Laboratory Manual

EPHY105L, Electromagnetics

B.Tech, 1st Year, 1st Semester

Department of Physics

School of Engineering and Applied Sciences

BENNETT UNIVERSITY

Table of Contents

Instructions, Rules and Regulations
First year Physics Laboratory,
Department of Physics

1. Attendance in the lab is mandatory for all students.
2. Students must join the lab session through Microsoft Teams on time and conduct the experiment during the lab session.
3. Students should login well prepared by reading the description of the experiment assigned to them.
4. Students are required to prepare a hand-written write-up / lab record, draw graphs on a graph paper (if needed), scan the entire thing and send it for evaluation via LMS.
5. In the write-up for each experiment, the following needs to be written:
   a) Aim of the experiment
   b) Formula used
   c) Observation table/tables
   d) Calculations and / or graphs
   e) Results and Conclusions
6. **Students must submit the write-up of an experiment by the end of the corresponding lab session**. A grace period of extra 10 minutes will be allowed after the class ends. Any write-up submitted after this time period will not be evaluated.
7. The name of submitted write-up should be as follows: Batch_No._Enrollment_No._Expt._No. (For e.g. EB05_ E20CSE001_1).

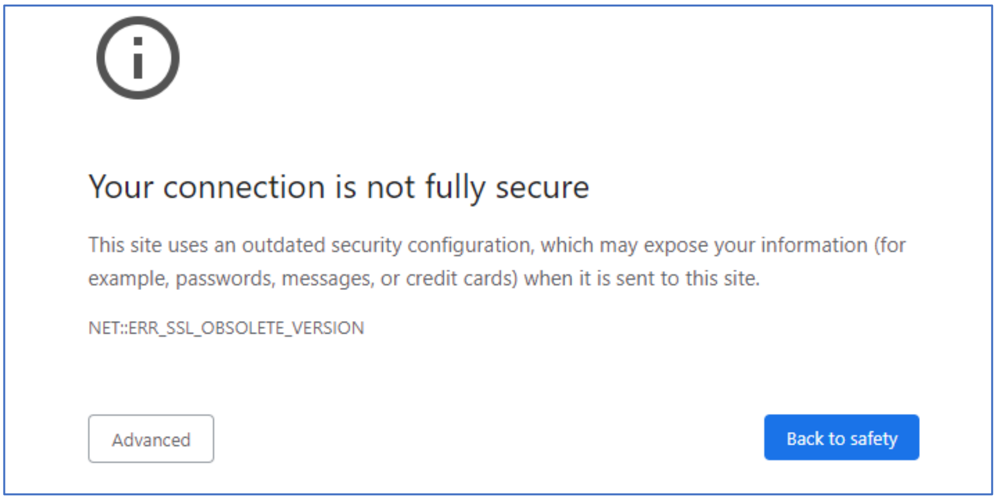
Total Lab marks: 20

Split-up of Lab Marks among different components:

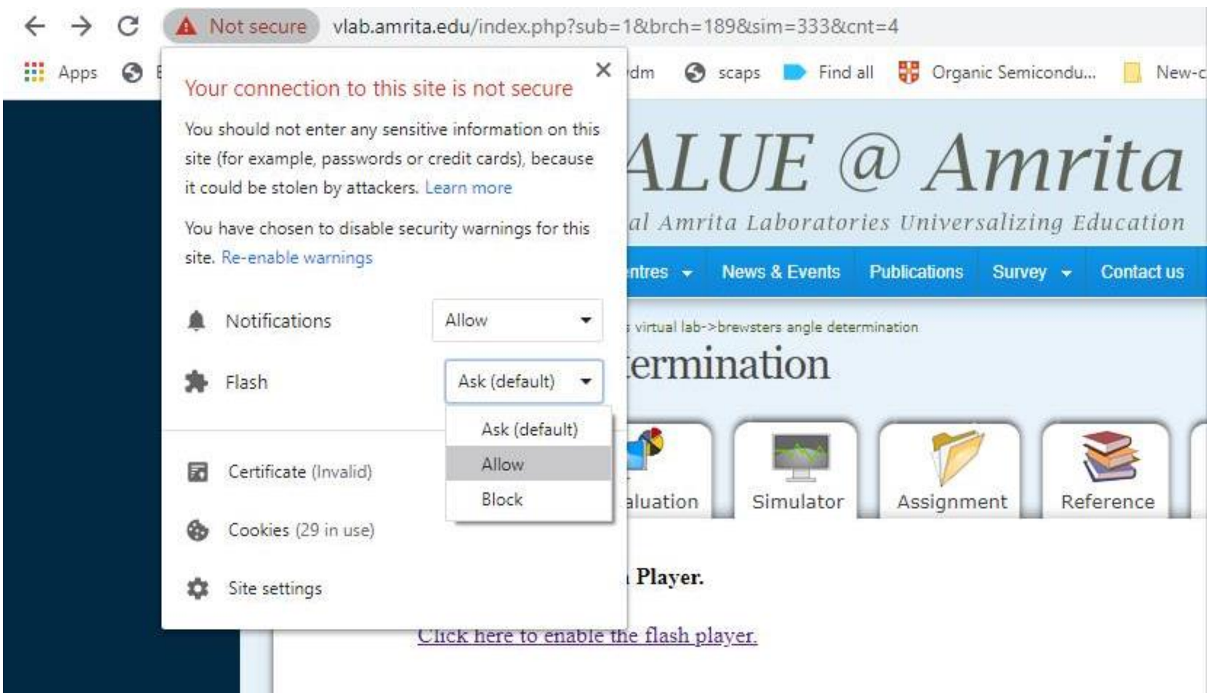
Components:	Continuous Lab Evaluation (Lab Record)	End Term Lab Exam
Marks:	10	10
Total Marks	20	

Instructions for Accessing Virtual Lab and performing the experiments.

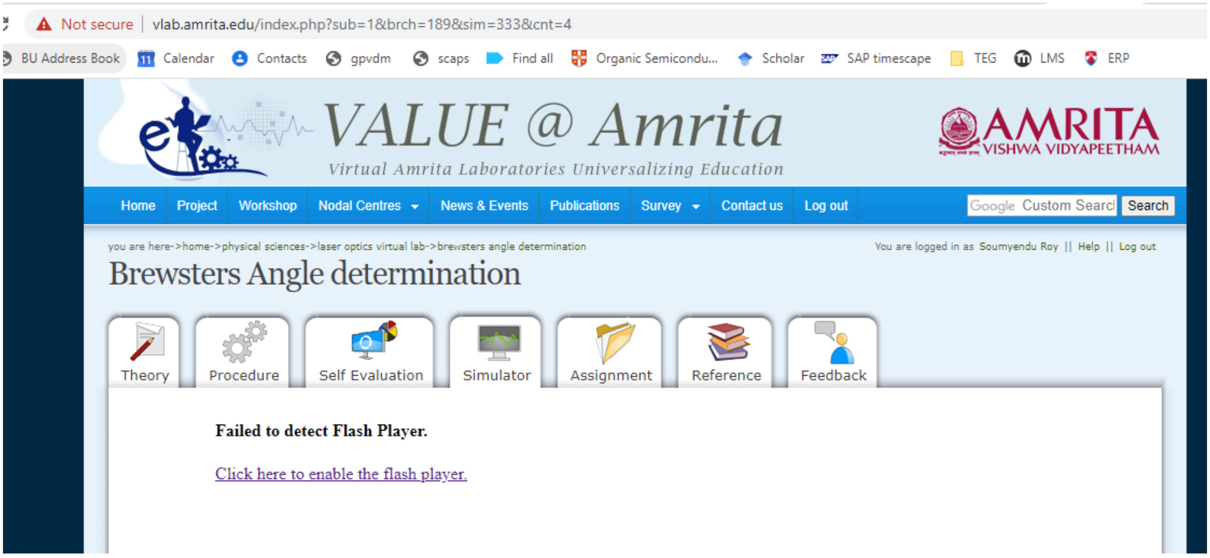
1. You will need to register yourself at the website of Amrita Vishwa Vidyapeetham's Virtual labs (https://vlab.amrita.edu/index.php?pg=bindex&bsub=guest_registration_form). Create a password to access the site
2. When opening the site your browser may not connect saying that the site is not secure. Click on "Advanced" and then "Proceed to vlab.amrita.edu".



3. You will have to allow flash player for running the simulation. You can click on "Not secure" indication on the left of URL and select "Allow" from the drop down list beside Flash (see the figure below). You may have to reload the webpage after this.



The above procedure is for Google Chrome in Windows 10. The option may be accessed differently in other browsers and operating systems.
Alternatively, you can use the “Click here to enable the flash player” option. This opens a set of instructions for different browsers. You may follow those and change the settings of your browser so that it can use the flash player.



You may have to try different options depending on your browser and operating system.

4. For performing the Brewster’s angle experiment you will need to download a visualization tool “ejs_waves_brewster.jar” from the following website: https://www.compadre.org/osp/items/detail.cfm?ID=7901#:~:text=The%20Ejs%20Brewster's%20Angle%20model,change%20of%20index%20of%20refraction
To run this tool you will require Java to be installed in your computer. Usually Windows computers have Java in them. In case you don’t have Java, you can download it from https://www.java.com/en/download/
When performing the Brewster’s angle experiment you should come prepared with these softwares.

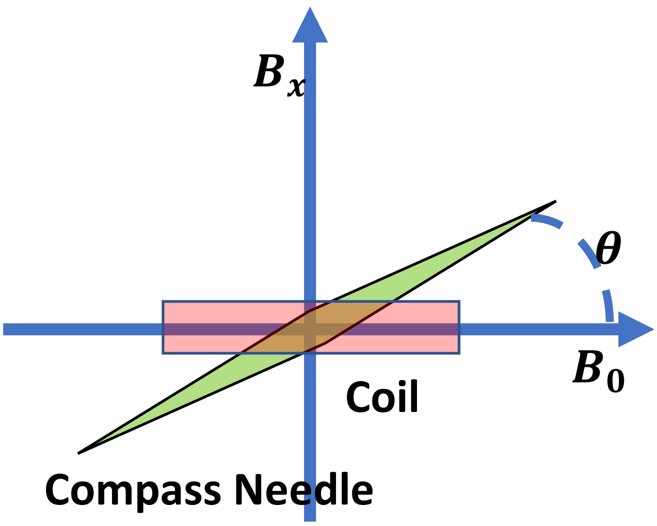
5. If you face any issues you can seek help from your faculty.

Experiment No. 1
Magnetic Field and Biot-Savart Law

Aim: Calculation of magnetic field along the axis of a circular current carrying coil using tangent law of magnetism and determination of the radius of the current carrying coil from Biot-Savart law.

Apparatus: Circular coil, compass box, ammeter, rheostat, commutator, cell, key, connection wires, etc. The purpose of the commutator is to allow the current to be reversed only in the coil, while flowing in the same direction in the rest of the circuit.

Theory: When a current carrying coil is placed with its vertical plane in the magnetic meridian, the magnetic field points perpendicular to the magnetic meridian. Hence on placing the deflection magnetometer at any point on the axial line of the coil, the field B_x produced by the current and the horizontal component of the earth magnetic field ($B_0 = 3.5 \times 10^{-5}\ T$) act in perpendicular directions on the magnetic needle of the magnetometer and deflects it through an angle θ. This is known as the Tangent Law of Magnetism.



The magnetic field produced by a circular currently carrying coil at any point along the axis is obtained from Biot-Savart law and is given by,

$$B_x = \frac{\mu_o n I r^2}{2(x^2+r^2)^{\frac{3}{2}}}\ \mathrm{T}$$

Here, r= radius of the coil (m)

n= number of turns in the coil

I= current passing through the coil (A)

x= distance of the point (magnetometer) from the centre of the coil along its axis (m)

The tangent law of magnetism compares the strength of two magnetic fields that are perpendicular to each other. If a compass is subjected to a magnetic field B_x that is perpendicular to the horizontal magnetic field of the earth B_0, it will rest at an angle θ to the earth's magnetic field. The relationship between the two magnetic fields is (see figure):

$$B_x = B_0 \tan\theta$$

Instructions:

Start the experiment with current between 0.2 A - 0.5 A, 5 cm coil radius and 10 turns in the coil. Later on, the radius will be changed, the other parameters will be kept fixed.

Procedure:

1. Go to the Amrita Vishwa Vidyapeetham virtual lab's s website for "Magnetic field along the axis of a circular coil carrying current"

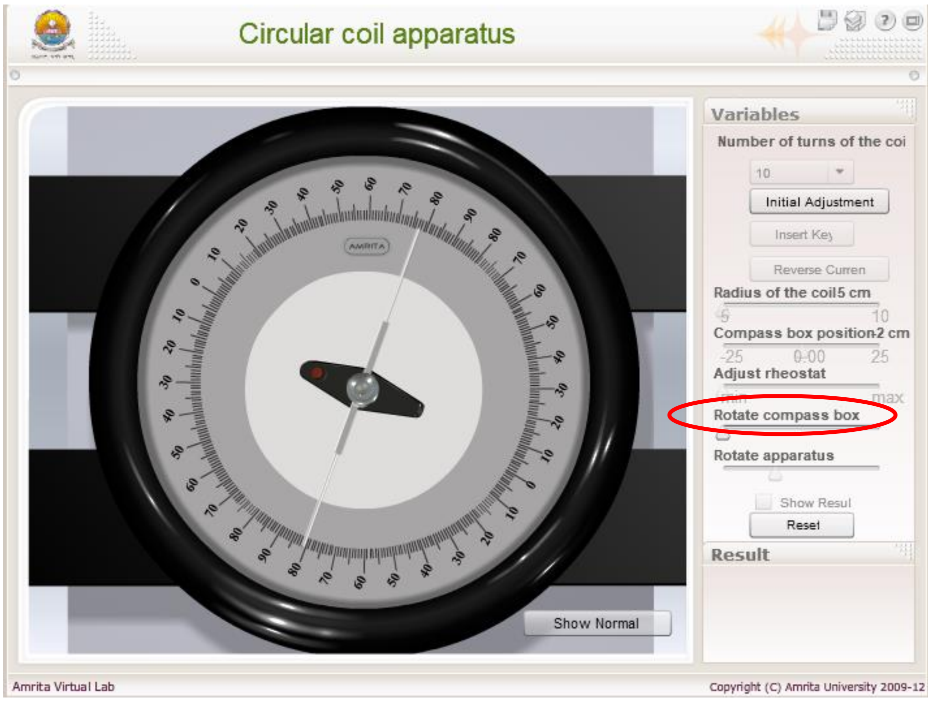
http://vlab.amrita.edu/?sub=1&brch=192&sim=972&cnt=1

2. Browse through the different tabs and read the material provided in the website to accustom yourself with the experiment. Note that the procedure mentioned below should be followed and not the procedure in provided in the site.

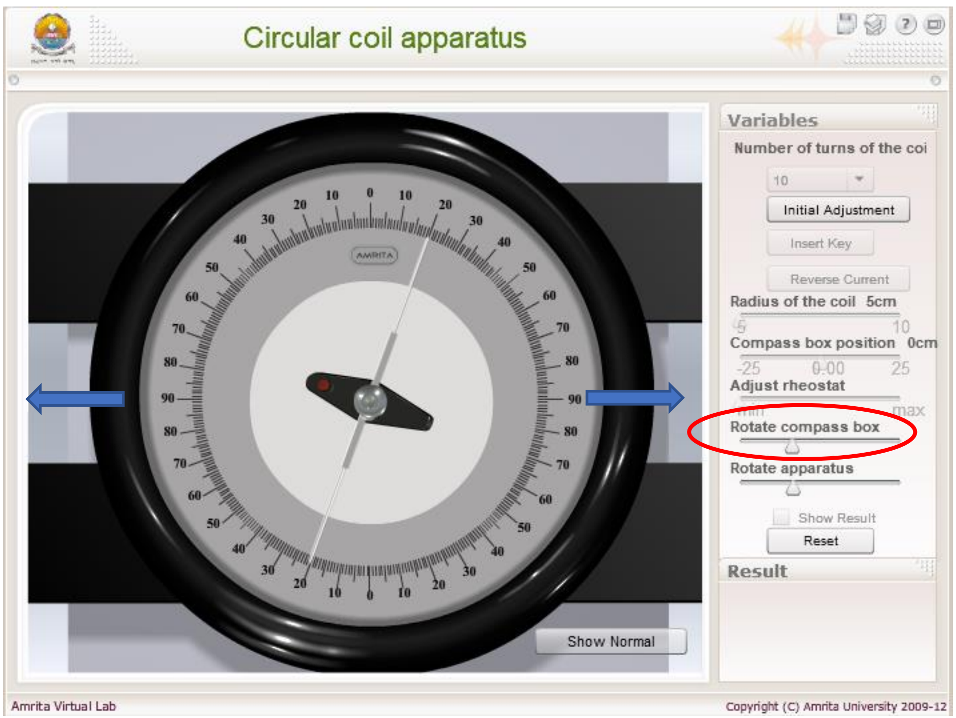
3. Click on the "simulator" tab and login with your registered credentials to initiate the virtual experiment.

