CCMR Educational Programs

Title:	**Diffraction and Interference of Light**
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Authors:	Gil Toombes, Kevin Dilley
Appropriate Level:	Physics: Grades 9 - 12
Abstract:	The diffraction and interference of light is a direct and tangible experiment of the wave properties of light. Furthermore, diffraction is at the root of many technologies, scientific techniques and common visual phenomena. Using a laser pointer, students examine diffraction patterns from a range of objects. The diffraction from metal meshes gives quantitative confirmation of the wave nature of light. Students then measure the track spacing on CDs and DVDs using the wave model of light. Finally, students are asked to apply their experience of light diffraction to electron and X-ray diffraction images of matter.
Time Requirement:	Two to three 40-minute class periods
NY Standards Met:	● Standard 1—Analysis, Inquiry, and Design *M3.1 Apply algebraic and geometric concepts and skills to the solution of problems.* ● Standard 4—The Physical Setting *PH4.3l: 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.*
Sections to Document:	Pages 1-7 – Student Worksheets 8-9 – Follow Up Questions 10-16 – Teacher Notes

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Physics Lab Student Name: ____________________

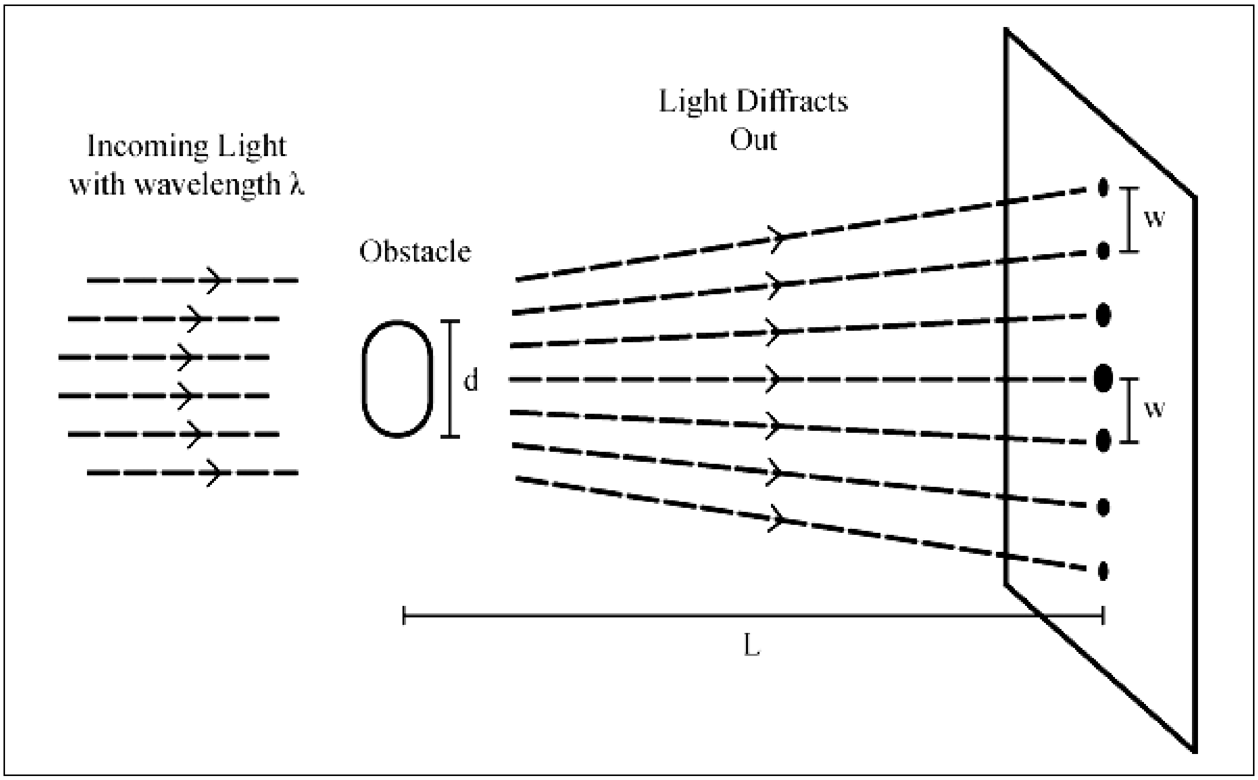
Class: ____________________

DIFFRACTION and INTERFERENCE of LIGHT

Introduction: When a wave encounters an obstacle, some of the wave bends or *diffracts*, around the obstacle. Diffraction depends upon the

