CHAPTER 5: LIGHT

In each of the following sentences, fill in the bracket the appropriate word or words given below.

solid, liquid, gas, vacuum, electromagnetic wave, energy

1. Light is a form of (                 ).
2. It travels in the form of (                           )
3. In can travel through (                           )
4. It travels fastest in the medium of (                  )
5. Light of different colours travels at the same speed in the medium of (       )

Light allows us to see objects.
Light can be reflected or refracted.

5.1 UNDERSTANDING REFLECTION OF LIGHT

Plane mirror and reflection: In the boxes provided for the diagram below, write the name of each of the parts shown.

Laws of Reflection: State the laws of reflection.

(i) ........................................................................................................................................
........................................................................................................................................

(ii) ........................................................................................................................................
........................................................................................................................................
**Exercise 1.** The diagram below shows how the relationship between incident angle and reflected angle can be investigated. 
Fill in the values of the angles of reflection, $r$ in the table below.

<table>
<thead>
<tr>
<th>$i$</th>
<th>$r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

**Exercise 2:**

Based on the diagram on the left, calculate the angle, $\theta$. Hence determine the angle of deviation, $d$.

**Exercise 3:**

Based on the diagram above, when the mirror is rotated an angle $\theta$, without changing the incident ray, what is the angle rotated, $\alpha$, for the reflected ray in terms of $\theta$?
**Image formed by a plane mirror:** Using the law of reflection, complete the ray diagram to determine the position of the image.

What can you say about the line joining object and image? ………………………………………

What can you say about the distances AB and BC? ……………………………………………..

**Differences between real and virtual image:**

<table>
<thead>
<tr>
<th></th>
<th>Real image</th>
<th>Virtual image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can be caught on a screen</td>
<td>Cannot be caught on a screen</td>
<td></td>
</tr>
<tr>
<td>Formed by the meeting of</td>
<td>Form at a position where rays</td>
<td></td>
</tr>
<tr>
<td>real rays.</td>
<td>appear to be originating.</td>
<td></td>
</tr>
</tbody>
</table>

**Characteristics of image formed by plane mirror:** Observe the pictures below as well as using previous knowledge, list the characteristics.

i)  

ii)  

iii) 

iv)
Exercise 1:
Complete the ray diagram below consisting of 2 rays originating from the object, reflected and entering the eye such that the eye sees the image.

Exercise 2:
Ahmad is moving with speed 2 m s\(^{-1}\) towards a plane mirror. Ahmad and his image will approach each other at

A. 1 m s\(^{-1}\)  
B. 2 m s\(^{-1}\)  
C. 3 m s\(^{-1}\)  
D. 4 m s\(^{-1}\)

Exercise 3:
Four point objects A, B, C and D are placed in front of a plane mirror MN as shown. Between their images, which can be seen by the eye?
ACTIVITY: Find out some of the uses of plane mirrors (application of reflection).
Curved Mirrors:

Terminology: Refer to the diagrams above and give the names for the following:
- C =
- r =
- P =
- PC =

Effect of curved mirrors on incident rays:

a) Incident rays parallel to the principal axis:

Study the diagrams above and fill in the blanks for the following sentences.
- Rays parallel to the principal axis converge at the ....................., F
- F is positioned at the ..................... between C and P
- FP is named the ..................... which is denoted by f.

Hence write an equation giving the relationship between r and f.
b) **Incident rays parallel to each other but not parallel to the principal axis:**

![Images of concave and convex mirrors showing focal plane and principal focus](image)

Study the diagrams above and fill in the blanks in the following sentences.

- Parallel rays converge at a point called .........................
- The focal plane joins \( F \), the principal focus and all .........................and is ................................. to the principal axis
- The ray passing through \( C \) is reflected back along the line of the.........................ray.
- The distance between the focal plane and the mirror is the .........................\( f \).

**Image formed by curved mirror** (ray diagram method)

**Principle of drawing ray diagrams:**

a. Rays parallel to the principal axis are reflected through the principal focus, \( F \).

Example:

![Ray diagrams of concave and convex mirrors](image)

**Exercise 1:** Complete the ray diagrams below:
b) Rays passing through the principal focus are reflected parallel to the principal axis.

