Diffraction

In this experiment you will use a He-Ne laser to measure the properties of the diffraction pattern of a single slit or a similar diffraction screen.
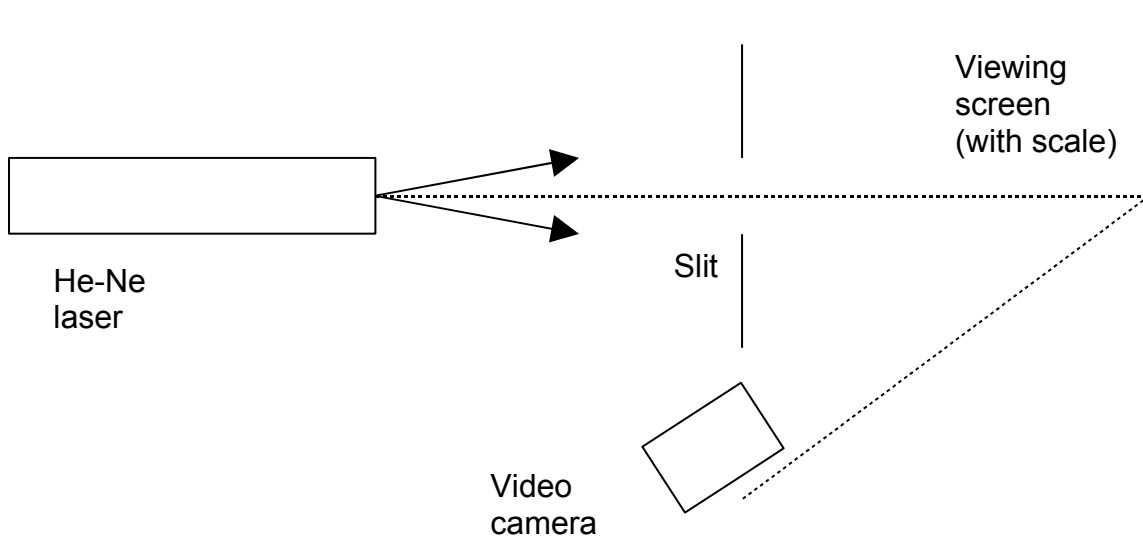

Figure 1. Single-slit diffraction apparatus. The slit is illuminated by the laser beam, and the video camera records the intensity of the resulting diffraction pattern on the screen.

Instructions. Set up the equipment as shown in Figure 1 and record the diffraction pattern with the video camera and the software. The video camera includes an extension tube, which pushes the lens away from the image plane. (Why?) You can therefore focus over only a smallish range of object distances, so be careful to ensure that the diffraction pattern is in focus.

Before storing any data, reduce the viewing area to a single line through the center of the diffraction pattern and ensure that the intensity does not saturate the video camera. You may adjust the overall sensitivity of the video camera by adjusting the iris on the lens or by inserting a neutral density (gray) filter in the laser beam. The neutral density filter is calibrated on a logarithmic scale, where a density of 1 means a transmittance of 0.1, a density of 2 means a transmittance of 0.01, and so on.

When you are ready to store data, expand the viewing area so that it encompasses the entire visible diffraction pattern; if you do so, then you will not have to align the viewing area so that it is precisely parallel to the line between the maxima.

When you set the viewing area for a single line, you will see noise owing to the *speckle pattern*, sometimes called *laser speckle*. Move the paper slowly, and you will see the speckle change somewhat. Expanding the viewing area averages over many speckles

and reduces the noise due to the speckle pattern. (If you examine the diffraction pattern of a circular aperture, however, you will not be able to expand the viewing area but will have to ensure that the radius of the first maximum is much greater than the width of 1 scan line.)

The far-field, or Fraunhofer, diffraction pattern (you will need to get a reference) is given by

$$I(\theta)=I_O\frac{\sin^2(u)}{u^2}$$
(1)

where $u=(\pi/\lambda)d\sin(\theta)$, d is the slit width, λ is the wavelength of the light, and I_O is the relative intensity at the center of the pattern.

Equation (1) presupposes that the distance between the source and the slit is at least several times greater than $d^2/4\lambda$, as is the distance between the slit and the viewing screen. See, for example, http://www.mines.edu/~mmyoung/PHCamera.pdf , but see if you can find additional references. If your diffracting screen is a multiple-slit screen, then the far-field condition has to be met for the distance between the first and last slits, not for the slit width.

Check to see whether the far-field condition is met for your experiment. The source is effectively located at the far end of the laser cavity (because the laser is a hemispherical cavity, since you asked). To see the transition from near-field diffraction to far-field diffraction, go to http://www.falstad.com/wave2d/ and set it for double slit; it is easier to see what is going than with a single slit. Falstad has a lot of other splendid applets you might find useful. *Discuss in your report whether the far-field condition is satisfied for your experiment.*

If you want to examine the diffraction pattern at large angles, open the iris until the center saturates and record another pattern; try to stitch the saturated and unsaturated patterns together to get a complete record.

Measuring with the scale. To calibrate the horizontal scale, photograph the measuring scale given. For this experiment, do not assume that the uncertainty of the measuring scale is related to one-half the least count, in part because you can interpolate accurately with a video camera, whereas you cannot do so visually. Instead, examine the data and estimate the greatest possible uncertainty in some other way.

Suggestions.   Record the diffraction pattern for different slit widths and compare with theory.   See whether the zeros are located where $\theta=m\lambda/d$, where m is an integer. See whether the peak intensities of the secondary maxima decay as $1/u^2$.   Measure a multiple-slit diffraction pattern and compare with theory. Perform a proper error analysis on your measurements.   Do not be content with measuring only the positions of the maxima; you can do so with a ruler. Instead (or in addition), use the relative intensity measurements from the video camera to compare with theory.