A. What You Already Know

Write down what you already know about what happens when light passes through small openings or hits small obstacles.

B. Examples of Diffraction

1. Describe the wave motion you see in the image below.

![Image of wave motion](image credit: Fjellanger Widerøe A.S.; image found at http://www.math.uio.no/~karstent/waves/index_en.html ("Rogue Waves Extreme Waves"))
2. We can observe water wave diffraction with a ripple tank—look at the simulations of water waves below. The lines that you see in the images are called *wavefronts*; wavefronts connect points on the wave with the same phase.

from the University of Melbourne’s “School of Physics Ripple Tank”
http://lecturedemo.ph.unimelb.edu.au/Wave-motion/Wave-properties/Wa-3-The-Ripple-Tank

3. Compare the two images above with the photograph of ocean waves on page 1.

4. Based on the two ripple tank images above, how do you think the width of the opening in the barrier affects the pattern of waves that are produced on the other side of the slit?

5. The drawings below show diffraction with sound waves. How are the sound waves shown in these drawings similar to the water waves that you saw above?

If a marching band is approaching on a cross street, which instruments will you hear first?

High pitched piccolo, short wavelength.

High pitched sounds tend to be more directional because they don’t diffract as much.

Low pitched bass drum, long wavelength.
C: Diffraction by Your Fingertips

Safety note: Stay at least 10 feet from the lamp.

1. Find the bright light bulb in the front of the room with the vertical filament.

2. Bring your finger and thumb together in front of your eye to make a small opening and look at the lamp through the opening. What do you see as you bring your finger and thumb slightly closer together or further apart?

3. Now find the red and blue plastic filters. Repeat step 2 above, but this time look through one of the filters. How does what you see now differ from what you saw in step 2?

4. When you bring your finger and thumb together, compare what you see through the red and the blue filter.

5. You can do the same experiment, but without the filters and light bulb, if you look through the slit made with your fingertips at a distant colored light at night.

D: Varying the Slit Width

1. Find the two pencils that are held together with rubber bands. Notice that there is a short piece of rubber band near one end, which produces a slit between the pencils.
2. Look at the lamp through the slit between the pencils and squeeze the pencils together. What do you see?

3. As you squeeze the pencils together, what happens to the width of the slit? With this in mind, can you relate this change in the pattern you see to anything you observed in activity B?

4. This time, look through a red or blue filter as you squeeze the pencils together. What do you see, and how is it different when you look through the red or blue filter?

E: Looking at the Lamp through Narrow Slits

1. Find the microscope slide and examine it with the magnifier. Notice that one side has been painted black, and slits have been cut into the paint. Find the individual slit, the pair of parallel slits, and the two slits that cross.

Safety note: Stay at least 10 feet away from the lamp.

2. Look at the lamp through the slits. Describe what you see through each kind of slit.

3. Repeat step 2, but this time look through either the blue or the red colored filter. Compare what you see when looking through each filter.

4. Find the single slit on the microscope slide. Hold the red filter so it overlaps the slide. Compare what you see when you look just through the red filter with what you see when you look through both the red filter and a single slit. Repeat with the blue filter.

5. Compare what you saw through the slit scratched on the paint with what you saw through the two pencils. How can you relate the width of the diffraction pattern to the size of the slit?
6. Now let's switch to particles. On the drawing below, show what happens when the particles, whose velocities are represented by arrows, pass through the slit.

7. Based on your answers to parts 4 and 6, answer this question: Does light exhibit the properties of a wave? Explain your reasoning.

F: Shining a Laser Beam on Narrow Slits

Laser safety notes:

- Laser light can burn your eye, causing permanent damage.
- Never look into the laser beam.
- Never look at laser light reflected off of a highly reflective surface. Instead, view the reflection of the beam from a less reflective surface, for example, from a piece of paper.
- Be careful to keep your eyes well above the laser beam; sit normally, and keep the laser on the tabletop or the top of the box.

1. Set up the screen, which will serve as a backstop. When you set up the laser, keep it pointed at the screen.

2. Find the small cardboard box with the rubber band wrapped around the top.

3. Mount the slide on the cardboard box by slipping it underneath the rubber band, as shown in the drawing at the right. Orient the slide so the painted side faces back towards the box. (That's so the laser beam will hit the paint, not the glass surface, to prevent reflections—the laser will sit on the box.)
5. Now bring the laser up close to the painted side of the microscope slide, oriented so that the beam will point toward the screen.