Example:

Exercise 2: Complete the ray diagrams below:

Exercise 3: Complete the ray diagrams below:

c) Rays passing through the center of curvature are reflected directly back.
**Image formed by concave mirror:**

Using the principles of construction of ray diagram, complete the ray diagrams for each of the cases shown below:

\[ u = \text{object distance}; \quad v = \text{image distance}; \quad f = \text{focal length}; \quad r = \text{radius of curvature} \]

**Case 1: \( u > 2f \)**

Hence state the characteristics of image formed:

i)  

ii)  

iii)  

**Case 2: \( u = 2f \text{ or } u = r \)**

Characteristics of image formed:

i)  

ii)  

iii)
Case 3: \( f < u < 2f \)

Characteristics of image formed:

i)  
ii)  
iii)  

Case 4: \( u = f \)

Characteristics of image formed:

i)  

Case 5: \( u < f \)

Characteristics of image formed:

i)  
ii)  
iii)  

Image formed by convex mirror: (using construction of ray diagram).
\[ u = \text{object distance} ; \ v = \text{image distance} ; \ f = \text{focal length} ; \ r = \text{radius of curvature} \]

Characteristics of image formed:

i)  
ii)  
iii)  

Uses of curved mirrors:

**Newton’s Telescope:** Fill in the boxes the type of mirror used

Activity: Find more uses of curved mirrors.
5.2 UNDERSTANDING REFRACTION OF LIGHT

What is the phenomenon which causes the bending of light in the picture above?

Why did this bending of light occur? (think in terms of velocity of light)

Refraction of light:
Fill in each of the boxes the name of the part shown.
Direction of refraction:

Draw on the diagrams above the approximate directions the refracted rays.

When light travels from a less dense medium to a denser medium, the ray is refracted (toward/away from) the normal at point of incidence.

When light travels from a more dense medium to a less dense medium, the ray is refracted (toward/away from) the normal at point of incidence.

Snell’s law:

Snell’s law states that ............................................................

What is the name and symbol of the constant? ............................

Exercise 1:

Referring to the diagram on the right,
Calculate the refractive index of liquid-X.
Exercise 2:
Referring to the diagram on the right, calculate the refractive index of liquid-Y.

Exercise 3:
On the diagram to the right, draw two rays which originate from the fish to show how a person observing from above the surface of the water is able to see the image of the fish at an apparent depth less than the actual depth of the fish.

Exercise 4:
An equation that gives the relationship between apparent depth, real depth and the refractive index of water for the diagram above is

\[ n = \frac{\text{real depth}}{\text{apparent depth}} \]

If the fish is at an actual depth of 4 m and the refractive index of water is 1.33, what is the apparent depth of the image?
5.3 UNDERSTANDING TOTAL INTERNAL REFLECTION OF LIGHT

Critical angle and total internal reflection:

Figures a, b and c show rays being directed from liquid-Y which is denser than air towards the air at different angles of incident, $\theta$.

Among the figures a, b and c, only Figure a has a complete ray diagram.

(i) Complete the ray diagrams for Figure b and Figure c.

(ii) The angle, $C$ is called ……………………

(iii) The phenomenon which occurs in Figure c yang is called ……………………

(iv) State 2 conditions which must be satisfied in order for the phenomenon you mentioned in (iii) to occur.

Exercise 1:

Referring to figure d and using Snell’s law, write an equation that gives the relationship between the critical angle, $C$, the refracted angle and the refractive index of liquid-Y.
Exercise 2:

Referring to Figure e, determine the refractive index of liquid-Z

Exercise 3:

Explain why a pencil partially immersed in water looks bent. (Use a ray diagram).

Exercise 4:

Complete the path of the ray in the diagram below and explain how a mirage is formed.
Exercise 5:

Completing the ray diagram below, to show how a periscope works: (critical angle of glass = 42°)
5.4 UNDERSTANDING LENSES

Thin Lenses:

Types of lenses: Name the types of lenses shown below.
(i)

- a.
- b.
- c.

(ii)

- a.
- b.
- c.

Formation of a convex lens and terminology: name the parts shown

Formation of a concave lens and terminology: name the parts shown
Refraction of rays parallel to the principal axis of a convex lens:

Draw in the following diagrams the paths of the rays after passing through the lens. Write in the boxed provided, the name of the point or line shown.

i) 

ii) 

iii) 

iv)
**Principles of constructing ray diagrams:** Complete the path of each ray after passing through the lens

i) ![Diagram](image1)

ii) ![Diagram](image2)

iii) ![Diagram](image3)

iv) ![Diagram](image4)

v) ![Diagram](image5)

vi) ![Diagram](image6)

vii) ![Diagram](image7)

viii) ![Diagram](image8)

**Exercise 1:**

State the meaning of each of the following terms:

i) Focal length, \( f \):

ii) Object distance, \( u \):

iii) Image distance, \( v \):

**Exercise 2:**

Describe how you would estimate the focal length of a convex lens in the school lab.
Characteristics of image formed by a convex lens: (Construction of ray diagram method)

Construct ray diagrams for each of the following cases and state the characteristics of the image formed.

i) **Case 1**: $u > 2f$ where $u =$ object distance; and $f =$ focal length of lens.