- d - Size of obstacle
- λ - Size of wave

Light is a wave so it diffracts. In the figure below, a beam of light from the left diffracts off an object, travels a distance L to the screen where it forms a pattern of spacing w.

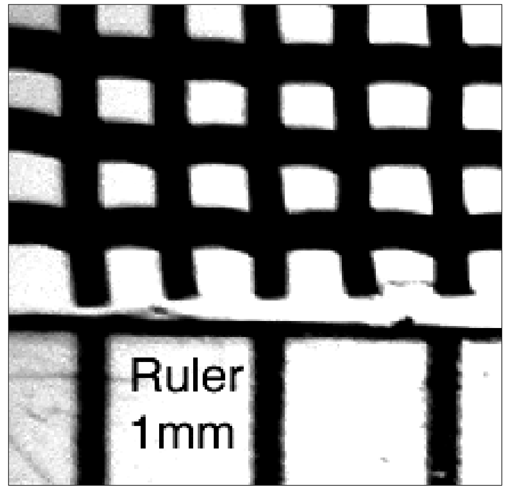


The diffraction equation**,**

$$\mathbf{w = L \times \lambda \div d}$$

w = Pattern Spacing
L = Distance to Screen
d = Size of Object
λ = Wavelength of light

relates the diffraction pattern to the object causing the diffraction. Diffraction patterns can include dots, rings and strips and the pattern tells you information about the object. We'll use diffraction to measure CD and DVD track spacing, the width of your hair and other small objects.



WIRE MESH Activity

Section One: Examining the Mesh

Examine the coarse and fine wire mesh with a hand lens. Using a ruler and the hand lens, measure the distance, **d**, between the wires on the mesh.

Coarse Mesh

Distance along Ruler = ...(mm)

Number of Wires = ...

Distance Between Wires

d = ...(mm)

d = ...(meters)

Fine Mesh

Distance along Ruler = ...(mm)

Number of Wires = ...

Distance Between Wires

d = ...(mm)

d = ...(meters)

Section Two: Predicting the Pattern

Use the diffraction equation to predict the spacing of the pattern for each mesh. A red laser light has a wavelength of about,

λ = 650 nanometers (6.5×10^{-7} meters).

The distance from the mesh to the screen will be,

L = 2 meters.

Coarse Mesh
Diffraction Pattern Spacing

$\mathbf{w = L \times \lambda \div d}$

w = ...(meters)

w = ...(mm)

Fine Mesh
Diffraction Pattern Spacing

$\mathbf{w = L \times \lambda \div d}$

w = ...(meters)

w = ...(mm)

Questions:

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

Section Three: Measuring Diffraction Patterns

Shine the laser onto the screen.
Place the wire mesh into the beam. The distance from the mesh to the screen should be L = 2 meters.

OBSERVE and RECORD the diffraction pattern you see on the screen.

