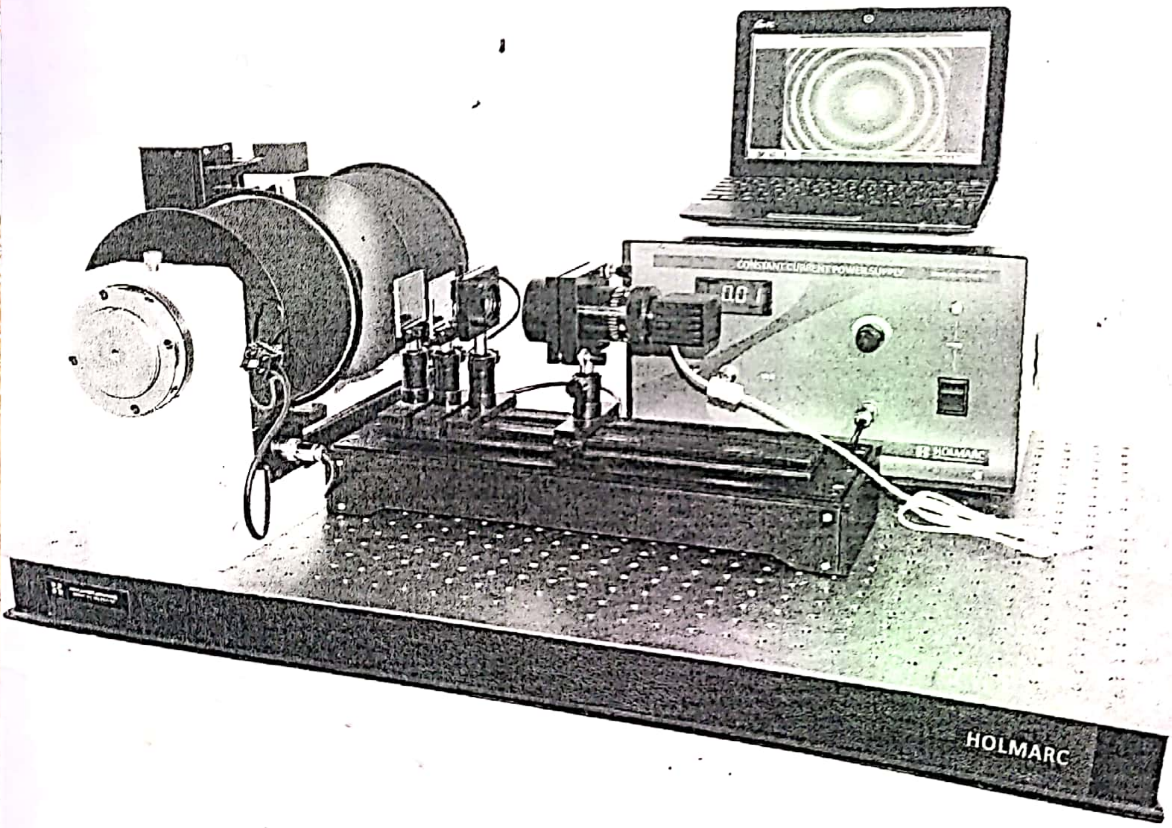
HOLMARC

Instruction Manual



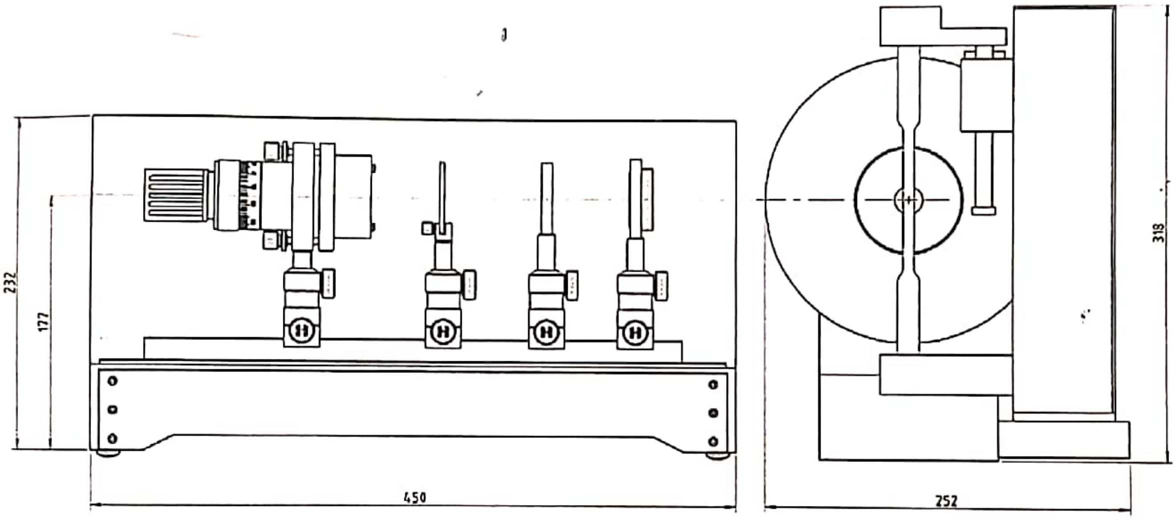
Zeeman Effect Apparatus

Model HO-ED-S-04

CONTENTS

Product Features

Holmarc's Zeeman Effect Apparatus Model: HO-ED-S-04 is designed for the verification of magnetic moment constant Bohr magneton (μ_0) and the fundamental constant hc. It demonstrates the effect of magnetic field on light emitted in a gas discharge, The Zeeman effect, and shows quantum nature of light and behavior of electrons. Traditional Zeeman Effect apparatus need more skills in operation and measurement. With its new and integrated design, this device is easier to setup and operate so that students can focus on understanding the principles and theories involved.



A low-pressure mercury lamp is placed between the pole pieces of a strong electromagnet. Light is passed through a narrow-band interference filter centered around the desired wavelength (546.1nm), and enters the Fabry-Perot etalon. This device consists of two reflective parallel plates which serve to transmit strong incoming radiation at different orders of wavelength. The apparatus has a built-in minimum separation of 3 mm. Small tilting knobs allow careful adjustment of the plate.

The significant difference in our setup is in the imaging system used for viewing and recording the interference patterns. We use a USB 2.0 camera; it can be directly connected to the PC to monitor the fringe pattern and can save the desired pictures. This makes the alignment of the optics much easier and eliminates the need for photographic processing.

:: Getting Started

a. Quick Start Guide

Kindly check the following items are delivered in respective carton boxes.

BOX - 1

1. C - Core

BOX - 2

1. Copper Coil Spool - 2 Nos.

BOX - 3

1. Shaft - 2Nos.
2. Lock Nut - 2 Nos.
3. Washers - 4 Nos.
4. Screws m4 x 12 - 8 Nos.
   m8 x 50 - 2 Nos.
   m3 x 4 - 4 Nos.
5. Wired 4 - pin mini brass connector male - 1 No.
6. Lever (For Adjusting Shafts) - 1 No.
7. Allen Key Set - 1 No.

BOX - 4

1. Power Supply for Electromagnet - 1 No.
2. Power cord - 1 No.
3. 4 - pin connection wire with female ends. - 1 No.

BOX - 5

1. Rail Based platform - 1 No.
2. IR filter mount - 1 No.
3. Green Filter Mount - 1 No.
4. Polarizer with variable aperture - 1 No.
5. Fabry Perot Set-up with
   Zoom lens assembly - 1 No.
6. IR Filter - 1 No.
7. Green Interference Filter - 1 No.
8. CCD Camera - 1 No.
9. Dust protective cover - 1 No.
10. Etalon tuning knobs-3 Nos.

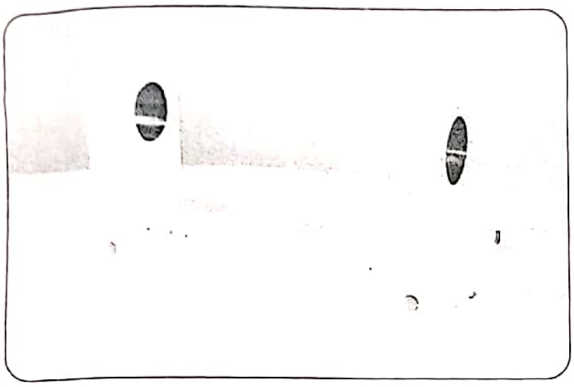
BOX - 6

1. Digital Gauss Meter - 1 No.
2. Gauss Probe Holder - 1 No.
3. Power cord - 2 Nos.
4. Lamp House - 1 No.
5. Mercury Discharge Lamp - 1 No.
6. Software CD - 1 No.
7. Laptop - 1 No.

