

Hydrogen Spectrum

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Phys. 2033: Quantum Lab

1 Purpose

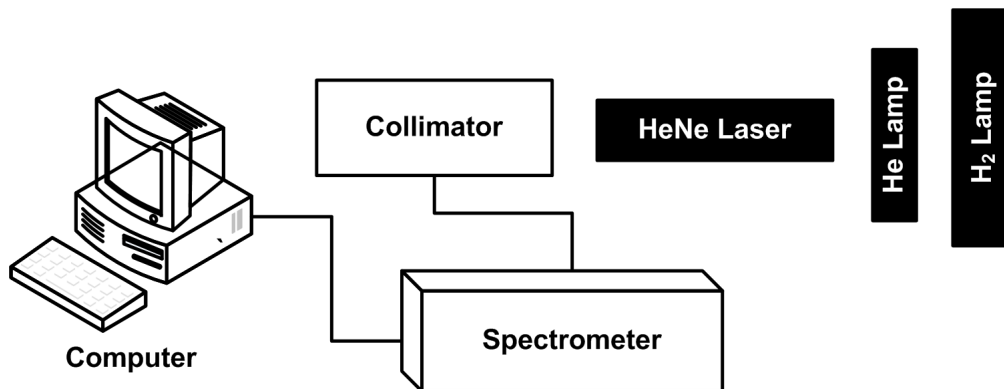
In this lab we used spectroscopy to examine the emitting properties of three light sources. We paid specific detail to the properties of the Hydrogen spectrum.

2 Methodology

We measured three light sources: a *HeNe* laser, an *H₂* lamp, and an *He* lamp. By observing their spectrums, we can make conclusions about Bohr's model of the Hydrogen atom, and also infer the source element based on an observed spectrum. Finally, we used the effects of Doppler Broadening to calculate the temperature of each source.

2.1 Equipment Used

We measured three light sources: a *HeNe* laser through a diffuser, an *H₂* lamp through a ground glass filter, and an *He* lamp. A collimator and spectrometer assembly measures the emitted spectrum from a source, and relays it to a laptop computer to be measured and recorded.



The spectrometer counts a number of events over a set integration time, and records that number as intensity. This approach has appeared in several other labs.

2.2 Physics Demonstrated

As the energy level of an atom transitions to a lower level, it emits a photon of a specific wavelength. Bohr predicted that the energy of that photon would be unique based on the initial and final energy levels of the transition inside the atom.

$$E = hf = \frac{2\pi^2me^4}{h^2} \left[\frac{1}{n_f^2} - \frac{1}{n_i^2} \right] = 13.6eV \left[\frac{1}{n_f^2} - \frac{1}{n_i^2} \right] \quad (1)$$

This model excellently describes the Hydrogen atom, but it fails to explain transitions of the Helium atom.

In reality we know that photon energies are distributed around the exact energy, following a Gaussian shape. The temperature and pressure of the source both contribute to this Gaussian shape through an effect known as Doppler Broadening. The half-width of the distribution is related to the standard deviation, and varies with temperature as follows:

$$\sigma = \Delta\lambda = \lambda_0 \sqrt{\frac{kT}{mc^2}} \quad (2)$$

When high temperature and high pressure situations are combined, the half-width of the distribution becomes extremely large, forming a continuum across many wavelengths.

3 Collected Data

We collected several sets of raw detector data, but condensed that information using VBA scripts to simplify to the following:

λ_0 (nm)	$\Delta\lambda$ (nm)
409.39	1.0762
433.78	0.8898
485.91	0.9379
656.58	1.2609

Table 1: Average discrete wavelengths λ for H_2 spectrum.

λ_0 (nm)	$\Delta\lambda$ (nm)
966.56	1.0315
923.08	1.0638
913.01	0.9539
867.35	0.9167
852.68	1.0779
827.00	0.9870
795.15	1.0750
772.87	1.0084
764.02	1.0104
738.83	1.0564
727.74	0.9907
714.77	1.1369
707.18	1.0809
696.88	1.0499

Table 2: Average discrete wavelengths λ for He spectrum.

4 Analysis and Results

4.1 Calibration

Using a *HeNe* laser of known wavelength, we found the offset correction for our detector. The weighted-average wavelength we calculated was $633.046nm$, giving us a detector offset of $0.2463nm$ to be used later in the lab.