6. Press down on the button to turn the laser on. Move the laser back and forth along the slide (horizontally) and observe the patterns you see on the screen as the beam hits the various slits that have been scratched in the slide. Describe what you see in each case.

7. When you shine the laser beam on the two slits that intersect, tilt the laser up and down slightly to change the separation between the slits. How does changing the direction of the beam affect what you see on the screen?

8. Visit the Hyperphysics URL "Single Slit Diffraction for Different Slit Widths" at http://hyperphysics.phy-astr.gsu.edu/HBASE/phyopt/fraungeo.html to see the diffraction patterns made by slits with different widths.

Activity G: The CD and DVD -- Diffraction Gratings

1. Slip the CD under the rubber band around one of the long sides of the cardboard box, so the uncovered part of the silvered side faces toward the box and is near one end. Add the CD-ROM and orient it in the same way, as shown in the drawing below.
2. Bring up the laser so the laser is as close to the exposed rectangle of the CD as possible. To make a backstop for the laser beam, bring the screen as close to the back of the box as you can, as shown in the drawing.

3. Compare the spacing of the tracks in the CD to the spacing between the pairs of slits scratched onto the painted microscope slide. Now relate this difference in spacing to the difference that you see in the diffraction patterns.

4. Tilt the laser slightly down so that the beam hits the exposed surface of the CD and then reflects onto the paper. What do you see?

5. Now repeat the above steps for the DVD.

6. Compare the diffraction patterns you saw for the CD and the DVD. Here is some useful information:
   CD track spacing: 1.6 µ (1 µ is 1 millionth of a meter)
   DVD track spacing: 0.74 µ
Activity H: Two-Dimensional Systems of Slits

1. Find the 35mm slide with metal mesh, and the other two pieces of unmounted mesh. This mesh has openings running in two perpendicular directions, with:
   - 50 x 50 wires per inch
   - 120 x 120 wires per inch
   - 200 x 200 wires per inch

2. With the laser on the cardboard box, and aimed at the backstop, hold the mesh pieces in the laser beam. Describe the patterns that you see, and how these patterns are different for the different kinds of mesh.

3. How are the patterns of your observations similar to patterns of observations in the previous activities?

Activity I: A Two-Dimensional Diffraction Grating

1. Find the 35mm slide that says "double axis diffraction grating." Mount the slide underneath the rubber band on the cardboard box. The grating on the film has two sets of perpendicular grooves, with 13,500 grooves to the inch.

2. Place the laser on the cardboard box and orient it so the beam will pass through the film and hit the screen. Turn on the laser. Describe the pattern that you see on the screen.

3. The material in the slide mount has slits running in two perpendicular directions. How does that help make the pattern that you observed plausible?

Activity J: Two-Slit Interference

1. To explain how diffraction happens, let's start with two-slit interference. The diagram below shows two sets of semicircular wave crests, produced by two slits.
2. Compare this diagram with the image on page 2, the one that showed diffraction of water waves through a single slit. How is this diagram similar to the image above?

The difference between the diagram and image on page 2 is that in the diagram above, there are two sets of semicircular waves, spreading out from two slits, and these waves interfere with each other.

3. Write a few sentences to describe what happens in wave interference.

4. Since the diagram above has a screen, let's think about light. Find a place on the screen where two crests meet. What would you see on the screen?

5. Find a place on the screen where a crest meets a trough. What would you see on the screen?

6. Starting in between the slits, look for lines where crest meets crests, or crests meet troughs; lines that extend all the way to the screen. Describe these lines.
7. Still on two-slit interference, but switching to water waves, look at the image below. Can you see the lines of big waves, alternating with lines of no waves? (If you visit the website, you can see this diagram animated.)

This University of Hannover image is from "Multi-beam interference: irridesence, luster..." at http://www.itp.uni-hannover.de/~zawischa/ITP/multibeam.html.

8. Looking back over your work today, where did you see two-slit interference?

Activity K: Wavelets

1. The drawings below shows what are called Huygen's wavelets:


In this model, each wave crest is the source of many circular wavelets, which are in phase. As mentioned earlier, lines that connect waves with the same phase are called wavefronts.