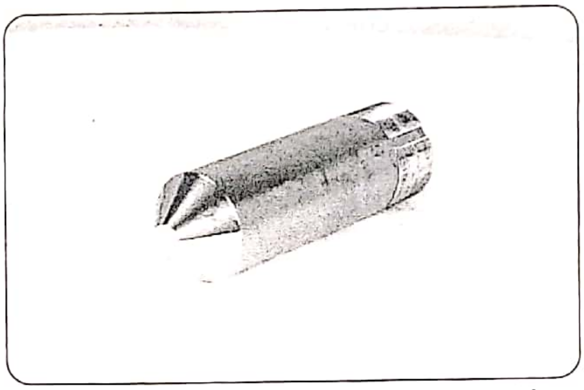
b. Parts listing and Installation instructions

1. Electromagnet - Parts listing

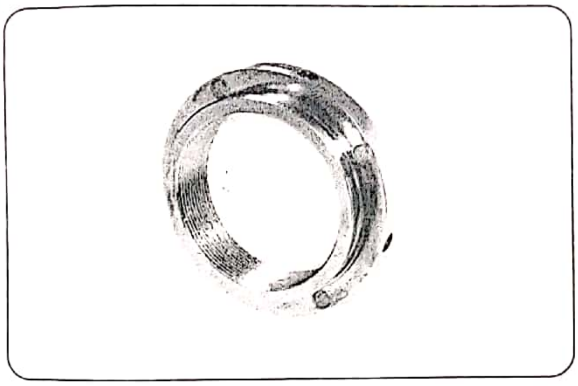
C - core



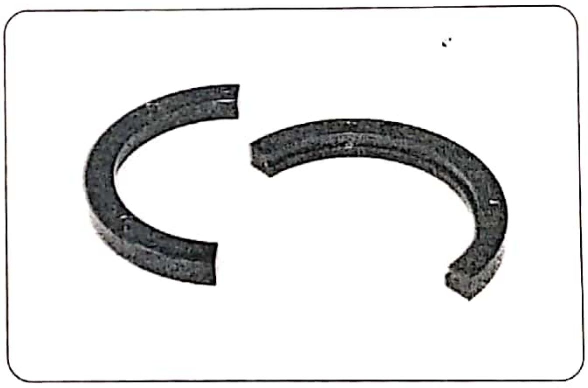
Shaft



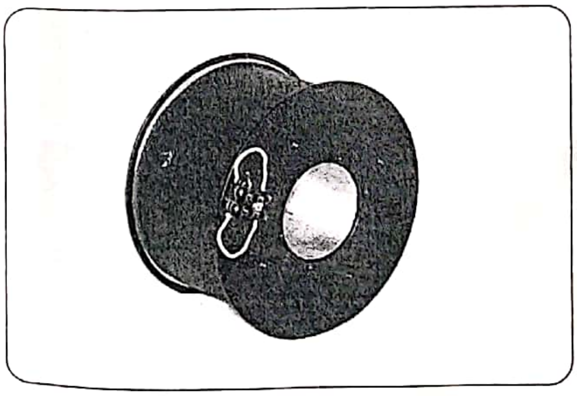
Lock Nut



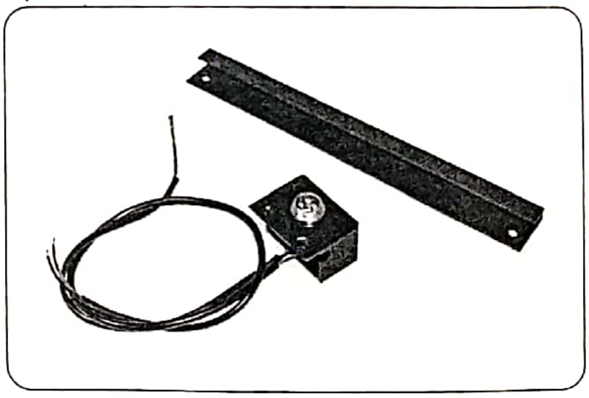
Washers



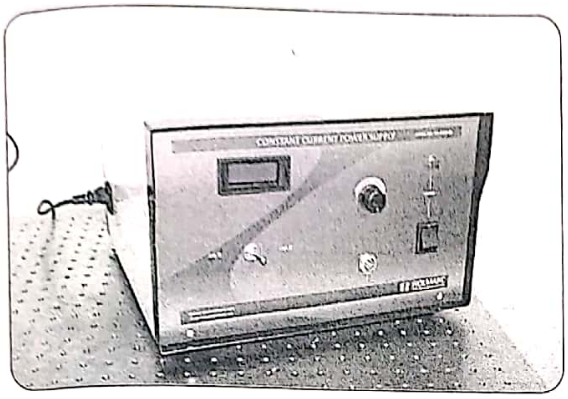
Copper coil Spool



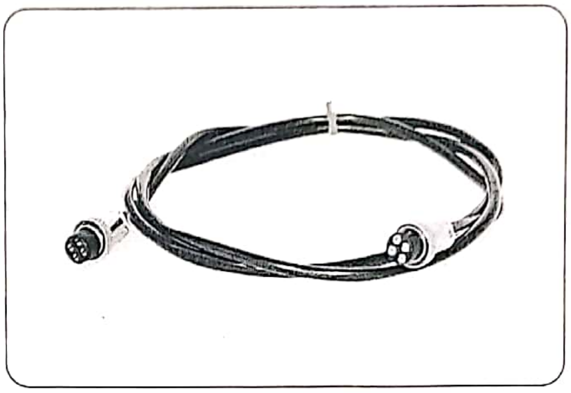
Wired 4 pin male brass connector



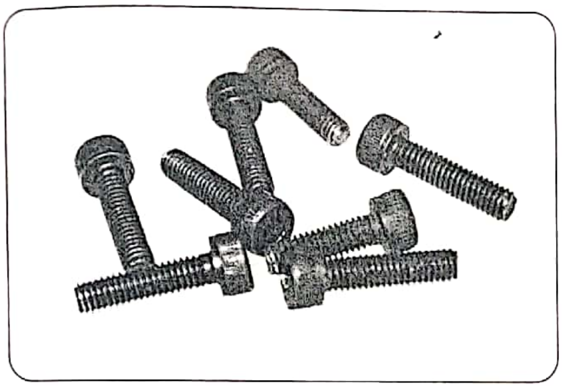
Electromagnet Power Supply

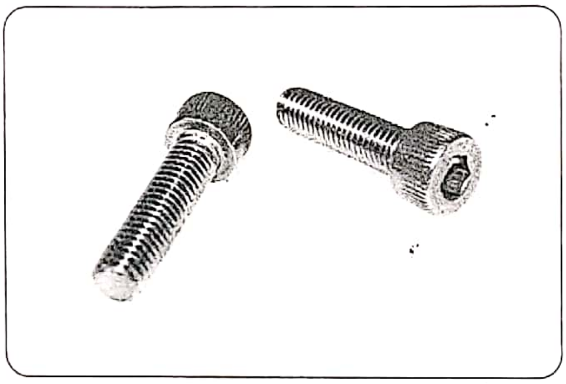


4 - pin connection wire with female ends



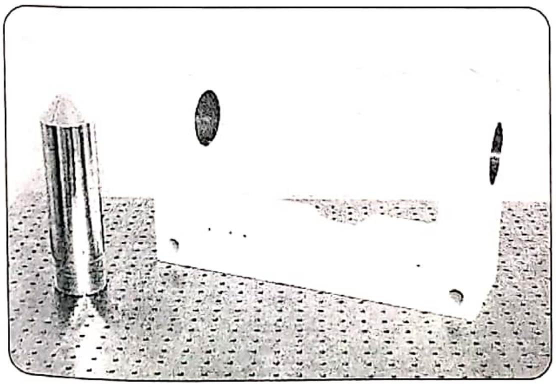
Screws



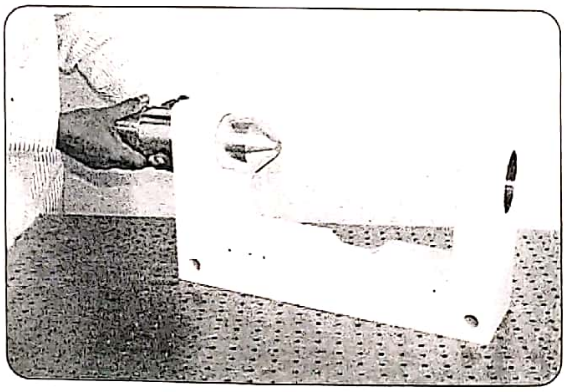


Assembling the Electromagnet

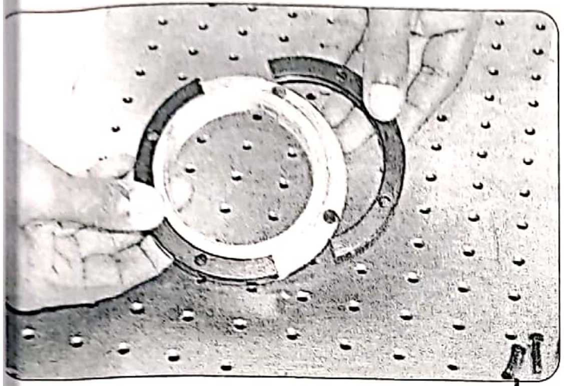
Place the C core on the table



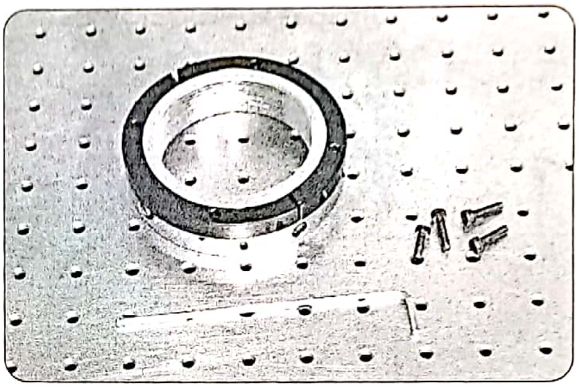
Insert one of the shafts



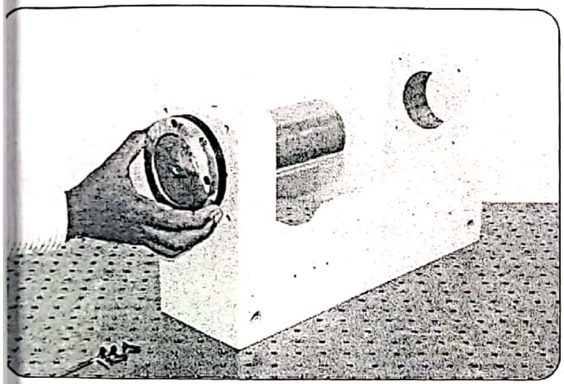
Take two washers and one lock nut



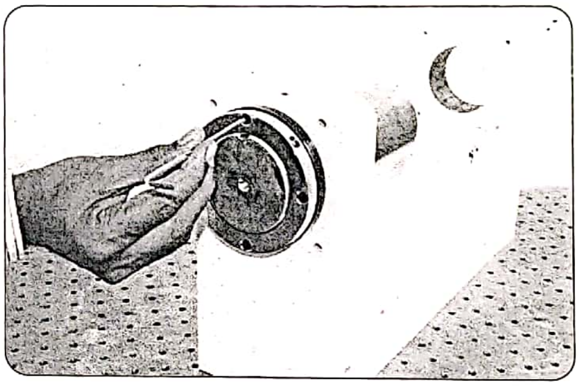