4. Initial figure: Choose "Initial Adjustment"

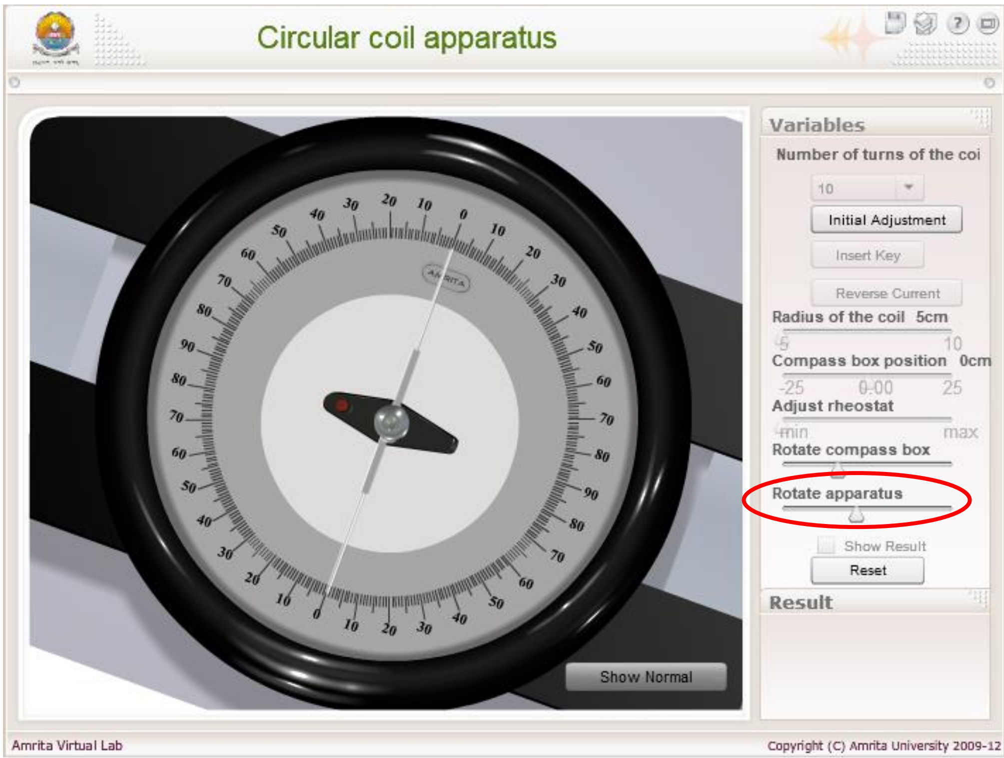
5. Choice of initial adjustment will lead to the following figure. Navigate with “Rotate Compass Box”



6. The compass box is rotated till the 90-90 line becomes parallel to the plane of the coil (in the simulation it will appear as shown below).

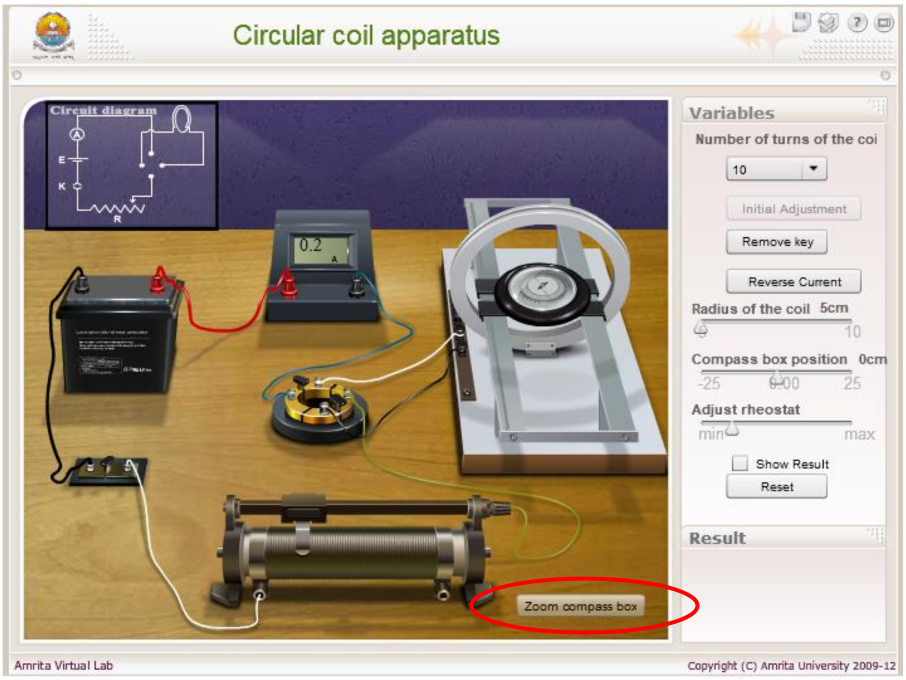


7. Then the apparatus is rotated till the aluminium pointer reads 0-0.

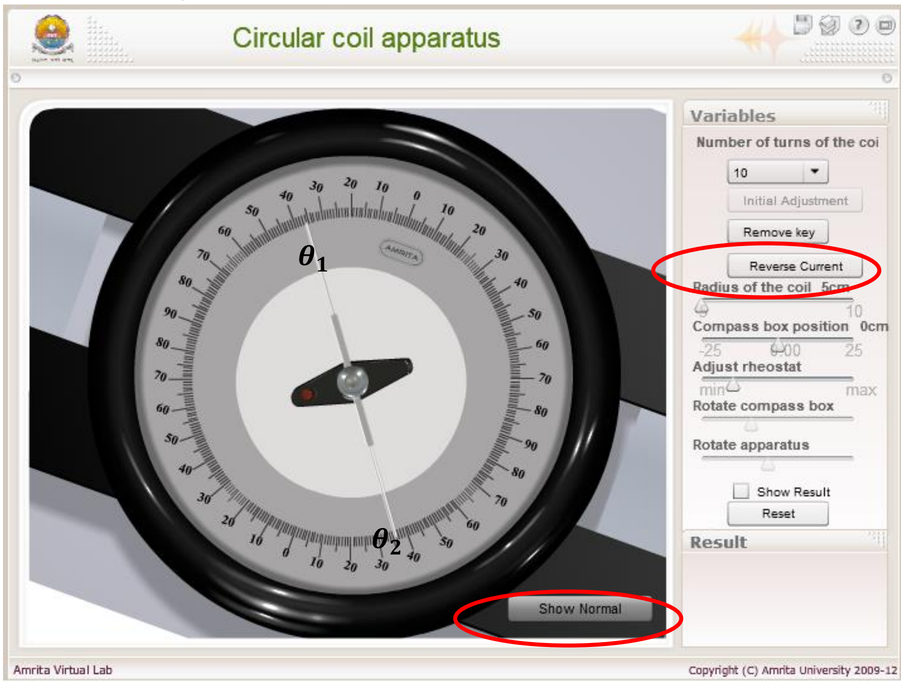


8. Press Show Normal.
9. Fix radius of the coil at 5cm.
10. Close the circuit and “Insert Key”.

11. Adjust the rheostat until the deflection lies between 30 and 60 degrees with compass box position at centre. The current will remain in between 0.2 A - 0.5 A for number of turns 10 and radius of the coil 5 cm.

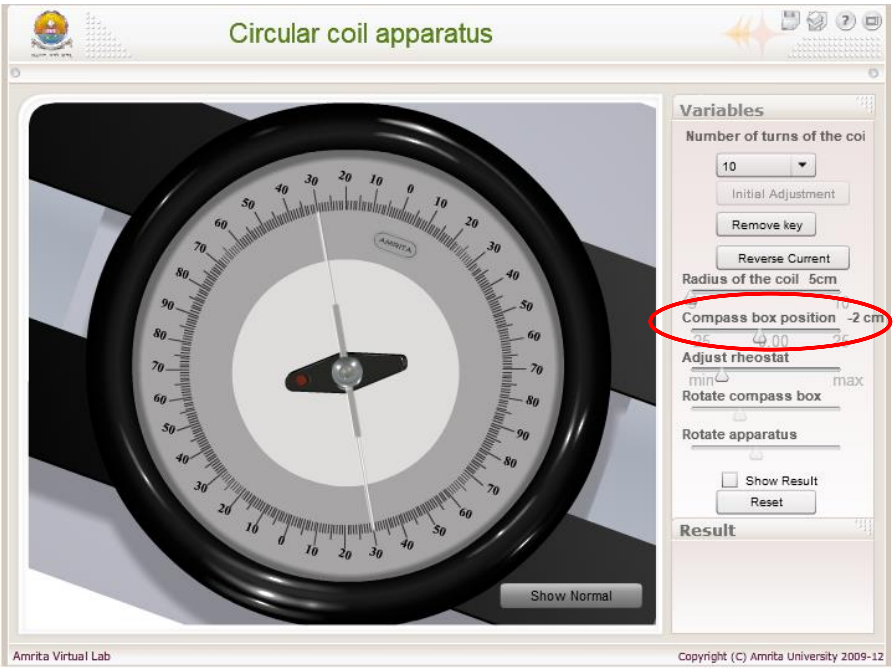


12. To note the deflection press “Zoom Compass Box”. Note down the deflection of the compass needle (θ_1, θ_2) and the current. One can define any one side of the needle as θ_1 and θ_2 as depicted in the figure. However, one must remain consistent with that definition throughout the experiment.



13. Reverse the current and note down the deflection again (θ_3, θ_4). θ_3 and θ_4 can be defined in the same way as one defines θ_1 and θ_2.
14. Pressing “Show Normal” will enable one to return to the original circuit. However, one can continue the experiment with the compass view.

15. Shift the compass box position in the left for 2 cm. Note the deflection. Again, note the deflection with reverse current.



16. Shift the box for another 2 cm and repeat the process.
17. Note at least 8 set of data points on each side.
18. Again, repeat process while sliding the box on the right side.
19. Increase the radius of the coil by using the slider, do not change the current or the no. of turns in the coil. Repeat the measurements (steps 12 – 18) with the new radius.

Observations and Calculation:

1. Prepare a table similar to Table-I.
2. Calculate the mean θ and tan θ.
3. Calculate B_x from Tangent law.
4. Plot B_x vs position x. Assign different signs to positions on the left and right of the centre of the coil.
5. Determine the radius of the coil r using the value of B_x at $x = 0$ from table I and the Biot-Savart law.
6. Compare your result with your initial input r.
7. Determine the % error where, % error = $\frac{|r_O - r_E|}{r_E} \times 100$. Here r_O is the radius calculated using Biot Savart Law and r_E is the value you fix at step 9.
8. Repeat the above steps (1-6) for the new radius of the coil. Plot both B_x vs x graphs on the same graph paper so that you can compare the results of the two experiments.
9. From the experiment (one of the tables or the graphs) calculate the ratio of the magnetic field at a point $x = r$ and at $x = 0$ and compare with the ratio obtained from Biot Savart law.

Data used for experiment and calculation

$n = 10;$

$I = \ldots\ldots\ldots\ \text{A}$

$B_0 = 3.5 \times 10^{-5}\text{T}$

$\mu_0 = 4\pi \times 10^{-7}\text{H/m}$

<u>Table-1</u>

$r = 5cm$

Position of Compass (cm)		**Direct Current**		**Reverse Current**		**Mean $\boldsymbol{\theta}$**	**tan$\boldsymbol{\theta}$**	$\boldsymbol{B_x} =$ $\boldsymbol{B_0}$ ×tan$\boldsymbol{\theta}$ ($\times \mathbf{10^{-5}}\boldsymbol{T}$)
		$\boldsymbol{\theta_1}$	$\boldsymbol{\theta_2}$	$\boldsymbol{\theta_3}$	$\boldsymbol{\theta_4}$			
Left Side	-14							
	-12							
	-10							
	-8							
	-6							
	-4							
	-2							
Center	0							
Right Side	2							
	4							
	6							
	8							
	10							
	12							
	14							

Table-2

$r =$ ……... cm

Position of Compass (cm)		Direct Current		Reverse Current		Mean θ	tanθ	$B_x =$ $B_0 \times$tanθ $(\times 10^{-5}T)$
		θ_1	θ_2	θ_3	θ_4			
Left Side	-14							
	-12							
	-10							
	-8							
	-6							
	-4							
	-2							
Center	0							
Right Side	2							
	4							
	6							
	8							
	10							
	12							
	14							

Conclusion:

Experiment No. 2
Newton's Rings

Aim:
The aim of the experiment is to determine wavelength of light using Newton's ring experiment.

Apparatus:
Monochromatic Light source, Travelling Microscope, Plano-convex Lens, Glass plates

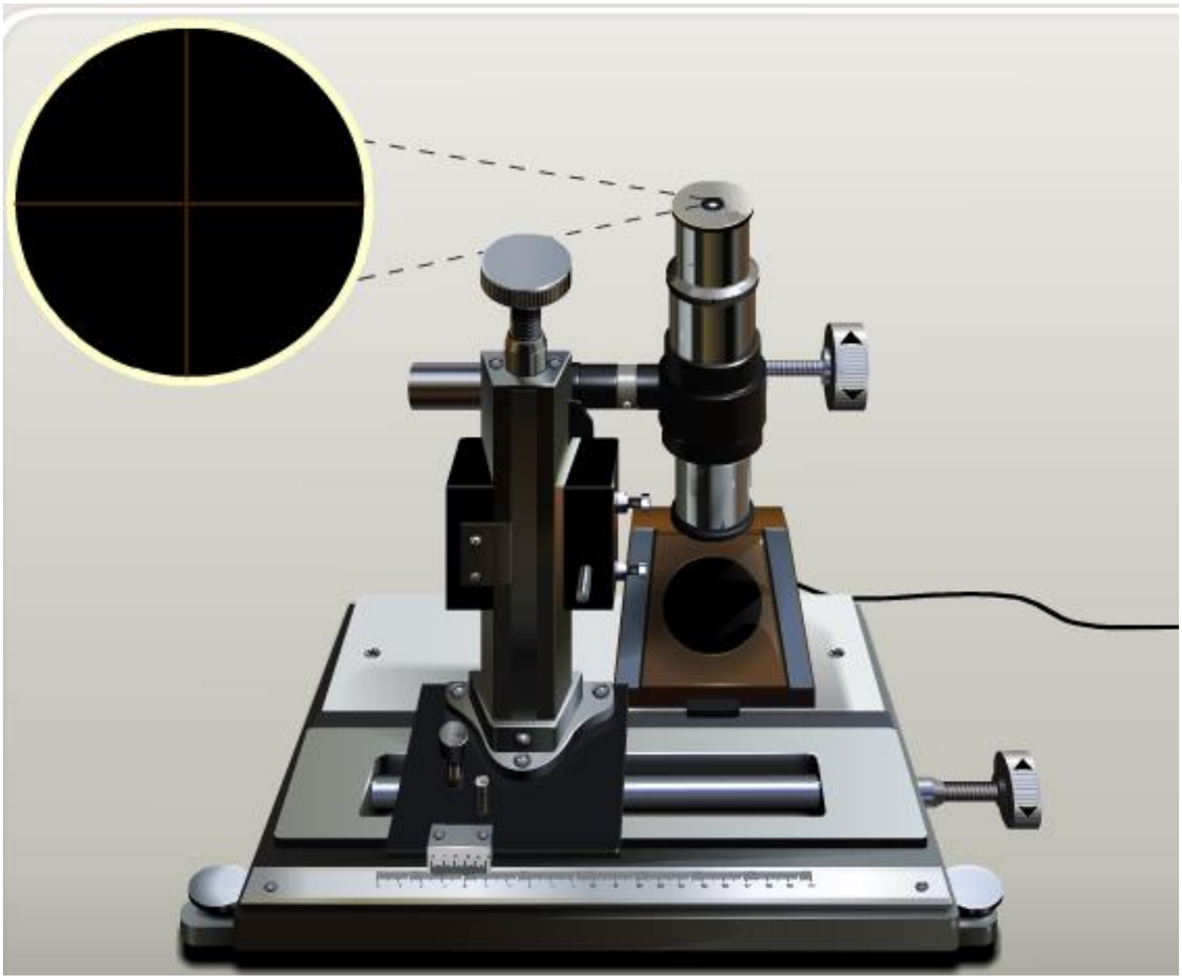


Fig. 1: Basic set-up of Newton’s rings experiment.
Source: Amrita Lab (https://vlab.amrita.edu/?sub=1&brch=189&sim=335&cnt=4)

