Physics 167 – Astronomy

Lab Project 3: Atomic Emission Spectra

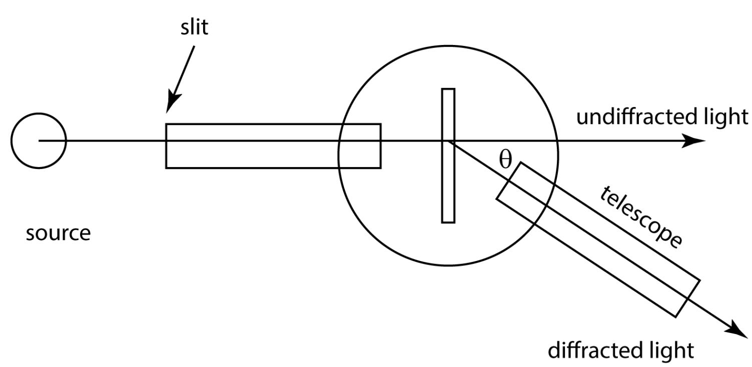
Introduction

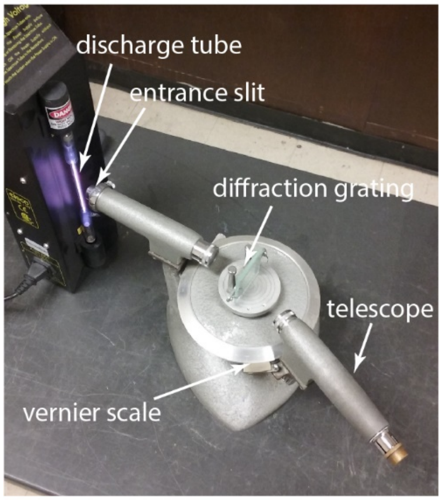
Electrons in atoms can occupy states of specific energy. When an electron in an excited state makes a transition to a lower energy state, a photon is emitted with energy equal to the energy difference between the two states. Since the wavelength of the photon depends only on its energy, excited atoms emit only specific wavelengths (specific colors). In this experiment, you will measure the wavelengths emitted by excited hydrogen atoms and compare your results with the predictions of quantum theory. For purposes of comparison, you will also observe the continuous spectrum of light emitted by a thermal radiation source.

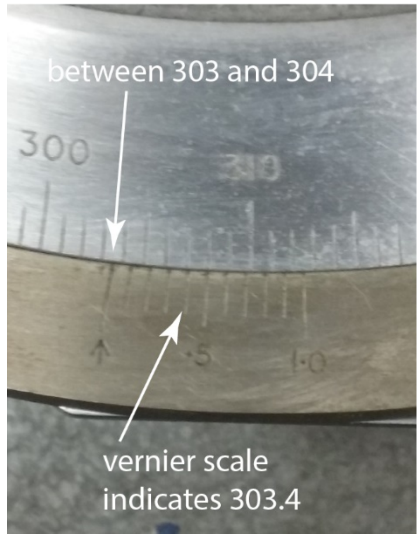
The instrument for measuring the wavelengths emitted by a light source is a grating spectrometer. The dispersive element (the component that spreads out or disperses different wavelengths of white light) is a diffraction grating, which consists of a glass or plastic substrate with a set of very fine, parallel grooves inscribed on it. The grooves act like a set of parallel slits, allowing light to pass through and diffract (spread out). The diffraction grating equation describes the angle θ at which a specific wavelength λ is diffracted:

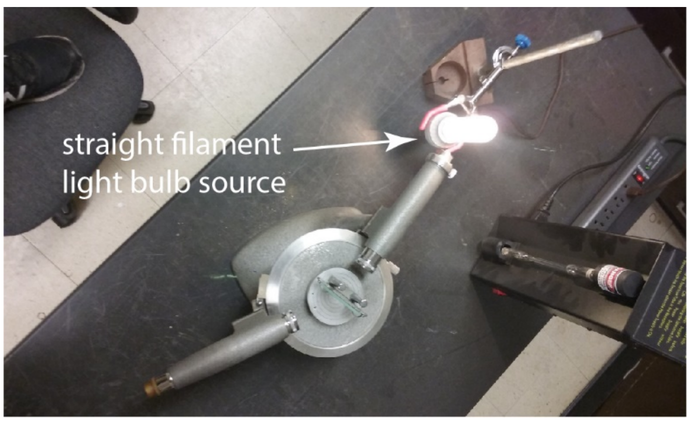
$$d \sin\theta = m\lambda.$$

Here d is the spacing between the grooves and m is an integer called the order. Our grating instrument is designed to be used in the first order (so $m = 1$ in the experiment). The figure below shows how the angle θ is measured.









