

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

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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  $90^\circ$ , 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.

## I. OBJECTIVE

1. Calibrate the C.D.S using a calibration source.
2. Determine the wavelength of the unknown spectra of the given metals in the arc lamp source.
3. Study the absorption spectrum of iodine vapour to determine (a) the energy level diagram of iodine molecule, (b) the electronic energy gap and vibrational energies, (c) bond dissociation limit and the (d) force constant for the excited state

## II. THEORY

### A. Constant Deviation Spectrometer

An instrument used to study the spectra with an unaided eye is called a spectroscope or spectrometer. For this experiment, a constant deviation prism of the angle of minimum deviation  $90^\circ$  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  $30^\circ$  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  $90^\circ$ , a ray would be passing through a position of minimum deviation.

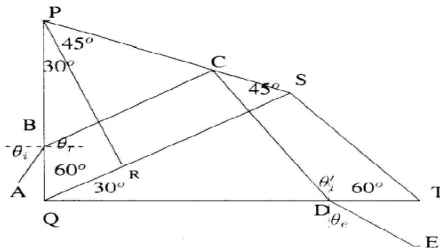


FIG. 1: Constant deviation Prism

### B. 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.

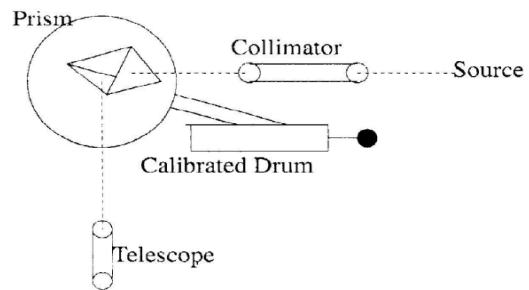


FIG. 2: Experimental Setup

### C. 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.

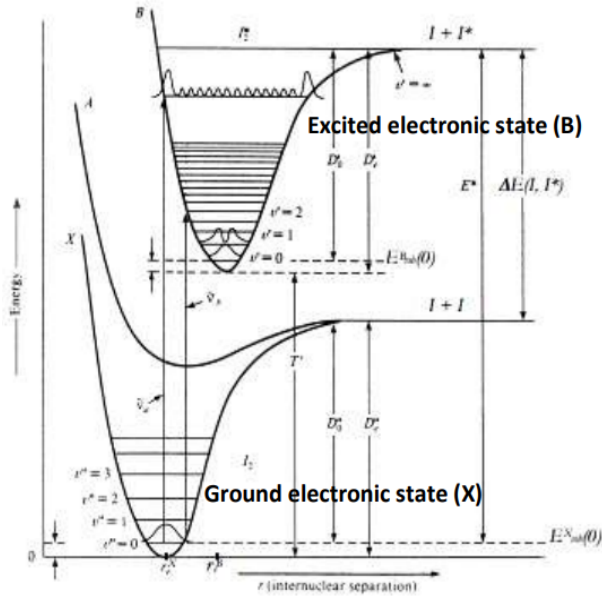


FIG. 3: Schematic energy level diagram of iodine

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  $20 \text{ to } 50 \leftarrow 0$  takes place. For the maximum energy level,  $\nu_{max}$  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:

$$f = 4\pi^2\mu (c\Delta\nu_{e'v'g})^2$$

### III. APPARATUS

1. A constant deviation spectrometer (C.D.S)
2. A calibration source (Hg lamp)

3. D.C. Power supply
4. An arc stand
5. Metal rods (Copper, Brass)
6. Spirit level

## IV. PROCEDURE

### Calibration of the spectrometer

1. Level the constant deviation spectrometer by means of a spirit level and focus the telescope.
2. Place the constant deviation prism on the prism table so that its  $90^\circ$  vertex faces towards the objective of the telescope.
3. Now, the Hg lamp is placed in front of the collimator
4. The drum is rotated so that it reads a value closest to the value of the single and prominent green line. Now, by slightly rotating the prism and looking through the telescope, the green line is made to coincide on the pointer
5. Once the spectral line coincides with the pointer, clamp the prism. Now, note down the closest values read by the drum ( $\lambda_{obs}$ ) corresponding to the given values ( $\lambda_{given}$ ) of different wavelength of mercury. Plot  $\lambda_{obs} \sim \lambda_{given}$  and fit it with a straight line to obtain the calibration parameters. Using these parameters any observed unknown wavelength can be calculated to determine the correct wavelength  $\lambda_{corr}$ .