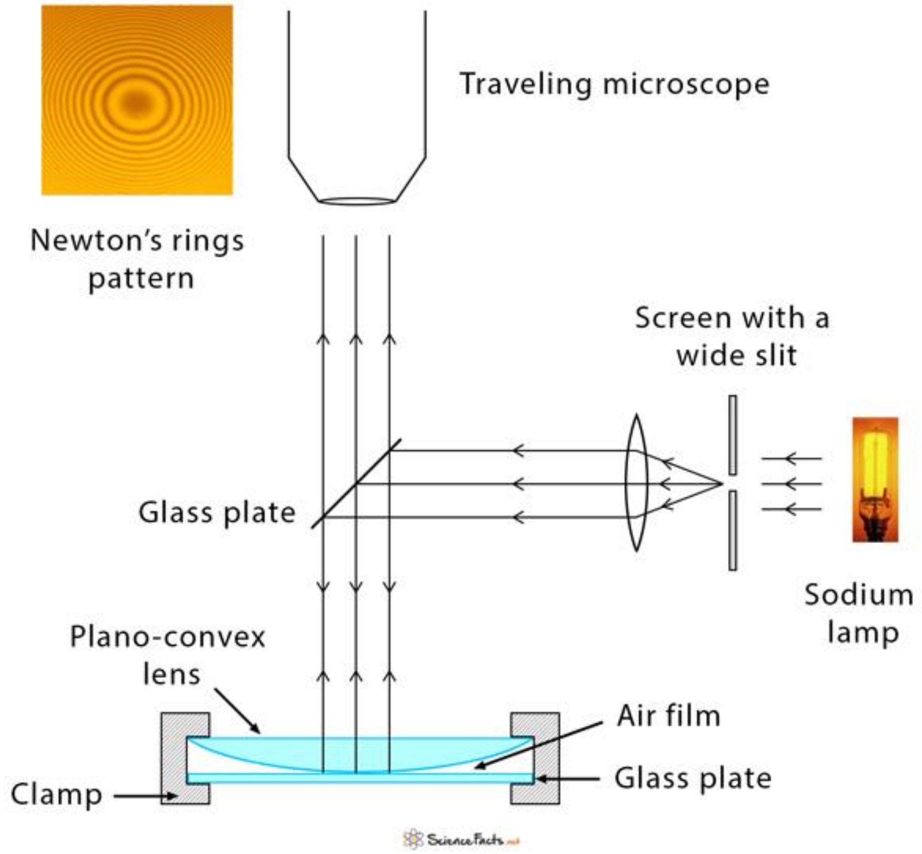


Fig. 2: A schematic ray diagram to explain how Newton's rings are formed.
Source: https://www.sciencefacts.net/newtons-rings.html

Theory:
Basic working principle of this experiment is schematically presented in Fig. 2. A plano-convex lens is placed with its convex surface on a plane glass plate, so as to enclose a thin film of air of varying thickness between the lens and the plate. Light from an extended monochromatic source (Sodium lamp and Red lamp) is converted into an almost parallel beam by using a convex lens of short focal length, and made to fall on a plane glass plate inclined at an angle of 45° from the horizontal direction, where it gets reflected onto the plano-convex lens. Interference takes place between the rays of light reflected from the upper and the lower surfaces of the wedge shaped air film, enclosed between the lens and the plane glass plate. As a result, alternate dark and bright circular interference fringes called Newton's rings are produced.

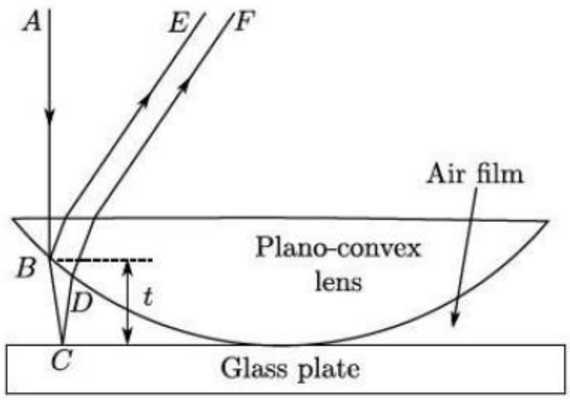


Fig. 3: Interfering rays formed from the upper and lower surfaces of the air-film.

Light rays involved in the formation of Newton's rings are shown in Fig. 3 which displays a wedge-shaped air film formed between the convex lens and the plane glass plate. The refractive index of the film is assumed to be given by μ. The incident ray AB is almost normal to the film. It suffers partial reflection (ray BE) and partial transmission (ray BC) on the convex surface. The ray BC again suffers partial reflection (ray CF) and partial transmission (not shown in the figure) on the plane surface at C. The bright rings in Fig. 2(c), are formed due to constructive interference between the reflected light rays BE and CF . The dark rings are caused by destructive interference between the same light rays BE and CF.

For normal incidence of monochromatic light (AB), the path difference between the reflected rays (BE and CF) is approximately equal to $2\mu t$, t being the thickness of the air-film. Note that here we ignore the reflections from top of the plano-convex lens and the bottom of the plane glass plate, because these reflected waves are incoherent with respect to each other and do not form any interference pattern and just contribute to overall glare.

Following Stoke's law, a phase shift of π (equivalent to the path difference of $\frac{\lambda}{2}$) is introduced in the beam BCD (Fig. 3), for the reflections at point C, because here the light is traveling from rarer medium (air) to a denser medium (glass), while no such phase change occurs for the reflection at point B where the light is traveling from a denser medium to a rarer medium. So the net path difference becomes $2\mu t + \frac{\lambda}{2}$, where λ is the wavelength of the light in free space.

Hence, the condition for the bright fringes (constructive interference) is given by,

$$2\mu t = (2n + 1)\frac{\lambda}{2} \ , \ n = 0,1,2, \ldots \tag{1}$$

and for the dark fringes (destructive interference), it is

$$2\mu t = n\lambda; n = 0, 1,2, , ,,. \tag{2}$$

At the center, since the air film is extremely thin, the path difference between the two interfering beam is almost equal to $\frac{\lambda}{2}$, satisfying the condition for dark fringes. Hence the center will be dark.

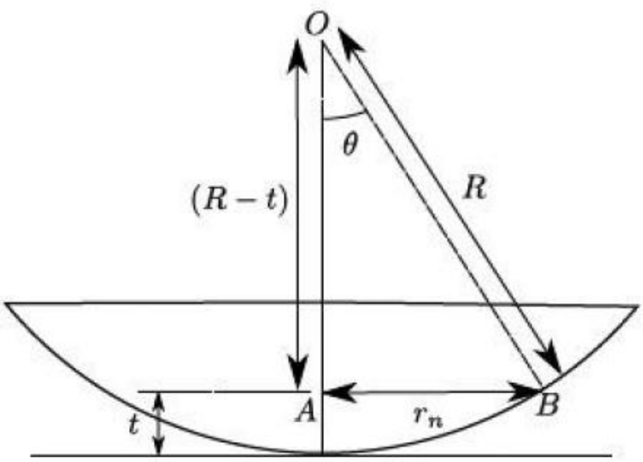


Fig. 4: Geometry used to determine the thickness of the air-film.

Determination of wavelength: In the right-angled triangle OAB of Fig.4, for the n-th fringe (ring) of radius r_n,

$$OB^2 = OA^2 + AB^2$$

or,

$$R^2 = (R-t)^2 + r_n^2$$

or,

$$r_n^2 = 2Rt,$$

(R is the radius of curvature of the plano-convex lens, and we assume that $t^2 << 2Rt$.)
Thus,

$$t = \frac{r_n^2}{2R}, \tag{3}$$

or,

$$t = \frac{D_n^2}{8R}, \tag{4}$$

where $D_n = 2r_n$ is the diameter of the n^{th} fringe.

We use diameter D_n instead of the radius of the ring, because the measurement of radius will involve large errors as it is not easy to locate the center of the ring accurately. On the other hand, measurement of the diameter will be much less error prone. Because dark fringes satisfy the condition $2\mu t = n\lambda$, eqn. 4 gives us the following expression for the diameter of dark rings

$$D_n^2 = \frac{4nR\lambda}{\mu}, \tag{5}$$

We will measure the diameters of the dark fringes in the experiment. Since, we are using air-film, $\mu = 1$. A plot between D_n^2 and n will be linear with slope (m) given by

$$m = 4R\lambda$$
$$\lambda = \frac{m}{4R} \tag{6}$$

The percentage error in the calculations of λ is defined as:

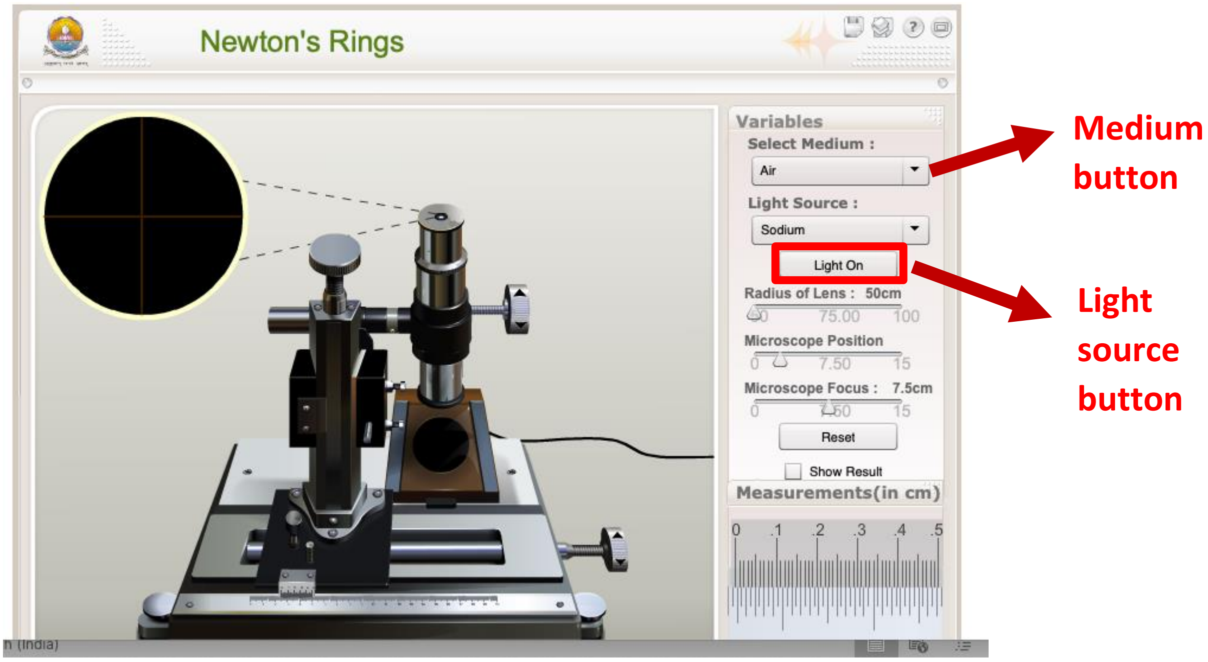
$$\frac{|\lambda - \lambda_0|}{\lambda_0} \times 100\%, \textit{where } \lambda_0 \textit{ is the actual wavelength of the used light} \tag{7}$$

Procedure:

1. Go to the Amrita Vishwa Vidyapeetham virtual lab website for “Newton’s Rings – Wavelength of light”.

https://vlab.amrita.edu/?sub=1&brch=189&sim=335&cnt=1

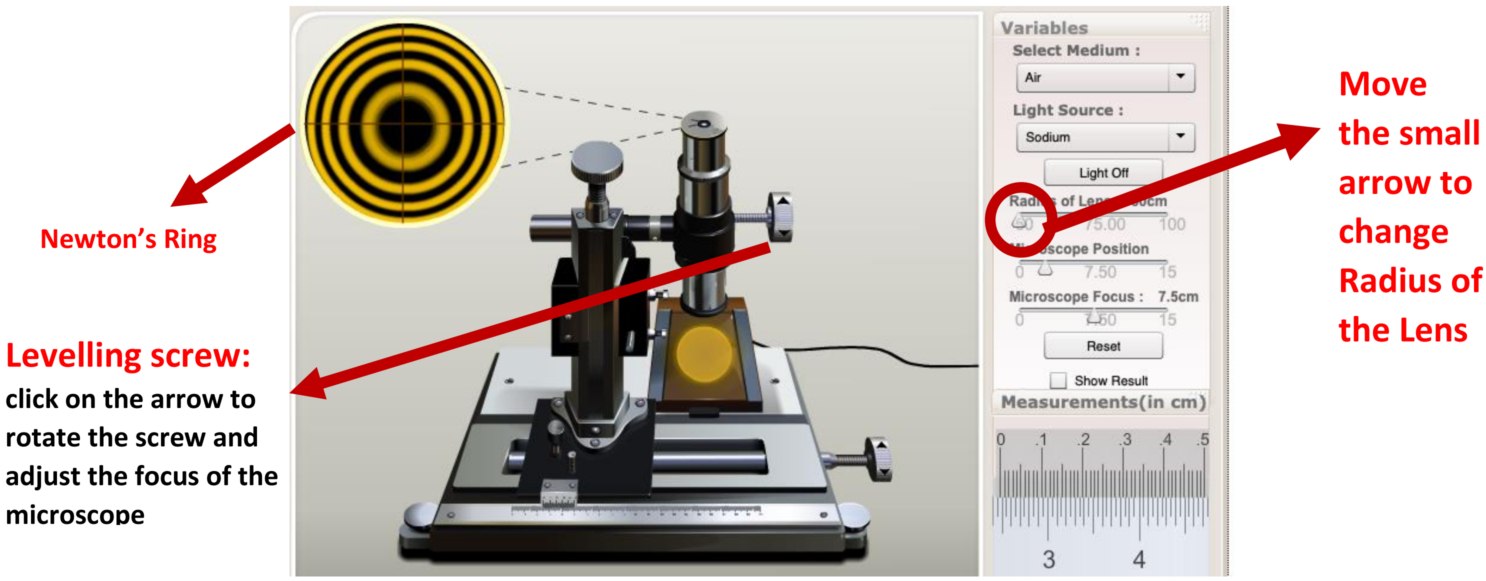
2. Browse through the different tabs and read the material provided in the website to accustom yourself with the experiment.



4. Select Medium and Light Source as indicated by arrow in the above picture.
For the 1st set of data, please choose
Medium* = *Air, and
Light source= Sodium.
Switch on the light by clicking "light on" button (highlighted by a red square). This will start the experiment.

5. As soon as you switch on the light, Newton's rings are formed. They appear at the left corner as indicated in the picture below. Choose the ***radius of the lens (R) = 80 cm*** and adjust the focus of the microscope using levelling screw till the rings are clearly visible. To rotate the screw, you need to click on the arrow as marked in the figure below.

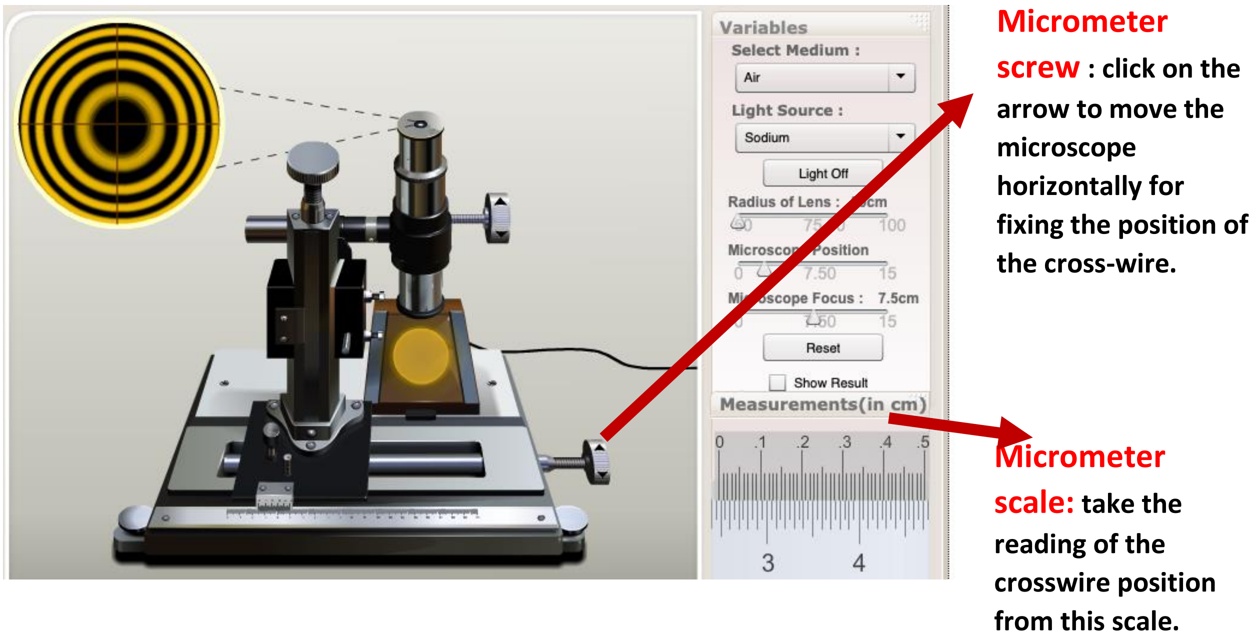
Note: Once it is properly focused, the fringes will appear bright and sharp and going away from the focus will make the fringes blurred.



