

# **Title: DIFFRACTION and INTERFERENCE of LIGHT**

**Appropriate Level:** All levels

## **NY Standards met:**

- Standard 1—Analysis, Inquiry, and Design  
*Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.*
- Standard 4—The Physical Setting  
*Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.*

**Abstract:** The diffraction and interference of light is direct and tangible experimental 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 Required:** 40-minute class period minimum. 2 periods allows deeper exploration

**Date:** March 8, 2003

## **Sections to Document :**

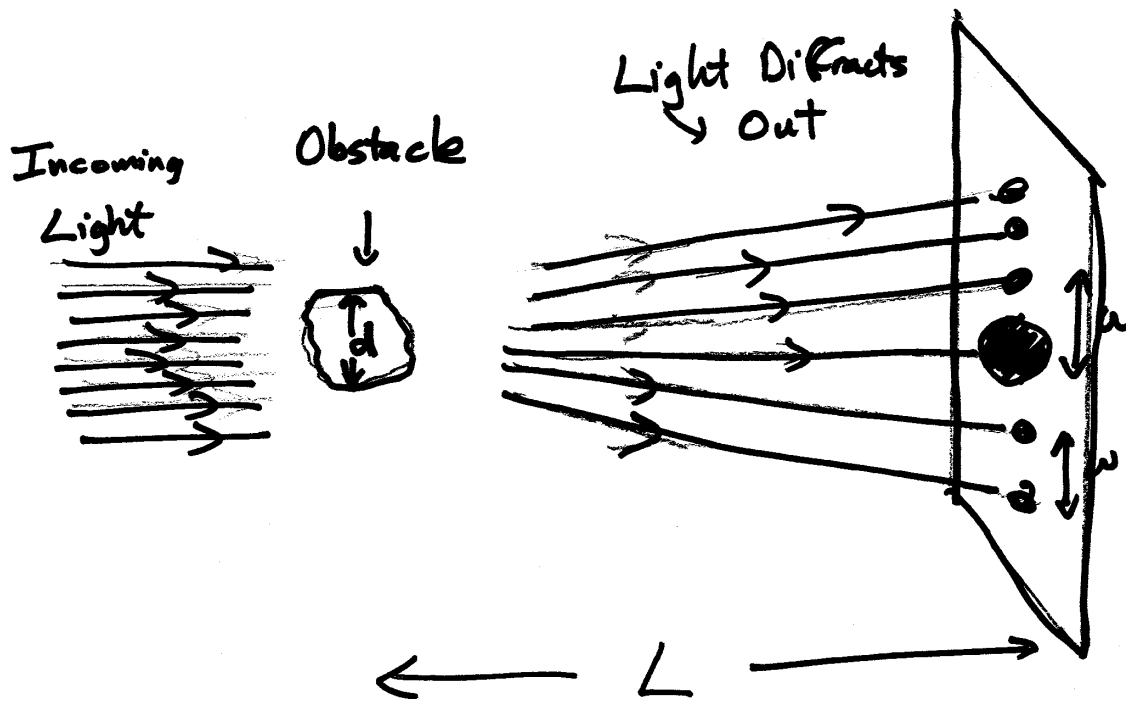
Pages 2-7 – Student Worksheet  
Pages 8-9 - Follow Up Questions  
Pages 10-12 – Teacher Notes  
Pages 13 - Teacher Demos  
Pages 14 – Applications of Diffraction  
Pages 15,16 – Extension activityies  
Page 17 – Work in Progress.

## Title: 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
- $\lambda$  - 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 size w.



The diffraction equation,

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

- w = Pattern Size
- L = Distance to Screen
- d = Size of Object
- $\lambda$  = 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.

## **Equipment**

Each group should have.

