EXPERIMENT NO: 6

SPIN ORBIT COUPLING

AIM: Determination of spin-orbit coupling constant of $\mathbf{4}_{\boldsymbol{F}}$ and $\mathbf{4}_{\boldsymbol{D}}$ states of copper.

APPARATUS: Copper rods**,** Graduated optical bench, XYZ translational mount, LED, Objective 20X, Optical fibre, Spectrometer, High voltage power supply, Sodium lamp, etc.

THEORY AND CALCULATION:

In atomic spectrum, to describe the fine structure, total energy of the atom can be expressed as

$$E = E_0 + \Delta E$$

Where Δ E represents the perturbation energy due to spin orbit coupling.

E_0 unperturbed energy of the atomic state. The perturbation energy due to spin orbit coupling can be expressed as

$$\Delta E = A(L,S)\vec{L}.\vec{S}$$

Where L = Total orbital angular momentum

S = Total spin angular momentum

A(L,S) spin orbit coupling constant

The Spin-orbit interaction couples the total spin and total orbital angular momentum (L) to form the total angular momentum J.

According to the coupling of angular momentum, the value of J = L+S…… |L-S| and the notation is $^{2S+1}L_J$ where L = 0,1, 2,3,.....are SPDF respectively.

The total angular momentum, $\vec{J} = \vec{L} + \vec{S}$

So , $J^2 = L^2 + S^2 + 2\vec{L}.\vec{S}$

Or, $\rightarrow$L . S $= \dfrac{J^2 - L^2 - S^2}{2}$

So, the perturbation energy is

$$\Delta E = \frac{1}{2}A\ (L,S)\ [J\ (J+1) - L\ (L+1) - S\ (S+1)] \qquad (1)$$

Now4$_F$ notation means (2S+1)$_L$

Where L&S defined earlier.

For example

4=2S +1 So, S= 3/2

and L = 0, 1, 2, 3, 4

S P D F G

So for ^4F; L = 3

S = 3/2

For ^4D; L= 2

S = 3/2

Now value of J according to the coupling of angular momenta

J = |**L**+**S**| ….to |**L-S**|

For ^4F J = 9/2, 7/2, 5/2, 3/2

For ^4D J = 7/2, 5/2, 3/2, 1/2

Thus due to spin orbit coupling, each level will split into 4 energy levels,

^4F $^4F_{9/2}$, $^4F_{7/2}$, $^4F_{5/2}$, $^4F_{3/2}$

^4D $^4D_{7/2}$, $^4D_{5/2}$, $^4D_{3/2}$, $^4D_{1/2}$,

ΔE_1 and ΔE_2 can be calculated from eqn. no. 1.

for example:

$$^4F_{9/2} \quad \Delta E_1\left(\frac{9}{2}\right) = \frac{A_1}{2}\ \left[\frac{9}{2}\left(\frac{9}{2}+1\right) - 3(3+1) - \frac{3}{2}\left(\frac{3}{2}-1\right)\right]$$

$=\frac{\mathbf{9}}{\mathbf{2}}A_1$

For $4\boldsymbol{F_{7/2}}$, $\Delta\boldsymbol{E_2}$ (7/2) = $\frac{A_1}{2}$ [7/2 (9/2) – 3.4 – (15/4)] =0