COARSE MESH

20 mm

w = Distance between spots

= ....(mm)

FINE MESH

20 mm

w = Distance between spots

= ....(mm)

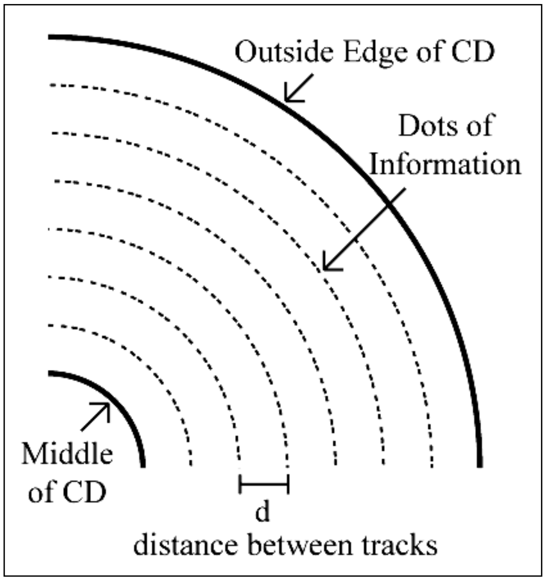
Questions:

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

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

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.

CD/DVD Activity

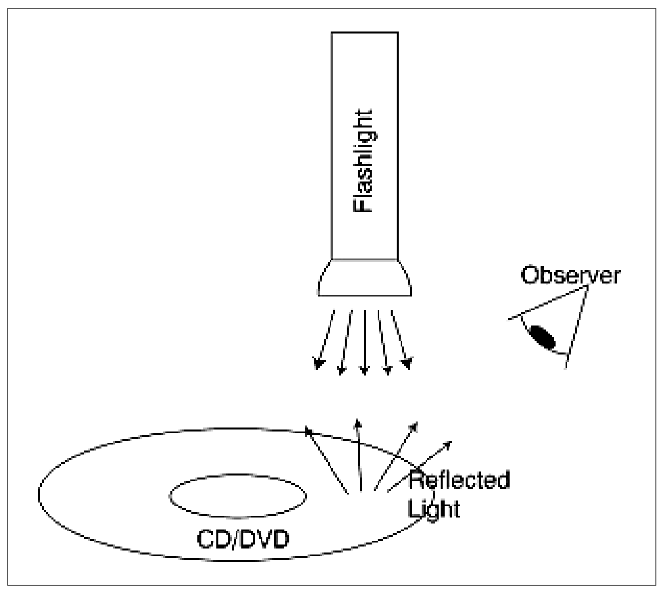


Introduction:

CDs and DVDs store information as dots on a plastic disk. The dots are in lines, known as tracks, as shown in the picture. To pack as much information onto the disk as possible, the tracks are spaced very close to each other. In a CD/DVD player, a laser is focused to a sharp spot and scans along the tracks reading each dot.

Using the concept of diffraction, we will measure how close the tracks are on CDs and DVDs.

Section One: Polychromatic Light



Examine the CD and DVD closely. Use a flashlight (as shown in the figure) to examine the colors and images reflected from the disk. (Hint: Try putting the CD/DVD facing upwards on the table. Shine light vertically down onto it, and, looking at the spot on the CD/DVD you've lit up move your head to different positions.)

Questions:

