Diffraction

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Subject: Physics
Level: High School Physics students
Standards: *New York State- Physics* *(www.emsc.nysed.gov/ciai/)*
Standard 1- Analysis, Inquiry and Design
Standard 4.31- Diffraction occurs when waves pass by obstacles or through openings.
Standard 7- Interdisciplinary Problem Solving
Schedule: Two to three 45-minute class periods

Objectives:

Learn about principles of light and light waves. Discover how diffraction and interference of light waves can be used to measure.

Students will:

- Examine diffraction patterns from a range of objects using a laser pointer.
- Work with the diffraction from metal meshes to gain quantitative confirmation of the wave nature of light
- Measure the track spacing on CDs and DVDs using the wave model of light
- Apply their experience of light diffraction to electron and X-ray diffraction images of matter
- Review and discuss concepts learned throughout the activity

Vocabulary:

Diffraction
Frequency
Wavelength
X-ray

Materials:

For Each Pair/Group:
Laser pointer
Ring stand & clamp to hold CD/DVD
Ring stand & clamp or wooden block to hold laser
Binder clip for laser
Projection screen
Meter stick
Ruler*
Magnifying lens
2cm X 2cm piece of fine wire mesh
2cm X 2cm piece of coarse wire mesh
CD
DVD
Hair mount
Activity Sheet 1: *Diffraction & Interference of Light*
Activity Sheet 2: *Wire Mesh Activity*
Activity Sheet 3: *CD/DVD Activity*
Activity Sheet 4: *Hair Thickness Activity*
Activity Sheet 5: *Further Questions*

For Teacher:
Prism
Chalk Dust*
Magnifying lens
Adjustable slit

*Provided by the teacher

Safety:

Students should use extreme caution when operating the laser pointer. The laser beam should never be pointed at anyone's eyes.

Science Content:

Pre-Teaching Concepts:

- Light is a wave.
- Wavelength of light is small.
- Spectrum of light is due to wavelength of light.
- Some exposure to milli, micro and nanometers.
- Ideally, students have seen water, sound or other physical waves diffract.
- Students must think through the difference between projection and diffraction.

What is LASER Light? Laser light is monochromatic, collimated, and coherent.

- Monochromatic- All the light waves are of the same frequency. It looks like one color. It does not spread out after passing through a prism.
- Collimated- All the light waves are parallel. Show the spot does not spread out. Use chalk powder to show the light path. Talk about bouncing lasers off the Moon.
- Coherent- All the light waves are in phase. Use a magnifying lens to spread out the laser beam into a broad spot on the screen. There are black and bright patches all across the spot. This is called "speckle" and only occurs for lasers and other types of coherent light.

- Materials needed: Prism, Chalk dust, and a magnifying lens.

Reciprocal Nature of Size and Angle –

Pass laser light through an adjustable slit. As the slit narrows the diffraction pattern grows in size. Small objects diffract widely. Large objects diffract a smaller amount.

- Materials needed: Adjustable slit

Preparation:

1. Photocopy print materials (*Activity Sheets 1-5*) for each student pair or group.
2. Distribute materials evenly to each student pair or group.

The following items can be purchased online from http://www.mcmaster.com/:

Item	Quantity	Part Number	Price
Wire Mesh 50 x 50 mesh/in. 0.009" wire dia. 0.011" opening width	1 sheet, 12"x12"	85385T865	$5.92
Wire Mesh 100 x 100 mesh/in. 0.0045" wire dia. 0.0055" opening width	1 sheet, 12"x12"	85385T872	$6.20
Wire Mesh 200 x 200 mesh/in. 0.0021" wire dia. 0.0029" opening width	1 sheet, 12"x12"	85385T877	$11.42
Wire Mesh 325 x 325 mesh/in 0.0014" wire dia. 0.0017" opening width	1 sheet, 12"x12"	85385T883	$18.02

Classroom Procedure:

Day One

Engage (Time: 15 mins)

Discuss the basic concepts of light outlined in 'Science Content' with the students. Demonstrate the 'Pre-Teaching Concepts' and discuss the terminology. When performing the demonstrations, ask students to try to explain the phenomena they are witnessing before giving them the answer.