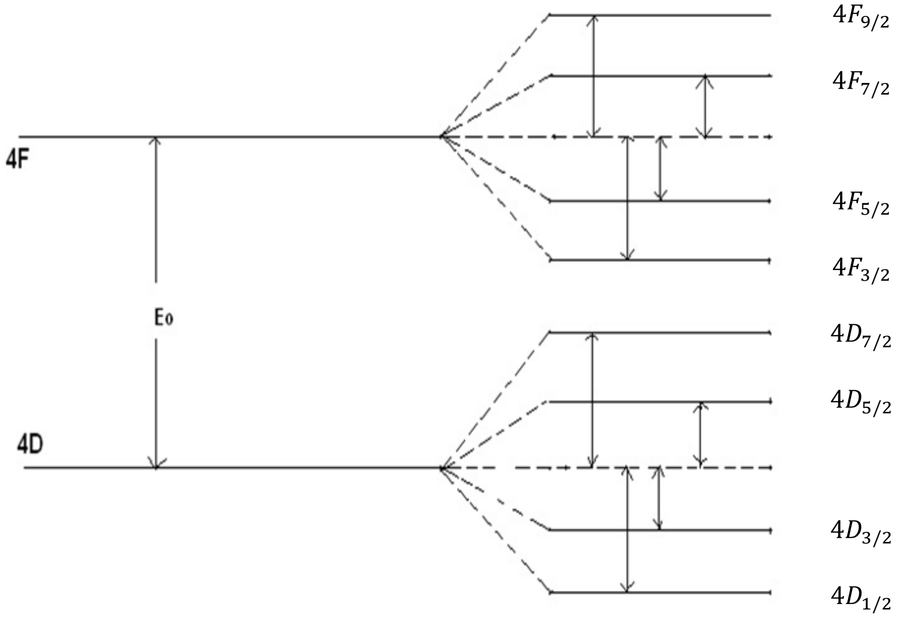
and so on

for $^4D_{7/2}$ ΔE_2 (7/2) = $\frac{A_2}{2}$ [(7/2) (9/2) – 2*3 – (15/4)]

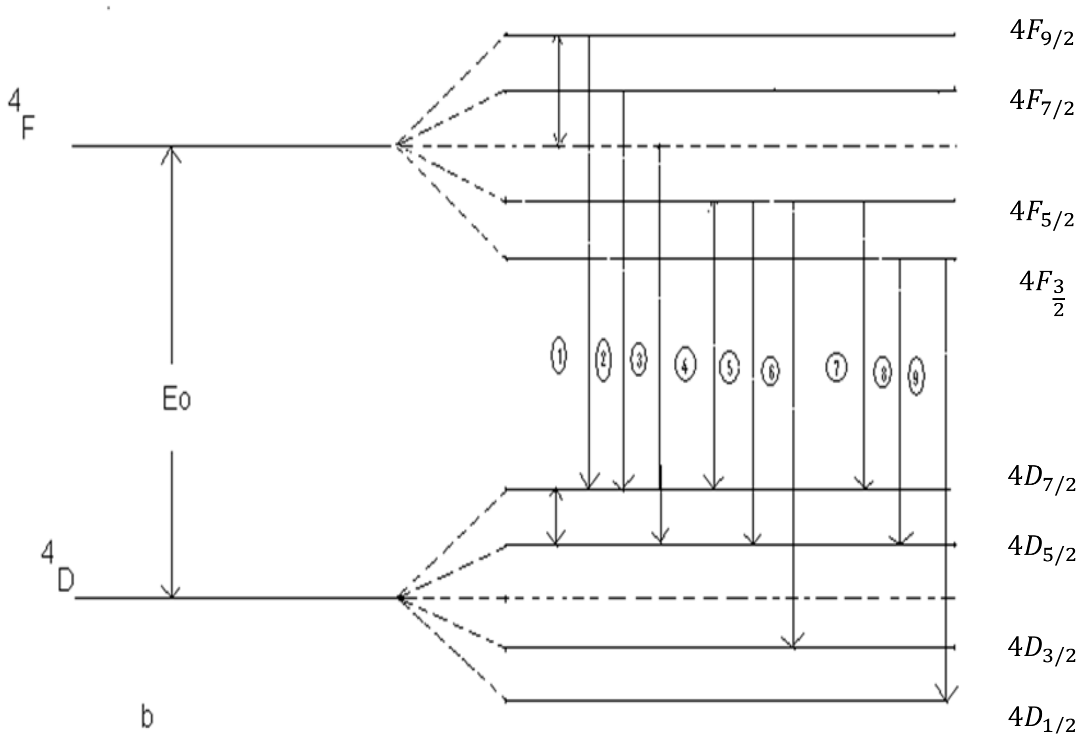
$$= \frac{A_2}{2} [63/4 - 6 - 15/4] = 3A_2$$

you construct the energy level diagram by calculating as shown above in term of spin orbit constants A_1 and A_2.