6. Now all the parameters are fixed and Newton's rings are clearly visible. Therefore you are in a position to measure diameters of the nth dark ring (D_n in equation -5).

In order to do that, move the microscope to the left (or the right) by using micrometer screw such that the vertical cross wire lies on the 14th dark ring. Now move the microscope backward, i.e. to the right (or the left). Note the reading on the micrometer scale once the cross-wire coincides with the 12th dark ring. Take the reading from micrometre scale.

(Note: micrometer screw, and micrometer scale are marked in the figure below)



7. Move the crosswire further and take the reading of 12th, 11th ....1st ring. Keep on moving and take the readings of 1st, 4th, …..12th ring of the other side.

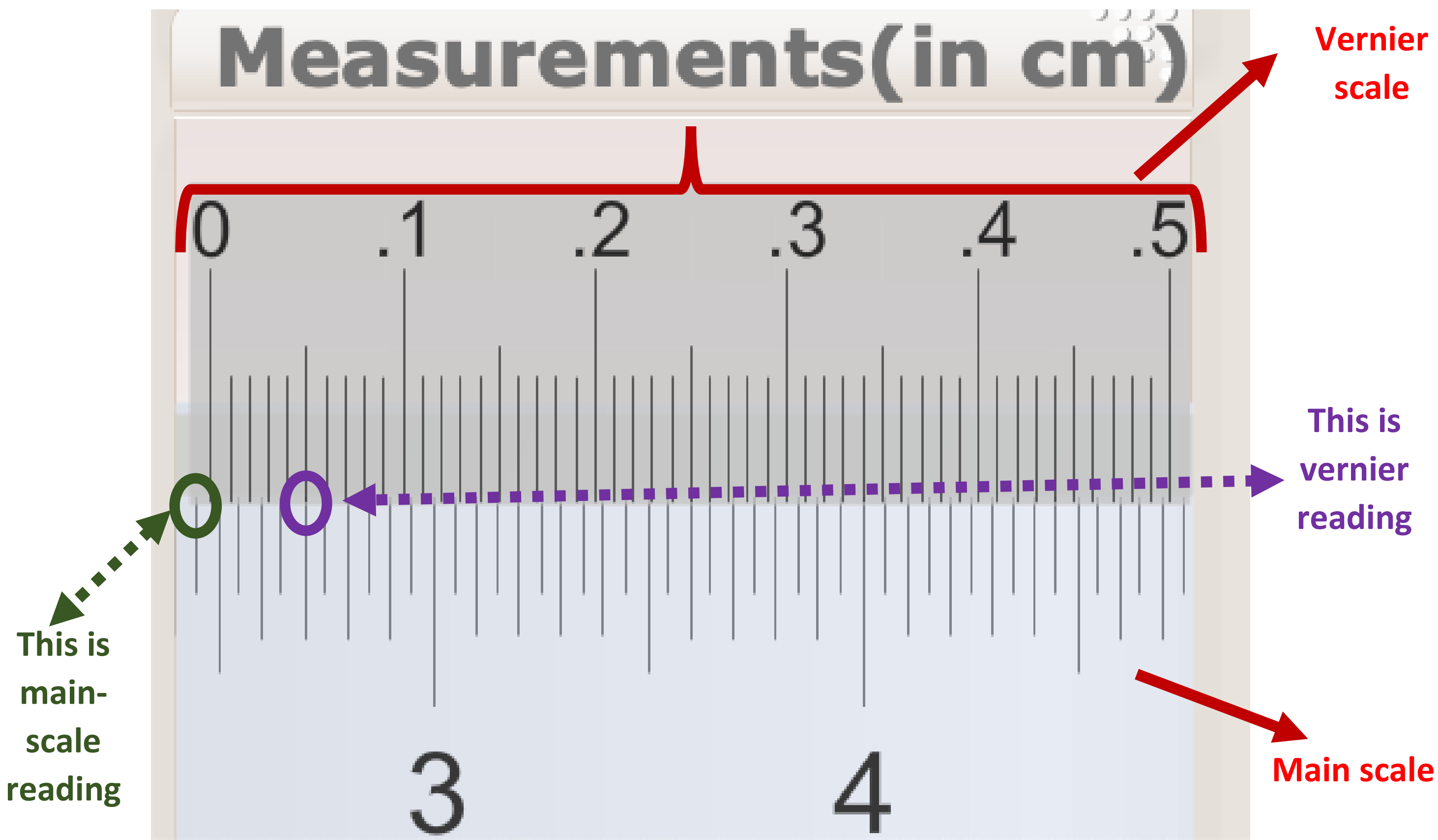
(Please note that you need to move the micrometer always in one direction, so that no backlash error appear in your reading.)

8. Enter the readings in the tabular column (Format of the table is provided below in Table I).

9. Now go back to step-4. Choose ***Light source* = *Red*,** and repeat the steps 5-8 to generate a second set of data. (keep Medium and radius of the lens same as before). Prepare a new Table II.

Description of the micrometer scale:

Zoom in the micrometer scale to record the readings accurately. Just right click on the scale and click on zoom in.



(i) ***Vernier constant or least count:*** This is the smallest length that the instrument can measure. However, the vernier scale of the simulator is faulty. For your experiment you can assume least count = 0.001 cm

(ii) ***Main scale reading:*** Take the reading of the main scale just before the 0^{th} position of the Vernier scale (marked as green circle)

(iii) ***Vernier scale reading:*** Only one line of the vernier scale is supposed to coincide with the main scale. Since the vernier scale of the simulator is faulty, you will find that multiple lines will coincide in general. Consider only the 1^{st} line on the vernier scale that coincides with a line on main scale (marked as purple circle). Take the reading of that point from Vernier scale.

Total reading = Main scale reading + (Vernier scale reading × Least Count)

Observations:

Table I: Measurement of the diameter of the dark rings for sodium light.

Ring no. (n)	Microscope reading						Diameter $D_n = \|a-b\|$ (in cm)	D_n^2 (in cm^2)
	Left side (a in cm)			Right side (b in cm)				
	Main	Vernier	Total	Main	Vernier	Total		
12								
11								
10								
9								
8								
7								
--								
….								

Table II: Measurement of the diameter of the dark rings for Red light.

Ring no. (n)	Microscope reading						Diameter $D_n = \|a-b\|$ (in cm)	D_n^2 (in cm^2)
	Left side (a in cm)			Right side (b in cm)				
	Main	Vernier	Total	Main	Vernier	Total		
12								
11								
10								
9								
8								
7								
--								
….								

Calculations:

1. Plot graphs of D_n^2 vs. n, with D_n^2 on y axis and n on the x axis using the data of Table I and II separately.
2. Find the slope (m) of the best fitted line in both the cases.
3. Calculate the wave-length λ of light using eqn. 6 for the above two cases (Sodium and Red lights).
4. Estimate the error for both the cases using equation 7.

Note:

The actual wavelengths of sodium and Red lights are **589.3 nm** and **670 nm,** respectively.

Results and conclusions:

Wavelength of the Sodium light is found to be = …. nm
Percentage of Error =

Wavelength of the Red light is found to be = …. nm
Percentage of Error =

Experiment No. 3
Tangent Galvanometer and Earth's Magnetic Field

Objective: (i) To determine reduction factor of a tangent galvanometer
(ii) To determine the horizontal component of earth's magnetic field.

Apparatus: The components used in this experiment are listed in table 1.

Component	**Symbol**
Tangent Galvanometer	TG
Commutator	C
Rheostat	R
Battery	E
Ammeter	A

Table: List of components with respective symbols

Theory: Tangent galvanometer (TG) is used to measure small electric currents. It consists of a coil of insulated copper wire wound on a circular non-magnetic frame. Its working is based on the principle of the tangent law of magnetism. When a current (I) is passed through the circular coil, a magnetic field $\left(\vec{B}_{Coil}\right)$ is produced at the centre of the coil in a direction perpendicular to the plane of the coil. Initially, TG is arranged in such a way that the horizontal component of earth's magnetic field ($\vec{B}_H$) is in the direction of the plane of the coil as shown in the figure 1(a). When no current is flowing through the coil, angle (θ) between the horizontal component of the earth's magnetic field and the compass is zero. When the current is passed through the coil, magnetic compass is then under the action of two mutually perpendicular fields ($\vec{B}_H$ and $\vec{B}_{Coil}$) and points in the direction of the resultant magnetic field as shown in figure 1 (b).

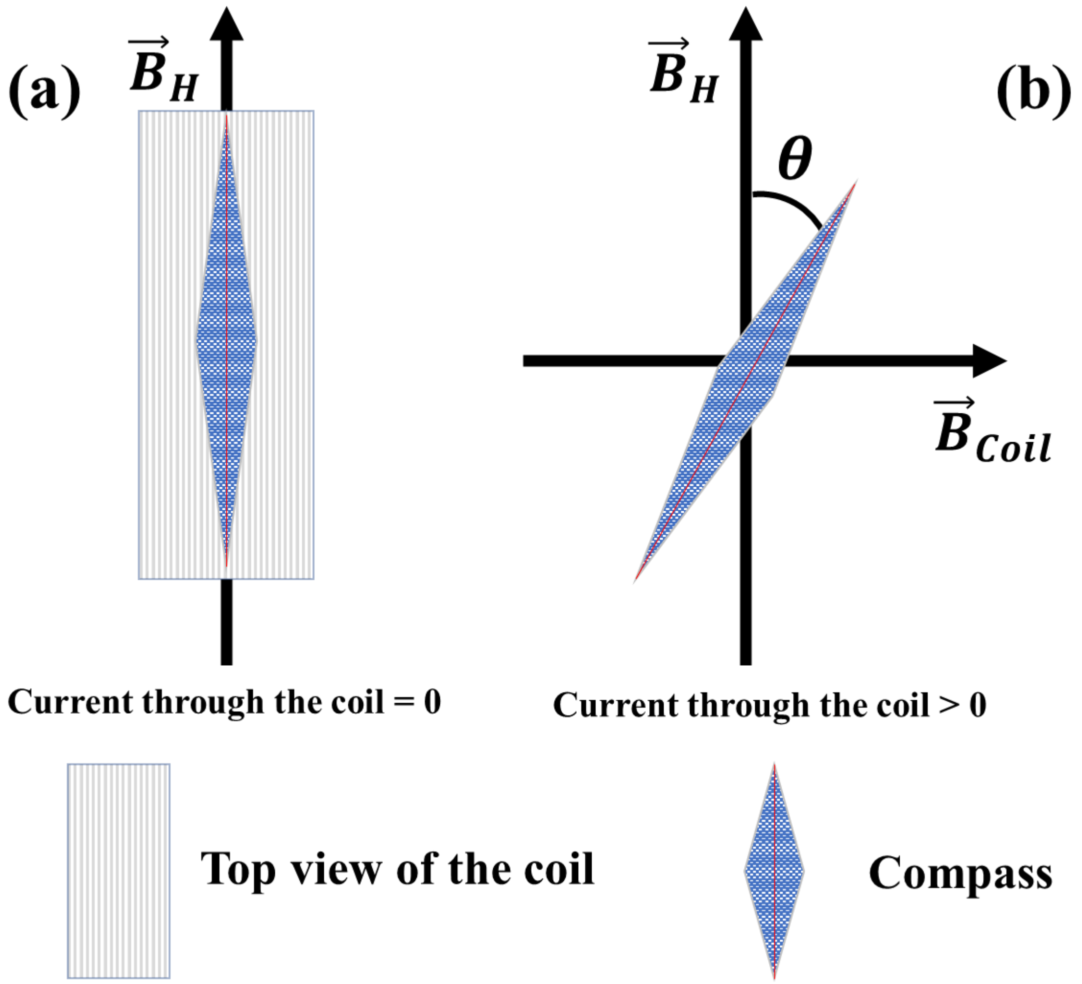


Figure 1

According to tangent law, the deflection of magnetic compass (θ) can be expressed as:

$$tan\theta = \frac{B_{Coil}}{B_H}$$

$$B_{Coil} = B_H\, tan\theta \qquad \dots\dots\dots (1)$$

Let 'I' be the current passing through the coil of radius 'a' with 'n' turns, then the magnetic field generated by the current carrying circular coil at its center is given by:

$$B_{Coil} = \frac{\mu_o n I}{2a} \qquad \dots\dots\dots (2)$$

By equating equation (1) and (2), we get

$$B_H tan\theta = \frac{\mu_o n I}{2a} \qquad \dots\dots\dots (3)$$

$$\Rightarrow \frac{2aB_H}{\mu_o n} = \frac{I}{tan\theta} \qquad \dots\dots\dots (4)$$

The left-hand side of equation (3) is a constant and is called the *reduction factor (K)* of the given tangent galvanometer,

$$K = \frac{I}{tan\theta} \qquad \dots\dots\dots (5)$$

Note that if θ = 45°, then $K = I$ and thus the reduction factor (K) is equal to the current required to be passed through the coil of a galvanometer to produce the deflection of 45^o.
By equating equations (3) and (5), horizontal component of the earth's magnetic field can be expressed in terms of reduction factor as follows:

$$B_H = \frac{\mu_o n K}{2a} \qquad \dots \dots \dots (6)$$

Experimental Procedure:

1. Go to the Amrita Vishwa Vidyapeetham virtual lab's website to perform "Tangent Galvanometer" experiment using following link:
   http://vlab.amrita.edu/?sub=1&brch=192&sim=1049&cnt=4

2. Click on the ***Simulator*** tab and login with your registered credentials to initiate the virtual experiment as shown in figure 2.

