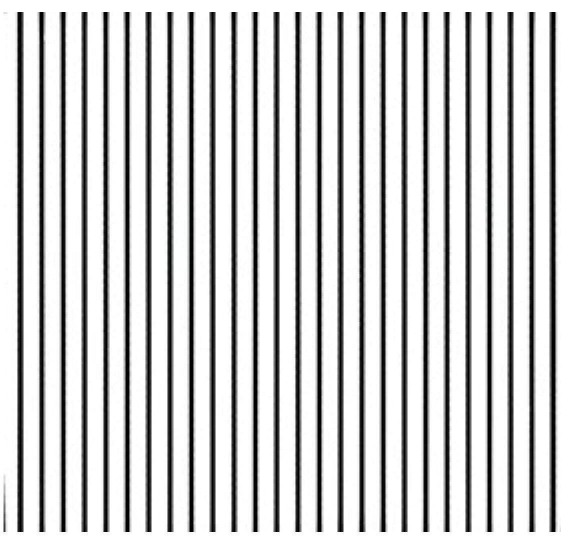
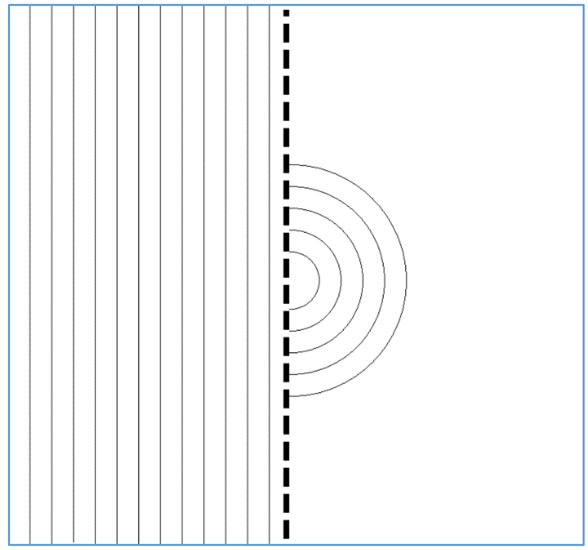
The Diffraction Pattern of a Grating

Equipment	Qty
optical bench	1
diffraction grating	1
ruler	1
meter stick	1
laser & power supply	1
screen	1
block to hold grating	1

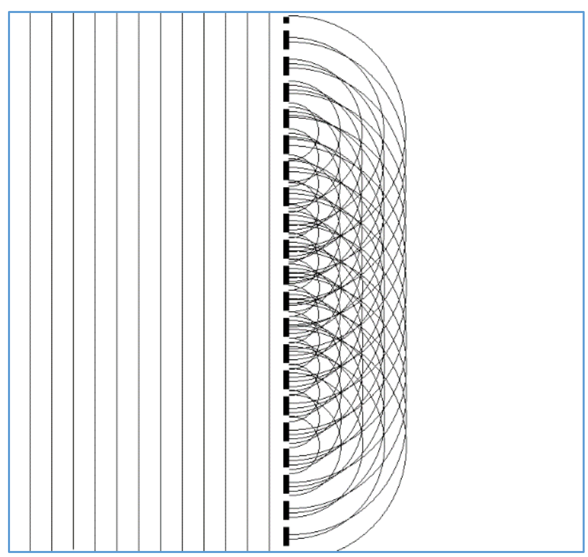
Waves diffract around obstacles. Since light is a wave phenomenon, diffraction is an important factor in the propagation of light. A diffraction grating consists of a series of opaque lines that interfere with a wave (hence the name grating). The figure below depicts such a grating as it would be seen by an incoming wave.



The next figure depicts the grating from above. The short dashes are the grating lines seen end on. Wave fronts are depicted approaching from the left. These will propagate through the slits between the lines, and will emerge from each slit as expanding cylindrical waves. The waves from one slit are shown propagating beyond the