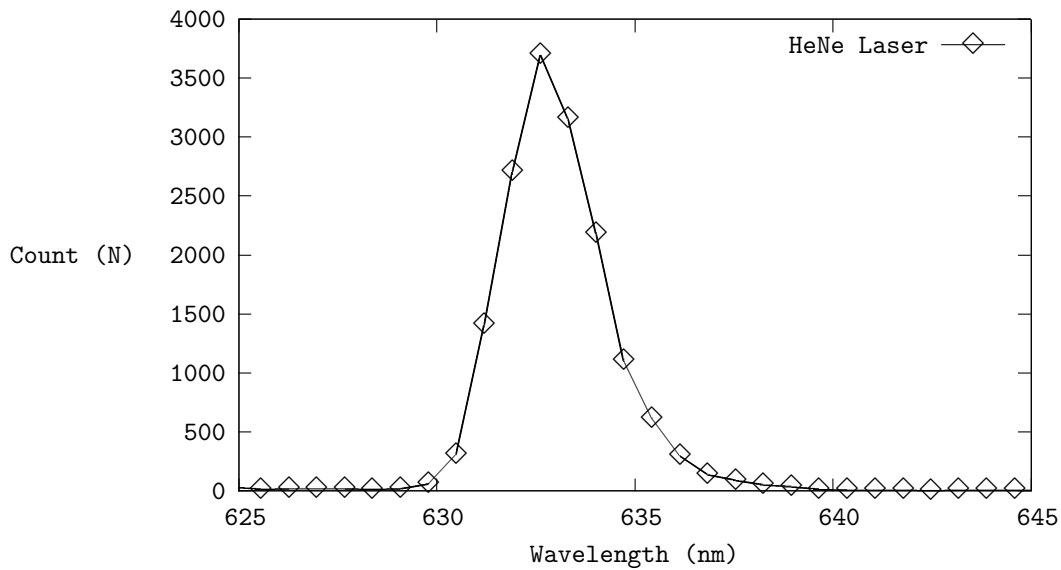


Figure 1: Output of *HeNe* laser centered around $632.8nm$. Integration time was $3000ms$.

The half-height was $1848.91N$, where N is counts over the set integration time. We intersected that half-height with the distribution above to find the half-width to be $2.79nm$, or $0.0086eV$.

4.2 H_2 Spectrum

We used the spectrometer to record the emissions from an H_2 lamp. For our analysis we converted wavelength λ to energy in eV using the formula:

$$E = \frac{1240eV \cdot nm}{\lambda} \quad (3)$$

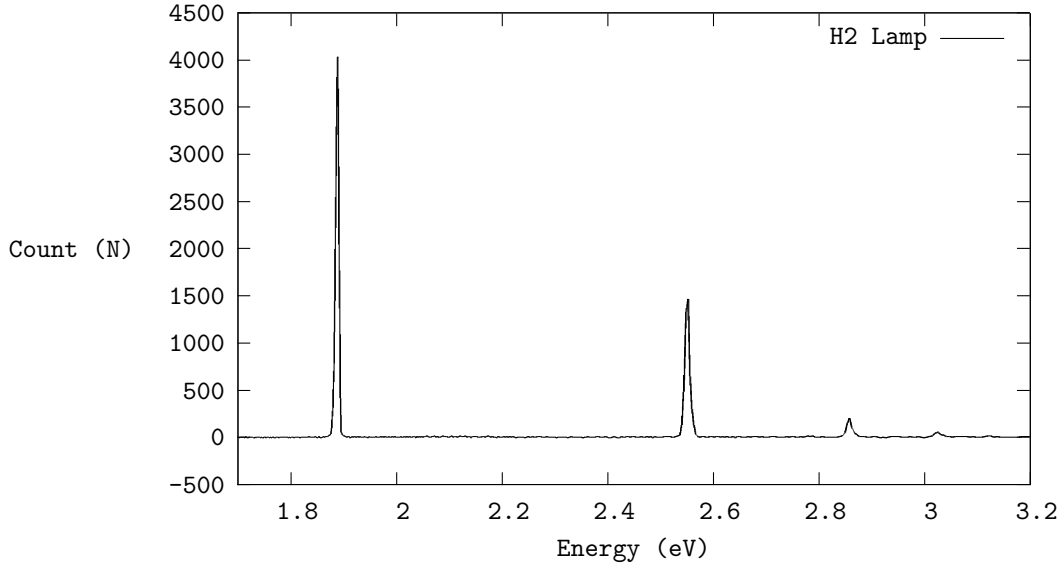


Figure 2: Output of H_2 lamp showing four energies. Integration time was $300ms$.

