Optical Simulation of a Transmission Electron Microscope

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Subject: Physics
Grade Level: 11, 12
Standards: *NY State Physics Core Curriculum*

Standard 1: S2.1 Devise ways of making observations to test proposed explanations. Design an experiment to investigate the relationship between physical phenomena

Standard 4: 4.3 Diffraction occurs when waves pass by obstacles or through openings. The wavelength of the incident wave and the size of the obstacle or opening affect how the wave spreads out.

Standard 6: 3.1 Describe the effects of changes in scale on the functioning of physical, biological, or designed systems.

Schedule: Two 50-minute class periods (one double lab period)

Description:

Students, in groups of 2 or 3, will build and analyze an optical simulator of a Transmission Electron Microscope (TEM) with the use of a light source, a 35 mm slide, several glass lenses, and a few other parts that will be mentioned in the Materials section. The light source will represent the TEM's electron source, the 35 mm slide represents the sample being investigated, and the glass lenses represent the electromagnetic lenses.

Objectives:

- Students will learn to use lenses and a light source to construct a model of a TEM.
- Students will learn the components of a TEM and see their analogous members in the optical model.
- Students will learn the function of each component in their model and compare and contrast to the function of the analogous component of the TEM.
- Students will learn some conditions necessary to use a TEM and model those conditions in their optical model.
- Students will research into the operation of a TEM.

Vocabulary:

- **Aperture**
- **Condenser Lens**
- **Converging Lens**
- **Electron Source**
- **Magnification**
- **Objective Lens**
- **Phosphorescent-Screen**
- **Projector Lens**
- **Resolution**
- **Sample**
- **Wavelength**

Materials:

- 100 – 150 Watt light bulb and lamp; Variac desirable to vary brightness
- 2 Converging lenses (5 cm diameter, 10 cm focal length)
- 1 Converging lens (5 cm diameter, 20 cm focal length)
- Lab jacks (or wood blocks) & modeling clay for mounting lenses and slide
- 2 3X5 cards, one with a 1 cm hole in center
- 35 mm slide with picture (black and white preferable) or 35 mm piece of transparent plastic with picture drawn upon it
- Stack of five 35 mm slides, with pictures
- A cross-hatched diffraction grating in a slide or from glasses

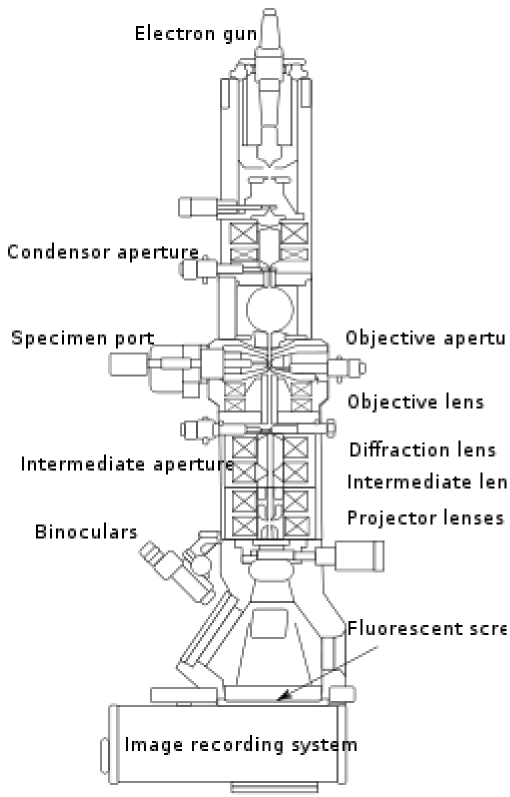
Safety:

Bulb is hot. Students need to be careful handling lamp and the bulb. Bulb is also bright. Students need to exercise care not to look directly at the lit bulb in the dark room.