![Ray diagram for case 1](image)

Characteristics of image:

ii) **Case 2**: $u = 2f$

![Ray diagram for case 2](image)

Characteristics of image:

iii) **Case 3**: $2f > u > f$

![Ray diagram for case 3](image)

Characteristics of image:

iv) **Case 4**: $u = f$
Exercise:

In each of the following statements below, fill in the space provide one of the following conditions. 
( u > 2f / 2f = u / 2f > u > f / u > f / u < f )

i) To obtain a real image, the object must be placed at a distance \( u \) such that ………

ii) To obtain a virtual image, the object must be placed at a distance \( u \) such that ………
**Characteristics of image formed by concave lens** : (by construction of ray diagrams)

Construct a ray diagram for each of the following and state the characteristics of the image formed

i)

![Ray Diagram 1](image1)

Characteristics of image:

ii)

![Ray Diagram 2](image2)

Characteristics of image :

**Note:** Image formed by a concave lens is always diminished, virtual and on the same side of the lens as the object.

**Power of a lens** \((p)\)

The power of the lens is given by:

\[
\text{Power of lens} = \frac{1}{\text{focal length}}
\]

**Sign convention** (for focal length) and the S.I. unit for power of a lens.

- The focal length of a convex lens is (positive/negative)
- The focal length of a concave lens is (positive/negative)
- The S.I. unit for the power of a lens is . . . . . and its symbol is . . . .
- When calculating the power of a lens, the unit of the focal length must be in \((m/cm)\)

**Exercise 1** : A concave lens has a focal length of 10 cm. What is its power?
Exercise 2: The power of a lens is +5 D. State whether it is a convex lens or a concave lens and calculate its focal length.

Linear Magnification ($m$):

Definition: \[ \text{Linear magnification} = \frac{\text{height of image}}{\text{height of object}} \]

\[ m = \frac{h_i}{h_o} \]

Based on the definition above and the ray diagram below, derive an expression for the relationship between linear magnification, $m$, the object distance, $u$, and the image distance, $v$.

Lens formula:

The relationship between the object distance, $u$, image distance, $v$, and the focal length, $f$, of a lens is given by

\[ \frac{1}{u} + \frac{1}{v} = \frac{1}{f} \]

- This lens formula is valid for both convex and concave lenses.

When using the lens formula, the ‘real is positive sign convention’ must be followed.
The rules stated in this sign convention are:

1)  
2)  
3)  

**Application of the lens formula:**

**Exercise 1.** An object is placed 10 cm in front of a converging lens of focal length 15 cm. Calculate the image distance and state the characteristics of the image formed.

**Exercise 2:** An object is placed 30 cm in front of a converging lens of focal length 25 cm.

a) Find the position of the image, and state whether the image is real or virtual.
b) Calculate the linear magnification of the image.

**Latihan 3:** An object is placed 30 cm in front of a diverging lens of focal length 20 cm. Calculate the image distance and state whether the image is real or virtual.
Lenses and optical instruments:

1. Magnifying glass (simple microscope):

A lens acts as a magnifying glass when the object is placed as in case 5 on page 23.

   i) A magnifying glass consists of a (converging / diverging) lens.
   ii) The object must be placed at a distance (more than $f$ / same as $f$ / less than $f$ / between $f$ and $2f$ / more than $2f$) in order for the lens to act as a magnifying glass.
   iii) The characteristics of the image formed by a magnifying glass are yang (real / virtual) ; (inverted / upright) ; (magnified / diminished) ; (on the same side as the object / on the opposite side of the object).
   iv) Greater magnification can be obtained by using a lens which has (long / short) focal length.

Complete the ray diagram below to show how a magnifying glass produces an image of the object.

Exercise 1: A magnifying glass produces an image with linear magnification = 4. If the power of the lens is +10 D, find the object distance and image distance.
Exercise 2: Which of the following lenses with their powers given below makes the magnifying glass with the highest power of magnification?