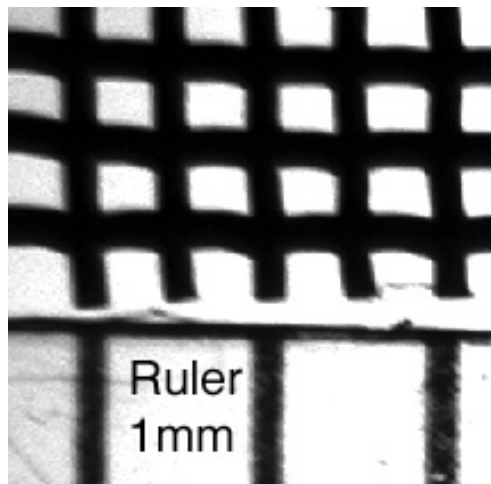
- Laser pointer
- Holder block and Clip to keep laser on.
- Screen on which to project diffraction patterns.
- Ruler.
- 2cm\*2cm piece of Fine and Coarse Wire Mesh
- Magnifying lens
- DVD and a CD.

**NEVER SHINE LASER LIGHT  
INTO YOUR EYE.**

# WIRE MESH Activity

## Section One : Examining the mesh

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



### Coarse Mesh

Distance along Ruler = .....(mm)

Number of Wires = .....

Distance Between Wires

$$d = \dots\dots\dots (\text{mm})$$

$$d = \dots\dots\dots (\text{metres})$$

### Fine Mesh

Distance along Ruler = .....(mm)

Number of Wires = .....

Distance Between Wires

$$d = \dots\dots\dots (\text{mm})$$

$$d = \dots\dots\dots (\text{metres})$$

## Section Two : Predicting the Pattern

Use the diffraction equation to predict the size of the pattern for each mesh. The laser light has a wavelength of,

$$\lambda = 650 \text{ nanometers } (6.5 \times 10^{-7} \text{ metres}).$$

The distance from the mesh to the screen will be,

$$L = 2 \text{ metres.}$$

### Coarse Mesh

Diffraction Pattern Spacing

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

$$w = \dots\dots\dots (\text{metres})$$

$$w = \dots\dots\dots (\text{mm})$$

### Fine Mesh

Diffraction Pattern Spacing

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

$$w = \dots\dots\dots (\text{metres})$$

$$w = \dots\dots\dots (\text{mm})$$

Prediction : The **FINE** mesh will produce a **Larger/Smaller** diffraction pattern than the **COARSE** mesh.

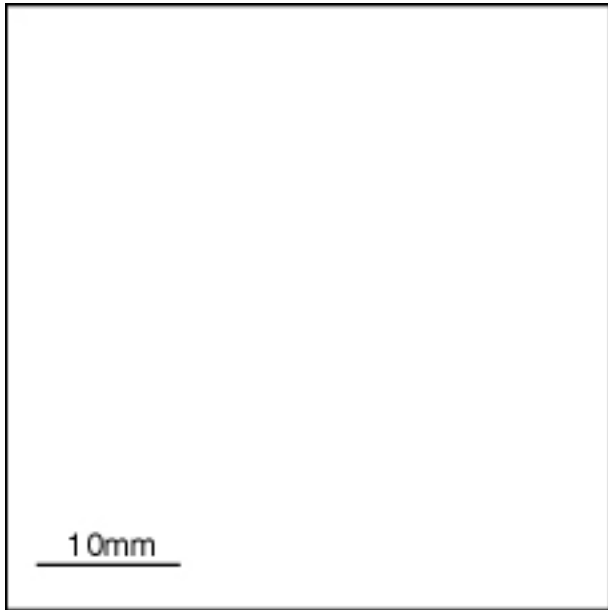
### Section Three : Measuring Diffraction Patterns

Shine the laser onto the screen.