### Studying the Emission Spectra of Metals

1. Replace the calibration source by the arc source using a particular metal arc of interest.
2. The D.C. power supply is connected to the arc stand holding the pointed metal arc one over the other. Switch ON the power supply and observe the arc begins to glow
3. The spectrum is observed in the CDS. Adjust the drum head to make the pointer/crosswire coincide on each of the spectral lines and read the characteristic wavelength of the different lines emitted by the metals directly.
4. Compare the values of spectral lines obtained for different metals with the literature values.

### Studying the Absorption Spectra of Iodine Vapour

1. Place an incandescent lamp as the source and observe the continuous spectrum
2. The D.C. power supply is connected to the arc stand holding the pointed metal arc one over the other. Switch ON the power supply and observe the arc begins to glow

3. The spectrum is observed in the CDS. Adjust the drum head to make the pointer/crosswire coincide on each of the spectral lines and read the characteristic wavelength of the different lines emitted by the metals directly.
4. Compare the values of spectral lines obtained for different metals with the literature values.

## V. OBSERVATION AND CALCULATIONS

Least Count of Calibrated Drum,  $\Delta\lambda = 1 \text{ nm}$

### Calibration of the spectrometer

$\lambda_{given} \text{ (nm)}$	$\lambda_{obs} \text{ (nm)}$
407	407
435	435
489	489
494	493
546	546
579	579
596	596
615	618
620	624

TABLE I: Calibration using Hg lamp

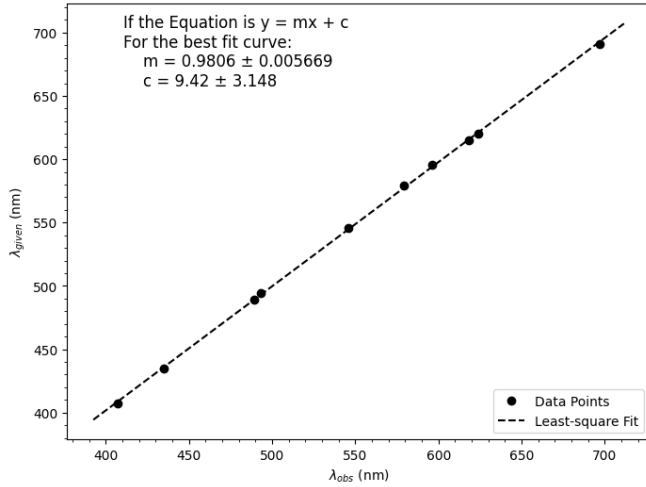


FIG. 4:  $\lambda_{given}$  vs  $\lambda_{obs}$  plot for Hg Spectrum

From Fig. 4, we find the equation for  $\lambda_{corr} = 0.9806 \lambda_{obs} + 9.42$

### Emission Spectra of Metals

- For Copper:

Color	$\lambda_{observed} \text{ (nm)}$	$\lambda_{corr} \text{ (nm)}$	$\lambda_{lit} \text{ (nm)}$
Yellow	579	577	581.5
	570	568	574.6
Green	521	520	524.5
	514	513	515
	509	509	511
Blue	469	469	465.4
	464	464	425.6
Violet	447	448	405
	427	428	400.3

TABLE II: Emission Spectrum for Copper

- For Brass:

Color	$\lambda_{observed} \text{ (nm)}$	$\lambda_{corr} \text{ (nm)}$	$\lambda_{lit} \text{ (nm)}$
Red	640	637	645.5
Yellow	579	577	581.9
	571	569	575.6
Green	521	520	514.5
	514	513	515.5
	509	509	523.0
Blue	479	479	471.9
	471	471	471.0
Violet	452	453	426.8
	450	451	403.0

