Laboratory Manual

EPHY105L, Electromagnetics

B.Tech, 1st Year, 1st Semester

Department of Physics

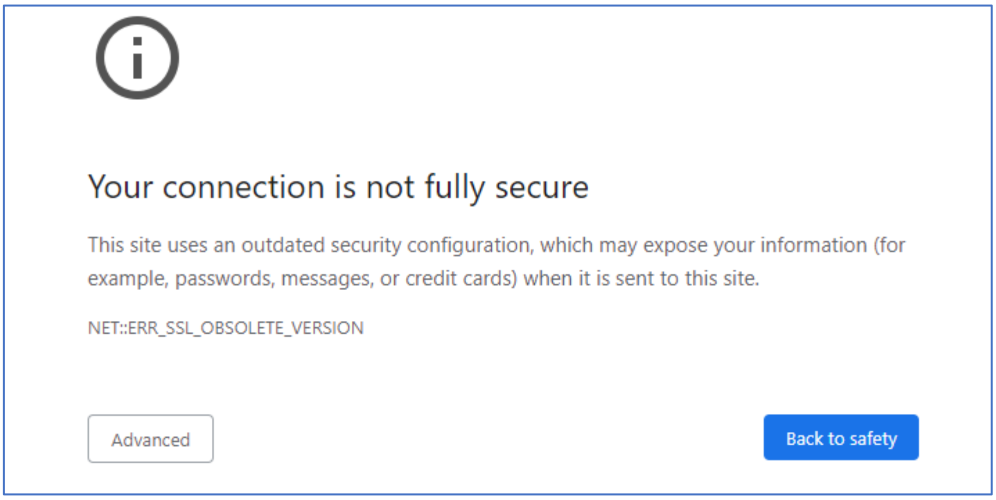
School of Engineering and Applied Sciences

BENNETT
UNIVERSITY

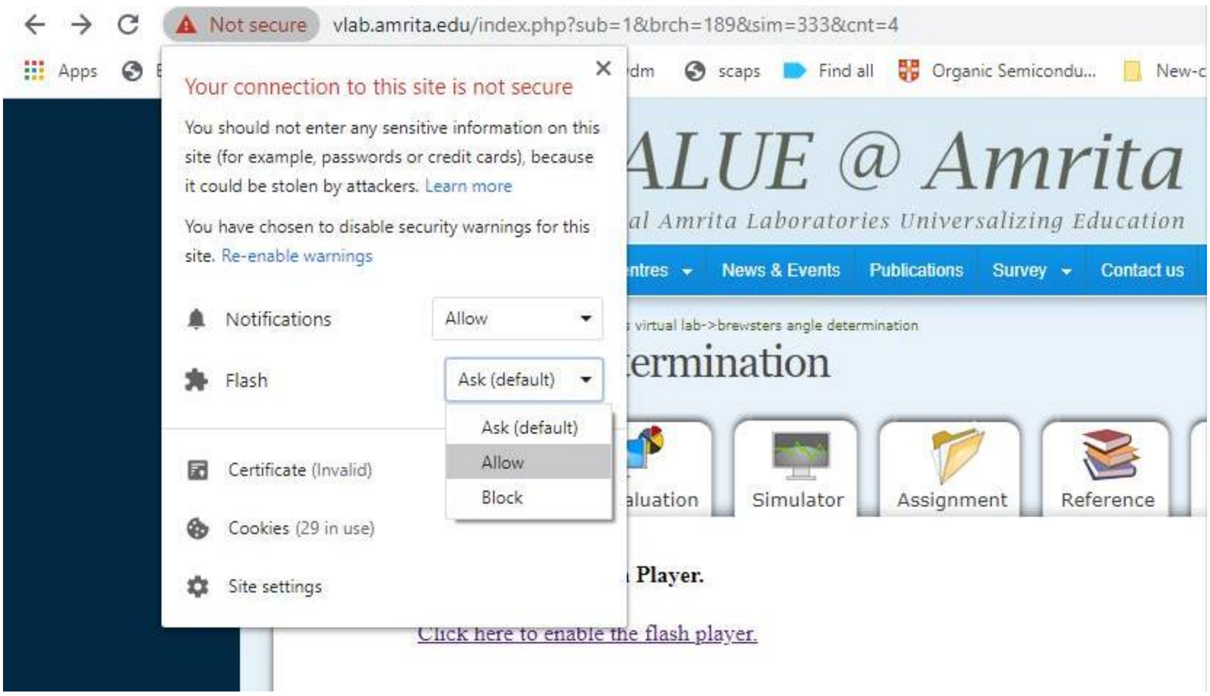
Table of Contents

Instructions for Accessing Virtual Lab and performing the experiments.

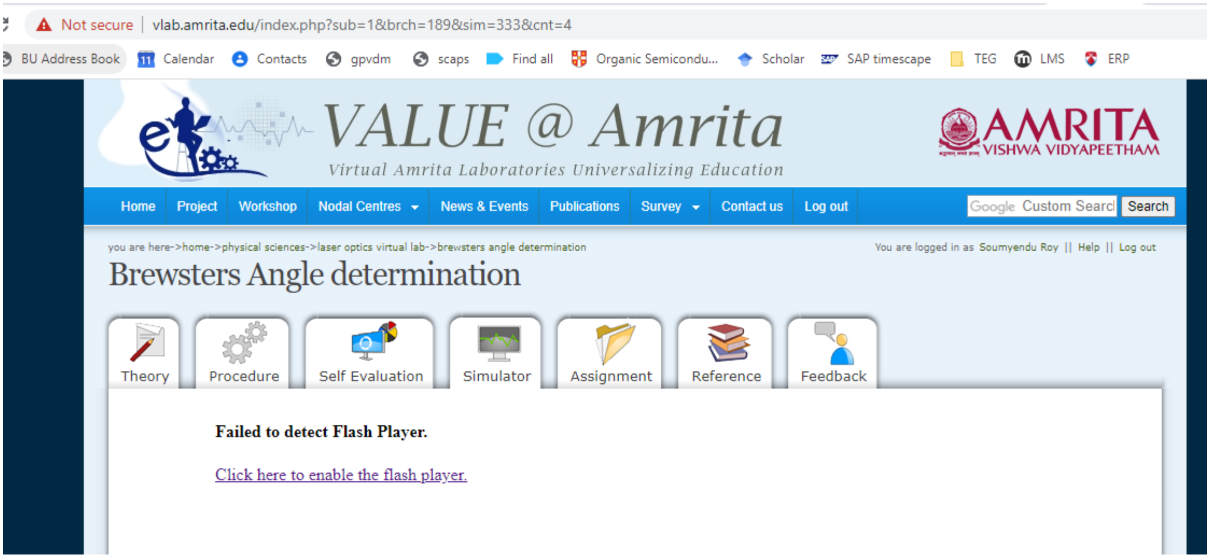
1. You will need to register yourself at the website of Amrita Vishwa Vidyapeetham's Virtual labs (https://vlab.amrita.edu/index.php?pg=bindex&bsub=guest_registration_form). Create a password to access the site
2. When opening the site your browser may not connect saying that the site is not secure.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

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

Experiment No. 1
Newton's Rings

Aim

The aim of the experiment is to determine wavelength of light using Newton's rings experiment.

Apparatus:

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

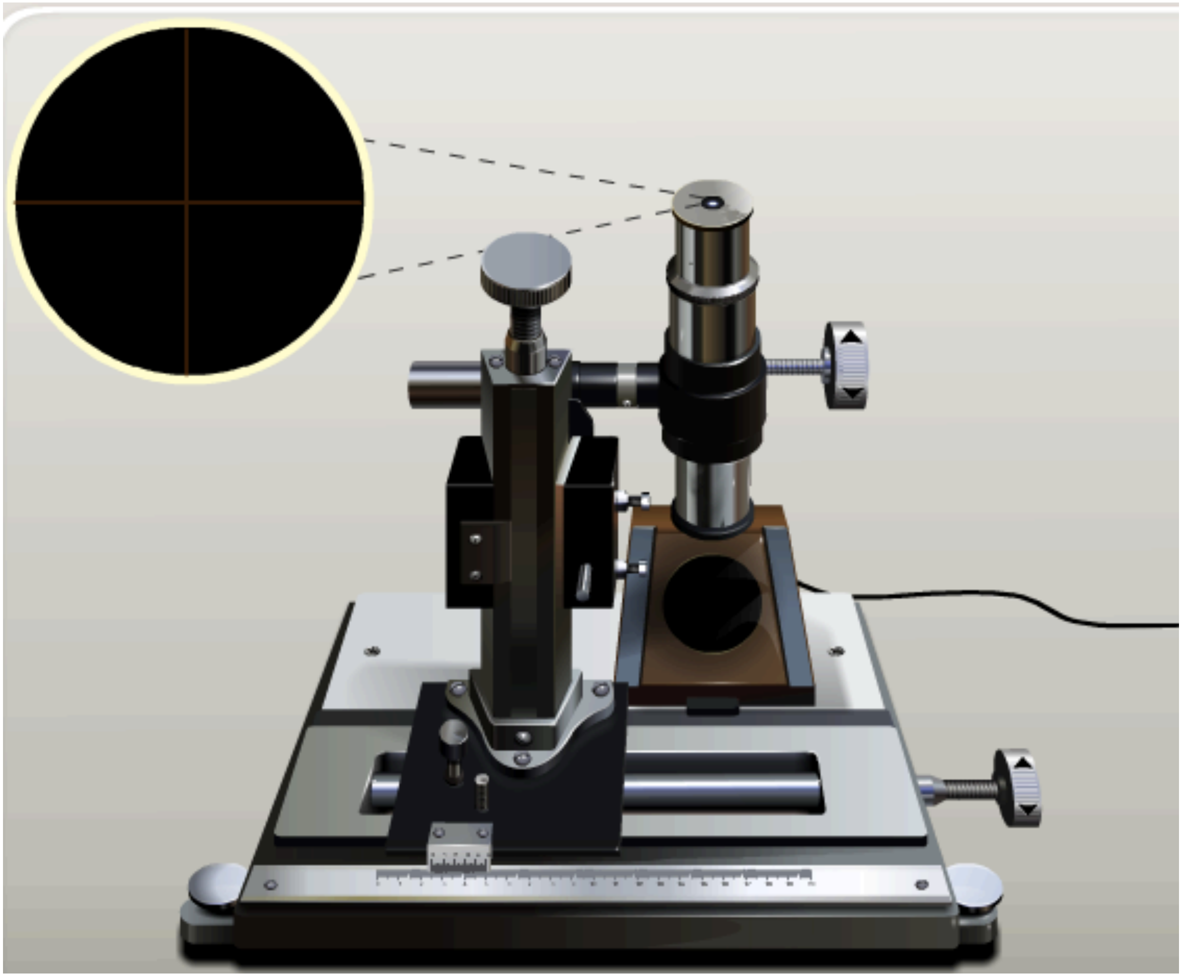


Fig. 1: Basic set-up of Newton's rings experiment.
Source: Amrita Lab (https://vlab.amrita.edu/?sub=1&brch=189&sim=335&cnt=4)