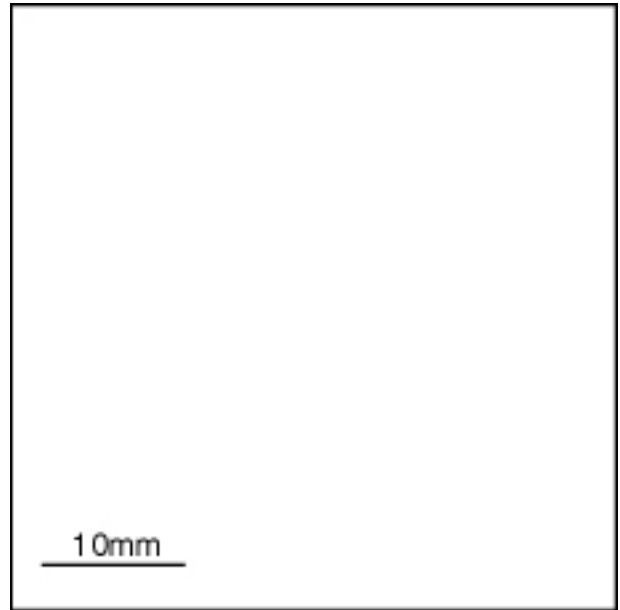
Place the wire mesh into the beam. The distance from the mesh to the screen should be  $L=2\text{m}$ .

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

**COARSE MESH**



**FINE MESH**



w = Distance between Spots  
= ..... (mm)

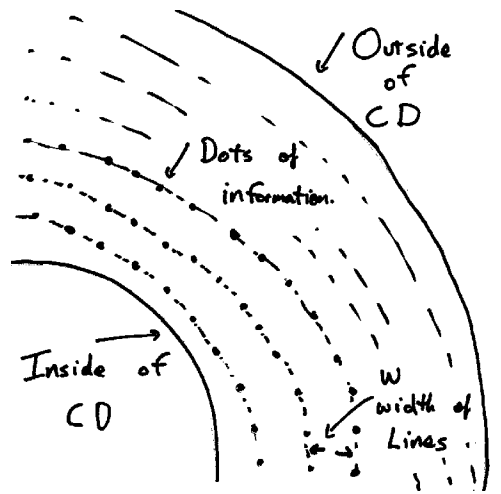
w = Distance between Spots  
= ..... (mm)

**Questions :**

1. Which mesh produced the larger diffraction pattern? Large mesh or small?
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 between the dots of  $w = 10\text{mm}$ . 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 :

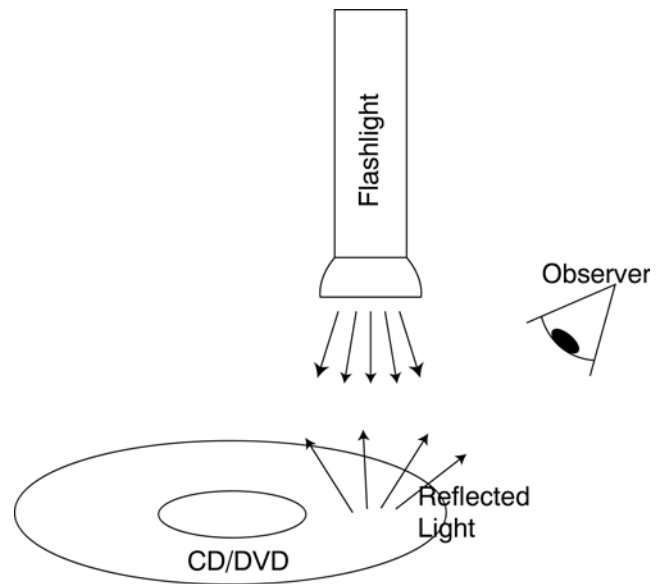
CDs and DVDs store information as dots on a plastic disk. The dots are in lines as shown in the picture. To pack as much information onto the disk as possible, the tracks are very close to each other. In a CD/DVD player, a laser is focused to a sharp spot and scans along the tracks reading each dot.

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.)

NOTE AT LEAST TWO DIFFERENCES BETWEEN THE CD AND DVD. RECORD ALL YOUR OBSERVATIONS.