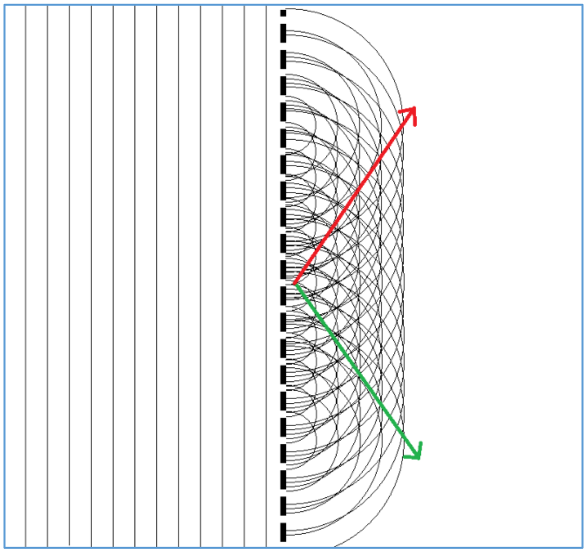


grating. The following figure shows waves propagating from 13 of the slits. It's evident from this figure that the waves from multiple slits add to produce a strong wave front

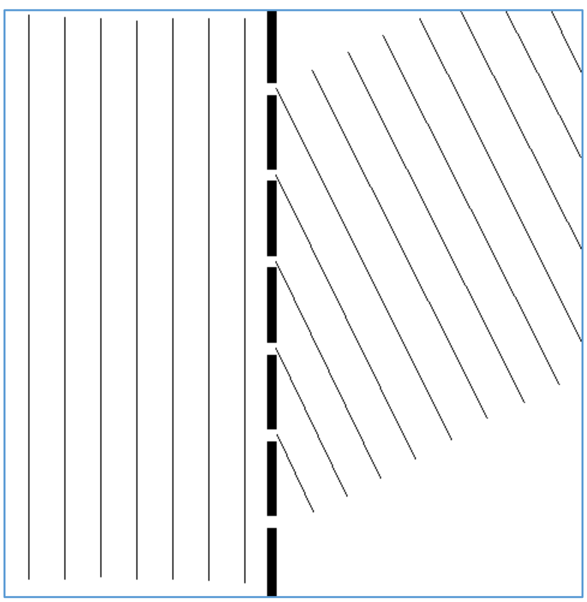


propagating in a direction perpendicular to the plane of the grating. This is because the wave peaks from the individual waves are in phase in a direction that is perpendicular to the grating. But at most other angles, the wave are not in phase, and so do not add constructively. But at certain angles, the waves are again in phase.

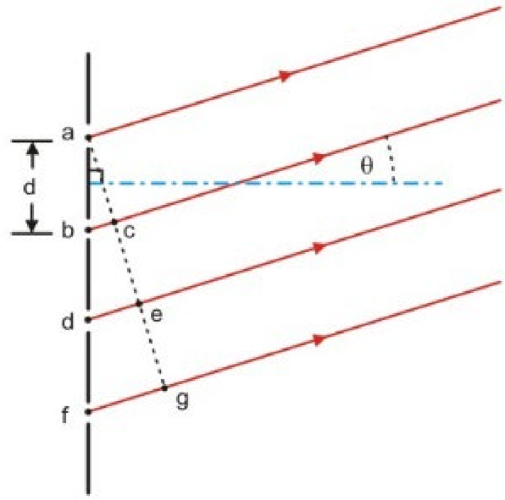
The arrows in the next figure depict the directions of two other strong waves (you can make out the wave fronts).



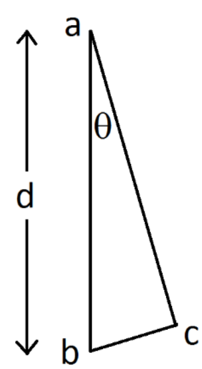
These occur because wave peaks are also in phase in this direction. The figure below illustrates how.



This figure shows that the waves emerging from two adjacent slits have different distances to travel, and the difference is equal to the wavelength. The next figure helps to quantify things. Distance bc is equal to the wavelength, de is twice the wavelength, and fg is three times the wavelength. Thus, at angle θ, the waves emerging from the four slits are again in phase.



Triangle abc is a right triangle (shown below).



