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Guidelines for diffraction grating experiment

1 Objectives

This laboratory has only a few specific goals you must achieve. How you achieve them, within reason, is up to you. Your objectives are:

1. Using a known diffraction grating and diode laser light source, measure the angular position of as many orders of diffracted beams as you can see. Compare these positions with the theoretically expected result.
2. Calibrate a CdS photoresistor using neutral density filters of known attenuation.
3. Using your calibrated photoresistor, measure the intensity of the $m = 0, \pm 1, \pm 2$ diffracted beams at their maxima. Compare with the theoretically expected result.
4. Verify whether the diffracted light is polarized or not.[i]
5. Qualitatively explore few-slit diffraction patterns.

2 Equipment

You will need the following equipment, at least:

1. diffraction grating
2. multimeter
3. magnetic optical mounts (x3)
4. laser (<1 mW); we have red and green
5. relative transmission (a.k.a. neutral density) filters
6. CdS photoresistors (on optical mount, prewired)
7. aperture/shield for CdS cell (Cu pipe; reject stray light)
8. various measurement tools (ruler, calipers)
9. optional: lens to focus beam onto CdS cell

[i] This implies you first know whether the laser is polarized or not.

3 Suggestions

You are free to accomplish the stated goals however you wish. Below are some suggestions and background.

3.1 Intensity of beams diffracted by a grating

In particular, measuring the intensity will not be trivial. As you know, the intensity as a function of the diffracted beam order drops fairly rapidly. Specifically,

$$I = I_o \left(\frac{\sin\beta}{\beta}\right)^2 \left(\frac{\sin N\alpha}{\sin\alpha}\right)^2 \tag{1}$$

where[ii] I_o is the intensity at $\theta = 0$ by any one slit, N is the number of slits *that the beam strikes*, and

$$\beta = \frac{1}{2}kb\sin\theta = \frac{\pi b}{\lambda}\sin\theta \tag{2}$$

$$\alpha = \frac{1}{2}ka\sin\theta = \frac{\pi a}{\lambda}\sin\theta \tag{3}$$

for a grating with slits of opening width b and center-to-center separation a. Recall that if a/b is the ratio of 2 integers, then there is a "missing order" in the diffraction. For example, if $a = 3b$, the 3rd-order $m = \pm 3$ diffraction peaks will be missing. *This particular fact can be crucial in figuring out the geometry of your grating,* as typically only $1/a$ is specified (as lines per mm or cm).[iii] The coincidental zeros of the $(\sin^2\beta)/\beta^2$ and $(\sin^2 N\alpha)/\sin^2\alpha$ terms lead to the missing order, and it is your only practical means of determining b.

Let me repeat that. Look for missing order spots to determine b/a. Do not assume that it is unity. Do not assume you all have the same gratings . . .

If you measure only the diffraction beam peak intensities, then the relative variation in diffracted beam intensity with beam order m is dictated only by the $(\sin^2\beta)/\beta^2$ term in Eq. 1, since the other term will by construction *always be at maximum* and equal to 1. Thus, for intensity comparisons, *knowledge of* β is crucial, as is a knowledge of the beam area – the N above is the number of lines the beam interacts with, dictated by the known number of lines per unit distance and the beam diameter you must determine. One clever idea might be just to take a picture of the beam spot next to a ruler for later magnification and measurement.

[ii] Warning! The definitions of α and β vary by a factor of two from text to text. The physics does not; be sure you know what *should* come out of the equation.

[iii] Of course, you can check a by noting that the diffracted beam peaks occur at $\sin\theta = n\lambda/a$ . . .

In the end, you may simply need to treat the beam area as an adjustable parameter (within reason): put upper and lower limits on its extent, and compare your experiment data with calculations for a family of curves with varying area. A point of caution: if you plan to use a lens to sharpen the beams, place it before the diffraction grating and fix its position relative to the grating.

3.2 Photoresistor

You will want to calibrate your resistor over an intensity range from 100% (unfiltered beam) to about 10% of that value. You may need a two filters in series (e.g., one Pasco and one Wratten filter or two Wratten filters). The intensity of the higher order beams may only be a few percent of the undiffracted beam, depending on your conditions.

One complication is that the response of a photocell is a non-linear function of incident light intensity. That is, if the incident light intensity doubles, the resistance will almost certainly not change by a factor of 2. You will need to calibrate your photocell by first varying the intensity of the laser in a known fashion using the variable transmission filters as noted above, and measuring the resistance versus percent transmission. Once this characteristic is known, subsequent measurements of resistance (using the same source of illumination) can be converted into accurate measurements of transmission percentage. Typically, the resistance R of a photoresistor obeys a power-law behavior with regard to intensity I to very good accuracy:

$$\mathsf{R} = \mathsf{R_o} I^{\gamma} \tag{4}$$

where $\mathsf{R_o}$ and γ are constants to be determined for your photoresistor, and I is the normalized intensity. After measuring your $\mathsf{R}(I)$ characteristic, perform a least-squares regression to determine the coefficients for the power law above. This will calibrate your photocell and allow relative intensity to be accurately determined from a resistance measurement.

Finally, make sure the whole beam of interest hits the photoresistor for the entire experiment. If some of the beam 'misses' the photoresistor, you have just artificially reduced the measured intensity! You may want to use a lens for this, as noted above, taking care with the lens placement.