

Emission spectra of metals and Absorption spectrum of Iodine vapour using constant deviation spectrometer

Aritra Mukhopadhyay
(Roll. No.: 2011030)

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1 Abstract

By the quantum description of energy states, the emission spectra of metals are due to the excitation and de-excitation of electrons through the various discrete energy levels of their bound states. As the electrons de-excite, they emit light of energy corresponding to the energy gap. Since a spectrum is unique to an element, it is used for its detection. By using a constant deviation prism, which deviates the dispersed light beams at a minimum deviation of 90° , we can observe and study the different wavelengths of light emitted by the source. In the experiment, we will be studying the emission spectra of metals (Brass and Copper) and the absorption spectrum of iodine vapours.

2 Theory

2.1 Constant Deviation Spectrometer

An instrument used to study the spectra with an unaided eye is called a spectroscop or spectrometer. For this experiment, a constant deviation prism of the angle of minimum deviation 90° is used such that the emission spectrum can be observed from a telescope placed perpendicular to the source and collimator (incident beam). For this purpose, the prism comprises three parts: two 30° prisms, PQR and QTS, and the reflecting prism PRS as shown in the figure below. When the angle of incidence is equal to the angle of emergence and the angle of deviation is 90° , a ray would be passing through a position of minimum deviation.

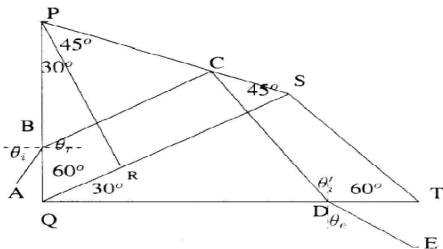


Figure 1: Constant deviation Prism

2.2 Emission spectra of metals

To observe the absorption spectra of the metals, the apparatus needs to be calibrated first. For this purpose, a mercury lamp of known wavelength and spectrum is used as a source. The experimental setup consists of the source, a collimator and the constant deviation prism. A telescope is placed perpendicular to the collimator to observe the spectra as shown in Figure 2. The cylinder has markings on it. We will fix the cylinder at the 546nm mark (the green light, because it is almost at the middle of the spectrum: this way we would be able to reduce the error). We have to place the prism on the table in such a way that the green band almost coincides with the crosshair. Next, we have to take the values of different wavelengths and calibrate the device markings with the actual measurements. For the spectra of metals, the metal source will be heated and placed in front of the collimator. The heating will excite the electrons and further de-excitation will produce the emission spectra.

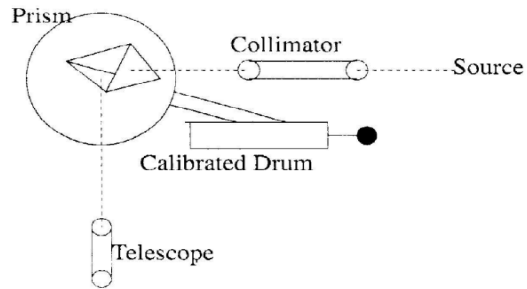


Figure 2: Experimental Setup

2.3 Absorption Spectrum of Iodine Vapour

The iodine absorption spectrum can be explained by vibronic transitions between the energy levels of different quantum states defined by their vibrational quantum numbers. For this experiment, Iodine vapours are excited by a source of white light and missing (absorbed) wavelengths of light are observed in the spectrum which appear as dark bands. The absorption involves the following transition: $(X, \nu'') \rightarrow (B, \nu')$ where X represents the ground state and B is the first excited electronic energy state. $\nu'' (= 0, 1, 2 \text{ etc})$ and

$\nu' (= 0, 1, 2, \text{ etc})$ represent the vibrational quantum numbers in the ground and excited electronic states, respectively.

As shown in the figure, for transitions between the ground state and the first excited state at room temperature, the first transition corresponds to $\nu'' = 0$ to $\nu' = 0$ which is labelled as the $0 \leftarrow 0$ absorption line.