1. Note at least two observations about the CD and DVD.
    -
    -

2. What are the differences you notice between the CD and DVD?

Section Two: Measuring Track Spacing

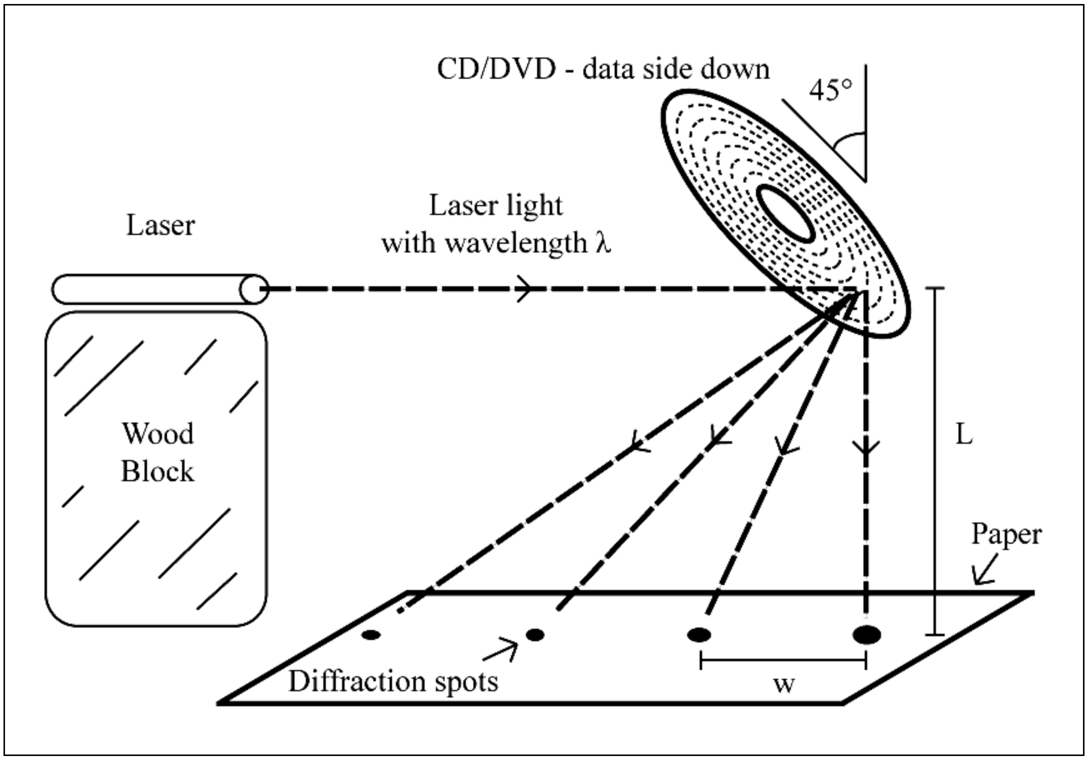
Set up the laser, CD and a sheet of paper as shown. When the CD is at a 45 degree angle to the horizontal, you should see a bright spot on the paper directly underneath the CD along with other diffraction spots in line with the laser. Mark the position of each spot on the paper. Measure

L = Distance of laser beam above paper

w = Distance between diffraction spots.

A red laser light has a wavelength of about,

λ = 650 nanometers (6.5×10^{-7} meters).



CD Track Spacing

L = ...(cm)

w = ...(cm)

d = Distance between CD Tracks
= $L \times \lambda \div w$

= ....(m)

= ....(mm)

Number of CD Tracks per millimeter

= ....

DVD Track Spacing

L = ...(cm)

w = ...(cm)

d = Distance between DVD Tracks
= $L \times \lambda \div w$

= ....(m)

= ....(mm)

