Introduction:

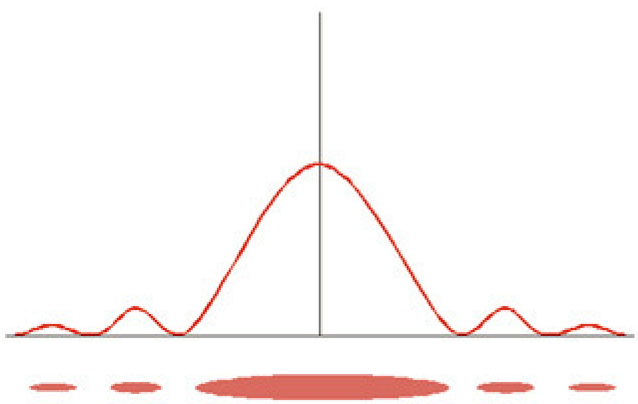
In this lab we will explore the wave and particle nature of light. In the first experiment we will measure the diffraction pattern of light as it passes through single, double and multiple slits. In the second experiment we will examine the emission spectrum from different gases

Experiment 1: Wave Properties of Light

Visible light is an electromagnetic wave, with wave length λ between 400 and 750 nm, and exhibits wave-like characteristics of interference and diffraction under certain circumstances.

Diffraction Patterns:

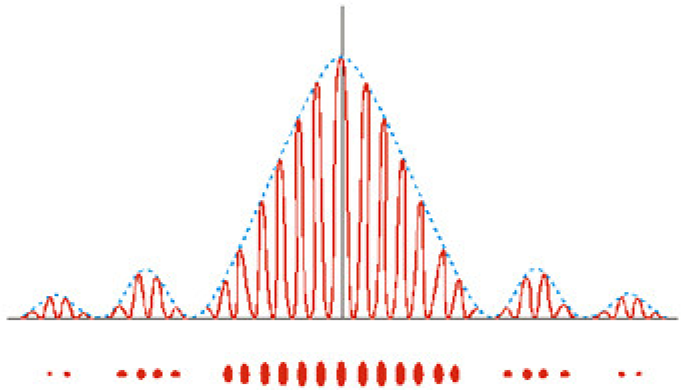
When light of wave length λ passes through a slit of width *a* and then strikes a screen which is a distance *L* from the slit, then a central bright beam of light forms opposite the slit, and then a series of secondary fringes form on either side as demonstrated in the diagram and graph below:



The width of the central beam, as measured from the centers of the two minima on either side, is $2L\lambda/a$. The width of the other fringes is $L\lambda/a$. Larger wavelengths give a larger separation. Smaller slit widths lead to a wider separation. If the slit width is very small it is possible that only a very wide central maximum is visible, and if the slit width is very large all the fringes may be so close together that only a single small spot will be visible.

Interference Patterns:

When light of wave length λ passes through two slits, each of width *a*, and separated by a distance *d* and then strikes a screen which is a distance *L* from the slits then a fringe pattern like the following may form:

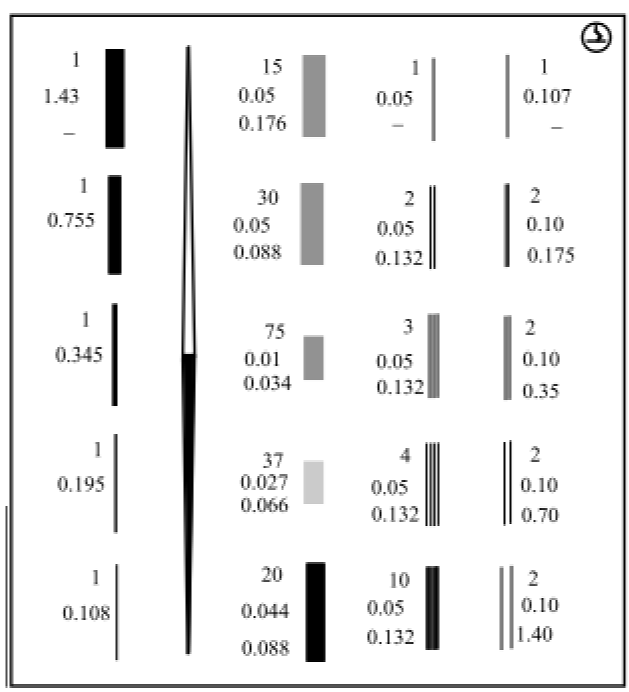


The separation between the fringes is $L\lambda/d$.

When there are more than two slits the interference pattern is similar, although the fringes are better defined – with smaller but brighter fringes.

Procedure:
In this experiment we will use two different lasers with different wavelengths and a variety of different slit combinations to explore the qualitative and quantitative features of these diffraction and interference patterns.

For the different slits we will use a Cornell slit plate which is illustrated below. The first column shows a series of different single slits, the second column shows a slit of variable width, the other columns show 2 or more slits, with different separations and widths. The numbers to the left of the slits show properties of the slits. The first number is the number of slits, the second is, *a*, the width of the slits in mm, and the third, when present, is, *d*, the distance between two slits.