Procedure

Do not touch the diffraction grating—it is delicate and can be ruined by a finger smudge.

I. Measurement of the Hydrogen Emission Spectrum

1. Turn on the hydrogen discharge lamp source. Do not touch the glass tube when it is on—it will be hot. Adjust the position of the lamp source so that it is in front of the spectrometer slit.

2. Rotate the telescope arm of the spectrometer so that it is aligned in a straight line with the source. Look through the telescope and adjust slightly if needed so that the bright line of the source is centered on the crosshairs. Record the angle of the spectrometer.

3. Turn the room lights off (you can leave the door ajar or a flashlight on so there is some light to work). While looking through the telescope, rotate the telescope arm (either left or right) until you see the diffraction lines of hydrogen. Be careful not to move the

source or the spectrometer during this measurement. You should see a red line, a blue-green line, and a violet line (which may be dim). You may need to wait a few minutes for your eyes to adjust to low-light viewing conditions. Carefully record the angle of each line when aligned on the crosshairs. Turn off the discharge lamp as soon as you finish this measurement in order to preserve its useful life.

II. Measurement of the Thermal Radiation Spectrum

1. Move the straight-filament incandescent light source in front of the spectrometer slit. Rotate the telescope arm of the spectrometer so that it is aligned in a straight line with the source. Look through the telescope and adjust slightly if needed so that the bright line of the source is centered on the crosshairs. Record the angle of the spectrometer.

2. With the room lights off and while looking through the telescope, rotate the telescope arm (either left or right) until you see the diffracted spectrum. Be careful not to move the source or the spectrometer during this measurement. You should see a continuous band of color from red to violet. Measure and record the angle of the edge of the red end of the spectrum and the edge of the violet end.

Questions

I. Hydrogen Emission Spectrum

1. For a specific observed color line, you can calculate the wavelength using the diffraction grating equation $d \sin\theta = m\lambda$, where $m = 1$ and d is the spacing between adjacent grooves (our grating has 600 grooves/mm). The angle θ is the difference in the angle readings $\theta = \phi - \phi_0$, where ϕ is the angle at which the line was observed and ϕ_0 is the angle of the direct (undiffracted) light. Make a table showing (1) a description of the color of the line (red, green, etc.), (2) the observed angle ϕ of the line, (3) the observed angle of the ϕ_0 direct light, (4) the calculated wavelength of the line in nanometers. Show one example calculation.

2. Quantum mechanics predicts the energy states of the hydrogen atom with the famous Bohr formula

$$E_n = -\frac{E_1}{n^2},$$

where E_n is the energy of the n^{th} state and n is a positive integer (n = 1, 2, 3…) The constant E_1 is called the ground state energy. The visible lines of the hydrogen spectrum that you observed correspond to transitions to the $n = 2$ level (i.e. $3 \to 2, 4 \to 2, 5 \to 2$, etc.) The red line corresponds to the $3 \to 2$ transition.

The energy ΔE of the photon emitted in a transition is the difference in the energies of the quantum states, so $\Delta E = E_n - E_{n'} = \frac{hc}{\lambda}$, where E_n is the energy of the initial state in Joules, $E_{n'}$ is the energy of the final state, $h = 6.636 \times 10^{-34}$ J.s is Planck's constant, $c = 2.998 \times 10^8$ m/s is the speed of light, and λ is the wavelength in meters.

Use your data to calculate the ground state energy E_1 for each of your observed lines (you should get around the same value for each line). Make a table showing (1) the observed wavelength, (2) the transition (for example, $3 \rightarrow 2$ for the red line), and (3) the calculated value of E_1 using that wavelength data. Give your values for E_1 in units of electron-volts, where 1 eV = 1.602×10^{-19} J. Also find the average of your E_1 values—this is your experimental determination of the ground state energy of hydrogen. Show one example calculation.

II. Measurement of the Thermal Radiation Spectrum

3. Make a table showing (1) a description of the color of the line (red or violet), (2) the observed angle ϕ of the line, (3) the observed angle of the ϕ_0 direct light, (4) the calculated wavelength of the line in nanometers. Show one example calculation.

How do your wavelengths compare with the conventionally described width of the visible part of the spectrum, from about 400 to 700 nm?