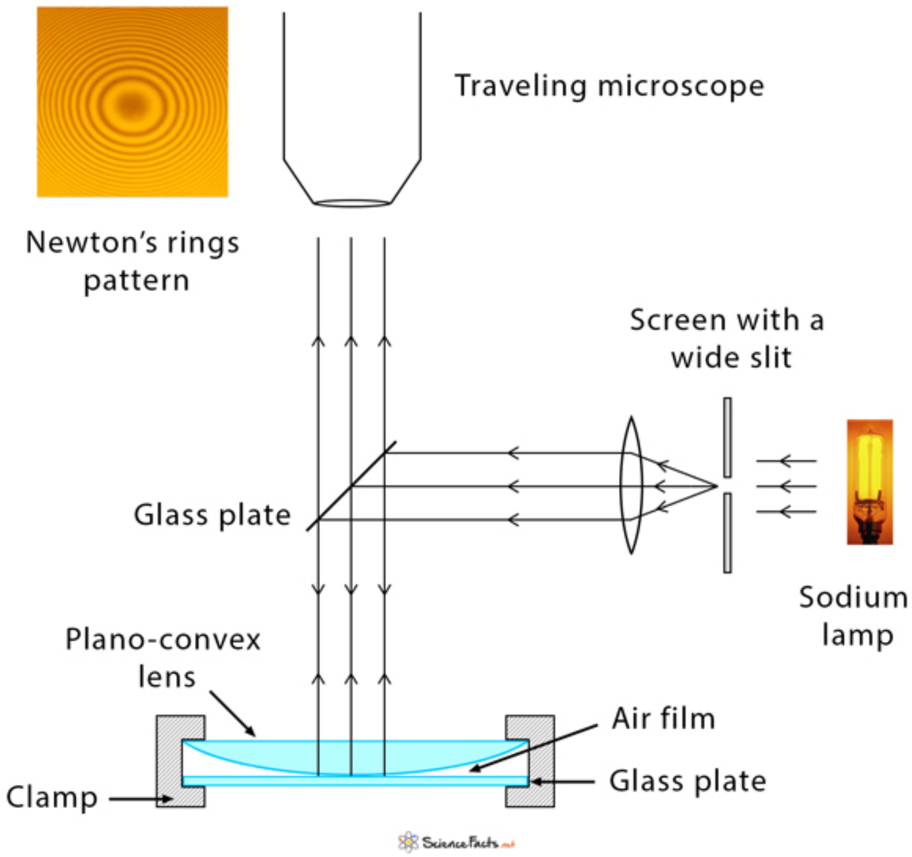


Fig. 2: A schematic ray diagram to explain how Newton's rings are formed.
Source: https://www.sciencefacts.net/newtons-rings.html

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 Neon 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.

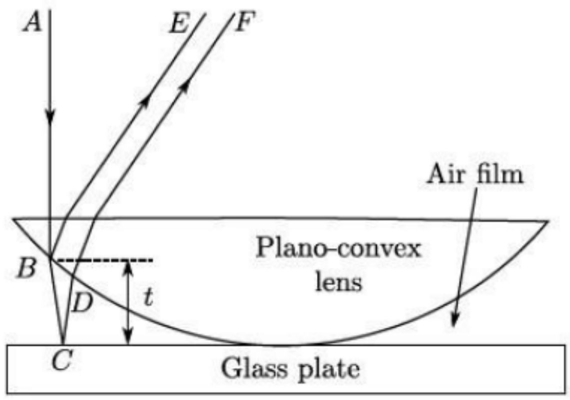


Fig. 3: Interfering rays formed from the upper and lower surfaces of the air-film.

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,

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

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.

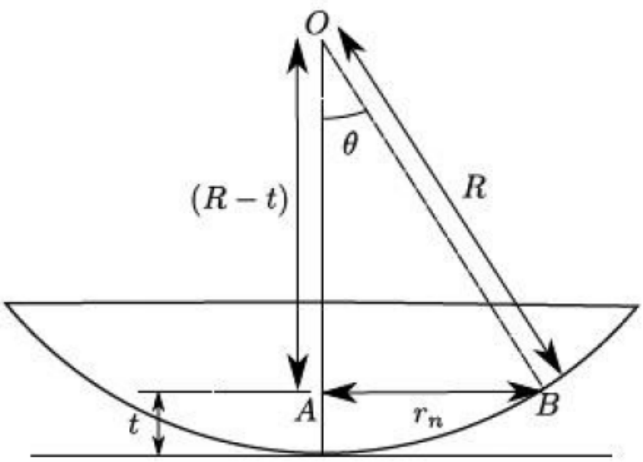


Fig. 4: Geometry used to determine the thickness of the air-film.

7Determination 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, μ = 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:

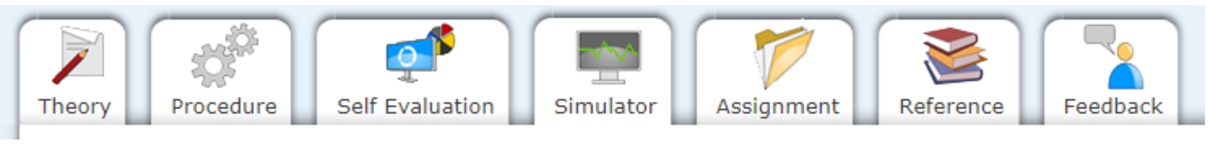
$$\frac{|\lambda - \lambda_0|}{\lambda_0} \times 100\%, where\ \lambda_0\ is\ the\ actual\ wavelength\ of\ the\ used\ light \tag{7}$$

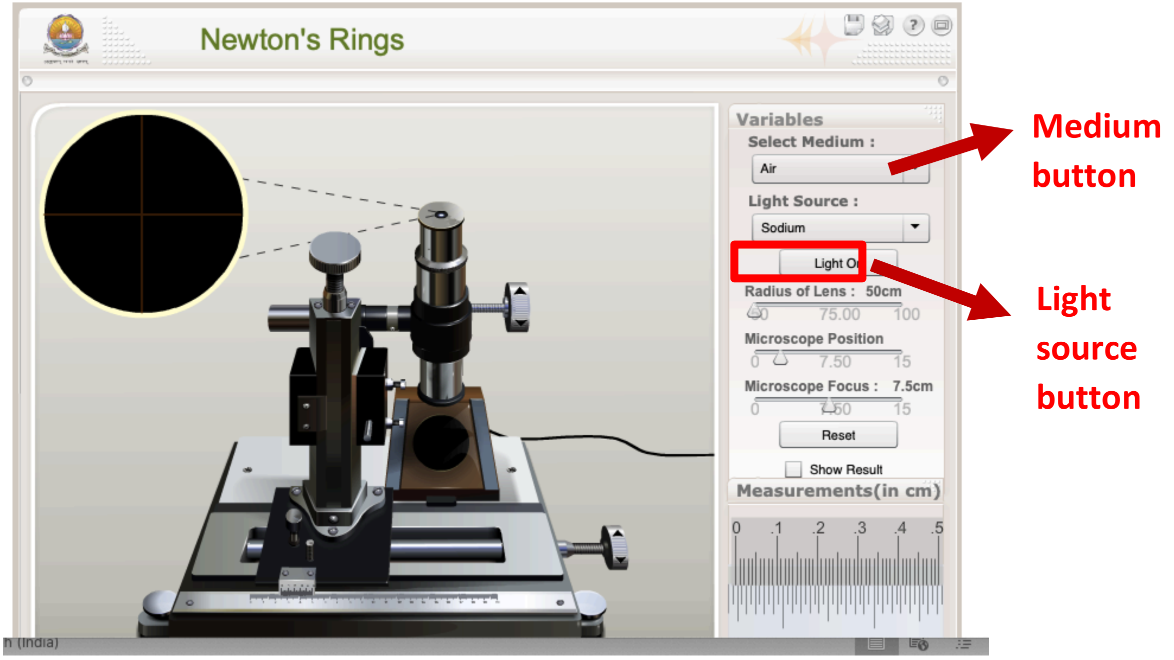
Procedure:

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.

