APPENDIX 1

Lorentz's explanation of Zeeman effect

Here is the brief of Lorentz's explanation of normal Zeeman effect observed in some of the atoms including He, Zn, Cd and Hg. The basis of this explanation is Bohr atomic model. When an electron revolves around a nucleus, the magnetic moment is generated as $\vec{\mu} = I\vec{A}$ where I is current constituted due to rotation of electron and $\vec{A}$ is area vector.

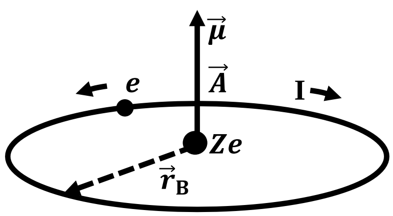


Fig A1.1: The rotation of charged particle constitute a current in closed loop which generates a magnetic moment. The Ze is charge of nucleus and r_B is Bohr radius.

Current generated by an electron, rotating at frequency f is given by $I = ef$ where e is charge of electron. The f is related to velocity by $f = \frac{|\vec{v}|}{2\pi|\vec{r}_B|}$ where $\vec{v}$ is velocity of electron and r_B is Bohr radius (see Fig A1.1). The area covered by electron orbit is $\pi|\vec{r}_B|^2$. Therefore, the magnetic moment $\vec{\mu}$ is

$$\vec{\mu} = \frac{ev}{2\pi|\vec{r}_B|}\ \pi|\vec{r}_B|^2\hat{a}$$

where $\hat{a}$ is vector in the direction of $\vec{A}$. The Bohr model suggest that angular momentum ($|\vec{L}|$) can only take multiple value of $\hbar$ or $h\backslash 2\pi$. The relation of velocity and angular momentum is $m|\vec{v}||\vec{r}| = \vec{L} = n\hbar$. Here n is positive non zero integer. Then, velocity of electron by Bohr model is given as, $|\vec{v}| = \frac{nh}{2\pi|\vec{r}_B|m_e}$, therefore,

$$\overrightarrow{|\mu|} = n\mu_B = \frac{neh}{4\pi m_e}$$

Hence, this is the magnetic moment generated by a rotating electron. This magnetic moment is combination of fundamental constants and μ_B is called Bohr magneton. Now, application of magnetic field can change the energy of atom by $\Delta E = \vec{\mu}.\vec{B} = m\mu_B B$.

This explains the quantization of energy splitting when magnetic field is applied. The sign of ΔE depends upon the angel between $\vec{\mu}$ and $\vec{B}$. Therefore, n is replaced with m which can take positive, negative and zero value.

APPENDIX 2

Working of Fabry-Perot interferometer

Fabry-Perot interferometer two partially reflecting mirrors placed parallel to each other*. Here is the brief explanation of its working. Two parallel rays 1 and 2 strikes at Fabry-Perot flat mirror at angle θ. If the difference between two plates is d, the path difference travelled by ray and 1 and 2 is $2dcos(\theta)$.

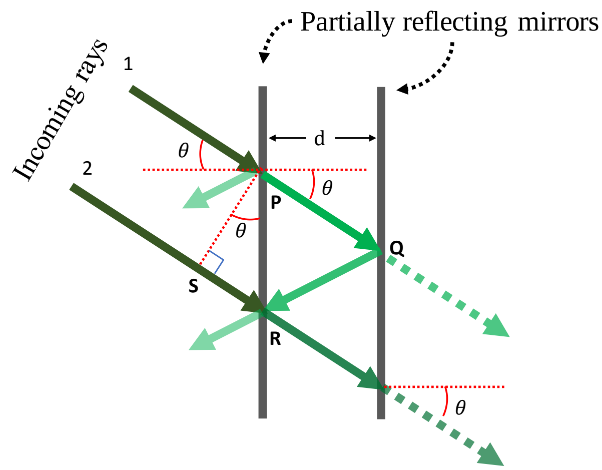


Fig. A2.1: Ray diagram of the working of Fabry-Perrot interferometer.