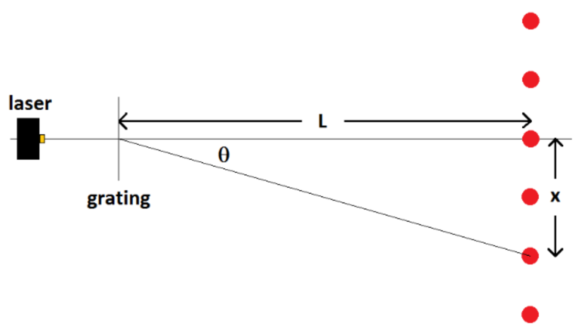
Since bc $= \lambda$, then

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

And the condition also holds when the opposite side of the triangle is an integer multiple of λ, so that the following equation is true:

$$d \sin\theta = n\lambda \qquad (eq. 1)$$

d is the distance between adjacent slits, and n is an integer. Thus, when light of a single wavelength shines through a diffraction grating, then it should propagate beyond the grating only in the directions that satisfy the above equation. You'll see multiple bright spots.



In this figure, L is the distance from the grating to the screen on which the pattern appears. In this case, $n = 2$ and $\tan\theta = x/L$. In this exercise, you'll make measurements of the pattern on the screen and then use $eq. 1$ to calculate d, the distance between adjacent slits.

Procedure

1. The wavelength of laser light is indicated on the laser itself. Record the wavelength in SI units.
   $\lambda =$ ____________ m
2. Put the laser source on one end of the optical bench and the screen on the opposite end, so that the laser beam appears on the screen.
3. Place the wooden block between the laser and screen and place the diffraction grating in the slot so that the beam can pass through the grating.
4. You can adjust the position of the block on the bench in order to change the diffraction pattern on the screen.
5. Arrange the block so that the central spot and one spot on either side appear on the screen.
6. Measure L and record it in the $n = 1$ row of the table below.
7. Measure x, the distance to the $n = 1$ off axis bright spot, and record it in the $n = 1$ row.
8. Determine θ from x & L. Recall that $\tan\theta = x/L$.
9. Use $eq. 1$ to find d.
10. Move the block so that both $n = 2$ dots appear on the screen. Measure x & L, and then calculate θ & d.
11. Repeat the process for $n = 3$, if you can find the $n = 3$ dots.

n	L	x	θ	d
1				
2				
3				
			Average	

12. Printed on the diffraction grating slide is the density of lines on the grating. Record this (state the units).
    $dens. =$ ____________
13. Using the line density, determine d in SI units.
    $d =$ ____________ m
14. Using the d calculated from the line density as the accepted value, find the percent error of the d determined from the experiment.
    $\%\ error =$ ____________ $\%$
15. Did the experiment work for $n = 3$? If not, why not?
16. Now switch to the other laser and repeat the experiment.
    $\lambda =$ ____________ m
    $\%\ error =$ ____________ $\%$

n	L	x	θ	d
1				
2				
3				
			Average	

The Diffraction Grating Spectrometer

Since θ is dependent on λ, the wavelength of light, then for each n, every λ will have its own θ. This means that light consisting of a range of wavelengths will be spread out over a range of angles. A diffraction grating thus serves as a highly effective way to view the spectrum of a light source.

The blue triangular device on your table is a simple diffraction grating spectrometer. The instructor will show you how to use it. The fluorescent light illuminating the room provides a good source. Point the spectrometer at one of the bright spots on the ceiling tiles, and you'll be able to see the spectrum of the light from the fluorescent tubes in the light fixtures. You'll see that the spectrum is complicated, with broad bands of wavelengths. This is because the light is emitted mostly by solid fluorescing coatings on the inside surfaces of the tubes. Solids generate very complicated emission spectra.

Another light source, one with a simpler spectrum, is on a cart in the back of the lab room. The light from the source is produced by energized mercury vapor. Since the atoms are in a gaseous state, the spectrum is not affected by the complicated interactions between atoms that occur in solids, and it is much simpler, consisting of just a few isolated wavelengths.

View the spectrum and identify as many wavelengths as you can. Note the units of wavelength that the device reads, and record your answers in nanometers.

$\lambda_1 =$ _________ nm

$\lambda_2 =$ _________ nm

$\lambda_3 =$ _________ nm

$\lambda_4 =$ _________ nm

$\lambda_5 =$ _________ nm

$\lambda_6 =$ _________ nm

$\lambda_7 =$ _________ nm

The gas inside fluorescent light tubes is in fact mercury vapor (along with a noble gas like argon). The fluorescing coatings absorb emission from the Hg vapor and emit broader spectral bands. The collective effect of these bands on the human visual system is to appear similar to sunlight.