Planning and carrying our investigations
- Obtaining, evaluating, and communicating information.

HS-LS1-3

- Planning and carrying out investigations
- Scientific investigations use a variety of methods

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