A. –5 D  B. –25 D  C. +5 D  D. +25 D.

2. Simple camera: The diagram below shows the structure of a simple camera. In the boxes provided, write the names of the parts shown.

For each of the parts you have named, state its function.

3. Slide projector: The diagram below shows the structure of a simple camera. In the boxes provided, write the names of the parts shown.

Complete the ray diagram above to explain how the slide projector works.
4. **Astronomical telescope** :

**Making of the astronomical telescope.**

- The astronomical telescope consists of 2 (converging / diverging) lenses.
- The objective lens has focal length, \( f_o \) and the eye lens has focal length, \( f_e \) where (\( f_o < f_e \) / \( f_o > f_e \)).
- The lenses are arranged such that the distance between the objective lens and the eye lens is (\( f_o - f_e \) / \( f_o + f_e \) / \( f_o \times f_e \) / \( f_o / f_e \)).

![Ray diagram of an astronomical telescope](image)

Complete the ray diagram above to show how the astronomical telescope works.

**Characteristics of image formed by an astronomical telescope:**

- The first image formed by the objective lens is (virtual/real ; upright/inverted ; diminished/magnified).
- The final image is (virtual/real ; upright/inverted ; diminished/magnified).
- The final image is located at (\( F_o \) / \( F_e \) / infinity).

**Magnifying Power (M) :**

\[
M = \frac{f_o}{f_e}
\]

**Exercise:**

An astronomical telescope with high power of magnification can be built using eye lens of (long / short) focal length and objective lens of (long / short) focal length.
5. **The compound microscope**:

**Structure of the compound microscope:**

- A compound microscope consists of 2 (converging / diverging) lenses
- The focal length of the eye lens is (long / short) and the focal length of the objective lens is (long / short).
- The objective lens is arranged such that the object distance, \( u \) is \( (u = f_o / f_o < u < 2f_o / u = 2f_o) \).
- The eye lens is used as a (magnifying / diverging / projector) lens.
- The total length, \( s \), between both lenses is \( (s = f_o + f_e; s > f_o + f_e) \)

![Ray diagram of a compound microscope](image)

Complete the ray diagram above to show how the compound microscope works.

**Characteristics of image formed by compound microscope:**

- The first image formed by the objective lens is (real/virtual ; diminished/magnified ; upright/inverted).
- The final image is (real/virtual ; diminished/magnified ; upright/inverted).

**Exercise 1 (a)**: A compound microscope consists of two lenses of focal lengths 2 cm and 10 cm. Between them, which is more suitable as the eye lens? Explain your answer.

(b): How would you arrange the lenses in (a) to make an astronomical telescope?
Reinforcement:

Part A:

1. Between the following statements about reflection of light, which is not true?
   - A. All light energy incident on a plane mirror is reflected.
   - B. The angle of incidence is always the same as the angle of reflection.
   - C. The incident ray, the reflected ray and the normal to the point of incidence, all lie on the same plane.
   - D. The speed of the reflected ray is the same as the speed of the incident ray.

2. A boy stands in front of a plane mirror. He observes the image of some letterings printed on his shirt. The letterings on his shirt is as shown in Figure 1.

   [Image of SABS]

   Figure 1

   Between the following images, which is the image observed by the boy?

   A  B  C  D

   [Images of SABS, SABS, SABS, SABS]

3. Figure 2 shows an object, O placed in front of a plane mirror. Between the positions A, B, C and D, which is the position of the image?

   [Diagram of object O and mirror, with labeled positions A, B, C, D]

   Figure 2

4. A student is moving with a velocity of 2 m s\(^{-1}\) towards a plane mirror. The distance between the student and his image will move towards each other at the rate

   A. 2 m s\(^{-1}\)  B. 3 m s\(^{-1}\)  C. 4 m s\(^{-1}\)  D. 5 m s\(^{-1}\)  E. 6 m s\(^{-1}\)

5. The table below shows the characteristics of the images formed by a concave mirror for various positions of the object. All symbols used have the usual meanings. Which of them is not true?
<table>
<thead>
<tr>
<th>Position of object</th>
<th>Characteristics of image</th>
</tr>
</thead>
<tbody>
<tr>
<td>A ( u &gt; 2f )</td>
<td>Diminished, inverted, real</td>
</tr>
<tr>
<td>B ( f &lt; u &lt; 2f )</td>
<td>Magnified, inverted, real</td>
</tr>
<tr>
<td>C ( u = f )</td>
<td>Same size, inverted, real</td>
</tr>
<tr>
<td>D ( u &lt; f )</td>
<td>Magnified, upright, virtual</td>
</tr>
</tbody>
</table>