Set the two washers on the locknut so that the four holes are parallel



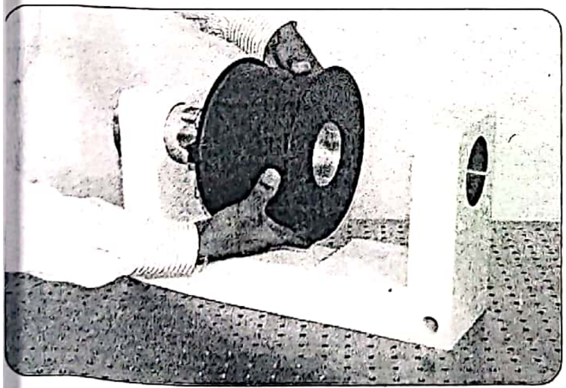
Screw the locknut on the shaft



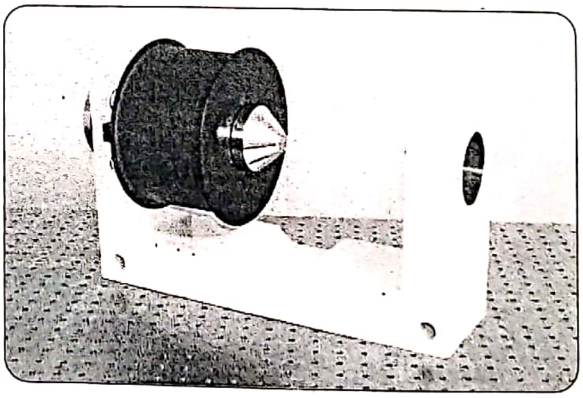
Tight the washers by using Allen (m4x12) screws



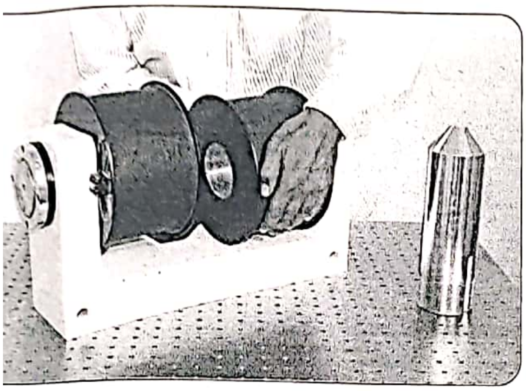
Take one of the coil



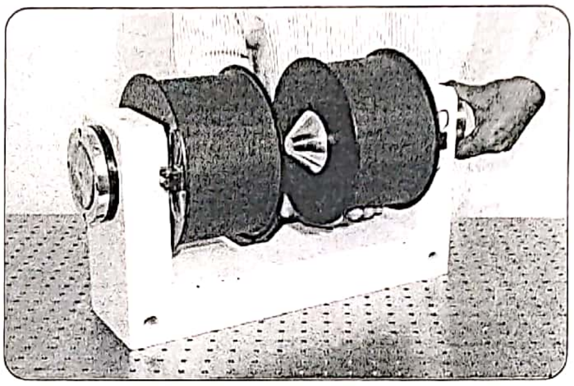
Insert the coil into the fixed shaft



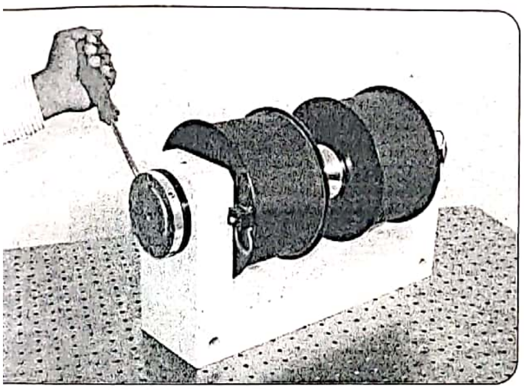
Take the other coil and keep it in the same position as the other coil



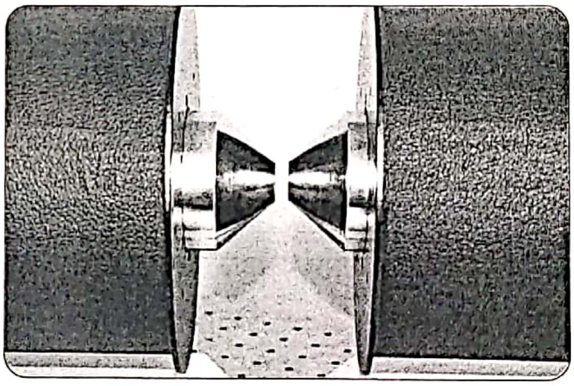
Insert the shaft though the coil and tight with lock nut and washers as done before.



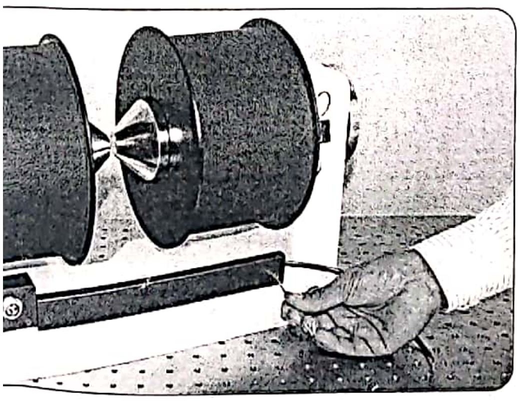
Adjust the spacing of the poles



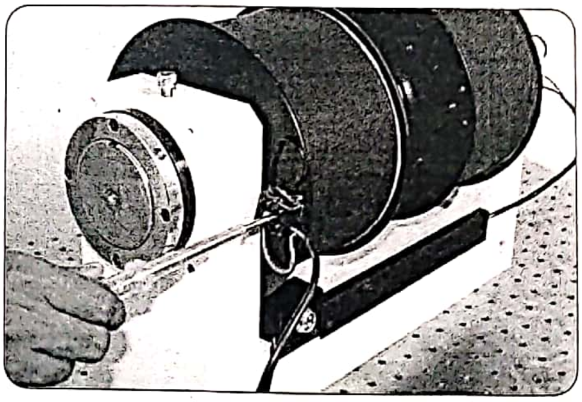
Make the spacing nearly 10mm



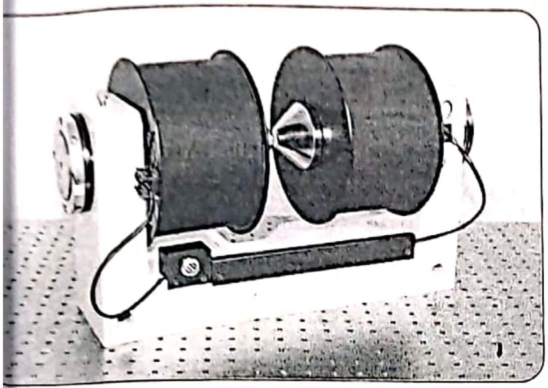
Fix the connector



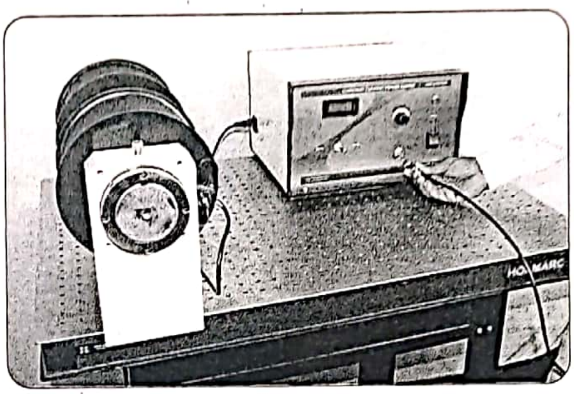
Connect the wires to the coil



Assembly completed



Connect the electromagnet and power supply
Using 4 pin connector wire



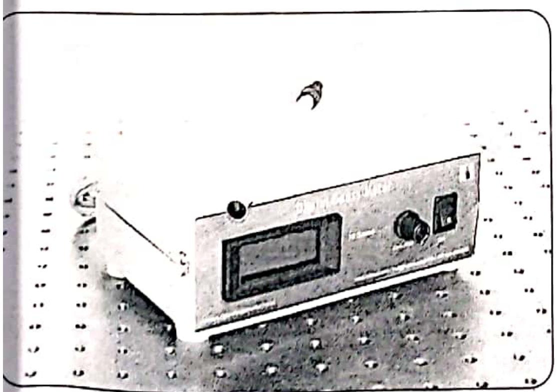
Specifications :

