Lab exercise II – Geometrical Optics

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Objective: Concepts of reflection, refraction, and colour.

Report: Hand in a report with filled in tables, drawings, and calculations.

Answer the questions that are marked in red.

Equipment:

Light Box & Collimating Lens	Rectangular Block
Power supply	Half Round Block
Set of 8 Colour Filters & Plates	45^o 45^o 90^o Prism
Three Slit Former Plates	60^o 30^o 90^o Prism
Spare Lamp: Axial, 12V.30W	60^o 60^o 60^o Prism
Experiment Book	Bi-Concave Lens
Protractor	Bi-Convex Lens
Pencil	Bi-Convex Lens (thick)
Graph paper	Plane Mirror
Calculator	Half Round Mirror
Unknown transparent liquid	Parabolic Mirror

This laboratory exercise provides an introduction to the principles of geometrical optics, focusing on the phenomenon of light refraction. The experiment assumes no prior knowledge of geometrical optics or wave theory. The exercise is divided into three sections:

Part A: Fundamentals of Light Reflection

This section will begin with fundamental concepts and basic experiments that demonstrate how light interacts with various materials. While questions will be provided to guide your understanding, the answers are not required for your final report.

Part B: Determining Refractive Index and Identifying an Unknown Liquid (Report Required)

This section consists of two exercises that will be documented in your report:

1. **Measurement of Refractive Index of Acrylic:** Following a detailed procedure with explanations, you will determine the refractive index of a supplied acrylic block.
2. **Identification of an Unknown Liquid:** Utilizing the knowledge gained from the first exercise and a provided table of refractive indices for various liquids, you will identify an unknown transparent liquid. Analysing potential errors and experimental uncertainties encountered during the experiment is an essential component of your report.

Part C: Exploration of Light Dispersion and Colour perception (Optional)

This optional section allows you to explore the phenomenon of light dispersion through experimentation with prisms and colour filters. This section is only recommended if you have sufficient time remaining after completing your report.

RECORDING RAY PATHS

To record ray paths, mark the position of the lens, prism or mirror being used by running a sharp pencil around the perimeter. Then mark the centre of the ray being observed in two positions, one dot close to the lens surface and one as far away as possible. If the ray pattern is complicated with rays crossing each other, number the dots representing each ray so that they can be easily followed.

Remove the lens or prism and carefully rule lines through the numbered points to show the ray paths to and from the device and also the path taken through the device. Mark arrow heads on the lines to indicate their direction of propagation.

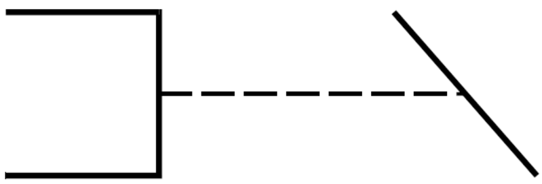
If in doubt as to the continuity of any line, replace the device in exactly the same position and retrace the ray.

Part A: Reflection

Experiment 1. Single ray

Project a single ray along the paper and mark its two ends. Place the plane mirror halfway along this path, crossing it at an angle.

Mark the position of:



- *The glass front face of the mirror.*
- *The reflecting rear face of the mirror.*
- *The reflected ray (or rays). Explain the second fainter reflected ray.*

Draw a line perpendicular to the mirror at the point where the incident and reflected rays meet the mirror face. Such a perpendicular is called the **NORMAL** to the mirror at this point.

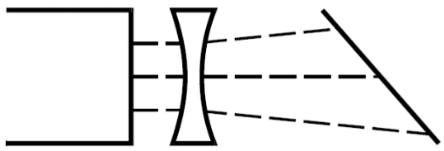
- Measure the angle between the **INCIDENT RAY** and the **NORMAL**. This angle is called the **ANGLE OF INCIDENCE**.
- Measure the angle between the **REFLECTED RAY** and the **NORMAL**. This angle is called the **ANGLE OF REFLECTION**.