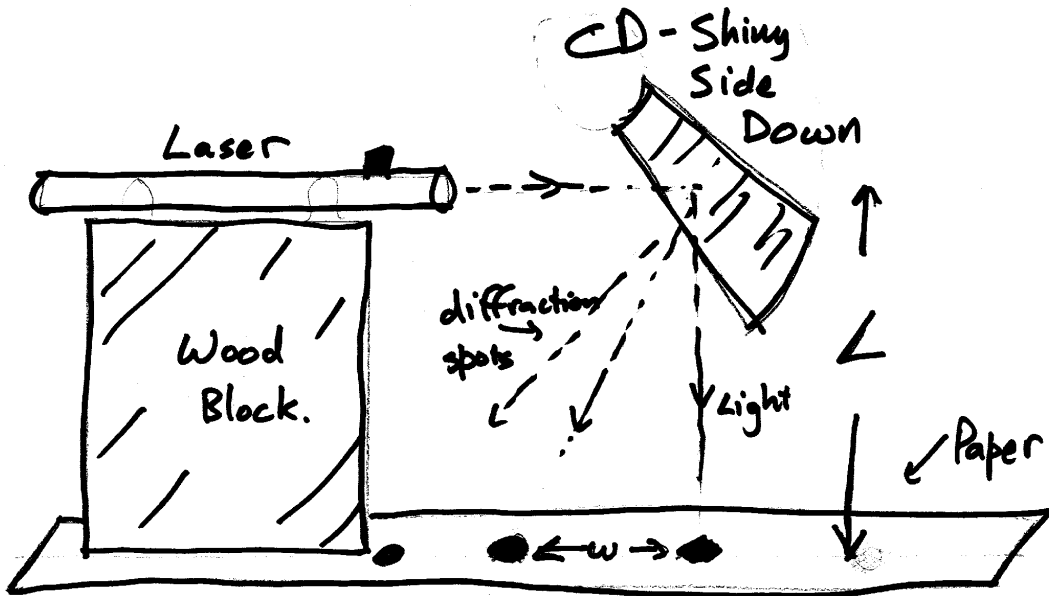


## Section Two : Measuring Track Spacing

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 dot on the paper directly underneath the CD along with other diffraction dots in line with the laser. Mark the position of each dot on the paper.

Measure

- L = Distance of laser beam above paper
- w = Distance between dots.



### CD Track Spacing

L = ..... (m)

w = ..... (m)

d = Distance between CD Tracks

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

= ..... (m)

Number of CD Tracks per centimeter

= .....

### DVD Track Spacing

L = ..... (m)

w = ..... (m)

d = Distance between DVD Tracks

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

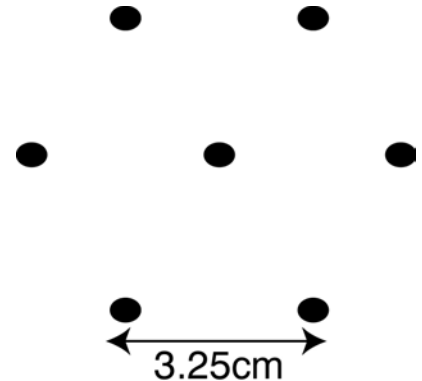
= ..... (m)

Number of DVD Tracks per centimeter

= .....

## 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 1m from the purifier membrane and produced a diffraction pattern with a size of 3.25cm as shown to the right.



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

Wavelength of laser pointer = 650nm.

2. Early in the morning, sunlight streams through an easterly 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 1.3mm. The distance between the western wall of the kitchen and the security mesh is 2.5m.

Assuming sunlight has a mean wavelength of  $\lambda=560\text{nm}$ , what is the size of the diffraction pattern projected onto the Western wall?

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

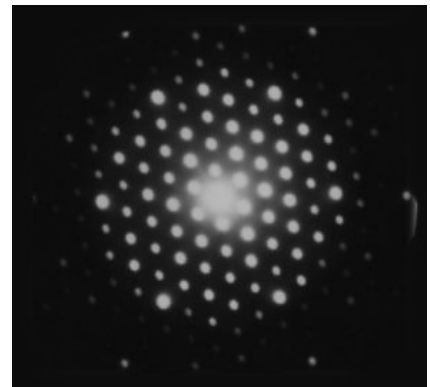
Suppose the security mesh is replaced with a much larger grill with a spacing of 1cm between the wires? How large would the diffraction pattern be now? Could you see something this small?

