Name Period Date

88 What's My Lambda?

Purpose

To use the basic principles of diffraction and interference to measure the wavelength of laser light

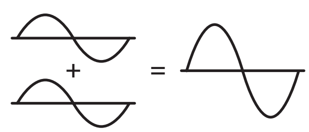
Required Equipment/Supplies

laser
meterstick or measuring tape
diffraction grating(s)
CD, DVD, and large binder clip

Discussion

Diffraction is a beautiful example of interference. When waves overlap and reinforce each other, they *constructively interfere*. Likewise, when two waves overlap and cancel one another, they *destructively interfere*.

Study Figure A. Waves from S spread out in all directions. Waves that impinge on the slits of a grating at S1 and S2 likewise spread out in all directions. Look at the waves from S1 and S2 which converge at "a." Since they travel exactly the same distance they arrive at the same time; they are in phase with each other. They constructively interfere and form a bright fringe called the *central maximum* (also called the *zeroth* fringe).



"in phase"

(reinforcement)

Now look at the waves from S1 and S2 that converge at "b." Since the waves from S2 travel exactly one-half wavelength farther than those from S1, the waves from S2 lag behind those from S1 by one-half wavelength; they are out of phase with each other. Therefore, they destructively interfere and form a dark fringe.

"out of phase"

(cancellation)

Now look at the waves from S1 and S2 that converge at "c." The waves from S2 travel exactly one wavelength farther than those from S1. Since the waves from S2 lag behind those of S1 by one complete wavelength, they are back in step with each other; they are in phase and constructively interfere. They form a bright fringe called the first-order bright fringe.

In summary, when the path-lengths differ by whole-number multiples of wavelengths (1λ, 2λ, 3λ, etc.), the result is constructive interference and bright fringes occur. Likewise, when the path-lengths differ by *odd* numbers of half-wavelengths ($\frac{1}{2}\lambda$, $\frac{3}{2}\lambda$, $\frac{5}{2}\lambda$, etc.), the result is destructive interference and dark fringes occur.

Let's take a closer look at waves that form the bright fringes. To see how these path differences cause fringes for

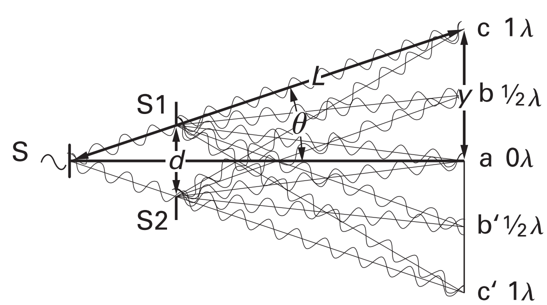


Fig. A

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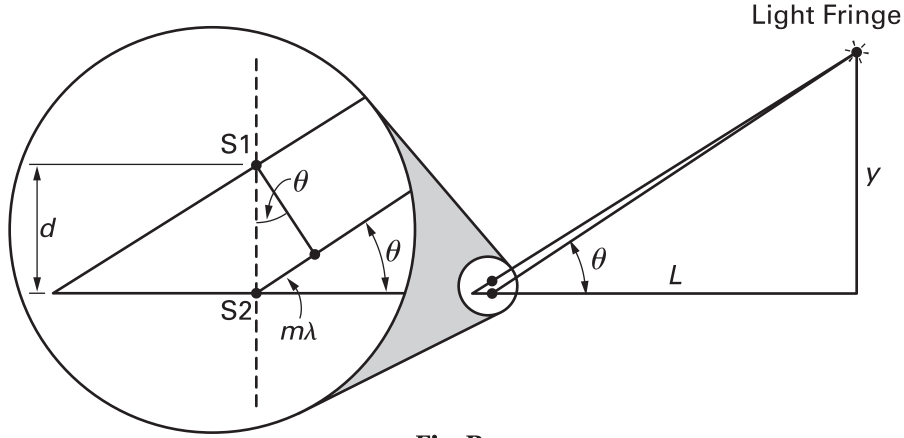

Fig. B

gratings, study Figure B. Since the distance between the slits of the grating is very small compared to the distance to the screen, the waves from each slit are very nearly parallel. Notice that the small triangle next to the slits is similar to the large triangle with the screen where the fringes are formed. Upon careful inspection, the extra distance that waves travel from S2 compared to S1 equals $d \sin \theta$. Since $\sin \theta$ is y/L, this relationship can be summarized by the following formula:

$$m\lambda = d \sin \theta$$

where m is the order of the spectrum (or the number of fringes from the central fringe), λ is the wavelength of the light being diffracted, d is the distance between slits in the grating, and θ is the angle between the central fringe and the mth fringe.

Since we know the spacing of the slits or grooves of the diffraction grating, we can measure the angle the laser light is diffracted to compute the wavelength of laser light.

Procedure ⚠

CAUTION: *Avoid shining laser light into people's eyes.*

Step 1: The distance between slits or grooves (usually referred to as *lines*) on the grating will be supplied by your teacher. Typically, this is in lines/mm or lines/inch. If it's lines/inch, you'll need to convert it using conversion 1 inch = 25.4 mm. Obtain the value for n from your teacher.