These angles are measured from the **NORMAL** because in later experiments you will be reflecting rays from curved mirrors. Since you cannot measure the angle between the ray and the curved surface of the mirror, you must draw a normal to the curved surface and from this straight line measure the angles of incidence and reflection.

Experiment 2. Divergent ray

Place a triple slit former in the narrow front groove of the Light Box. Project a set of diverging rays along a sheet of paper and mark the ray paths. Place a plane mirror so that the rays meet it at angles that are not 90^o. Mark the reflecting surface of the mirror and the paths of the reflected rays. Draw normals to the mirror surface at each point of the reflection.
Measure the angle of incidence and angle of reflection at each point of reflection.

Tabulate your results as follows:



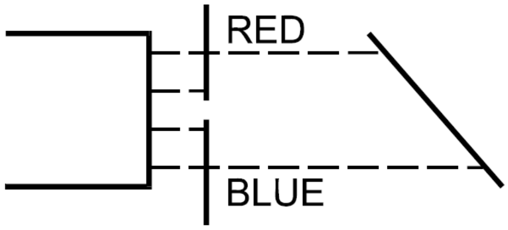
RAY	ANGLE OF INCIDENCE	ANGLE OF REFLECTION
A		
B		
C		

- *Is the angle of incidence greater than, less than, or equal to the angle of reflection?*
- *You have discovered one of the laws of reflection – what is it?*
- *Did the diverging rays remain diverging after reflection?*
- *Do parallel rays remain parallel after reflection? Try it and see.*
- *Do converging rays remain converging after reflection? Try it and see.*

Experiment 3. Lateral and vertical Inversion

Set the ray box to project two parallel rays. Place a colour filter (blue) over the left hand beam (as viewed from the front or slit end of the box) and colour the right hand beam red. Reflect the two beams from then plane mirror as previously.

Face the mirror and look at the reflection of the rays.
- *Is the left beam red or blue?*



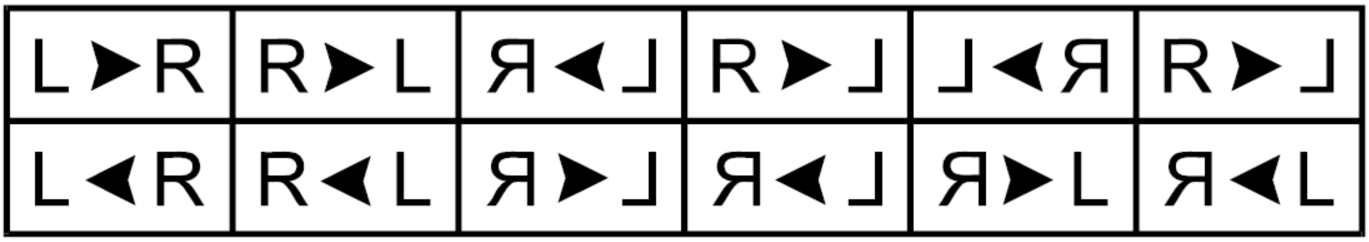
Record the rays in coloured pencil showing the red and blue beams.
- *What happens to an image on reflection in a plane mirror?*
- *Is the image you see of yourself in a mirror the same as the image your friends see of you?*

- *If your face is reversed from left to right in reflection why is it not reversed from top to bottom?*

If you turn your head sideways, so that it is horizontal, your reflection will be reversed vertically. Try it and see.

- *What is meant by "LATERAL INVERSION ON REFLECTION?"*

If you hold a card labelled L → R so that it is reflected in a mirror, which one of the following examples should be the reflection?



Do not try it until you have predicted the result. When scientists believe they know the rules of how things behave, they say that they have a theory and they predict what should happen under certain circumstances. Then they experiment to test their prediction. Depending on the result of their experiments they either accept, reject or modify their theory.

- *Did your experiment lead you to accept, reject or modify your theory?*
  Try another prediction.

- *What should the reflection of the following capital letter word look like if a plane mirror is placed vertically along the dotted line and the reflection is observed in the mirror from a position at the bottom of the page?*

CARBON-DI-OXIDE

Write down the expected image before you actually try the experiment.