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 3m away. Using a red laser pointer ( $\lambda=630\text{nm}$ ) the smiley face has a diameter of 63cm. If a blue laser ( $\lambda=400\text{nm}$ ) 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  $\lambda = 1.2 \times 10^{-11} \text{m}$ . This image was taken  $L=30\text{cm}$  back from the aluminum film and the spots are separated by a distance of 1.6cm. What is the distance between the aluminum atoms?

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

# Abbreviated Teacher Note Section

## 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.

## WIRE MESH Activity

For the fine mesh,

$d = 250$  microns ( 100 lines per inch)

$w = 5.2$  mm = dot-dot spacing on pattern

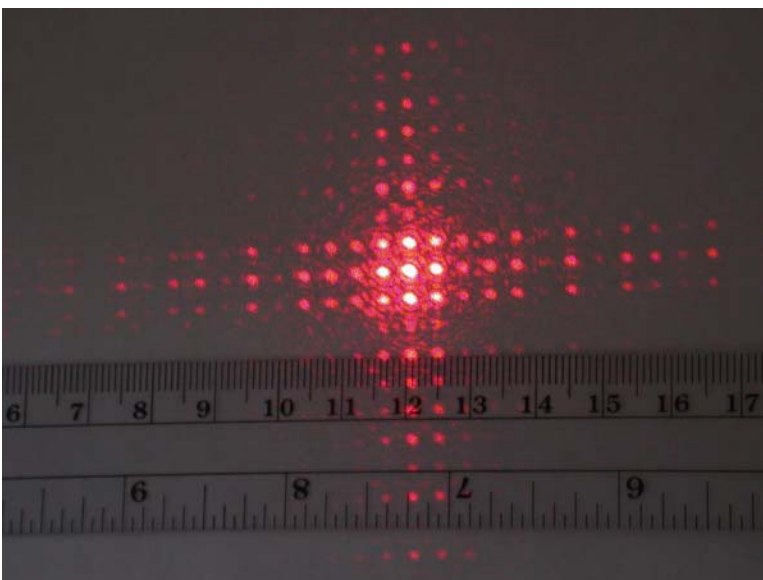
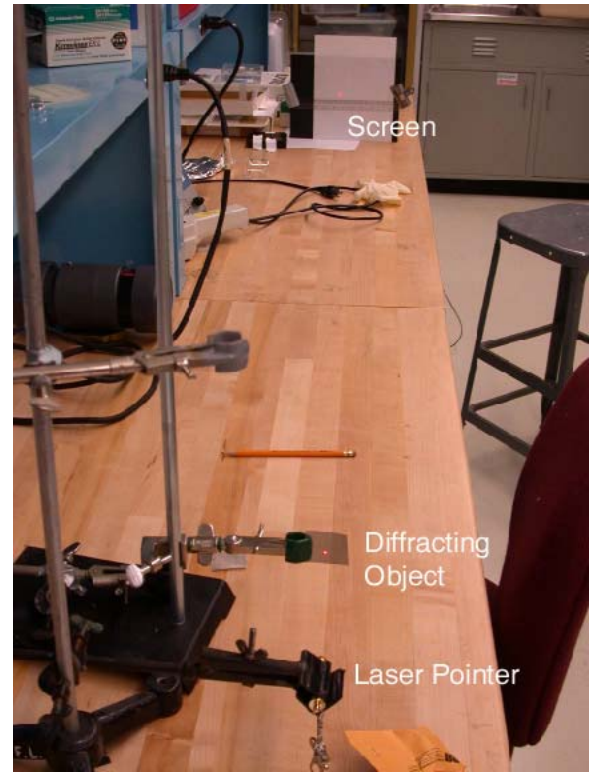
For the coarse mesh

$d = 500$  microns (50 lines per inch)