Explore (Time: 20 mins)

Divide students into groups of two or three to complete the four activities:
1) Wire Mesh Activity
2) CD/DVD Activity,
3) Hair Thickness Activity
4) Further Questions.
Distribute all print materials (Activity Sheets 1-5) to each student pair or group. Students should begin working on Activity Sheets 1 and 2.

Explain (Time: 10 mins)

Have the class come together for a discussion of what they learned. Discuss the lab questions as well as any points the students are still unclear about. (Answers provided in 'Supplemental Information' at end of document.)

Day Two

Engage (Time: 5 mins)

Review the concepts students learned the previous day and answer any further questions they may have.

Explore (Time: 30 mins)

Students should begin working on Activity Sheet 3: CD/DVD Activity. Encourage the groups to try to complete most of Activity Sheet 4: Hair Thickness Activity before the end of the class period.

Explain (Time: 10 mins)

Allow time for a question and answer session. Review and discuss the concepts learned during the day's activity.

Day Three

Explore (Time: 30 mins)

Students should complete Activity Sheet 4 before continuing with Activity Sheet 5. Encourage discussion within groups once the students begin working on the last activity sheet.

Explain (Time: 15 mins)

Have the class come together for a question and answer session. Ask different groups the lab questions and have them explain their findings and answers. Answer any questions the students may have regarding the principles they learned.

Assessment:

The following rubric can be used to assess students during each part of the activity. The term “expectations” here refers to the content, process and attitudinal goals for this activity. Evidence for understanding may be in the form of oral as well as written communication, both with the teacher as well as observed communication with other students. Specifics are listed in the table below.

1= exceeds expectations
2= meets expectations consistently
3= meets expectations occasionally
4= not meeting expectations

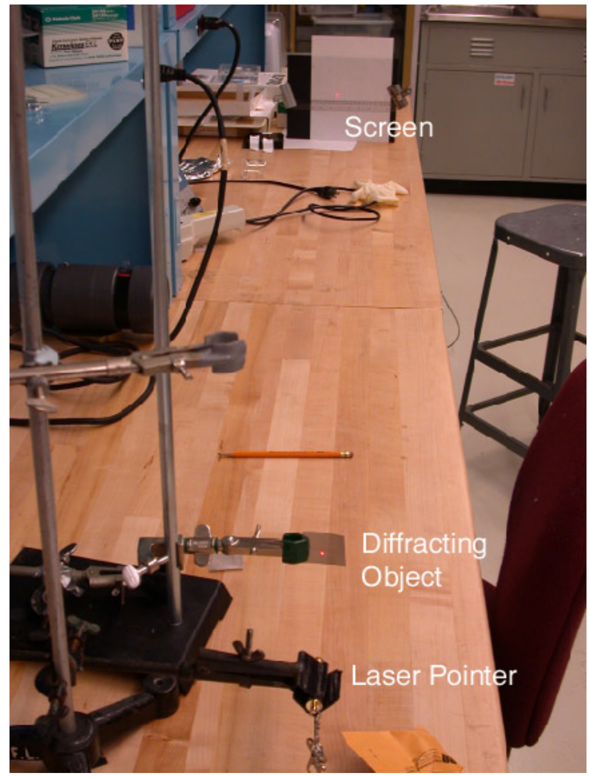
	Engage	Explore	Explain
1	Shows leadership in the discussion and offers creative ideas reflecting a good understanding of the physics behind light waves.	Completes work accurately while providing an explanation for what is observed. Works very well with partner.	Provides an in-depth explanation of findings, making good use of vocabulary terms. Fills out worksheet clearly.
2	Participates in the brainstorm and shows an understanding of the physics related to light waves.	Completes work accurately and works cooperatively with partner.	Provides clear explanation of findings. Fills out worksheet clearly.
3	Contributes to the brainstorm, but shows little understanding of light waves.	Works cooperatively with partner, but makes some mistakes with the procedure.	Provides a limited explanation of findings. Fills out some of the worksheet.
4	Does not participate in brainstorm. Shows no understanding of light waves.	Has trouble working with partner. Does little to complete the procedure.	Is not clear in explanation of findings. Does not fill out worksheet.