6. Which of the following ray diagram is correct?

A

\[
\begin{array}{c}
\angle 50^\circ \\
\angle 50^\circ \\
\text{Plane mirror}
\end{array}
\]

B

\[
\begin{array}{c}
\text{Convex mirror}
\end{array}
\]

C

\[
\begin{array}{c}
\text{Concave mirror}
\end{array}
\]

7. The depth of a swimming pool appears to be less than its actual depth. The light phenomenon which causes this is

A. Reflection  
B. Refraction  
C. Diffraction  
D. Interference

8. The critical angle in glass is 42°. What is the refractive index of glass?

A. 1.2  B. 1.3  C. 1.4  D. 1.5  E. 1.6

9. Which of the following are the characteristics of an image formed by a magnifying glass?

A. Magnified, virtual, inverted  
B. Diminished, real, upright  
C. Magnified, virtual, upright  
D. Diminished, virtual, inverted
10. A student is given three convex lenses of focal lengths 2 cm, 10 cm and 50 cm. He wishes to construct a powerful astronomical telescope. Which of the following arrangements should he choose?

<table>
<thead>
<tr>
<th></th>
<th>Focal length of objective lens / cm</th>
<th>Focal length of eye lens / cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>D</td>
<td>50</td>
<td>10</td>
</tr>
</tbody>
</table>

**Part B**

1.

![Figure 3](image)

Figure 3 shows the eye of a person looking at a fish.

a) Sketch a ray diagram consisting of 2 rays originating from the eye of the fish to show why the image of the fish is seen closer to the surface.

b) The fish is at a depth of 2 m. If the refractive index of water is 1.33, calculate the apparent depth of the fish.
2. 
   a) Starting with the lens formula, \( \frac{1}{u} + \frac{1}{v} = \frac{1}{f} \), derive an equation that gives the relationship between linear magnification, \( m \) and the image distance, \( v \). Hence sketch the graph of \( m \) against \( v \) on the axes provided below.

(b) State the value of \( m \) at the point of intersection of the graph with the vertical axis.

(c) Describe how you would determine the focal length of the lens using the graph.
Part C

1.

A student used a slide projector to project a picture onto the screen. Figure 1a and 1b show the relative positions of the slide, projector lens and the screen. It is observed that when the screen is moved further away (Figure 1b), the lens of the projector has to be moved nearer to the slide to obtain a sharp image.

Based on your observations and knowledge of lenses;

a) make one suitable inference.

b) state an appropriate hypothesis that could be investigated.

c) describe how you would design an experiment to test your hypothesis using a convex lens, filament bulb and other apparatus.

In your description, state clearly the following:

(i) aim of the experiment
(ii) variables in the experiment

(iii) List of apparatus and materials

(iv) Arrangement of the apparatus

(v) The procedure of the experiment, which includes the method of controlling the manipulated variable and the method of measuring the responding variable

(vi) The way you tabulate the data
(vii) The way you would analyse the data

2. A student carried out an experiment to investigate the relationship between object distance, \( u \), and image distance, \( v \), for a convex lens. The student used various values of \( u \) and recorded the corresponding values of \( v \). The student then plotted the graph of \( uv \) against \( u + v \) as shown in Figure 2.
a) Based on the graph in Figure 2,

(i) state the relationship between $uv$ and $u + v$

(ii) determine the value of $u + v$ when the value of $uv = 400 \text{ cm}^2$. Show on the graph how you obtained the value of $u + v$.

From the value of $u + v$ obtained, calculate the image distance, $v$ when $u = 20 \text{ cm}$.

(iii) calculate the gradient of the graph. Show clearly on the graph how you obtained the values needed for the calculation.

b) Given that the relationship between $u$, $v$ and focal length, $f$ of the convex lens used, is represented by the equation
\[
\frac{1}{u} + \frac{1}{v} = \frac{1}{f}
\]
Derive an equation which gives the relationship between $uv$ and $(u + v)$.

c) Using the equation derived in (b), and the value of gradient calculated in (a)(iii), determine the focal length of the lens used in the experiment.

d) State one precaution taken to ensure the accuracy of the experiment.