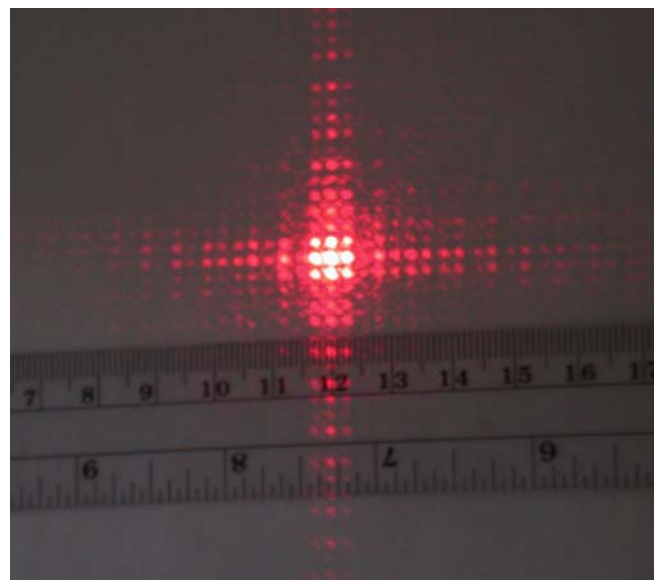
$w = 2.6$ mm = dot-dot spacing

The coarse mesh has 50 lines per inch ( $d=500$  microns).

The fine mesh has 100 lines per inch ( $d=250$  microns).



Fine Mesh ( $w=5$ mm)



Coarse Mesh ( $w=2.5$ mm)

## CD/DVD Activity

Both the DVD and CD split white light into a spectrum of colours. However, the DVD sprays the colours over wider angles because the lines on it are far closer.

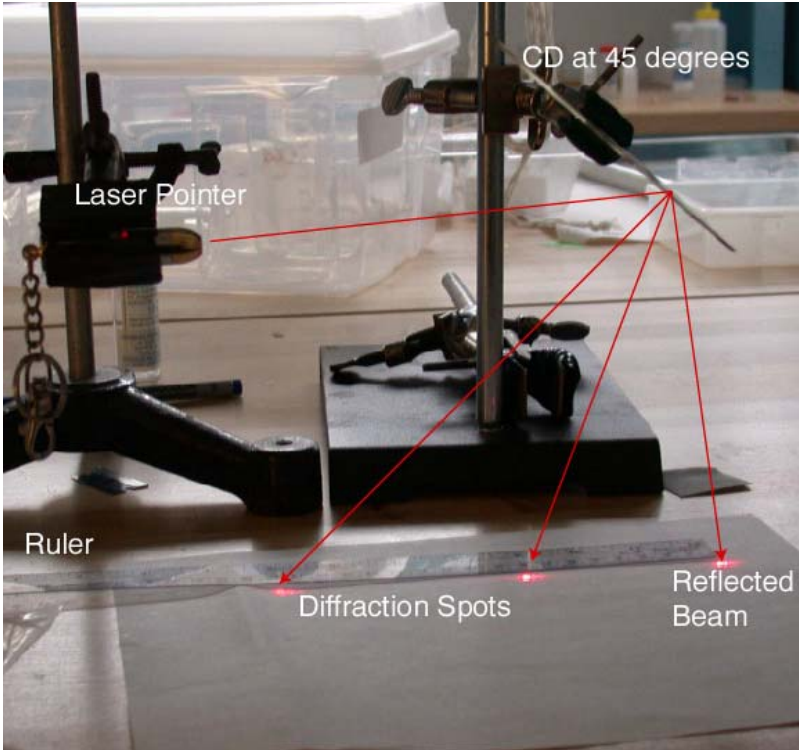
Measuring the track spacings

CD - Distance to paper  $L = 9\text{cm}$   
 Distance between spots =  $4.5\text{cm}$   
 Track Spacing =  $L * \lambda / w$   
 =  $9\text{cm} * 0.65 \text{ microns} / 4.5 \text{ cm}$   
 =  $1.3 \text{ microns.}$   
 Tracks per centimeter =  $770 \text{ tracks per cm.}$   
 Accepted track spacing is  $1.6 \text{ microns.}$