Supplemental Information:

WIRE MESH Activity

Section One:

Mesh #1 has 50 lines per inch (d ≈ 0.500 mm)
Mesh #2 has 100 lines per inch (d ≈ 0.250 mm)
Mesh #3 has 200 lines per inch (d ≈ 0.125 mm)
Mesh #4 has 325 lines per inch (d ≈ 0.076 mm)



-For mesh #1:

d = 0.500 mm (50 lines per inch)

$w = L \times \lambda \div d$

$= 2\ m \times 6.5x10^{-7}\ m \div 0.0005\ m$

= 2.6 mm = dot-dot spacing in pattern

-For mesh #2:

d = 0.250 mm (100 lines per inch)

w = 5.2 mm = dot-dot spacing in pattern

-For mesh #3:

d = 0.125 mm (200 lines per inch)

w = 10.4 mm = dot-dot spacing in pattern

-For mesh #4:

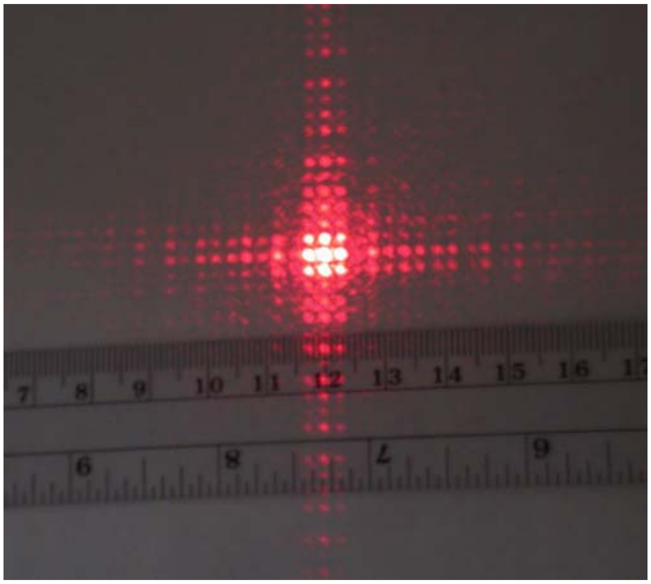
d = 0.076 mm (325 lines per inch)

w = 17.1 mm = dot-dot spacing on pattern

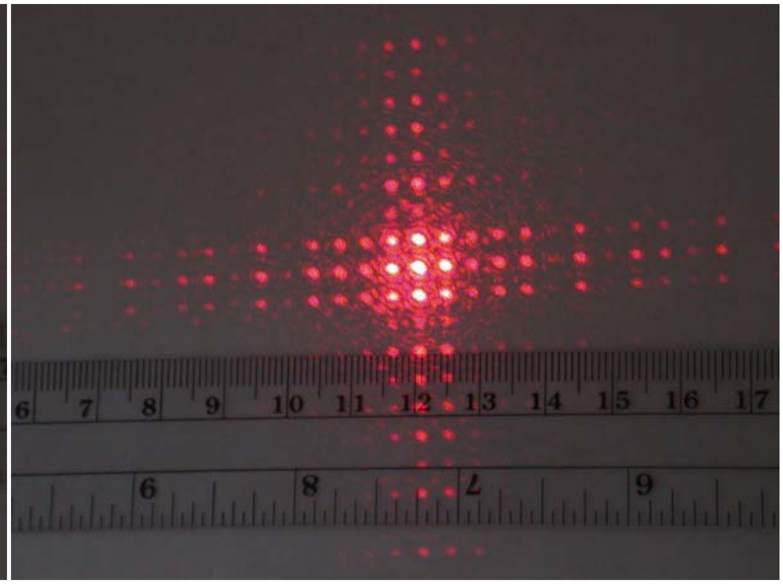
Section Two Questions:

1. Will the fine mesh produce a larger or smaller diffraction pattern spacing than the coarse mesh?

   The fine mesh will produce a larger diffraction pattern.