- *Was your prediction correct?*
- *Was this LATERAL INVERSION?*
- *If you were told to hold the word, CARBON-DI- OXIDE and observe its reflection in a mirror, how would you hold it?*
- *Is this the way it was presented to the mirror in the previous experiment?*
- *If the word is written on transparent paper and presented to the mirror in the two manners described, how would it look to you if you viewed the mirror through the paper? Try it and see.*
- *Is this last inversion due to the mirror, or due to the way the word is presented to the mirror?*
- *Why do some of the letters show reversal while others do not?*

If both halves of an object or image are mirror images of each other about a central line, they are called SYMMETRICAL.

- *Is your face symmetrical?*

Place a large plane mirror so that it stands out vertically from your face, straight down the centre of your nose, then look at yourself in another mirror

- *Do you look normal with a perfectly symmetrical mirror image type of face?*
- *Which half reflected do you like best?*

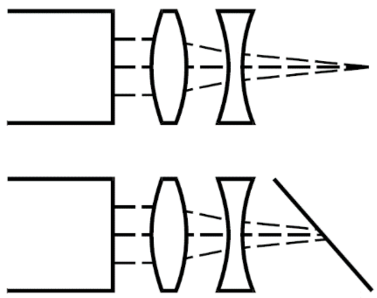
Move the mirror to the other side of your nose.

- *Is having two noses an improvement?*

Move the mirror to the other side of your nose.

- *Do you like yourself with no nose and two eyes close together?*

Experiment 4. Position in a Plane Mirror



When looking into a mirror, your reflected image appears to be somewhere behind the mirror.

If you move backwards half a metre, the reflection also moves away from you. The following experiment will help you to locate the image position.

Project a set of converging rays across your sheet of paper and record their positions and focal point.

- Use the lens combination shown and move them relative to one another to adjust your focal length.
- Place a plane mirror across the rays at an angle and record the paths of the reflected rays.
- While looking in the mirror at the reflection of the converging rays, lift the mirror and observe the real converging rays.
- Remove and replace the mirror several times vertically, noting the similarity of the real and reflected rays.

• *Would you say the point where the real rays meet is the reflection of the point where the reflected rays meet?*
Record these two points of convergence and the position of the reflecting surface of the mirror.
Draw a line joining the two points of convergence.

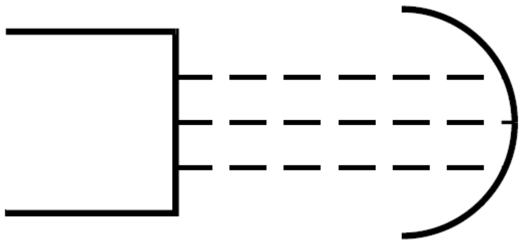
• *What angle does the line make with the mirror?*

• *What is the distance of the real convergence point and of the reflection convergence point from the mirror?*
Repeat the experiment with another piece of paper, another set of converging rays and the mirror closer to or further from the point of convergence.
Locate the convergence points and the mirror position, then draw lines and measure angles as before.
Stand a pin vertically in the paper (using cardboard beneath it) exactly at the two convergence points.
You now have a pin in front of the mirror and another pin hidden behind the mirror.
Lift the mirror vertically until you can see the hidden pin, then replace it and lift it several times.

• *Is the hidden pin located at the position of the reflected image of the front pin?*

• *Does any shift in your (the observer's) position affect the location of the image position?*
Leave the front pin and the mirror unaltered. Try it and see.

Experiment 5. REFLECTION in a Circular, Concave Mirror.



Select the semi-circular curved mirror. Aim a set of parallel rays into the centre of the inside curve of the mirror so that the rays are parallel to the axis of symmetry of the mirror. Record the incident and reflected rays and note where they meet. This point is called the **FOCUS** of the mirror.

• *How far is the* ***focus (or FOCAL POINT)*** *from the mirror?*
This distance is called the **FOCAL LENGTH** of the mirror.

If the focal point appears blurred and broad, with too many rays overlapping through it, block the outer rays as they leave the Light Box and use only the central ones.