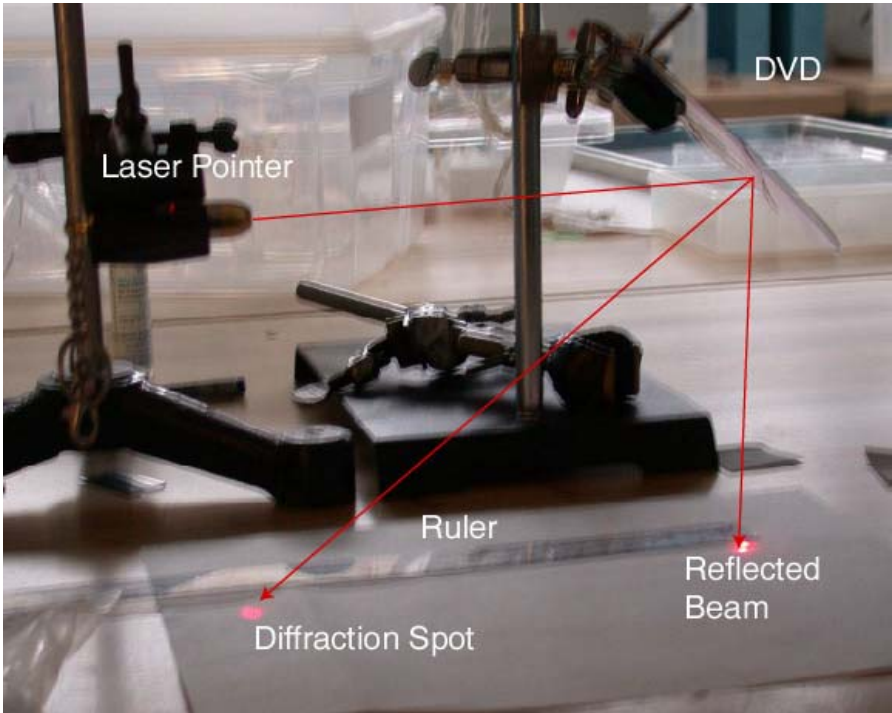
DVD- Distance to paper  $L = 9\text{cm}$ ,  
 Distance between spots =  $14.5\text{cm}$   
 Track Spacing =  $L * \lambda / w$   
 =  $9\text{cm} * 0.65 \text{ microns} / 14.5\text{cm}$   
 =  $0.5 \text{ microns.}$   
 Tracks per cm =  $2000$   
 Accepted track spacing is  $0.74 \text{ microns.}$

	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 -**



## Teacher Demos/Introduction

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

Monochromatic – It looks like one color.

It doesn't spread out after passing through a prism.

Collimated - Show the spot doesn't spread out.

Use chalk powder to show the light path.

Talk about bouncing lasers off the Moon.

Coherent - 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. Explaining speckle's a bit of a nuisance, but it looks cute.

Need – 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.

Need : Adjustable slit

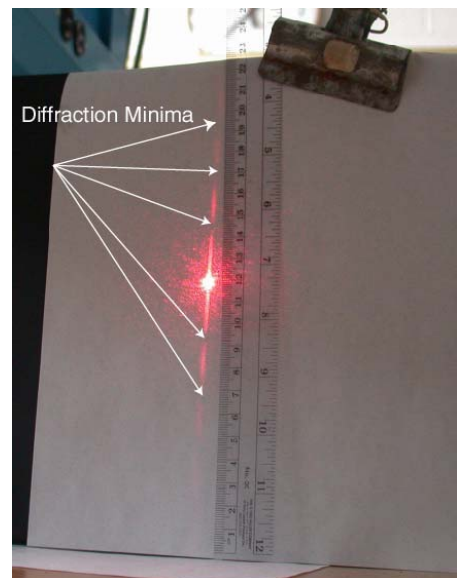
### Measure Small Objects

Project the diffraction pattern from a hair at least 1.5 metres onto a screen. Measure the spacing of the diffraction spots to get the hair width. Can also use thin wire.

