Phys112K: Spectroscopy

Name:

Group Members:

Date:

TA’s Name:

Apparatus: spectrometer; light shield; diffraction grating; hydrogen, helium, and unknown spectrum tubes; spectrum tube power supply, lab jack; desk lamp

Objectives:

1. To observe the operation of a diffraction grating.
2. To use a diffraction grating to investigate the atomic emission lines from several gas discharge tubes.

Part 1: Introduction

In an experiment early in the semester you investigated what happens when monochromatic light is passes through a double slit. You saw that the double slit interference created a pattern of bright and dark fringes. The larger the distance between the two slits, the closer together the fringes were. Conversely, the closer together the slits, the farther apart the bright fringes were from each other.

The equation we learned earlier that gives for the angles which the correspond to the bright fringes was

\[ \sin \theta = \frac{m \lambda}{d} \]

where \( d \) was the slit separation (measured center of one slit to center of the other), \( m \) was the order number where \( m = 0, \pm 1, \pm 2, \ldots \), and \( \theta \) was the angle at which the bright fringe was observed.

A diffraction grating is an extension of the double slit. The grating has many clear slits that are spaced evenly apart. Each slit transmits light. The interference of the light from all of these slits has an effect similar to the double slit, except the bright fringes are very sharp (narrow) with lots of dark space in between. The equation for the location of the bright fringes from the diffraction grating is exactly the same as the equation for the double slit given above. Because the slits in the diffraction grating are much closer together than for the double slit, that is, the value of \( d \) is much smaller, the bright fringes will be more spread out. In other words, the grating has higher resolution.

The inverse of the slit separation, \( \frac{1}{d} \), is called the slit density. It is usually given in lines/unit length. This number is less cumbersome than the slit separation which is a very small number. In this experiment you will find the slit density of your grating experimentally.
Part 2: Aligning Spectrometer and Investigating the Yellow Line of Helium

This experiment must be performed in a dark room. Shield your apparatus so that stray light does not enter the grating.

Focus the spectrometer. Place the telescope on 0° and adjust the position of the slit, if necessary, so that the image of the slit appears in the crosshairs. Adjust the slit, the crosshairs, and the objective of the telescope to get the best focus.

Place the helium tube in the power supply. Place the power supply on the lab jack, position it against the spectrometer slit and turn it on. Put the grating in the holder and mount the holder on the spectrometer so that the grating is perpendicular to the collimated beam of light. The hollow side of the grating should face the slit.

1. We need to align the grating so that the spectra will be symmetric about 0°. To do this, use the telescope to find the first order yellow line on the right and left side of 0°. These lines correspond to $m=±1$ for the yellow line. Record these angles and average them.

   Angle for yellow line on left side = ____________________________

   Angle for yellow line on right side = ____________________________

   Average of angles for two yellow lines = ____________________________

2. Now set the telescope to this angle and rotate the grating holder until the yellow line appears in the crosshairs. Record the angles for the two yellow lines again.

   Angle for yellow line on left side = ____________________________

   Angle for yellow line on right side = ____________________________

3. Are the two angles the same (within 0.1° of each other)? Check yes ____ or no ____?

   If yes, go on to Question 5.

   If no, calculate the average again, rotate the telescope to this average angle, and rotate the grating again just as you did in Question 3. Continue to do this until the left and right angles are within 0.1° of each other. If you have problems with this, call the lab instructor. Your grating is now aligned. **Do not move it for the rest of the experiment.**

4. Rotate the telescope and observe what you see at different angles. Describe what you see.
5. Do you see bright light at all angles? What do you notice about the colors of light?

6. What do you conclude about the light emitted from the helium atoms in the discharge tube?

7. Set the telescope at the first order yellow line on either the right or left side. Now rotate to larger angles until you find the second order yellow line on either the right or left side.

Angle for first order yellow line = $\theta_1 =$ __________________________

Angle for second order yellow line = $\theta_2 =$ __________________________

8. Is the second order line at an angle twice as large as the first order line?

9. Look back at the equation given earlier for the angles where the bright lines occur. Both yellow lines have the same color (same wavelength, $\lambda$) and we are using the same diffraction grating (same slit spacing, $d$). Using that equation, what other quantity should double when the order number, $m$, is doubled from one to two?