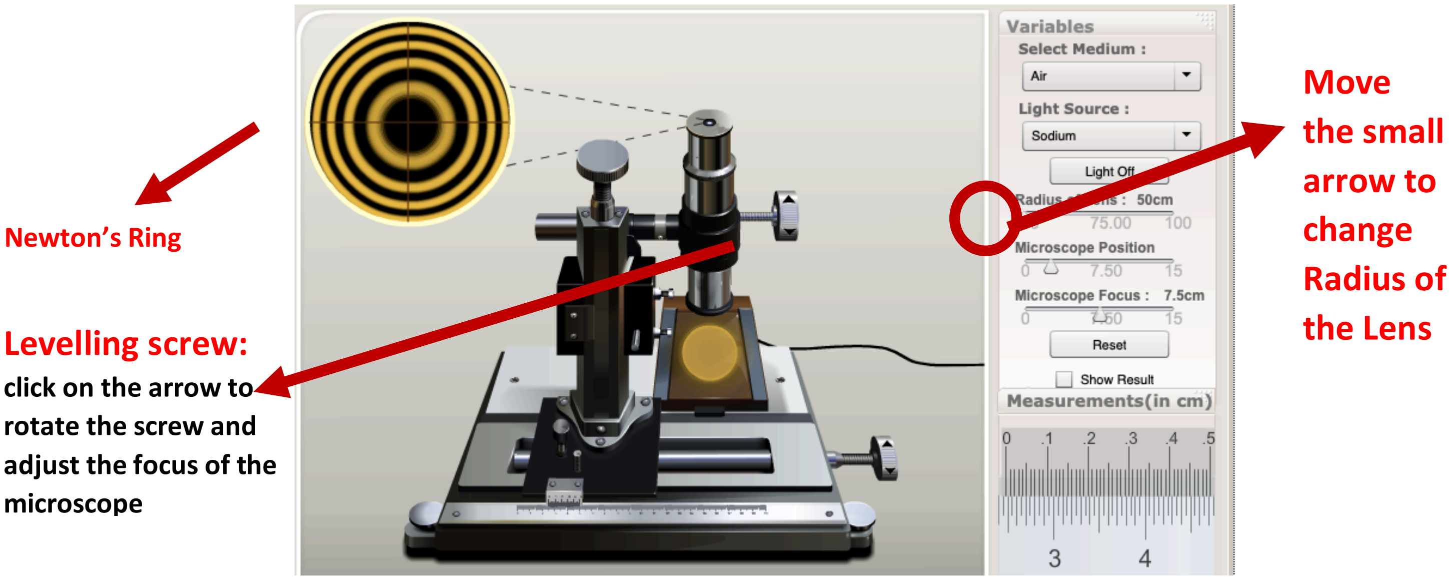




4. Select Medium and Light Source as indicated by arrow in the above picture.
For the 1st set of data, please choose
Medium = Air, and
Light source= Sodium.
Switch on the light by clicking "light on" button (highlighted by a red square). This will start the experiment.

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.

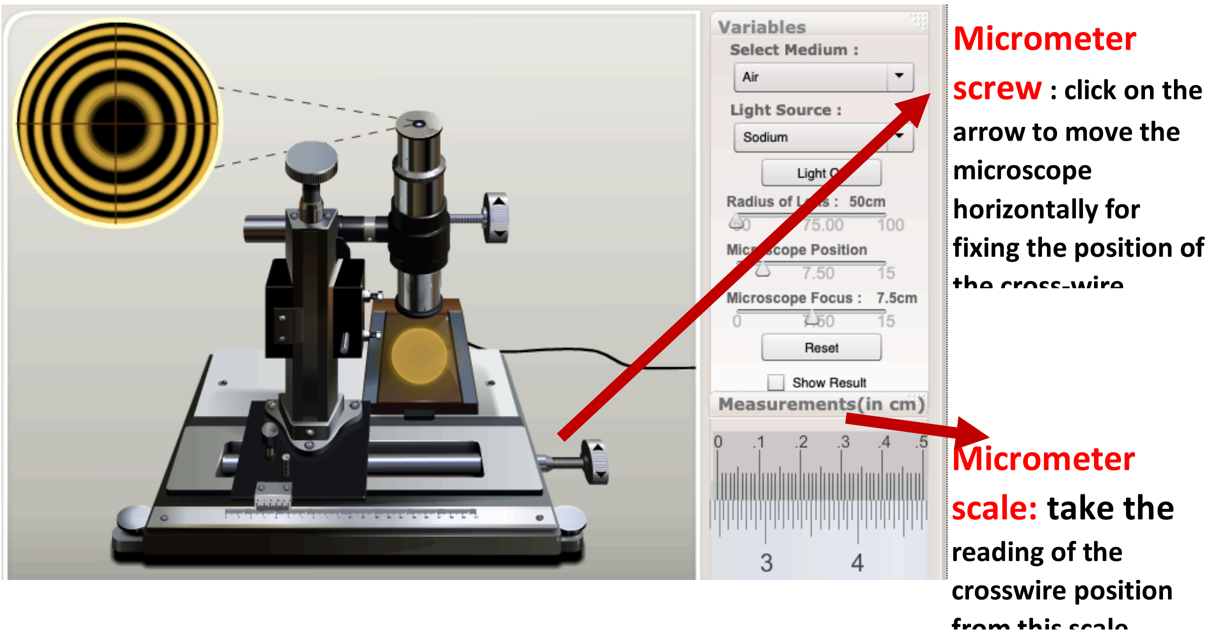
Note: Once it is properly focused, the fringes will appear bright and sharp and going away from the focus will make the fringes blurred.



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 14^{th} 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 12^{th} 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 12^{th}, 11^{th} ....1^{st} ring. Keep on moving and take the readings of 1^{st}, 4^{th}, …..12^{th} ring of the other side.

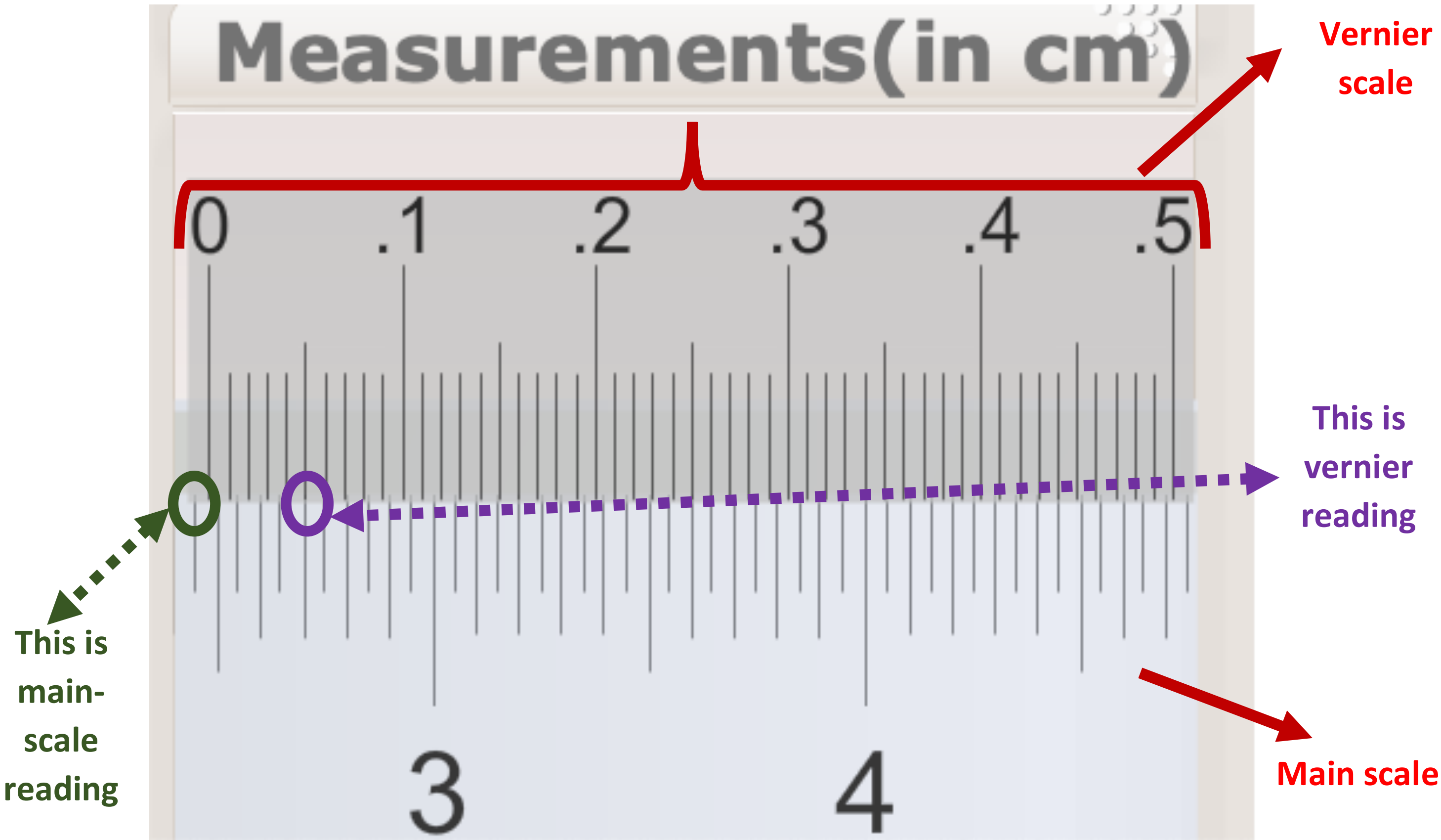
(Please note that you need to move the micrometer always in one direction, so that no backlash error appear in your reading.)

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* = *Neon*,** 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) Calculation of the Vernier constant or least count:
1 main scale division = 0.05 cm
10 Vernier division = 9 Main scale division
Vernier Constant = (1-9/10) x 0.05 = 0.005 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:*** One of the line of the Vernier scale will coincide with the main scale (marked as purple circle). Take the reading of that point from Vernier scale. **Please note that you need to find the coincidence within the first 10 divisions of the 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 $D_n = \lvert a-b \rvert$ (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 Neon light.

Ring no. (n)	Microscope reading						Diameter $D_n = \lvert a-b \rvert$ (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 Neon).
4. Estimate the error for both the cases using equation 7.

Note: The actual wavelengths of sodium and Neon lights are **589.3 nm** and **632.8 nm,** respectively.

Results:

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

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

Experiment No. 2
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.