- Above, the wavelets show how straight and circular waves propagate.
- In the drawing on the next page, wavelets show what happens when straight waves strike a slit.
2. The image above shows what happens when a wave represented with wavelets goes through a slit, so part of the wavefront is cut off. (For another example, see the images at the top of page 2.) We can see how the wavelets form the waves that emerge from the slit. Notice that some of these waves move out into the region above and below the slit. Also, these wavelets can interfere to produce diffraction bands.

3. We can understand diffraction as interference from wavelets made in different parts of the slit. It's as though the slit were made up of separate pieces, side-by-side, with each piece putting out semicircular waves that interfere with each other. (See the diagram above.)

4. Below is an example from astronomy. This succession of images shows the same double-star system photographed through a series of telescopes of increasing aperture, moving from left to right, from .15 m on the left to .51 m on the right. The number above each image gives the aperture of the telescope.

5. How does what happens to the image of the double star make sense in terms of what you have learned about diffraction? (Think about diffraction patterns produced by large and openings of different sizes.)

Activity L: Diffraction Pattern of Human Hair

1. Find the 35mm slide mount. Have each person in your group contribute a hair, and tape them across the slide mount, with all the hairs parallel.

2. Because the diffraction pattern of hair is faint, it's necessary to prevent room light from hitting the screen. Set up the screen by fastening a white piece of paper to the bottom of a cardboard box, and setting the box on its side so the laser beam can hit the paper.

3. Mount the slide on the cardboard box with the hairs running up and down, as shown, and shine the laser one slide so the beam hits the screen. What does the pattern look like?

4. How is the pattern on the screen different for the three different hairs? Can you relate this difference to the thickness of the hairs?

5. To learn more, Google "Babinet's Principle,"

Summary

Write down what you now know about diffraction. Try to emphasize what happens when light passes through small openings or hits small obstacles. Cite specific activities to provide evidence for your main ideas.

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**Extension: Moire Patterns**

Look at the projection of pairs of concentric semicircles. This is a model of the interference pattern of two slits, as their separation increases.

- Everywhere a line from one pattern falls on a line from the other pattern, the waves reinforce and produce large waves.
- Where a line from one pattern lies equally distant from two lines in the other pattern is a node--that's where complete cancellation occurs and no waves are found.
<table>
<thead>
<tr>
<th>Item</th>
<th>Possible Sources</th>
<th>Cost</th>
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<tbody>
<tr>
<td>Class 2 laser pointer</td>
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<tr>
<td>Microscope slides</td>
<td>Science supply company</td>
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<tr>
<td>Crossed diffraction gratings in 35mm slide mounts</td>
<td>Edmund Scientifics</td>
<td>$39.99 for package of 80</td>
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<tr>
<td>Medal wire cloth</td>
<td>McMaster-Carr</td>
<td>For 12&quot; x 12&quot; sheets: $3/sheet for 50 x 50, $24/sheet for the other two</td>
</tr>
<tr>
<td>Medal wire cloth</td>
<td>McMaster-Carr</td>
<td></td>
</tr>
<tr>
<td>Cardboard boxes to support the CD, DVD, and slide mounts</td>
<td>These 6 inch long boxes hold business cards are available at local printing companies.</td>
<td>About $1 per box</td>
</tr>
<tr>
<td>Flat black enamel paint (for painting microscope slides)</td>
<td>Hobby shop</td>
<td>$3 for a small bottle</td>
</tr>
<tr>
<td>Magnifier</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plastic filters, Roscolux #80 (primary blue) &amp; #27 (medium red); each is 20&quot; x 24&quot;</td>
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<tr>
<td>Magnifier</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concentric circle transparencies</td>
<td>Staples or Kinko's</td>
<td>about $4 for both two copies of each</td>
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</table>
National Science Standards Addressed by Diffraction

National Science Education Standards (NSES)

Abilities Necessary to Do Scientific Inquiry
- Design and conduct scientific investigation: use evidence, apply logic, and construct an argument for... the proposed explanations.

Benchmarks for Science Literacy

Scientific Inquiry
- [Scientific investigations] all have in common certain basic beliefs about the value of evidence, logic, and good arguments.

Motion
- Waves can superposed on one another, bend around corners... all these effects vary with wavelength...