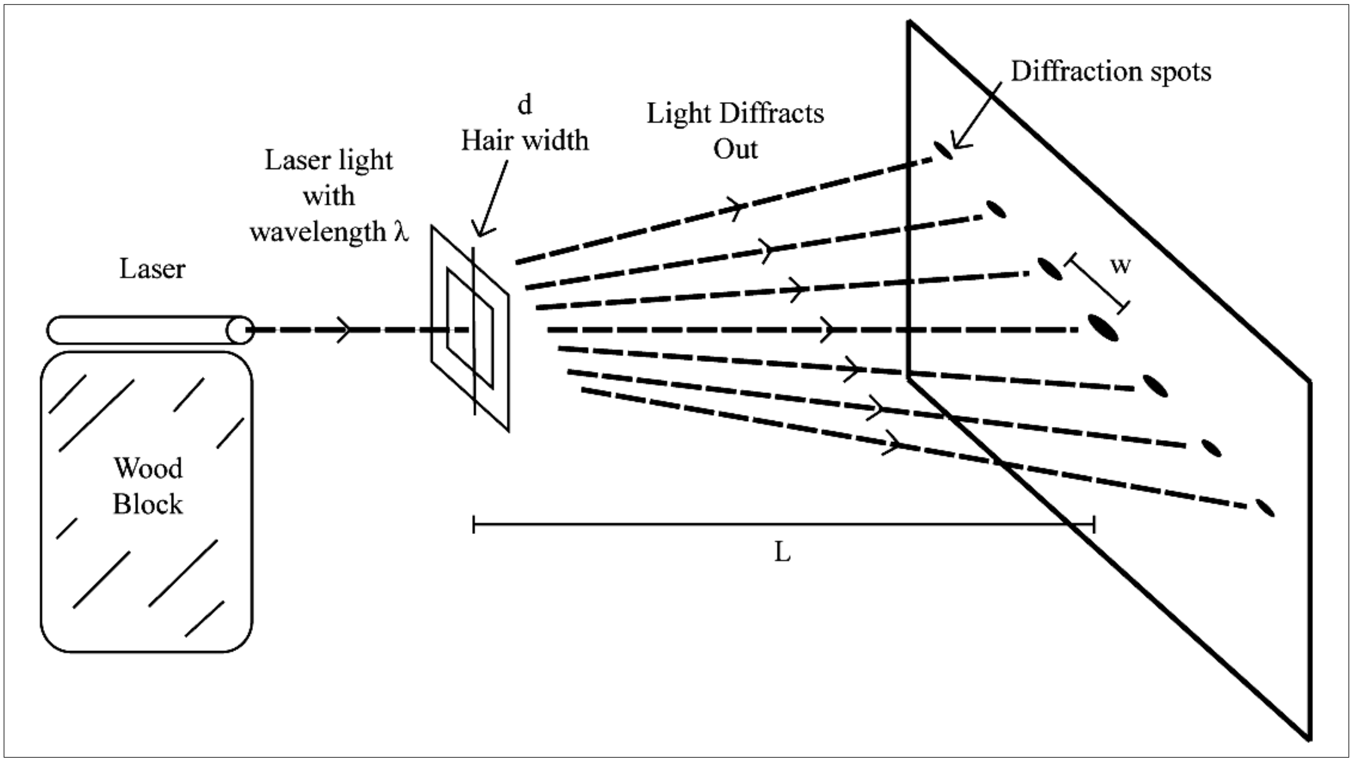
Number of DVD Tracks per millimeter

= ....

Hair Thickness Activity

Introduction:

Diffraction can be used to measure very small lengths. A common object, which is often used when referring to small things, is a human hair. Using the concept of diffraction, we will measure how thick a human hair actually is.



Section One: Measuring a Hair

Set up the laser to shine on the screen a distance of 1 to 2 meters (further is okay, but the brightness of everything decreases so you'll need a darker room). Notice that the beam from most laser pointers is a rectangle. Set it up so the long side of the rectangle is vertical on the screen.

Take a human hair (preferably a dark, firm one to start with but it really doesn't matter much) and intercept the laser beam with it. You will see a set of bands centered on the main beam. Rotate the hair so it is vertical. Now you should be able to mark out the bright and dark bands quite clearly. Measure

L = Distance between hair and screen

w = Distance between diffraction spots.

The width of the hair, d should be given by,

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

The wavelength of light for a red laser pointer is about 650 nm (6.5×10^{-7} m).

Hair Thickness

L = ...(m)

w = ...(m)

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

= ....(m)

Thickness of human hair in centimeter

= ....(cm)

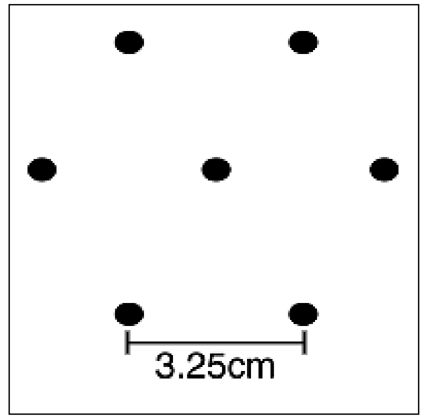
Questions:

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

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

Further Questions

1. The membrane from a water purifier has millions of very small holes in it. A laser pointer was used to project the diffraction pattern from the membrane onto a screen. The screen was 1 m from the purifier membrane and produced a diffraction pattern with a spacing of 3.25 cm as shown to the right.

