Optical Spectroscopy: Hydrogen, Deuterium, and the Unidentified Mystery Tube

Rachel Bowens-Rubin
Outline

• Hydrogen and Deuterium Spectra
  – Purpose of Experiment
  – Theory: Rydberg Formula and Calculating Mass
  – Apparatus: Inside the Monochromator
  – Measuring H and D
  – Rh and Rd
  – Mass ratio

• Unknown lamp
  – What could it be?
  – Compare to other measures
  – Conclusions
Purpose: Hydrogen and Deuterium

1) Measure the Balmer lines of hydrogen and deuterium -- to find the shift
2) Calculate the Rydberg Constant
3) Determine the mass ratio the deuteron to the proton
Transitions Between Energy Levels

Rydberg Formula

\[
\frac{1}{\lambda} = \mu R_\infty \left( \frac{1}{1/n_f^2} - \frac{1}{1/n_0^2} \right)
\]

\(\lambda\) = wavelength
\(\mu\) = reduced mass = \(\frac{M_{\text{nucleus}}}{M_{\text{nucleus}}+M_{\text{electrons}}}\)
\(R_\infty\) = Rydberg constant = \(1.0973731569 \times 10^7 \text{ m}^{-1}\)
\(n_0\) = initial energy states
\(n_f\) = final energy states of the electron

\(n_0 = 4\)
\(n_f = 2\)
Inside the Monochromator

Grating Disperses Light following the Grating Equation:

$$n\lambda = a \left( \sin i - \sin \theta \right)$$
Data Collection

- Measured 6 Balmer Lines
- Calibrated using Hg fit
  - Air → Vacuum
  - Error on each point is dominated by the fit = 1.97 Å

Example Data Set: Delta line of D
- Peak on right from H in the tube
Results for Rydberg Constants

Determining $R$ for Hydrogen

\[ \frac{1}{\lambda} = \mu R_\infty \left( \frac{1}{1/4 - 1/n_0^2} \right) \]

\[
R_h = \mu_h R_\infty = 1.0959 \times 10^7 \pm 0.00020 \times 10^7 \text{ m}^{-1}
\]

Determining $R$ for Deuterium

\[
R_d = \mu_d R_\infty = 1.0970 \times 10^7 \pm 0.00026 \times 10^7 \text{ m}^{-1}
\]
Mass Ratio

\[ M_d = \frac{M_e \lambda_H}{M_e \lambda_H - \Delta \lambda - \Delta \lambda M_e} \]

\[ M_d = \text{mass of a deuteron} \]
\[ M_e = \text{mass of an electron} \]
\[ \lambda_H = \text{measured hydrogen line} \]
\[ \lambda_D = \text{measured deuterium line} \]
\[ \Delta \lambda = \lambda_H - \lambda_D \]

\[ \frac{M_d}{M_p} = 2.3508 \pm 0.4495 \]

- Assumed mass proton = 1 amu
- Measured mass ratio within one std of expected ratio = 2
Summary

<table>
<thead>
<tr>
<th></th>
<th>Measured $\lambda$</th>
<th>Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_h$</td>
<td>$1.0959 \times 10^7 \pm 0.00020 \times 10^7 m^{-1}$</td>
<td>$1.0967 \times 10^7 m^{-1}$</td>
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<tr>
<td>$R_d$</td>
<td>$1.0970 \times 10^7 \pm 0.00026 \times 10^7 m^{-1}$</td>
<td>$1.0971 \times 10^7 m^{-1}$</td>
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<tr>
<td>$M_d/M_p$</td>
<td>$2.35 \pm 0.45$</td>
<td>$2.00$</td>
</tr>
</tbody>
</table>

- Rh, Rd, and the mass ratio were within one std of the expected
- Error from fit > Measurement Error
What is in the Mystery Lamp?

- Narrowing the options:
  - Only experiment in back room using tubes
  - Oriel makes 5 Calibration tubes: Ar, Kr, Ne, Xe, Hg/Ne
  - Color slightly redder than H and D
  - Investigated some other options

- Compared to lines listed in:
  - Oriel Catalog
  - CRC Handbook for Chemistry and Physics
Intensities vs Measured Wavelength - Mystery Lamp

<table>
<thead>
<tr>
<th>Measured $\lambda$ (nm)</th>
<th>CRC (nm)</th>
<th>Oriel (nm)</th>
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</thead>
<tbody>
<tr>
<td>337.5 ± 0.2</td>
<td>337.8</td>
<td>337.0</td>
</tr>
<tr>
<td>354.0 ± 0.2</td>
<td>354.2</td>
<td>352.1</td>
</tr>
<tr>
<td>358.0 ± 0.2</td>
<td>357.4</td>
<td>359.4</td>
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<tr>
<td>607.3 ± 0.2</td>
<td>607.4</td>
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</table>
Compare to Other Measures:
450 to 630nm

Published Neon Tube Spectrum data (Astrosurf)

8.13 Mystery Tube
Compare to Other Measures:
330 to 360nm

Typical Spectra of Oriel Spectral Calibration Lamps: Ne

High number of intense peaks

8.13 Mystery Tube

High number of intense peaks
Unexplained Region

- 375nm to 450nm
- The 5 Oriel calibration lamps do not have peaks in this region
- Probably another element
Conclusions

- Neon
  - Main Peaks match
  - Similar Overall Shape
- Plus another element
- More data should be taken to confirm
References

- CRC: Handbook for Chemistry and Physics
- MIT Physics Department, Junior lab written report notes (2007).
- Georgia State University. Hyperphysics [http://hyperphysics.phyast.gsu.edu/hbase/quant](http://hyperphysics.phyast.gsu.edu/hbase/quant)
Balmer Series

$n_f = 2$

$n=1$

$n=2$

$n=3$

$n=4$

$n=5$

$n=6$

$n=7$
<table>
<thead>
<tr>
<th>Intensity</th>
<th>Wavelength/Å</th>
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<tr>
<td>360</td>
<td>3919.00</td>
<td>II</td>
</tr>
<tr>
<td>90</td>
<td>3938.52</td>
<td>III</td>
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<tr>
<td>450</td>
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<tr>
<td>1000</td>
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<td>550</td>
<td>4601.48</td>
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Nitrogen Lines
Inside the Monochromator

Grating Disperses Light following the Grating Equation:

\[ n\lambda = a (\sin i - \sin \theta) \]
Monochromator

- Input Slit
- Exit Slit
- Photomultiplier Tube
- Grating
- Concave Mirror 1
- Concave Mirror 2
Mass of a Deuteron

\[ M_d = \frac{M_e \lambda_H}{M_e \lambda_H - \Delta \lambda - \Delta \lambda M_e} \]

\[ M_d = \text{mass of a deuteron} \]
\[ M_e = \text{mass of an electron} \]
\[ \lambda_H = \text{measured hydrogen line} \]
\[ \lambda_D = \text{measured deuterium line} \]
\[ \Delta \lambda = \lambda_H - \lambda_D \]
Apparatus
Inside the Monochromator

Grating Disperses Light following the Grating Equation:

\[ n\lambda = a (\sin i - \sin \theta) \]