Path difference between ray 1 and 2 is

$$PQ + QR - SR = 2dcos(\theta)$$

$$\frac{2d}{\cos(\theta)} - 2d.tan(\theta)\sin(\theta) = \frac{2d}{\cos(\theta)} - \frac{2d\sin^2(\theta)}{\cos(\theta)}$$

$$= 2d.cos(\theta)$$

If path difference $2dcos(\theta) = n\lambda$ i.e. integer multiple of wavelength, then there is constructive interference. To make these rays interfere, a lens of focal length F is used in front of etalon and rays are focused at CCD camera. The point of interference from principal axis is $\chi \approx F\theta$ in the small angle approximation.

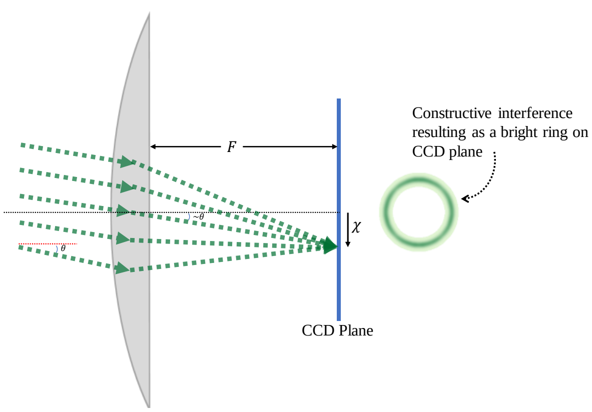


Fig. 11 The parallel lines from etalon focused on CCD camera.

Due to circular symmetry of rays around principal axis, there is ring formed with radius χ.

For $\theta = 0$; $(\cos(\theta) = 1)$, the value of n will be maximum

$$n_{maximum} = N = \frac{2d}{\lambda}$$

Exercise A2.1: Calculate the approximate order of N when value of d is calculated. $N \approx$ ....

The next ring of bigger radius will be formed at and θ_n when condition of $n = N - 1$ is satisfied and so on, as shown in figure 12. We use two such rings where,

$$2d.cos(\theta_n) = n\lambda \tag{A2.a}$$

$$2d.cos(\theta_{n-1}) = (n-1)\lambda \tag{A2.b}$$

Subtracting (b) from (a)

$$2d\big(cos(\theta_n) - cos(\theta_{n-1})\big) = \lambda \tag{A2.c}$$

The tailer series of cos is

$$cos(\theta) = 1 - \frac{\theta^2}{2!} + \frac{\theta^4}{4!} - \cdots$$

for smaller angles $\frac{\chi}{F} \ll 1$, higher orders can be ignored.

$$cos(\theta) = \left(1 - \frac{\theta^2}{2}\right)$$

and $\theta \approx \frac{\chi}{F}$, and replace this value in equation (c)

$$2d\left(\left(1 - \frac{\chi_n^2}{2F^2}\right) - \left(1 - \frac{\chi_{n-1}^2}{2F^2}\right)\right) = \lambda$$

and value of d is

$$d = \frac{\lambda F^2}{(\chi_{n-1}^2 - \chi_n^2)}$$

Exercise A2.2: What will be the formula of d if instead of consecutive radii (n and $n-1$) the

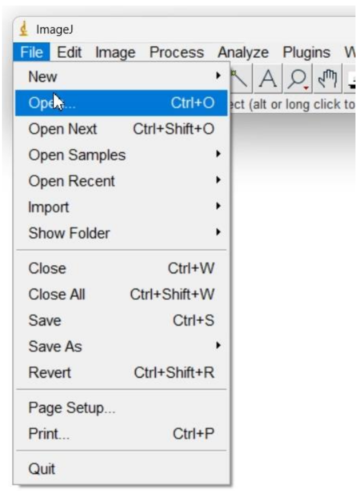
*There are other designs available depending upon the application, where plane mirrors are replaced with concave mirrors.