Science Content for the Teacher:

The Transmission Electron Microscope (TEM) is one of a variety of what are known as electron microscopes, including Scanning Electron Microscopes (SEM) and Scanning Transmission Electron Microscopes (STEM). The TEM was the first electron microscope invented, in 1931 by Ernst Ruska and Max Knoll. In some ways, a TEM is analogous to the operation of an optical microscope, which was the impetus for the lesson. An optical microscope has a visible light source, a sample, and glass lenses to form the enlarged image of the sample. Depending upon the optical microscope, light may be reflected from a sample or transmitted through a sample…if transmitted, the sample must generally be thin. A TEM has an electron source, a sample through which electrons are transmitted, and electromagnetic lenses to form the image. The reason behind the need for an electron microscope, which is physically more complex than an optical microscope, is due to the wave nature of both light and electrons and the ability to resolve points that are separated in space. Assume light passes through two holes in a microscope slide and you wish to distinctly see (resolve) the two holes. The closer together the two holes, the more difficult it is to resolve them. Due to the wave property of light known as diffraction, when light passes through the holes it spreads out…the wider the whole, the less the spread, the narrower the hole, the more the spread. If the holes are small and very close together, then the spreading of light through the two holes may be such that their regions of spread overlap and you can not resolve the two holes as distinct from one another. One way to help resolve the holes again has to do with a feature of light, it's wavelength, and its effect upon diffraction. The smaller the wavelength of light, the less diffraction it experiences when passing through the hole (or around the edge of an object). Therefore, resolution can be improved by using light of a smaller wavelength…with visible light, this is light toward the violet end of the spectrum. Unfortunately, even with violet light, the wavelength is approximately 400 nanometers, and it happens that the ability to spatially resolve objects can be approximately no better than the light being used. Therefore, this limits optical microscopy to a 400 nm, though there are techniques to improve this somewhat. However, if one wishes to look at objects whose sizes are considerably smaller than this, such as very small cellular components, grain structures of a crystal, or interatomic spacing, visible light if no good. Even ultraviolet light, which can be imaged with appropriate screens, is much too large. X-rays of wavelengths much less than 1 nm, which can be detected, are useful for certain characteristics based upon diffraction patterns produced by atomic spacings in crystals, however actual imaging techniques are not yet available. Which is where the electron enters the scene. As first elaborated upon by Louis de Broglie in 1924, matter such as electrons possess a wavelike nature and therefore can be subject to diffraction. However, the faster the electron moves, the shorter its wavelength. Plus, moving electrons paths can be diverted by electric and magnetic fields, therefore allowing a beam of them to be focused onto a phosphorescent screen, much as light can be focused with glass lenses onto a screen.

The main features of a TEM are an electron source, an electric field used to accelerate the electrons to a high speed, condenser lens(es) to focus the beam upon a small portion of a thin sample, an objective lens to form the first image, subsequent (intermediate and projector) lenses to increase the magnification, apertures for the lenses, and a phosphorescent screen upon which to project the final image. It should be noted that the lenses are all electromagnetic.



(source: Wikipedia)

Classroom Procedure:

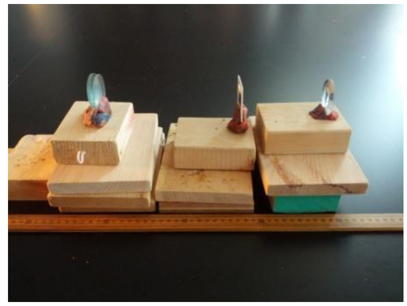
Prior to this activity, students should go to the site TEM Basics http://www.matter.org.uk/tem/ and read sections A through G. Particular emphasis will be placed upon section G, which employs the various lenses used in TEM. Students should also be familiar with geometric optics and images formed with single lenses. A short introduction into the wave nature of light, particularly diffraction, is also suggested.