Examining those four energies, we noticed that they are very similar to transition energies predicted by the Bohr model. An exact comparison below shows very low error.

Transition ($n =$)	E_{pred} (eV)	E_{meas} (eV)	E Error	HW (eV)
$3 \rightarrow 2$	1.8889	1.8891	-0.012%	0.0073
$4 \rightarrow 2$	2.5500	2.5499	0.003%	0.0098
$5 \rightarrow 2$	2.8560	2.8579	-0.068%	0.0117
$6 \rightarrow 2$	3.0222	3.0143	0.263%	0.0159

Table 3: Predicted E_{pred} and measured E_{meas} along with observed half-width (HW).

We observed no other discrete lines in the graph, confirming that our source was an H_2 lamp. However, we also noticed a continuum caused by stray background light in the room.

The observed half-width for the last three energies was larger than the *HeNe* laser above. We note that half-width seems to increase linearly with energy, which we will investigate later for the *He* spectrum. For now, we remember that half-width is related to temperature, which we can estimate:

$$T = \frac{(\Delta\lambda)^2 mc^2}{k\lambda_0^2} \quad (4)$$

E (eV)	λ_0 (nm)	$\Delta\lambda$ (nm)	T ($\times 10^7 K$)
1.8886	656.58	1.2609	3.9866
2.5519	485.91	0.9379	4.0269
2.8586	433.78	0.8898	4.5488
3.0289	409.39	1.0762	7.4694

Table 4: Estimated T for four energies of H_2 using above formula.

These larger $\Delta\lambda$ values are the result of Doppler Broadening, which explains how thermal movement of atoms broadens the observed distribution. Above we see how higher energies clearly have higher temperatures.

4.3 *He* Spectrum

We used the spectrometer to record the emissions from an *He* lamp. Again, we converted wavelength λ to energy eV .

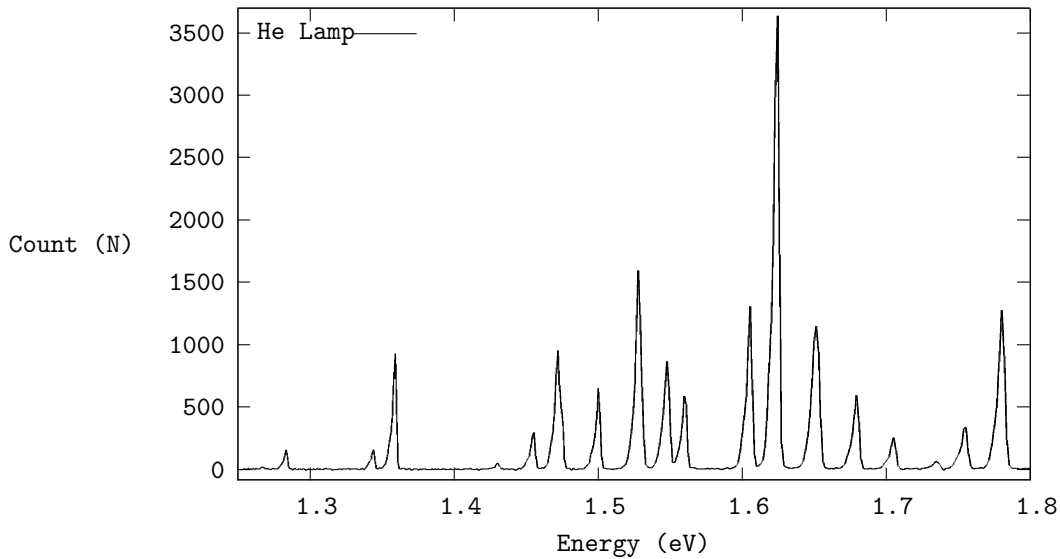


Figure 3: Output of *He* lamp showing 18 energies. Integration time was 3ms.