Coarse Mesh (w ≈ 2.5 mm)



Fine Mesh (w ≈ 5 mm)

Section Three Questions:

1. Which mesh produced the larger diffraction pattern? Coarse mesh or fine?

   The fine mesh produced a larger diffraction pattern.

2. Did the size of each diffraction pattern match the prediction you made?

   Several things can affect accurate measurements such as miscounting when viewing the mesh through the magnifying glass.

3. Suppose a third wire mesh produced a diffraction pattern with a spacing of w = 8 mm. Would the mesh be?
   a. Larger than the coarse mesh.
   b. Smaller than the coarse mesh but larger than the fine mesh.
   c. Smaller than the fine mesh.

   The answer will depend on which of the four meshes were used for the first sections.

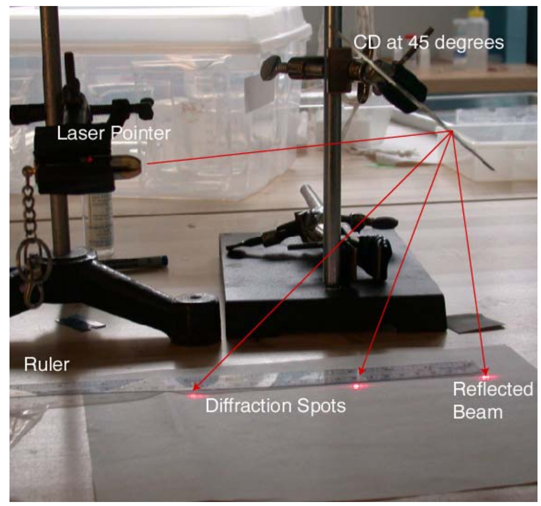
CD/DVD Activity

Section One Questions:

1. Note at least two observations about the CD and DVD.
    - *The CD and DVD split white light into a spectrum of color.*
    - *The colors that are seen in the CD and DVD are different.*
2. What are the differences you notice between the CD and DVD?

    The DVD sprays the colors over wider angles because the lines on it are far closer.

Section Two Questions:



CD Diffraction

CD - L = 9 cm

w = 4.5 cm

Track Spacing = $L \times \lambda \div w$

= 9 cm × 0.65 microns/ 4.5 cm

= 1.3 microns

Tracks per mm = 770 tracks/mm

Accepted track spacing is 1.6 microns.

DVD- L = 9 cm,

w = 14.5 cm

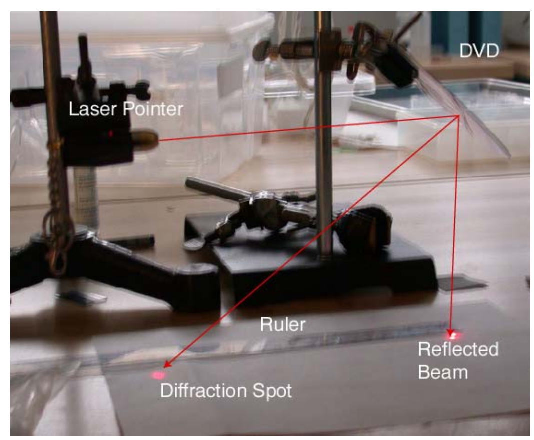
Track Spacing = $L \times \lambda \div w$

= 9cm × 0.65 microns/ 14.5 cm

= 0.5 microns

Tracks per mm = 2000 tracks/mm

Accepted track spacing is 0.74 microns.