   What is the average distance between the holes in the water purifier membrane?

   Wavelength of laser pointer = 650 nm.

2. Early in the morning, sunlight streams through an east facing kitchen window and projects an image of the window onto the western wall of the kitchen. The window is covered by a mesh security screen. The grid spacing of the security mesh is 1.3 mm. The distance between the western wall of the kitchen and the security mesh is 2.5 m.

   Assuming sunlight has a mean wavelength of λ = 560 nm, what is the spacing of the diffraction pattern projected onto the western wall?

   The window is 1.3 m high and 0.85 m wide. Compare the spacing of the diffraction pattern to the size of the window. Would you be able to see diffraction at the edges of the image?

   Suppose the security mesh is replaced with a much larger grill with a spacing of 1 cm between the wires? How large would the diffraction pattern be now? Could you see something this small?

3. Laser pointers often come with a little kit of holograms. One hologram, when illuminated with the laser, projects a smiley face onto a wall 3 m away. Using a red laser pointer (λ = 630 nm) the smiley face has a diameter of 63 cm. If a blue laser (λ = 400 nm) were used to project the same hologram how large would the smiley face be?

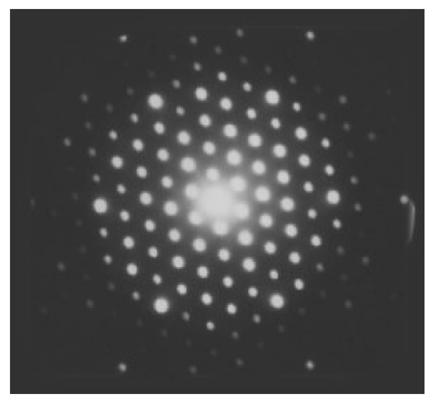
4. Shine the laser pointer onto the wall. Try to “pinch” off the beam with your finger and thumb. What do you see as the gap gets small? Explain, using the idea of diffraction, why the spot doesn’t just “blink out”.

5. LPs (vinyl records) also have circular tracks or grooves. Voyager, the spacecraft that visited all the planets, has a gold LP on it. LPs have 240 grooves per inch. Suppose you performed the CD/DVD experiment with the gold LP. What would be the spacing of the dots you would observe?

   Why can’t you store as much information on a vinyl record as a CD or DVD?

6. In an electron microscope, a beam of electrons is accelerated to great energy (1 KeV or more) and fired through thin films of material. The beam is then projected onto a screen. Here is the pattern that forms when the beam passes through a thin sheet of aluminum.

   Are the electrons behaving like a wave or a particle? Each atom in the aluminum film acts like a point on a mesh grid.



   Electrons with an energy of 10 KeV have a wavelength of $\lambda = 1.2\times10^{-11}$ m. This image was taken L = 30 cm back from the aluminum film and the spots are separated by a distance of 1.6 cm. What is the distance between the aluminum atoms?

   Check that your answer is reasonable. One mole of aluminum atoms (6.02×10^{23}) occupies a volume of 10 milliliters. What is the average volume for each atom? If each atom were spherical, what radius would that correspond to?

Teacher Notes

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 doesn't spread out after passing through a prism.

Collimated – All the light waves are parallel.
Show the spot doesn't 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

Equipment

Each group should have:

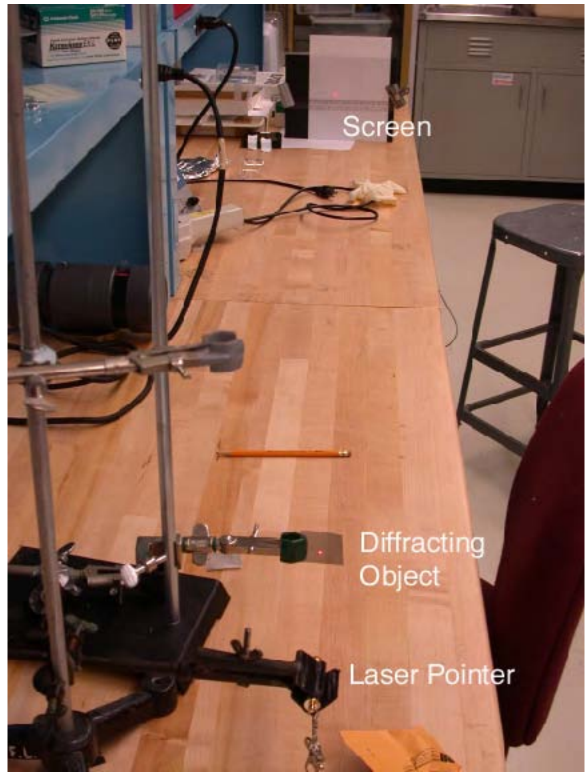
- Laser pointer
- Ring stand and clamp to hold CD/DVD
- Rind stand and clamp or wooden block to hold laser
- Binder clip to keep laser on
- Projection screen
- Meter stick
- Ruler
- Magnifying lens
- 2cm x 2cm piece of fine wire mesh
- 2cm x 2cm piece of coarse wire mesh
- CD
- DVD
- Hair mount

Caution: Never look into the laser beam or point it at someone's eye

The following items 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

WIRE MESH Activity



Section One:

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

For mesh #1:

$d = 0.500$ mm (50 lines per inch)
$w = L \times \lambda \div d$
$= 2 \text{ m} \times 6.5\text{x}10^{-7} \text{ m} \div 0.0005 \text{ m}$
$= 2.6$ 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:

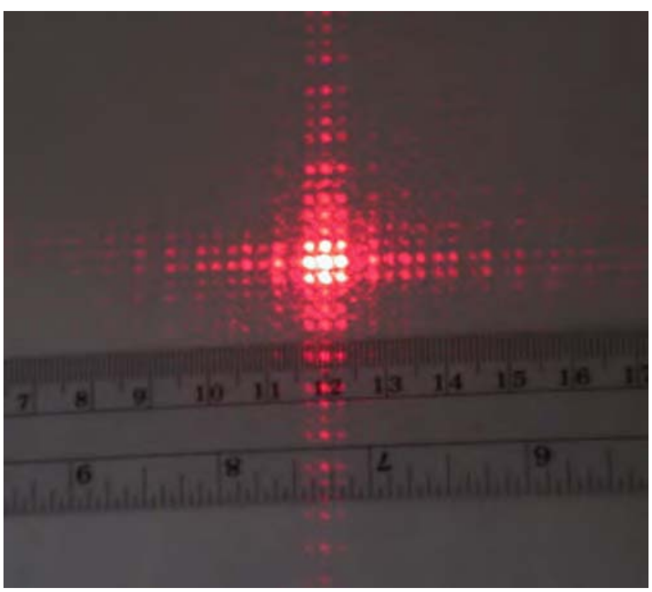
$d = 0.125$ mm (200 lines per inch)
$w = 10.4$ mm = dot-dot spacing in pattern

For mesh #4:

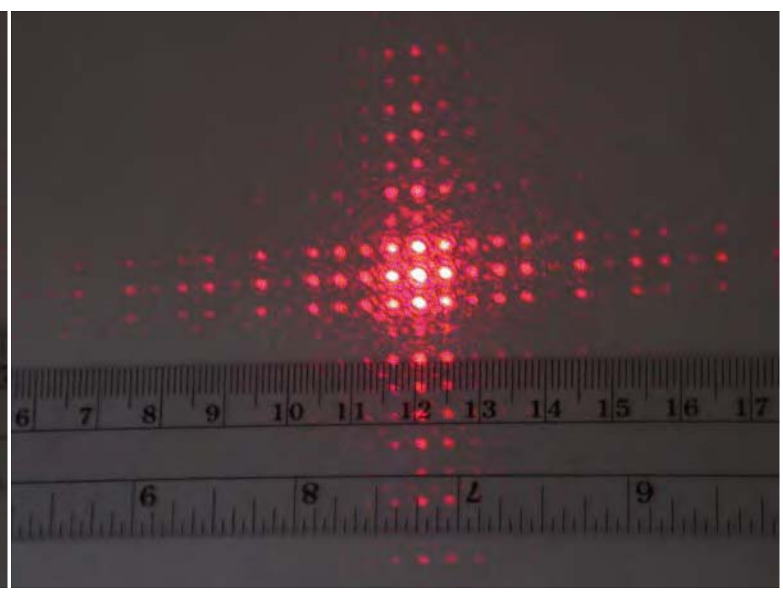
$d = 0.076$ mm (325 lines per inch)
$w = 17.1$ mm = dot-dot spacing on pattern