10. From your data in Question 8, calculate the sine of the angles for the first and second order yellow lines.

$sin \theta_1 =$ __________________________

$sin \theta_2 =$ __________________________

11. Is the sine of the angle for second order line twice the sine of the angle for the first order line? Is it approximately twice as large?
Part 3: Investigating the Spectrum of Helium

12. Find six spectral lines of helium (each will be a sharp line of a different color) and record the color and angles at which they appear in the first order. Because the grating is aligned you need only take data from one side (right or left) of the spectrometer.

<table>
<thead>
<tr>
<th>Color</th>
<th>$\theta_1$ (degrees)</th>
<th>$\lambda$ (nm)</th>
<th>$\sin\theta_1$</th>
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13. Using the table at the end of the lab, identify the wavelength for each of the lines. Some of the entries in the table may have been so faint that you didn’t see them well. Some of the entries in the table have two lines close together. They would be merged into one line when viewed in our spectrometer. So in that case, use the average of the two values in the table.

14. Enter you angles and wavelengths into an Excel spreadsheet. Create a column for $\sin\theta_1$ use formula entry to calculate it. Then plot $\sin\theta_1$ vs. $\lambda$.

15. Does your graph indicate that $\sin\theta_1$ is linearly dependent on the wavelength, $\lambda$?

16. Rearrange the equation given in the introduction as needed to find an expression for the slope of the graph of $\sin\theta_1$ vs. $\lambda$.

Slope =

What would this expression be if we just used the first order lines?

Slope =

17. Fit a linear trend line to your data and determine the slope. Remember the units.

Measured slope of $\sin\theta_1$ vs. $\lambda$ = ________________

18. Use the slope you measured to find $d$, the slit separation, and $1/d$, the slit density. Remember units.

d = ____________________________

$1/d$ = ____________________________
Part 4: Investigating the Spectrum of an Unknown Element

Turn off the power supply and remove the helium tube. Use a paper towel to handle the tube because it will be hot.

Do not move the grating. Replace the helium tube with the "unknown" tube and turn everything back on. Record the letter marked on the unknown tube.

Unknown: _______________________

19. Pick four or five lines of the unknown spectrum and record the color and angles at which they appear in the first order.

<table>
<thead>
<tr>
<th>Color</th>
<th>$\theta_1$ (degrees)</th>
<th>$\sin \theta_1$</th>
<th>$\lambda_{observed}$ (nm)</th>
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20. Calculate the sine of the angle for each line. Then use the value of $d$ you determined using helium to calculate the wavelength for each line. Check your calculations by seeing if the wavelength matches with the color you observed.

21. Using the table, identify the element whose spectral lines match your observed lines the best. Write the name of the element and copy the observed wavelengths and the best match expected wavelengths for that element as found in the table.

<table>
<thead>
<tr>
<th>$\lambda_{observed}$ (nm)</th>
<th>$\lambda_{expected}$ (nm) for __________</th>
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22. How confident are you that you have correctly identified the unknown? Explain why?
Part 5: Conclusions and Applications

23. Describe what a diffraction grating does when a source of light containing multiple wavelengths is directed at it.

24. How would the result be different if the diffraction grating had more lines per millimeter?

25. The excited gases in the tubes you used also produced spectral lines in the ultraviolet and the infrared. These are not visible to our eyes, but could be view by other means. Where would these lines appear on the spectrometer relative to the visible lines?
### Wavelengths of Some Prominent Spectral Lines (in nm)

<table>
<thead>
<tr>
<th>Hydrogen</th>
<th>Mercury</th>
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<tbody>
<tr>
<td>v</td>
<td>v</td>
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<tr>
<td>v</td>
<td>v</td>
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<tr>
<td>b</td>
<td>v</td>
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<tr>
<td>bg</td>
<td>v</td>
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<tr>
<td>r</td>
<td>v</td>
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* v=violet, b=blue, bg=blue-green, g=green, y=yellow, o=orange, ro=red-orange, r=red