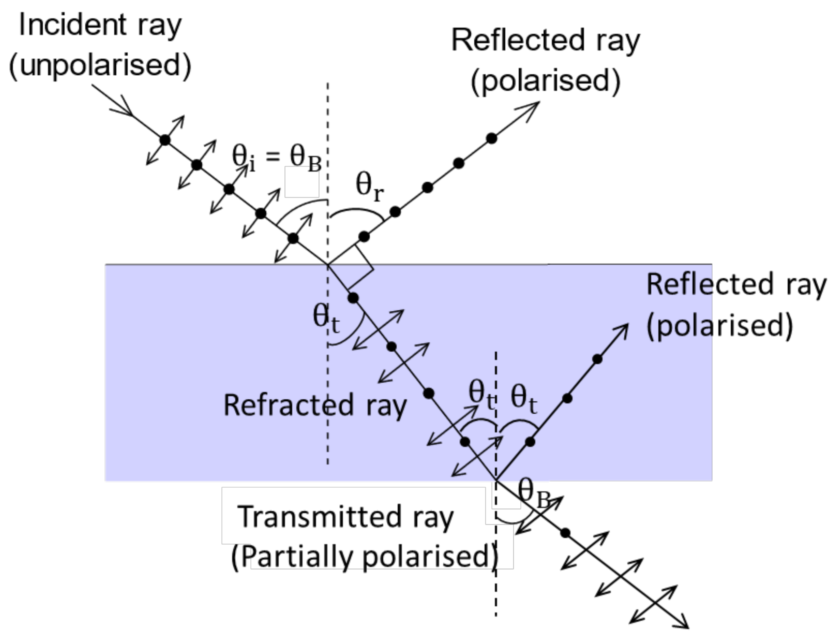


Figure 1. Polarisation of light due to reflection. ↕ and • indicate polarisations parallel and perpendicular to the plane of incidence.

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.

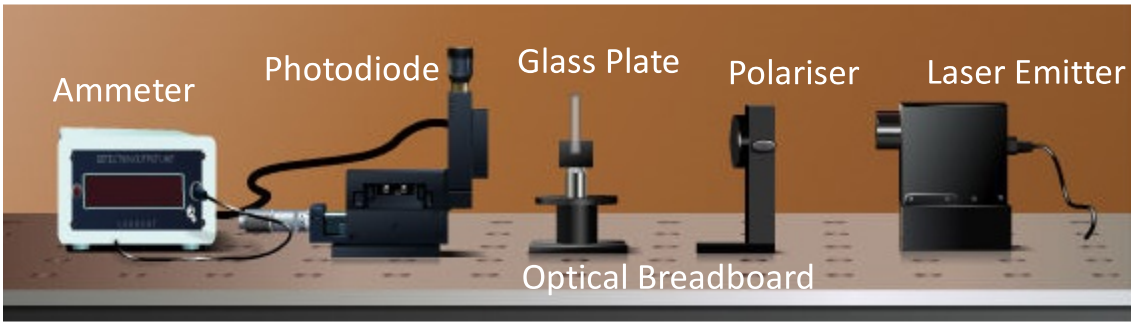


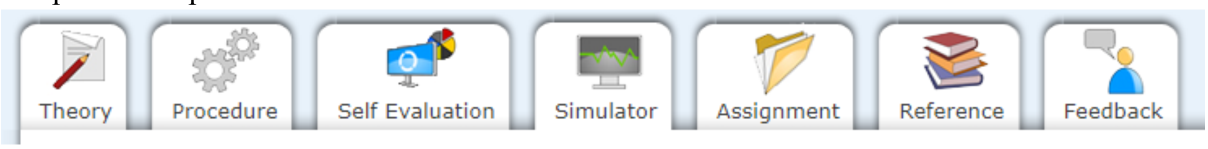
Figure 2. Experimental setup for determination of Brewster's angle.
Source: vlab.amrita.edu/index.php?sub=1&brch=189&sim=333&cnt=4

Experimental set-up used is shown in figure 2. The polariser is set such that it polarises the light perpendicular to the plane of incidence (i.e. the vertical 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 is completely polarised perpendicular to the plane. Since the incident light in this experiment is already polarised perpendicular to the plane, at Brewster's angle most of the light is reflected back and the intensity of transmitted beam becomes minimum.

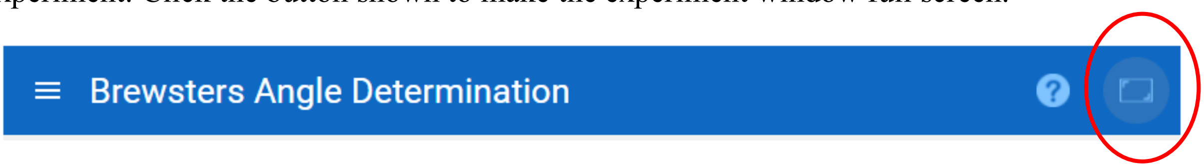
Procedure for the virtual experiment

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.



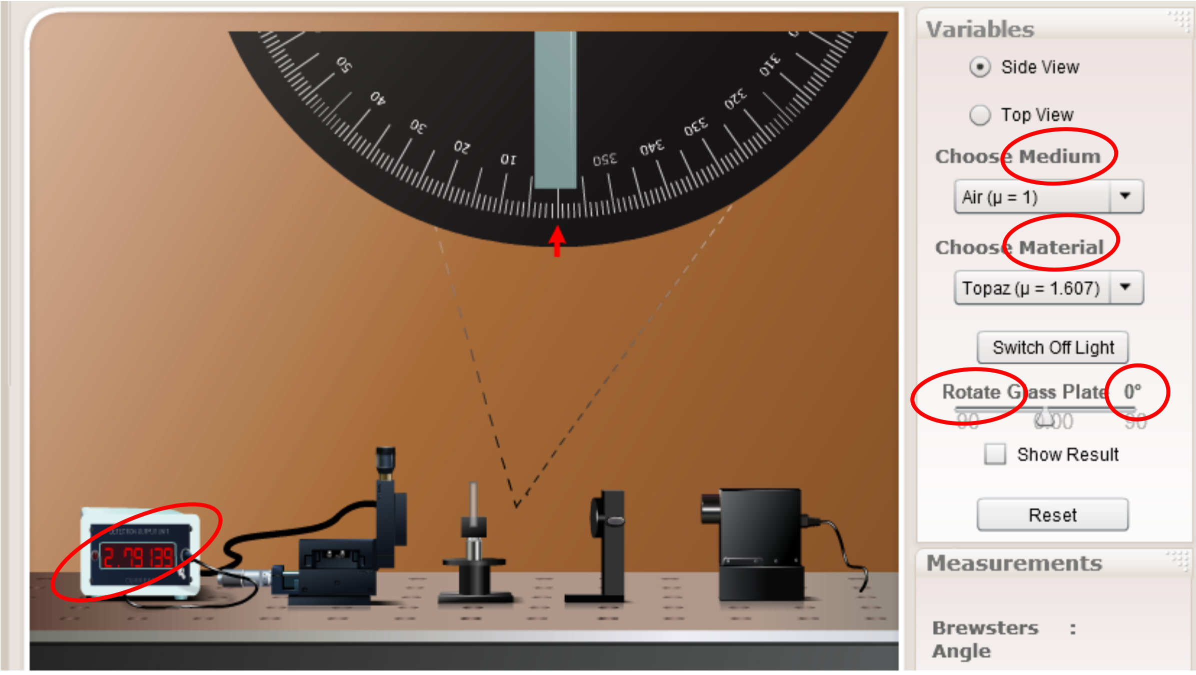
3. Click on the "simulator" tab and login with your registered credentials to initiate the virtual experiment. Click the button shown to make the experiment window full screen.



4. Drag the different components to the optical breadboard to prepare the experimental set-up. Note that there is only one predefined way in which you can place the components (see the figure 2).

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 minimum. Note down this angle as $\theta_1{}^0$. Check the ammeter readings for negative values of angle of incidence and note down the angle ($\theta_2{}^0$) for which the reading is minimum once again. Take the average of the magnitudes of the two angles. This gives the experimentally obtained value of Brewster’s angle ($\theta_B{}^0$) 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:

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

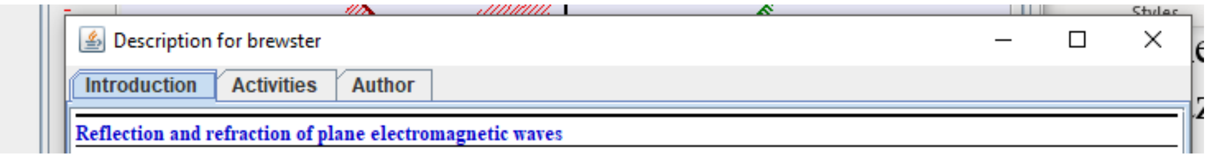
Note: Keep numbers upto 3-4 decimal places in all your calculations

11. Repeat steps 7-10 after changing “material” to “crown glass” and “flint glass”. These are different forms of glass. Keep “air” as the “medium” during these experiments.

Verification of Brewster's Law using an electromagnetic wave visualization tool

12. 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/

13. 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.



14. In the visualization tool 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 $\left(\frac{\mu_2}{\mu_1}\text{ is referred to as }\frac{n_2}{n_1}\text{ here}\right)$ in the visualization tool that is the closest match to the "medium" - "material" combination of air and topaz. Clicking on the "start" button shows the propagation of the waves.

15. Now vary the angle of incidence till the amplitude of the reflected wave reaches a minimum ($\approx$ 0). This happens because at the Brewster's angle, reflected wave must be polarised perpendicular to plane of incidence, but there is no perpendicular component in the incident light. Note down this angle ($\theta_{B2}{}^{0}$) 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.

16. 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.

17. 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.

18. 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 ($\theta'_{B2}{}^{0}$). Note down this value and verify that the sum of the angles ($\theta_{B2}{}^{0} + \theta'_{B2}{}^{0}$) 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	θ_1^0	θ_2^0	Brewster's angle (virtual experiment)	Brewster's angle (expected)	% error
1	Air		Topaz						
2			Crown glass						
3			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.

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

Conclusions:

Experiment No. 3
Diffraction Grating

<u>Aim of the experiment</u>:

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.