Figure 2

Experimental procedure:

3. Choose the option ***Initial setup*** as shown in the figure 3.

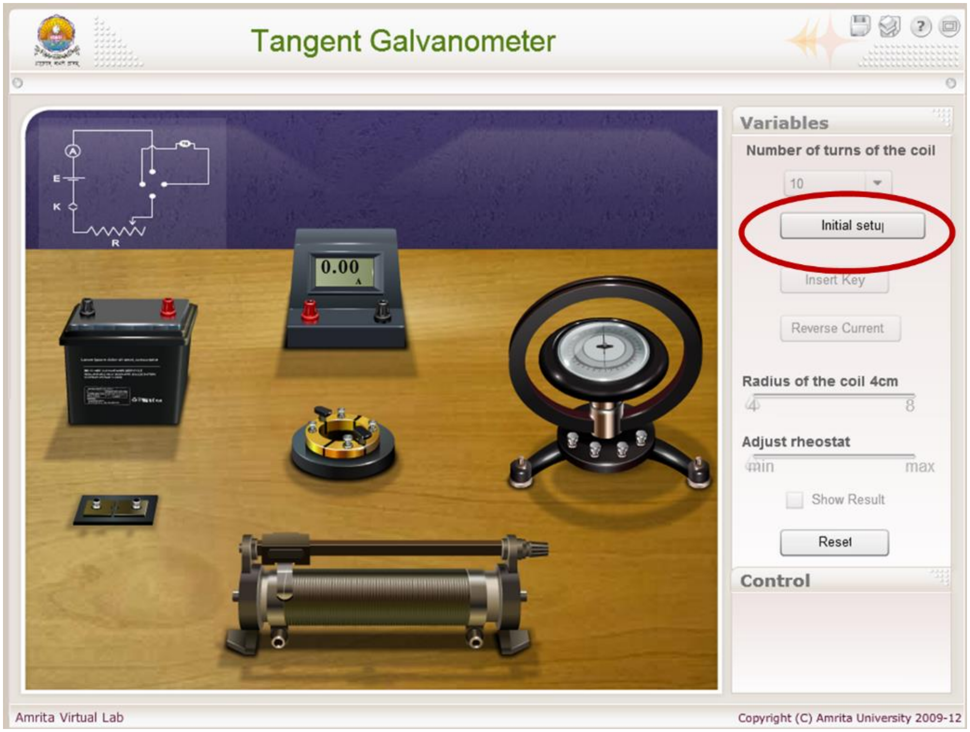


Figure 3

4. Choice of ***Initial Setup*** will lead to the zoomed view of the compass box as displayed in the figure 4:

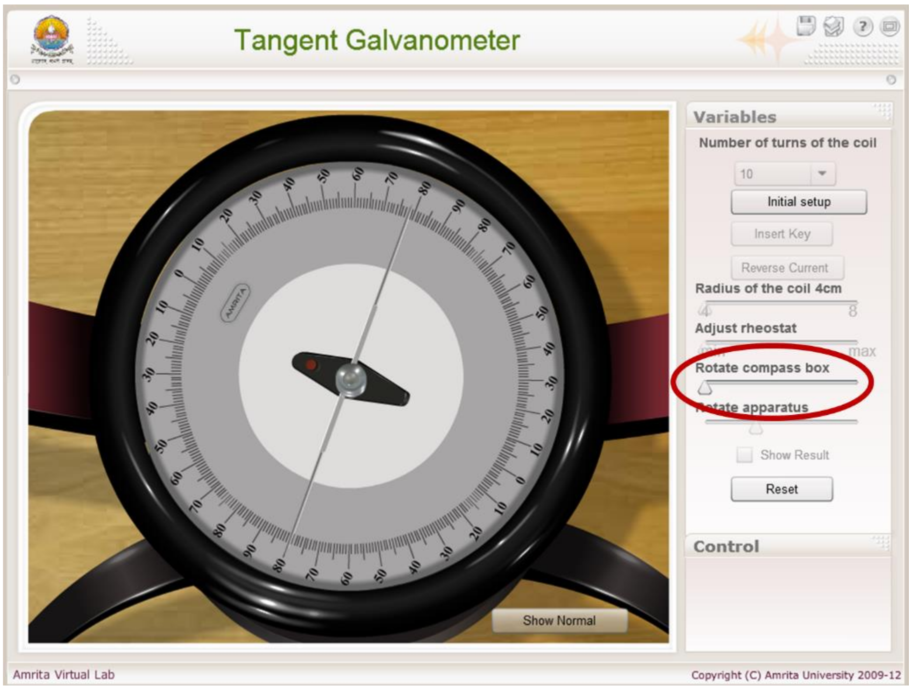


Figure 4

5. Adjust the slider of ***Rotate compass box*** (figure 4) till the 90-90 mark of the compass box becomes parallel to the plane of the coil.
6. If this adjustment is accurate, the ***Rotate apparatus*** (figure 5) slider will be activated. Then adjust the slider of ***Rotate apparatus*** to make the aluminium pointer reads 0-0.

Figure 5

7. Press ***Show normal*** button provided in the compass box section.
8. Make the connections as shown in the circuit diagram provided on the left-hand side top corner of the apparatus section. The cursor changes to a hand symbol when pointed to the terminals of each component by clicking a connecting wire will appear, drag the cursor to connect the components.
9. Once the connections are complete, ***Insert Key*** button will be activated as shown in the figure 6.

Figure 6

10. Pressing ***Insert Key*** enables the access to the following variables:

Variable	**Set points**
Number of turns of the coil	10, 15, 20, 25, 35, 45
Reverse Current	Used to reverse the direction of current
Radius of the coil	4, 5, 6, 7 and 8 cm
Adjust rheostat	Used to adjust the coil current between 0.05 to 1 A.

Note: To read compass box, press ***Zoom Compass Box*** tab to access zoomed view.

Experiment 1

(a) Calculate the reduction factor (K) at variable current values for given radius and number of turns of the coil, respectively.

Radius of the coil: 5 cm

Number of turns: 10

(b) Plot the graph between current (I) vs tanθ and calculate reduction factor (K) using the slope.

(c) Calculate the value of horizontal component of the earth's magnetic field using equation 6.

Radius of Coil	**Number of turns**	**Ammeter readings**	**Pointers deflection in degrees**				$\boldsymbol{Mean\ \theta}$	$\boldsymbol{tan\ \theta}$	$\boldsymbol{K = \frac{I}{tan\theta}}$	**Average** $\boldsymbol{'K'}$	$\boldsymbol{B_H}$
$(\boldsymbol{cm})$		$\boldsymbol{I}\ (\boldsymbol{A})$	**Direct**		**Reverse**		$(\boldsymbol{Degree})$	$(\boldsymbol{Degree})$	$(\boldsymbol{A})$	$(\boldsymbol{A})$	$(\boldsymbol{T})$
			$\boldsymbol{\theta_1}$	$\boldsymbol{\theta_2}$	$\boldsymbol{\theta_3}$	$\boldsymbol{\theta_4}$					
5	10	0.1									
		0.2									
		0.25									
		0.5									
		1									

Experiment: 2

(a) Calculate the reduction factor (K) at varied number of turns of the coil for given radius of coil and current, respectively.

Radius of the coil: 5 cm

Current passing through the coil: 0.25A

(b) Plot the graph between $K\ (A)\ Vs\ 1/Number\ of\ the\ turns\ of\ the\ coil$ and calculate the value of horizontal component of earth's magnetic field (B_H) using the slope of the curve. $[\mu_o = 4\pi \times 10^{-7}\ H/m\ ]$

Radius of Coil	**Ammeter readings**	**Number of turns**	**Pointers deflection in degrees**				**Mean θ**	**tan θ**	$\boldsymbol{K = \frac{I}{tan\theta}}$	$\boldsymbol{B_H}$
$(\boldsymbol{cm})$	$\boldsymbol{I}\ (\boldsymbol{A})$		**Direct**		**Reverse**		$(\boldsymbol{Degree})$	$(\boldsymbol{Degree})$	$(\boldsymbol{T})$	**(T)**
			$\boldsymbol{\theta_1}$	$\boldsymbol{\theta_2}$	$\boldsymbol{\theta_3}$	$\boldsymbol{\theta_4}$				
5	0.25	10								
		15								
		20								
		25								
		35								
		45								

Conclusions:

Experiment No. 4
Polarization of Light and Brewster's Angle

Aim: To determine Brewster's angle for a given pair of media using polarized monochromatic light.

Apparatus: Monochromatic light source (for e.g. a laser), polarizer, photodiode, Ammeter, glass slab, stands, optical breadboard or optical table.

Theory

Light is an electromagnetic wave, involving oscillating electric and magnetic fields that propagate through space. It is a transverse wave, implying that the electric and magnetic fields are perpendicular to the direction of propagation of the wave and also perpendicular to each other. Direction of oscillations of the electric (or magnetic) field decides the state of polarization of an electromagnetic wave. Simplest example is that of a linearly polarised light, in which the electric (or magnetic) field is always pointing along a fixed direction. This is also called plane polarized light, the direction of electric field (**E**) and the direction of propagation defines the plane of polarization. In commonly used light sources, waves are emitted by trillions and trillions of un-correlated atoms or molecules. The electric (or magnetic) field in the resulting light wave has no fixed direction and the direction keeps changing randomly with time. Such a wave is known as unpolarised wave.

The state of polarization of light can be affected by several ways. One such device is polariser, it consists of materials that can absorb waves which are polarised perpendicular to a particular direction. Thus, irrespective of the state of polarisation of incident wave, the waves transmitted by a polariser is always linearly polarised along this direction, which is referred to as the polarisation axis or transmission axis or simply pass axis.

Whenever light encounters a change of medium, a part of it is reflected at the interface and the remaining part is transmitted into the second medium. Recall the laws of reflection: the angles of incidence (θ_i) and reflection (θ_r) are always equal and the incident ray, reflected ray and the normal to the interface all lie in one plane, called the plane of incidence. The angles of incidence (θ_i) and refraction (θ_t) are related by the Snell's law: $\frac{\sin\theta_i}{\sin\theta_t} = \frac{\mu_2}{\mu_1}$, where μ_1 and μ_2 are the refractive indices of the two media and the direction of propagation of light is from medium 1 to medium 2.

The reflection coefficients of light is different for the component in the plane of incidence and the component perpendicular to the plane of incidence. Due to this when unpolarized light is incident on the surface, the reflected light is usually partially polarized perpendicular to the plane of incidence, and the degree of polarization depends on the angle of incidence. For a certain angle of incidence, which is unique for a given pair of media, the reflected light becomes linearly polarized perpendicular to the plane of incidence. This angle is called Brewster's angle. The situation is depicted in the figure 1.

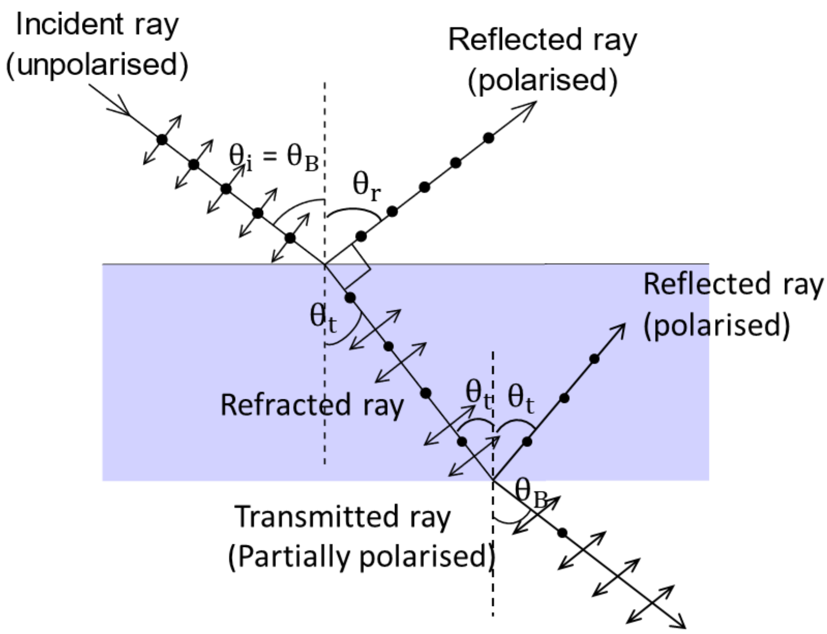


Figure 1. Polarisation of light due to reflection. ↕ and • indicate polarisations parallel and perpendicular to the plane of incidence.

The Brewster's angle (θ_B) is given by: $\tan\theta_B = \frac{\mu_2}{\mu_1}$. This relation is often referred to as the Brewster's law. Using Snell's law it can be easily shown that when incidence is at Brewster's angle, the reflected and refracted beams are perpendicular to each other ($\theta_B = \theta_r = 90^0 - \theta_t$). The beam transmitted into the glass slab at the top / front surface will undergo refraction and reflection once again at the bottom / back surface. The Brewster's angle (θ'_B) for reflection at the back surface is given by: $\tan\theta'_B = \frac{\mu_1}{\mu_2}$, because now the direction of propagation is from medium 2 to medium 1. If the glass slab has parallel surfaces, then the angle of incidence at the back surface is same as the angle of refraction (θ_t) at the front surface (see figure 1). Now, $\tan\theta_t = \frac{\sin\theta_t}{\cos\theta_t} = \frac{\sin\theta_t}{\cos\,(90^0-\theta_i)} = \frac{\sin\theta_t}{\sin\theta_i} = \frac{\mu_1}{\mu_2}$ (by Snell's law). Thus, θ_t must be $=\ \theta'_B$, implying that the refracted ray from the front surface falls on the back surface at the Brewster's angle. Light reflected from the back surface will also be polarised perpendicular to the plane of incidence. If light is passed through multiple slabs with parallel surfaces and it is incident on the front surface at Brewster's angle, then all reflected beams will be polarised perpendicularly. The beam transmitted from each slab will be partially polarised, containing lesser and lesser amount of the perpendicularly polarised component. If we use sufficient number of slabs then the light transmitted by the last slab will have negligible amount of perpendicularly polarised component left in it and can be regarded as polarised parallel to the plane of incidence. This provides a very easy technique to produce light that is polarised along two mutually perpendicular directions, starting from a completely unpolarised light.

The refractive index μ of a medium is usually dependent on the wavelength of the incident light, which gives rise to the phenomenon of dispersion. This dependence implies that for the reflected light to be polarised the incident light must be monochromatic, i.e. have a single wavelength. Hence laser is preferred as the light source in this experiment.

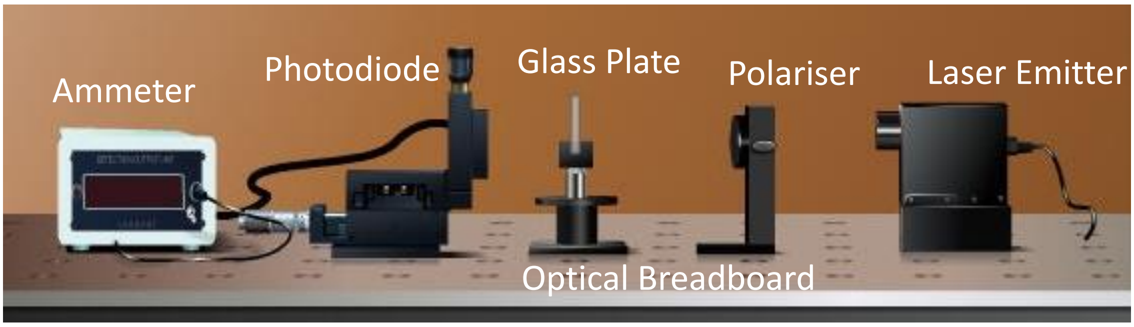


Figure 2. Experimental setup for determination of Brewster's angle.
Source: vlab.amrita.edu/index.php?sub=1&brch=189&sim=333&cnt=4

Experimental set-up used is shown in figure 2. The polariser is set such that it polarises the light in the plane of incidence (horizontal plane). Reflected beam for any general angle of incidence will contain light components polarised in the plane of incidence, as well as perpendicular to the plane. But, when light is incident at Brewster's angle the reflected light cannot have any component polarised in the plane. In this experiment incident light is already polarised in the plane, so at Brewster's angle no light is reflected and the intensity of transmitted beam becomes maximum.

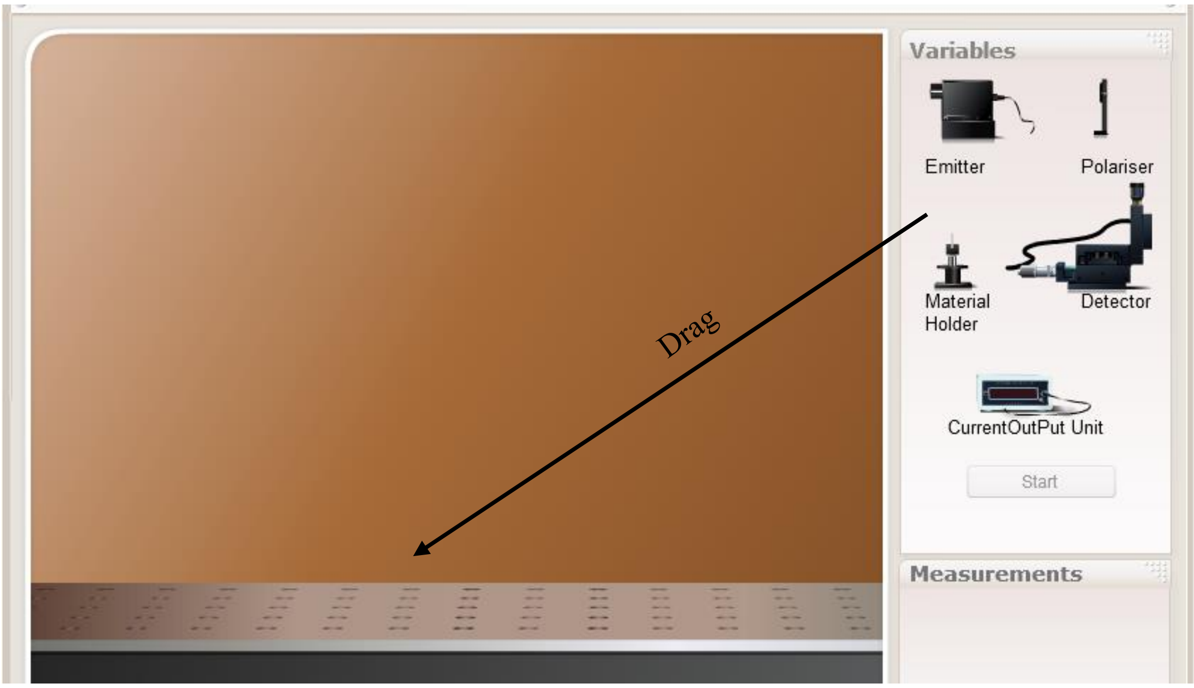
Procedure for the virtual experiment

1. Go to the Amrita Vishwa Vidyapeetham virtual lab's s website for Brewster's angle experiment:
https://vlab.amrita.edu/index.php?sub=1&brch=189&sim=333&cnt=1

2. Browse through the different tabs and read the material provided in the website to accustom yourself with the experiment. Note that the procedure mentioned below should be followed and not the procedure provided in the site.