TABLE III: Emission Spectrum for Brass

### Absorption Spectra of Iodine Vapour

$\lambda_{obs} \text{ (nm)}$	$\lambda_{corr} \text{ (nm)}$	Wave number $\bar{\nu}_e \text{ (cm}^{-1}\text{)}$	Difference in Wave number $\Delta\bar{\nu}_e \text{ (cm}^{-1}\text{)}$
568	566	17655	
571	569	17564	91
575	573	17444	120
577	575	17384	59
580	578	17296	88
585	583	17151	145
589	587	17036	115
592	590	16951	85
596	594	16839	112
602	600	16674	165
607	605	16539	135
610	608	16459	80
615	612	16327	132
618	615	16249	78
622	619	16146	103
626	623	16044	102
630	627	15944	100
635	632	15820	124
639	636	15723	98

TABLE IV: Absorption Spectrum for Iodine

#### 1. Calculating bond Dissociation Energy

Bond Dissociation Energy,

## B. Force Constant

$$\begin{aligned}
 D_0 &= E(\nu' = \nu_{max}) - E(\nu' = 0) \\
 E(\nu' = \nu_{max}) &= hc\nu_{max} \\
 \therefore E(\nu' = \nu_{max}) &= \frac{17655}{8068} \text{ eV} \\
 E(\nu_{max}) &= 2.19 \text{ eV}
 \end{aligned}$$

Similarly for lowest energy state

$$E(\nu' = 0) = hc\nu_{min} = \frac{15723}{8068} \text{ eV} E(\nu_{min}) = 1.95 \text{ eV}$$

Therefore  $D_0 = 2.19 - 1.95 = 0.24 \text{ eV/molecule}$

### 2. Calculation of Force Constant

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

From table IV  $\Delta\nu_{e^{-}vg} = 107 \text{ cm}^{-1}$

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

$$\therefore f = 40.30 \text{ Nm}^{-1}$$

## VI. ERROR ANALYSIS

### A. Bond Dissociation Energy

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

$$= hc \left( \frac{\delta\nu_{min}}{\nu_{min}} + \frac{\delta\nu_{max}}{\nu_{max}} \right)$$

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

$$\therefore \frac{\delta D_0}{D_0} = -hc \delta\lambda \left( \frac{1}{\lambda_{min}^2} + \frac{1}{\lambda_{max}^2} \right) = -8.12 \times 10^{-3} \text{ eV}$$

$$\delta D_0 = -1.94 \times 10^{-3} \text{ eV/molecule}$$

$$\delta f = \frac{2f}{\Delta\nu_{e^{-}vg}} \delta(\Delta\nu_{e^{-}vg}) = 2 \times 40.30 \times \frac{25.69}{107} \text{ Nm}^{-1}$$

$$\therefore \delta f = 19.35 \text{ Nm}^{-1}$$

## VII. DISCUSSION AND CONCLUSION

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 almost all the major wavelengths mentioned in the literature. Since 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 remains the same.

From the absorption spectrum of Iodine, we calculated the following parameters,

- Bond dissociation energy

$$D_0 = (0.240 \pm 0.002) \text{ eV/molecule}$$

- Force constant

$$f = (40.30 \pm 19.35) \text{ N m}^{-1}$$

Here we can see that the value of  $f$  is close to the literature value of  $41 \text{ Nm}^{-1}$  while  $D_0$  is far from the literature value of  $1.54 \text{ eV/molecule}$ . The error in bond dissociation energy can be associated with the fact that during the experiment the line weren't sharply 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 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.

## VIII. PRECAUTIONS

1. Handle the metal arcs carefully
2. Turn the drum only in one direction to avoid backlash error
3. Make sure the telescope is properly focused and that the crosswire is parallel, before taking any readings.

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[1] SPS, *Emission spectra of metals using constant deviation spectrometer*, NISER (2023).