Bohr's model can barely account for the five lines of lowest energy, and it cannot explain more than half of the energies observed.

Again, as above, we looked at how the half-width was related to temperature. We found that temperature increased linearly with each energy level observed.

E (eV)	λ_0 (nm)	$\Delta\lambda$ (nm)	T ($\times 10^7 K$)
1.2807	966.56	1.0315	1.2311
1.3432	923.08	1.0638	1.4357
1.3582	913.01	0.9539	1.1799
1.4296	867.35	0.9167	1.2074
1.4542	852.68	1.0779	1.7275
1.4994	827.00	0.9870	1.5395
1.5594	795.15	1.0750	1.9757
1.6043	772.87	1.0084	1.8401
1.6231	764.02	1.0104	1.8905
1.6782	738.83	1.0564	2.2101
1.7039	727.74	0.9907	2.0032
1.7329	714.77	1.1369	2.7349
1.7536	707.18	1.0809	2.5253
1.7793	696.88	1.0499	2.4534

Table 5: Estimated T for energies of He spectrum.

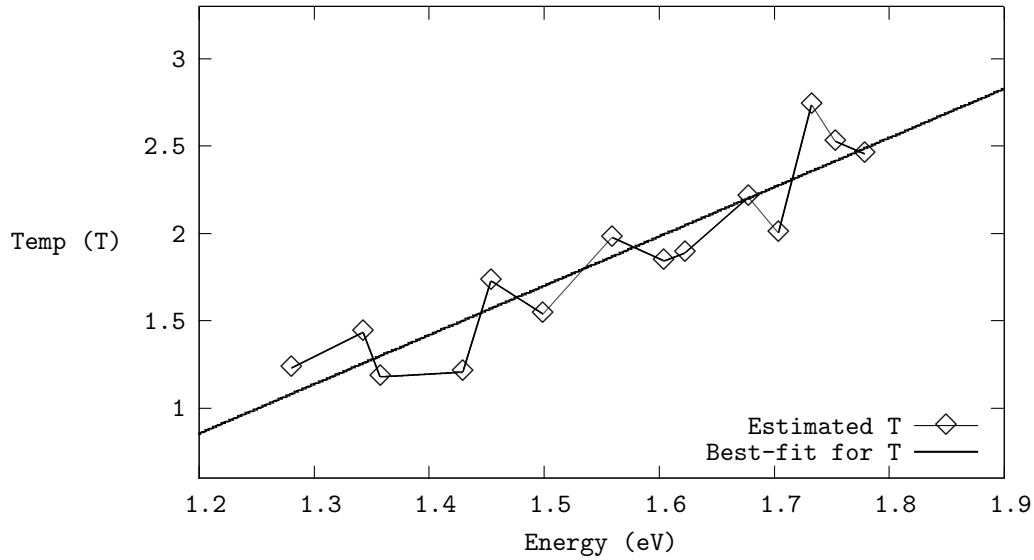


Figure 4: Estimated T from above plotted across energy eV .

We can see the linear fit plotted above with a correlation of 0.922. The best-fit equation found and plotted above is given by:

$$T = 2.82E - 2.53 \tag{5}$$

5 Error Analysis

The collimator and spectrometer were the only sources of error. Using the known wavelength of an *HeNe* laser, we found an offset correction of $0.2463nm$. Because our experiment room was not perfectly dark, other ambient light leaked into the collimator, which we observed as a low underlying continuum.

Because no human interaction was required, no human error was introduced into our data. However, we used VBA scripts to calculate average wavelength and half-width values. Those scripts were tested to work correctly for certain cases.

6 Conclusion

We examined three different light sources, making measurements on each. Using the *HeNe* laser, we calculated the offset correction of our detector assembly to be $0.2463nm$. For the H_2 lamp, we recorded the four prominent energy lines, and confirmed that the Bohr model perfectly predicted those lines.

Also, we investigated the relationship between temperature and energy explained by Doppler Broadening. Using the *He* lamp, we claimed that temperature increased with successive energy levels. Because our best-fit correlation was 0.992, we concluded that temperature is indeed linearly related to energy.