The energy diagram,



Now, the electronics transitions which give size to spectrum depends on the selection rule (for atomic spectra, the electron transition selection rules are)



$\Delta S = 0$
$\Delta J = 0, \pm 1$

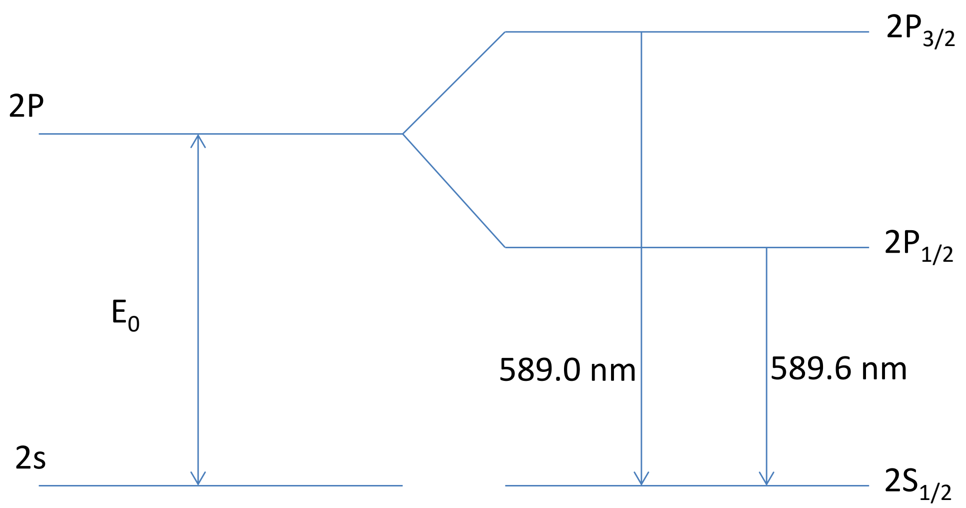
Total 9 (nine) transitions are possible. The transitions energies, such as

$\boldsymbol{4F_{9/2} \rightarrow 4D_{7/2}}$

$E^{(1)} = E_0 + \Delta E_1\,(9/2) - \Delta E_2\,(7/2) = 1/\lambda(\text{in cm}^{-1})$

From several observed transitions, we can determine the spin orbit constants for ^4F and ^4D levels which are A_1 and A_2.

For sodium, transition takes place from $2P_{3/2} \rightarrow 2S_{1/2}$ and $2P_{1/2} \rightarrow 2S_{1/2}$.



LED Alignment:

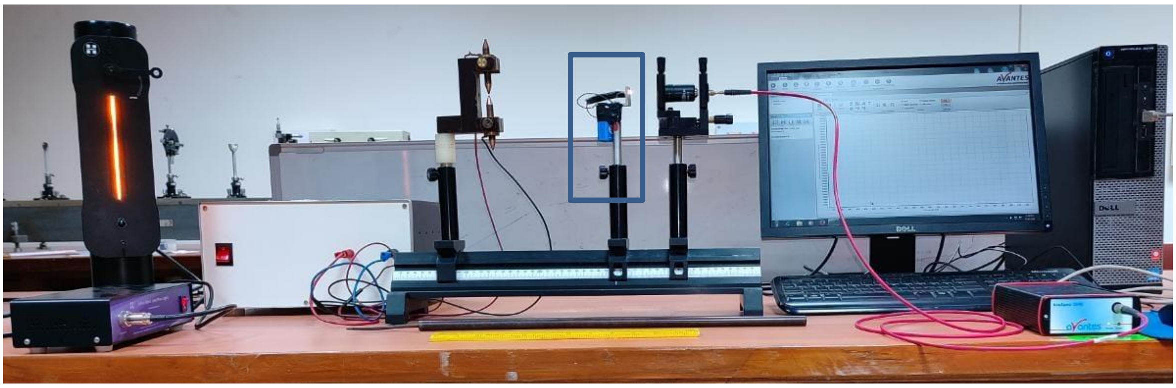


Figure 1. Set up showing LED alignment.