<u>Apparatus required</u>:

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

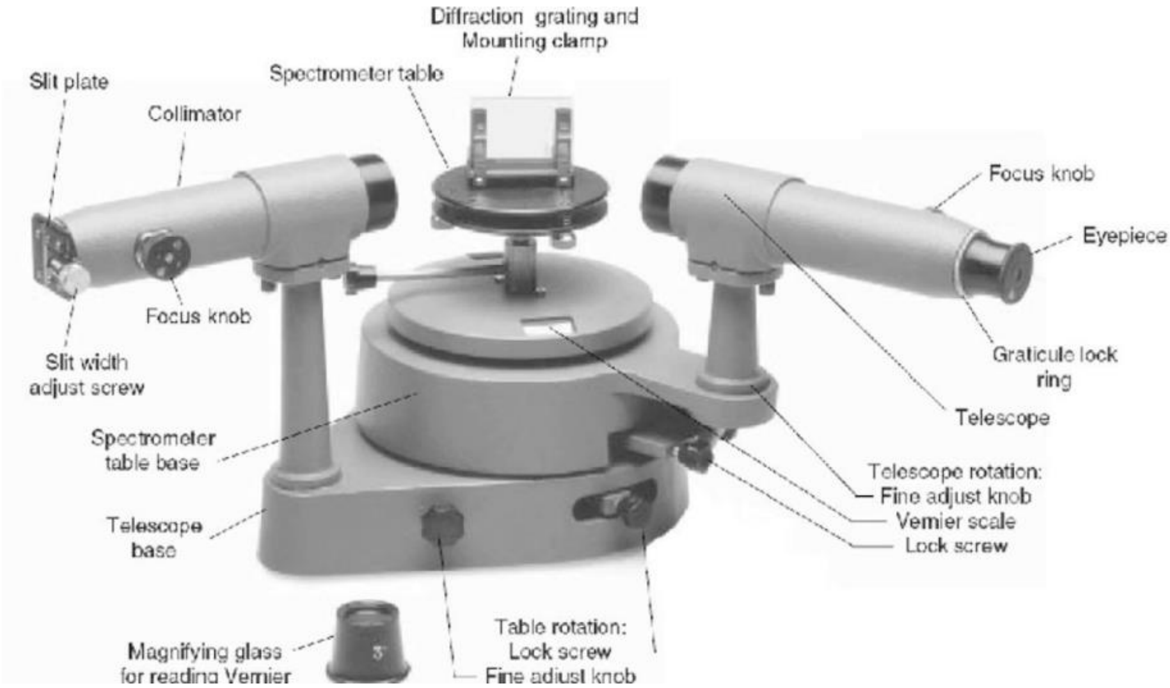


Fig. 1: Picture of the spectrometer with diffraction grating.

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.

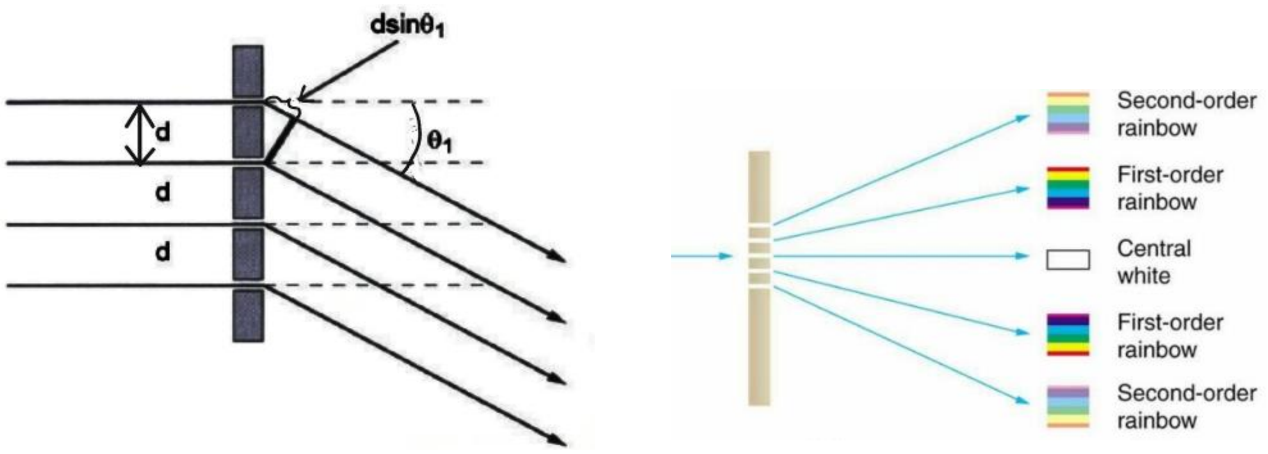
According to Fig. 2, the path difference between the incident and diffracted wave is $d \sin \theta_1$ (θ_1 is the angle between incident and diffracted waves) and bright fringe is observed when the equation $d \sin \theta_1 = \lambda$ is satisfied. At some larger angle θ_2, when the path difference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

$$d \sin \theta_n = n \lambda \qquad (1)$$

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 ≥ 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.

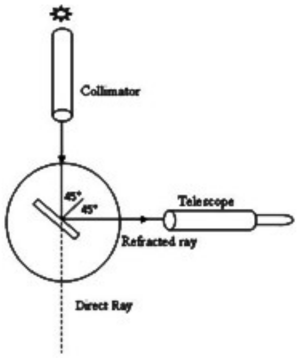


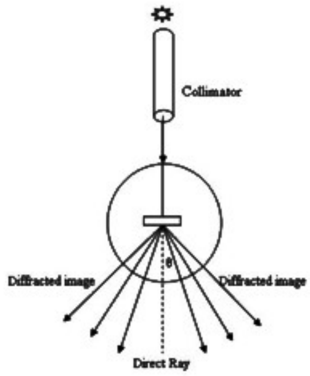
(a) (b)

Fig. 2: (a) Geometrical conditions for the diffraction from multiline grating. (b) Different orders of spectra from diffraction 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.

INSTRUCTIONS FOR VIRTUAL LAB:

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:

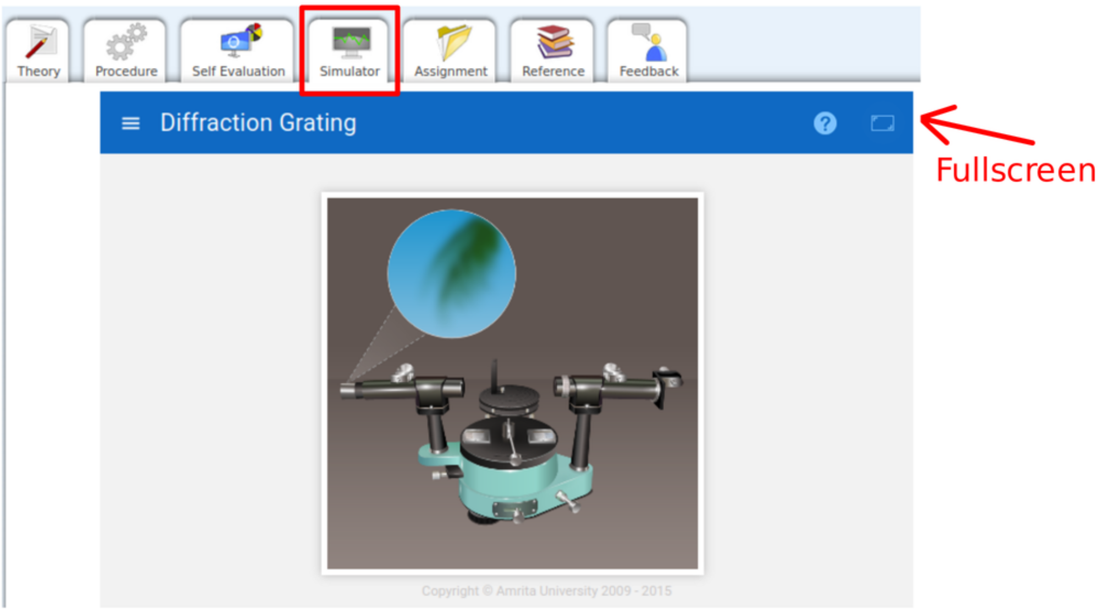
1. **Telescope Calibrate Slider** : This slider helps the user to change the focus of telescope.
2. **Start Button** : Helps the user to start the experiment after setting the focus of telescope. The Start Button can be activated only if the focus of the telescope is proper.
3. **Light Toggle Button** : 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:

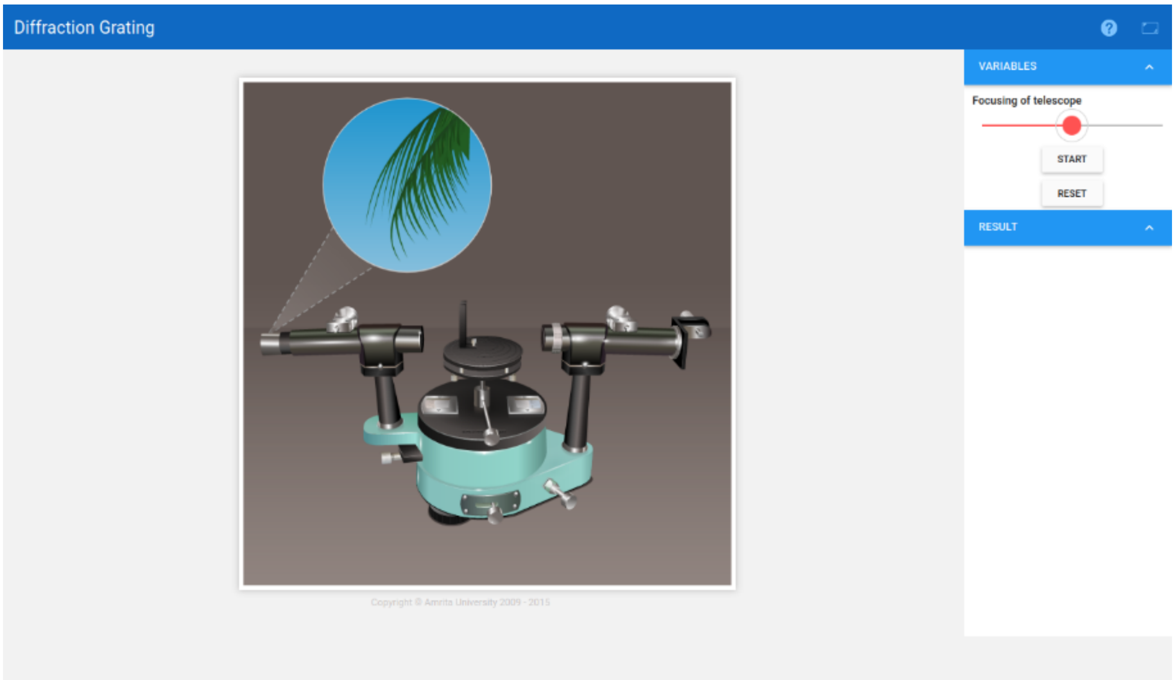
1. Go to the Amrita Vishwa Vidyapeetham virtual lab's website for "Diffraction grating" https://vlab.amrita.edu/?sub=1&brch=281&sim=334&cnt=4