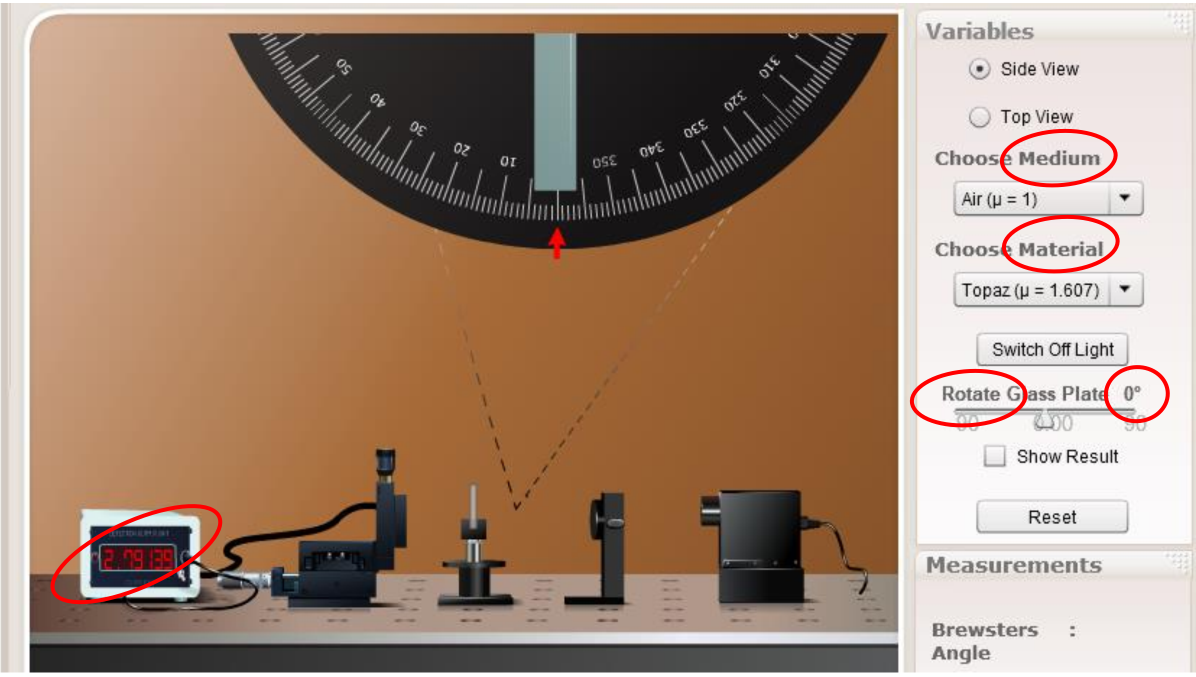
3. Click on the "simulator" tab and login with your registered credentials to initiate the virtual experiment.

4. Drag the different components from the "variables" panel on the right to the optical breadboard to prepare the experimental set-up (see the figure below). Note that there is only one predefined way in which you can place the components.



5. Click the "start" button. Additional options now become available in the "variables" panel and a magnified view of the circular scale attached to the glass slab / plate is visible. The circular scale is calibrated to directly read the angle of incidence.

6. Click "switch on light". Now the laser is turned on, part of the light is reflected and a part transmitted by the glass plate. The transmitted part falls on the photodiode and excites a current in it, which can be read from the ammeter.



7. Choose a "medium" and a "material" in the "variables" panel. "Medium" is the gaseous atmosphere in which all the components are placed and the experiment is being conducted. "Material" refers to the material of the glass plate. These options are encircled in the above figure. To start the experiment choose "air" as "medium" and "topaz" as "material".

8. Drag "rotate glass plate" slider to change the angle of incidence. The angle is displayed near the slider and can also be seen in the magnified circular scale.

9. Change the angle of incidence while observing the reading on the ammeter. At a certain value of the angle the reading becomes maximum. Note down this angle as $\theta_1{}^{\mathbf{0}}$. Check the ammeter readings for negative values of angle of incidence and note down the angle ($\theta_2{}^{\mathbf{0}}$**)** for which the reading is maximum once again. Take the average of the magnitudes of the two angles. This gives the experimentally obtained value of Brewster's angle ($\theta_B{}^{\mathbf{0}}$) for the chosen pair of "medium" and "material".

10. Calculate the Brewster's angle using the relation $\theta_{B1} = \tan^{-1}\frac{\mu_2}{\mu_1}$. This gives the expected value. Compare the expected value with the experimental value obtained in the virtual experiment and compute the % error using the relation:

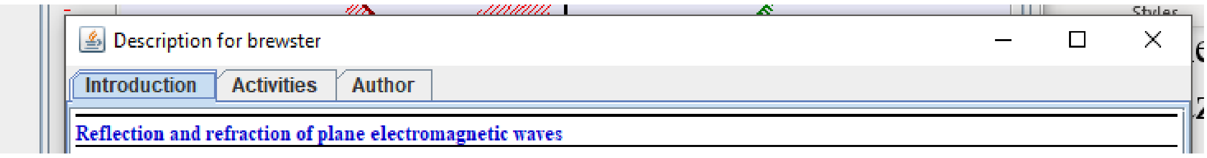
$$\%\ \text{error} = \frac{|(\text{experimental value} - \text{expected value})|}{\text{expected value}} \text{ x } 100$$

Note: Keep numbers upto 3-4 decimal places in all your calculations

11. Repeat steps 7-10 with different sets of "medium" and "material". From "medium" choose "air" and "carbon dioxide". You can skip "hydrogen" and "helium". For each of the 2 "mediums" determine the Brewster's angle for the "materials": "topaz", "crown glass" and "flint glass". These are different forms of glass.

13. Go to the following website and download the visualization tool "ejs_waves_brewster.jar" https://www.compadre.org/osp/items/detail.cfm?ID=7901#:~:text=The%20Ejs%20Brewster's%20Angle%20model,change%20of%20index%20of%20refraction.
To run the program you will require Java to be installed in your computer. Usually Windows computers have Java in them. In case you don't have Java, you can download it from https://www.java.com/en/download/

14. Run the program. Two windows will open, one is the visualization tool and the other has "description" of the program. In the "description" window go to the "introduction" tab and read the contents to understand how to use the tool.



15. In the visualization tool set up the same conditions as in the virtual experiment. Make the incident light polarised parallel to the plane of incidence (make Epar = 10 and Eper = 0) and set the phase difference (δ) between the 2 components of electric field (**E**) to 0. Choose a ratio

of refractive indices $\left(\frac{\mu_2}{\mu_1}\right.$ is referred to as $\frac{n_2}{n_1}$ here$\left.\right)$ in the visualization tool that is the closest match to the "medium" - "material" combination of air and topaz.

16. Start the simulation and vary the angle of incidence till the amplitude of the reflected wave reaches a minimum (≈ 0). Note down this angle ($\theta_{B2}{}^{\mathbf{0}}$) and verify that it is a close match to the Brewster's angle determined in the virtual experiment. Take a screenshot after pausing the simulation at the Brewster's angle and paste it in your record. All parameters set in the visualisation tool should be clearly visible.

17. Keeping the incident ray at Brewster's angle change the state of polarisation of incident ray. Add perpendicularly polarised component (set Eper = 10). The net electric field will be a sum of the parallel and perpendicular components. In the current set-up, since Epar = Eper, the sum will be at an angle of 45^0. Thus, the incident light is now polarised at angle of 45^0 with the plane of incidence. The amplitude of the reflected wave becomes non-zero now. Verify that the reflected wave is linearly polarised perpendicular to plane of incidence (i.e. it has only Eper component), thus confirming Brewster's law. Tick the box on the left on "incidence". This will display the plane of incidence in the visualisation window. Take a screenshot of the visualisation tool.

18. Change the angle of incidence, verify that now the reflected light has both parallelly and perpendicularly polarised components. Take a screen shot of the visualisation tool.

19. Once again make the plane of polarisation of incident light parallel to plane of incidence (set Eper = 0). Set $\frac{\mu_2}{\mu_1}$ or $\frac{n_2}{n_1}$ equal to the reciprocal of the value set in step 15, to simulate reflection at the back surface of the glass plate. Vary the angle of incidence till the amplitude of the reflected wave reaches a minimum (≈ 0). This gives the Brewster's angle for reflection at the back surface ($\theta'_{B2}{}^{\mathbf{0}}$). Note down this value and verify that the sum of the angles ($\theta_{B2}{}^{\mathbf{0}}$ + $\theta'_{B2}{}^{\mathbf{0}}$) is close to the expected value, i.e. 90^0.

Observations and Calculations:

Table I. Determination of Brewster's angle from virtual experiment

S. No.	Medium	μ_1	Material	μ_2	$\theta_1{}^0$	$\theta_2{}^0$	Brewster's angle (virtual experiment)	Brewster's angle (expected)	% error
1	Air		Topaz						
2			Crown glass						
3			Flint glass						
4	Carbon dioxide		Topaz						
5			Crown glass						
6			Flint glass						

Table II. Brewster's angle from visualization tool

S. No.	Medium	Material	μ_2/μ_1 set in visualization tool	Brewster's angle (virtual experiment)	Brewster's angle (expected)	Sum, $\theta_{B1}{}^0$ + $\theta'_{B1}{}^0$ =	Brewster's angle (visualization tool)	Sum, $\theta_{B2}{}^0$ + $\theta'_{B2}{}^0$ =
1	Air	Topaz			$\theta_{B1}{}^0$ =		$\theta_{B2}{}^0$ =	
2	Topaz	Air		N.A.	$\theta'_{B1}{}^0$ =		$\theta'_{B2}{}^0$ =	

(a)

(b)

(c)

Figure 1: Screenshots from the visualization tool. (a) Reflection at Brewster's angle from the surface of glass, with incident light polarised in the plane of incidence. (b) Reflection at Brewster's angle from the surface of glass, with incident light polarised at 45^0 to the plane of incidence. (c) Reflection from the surface of glass at an arbitrary angle of incidence, with incident light polarised at 45^0 to the plane of incidence.

Question: What is the working principle of Polaroid sunglasses? Your answer should not be more than 4-5 lines.

Conclusions:

Experiment No. 5
Diffraction Grating

Aim of the experiment:

1. To determine the number of lines per millimeter of the grating using the green line of the mercury spectrum.
2. To calculate the wavelength of the other prominent lines of mercury by normal incidence method.

Apparatus required:

- A white light source (Mercury vapor lamp)
- Diffraction grating
- Spectrometer
- Spirit level

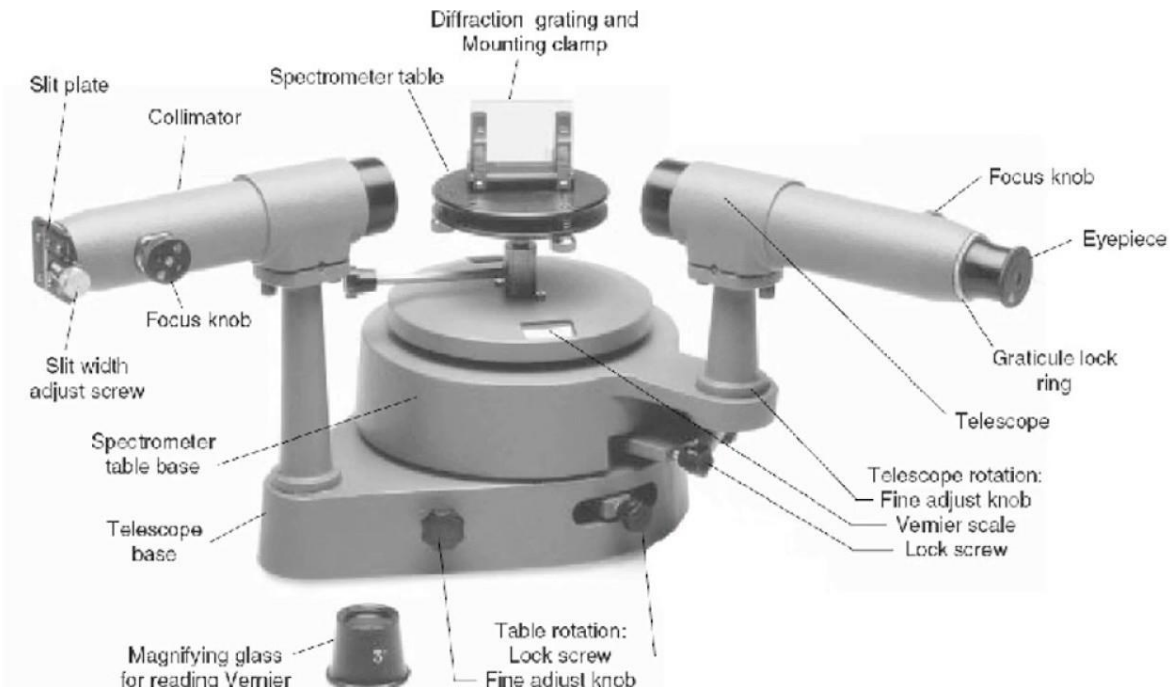


Fig. 1: Picture of the spectrometer with diffraction grating.

Theory:

Diffraction Gratings:

Diffraction grating is an arrangement of large number of identical, equidistant and parallel slits. The distance between the slits is called the grating constant, or *d* (see Fig. 2).

Light rays that strike the transparent portion of the grating will undergo diffraction as they emerge. If the deviated light waves from adjacent rulings on the grating are in phase, a bright fringe is produced. This will be true when the adjacent waves differ in path length by an integral number of wavelengths of the light. Thus, for a given wavelength λ, there will exist a series of angles at which image would be formed.

According to Fig. 2, the path difference between the incident and diffracted wave is $d \sin \theta_1$ (θ_1 is the angle between incident and diffracted waves) and bright fringe is observed when the equation $d \sin\theta_1 = \lambda$ is satisfied. At some larger angle θ_2, when the path difference is equal to 2λ, then the equation $d \sin\theta_2 = 2\lambda$ is satisfied, and again leading to constructive interference.

In general, bright fringes are formed at any angle θ_n for which the adjacent waves from adjacent rulings have a path difference equal to $n\lambda$, where n is an integer called the order number. Thus, the general case is described by the grating equation

$$d \sin\theta_n = n\lambda \,. \quad (1)$$

The maximum formed along the original path of the light rays is called the zeroth order. For each of the higher orders (i.e. $n \geq 1$), there are two images formed symmetrically at different sides of the zeroth order image.

Light emitted from an elemental gas typically consists of a number of discrete wavelengths (colors). A grating spectrometer can be used to determine the wavelengths of these emissions.

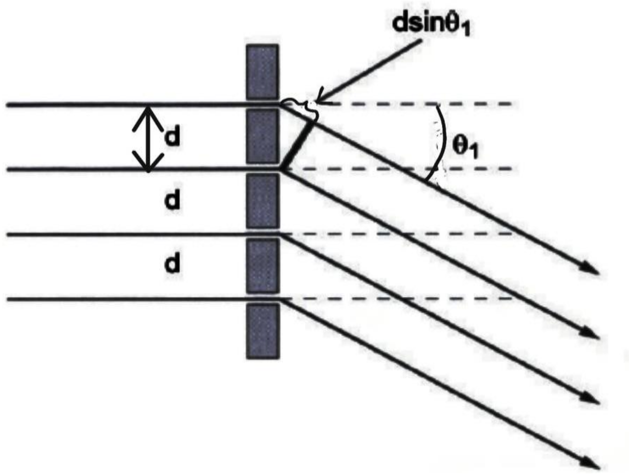
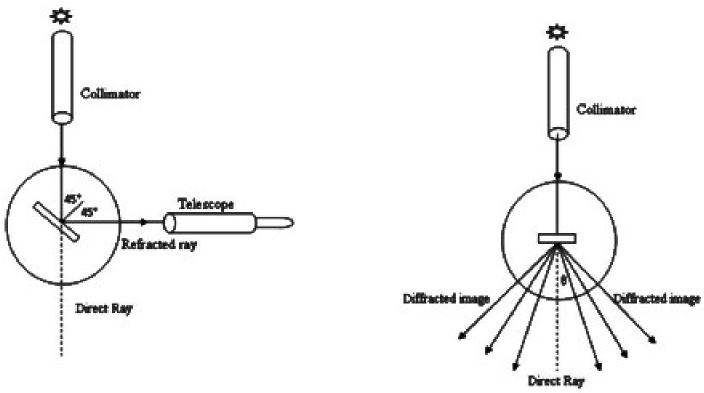


Fig. 2: Geometrical conditions for the diffraction from multiline grating.

