Physics 41: The Visible, Bright Line Spectra of Hydrogen

The bright line spectrum of a gas can be explained with the Bohr model of the atom, which shows that electrons in an atom are in discrete energy states and emit photons of electromagnetic radiation when going from a higher energy level to a lower energy level. The energy of the emitted photon is just the difference between the energy levels of the initial ($n_i$) and final ($n_f$) states. The Balmer series of spectral lines are visible and are due to transitions from higher states to the $n_f = 2$ state. The energy of the photon emitted in these transitions is $E_{\gamma} = \frac{hc}{\lambda} \gamma$ which is also equal to the difference in initial and final energy levels:

$$E_{n_i} - E_{n_f} = 13.6eV\left(\frac{1}{2^2} - \frac{1}{n_i^2}\right) \quad (1)$$

Today we are going to investigate the visible spectra of hydrogen using a spectrometer with a diffraction grating. On the left you see a hydrogen discharge tube. In the center are the visible spectral lines. On the right is shown the relative intensities of the lines.

The photon colors associated with some of the Balmer series lines are given in the table below.

<table>
<thead>
<tr>
<th>$n_i$</th>
<th>color</th>
<th>Wavelength (in nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>red</td>
<td>656.3</td>
</tr>
<tr>
<td>4</td>
<td>blue-green</td>
<td>486.1</td>
</tr>
<tr>
<td>5</td>
<td>blue-violet</td>
<td>434.0</td>
</tr>
<tr>
<td>6</td>
<td>violet</td>
<td>410.1</td>
</tr>
</tbody>
</table>
Procedure

1. Make a table for your data: grating lines, color, angle and wavelength, etc.

2. Set up your spectrometer. To do this:
   1. Familiarize yourself with the various adjustments of the spectrometer and the reading of the scale and Vernier.
   2. Adjust the focus of the viewing telescope. To do this:
      a. “Unfocus” the view through the telescope and adjust the focus of the cross-hairs.
      b. Focus the telescope for parallel rays by sighting on a distant object through a window, adjusting the focus to eliminate parallax between the crosshairs and the image of the distant object. (Parallax is eliminated when there is no relative motion between the cross-hairs and the image as the eye is moved from side to side. Be careful not to disturb the telescope once this adjustment is made.)
      c. Adjust the collimator by illuminating the slit with any source of light and adjusting the position of the slit until a sharp image with no parallax is seen.
      d. Set the diffraction grating table at the proper height (adjusting the leveling screws if present and necessary), and mount the diffraction grating on the table.
      e. Rotate the diffraction grating table until the diffraction grating is perpendicular to the beam of light.

3. Adjust the slit width and zero your spectrometer on the bright central light source. Determine the units of angle measurement for your spectrometer.

4. Find the red line first. The crosshairs should be in the center of each line. Measure the angle for each line on one side of the bright source. Careful units! Find the next 3 lines. Repeat for the other side. You may want to use an average for your final angle. Discuss your method.

5. Calculate the wavelength of each line using the diffraction equation for the 1st order images: \( \lambda = \frac{d \sin \theta}{D} \). Careful with units! D is spacing between two lines on the diffraction grating set. Your set has 15000 lines per inch (15000 lines per 2.54 cm.) This gives us \( d = 1.69 \times 10^{-6} \) m. Otherwise the lines per inch is marked on your diffraction grating and you can calculate d from (#lines/2.54*100) to get lines/m invert to get d in meters.

6. Calculate the energy of each photon (in eV and in joules) using \( E_{\text{photon}} = hf = \frac{hc}{\lambda} \) as \( f = \frac{c}{\lambda} \) (in eV and in joules). Note: h is Planck’s constant and c is the velocity of light in vacuum (3 x 10^8 m/s). You may look up the values of these constants in your physics text book. Be careful about the units.

7. Calculate the wavelength and energy of each photon using equation 1.

8. Calculate the percent difference between the photon wavelength and energy using the two methods. Briefly discuss your sources of error and results.