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

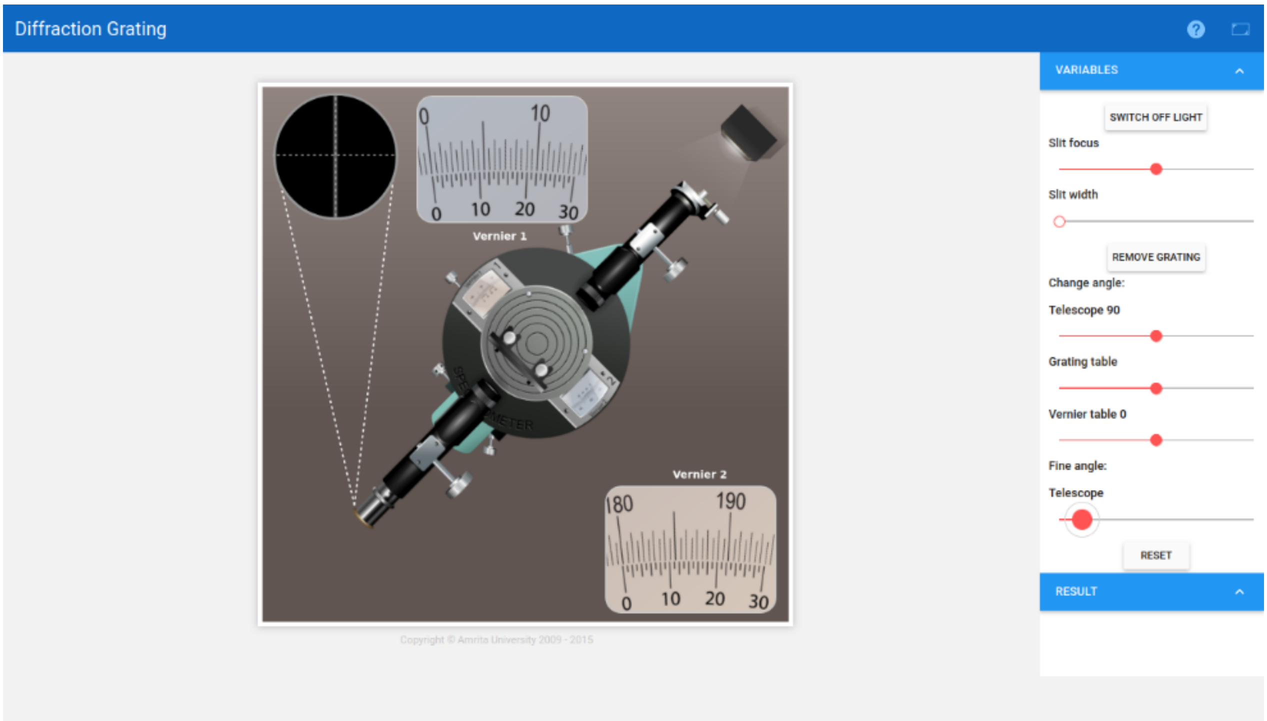
3. Click on the "Simulator" tab and login with your registered credentials to initiate the virtual experiment. Click on the rectangle symbol to view it in fullscreen and to see the controls.

4. 

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.

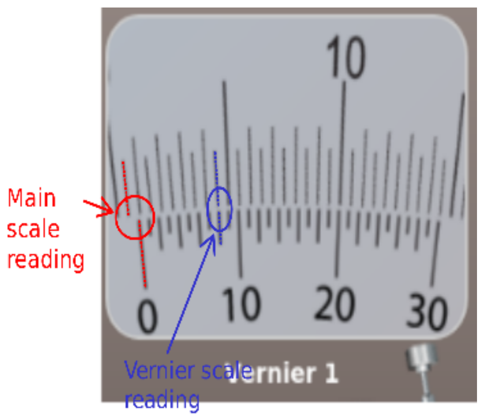
10. Two scales are be visible at two opposite side of the vernier table. One scale is attached with the vernier table showing divisions from 0 to 30 and the other is attached with the telescopes that goes from 0 to 360 degree which is the main scale. Calculate the value of one small division in the main scale and least count of the vernier scale.

The least count can be calculated by using the formula:

Least count (LC) = (1 – MSD/VSD) x value of 1 small div. in main scale
where MSD is the minimum (integer) number of main scale divisions that match exactly with (integer) number of vernier scale divisions VSD. In this case, 10 VSD matches with 9 MSD, therefore, LC = 0.05 degree.

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.



However, the fine control on the telescope cannot be controlled that minutely to get reading as low as LC, but can be adjusted upto 0.1 degree. So you may also note the readings from the number that shows beside the Telescope variable.

11. 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, or the telescope.
    - 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.
12. 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 in the simulator spectra must be in the order 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, find the wavelength λ for each color and note down in table 2&3

Results

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. 4
Refractive index and Cauchy's constants

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

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

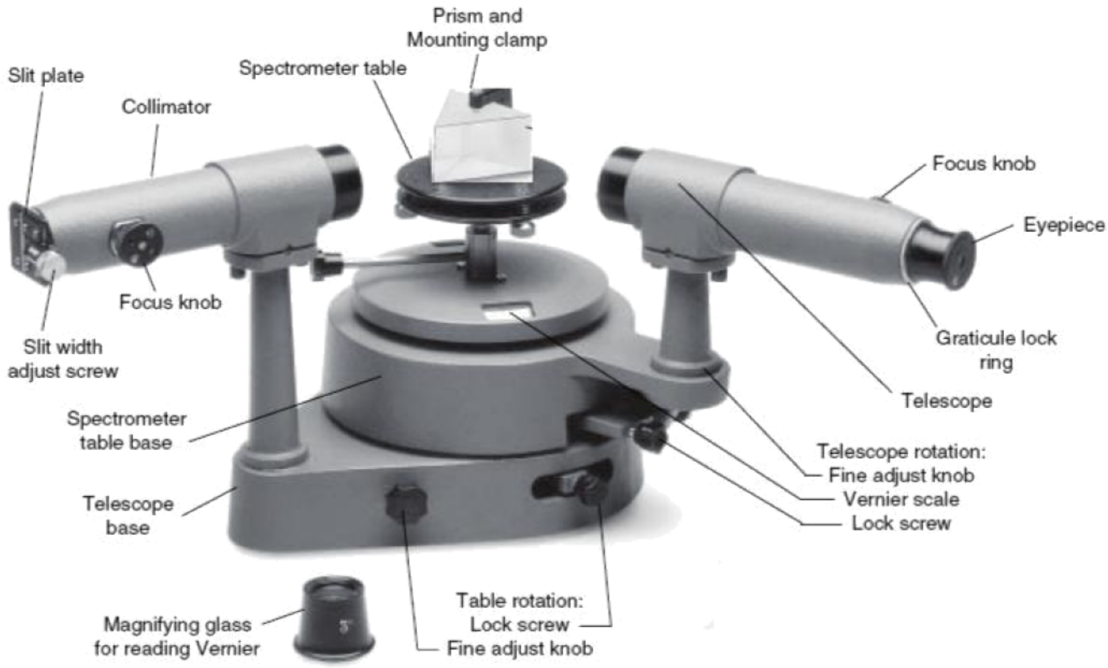


Fig. 1: Different parts of the spectrometer used in the laboratory

<u>Theory</u>:

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.

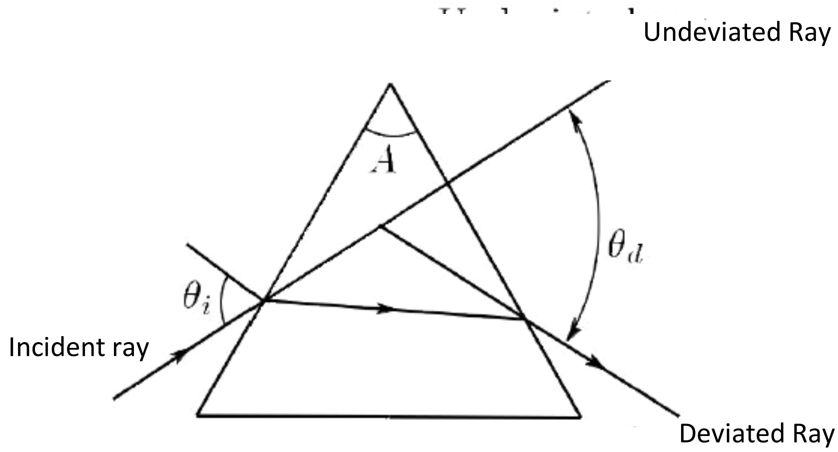


Fig. 2: Refraction of light through the prism.

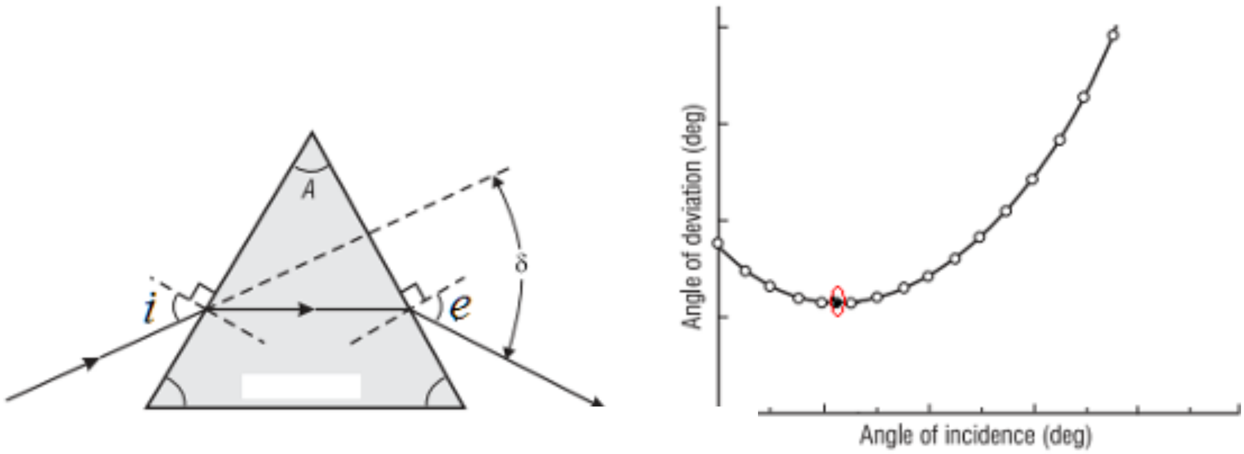


Fig. 3: Graph of the angle of deviation as a function of angle of incidence.