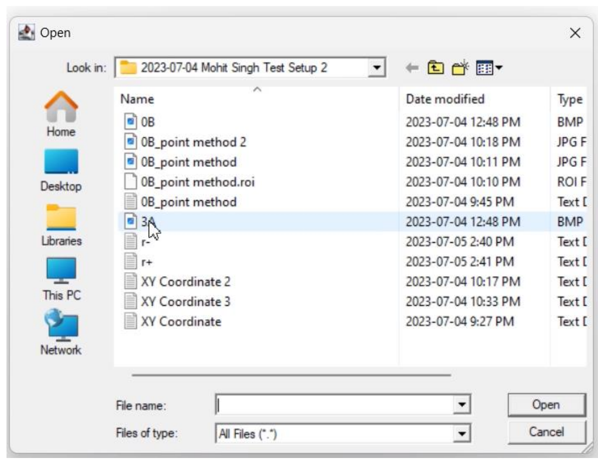
APPENDIX 3

I. How to use ImageJ software for radius calculation

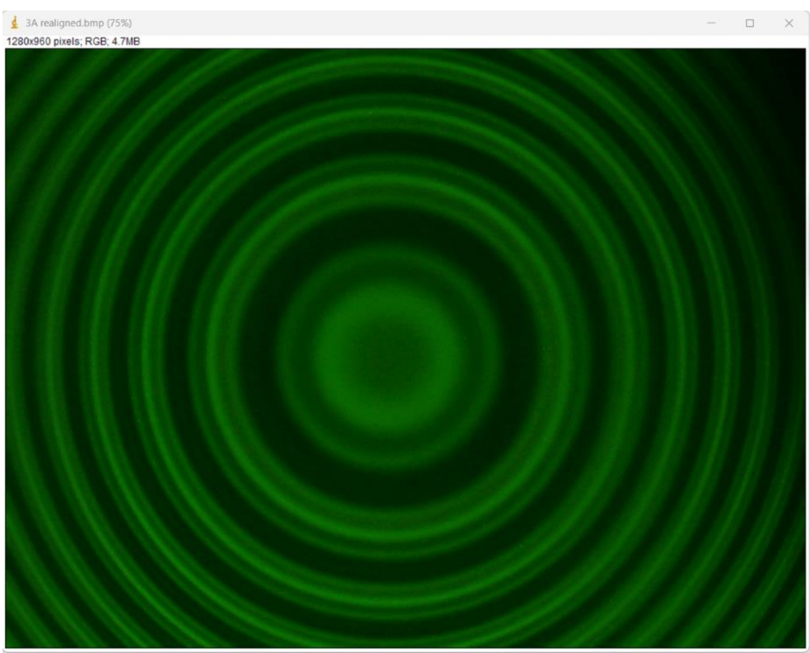
Step 1: Open the software from computer desktop. The ImageJ software icon 

Step 2: In the software toolbar go to File>Open>Select Image>Open

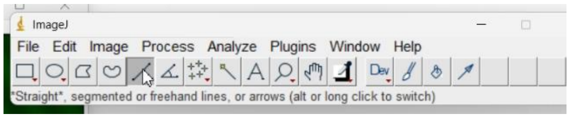




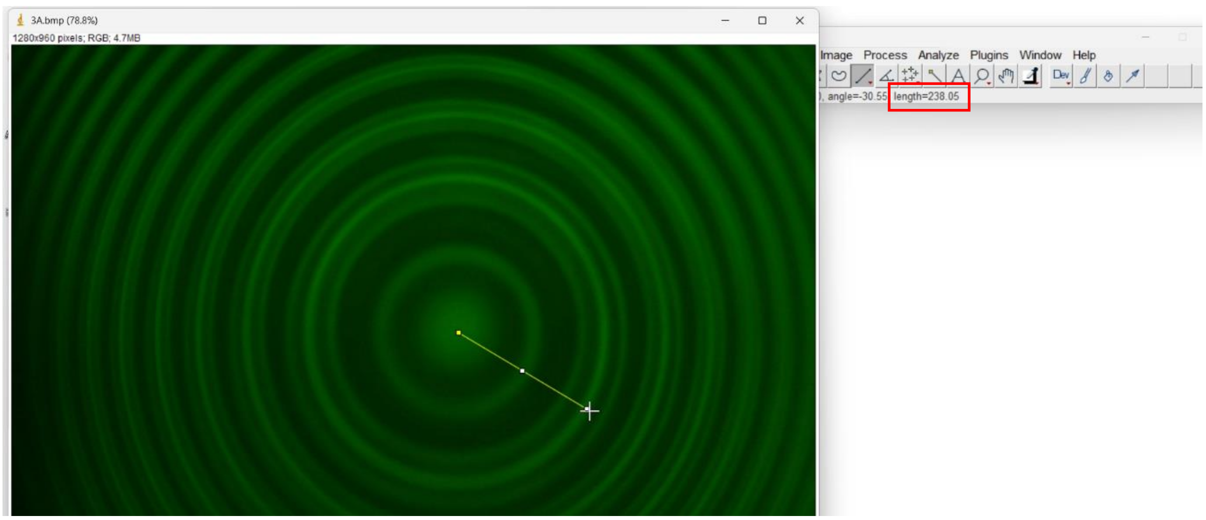
The image will open in another window. This window can be resized for better visual.