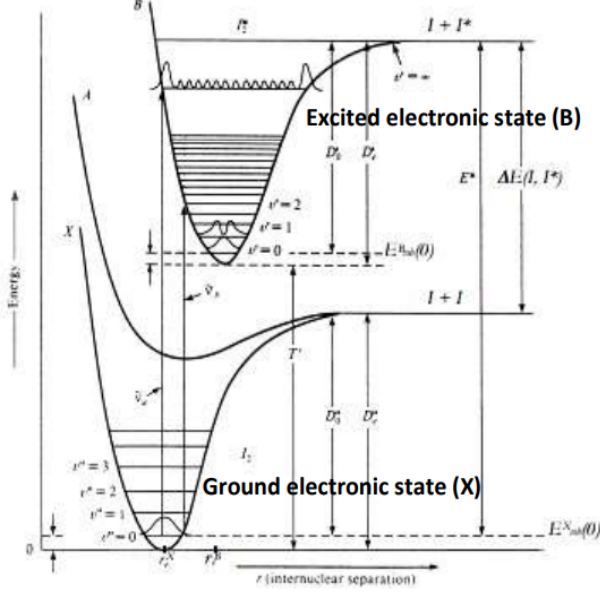


Figure 3: Schematic energy level diagram of iodine

According to the Franck-Condon principle, only those wavefunctions of the two states don't significantly overlap with the ground state wavefunction, therefore usually the transition from 20 to $50 \leftarrow 0$ takes place. For the maximum energy level, ν_{max} the energies form a continuum rather than being quantized and hence bond dissociation occurs given by:

$$(D_0) = E(\nu' = \nu_{max}) - E(\nu' = 0)$$

Since the vibronic energy levels are coarsely placed, one can apply the simple harmonic oscillator equations involving Morse potential to solve for energy levels, giving the force constant to be:

$$f = 4\pi^2\mu (c\Delta\nu_{e^{-}vg})^2$$

3 Observation

Least Count of Calibrated Drum = $(\delta\lambda) = 1 \text{ nm}$

Table for calibration using mercury lamp:

Sl. No	$\lambda_{given} \text{ (nm)}$	$\lambda_{given} \text{ (nm)}$
1	546	546
2	577	577
3	579	579
4	502	493
5	435	437

Table 1: Calibration using Hg lamp

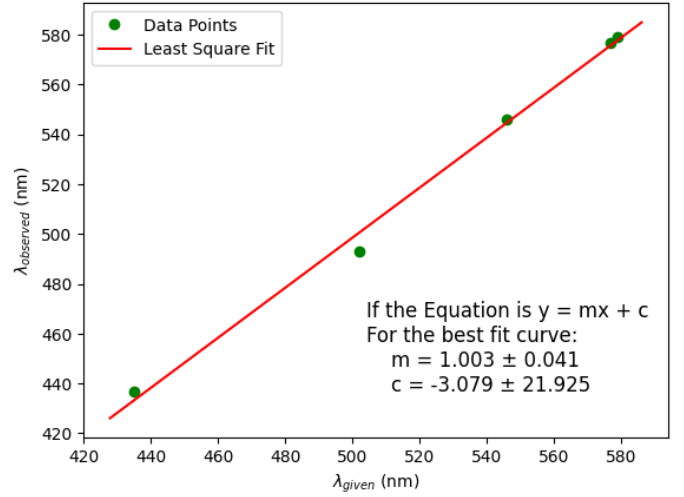


Figure 4: $\lambda_{given}(l)$ vs $\lambda_{observed}(L)$ Plot

$$\lambda_{corrected} = m\lambda_{observed} + c$$

From the Graph we Get:

$$\text{slope } (m) = 1.003 \pm 0.041$$

$$\text{intercept } (c) = -3.079 \pm 21.925$$

Table for emission spectrum of metals:

• For Copper:

Sl.No	$\lambda_{observed} \text{ (nm)}$	$\lambda_{corr} \text{ (nm)}$	$\lambda_{lit} \text{ (nm)}$
1	511	509	510
2	516	514	515
3	523	521	522
4	570	569	570
5	578	577	578

Table 2: Emission Spectrum for Copper

• For Brass:

Sl.No	$\lambda_{observed} \text{ (nm)}$	$\lambda_{corr} \text{ (nm)}$	$\lambda_{lit} \text{ (nm)}$
1	510	508	510
2	516	514	515
3	523	521	522
4	570	569	570
5	577	576	578
6	637	636	636
8	474	472	472

Table 3: Emission Spectrum for Brass

Table for absorption spectrum of iodine:

Sl.No	$\lambda_{observed} \text{ (nm)}$	$\lambda_{corr} \text{ (nm)}$	Wave number $\nu_e \text{ (cm}^{-1}\text{)}$	Wave number $\delta\nu_e \text{ (cm}^{-1}\text{)}$
1	563	562	17806	—
2	566	565	17711	95
3	568	567	17648	63
4	572	571	17524	124
5	575	574	17432	92
6	578	577	17341	91
7	582	581	17222	120
8	585	584	17133	89
9	589	588	17016	117
10	593	592	16900	115

Sl.No	$\lambda_{observed}$ (nm)	λ_{corr} (nm)	Wave number $\bar{\nu}_e$ (cm^{-1})	Wave number $\delta\bar{\nu}_e$ (cm^{-1})
11	597	596	16787	114
12	600	599	16702	84
13	604	603	16591	111
14	609	608	16454	137
15	613	612	16346	108
16	617	616	16240	107
17	621	620	16135	105
18	625	624	16031	104

Table 4: Absorption Spectrum for Iodine

4 Calculation

4.1 Calculating bond Dissociation Energy

Bond Dissociation Energy (D_0) = $E(\nu' = \nu_{max}) - E(\nu' = 0)$

$$E(\nu' = \nu_{max}) = h\nu_{max}$$

$$\therefore E(\nu' = \nu_{max}) = \frac{17806}{8068} eV$$

$$E(\nu_{max}) = 2.2 eV$$

Similarly for lowest energy state $E(\nu' = 0)$:

$$E(\nu' = 0) = h\nu_{min} = \frac{16031}{8068} eV$$

$$E(\nu_{min}) = 1.98 eV$$

Therefore $D_0 = 2.2 - 1.98 = 0.22 eV/molecule$

4.2 Calculation of Force Constant

Force Constant is given by: $f = 4\pi^2\mu (c\Delta\nu_{e^{avg}})^2$

From table Table 4 $\Delta\nu_{e^{avg}} = 104 cm^{-1}$

Reduced mass $\mu = 1.05 \times 10^{-25} kg$

$$\therefore f = 40.35 Nm^{-1}$$

5 Error Analysis

5.1 Bond Dissociation Energy

$$\frac{\delta D_0}{D_0} = \frac{\delta E(\nu' = \nu_{max})}{E(\nu' = \nu_{max})} + \frac{\delta E(\nu' = 0)}{E(\nu' = 0)} = hc \left(\frac{\delta\nu_{min}}{\nu_{min}} + \frac{\delta\nu_{max}}{\nu_{max}} \right)$$

$$now, \delta\nu(\lambda) = -\frac{\delta\lambda}{\lambda^2}$$

$$\therefore \frac{\delta D_0}{D_0} = -hc \delta\lambda \left(\frac{1}{\lambda_{min}^2} + \frac{1}{\lambda_{max}^2} \right) = -7.11 \times 10^{-3} eV$$

$$\delta D_0 = -1.56 \times 10^{-3} eV/molecule$$

5.2 Force Constant

$$\delta f = \frac{2f}{\Delta\nu_{e^{avg}}} \delta(\Delta\nu_{e^{avg}}) = 2 \times 40.35 \times 41/104 Nm^{-1}$$

$$\therefore \delta f = 31.8 Nm^{-1}$$

6 Result

- $D_0 = 0.22 \pm 1.56 \times 10^{-3} eV/molecule$
- $f = 40.35 \pm 31.8 Nm^{-1}$

7 Conclusions

- For the emission spectra of metals, comparing the literature value of the wavelengths with the observed wavelength, we find that they are quite close. For Copper, we found all the major wavelengths mentioned in the literature. Brass is a mixture of copper and zinc. We observed both the characteristic wavelengths of copper and zinc in brass. This tells us, that, in Brass, the chemical properties of the two metals remain protected.
- For the absorption spectra of Iodine, the value of f is close to the literature value of $41 Nm^{-1}$ while D_0 is far from the literature value of $1.54 eV/molecule$. The error in bond dissociation energy can be associated with the fact that during the experiment the lines green weren't visible and the intensity continued to decrease, thereby lowering the range of observation and thus the difference of energy between the highest and lowest energy state.
- The large value of error in the calculation of f is due to the large value of least count of the device. Also, there must have been a lot of random errors involved. The Source of one such error might be due to the fact that the fringes were not perfectly focussed, and while taking a reading, we might have taken reading at a position slightly beside the position of the actual minima.

References

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