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 ($\theta i - \theta r$). 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.

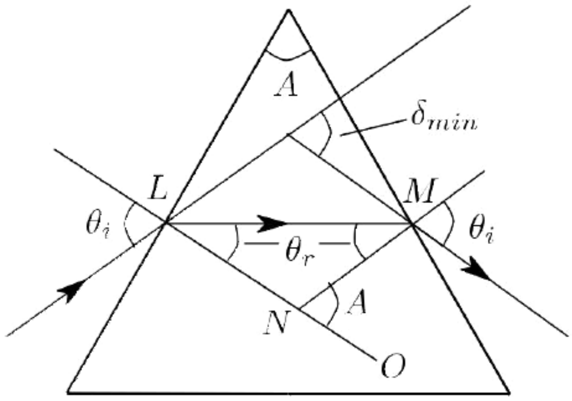


Fig. 4: Arrangement to determine angle of minimum deviation

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%, $\delta_{\min}$ 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:

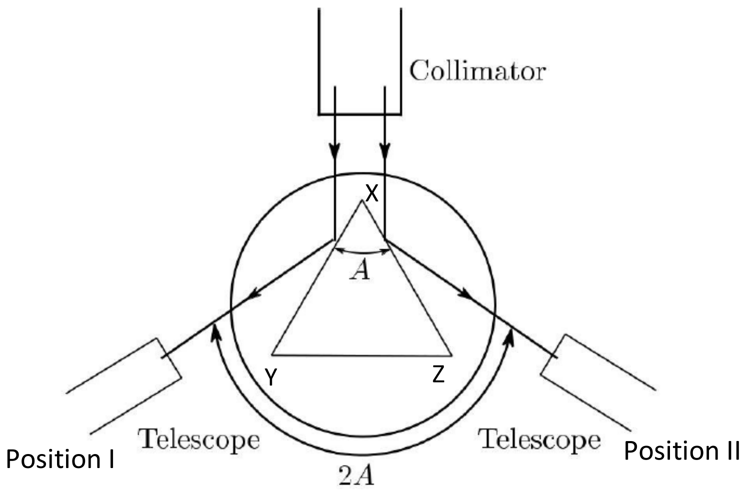


Fig. 5: Schematic set-up to measure the angle of prism

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 which is 2θ. From this find the angle of the prism θ.

Measurement of the angle of minimum deviation, $\boldsymbol{\delta}_{\text{min}}$ for each wavelength:

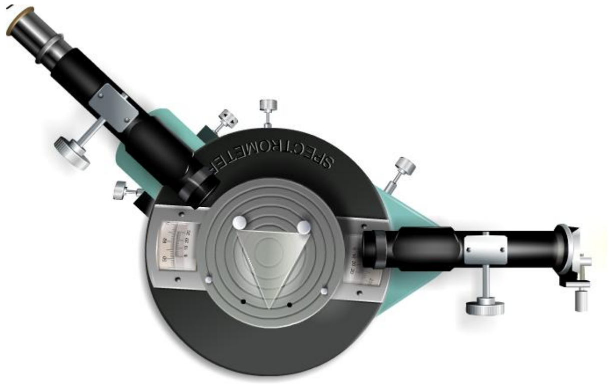


Fig. 6: Arrangement of setup to measure Cauchy's constants

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 ($\boldsymbol{\theta}$) of the telescope in the observation table.
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 ($\boldsymbol{\theta'}$).
6. Calculate angle of minimum deviation ($\boldsymbol{\delta_{\text{min}} = \theta - \theta'}$) for each color and tabulate it.
7. Calculate refractive index ($\boldsymbol{\mu}$) 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 ($\boldsymbol{\delta}_{\mathbf{min}}$)

[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 μ (use eqn. 3)**	**λ (in nm)**	**$1/\lambda^2$ (nm^{-2})**
1	Indigo					
2	Blue					
3	Green					
4	Yellow					
5	Orange					
6	Red					

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.

Experiment No. 5
Planck's constant using photoelectric effect

Aim of the experiment:
Measurement of Planck's constant using photoelectric effect and to determine work function and threshold frequency of the cathode material.

Apparatus used:
Light source with arrangement for producing light with different wavelengths and intensity, vacuum tube for photoelectric effect, voltage supply, ammeter.

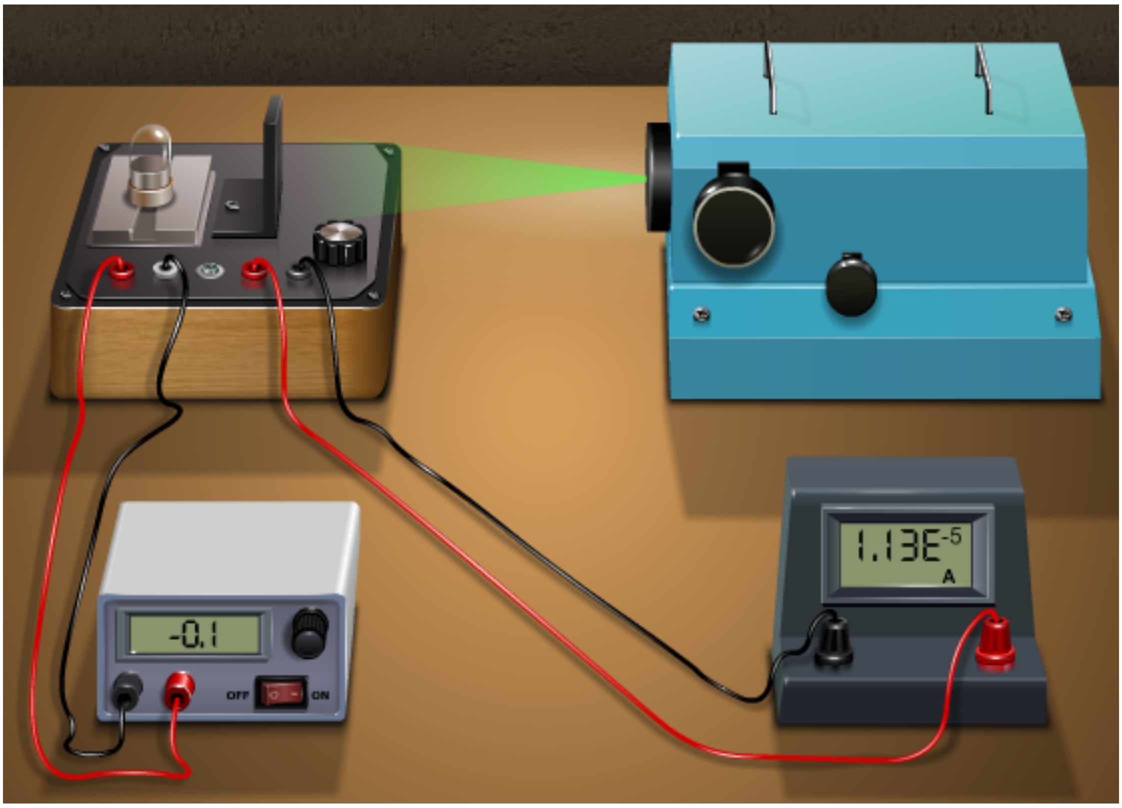


Figure 1: Experimental setup.

Theory:

The photoelectric effect is the emission of electrons when light shines on a material. Electrons emitted in this manner are also known as photo-electrons. The phenomenon was first observed by Heinrich Hertz in 1880 and explained by Albert Einstein in 1905 using Max Planck's quantum theory of light. Electrons are dislodged only by the impingement of photons when those photons exceed a certain minimum frequency (threshold frequency). Below that threshold, no electrons are emitted from the material regardless of the light intensity or the length of exposure to the light.

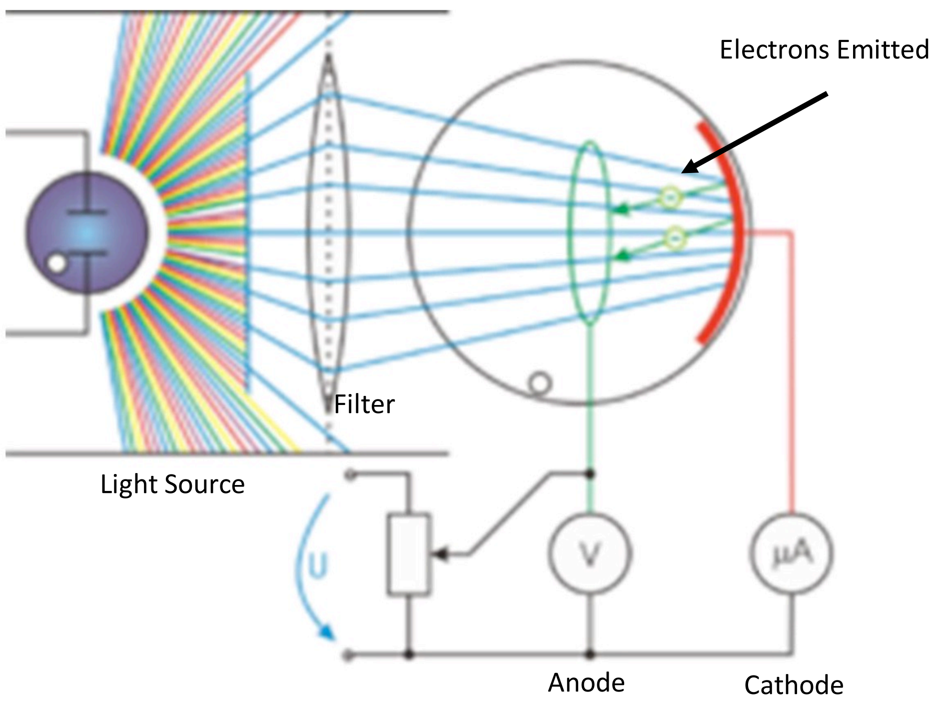


Figure2: Schematic diagram to demonstrate photoelectric effect.