Experiment 6. Centre of Curvature, Radius of Curvature, Focal Length of a Circular Mirror

Set up as in the last experiment and, on paper, trace the inside reflecting surface of the concave mirror. Move the mirror around the curve and continue tracing until you have a complete circle. Measure the diameter of this circle in several directions and calculate an average diameter.

• *What is the radius of the circle?*
Find the centre of curvature, i.e. the centre of the circle.

• *How does the radius compare with the focal length you found in the last experiment?*
Another method of finding the centre of curvature is to aim a single ray at the inside curve of the mirror so that it reflects straight back on itself.

To do this, the ray must be meeting the surface along its ”normal” or must be perpendicular to the surface at that point and must be reflected back along this radius position through the centre of curvature. Record this ray position and without moving the mirror, move the ray box to another position where the ray again reflects back on itself and record the new ray position. Repeat this procedure a third time.

The point where the rays meet is the **CENTRE OF CURVATURE** and the distance from this point to the curve of the mirror is the **RADIUS OF CURVATURE**.

Experiment 7. Convex Mirror

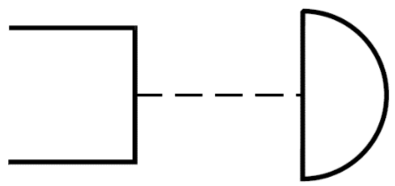
Project a number of parallel rays to strike the OUTSIDE surface of the semi circular mirror, parallel to its axis. Record the mirror position and ray paths and indicate the ray directions with arrow heads.

• *Where do the diverging rays appear to come from?*
Locate this point by drawing the diverging rays backwards through the mirror position. The point they come from is called the **VIRTUAL FOCUS** and the distance of this point from the mirror is called the **VIRTUAL FOCAL LENGTH**.

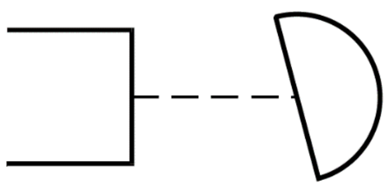
• *How does this focal length compare with the focal length of the concave side of the mirror?*
• *How does it compare with the radius of curvature of the mirror found previously?*
• *By how much do the results differ?*
• *Can this amount be related to the mirror construction?*
• *Suggest why slightly convex mirrors are used as rear vision mirrors in cars.*
If a line is drawn from the centre of curvature through the point where a ray strikes the mirror, this line is normal to the surface. Draw several of these normals.
For each reflection, measure the angle of incidence (between the incident ray and the normal) and the angle of reflection (between the reflected ray and the normal)
• *For each reflection, does the angle of incidence equal the accompanying angle of reflection?*

Part B: Refraction
This is the main experimental part of this lab exercise, that must be included into your report.

Experiment 1. Semi Circular Block



Aim a single beam at an angle of 90° at the centre point of the flat side of the semi circular block. Record the block position and the ray path.
• *Is there any deflection in the beam?*
If there is, the angle is not 90°.



Move the Light Box so that the ray strikes the same central point on the flat side of the block, but at an angle of 10° to the normal.
Record the ray path into and out of the block, so that when the block is removed the ray path through it can be clearly seen.

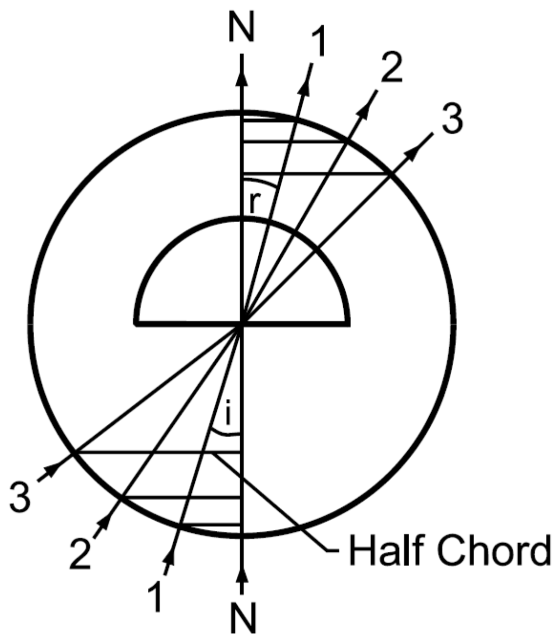
Move the Light Box several times and using coloured pencils record with different colours the new ray paths (all entering the same place on the block).