Electromagnet
Max magnetic field : 1.7 Tesla (at 10mm pole space)

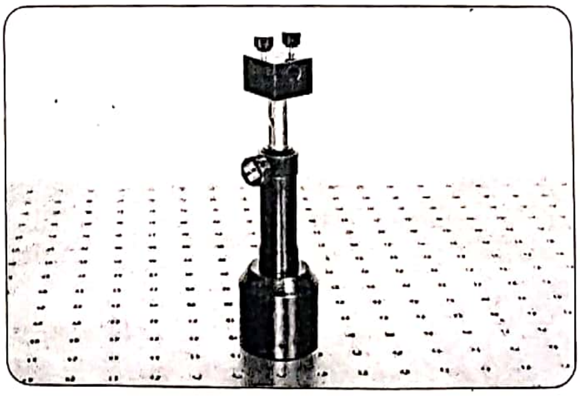
Power supply
40 V DC, 0-4 A variable

2. Digital Gauss meter with probe holder - Parts listing & Assembling

Digital Gauss meter

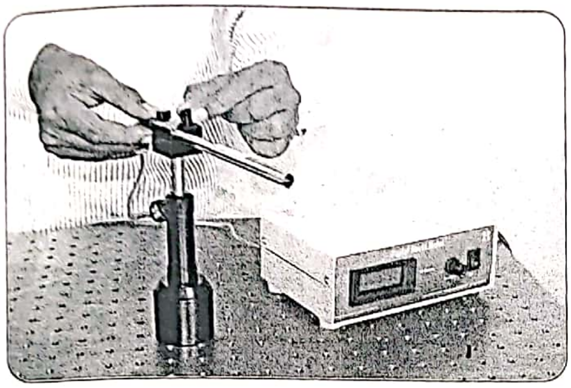


Probe holder

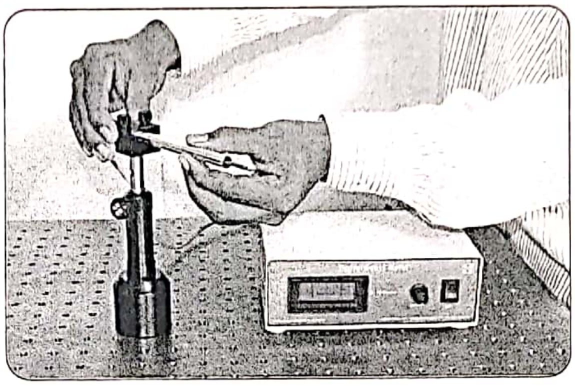


Magnetic field Calibration

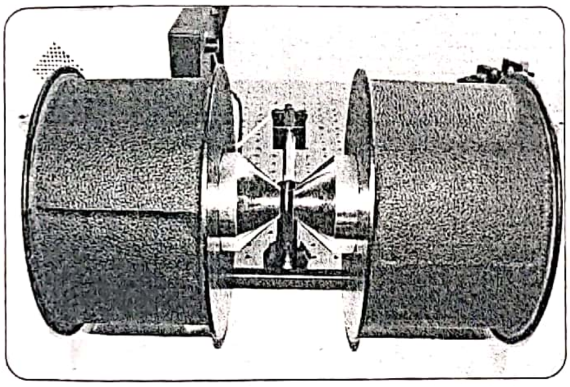
Fix the gauss probe in the probe holder



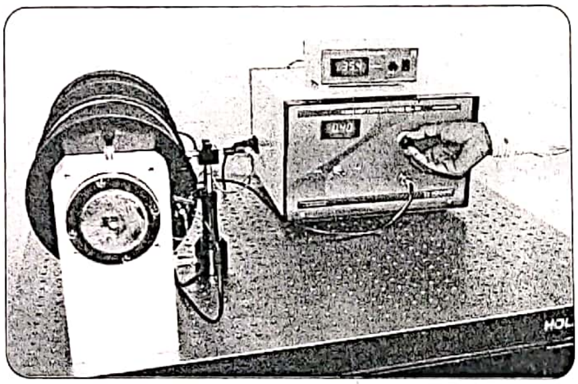
Pull back the cover of Hall probe



Place the probe on the centre of the Electromagnet.



Vary the current & note the magnetic field.

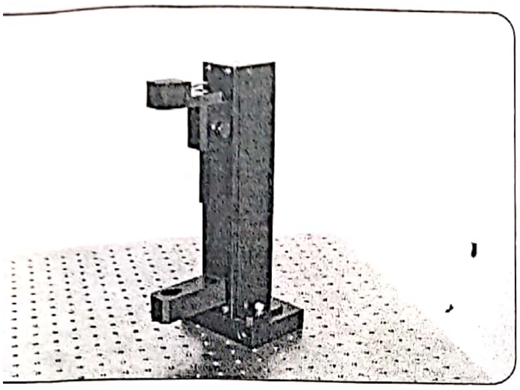


Specifications : Gauss meter

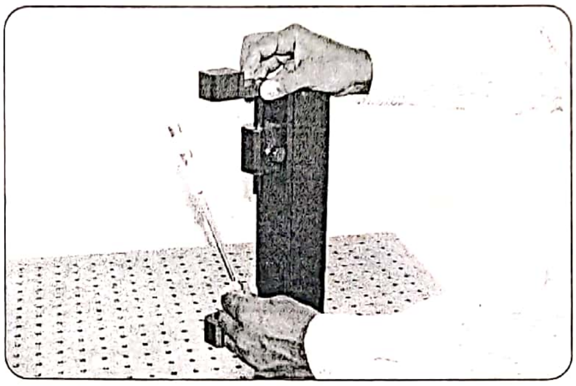
Range	0-2KG & 0-20KG
Resolution	1G at 0-2KG
Accuracy	+/- 0.5%
Display	31/2 digit, 7 segment LED
Power	220V +/- 10%, 50Hz
Transducer	Hall Probe - InAs

Lamp house - Assembling

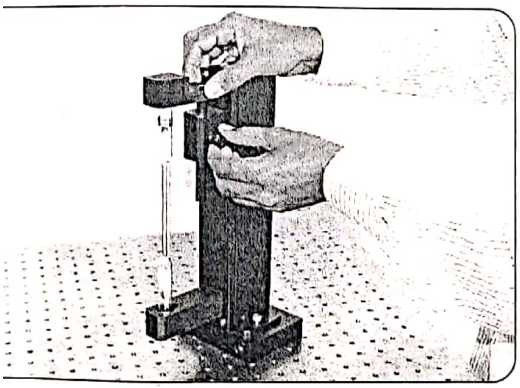
Place the lamp house on the table



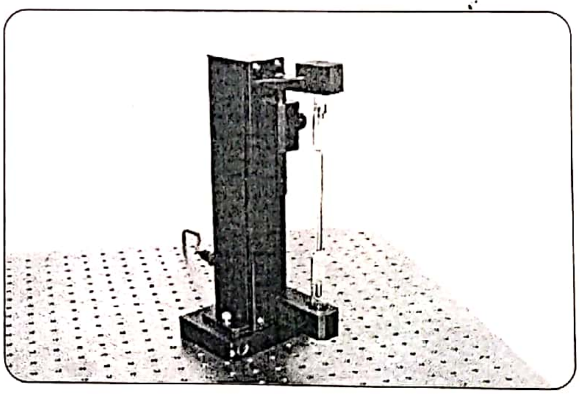
Release the upper holder knob.



Insert the Lamp and tight the knob.



Lamp assembly completed.