Setting up the apparatus:

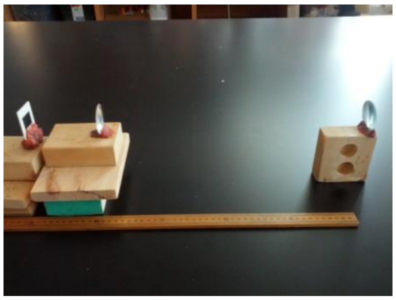
- Obtain all the equipment. You will need approximately two meters to lay out the various components…a lab table would be ideal.
- Place the light source at one end of the table with the bulb about 15 cm above the table. All subsequent elements must be at the same height above the table as the center of the bulb. The lenses and screen can be mount with modeling clay upon labjacks or pieces of wood.
- Place the 15 cm focal length lens about 40 - 80 cm from the light source.
- Place the 35 mm slide about 20 cm from the first lens.
- Place one of the 10 cm focal length lenses about 15 cm from the sample (the sample is about 1.5 times the distance of the focal length).
- Place the last 10 cm lens around 35 cm from the second lens. A 3X5 card, or some other appropriate screen, will be placed somewhere beyond the third lens, at a position where an image can be clearly focused upon the screen. The third lens' position will probably have to be adjusted such that the final image produced by it upon the screen is sufficiently large and visible.

Please refer to the photos to see sample placements and alignments.

Light source, first lens, 35 mm slide, and second lens

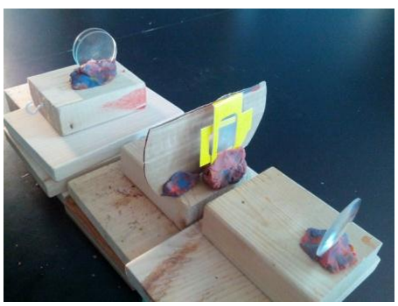


First lens, 35 mm slide, and second lens

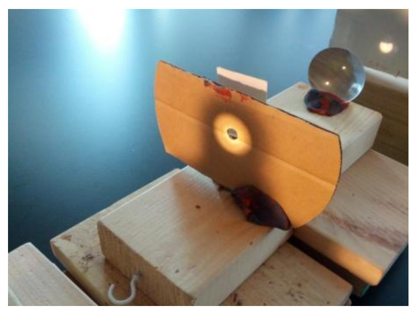


35 mm slide, second lens and third lens

Third lens and screen for image (placed in shoebox to reduce stray light)



First lens, aperture, diffraction grating, and second lens



Aperture in front of diffraction grating

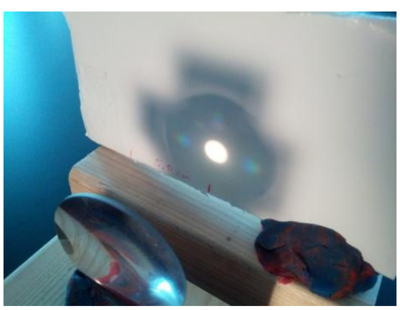


Image of diffraction pattern from grating, produced in focal plane of second lens

Image of 35 mm slide formed by third lens

Extensions:

1. Students can place a colored filter in front of the condenser lens in order to compare it to the use of a single energy of electrons in a TEM.
2. Students can use the diffraction pattern produced with the diffraction grating to determine the vertical and horizontal line spacing of the grating. This could be contrasted with the use of the diffraction pattern in a TEM to determine interatomic spacings.
3. Students can move the 35 mm slide to illuminate various portions of the slide and therefore highlight various portions of the image and then contrast this to the manner in which a TEM scans different regions of a sample.
4. Contact a college or university that may have remote access to their electron microscope facilities in order to get control and obtain actual data from an electron microscope.
   (http://www.hssemgroup.com/students-enjoying-their-sems/web-sem is a site listing remote access SEM facilities, which can be used by high school students)

Assessment:

Students will complete the attached student sheets. Assessment will be based upon the work submitted on the sheets, along with the participation in the classroom procedure.

Acknowledgements:

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http://www.matter.org.uk/tem/ 'TEM Basics ', from matter.org ; student and teacher resource