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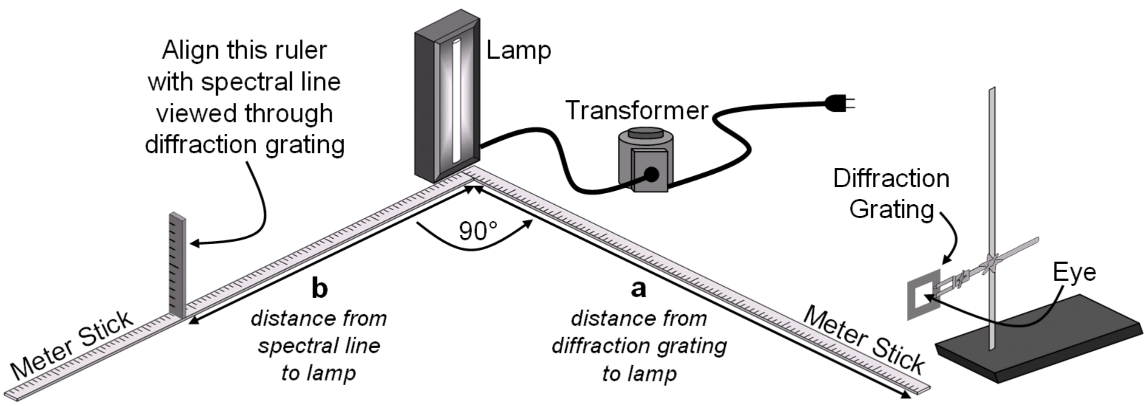
Experiment #9: Emission Spectra of Hydrogen, Helium, and Mercury

According to quantum theory, electrons exist in specific energy levels. Moreover, an electron can transition from one level to another by absorbing or emitting a certain amount of energy equal to the difference between the final and initial states. When this energy takes the form of light, the frequency (v) can be calculated using the important equation $\Delta E = hv$, where h = 6.626 x 10^{-34} J·s (Planck's constant).

In this experiment, you will excite electrons to higher energy levels using electricity. As electrons return to lower energy levels and emit light, you will observe various colored lines in the hydrogen spectrum, a green line in the mercury spectrum, and a yellow line in the helium spectrum. We will first measure the wavelength of the light (λ), then convert it to frequency (v), and finally calculate ΔE.



The schematic above shows the apparatus for measuring the wavelength of light given off by hydrogen, mercury and helium. The only measurements needed to calculate λ are the distance (a) from the grating to the light source, and the distance (b) between the light source and the appearance of the spectral line. λ can then be calculated using the Bragg equation:

$$\lambda = d \sin \theta$$

where d is the distance between the lines in the diffraction grating.

Our gratings contain 600. lines per mm. You will need to convert this to cm/line. θ is the angle between looking straight at the light source and the peripheral image of the spectral line. Sin θ can be calculated in 3 steps:

1. $b/a = \tan \theta$
2. $\tan^{-1}(b/a) = \theta$
3. compute $\sin \theta$ using the sine trigonometric function on your calculator

The frequency is found using the equation $\nu = c / \lambda$, where $c = 3.00 \times 10^{10}$ cm / s (speed of light). Finally, ΔE can be calculated.

You will also be asked to predict the wavelength for various energy changes for hydrogen's electron using the Rydberg equation:

$$\frac{1}{\lambda} = 109{,}678 \text{ cm}^{-1} \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$

where n_i and n_f are the initial and final energy levels of the electron, respectively. Please note that this equation only works for the hydrogen atom or any other one-electron system.

Procedure

Using the apparatus previously described, set the diffraction grating one meter from the light source, distance (a). Tape the meter sticks at right angles to each other. Darken the room, and the student looking through the diffraction grating should direct a second student to move a vertical ruler along the meter stick, distance (b), until it just coincides with the spectral line. Record all your collected data in the provided data table.

Data and Calculations

Given that the diffraction grating has 600. lines / mm, determine the distance (d) between two of these lines in cm. Show your calculation and answer in the "blank space" on the next page. (Hint: It may help to think of this distance as having the units cm / line.)

Determine the energies corresponding to the colors you are instructed to observe for H, He, and Hg. Then, use the Rydberg equation to predict the energy changes for the transitions in exercises 1 – 3 and 6 – 10. Notice some of the exercises involve $n = \infty$. This means the electron has escaped from the atom, a phenomenon known as ionization; the atom losing an electron becomes a positively charged ion. Finally, determine which region of the electromagnetic spectrum (i.e. UV, Visible, or IR) corresponds with each electronic transition.

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Source and Color of Line	a (cm)	b (cm)	d (cm)	Wavelength (cm)	Wavelength (nm)	Frequency (s^{-1})	Energy (J/photon)	Energy (kJ/mole)	Rydberg Eq calculation of λ (nm)
1. H (red) $n = 3 \rightarrow n = 2$									
2. H (blue) $n = 4 \rightarrow n = 2$									
3. H (violet) $n = 5 \rightarrow n = 2$									
4. He (yellow)									
5. Hg (green)									
6. H $n = 2 \rightarrow n = 1$	Show calculation to determine d here:								IR, Vis, UV
7. H $n = \infty \rightarrow n = 1$									IR, Vis, UV
8. H $n = 4 \rightarrow n = 3$									IR, Vis, UV
9. H $n = \infty \rightarrow n = 3$									IR, Vis, UV
10. H $n = \infty \rightarrow n = 2$									IR, Vis, UV