Step 3: Select the 'Line selection tool' from ImageJ toolbar. (For higher version of ImageJ, the Line selection tool has multiple options, select straight line).



Step 4: Place the mouse-pointer at the center of ring, hold the left mouse key and drag the pointer to the radial point. A yellow straight line is formed between two chosen points. At the bottom of ImageJ toolbar, the 'length= xxx' shows the length of yellow line in pixel.



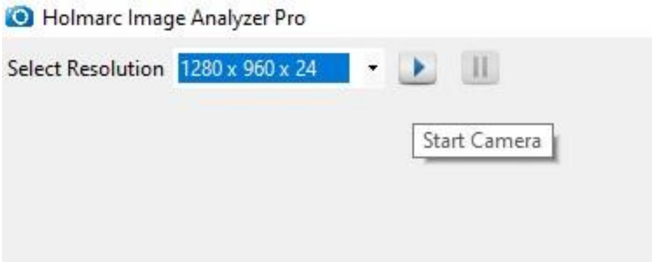
Step 5: Note down the radii and proceed to the calculations.

For the images taken at camera resolution of

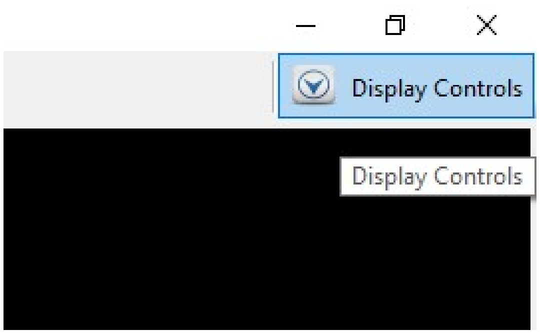
Resolution	Pixel length
640×480	1 pixel = 7.8 μm
1280×960	1 pixel = 3.9 μm

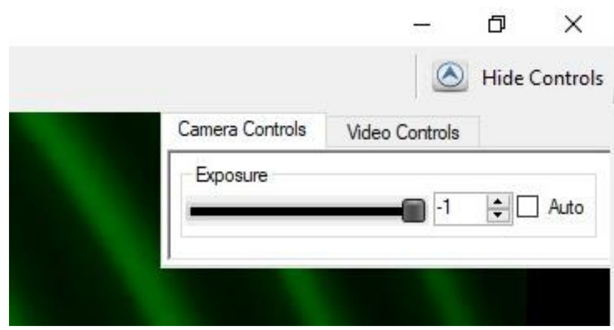
II. How to use camera software for image capture

Step 1: Open the Holmarc Image analyser Pro software. Select the resolution from drop down list and start the camera.

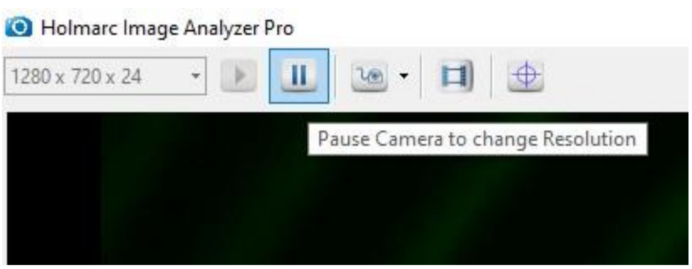


Step 2: Change the exposure time to enhance the image from display control.