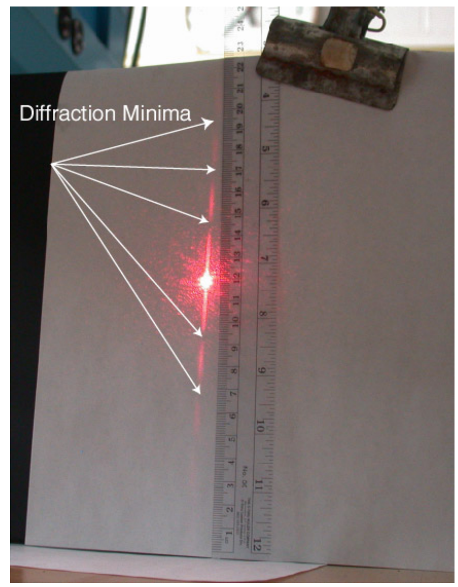


DVD Diffraction

Measurements can vary greatly in this activity. One common place of error is that the CD/DVD is not exactly at 45^0. This can drastically change the w measurement.

	CD	DVD
Diameter (mm)	120	120
Disk Thickness (mm)	1.2	1.2
Substrate Thickness (mm)	1.2	0.6
Track Pitch (micrometers)	1.6	0.74
Minimum Pit Size (micrometers)	0.83	0.4
Wavelength of Laser Reader (nm)	780	635/650
Data Stored on One Layer (Gigabytes)	0.65	4.7

Hair Thickness Activity



A simple and cheap hair mounting devise can be made with cardboard and double sided tape.

Thin wire can also be used as a substitute for hair.

Measurements can be made from the center of diffraction minima or maxima.

$$
\begin{aligned}
d &= L \times \lambda \div w \\
&= 2\text{ m} \times 6.5\text{x}10^{-7}\text{ m} \div 0.025\text{ m} \\
&= 5.2\text{ x}10^{-5}\text{ m} \\
&= 0.052\text{ mm}
\end{aligned}
$$

Section One Questions:

1. Measure several different hairs. Are all of your hairs the same thickness?

   Hair thickness can vary even from the same person. The average human hair thickness is between 0.02 mm – 0.12 mm.

2. Are your hairs the same thickness as other people's hairs?

   Hair thickness varies greatly from person to person. The average human hair thickness is between 0.02 mm – 0.12 mm.

Applications of Diffraction of Light

Here are a few places where diffraction is important.

a) CDs and DVDs –
The finely spaced dots on a CD diffract light of all colors.

What limits how small the dots on the CD or DVD can be?
What would happen if the dots were smaller than a wavelength of light?
Why are scientists trying to develop blue lasers for a new type of CD?

b) The “iridescent” colors of some animals are not just due to dyes.

For example, the Morpho didius Butterfly (Amazon rainforest) is a bright blue because of “natural gratings” on its wings.

A combination of interference and diffraction effects produce the colors of peacock tails, pearl shells and opals.

c) Haloes around the moon.

When the moon shines through light clouds you often see one or more rings of colored light round it. The light from the moon diffracts off the water and ice droplets in the cloud.

Similar haloes appear around street lighting on misty or foggy nights.

d) Smog looks hazy because the particles in the air diffract, scatter and absorb the light. Diffraction (along with absorption and scattering measurements) is used to evaluate the cleanliness of air and turbidity of water.

e) Diffraction is often used to measure very small distances.

f) Diffraction gratings (like the diffraction glasses) diffract each color of light through a different angle. This is used in a spectroscope to see what colors of light are in a particular source.

g) Holograms (like those on bank credit cards, for example) work because of diffraction. A complicated pattern of lines on the card diffracts light into the pattern you see.

h) Not just light diffracts. X-rays (high energy light) can be diffracted off solid matter and the diffraction pattern tells you how about the spacing of atoms inside the solid. Water waves, sound waves and indeed, all kinds of waves diffract.

Safety:

- Students should use caution when operating the laser beam to prevent injury to the eyes.