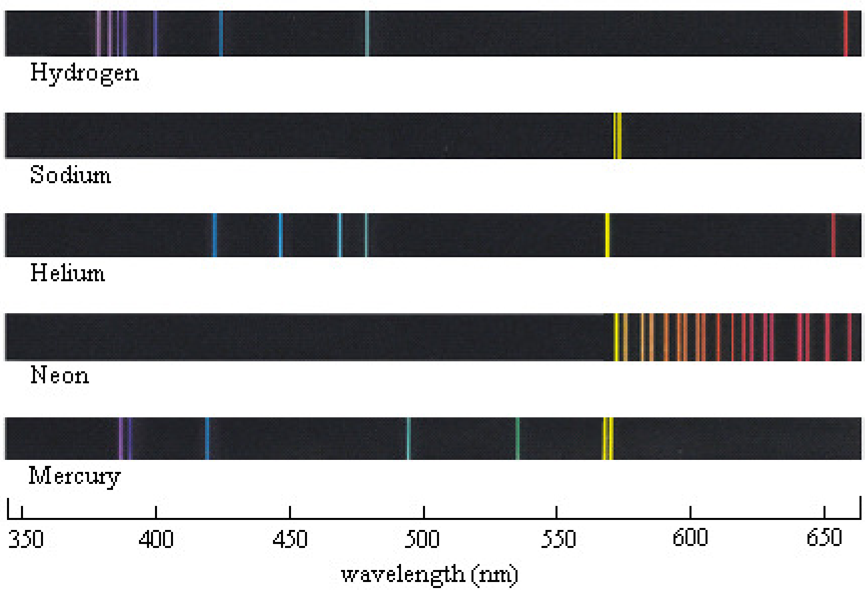


1. Set the slit plate on the stand and one of the lasers opposite it. Make sure the whole apparatus is a distance of 4 or more meters from the screen. Measure this distance. When it is safe to do so turn on the laser (do not look into the laser, it can damage your retina).
2. First aim the laser through a few of the single slits and qualitatively compare the diffraction patterns you see. Sketch a few of the patterns. For the narrowest slit measure the separation of the fringes and use the formula to determine the wave length of the light. Repeat for the other laser. Confirm that the larger wavelength corresponds to larger fringe separation. (Note: the red laser is reported to have wavelength 632.8 nm and the green has wavelength 532 nm. Find the percentage error between your measured value and the reported value.)
3. Now aim the laser through some of the double slits in the right most column and qualitatively compare these interference patterns. Sketch the pattern for a few of these. For the double slit with the smallest separation distance measure the distance between the fringes and check the formula to see if you obtain the same value of the wave length of light. Repeat for the other laser.
4. Now aim the laser through some of the multiple slits. In particular, use the slits in the second column from the right in the diagram above. As you go down the column the number of slits increases from 1 to 2 to 3, up to 10. Draw sketches of the full diffraction pattern for 1, 2 and 10 slits next to each other. What are the differences and similarities?
5. Finally, obtain a diffraction grating, which has 600 slits per mm. Place this diffraction grating in the holder and place white screen about a 1 meter from the grating. Turn on your laser and measure the separation between the fringes that you see. Because the slit separation in this grating is so small the fringe separation is quite large. What is the separation between two slits if there are 600 slits per mm? The interference formula given above is actually only an approximation to the formula that applies when the fringe separation is small compared to the distance from the screen. The correct formula is $d\sin\theta=\lambda$, where θ is the angle between the line from the grating to the central fringe and the line form the grating to next fringe. You can determine the angle with trigonometry by measuring the distance between the fringes on the screen, y, and the distance between the screen and the grading, L. Then

$$\theta = \tan^{-1}(y/L)$$

Experiment 2: Particle Properties of Light

When a gas in a discharged tube is excited it emits light with characteristic frequencies. This light is produced when electrons in specific orbitals drop to lower orbitals and as a result emit a photon of a particular energy. Einstein showed the frequency of the photons was proportional to their energy. Thus only certain frequencies of light are emitted from the gases, depending on the nature of their orbitals. These frequencies are called the emission spectrum of the atom. Thus each atom has its own unique fingerprint that can be used to identify it. The emission spectrum can be observed by looking at the light from the discharge tube through a diffraction grating. The diffraction grating causes the light to separate into its component colors. We will view the light from the discharge tube using a spectrometer. This is essentially a diffraction grating with a scale calibrated to give the wavelengths of the light that is diffracted through the grating. The emission spectra from a few elements are shown below:



Bohr's model of the atom provides a good explanation for the emission spectrum of hydrogen. The visible part of the spectrum of hydrogen is called the Balmer series, named after a Swiss highschool teacher who observed them. This series comes from the emission of light due to electrons that drop from higher energy levels down to the second energy level. The wavelengths of the emitted photons fit the pattern:

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

Where R is 1.0973×10^7 m^{-1} and n is the energy level (n=3,4,5), with n=3 corresponding to the red light, n=4 to the blue light and n=5 corresponding to violet light. (Other parts of the spectrum may also be visible).

Procedure:

1. Obtain a hydrogen discharge tube, place it in the lamp and turn it on. Observe the tube through the spectrometer, with the light from the lamp entering the small slit. Look for the bands of light on the left corresponding to the different frequencies of light.
2. Record the wavelengths of each part of the brightest fringes of light and test the above formula.
3. Obtain the three mystery discharge tubes labeled A,B and C. And repeat part 1. above. Record the values of the wavelengths of the brightest four fringes or so for each. Then using the diagram above identify each of the elements in the tubes.