Procedure for real lab:

Do the spectrometer adjustment as described in Appendix 1.

Adjustment of the grating for normal incidence: The plane transmission grating is mounted on the prism table. The telescope is released and placed in front of the collimator. The direct reading is taken after making the vertical cross-wire to coincide with the fixed edge of the image of the slit, which is illuminated, by a monochromatic source of light. The telescope is then rotated by an angle 90° (either left or right side) and fixed. The grating table is rotated until the reflected image of the slit coincides with the vertical cross-wire. This is possible only when a light emerging out from the collimator is incident at an angle 45° to the normal to the grating. The vernier table is now released and rotated by an angle 45° towards the collimator. Now light coming out from the collimator will be incident normally on the grating.



Determination of the deviation angle:

(i) Place the mercury lamp in front of the entrance slit of the collimator.

(ii) Rotate the telescope so that it is in line with the collimator axis and view the slit through the telescope. If required, adjust the slit width while observing it through the telescope.

(iii) Rotate the telescope to the left of the collimator axis and observe the lines in the Mercury spectrum.

(iv) Align the cross hairs with the visible lines. Read the circular and vernier scales for each line. (Note that the first set of visible lines belong to the first order spectrum).

(v) Move the telescope to the other side of the collimator axis and align the cross hairs to all the visible lines in a similar way as above and again note down the readings.

<u>INSTRUCTIONS FOR VIRTUAL LAB:</u>

I. Please go through the appendix to know about the Spectrometer, its components and functions.

II. Learn to use a vernier scale, how to read and calculate readings.

Note: Once you start the experiment, do not change tab or leave page. You will lose the data and you will have to start the experiment from the beginning.

Components: Spectrometer, Grating and Mercury Vapour Lamp.

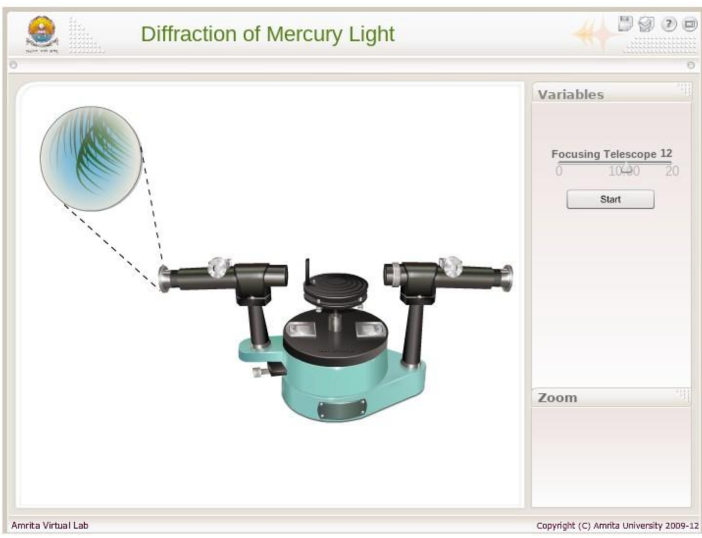
Variable Region:

1. **Telescope Calibrate Slider** : This slider helps the user to change the focus of telescope.
2. **Start Button** : Helps the user to start the experiment after setting the focus of telescope. The Start Button can be activated only if the focus of the telescope is proper.
3. **Light Toggle Button** : Helps the user to switch the lamp ON or OFF.
4. **Grating Toggle Button** : Helps the user to place or remove the grating.
5. **Telescope Angle Slider** : This slider helps the user to change the angle of telescope.
6. **Vernier Angle Slider** : This slider helps the user to change the angle of the Vernier.
7. **Telescope Angle Slider** : Helps make minute changes of the telescope angle.
8. **Calibrating Telescope Button** : Helps the user to calibrate the telescope after starting the experiment, if needed.

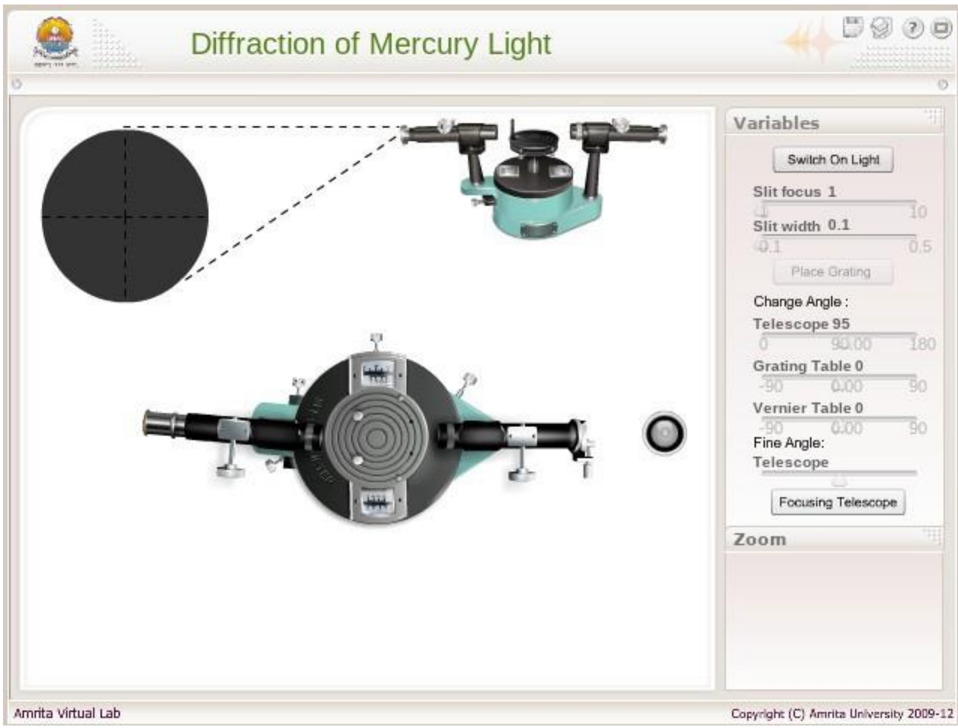
Procedure:

1. Go to the Amrita Vishwa Vidyapeetham virtual lab's website for "Diffraction grating" https://vlab.amrita.edu/?sub=1&brch=281&sim=334&cnt=4
2. Browse through the different tabs and read the material provided in the website to accustom yourself with the experiment.

3. Click on the "Simulator" tab and login with your registered credentials to initiate the virtual experiment.
4. At first you have focus telescope. Drag the slider to focus the image that appears in the top left corner circle. When the focusing is done, click on "Start" under the slider to start your experiment.



5. You get a page as in below image after you start the experiment.



6. Click on “Switch On Light” in the variables column.
7. Focus the slit by dragging the pointer on the bar.

Once the slit is focused, you may adjust slit width by dragging the pointer in the bar “Slit width” just below the Slit focus. Note that finer slit introduces less error in the reading. So you may keep it at the minimum value.

8. Place grating on the grating table by clicking on “Place Grating”.
9. Change the angle of the telescope to see the spectrum in both the sides of the direct white light by dragging the pointer.

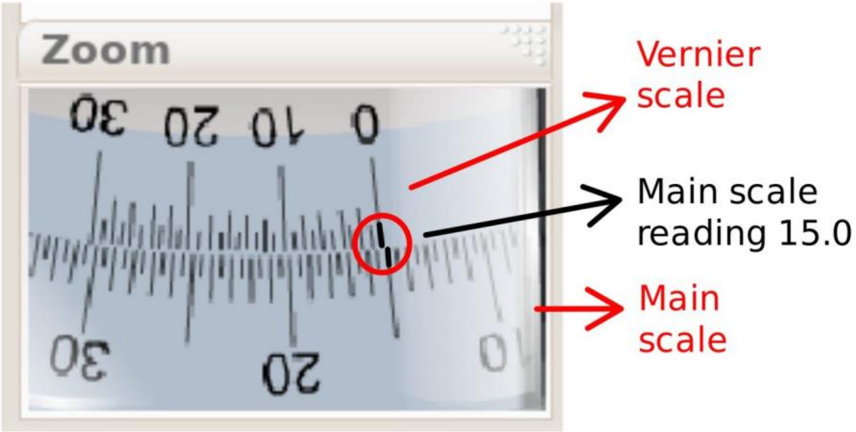
Grating table can be rotated by dragging the pointer in the “Grating Table” bar. This can be rotated to adjust the grating orientation, so that the incident ray falls perpendicularly on the grating. Once set, do not change it throughout the experiment. Same holds for the Vernier table.

10. You can zoom in a part of the apparatus if you roll over mouse pointer on image. The zoomed in image will be visible in the “Zoom” window.
11. Zoom in the reading scales.

Two scales will be visible side by side. One scale is attached with the vernier table showing divisions from 0 to 30 and the other is attached with the telescopes that goes from 0 to 360 degree which is called the main scale. Calculate the value of one small division in the main scale and least count of the vernier scale. Take the readings by using these two scales. Main scale reading: The reading on main scale which the 0 of vernier scale has crossed. (Do not approximate by eye estimation or round up)

Vernier reading: The division of the vernier scale that matches exactly with any of the main scale divisions.

(Note: The purpose of using a vernier scale is to increase accuracy. But in the simulator the vernier scale divisions are same as main scale division, which fails to serve its purpose. So **please use only the main scale reading** for this simulator experiment.)



12. To standardize the grating:
    - Turn the telescope to obtain the image of the slit.
    - Turn the telescope to *both* sides to obtain green lines. Use “Fine Angle” adjustment bar to bring the green line on the vertical line of the crosshair. Note the reading of both the verniers. Don’t forget to save the data after each new reading .
    - Calculate the difference in the reading to obtain the diffraction angle. Then from the equation, number of lines per unit length of the grating can be calculated. This number is called the grating constant or grating element.
13. To calculate the wavelength of different lines
    - Obtain the direct image.
    - Telescope is moved to make the cross-wire coincide with each line of the spectrum.
    - Please note that the order of colors are not correct in the simulator spectra which appears in the order Indigo, Violet, Blue, Green, Yellow. Correct order should be VIBGY. So assume the color codes accordingly in the data table.
    - Note the main scale readings and calculate the diffraction angle.
    - Then calculate the wavelength of each color.
    - Please be careful in calculating the difference in angle θ when it crosses 0 or 360.

Observation and calculation:

Table 1: To find the grating constant

To standardize grating:										
Color	**Wave-length λ, (nm)**	**Order n**	**Vernier 1**		**θ1= (R1-L1)/2 (degrees)**	**Vernier 2**		**θ2 = (R2-L2)/2 (degrees)**	**Mean θ= (θ1+θ2)/2**	**N = Sin θ /λ (lines/nm)**
			Left (L1)	**Right(R1)**		**Left (L2)**	**Right(R2)**			
Green	546	1								

Table 2: To find the wavelengths of different colors of spectrum for order n=1

Grating constant (N) = lines/nm

To find wavelength:								
Color	**Vernier 1**		**θ = (R1-L1)/2 (degrees)**	**Vernier 2**		**θ = (R2-L2)/2 (degrees)**	**Mean θ=(θ1+θ2)/2**	**Wavelength λ = Sin θ /N (nm)**
	Left (L1)	**Right (R1)**		**Left (L2)**	**Right (R2)**			
Yellow								
Green								
Blue								
Indigo								
Violet								

Table 3: To find the wavelengths of different colors of spectrum for order n=2

To find wavelength:								
Color	**Vernier 1**		**θ = (R1-L1)/2 (degrees)**	**Vernier 2**		**θ = (R2-L2)/2 (degrees)**	**Mean θ=(θ1+θ2)/2**	**Wavelength λ = Sin θ /(2N) (nm)**
	Left (L1)	**Right (R1)**		**Left (L2)**	**Right (R2)**			
Yellow								
Green								
Blue								
Indigo								
Violet								

Use the grating equation to find the wavelength λ for each color and note down in table 2 & 3

Results and Conclusions:

The wavelength of Yellow = nm
The wavelength of Green = nm
The wavelength of Blue = nm
The wavelength of Indigo = nm
The wavelength of Violet = nm

Experiment No. 6
Refractive index and Cauchy's constants

<u>Aim</u>:
Determination of the refractive index μ of glass for different wavelengths λ, and Cauchy's constant a, b with the help of a prism.

<u>Apparatus required</u>:

- A white light source (Mercury vapor lamp)
- Prism
- Spectrometer

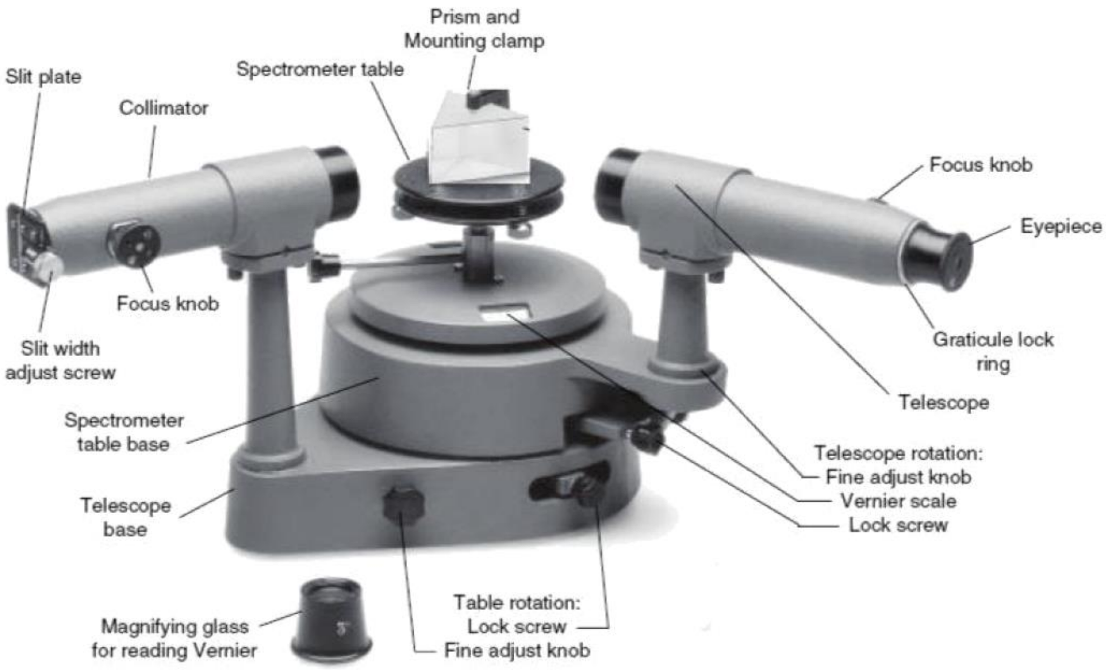


Fig. 1: Different parts of the spectrometer used in the laboratory.

Theory:

A prism is a refracting material bounded by three planes. The prisms we use in the lab are equilateral prisms whose one face is etched or frosted so that light does not pass through it and the other two faces are the refracting faces. The line at which two refracting faces meet is called a refracting edge. Since there are only two refracting faces, there is only one refracting edge. The angle between these two faces is known as refracting angle or angle of prism (*A* in Fig. 2). A ray of light incident on one of the refracting faces gets refracted through the prism and finally emerges as displayed in the Fig. 2. The angle between the original direction of the incident ray and the emergent ray is called the angle of deviation θ_d. Angle of deviation depends upon the angle of incidence θ_i and the wavelength of the light . For a certain angle of incidence, the deviation will be minimum as schematically explained in Fig. 3. This is called *angle of minimum deviation* (δ_{min}). In this experiment the refractive index is obtained for a variety of wavelengths by measuring this minimum deviation angle for each wavelength.