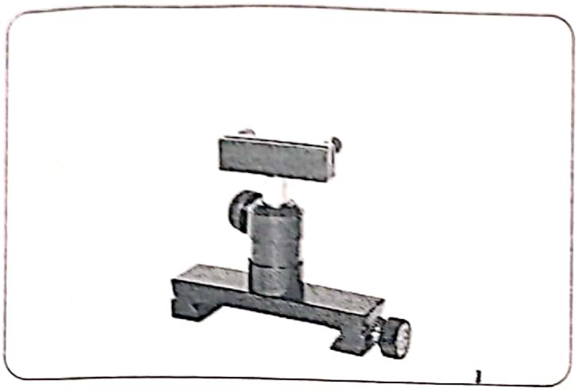


ecifications :

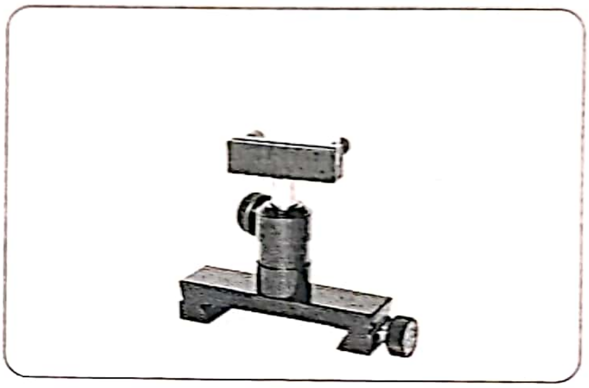
ercury discharge lamp
wer supply 230V 50 Hz
itput 4 KV, 30 mA

4. Fabry Perot interferometer - Parts listing & Assembling

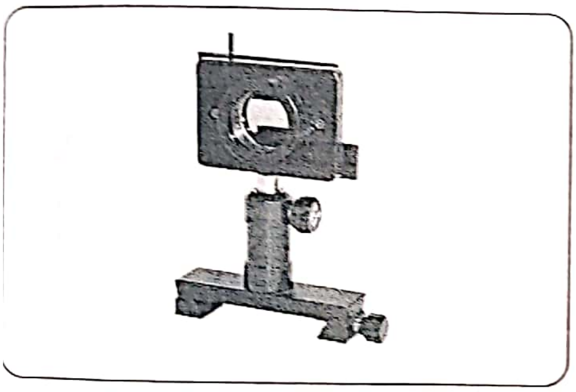
Hot Mirror



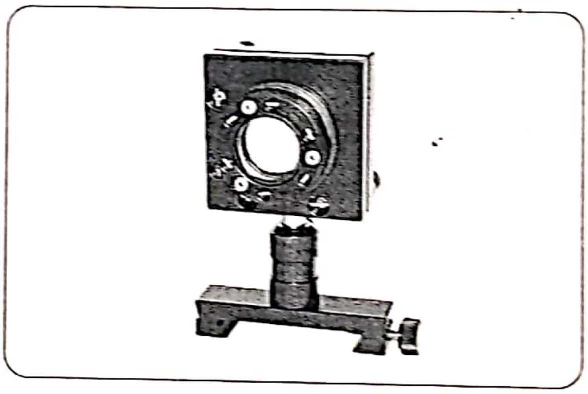
Green Filter



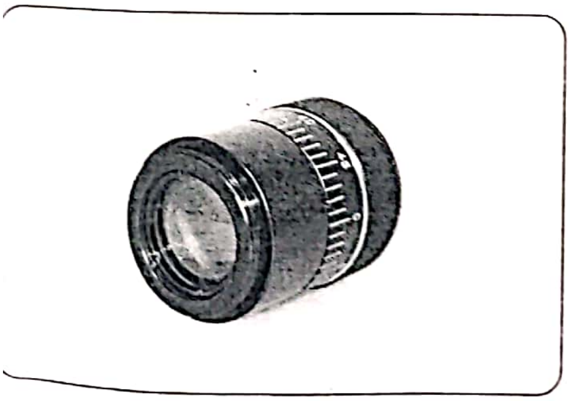
Polarizer with Variable aperture



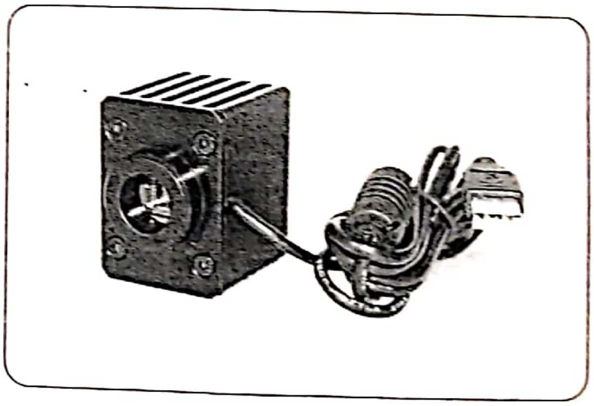
Fabry- Perot Etalon



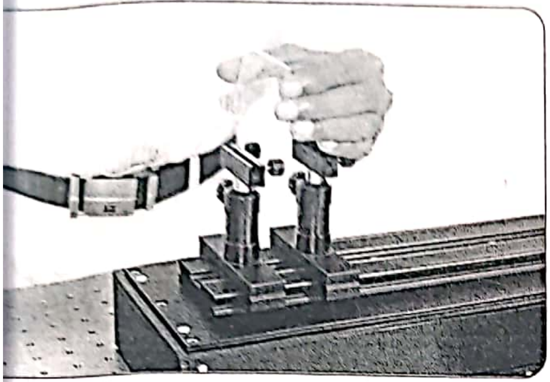
Zoom Lens



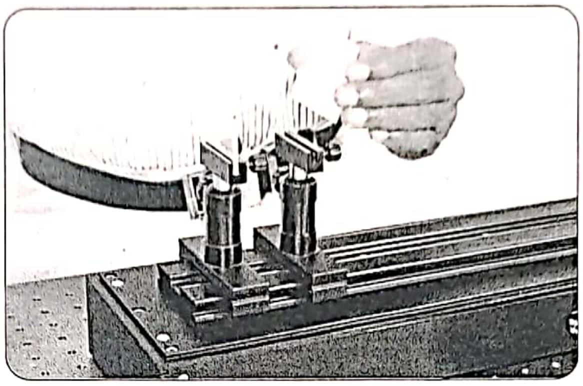
CCD Camera



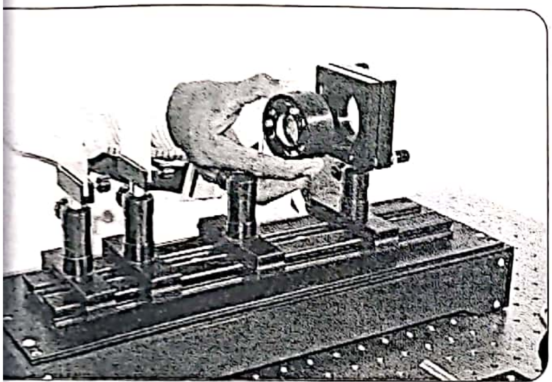
Fixing the IR filter.



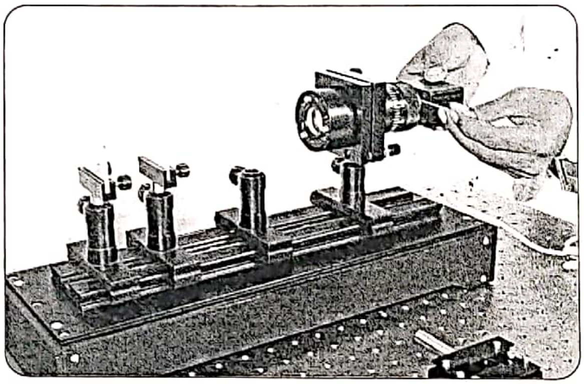
Fixing the Green filter.



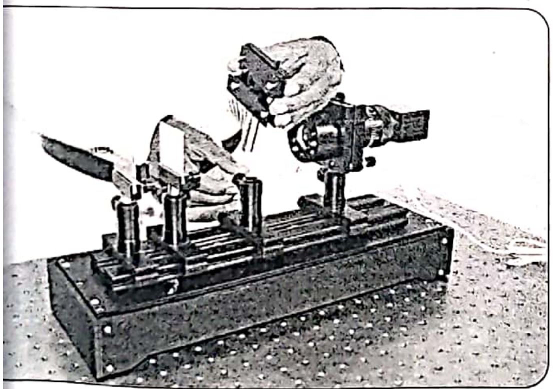
Fixing the Fabry-Perot Etalon.



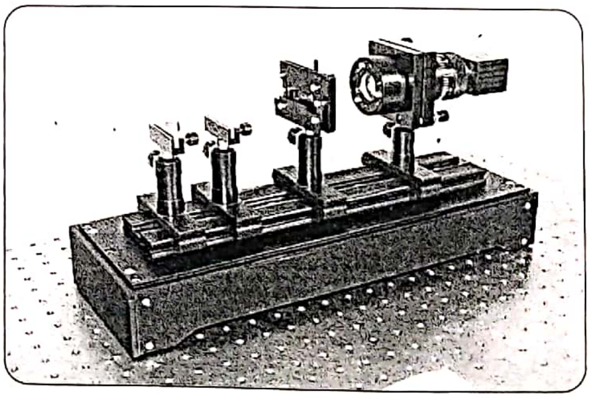
Fixing the camera and zoom lens assembly.



nserting the polarizer with variable aperture.



Fabry Perot interferometer assembly completed.



Specifications :

Dichroic Green Filter

Type	Additive
Color	Green
Dimensions (mm)	50 x 50
Clear Aperture (%)	≥ 85
Thickness (mm)	2 nominal
Surface Quality	80 - 50
Angle of Incidence (°)	0
Substrate	BOROFLOAT™

Hot mirror

50mm Square, 0 Degree AOI, Hot Mirror

Dimensions (mm)	50 x 50
Thickness (mm)	3.30
Substrate	BOROFLOAT
Transmission (%)	> 92, 425 - 675nm
Reflection (%)	> 95, 750 - 1150nm

Polarizer with variable aperture

Material	Sheet polarizer
Rotation	360
Diameter	25 mm

Fabry perot etalon

Aperture	30mm
Separation of plates	3 - 4mm variable
R / T ratio	85 / 15

CCD camera and Lens assembly

Resolution	Selectable
Connectivity	USB 2.0
Zoom lens focal length	65 mm

- It is recommended that students work in pairs - one to take photograph of the images and other person to vary the magnetic field.

- Care should be taken while tuning the etalon. It is not an easy job to make the plates of the etalon exactly parallel.