Copper Spectrum Experimental Set-up:

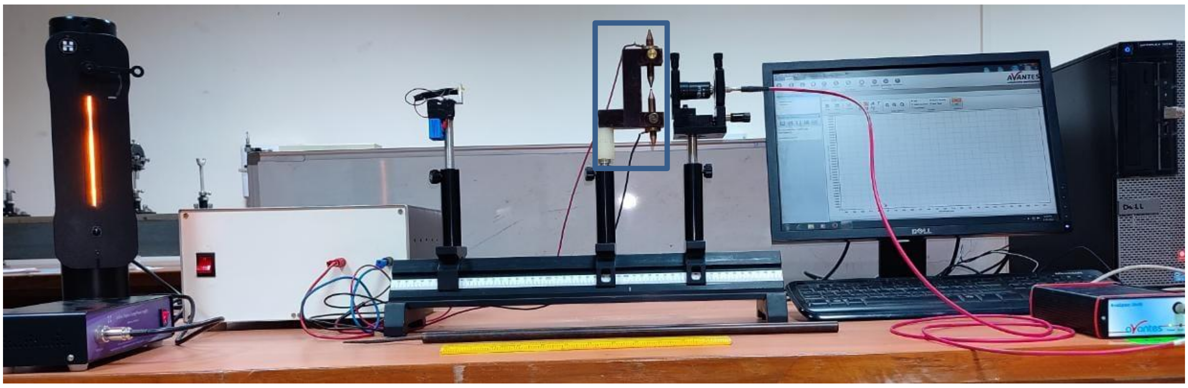


Figure 2. Set up showing Copper rods.

PROCEDURE:

1. For Sodium spectrum, place the fiber near the sodium lamp and collect the spectrum.

2. For copper spectrum, align the yellow LED to get a tight spot at the end of fiber coupler. The alignment can be optimized by changing XYZ position of the mount.
3. Connect one end of fiber to the SMA port and other end to the spectrometer.
4. Connect spectrometer with the computer through USB cable.
5. Open the Avantes software (Avasoft 8.1) and select scope mode (S). Set appropriate integration time and average value in the software.
6. Take the spectrum and save it by clicking at "save the dark spectrum". Click on Sd mode, the counts which were present in the scope mode due to electronic noise or ambient light will be subtracted.
7. Make the alignment in such a way so that you can get more than 30000 counts in the spectrum of yellow LED (at 590 nm) in the Sd mode.
8. Once you get the spectrum, replace the LED with copper rods .
9. Turn ON the power supply and short the two copper rods with a third metal rod. You will observe a green colour light with spark.
10. Collect the spectrum and identify the peak positions (nm) of 9 transitions of copper.
11. Turn OFF the supply voltage and discharge the copper rod with other metal rod.

CALCULATIONS:

Once the spectrum is recorded, you can assign the peaks to specific transitions as mentioned in Table 1. The spin orbit coupling constants A1 and A2 can be calculated by solving equation1 for any 2 transitions.

Table 1. ^4F to ^4D transition state of copper.

$4_F \rightarrow 4_D$ Copper Spectrum

	$^4D_{7/2}$	$^4D_{5/2}$	$^4D_{3/2}$	$^4D_{1/2}$
$^4F_{9/2}$	**100** 4651.13 Å **21494.2 cm^{-1}**			
$^4F_{7/2}$	**22** 4704.60 Å **21249.9 cm^{-1}**	**57 U** 4586.97 Å **21704.8 cm^{-1}**		
$^4F_{5/2}$	**2** 4797.04 Å **20840.4 cm^{-1}**	**21 U** 4674.76 Å **2186.60 cm^{-1}**	**30 U** 4539.70 Å **22021.7 cm^{-1}**	
$^4F_{3/2}$		**2 U** 4842.20 Å **20646.0 cm^{-1}**	**13 U** 4697.49 Å **21282.0 cm^{-1}**	**12** 4509.30 Å **22169.8 cm^{-1}**

Recalculate the transition energy (ΔE) for all the other transitions and find the error between calculated and recorded value.

PRECAUTIONS:

1. The voltage supply has high voltage in the range of 10,000 V. So make sure to not touch the copper rods.
2. After finishing the experiment, always discharge the copper rod with third metal rod.
3. While performing the experiment, make sure that fan of power supply should be ON.
4. First close the software and then remove the connection of spectrometer and computer.
5. The optical fiber should not be folded or bent.

Quiz questions

a. Explain Hund's rules?

b. What is meant by spin orbit coupling?

c. Write the electronic configuration of Cu and find out the electronic transitions term in the form of $^{2S+1}L_J$

d. What is the principle of optical fiber cable operation?

e. What is the difference between emission spectrum and absorption spectrum?

References:

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