Spectroscopy Lab–Identifying Unknown Elements

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The purpose of this lab is to investigate the properties of emission lines emitted from a high voltage discharge in a rarified gas. Students will use known sources to determine the number of lines per cm on their diffraction gratings. At the same they will make a “fit” to produce a calibration curve describing wavelength as a function of angle (λ vs. θ). Using this information, students will determine the wavelengths of emission lines from unknown sources, and determine the identity of these unknown sources.

I. BACKGROUND

Since the late 1800’s, scientists observed emission lines radiating from substances heated to high temperatures (e.g., Bunsen burners). Meanwhile emission lines were also observed from electrical discharge tubes containing rarified gasses of both light and heavy elements (e.g., Na, He, H, Ur, etc.). The spectrum from light gasses in a discharge tube were observed to have a geometrical spacings, something that guided early scientists in their formulation of the first atomic models. Since then, astronomers have made numerous measurements of the wavelengths due to absorption lines and emission lines from stars and comets in order to determine their chemical makeup.

When a high voltage discharge passes through a rarified gas, the electrons in the discharge “knock” the electrons in the gaseous atoms from lower energy levels to higher energy levels resulting in a process called *excitation*. The lifetime for electrons in these excited states is very small (~ 10 ns), and so they seek out lower energy levels to fill, consistent with the selection rules in atomic physics. As the atomic electron transits between a high energy state to a low energy state, the atomic system must conserve energy. In doing so, it emits a photon.

The following equation uses *conservation of energy* to describe a Balmer series transition in hydrogen from the $n = 3$ to the $n = 2$ state:

$$E_3 = E_2 + \frac{hc}{\lambda} \tag{1}$$

where $E_n = \frac{1}{2} m_e c^2 \alpha^2 / n^2 = 13.6\ \text{eV}/n^2$. Making the appropriate substitutions for $n = 2$ and $n = 3$ in Eq. 1 we find:

$$\frac{hc}{\lambda} = \frac{1}{2} m_e c^2 \alpha^2 \left(\frac{1}{4} - \frac{1}{9} \right) \tag{2}$$

Solving the above equation for λ we find:

$$\lambda = \frac{hc}{\frac{1}{2} m_e c^2 \alpha^2 \left(\frac{5}{36}\right)} = \frac{1240\,\text{eV}\cdot\text{nm}}{13.6\,\text{eV}\left(\frac{5}{36}\right)} = 656.5\,\text{nm}$$

which corresponds to the wavelength of the emission line observed in hydrogen, in the *red* part of the spectrum.

II. THE EXPERIMENT

In this experiment, the electrons produced in an electrical discharge collide with atomic electrons causing them to move into excited states. Discrete emission lines are produced when the electrons make transitions from high energy states to low energy states. A spectrometer is used to measure the wavelengths of the emission lines. Light from the discharge tube passes through a narrow slit and then through a diffraction grating located in the middle of the spectrometer. As the light passes through the spectrometer, it creates multiple wavefronts that constructively interfere at particular angles for a given wavelength. The constructive interference is described by the following equation

$$d \sin\theta = m\lambda \tag{3}$$

where d is spacing between adjacent lines on the diffraction grating, θ is the angle where the constructive interference occurs, λ is the wavelength of the emission line, and m is the order of the diffraction ($m = 1, 2, 3, \ldots$).

III. THE EQUIPMENT

The spectrometer and the discharge tube are shown in Fig. 1. The equipment is described on my `physics` website under the “Experiment Description.” This leaflet gives a thorough explaination of the equipment used in this lab. Please read it for more details.

IV. PROCEDURE

You will find more information regarding the experimental procedure in the “Experiment Description” leaflet for this lab. The procedure starts on page 4 of this document. When you arrive at step 8, you should not presume that you know the number of lines/cm of your diffraction grating. Instead you should plot the wavelength as a function of angle ($\sin\theta$), and fit the data to determine d the diffraction grating spacing (see Eq. 3). Don’t forget to do the error analysis to determine the uncertainty in d (i.e., δd).

FIG. 1. The spectroscopy experiment is shown in the figure above. A glass tube containing a rarified gas is mounted in the vertical HV apparatus. When the discharge tube is turned on, light passes through a collimator (seen facing the tube), and goes to the diffraction grating (not shown), and then bent toward the telescope where the observer makes the measurement (the diffraction angle, θ).

Once you have determined the spacing d, you are now ready to analyze an *unknown* gas using the spectrometer. Using your fitted value of d, you can use Eq. 3 to calculate the wavelength of emission lines radiating from the *unknown* gas. Again, don't forget to calculate the uncertainty in your wavelengths $\delta\lambda$ by propagating your uncertainty of the diffraction spacing, δd. Once you have determined the wavelengths, you can then go the wavelength tables for various elements (or go to websites containing this information) and identify your *mystery* gas.

V. IMPORTANT CONSIDERATIONS

- **Be careful.** You will be using high voltage in this experiment.
- Again, if you are unsure about operating the apparatus, please ask for assistance. The equipment is moderately expensive; however, your health and well-being are more important.
- **Don't forget** to do your error analysis. You will need to do the error analysis of a straight line fit, and afterwards propagate the uncertainties correctly to quote your final answer in the following format:

$$\lambda_{\text{unknown}} = (\lambda)_{\text{calculated}} \pm \delta\lambda$$

- Answer the questions in the last paragraph of the "Experiment Description" writeup.