- Make sure that there are no bubbles in the narrow path of mercury discharge tube. It will cause burning of the mercury vapour.

Caution : Do NOT sustain a high Magnetic field for more than 2min.for taking the Photographs. It will lead to the damage of both coil and Power supply. It also causes residual magnetism in the core part.

Fundamentals

Aim:

1. Thickness of the etalon
2. Calculation of fundamental constant μ_0 / hc

Principle :

When a light-emitting atom is subjected to a magnetic field, its emission lines are split into multiple components at slightly shifted wavelengths. This phenomenon is known as the Zeeman Effect, named for Pieter Zeeman, who first observed the phenomenon in 1896 in Leyden (Netherlands), and received the 1902 Nobel Prize in Physics for his discovery.

Levels and light-emitting transitions between levels which were all of the same energy at zero field regardless of the electron orientation have now become a series of different, orientation-dependent transitions at slightly differing energies. This is experienced as a "splitting" of the observed spectral line on imposing a magnetic field.

The atomic magnetic moments along a given axis are quantized and assume defined orientations when subjected to a magnetic field. In these orientations, the atom's bound electrons have different energies than in the zero-field state, the amount of the difference depending on which of the several allowed orientations an electron assumes. Each energy level is therefore now split into several sub-

The transitions which can be observed in a magnetic field are governed by the selection rule for the magnetic quantum number M, namely that for allowed transitions $\Delta M = 0$ or ± 1, and also by the state of polatization of the emitted light. Linearly polarized light is observed in a direction transverse to the magnetic field, while circularly polarized light is emitted parallel to the field.

In this appratus the spectral line observed is the green line of mercury at 546.1nm, which splits into nine components.

When the lines are observed perpendicular to the magnetic field direction, all nine components will be visible. They include three π polarized lines and six σ polarized ones.

The three π lines are located in the center of the pattern and are the most intense. The six σ lines are weaker and located on the outside of the pattern. Overlapping of the closely spaced lines makes observation and measurement difficult. However, since all the lines are linearly polarized, a polarizing filter can be used to block the six σ lines, leaving the three cental π lines more clearly visible for measurement. Rotation of the filter enables the existence and polarization state of the six σ lines to be confirmed.

Computation of the Fundamental Constants

We have,

$$\Delta E_{Zeeman,\ 6^3P_2} = g_0 \, |B|$$

$$\Delta E_{Zeeman,\ 7^3S_1} = g_1 \, |B|$$

for some constants g_0 and g_1.

Using a linear polarizer, one can selectively choose to observe $\Delta m = 0$ ansitions only and therefore extrapolate the experimental value of $g_1 - g_0$.

$$\Delta E_{Zeeman,\,7^3S_1} - \Delta E_{Zeeman,\,6^3P_2} = (g_1 - g_0)\,|B|$$

but $$(g_1 - g_0)\,|B| = (\Delta\nu_{ab} + \Delta\nu_{bc})/2$$

$$\Delta\nu_{ab} = \frac{<\delta_{ab}>}{2t<\Delta>}$$

Where $<\Delta>$ is the average of the δ_{12}, δ_{23}, and δ_{34} values, 't' is he thickness of the Etalon. By putting δ_{bc} in the above equation, we can also find $\Delta\nu_{bc}$. From he above discussions, we know that,

$$\mu_0 / hc = (\Delta\nu_{ab} + \Delta\nu_{bc}) / |B|$$

This comparable to the expected value of μ_0/hc, 4.6654×10^{-5} cm^{-1}/gauss. The experiment can be repeated for various values of currents and can take the average value.

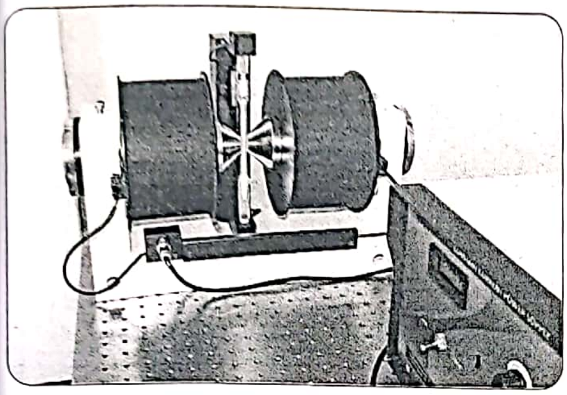
Fundamental constants :-

Bohr magneton (μ_0) = 9.27400915×10^{-28} Joule/Gauss
Planks constant (h) = 6.62606896×10^{-34} Joule- Sec
Velocity of light (c) = 3×10^{10} cm / Sec

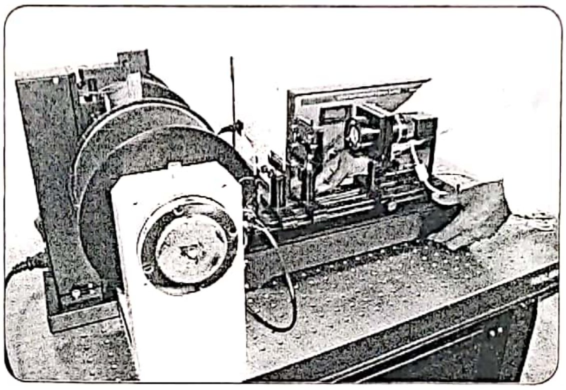
From experiment, μ_0 / hc =......................
μ_0/hc = 4.6654×10^{-5} cm^{-1}/gauss
Percentage Error = ...

Apparatus setting for experiment

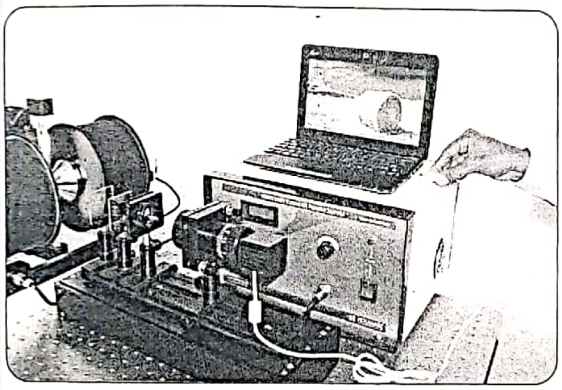
Setting up the mercury lamp at the Centre of the electromagnet



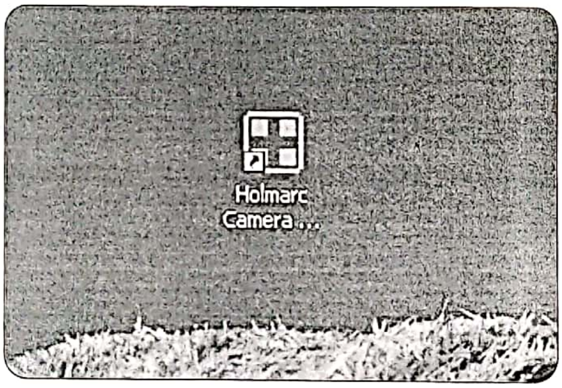
Place the Fabry Perot interferometer so that it collects the light from the center part of EM



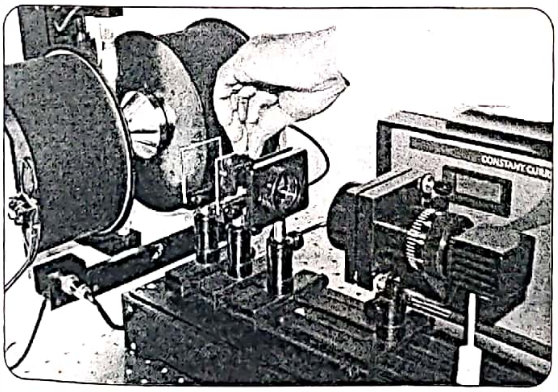
Connect the camera to Laptop



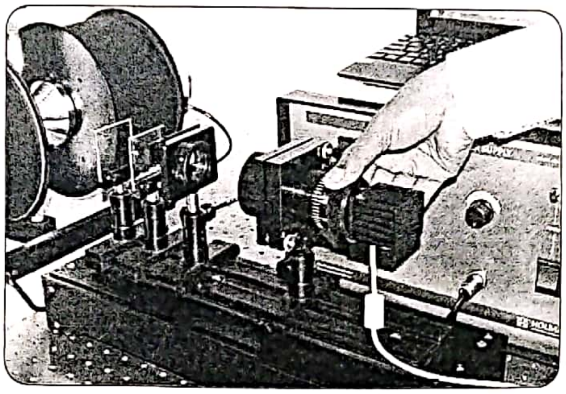
Open the Holmarc camera application



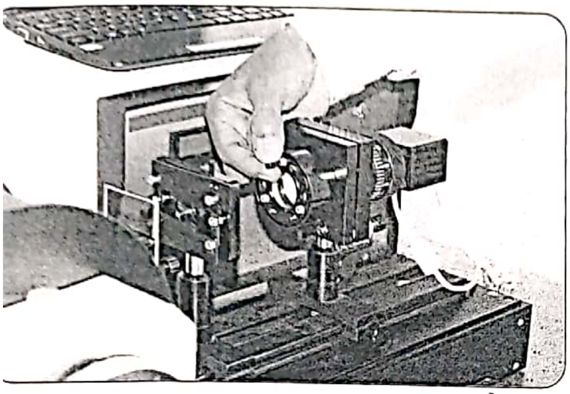
Adjust the variable slit to get the desired intensity