Need : Hair, ruler

Picture on Following Page shows Diffraction from hair projected (red laser pointer) projected onto a screen 2m away. The diffraction minima are approximately 2.5cm apart. Using the diffraction formula,

$$\begin{aligned}d &= \lambda * L / w \\ &= 0.65 \text{ microns} * 200 \text{ cm} / 2.5 \text{ cm} \\ &= 50 \text{ microns or so.}\end{aligned}$$



## 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 tail, 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.**

## Extra Experiments for Students

### A) Diffraction Glasses

These are glasses with 2D dot grid slides over each eye.

Get students to look at different lights with them, especially the flashlight.

Get them to place them in front of the laser to measure the diffraction pattern.

Since the Fourier Transform of a square lattice is a square lattice, you get a grid of dots.

The angular separation between the dots tells you the spacing of the lattice on the glasses.

You can also look at what happens when you pass the laser through two of the glasses at different angles.

### B) DIFFRACTION GRATINGS

At present we only have 500 lines per mm, but if we could get ones with 50, 100, 200, 400, 800 etc. you could make a plot of spacing versus diffraction angle.

Also, it would be good to get ones that are amplitude rather than phase holograms. Then students could use a microscope to see the lines.

Look at crossing two over.

What happens if you rotate the grating not parallel, but perpendicular to the laser direction.

It's especially worthwhile to look at a TV screen/computer monitor, fluorescent light and incandescent light with a diffraction grating.

### C) HAIR THICKNESS.

With out laser pointers this isn't especially easy to do, but it can be done. The darker the room the better.

Set up the laser to shine on the screen a distance of 1-2m (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 horizontal 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 horizontal. Now you should be able to mark out the bright and dark bands quite clearly. Measure the spacing between the bands. The width of the hair,  $d$  should be given by,

$$d = L * \lambda / w$$

L is the distance to the screen,  $\lambda$  the wavelength (650nm or so for a red laser pointer) and  $w$  the spacing between the bands.

#### **D) MEASURING WAVELENGTH OF LIGHT OF A RULER**

This isn't too tricky. Take a metal ruler (preferably with 0.5mm markings on it) and make sure a small part of it is shiny (polishing it helps).

Reflect the laser onto the rulings so they reflect almost directly back onto a screen.

The diffraction pattern is a set of bands.

$$\lambda = d * w / L$$

where  $d$  is the spacing of the lines on the ruler,  $w$  the spacing of the bands on the diffraction pattern and  $L$  the distance to the screen.

Using a  $L > 1.2\text{m}$  works well for a standard laser pointer.

#### **E) OPALS, HOLLOW FIBRES, ETC.**

#### **F) Measure Shape of Objects**

Sprinkle lycopodium spores onto a glass slide. Look at the diffraction pattern. From the rings you can tell –

- a) Spores are round.
- b) Estimate spore size.

In contrast, a thin wire gives spots.

#### **G) HOLOGRAMS**

These show that a fancy pattern on a slide can make a fancy diffraction pattern.

#### **H) X-ray diffraction used to determine DNA Structure**

Go to the Institute for Chemical Education (ICE) for details

References :

“How a Diffraction Grating Works” – 1996 S.F. Jacobs, Optical Science Center, University of Arizona – Available from <http://www.teachersource.com>

I didn't use this but it has good pictures in it that would come in handy in the future. Copyright problem at the present.

# Work in Progress

1. Give an alternative and more rigorous introduction to diffraction.  
    Show pictures of water waves going around objects.  
    Reference appropriate textbooks.  
    Allow for large angle limit.
2. Write up Lycopodium section and link it to X-ray scattering from viruses.
3. Add a supplier page.
4. Looking through wire mesh at light sources. Get “white” LED and LED colours.
5. Use laser printer to make up copies of interesting diffraction patterns.