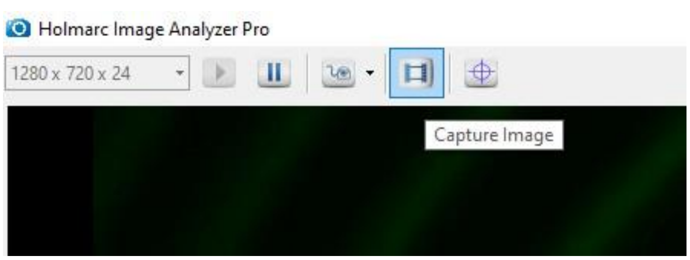




Step 3: Change resolution if required



Step 4: Capture image



APPENDIX 4

I. Calculation of Lande factor g_J from term symbol

The term symbol ${}^{a}b_{c}$ indicates

a = 2S+1

b = L with alphabetic symbols S=0, P=1, D=2, F=3

c = J

Example: For the energy level marked as $6s7p\ {}^{3}P_{2}$, S L and J values are

Here, $6s7p$ is electronic configuration for valance electrons (Outer subshells unpaired electrons)

${}^{3}P_{2}$ is term symbol which indicates

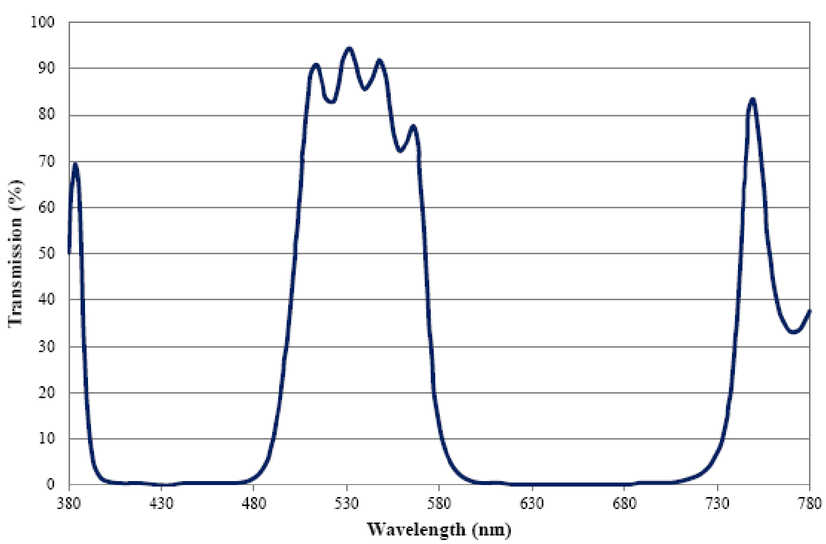
$3 = 2S + 1 \implies S = 1$

$P = 1 \implies L = 1$

$2 = J$

With these values g_J can be calculated to be 3/2.

II. Transmission spectrum of the Green filter



APPENDIX 5

Specifications

Lamp	Mercury discharge lamp, slim design, AC, 5 W
Electromagnet	Built-in current-controlled power supply, 65V DC, 0-3.5A
Maximum Magnetic Field at 10mm pole space	1.8 Tesla
Fabry-Pérot (interferometer) Etalon	Aperture: 30 mm
Separation of Etalon Plates	3-5 mm
Distance between Etalon & the camera	85 mm
Interference Filter	Central Wavelength: 546.1 nm
Collimating Lens	Aperture: 37.0 mm, Focal Length: 85mm
Power Input	230VAC, 50 Hz. (110VAC optional)

Fundamental Constants

$\mu_B = 9.27400915\text{x}10^{-28}$ Joule/Gauss

APPENDIX 6

Setup 1 (Transverse mode)

Current (A)	Magnetic field (Gauss)
0	400
0.25	1650
0.5	2965
0.75	4250
1	5640
1.25	6880
1.5	8150
1.75	9305
2	10490
2.25	11585
2.5	12615
2.75	13490
3	14320
3.25	15010
3.5	15575

Setup 2 (Longitudinal mode)

Current (A)	Magnetic field (Gauss)
0	450
0.25	1675
0.5	2935
0.75	4545
1	5530
1.25	6695
1.5	7905
1.75	9045
2	10165
2.25	11190
2.5	12175
2.75	13090
3	13920
3.25	14645
3.5	15270