What happens when a light ray:
• *Passes from one medium (air) to another medium (acrylic plastic) at an angle of 90°?*
• *Passes as before, but at an angle of not 90°? (i.e. the angle of incidence is not zero).*
• *Passes from the acrylic plastic back into the air?*

• *Why does no bending (refraction) occur as the ray passes through the semi circular face while it does bend (refract) passing through the flat face?*

Remove the block after making about six rays and mark the position of the flat side of the block. (Rays can be used on both sides of the normal to the flat surface.)
Carefully draw all the rays meeting at the mid point of the flat side and their subsequent paths.
Draw a 100 mm diameter circle where the centre is the point of incidence. Carefully extend the incident and refracted rays to intersect the circle. Draw the normal N to the incident surface, through the point of incidence.
Draw perpendiculars to the normal line from where the rays and circle intercept.

Your diagram should look like this:



Compile a table of observations as follows:

RAY #	ANGLE OF INCIDENCE **i**	ANGLE OF REFRACTION **r**	DIFFERENCE BETWEEN ANGLES **i-r**	RATIO OF $\frac{i}{r}$	LENGTH OF HALF CHORD **i**	LENGTH OF HALF CORD **r**
1.						
2.						
3.						
4.						
5.						
6.						

RAY #	RATIO OF: $\frac{\text{HALF CHORD } \mathbf{i}}{\text{HALF CHORD } \mathbf{r}}$	SIN **i**	SIN **r**	RATIO OF: $\frac{\text{SIN } \mathbf{i}}{\text{SIN } \mathbf{r}}$
1.				
2.				
3.				
4.				
5.				
6.				

If you have not studied TRIGONOMETRY or LOGARITHMS, you may not know how to fill in the last three columns, but this does not matter. They are simply a more accurate way of checking the answers obtained in the fourth last column.

- *Is the difference between angle i and angle r always the same?*
- *Is the ratio of:* $\frac{angle\ i}{angle\ r}$ *always the same?*
- *Is the ratio of:* $\frac{half\ chord\ i}{half\ chord\ r}$ *always approximately the same?*
- *Is the ratio of:* $\frac{\sin i}{\sin r}$ *always the same?*

The man who discovered this phenomenon was named Snell. **Snell's Law** states:

* When a light ray passes from one medium (material) to another medium at an angle (not perpendicular to their interface), it undergoes bending (**REFRACTION**) and the ratio of: $\frac{\sin i}{\sin r}$ (or the ratio of the half chords) is a constant **for these two particular media**.

* The incident ray, the normal to the interface and the refracted ray, lie on one plane (i.e. they are called **CO-PLANAR**).

The ratio of: $\frac{\sin i}{\sin r}$ (or the ratio of the half chords) is a called sin r the **REFRACTIVE INDEX** for the two materials.

- *What is the refractive index for an AIR-ACRYLIC Plastic interface?*

Experiment 2. Identification of an Unknown Liquid

To observe and record the different bending properties (different **REFRACTIVE INDICES**) of materials other than acrylic, use either a glass block in place of the acrylic block, or use a shallow semi circular plastic tray partly filled with water, kerosene, paraffin, or other clear liquid.
Disregard what eventually happens to the rays but record only the first interface bending.

Utilizing the knowledge gained from the first exercise and a provided table of refractive indices for various liquids, you will identify an unknown transparent liquid. Analysing potential errors and experimental uncertainties encountered during the experiment is an essential component of your report.

Part C: Light dispersion and colour observation

These experiments can be undertaken at your discretion, provided Parts A and B have been completed. Follow experiments number 19, 20 and 27-30 from the experimental book.