$n =$ ________ lines/mm

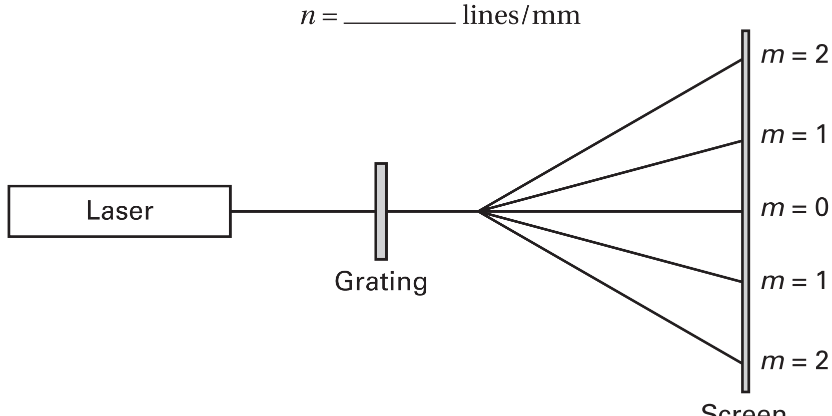

Fig. C

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Step 2: Arrange the laser so that it shines directly into the diffraction grating producing a fringe pattern on a screen located about a meter away as shown in Figure C. If space permits, you can use a white board as a screen. Measure the distance from the grating to the screen, L, and the distance to the first ($m = 1$) bright fringe, y. Record your values for y and L, and then compute the wavelength of the laser.

$y =$ ________

$L =$ ________

Since $\sin \theta = y/L$, calculate $\sin \theta$ by measuring y and L, where y is the distance between the zeroth fringe and the first-order fringe and L is the distance the laser light travels to the first fringe. You'll note the fringe spacings are *nonlinear* (not equally spaced), becoming closer with higher m's. Depending on distance from the laser and ruler, y is likely to be several centimeters. Since $m = 1$ for the first fringe, the wavelength formula becomes:

$$\lambda = \frac{1}{m}(d \sin \theta) = d\frac{y}{(L)}$$

Step 3: Calculate the wavelength of the laser light.

$\lambda_{\text{measured}} =$ ________ m

Step 4: How well does your computed value of the wavelength compare with the actual value (as supplied by your teacher)? If they are available, repeat using lasers of different wavelengths. Record your results.

$\lambda_{\text{given}} =$ ________ m

____

____

Step 5: Use a laser of known wavelength to figure out how many lines or slits per centimeter that grating has. This time, shine a laser directly through the diffraction grating so that you get a horizontal pattern on a screen. Position the screen a meter away from the laser and grating. Measure the distance from the central maximum to the second-order maximum. Use the formula $m\lambda = d \sin \theta$ to find the d, the width of the slits or lines on the diffraction grating. Show your calculations.

$d =$ ________ cm/line

Step 6: The number of lines per centimeter, n, is the reciprocal of d. Compare your calculated value for n to the value stamped on the grating or supplied by your teacher.

$n = 1/d =$ ________ lines/cm   % difference = ________

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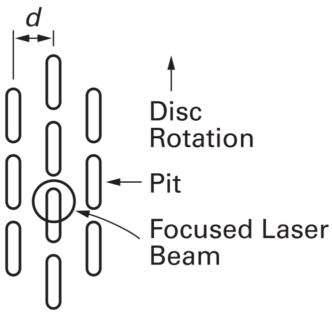

Fig. D

Going Further

The bottom side of a compact disc is a highly reflective surface containing a spiral of "pits." If stretched out, this spiral would be about 5 km long! The pits are arranged in a fashion similar to that shown in Figure D. Each pit is 0.5 μm (0.5×10^{-6}m) wide and is separated from each adjoining row by a distance of 1.6 μm—an industrial standard. The spiral of pits behaves much the same as a diffraction grating. You probably suspected this because of the rainbow of colors reflected from them.

When a laser beam is reflected off the bottom side of the disc, a familiar diffraction pattern is formed. If the angle of the laser beam is small, the distance between the rows of pits, *d*, can be estimated by:

$$d = \frac{m\lambda}{\sin \theta}$$

where *m* is the diffraction order, and θ is the angular position of the *m*th maximum (bright fringe).

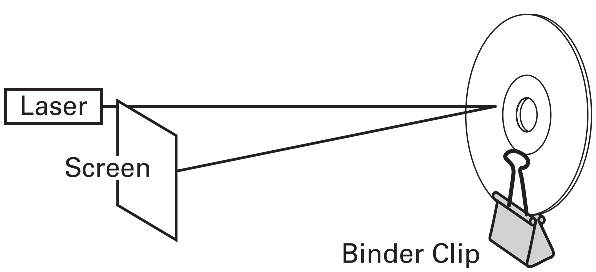

Fig. E

Step 7: Arrange a disc, laser, and screen as shown in Figure E. Direct the laser beam so that it strikes the disc approximately halfway up the CD, as shown in Figure F. Mount the CD using a large binder clip as shown. The binder clip makes it easy to adjust the height of the CD so that the laser beam strikes the horizontal diameter of the CD. This arrangement will give you a horizontal diffraction pattern on the screen so that the first-, second-, third-order (etc.) maximums will appear on either side of the bright central maximum.

Step 8: Determine the angular position, θ, of the first-order maximum, from the geometry of your experiment. Since the angle is large, you *cannot* use the small angle approximation that $\sin \theta = \tan \theta$.

θ = ________

Step 9: Calculate the distance *d* between the pits. How does your value compare with 1.6 μm? Compute the percentage difference.

d_{CD} = ________

% difference = ________

Step 10: Repeat using a DVD. How does your measured value for the distance between the pits for a CD and a DVD compare?

d_{DVD} = ________

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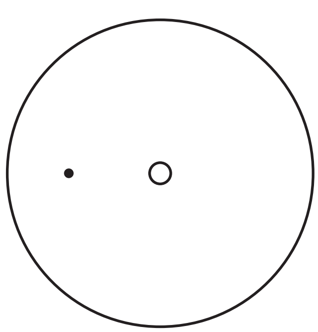

Fig. F

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