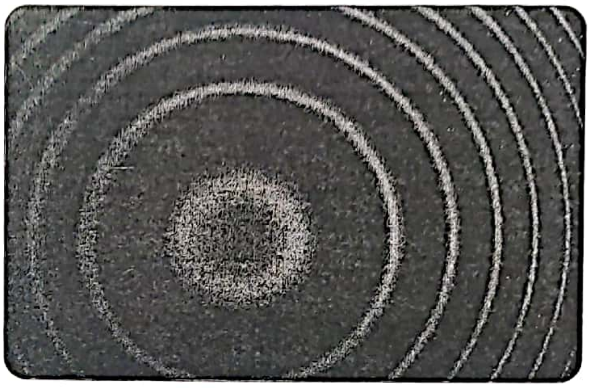
Adjust the zoom lens to get sharp fringes



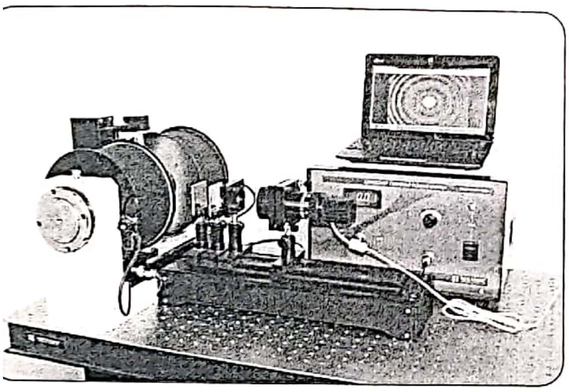
Fine tune the etalon to get clear sharp circular fringes



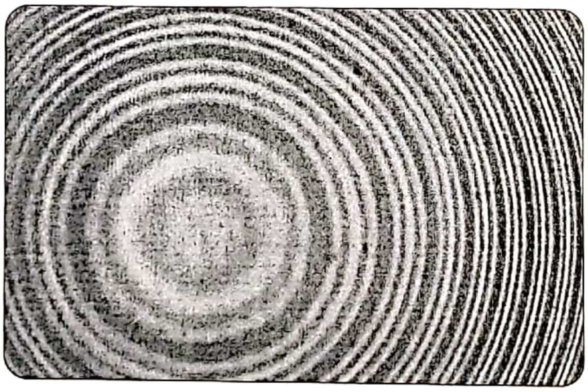
Fine tuned fringe



After getting sharp circular fringe, apply the magnetic field.



Observe the Fringe Splitting

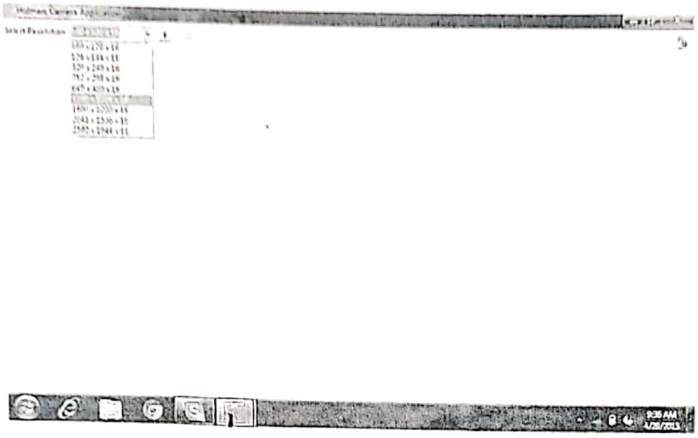


:: Software Installation

CCD Camera Software

Holmarc camera application software helps to capture the images with different magnetic fields of Zeeman Effect experiment. Install the Holmarc camera application and then connect the camera to the computer.

While tuning the etalon select 320 x 240 resolution. After getting sharp circular fringes change the resolution to 1280 x 1024.



Then capture the image without applying the magnetic field. Also capture the images at different magnetic fields.

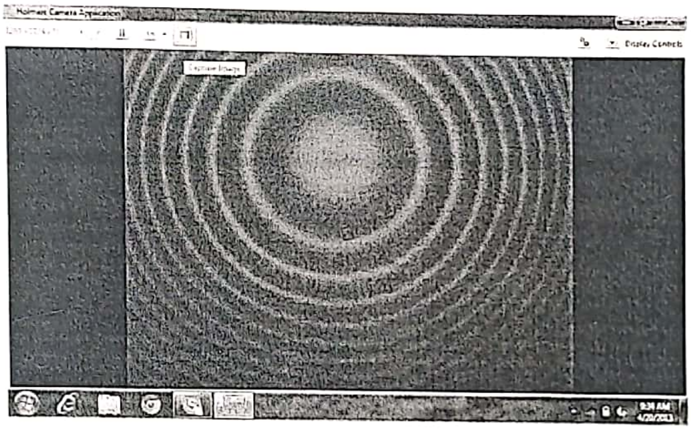
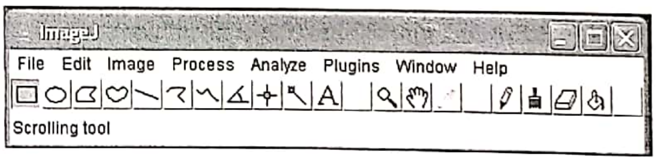


Image Analysis Software

Install the 'Image J' software in the computer. 'Image J' software helps to analyse the fringes.



Experimental Procedure

Magnetic Field Calibration:

A gauss meter is used for the calibration of magnetic field. Introduce the gauss meter probe between the poles of electromagnet. Always make changes in the voltage fairly slowly. Run the current from zero up to its maximum value and from maximum to zero. Note the corresponding field strength from gauss meter at different intervals. Sl. No Current I (Amp) Magnetic field Increment (Gauss) Magnetic Field Decrement (Gauss) Average B |B| (Gauss)

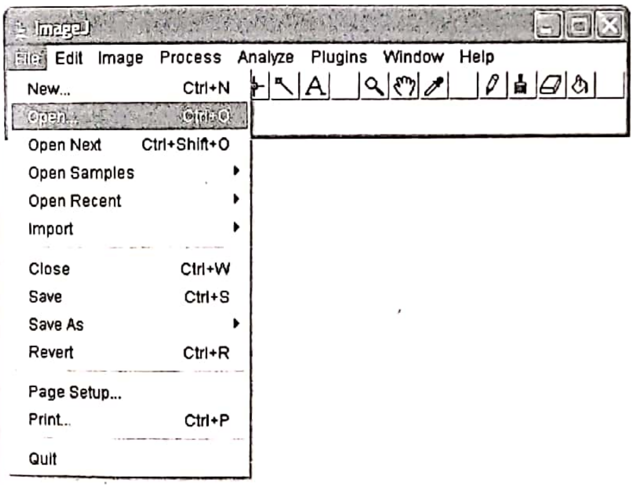
Sl. No	Current I (Amp)	Magnetic field Increment (Gauss)	Magnetic Field Decrement (Gauss)	Average B |B| (Gauss)
1.	0.00			
2.	0.25			
3.	0.50			
4.	0.75			
5.	1.00			
6.	1.25			
7.	1.50			
8.	1.75			
9.	2.00			
10.	2.25			
11.	2.50			
12.	2.75			
13.	3.00			
14.	3.25			
15.	3.50			
16.	3.60			

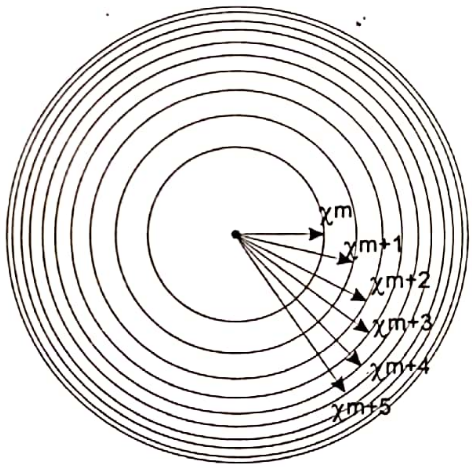
Experiment using Mercury Source:

Replace the Gauss meter probe with mercury lamp. Setup the Zeeman effect in the "apparatus setting for the experiment " section.

Thickness of the Etalon:

For finding the thickness of the etalon we measure the radius of the circular fringes. Open the image of zero magnetic field with the image analysis software 'Image J'. {File : open (file name)}. Select '\'.Measure the length of the fringe by dragging the mouse. Note that the line should be exactly straight. We can take the readings from the top menu of the software window. The radius of the first circular fringe is taken as χ_m and the following as $\chi_m, \chi_{m+1}, \chi_{m+2}, \chi_{m+3}$ etc. These values are in pixels. Convert these values in to standard units.