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 ($w \approx 2.5$ mm)



Fine Mesh ($w \approx 5$ 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.

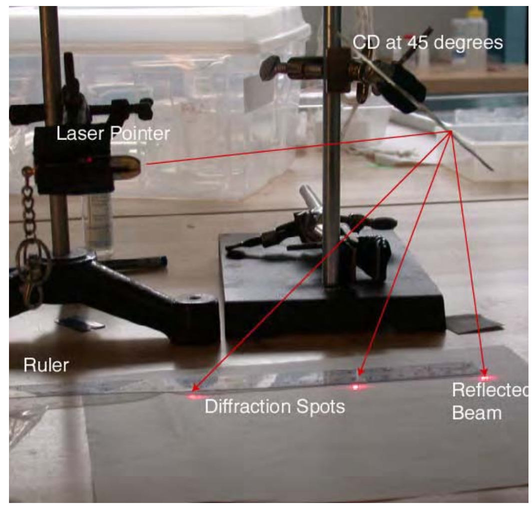
Section Two:

CD -
L = 9 cm
w = 4.5 cm
Track Spacing = L × λ ÷ 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.

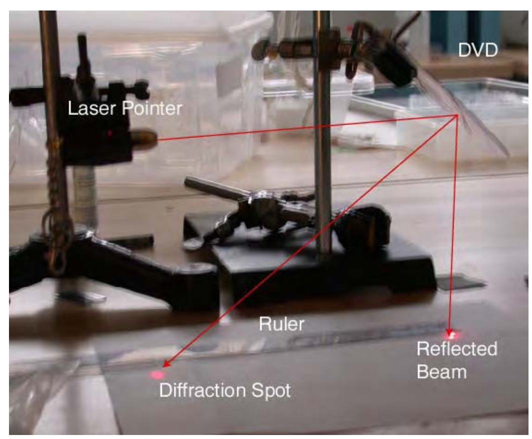
DVD-
L = 9 cm,
w = 14.5 cm
Track Spacing = L × λ ÷ w
= 9 cm × 0.65 microns ÷ 14.5 cm
= 0.5 microns
Tracks per mm = 2000 tracks/mm
Accepted track spacing is 0.74 microns.

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

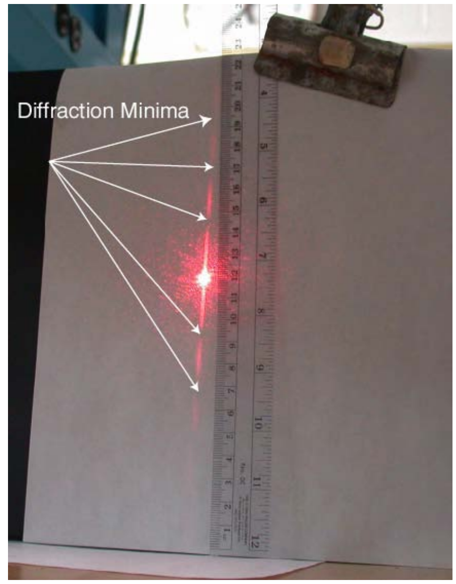


CD Diffraction



DVD Diffraction

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.

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

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.