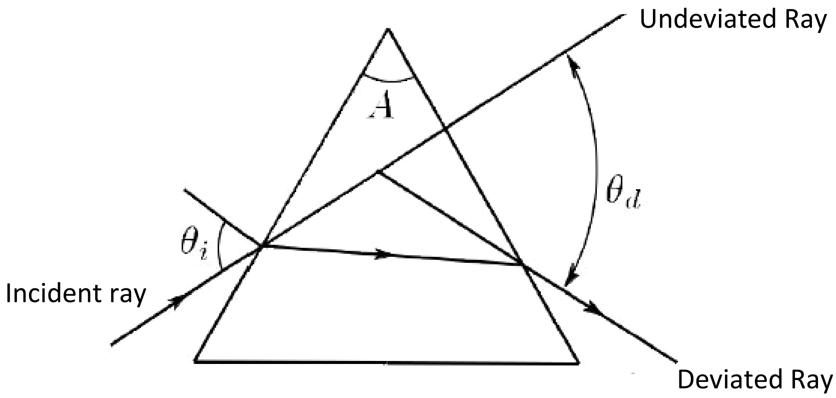


Fig. 2: Refraction of light through the prism.

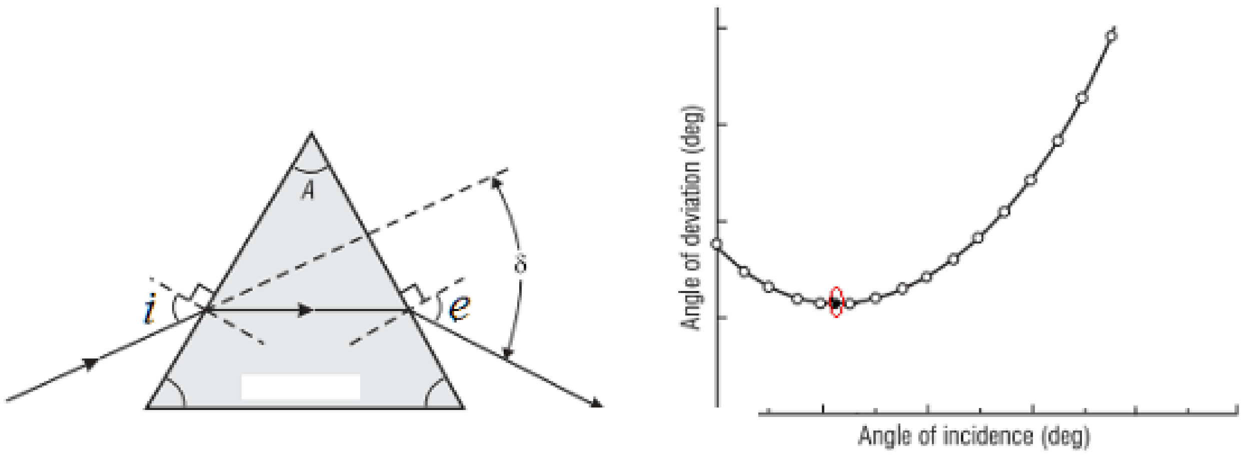


Fig. 3: Graph of the angle of deviation as a function of angle of incidence.

Relation between μ and λ:

It can be established that the prism is at the minimum deviation position when the ray passes through the prism symmetrically. It means that the angle at which the light emerges is equal to the angle of incidence such that the ray passes parallel to the base of the prism as shown in Fig. 4. At each face the ray changes its direction by an angle of (θ_i – θ_r). Therefore the total minimum deviation is

$$\delta_{min} = 2(\theta_i - \theta_r). \tag{1}$$

From Fig. 4, it can be shown that the angle MNO is the same as that of the refracting angle of the prism. Referring to the triangle LMN, one obtains using trigonometry

$$A = 2\theta_r. \tag{2}$$

According to Snell's Law, refractive index μ of the material of the prism = $\sin\theta_i/\sin\theta_r$.
Hence using eqn. 1 and 2, we obtain the following expression:

$$\mu = \frac{sin(\frac{A + \delta_{min}}{2})}{sin(\frac{A}{2})} \ . \tag{3}$$

Thus, by measuring δmin for a variety of wavelengths, the variation of μ with wavelength can be determined.

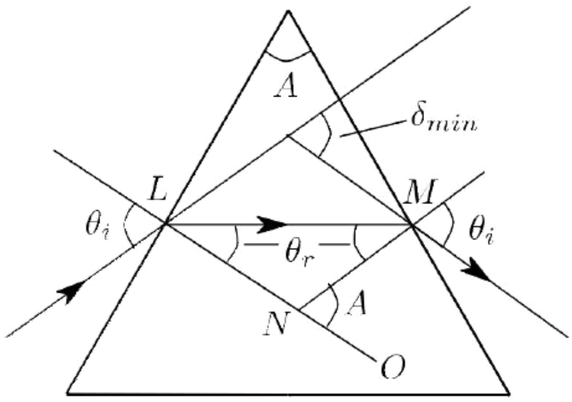


Fig. 4: Arrangement to determine angle of minimum deviation

An empirical equation of the form $\mu = a + \frac{b}{\lambda^2} + \frac{c}{\lambda^4} + \ldots$ was developed by Cauchy to describe the variation of μ with wavelength. Here *a, b* and *c* are coefficients that can be determined for a material by fitting the equation to measured refractive indices at known wavelength.

Usually, it is sufficient to use a two-term form of the equation:

$$\mu = a + \frac{b}{\lambda^2} \tag{4}$$

Note: As the variation in refractive index over the whole visible range of light is only of the order of 3%, δ_{min} varies slowly with wavelength. Great care in making the various measurements are necessary if reasonable results are to be attained.

Procedure:

Go to the following webpage and login with your email address and password.
http://vlab.amrita.edu/?sub=1&brch=281&sim=1514&cnt=4

Preliminary adjustments:

1. Focus Telescope on distant object.
2. When focus is correct, *Start* button is activated. Then click *Start* button.
3. Switch on the light by clicking *Switch On Light* button.
4. Focus the slit using *Slit focus* slider.
5. Adjust the slit width using *Slit width* slider.

Measurement of the angle of prism:

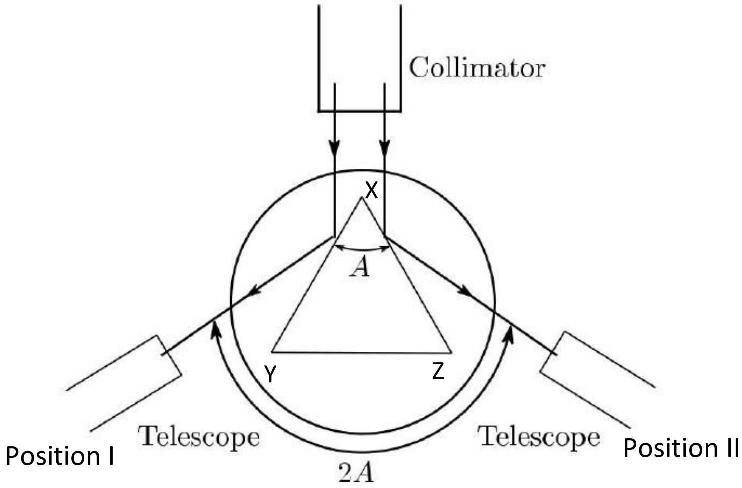


Fig. 5: Schematic set-up to measure the angle of prism

1. Click *Place Prism* button.
2. Place the edge of the prism, pointed towards collimator (as shown in Fig. 5).
3. Move the telescope using *Telescope* slider to see slit image reflected from one side of the prism. Coincide slit image with the cross wires of the telescope by using *Fine Angle: Telescope* slider. Then note down the reading in the tabular column.
4. Move the telescope in the opposite direction and do the same.
5. Find the difference between the two angles i.e., 2θ. From this find the angle of the prism *A* which is equal to θ.

Measurement of the angle of minimum deviation, δ_{min} for each wavelength:

Fig. 6: Arrangement of setup to measure Cauchy's constants

1. Rotate the vernier table so that light from the collimator fall on one face of the prism and emerge through the other face (refer Fig.6).
2. Rotate the telescope as shown in Fig.6 to observe the spectrum of colors. If not, slightly rotate the vernier table and telescope so that you see these colors.
3. Once the spectrum of colors is observed, keep the telescope fixed and slowly rotate the vernier (prism) table in one direction. The spectrum moves along with this rotation and at certain angle the spectrum turns back and moves in opposite direction. The angle where exactly the spectrum turns back is the angle of minimum deviation δ_{min}. Exactly at this point, keep the vernier table fixed.

   (Note: You may not observe this turning back of spectrum of colors in your first try. In that case, play with fine rotations of telescope and vernier table till you observe it. Remember that for minimum deviation to occur the ray direction inside the prism must be parallel to the base. This should give you an intuition on how to arrange the positions of telescope and vernier table.)
4. Once the vernier table is fixed at the angle of minimum deviation, slowly rotate the telescope so that the cross wires of the telescope coincide with one of the colors of the spectrum. Repeat this procedure for all the colors and note down the corresponding rotation angles (θ) of telescope in the observation table.

   (Note: Blue and Indigo are flipped in the order of colors. Please take this into account.)
5. Now, remove the prism from the vernier table and rotate back the telescope to place its cross wires on the undeviated ray. Note down the corresponding telescope reading (θ').
6. Calculate angle of minimum deviation ($\delta_{\min} = \theta - \theta'$) for each color and tabulate it.
7. Calculate refractive index (μ) for each color from equation 3 and tabulate it.

Observations:

Table I: Measurement of angle of prism (A)

Position I $\boldsymbol{\theta_1}$ in deg.	**Position II** $\boldsymbol{\theta_2}$ in deg.	**2A = $\boldsymbol{\theta_2 - \theta_1}$**(in deg.)	**Prism Angle A (**in deg.)

Table II: Measurement of angle of minimum deviation ($\boldsymbol{\delta_{min}}$)

[Angle of undeviated ray ($\boldsymbol{\theta'}$) = ... in deg.]

Sl.	**Color**	**Angle of deviated ray ($\boldsymbol{\theta}$)**	$\boldsymbol{\delta_{min} = \theta - \theta'}$ **(in deg.)**	**Refractive Index** $\boldsymbol{\mu}$ **(use eqn. 3)**	**λ (in nm)**	**1/λ²** **(nm⁻²)**
1	Indigo				435.83	
2	Blue				491.66	
3	Green				546.07	
4	Yellow				578.0	
5	Orange				615.20	
6	Red				690.75	

Results and Calculations:

1. Draw a graph of μ vs $1/\lambda^2$.
2. Extract values for the Cauchy constants, *a* (intercept) and *b* (slope) from your graph. Note *a* is unitless and *b* has units of nm^2. Please note that the intercept has to be obtained at the value of $1/\lambda^2 = 0$.
3. From the calculated values of the constants *a* and *b* and the formula given by Eq. (4), plot the variation of refractive index μ with respect to wavelength in the visible region of the spectrum from 400 nm to 750 nm.

Appendix 1
Spectrometer and its Adjustment

Basic description of a Spectrometer:

The spectrometer is an instrument for studying the optical spectra. Light coming from a source is usually dispersed into its various constituent wavelengths by a dispersive element (prism) and then the resulting spectrum is studied. A schematic diagram of prism spectrometer is shown in Fig.1. It consists of a collimator, a telescope, a circular prism table and a graduated circular scale along with two verniers. The collimator holds an aperture at one end that limits the light coming from the source to a narrow rectangular slit. A lens at the other end makes a parallel beam which falls on the face of the prism. The telescope receives the light dispersed by the prism and focuses it onto the eyepiece. The angle between the collimator and telescope are read off by the circular scale. The detail description of each part of the spectrometer is given below.

(i) Collimator (C): It consists of a horizontal tube with a converging achromatic lens at one end of the tube and a vertical slit of adjustable width at the other end. The slit can be moved in or out of the tube by a rack and pinion arrangement and its width can be adjusted by turning the screw attached to it. When properly focused, the slit lies in the focal plane of the lens. Thus, the collimator provides a parallel beam of light.

(ii) Prism table (P): It is a small circular table and capable of rotation about a vertical axis. It is provided with three leveling screws. On the surface of the prism table, a set of parallel, equidistant lines parallel to the line joining two of the leveling screws, is ruled. Also, a series of concentric circles with the center of the table as their common center is ruled on the surface. A screw attached to the axis of the prism table fixes it with the two verniers and also keep it at a desired height. These two verniers rotate with the table over a circular scale graduated in fraction of a degree. The angle of rotation of the prism table can be recorded by these two verniers. A clamp and a fine adjustment screw are provided for the rotation of the prism table. It should be noted that a fine adjustment screw functions only after the corresponding fixing screw is tightened.

(iii) Telescope (T): It is a small astronomical telescope with an achromatic doublet as the objective and the Ramsden type eye-piece. The eye-piece is fitted with cross-wires and slides in a tube which carries the cross-wires. The tube carrying the cross wires in turn, slides in another tube which carries the objective. The distance between the objective and the cross-wires can be adjusted by a rack and pinion arrangement using the focus knob. It can be rotated about the vertical axis of the instrument and may be fixed at a given position by means of the clamp screw and slow motion can be imparted to the telescope by the fine adjustment screw.

(iv) Circular Scale (C.S.): It is graduated in degrees and coaxial with the axis of rotation of the prism table and the telescope. The circular scale is rigidly attached to the telescope and turned with it. A separated circular plate mounted coaxially with the circular scale carries two verniers, 180° apart. When the prism table is clamped to the spindle of this circular plate, the prism table and the verniers turn together. The whole instrument is supported on a base provided with three leveling screws. One of these is situated below the collimator.

<u>Adjustments of a Spectrometer</u>: The following essential adjustments are to be made step by step in a spectrometer experiment:

(i) Adjusting cross wires and focusing image: Rotate the telescope towards any illuminated background at a far off point. On looking through the eye-piece, you will probably find the cross-wires appear blurred. Move the eye-piece inwards or outwards until the cross-wire appears distinct.

Place the telescope in line with the collimator. Look into the eye-piece without any accommodation in the eyes. The image of the slit may appear blurred. Make the image very sharp by turning the focusing knob of the telescope and of the collimator, if necessary. If the image does not appear vertical, make it vertical by turning the slit in its own plane. Adjust the width of the slit to get an image of desired intensity.

(ii) Optical leveling of a prism: The leveling of a prism makes the refracting faces of the prism vertical only when the bottom face of the prism, which is placed on the prism table, is perpendicular to its three edges. But if the bottom face is not exactly perpendicular to the edges, which is actually the case, the prism should be leveled by the optical method, as described below:

(a) Illuminate the slit by mercury light and place the telescope with its axis making an angle of about 90° with that of the collimator.

(b) Place the prism on the prism table with its vertex coinciding with that of the table and with one of its faces perpendicular to the line joining two of the leveling screws of the prism table.

(c) Rotate the prism table till the light reflected from this face AB of the prism enters the telescope. Look through the telescope and bring the image at the center of the field of the telescope by turning the two screws equally in the opposite directions.

(d) Next rotate the prism table till the light reflected from the other face AC of the prism enters the telescope, and bring the image at the center of the field by turning the third screw of the prism table.

The following alternate method can also be used to focus Telescope and collimator in a dark room.

Focusing for Parallel rays by Schuster's method: This is the best method of focusing the telescope and the collimator for parallel rays within the space available in the dark room. In order to focus the telescope parallel light rays are required and this in turn requires a properly adjusted collimator. For this reason, the adjustment of the telescope and the collimator are usually done together.

Schuster's method is based on the fact that the effect of the prism on the divergence of the beam is different on opposite sides of this minimum deviation position. As explained in the theory section, the emergent beam will be less divergent (or more divergent) than the incident beam as the angle of incidence is increased (or decreased) from the minimum deviation value. This property of the prism can be used to obtain an accurately collimated beam. The method is explained below:

(a) Place the prism on the spectrometer table and set the telescope at a particular angle.

(b) Illuminate the slit of the spectrometer with light from a sodium lamp. Rotate the prism table and observe the images of the slit through the telescope as it passes through the minimum deviation position.

(d) Lock the telescope at an angle a few degrees greater than this position.

(e) Turn the prism table away from its minimum deviation position so that apex A moves towards the telescope and a spectral line is brought into the center of the field of view of the telescope. Adjust the focus of the telescope until this line image is as sharp as possible.

(f) Turn the prism table to the other side of the minimum deviation position until the same spectral line is again at the center of the telescopes field of view. Now adjust the focus of the collimator until a sharp image is once more obtained.

(g) Repeat this process until no further adjustment is required. If the same line image is sharply focused when viewed on either side of the minimum deviation position, then the light beam through the prism is properly collimated.