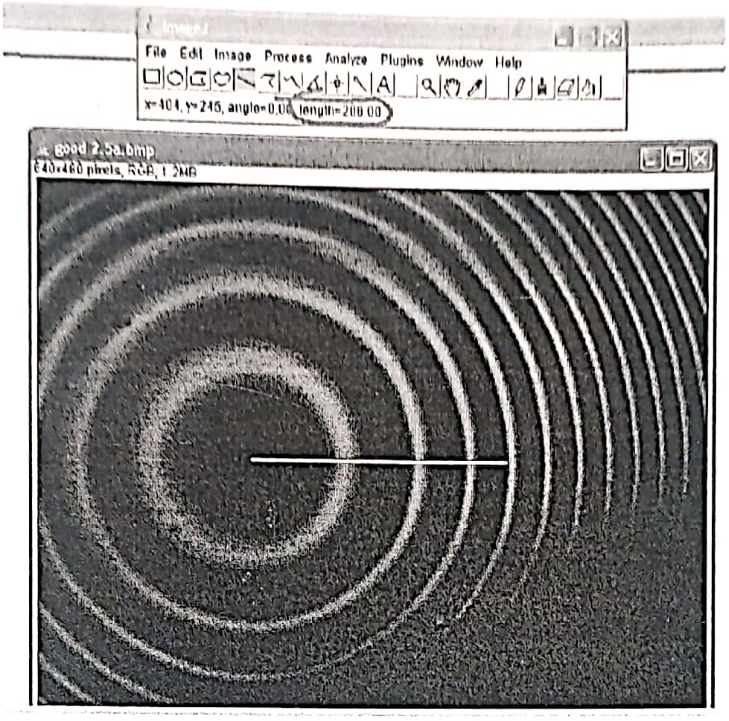




Line drawing of Fabry Perot fringe pattern

For taking photographs, we can use the snapshot icon on the menubar. Right click the mouse and select snapshot . Save the image of zero magnetic field as Z_0 (say).

The distance between the etalon and the camera as D. Here, D = 65mm = .065m.



1 Pixel = 2.8 microns

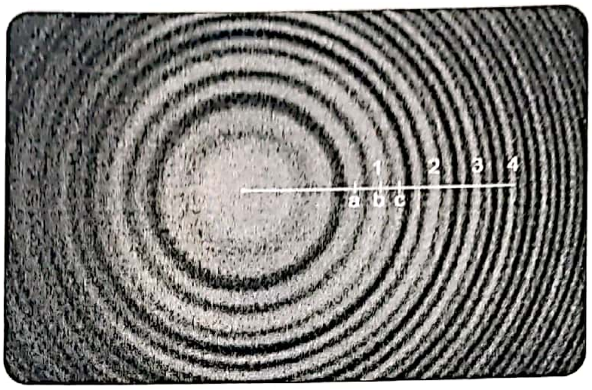
Distance between Etalon and the camera, D = ... m

Order	Radius (Pixel)	Radius (m) x 10^{-6}	Radius^2 (m^2) x 10^{-6}	$\chi_n^2 = \chi_{m+n}^2 - \chi_m^2$ (m^2) x 10^{-6}	$t = nD^2\lambda/\chi_n^2$ x10^{-3} (m)
χ_m					
χ_{m+1}					
χ_{m+2}					
χ_{m+3}					
χ_{m+4}					

Average thickness, t = ... m

Switch on the electromagnet power supply and increase the current. Rotate the polarizer in order to get only two transitions on a single line.

Apply magnetic field with different currents. Take the photographs for different currents. Open the photographs with Image Analysis software and take the measurements.



Observations:-

Current = ... A   Magnetic Field = ... Gauss

Ring No		Radius (Pixel)	Radius^2 (Pixel)
1	a		
	b		
	c		
2	a		
	b		
	c		
3	a		
	b		
	c		
4	a		
	b		
	c		

Ring No	Radius² (m²) x 10^{-6}					Average
	a	δ_{ab}	b	δ_{bc}	c	
1.						
δ_{12}						
2.						
δ_{23}						
3.						
δ_{34}						
4.						
Average		δ_{ab} =		δ_{bc} =		

$< \Delta > =$

$\Delta V_{ab} = < \delta ab > / 2t < \Delta > =$

$=$ ....

$\Delta V_{bc} = < \delta bc > / 2t < \Delta > =$

$=$ ....

$\mu 0 / hc = (\Delta V_{ab} + \Delta V_{bc}) / |B|$

$=$ ....

$\mu 0 / hc =$ .... cm^{-1} /Gauss

Caution : Do NOT sustain high Magnetic field for more than 2 min. for taking the Photographs. It will lead to the damage of both coil and Power supply. Also that causes residual magnetism in the core part.

Experiment Example

agnetic Field Calibration:

Sl. No	Current I (Amp)	Magnetic field Increment (Gauss)	Magnetic Field Decrement (Gauss)	Average B |B| (Gauss)
1.	0.00	1550	1420	1480.5
2.	0.25	2550	2860	2700.5
3.	0.50	4000	4610	4300.5
4.	0.75	5750	6100	5920.5
5.	1.00	7070	7590	7330.0
6.	1.25	8380	8970	8670.5
7.	1.50	9790	10420	10100.5
8.	1.75	11120	11800	11460.0
9.	2.00	12460	13040	12750.0
10.	2.25	13720	14220	13970.0
11.	2.50	14900	15270	15080.5
12.	2.75	15930	16200	16060.5
13.	3.00	16690	16870	16780.0
14.	3.25	17300	17420	17310.0
15.	3.50	17830	17910	17870.0
16.	3.60	18080	18080	18080.0

$R_1 = x_2^2 - x_1^2$

Thickness of the Etalon:

1 Pixel = 2.8 X 10^{-6} m

Distance between Etalon and the camera, D = 65mm = 0.065m

Order	Radius (Pixel)	Radius (m) x 10^{-6}	Radius^2 (m^2) x 10^{-6}	$\chi_n^2 = \chi_{m+n}^2 - \chi_m^2$ (m^2) x 10^{-6}	$t = nD^2\lambda/\chi_n^2$ x10^{-3} (m)
χ_m	175	490	0.24	0.00	-
χ_{m+1}	340	952	0.91	0.66	3.5
χ_{m+2}	446	1248.8	1.56	1.32	3.49
χ_{m+3}	528	1478.4	2.18	1.94	3.57
χ_{m+4}	612	1714.6	2.94	2.70	3.42

Average thickness, t = 3.5 X 10^{-3} m

Current = 3.5 A Magnetic Field = 1730 Gauss

Ring No		Radius (Pixel)	Radius^2 (Pixel)
1	a	298	88804
	b	340	115600
	c	378	142884
2	a	438	191844
	b	466	217156
	c	498	248004
3	a	544	295936
	b	566	320356
	c	592	350464
4	a	630	396900
	b	650	422500
	c	670	448900

Ring No	Radius² (m²) x 10⁻⁶					Average
	a	δ ab	b	δ bc	c	
1.	88804	26796	115600	27284	142884	
δ_{12}	103040		101556		105120	*103238*
2.	191844	25312	217156	30848	248004	
δ_{23}	104092		103200		102460	*103250*
3.	295936	24420	320356	30108	350464	
δ_{34}	100964		102144		98436	*100514*
4.	396900	25600	422500	26400	448900	
Average		δ_{ab} = ***25532***		δ_{bc} = ***28660***		***102334***

$<\Delta> =$ **102334**

$\Delta V_{ab} = <\delta ab> / 2t <\Delta> = 25532 / (2 \times 3.5 \times 10^{-3} \times 102334)$

$= 35.64\ m^{-1}$

$\Delta V_{bc} = <\delta bc> / 2t <\Delta> = 28660\ / (2 \times 3.5 \times 10^{-3} \times 102334)$

$= 40.00\ m^{-1}$

$\mu 0 / hc = (\Delta V_{ab} + \Delta V_{bc}) / |B|$

$= (35.64 + 40.00) / 17870 = 4.23 \times 10^{-3}\ m^{-1}$ /Gauss

$\mu 0 / hc =$ **$4.23 \times 10^{-5}\ cm^{-1}$ /Gauss**

Maintenance Notes

1. Always keep the equipment in a moisture and dust free atmosphere.
2. Do not touch the optical components with bare hands
3. Care must be taken while tuning the Etalon.

Troubleshooting

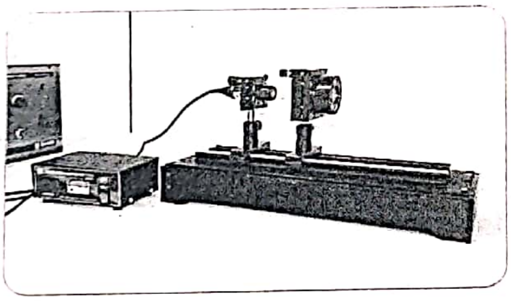
1. Alignment using Diode Laser

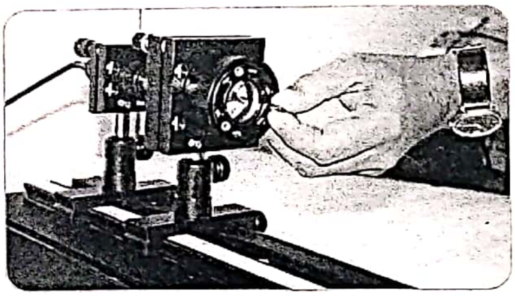
While viewing through camera if there is no fringe, we can make the plates of the etalon parallel with the help of a diode laser.

For that, insert the laser module in the laser mount. Place the etalon in front of the diode laser. Project the beam on to the screen. Now we can see multiple spots on the screen. Make the spots coincide by tuning the three knobs situated in front of the etalon.

If all the spots coincide, we can see a small part of the fringe on the screen.

Now we can place the etalon at the former position in the Zeeman Effect Experimental set up.





2. Replacing the Mercury Tube

While applying the magnetic field, if the image is not clear, then check the working of the mercury tube. If the ends of mercury tube is very dark, we can conclude that the tube is damaged. Replace the mercury tube with a fresh one and confirm that it is not damaged by repeating the checking process.