According to Max Planck, radiation/light cannot have any arbitrary value of energy, instead it can only have values that are integral multiples of a certain fundamental/smallest unit, which is referred to as a quantum (plural quanta) of energy. In other words, energy of light is not continuous but discrete. In case of light this quantum of energy is also called a photon. For radiation with frequency ν or wavelength λ, the energy quantum or photon's energy is given by

$$E = h\nu = hc/\lambda \tag{1}$$

where $c = \nu\lambda$ is the speed of light ($c = 3\text{x}10^8$ ms^{-1} in free space), and h is the Planck's constant. Planck's theory is one of the foundational theory of quantum mechanics. According to Einstein's theory, light has a dual wave-particle nature and each photon can be treated as a particle of light. When a photon falls on the surface of metal it collides with an electron there and its entire energy is transferred to the electron. The electrons inside a metal are bound to the metal and in order to escape they have to overcome a potential barrier, referred to as the work function of the metal. A part of the incident photon's energy is used by the electron to jump over this potential barrier and the rest stays with it as its kinetic energy. Therefore, the relation between the energy of incident photon and kinetic energy of the ejected photoelectron is

$$h\nu = \frac{1}{2}mu^2 + e\phi \tag{2}$$

where ν is the frequency of incident radiation, m is the mass of electron, e is charge of electron (1.6×10^{-19} C) , u is velocity of electron and ϕ is the work function of cathode material (in units of eV).

Photo-electrons ejected from cathode with kinetic energy $mu^2/2$ move towards the anode and constitute a photocurrent in the circuit. Now if we apply an opposing/negative voltage to the anode the electrons will be deaccelerated. On increasing the negative voltage the photocurrent gradually decreases and becomes zero at a particular value called stopping potential (suppose the magnitude of the negative stopping potential is V_S). At this point all the kinetic energy of the electrons is converted to potential energy (eV_S) due to the negative stopping potential and their velocity at the anode is 0.

$$h\nu = eV_S + e\phi \tag{3}$$

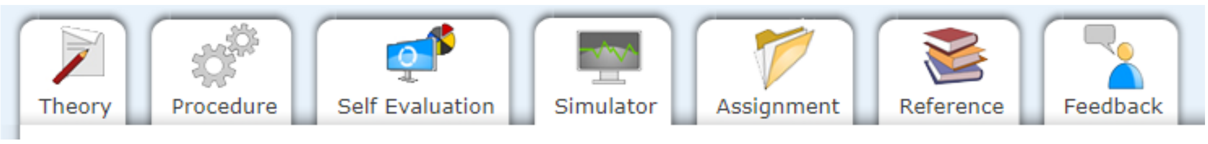
$$V_S = h\nu/\mathrm{e} - \phi \tag{4}$$

Thus, a graph between stopping voltage (V_S) and frequency of incident light (ν) would be linear with a slope (h/e). Planck's constant h can be obtained by multiplying the slope with electronic charge e. Intercept on V_S axis would give the work function ϕ in eV. Intercept on ν axis would give the threshold frequency $\left(\nu_T = \frac{e\phi}{h}\right)$ below which there is no photoelectric emission.

Procedure:

1. Go to the Amrita Vishwa Vidyapeetham virtual lab's website for Photoelectric effect experiment:
https://vlab.amrita.edu/?sub=1&brch=195&sim=840&cnt=4

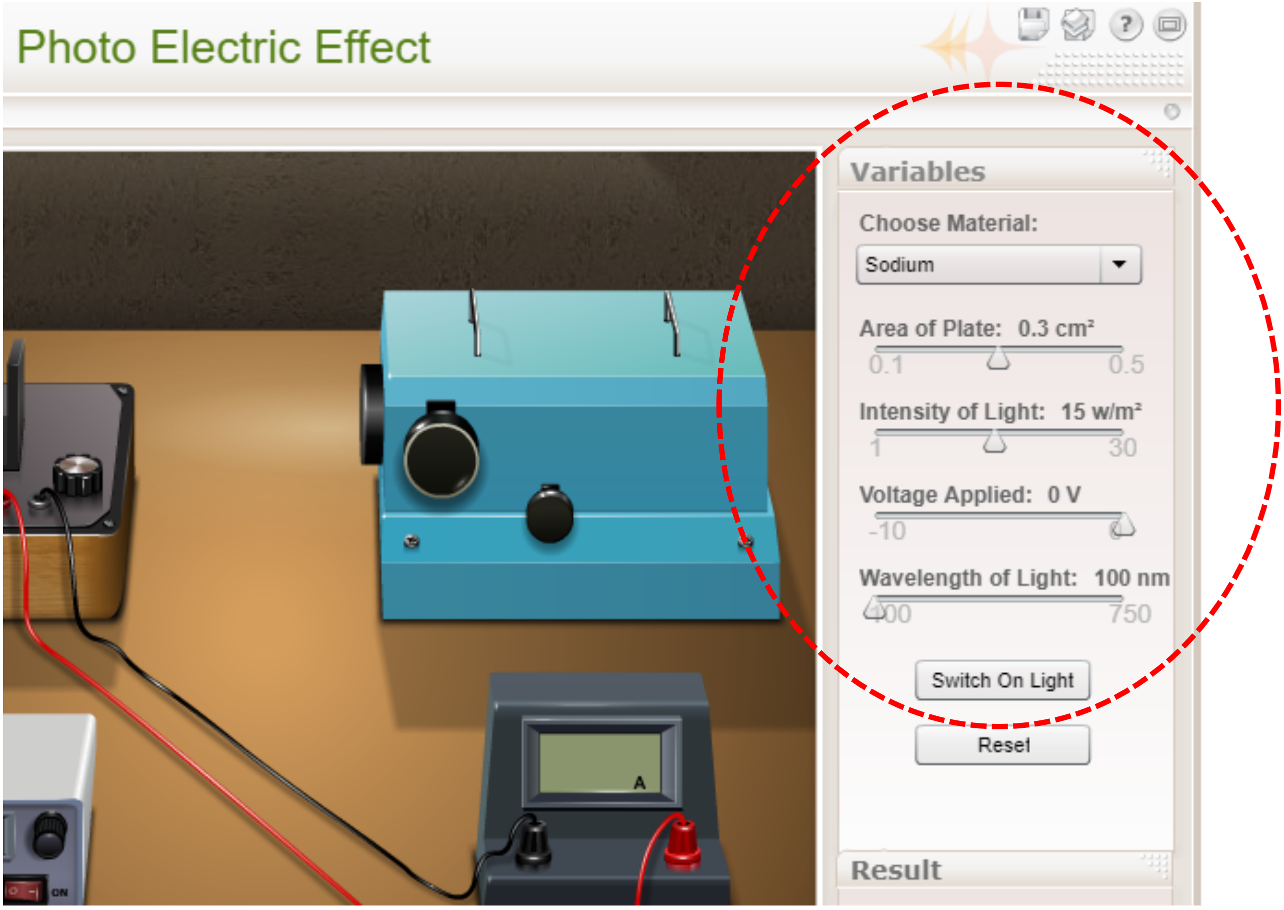
2. Browse through the different tabs and read the material provided in the website to accustom yourself with the experiment. Note that the procedure mentioned below should be followed and not the procedure provided in the site.



3. Click on the "simulator" tab and login with your registered credentials to initiate the virtual experiment. Click the button shown to make the experiment window full screen.

4. From the "variables" panel on the right select "sodium" from the options provided under "choose material".

5. Click on the button "switch on light".



6. In the "variables" panel adjust the sliders to make "area of plate" 0.3 cm^2 and "intensity of light" 15 W/m^2.

7. Adjust the slider "wavelength of light" and set the values provided in table I in the observations section below.

8. For each wavelength, adjust the slider "voltage applied" till the current reading in ammeter is 0. The voltage at which this happens is the stopping voltage V_S. Note down its magnitude in table I.

Observations:

Material of plate (cathode) used for photoelectric emission: Sodium
Area of the plate: 0.3 cm^2
Intensity of light: 15 W/m^2

Table I: Stopping potential versus frequency of incident light

S. No	Wavelength, λ (nm)	Frequency, $\nu = c/\lambda$ (10^{15} Hertz)	Magnitude of stopping potential, V_S (Volt)
1	150		
2	200		
3	250		
4	300		
5	350		
6	400		
7	450		

Calculations:

1. Plot the magnitude of stopping potential V_S (Y-axis) versus frequency ν (X-axis). <u>Note: Draw the X axis near the middle of your graph paper and keep both + and – Y axis,</u> because the intercept on Y axis will be in -ive Y direction.
2. Draw a best fit straight line and from the slope of the line calculate the Planck's constant, h in SI units (J.s or Kg.m^2.s^{-1}). Refer eqn. 4 for the calculation.
3. Find the Y-axis intercept to get the work function (ϕ in eV).
4. Find the X-axis intercept to get the threshold frequency (ν_T in 10^{15} Hz) of the cathode material.
5. Calculate the percentage errors in the obtained values of Planck's constant and work function. Use the following relation for your calculations:
   % error = $\frac{|\text{Actual value} - \text{Experimental value}|}{\text{Actual value}} \times 100$
   Actual values: $h = 6.63 \times 10^{-34}$ J.s and ϕ for sodium = 2.3 eV.

Results and Conclusions:

Planck's constant, h = ……….. Error = …………
Work function of sodium, ϕ = ……….. Error = …………
Threshold frequency of sodium, ν_T = ………..

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.

Adjustments of a Spectrometer: 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.
(c) Lock the telescope at an angle a few degrees greater than this position.
(d) 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.
(e) 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.
(f) 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.