LIGHT & LENSES

BY: C. ALLAN

LIGHT

- Light is a **form of energy** that travels in waves and allow us to see things.
- Light makes the world around us visible.
- Below are **some** of the properties of light:
  - Travels in a straight line.
  - Can be reflected, **refracted**, and absorbed.
  - It is produced by various sources.
- Light **bend** when passing from one medium into another.
- When light passes through an object called a **lens**, it bends to **converge** at a particular point, or **diverge**.

Note:

- To converge means to come together or meet at a certain point.
- To diverge means to move apart or to separate from a common point.

LENS & THEIR TYPES

- A lens is a transparent optical device that refract or bends light rays, causing them to converge or diverge.
- Lens are basically made of **glass** or **plastic** that have curved surfaces.
- Lens are used in some of the following devices:
  - Cameras
  - Telescopes
  - Microscopes
  - Eye glasses
- We basically have two types of lenses, namely: **Convex Lens** and **Concave Lens**.

1. **Convex Lens**
   - Also know as a **converging** lens.
   - It is a lens that converge light incident on them.
   - This lens is **thicker in the middle and thinner at the edges**.
   - This lens cause light rays to converge at a **focal point** after passing through it.
   - This type of lens is commonly used in magnifying glasses, cameras, and telescopes.
   - Examples of convex lenses are:
     - Biconvex or double convex lens.
     - Plano convex lens.
     - Concavo-convex lens or converging meniscus.

3

CONVEX LENS

- **Figure 1** below shows examples of convex lenses:

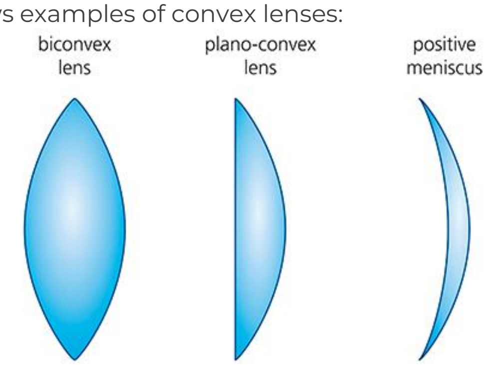


Figure 1

4

CONCAVE LENS

- Also know as **diverging** lens.
- It is a lens that disperse light incident on them.
- This lens is **thinner at the middle and thicker at the edges**.
- It causes light rays to diverge as it passes through the lens.
- This type of lens is mostly used in correcting vision problems in eyeglasses and in optical devices such as microscopes.
- Examples of concave lenses are:
  - Biconcave or double concave
  - Plano concave lens
  - Convexo-concave lens or diverging meniscus.
- **Figure 2** below shows examples of concave lenses.

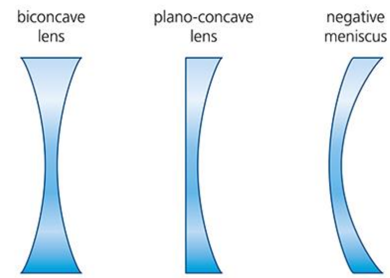


Figure 2

5

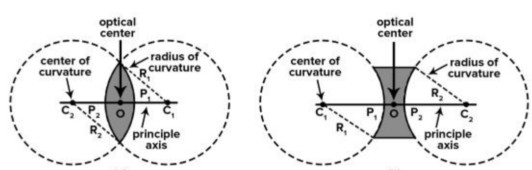
TERMS ASSOCIATED WITH LENSES

a. **Centre of curvature (C):** This is the centre of the sphere that the lens or mirror is part of. This point is used in determining the focal length and the overall behaviour of a lens. (**C_1** and **C_2**)

b. **Radius of curvature (r):** this is the distance between centre to the circumference of a sphere that the lens is part of. (**R_1** and **R_2**)

c. **Principle axis:** This is a imaginary line passing through the centre of curvature, the optical centre, and the principal focus of a lens. (**P_1** and **P_2**)

Figure 3 on the right shows some of the terms associated with lenses.



a: Convex lens

b: Concave lens

Figure 3

6

TERMS ASSOCIATED WITH LENSES

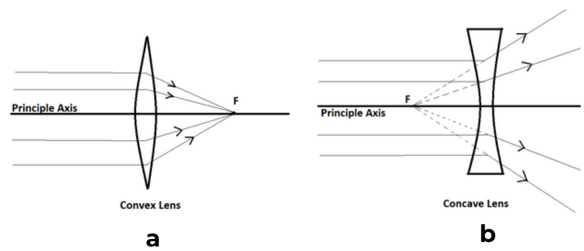
d. Principal focus (F): This is a **specific point** where light rays parallel to the principal axis of a lens converge or appears to diverge from. It is also called the **focal point**.

i. **Principal focus on a convex lens.**

- The principal focus of a convex lens can be displayed on a screen as such it is called **a real principal focus**.
- **Figure 4a** illustrates the principal focus of a convex lens.

ii. **Principal focus on a concave lens.**

- The principal focus of a concave lens can not be displayed or projected on a screen as such it is called a **virtual principal focus**.
- **Figure 4b** illustrates the principal focus of a concave lens.



a: Principal focus of a convex lens

b: Principal focus of a concave lens

Figure 4

7

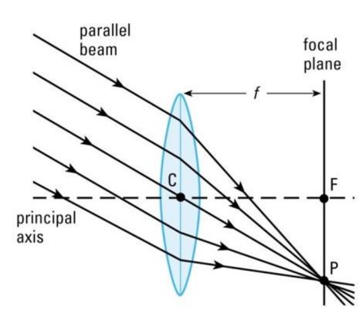
TERMS ASSOCIATED WITH LENSES

e. Focal Plane: This is a plane perpendicular (at 90 degrees) to the principal focus on which light rays converge.

- **Figure 5** shows a focal plane of a convex lens.

f. Optical centre (P): This is the midpoint (centre) of the lens. It is also called the centre of curvature.

- It is a point on the lens where light rays either reflect or refract without changing direction.
- **Figure 3** shows the optical centre of both a convex and concave lens.



Focal plane of a convex lens

Figure 5

8

TERMS ASSOCIATED WITH LENSES

g. **Focal Length (*f*)**: This is the distance between the optical centre of a lens and its principal focus or focal point.
- Biconvex and biconcave lenses have a focal length on each side of the lens.
- **Figure 6** below shows the focal length (*f*).

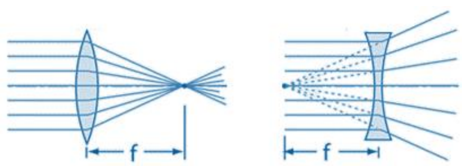


Figure 6

Note:

- The **centre of curvature** is **double the focal length** as such it is described as **2*F***.
- Where two or more light rays **meet** (converge) is where an **image is formed**, thus on the **principal focus (focal point)** or along the **focal plane**.
- To trace the location where the image is formed we can use a **ray diagram**.

9

RAY DIAGRAM

- This is a **graphical representation** used in physics and optics to **illustrate** the **behaviour of light rays** as they interact with optical systems such as lenses.
- The diagram typically consists of **lines representing the path of light rays** from an object to an image formed by the optical system such as a lens.
- On the right are the **rules** used to follow when drawing a ray diagram.

RULES WHEN DRAWING A RAY DIAGRAM

i. Use **at least two** rays of light from the object.

ii. One of the light rays used **must** pass through the optical centre.
   - **Where the two rays meet is where the image will be formed**.

iii. The ray of **light that bends must pass through the principal focus** (focal point).

Figure 7 on the next slide shows a simple ray diagram.

10

RAY DIAGRAM

- Below is a simple ray diagram

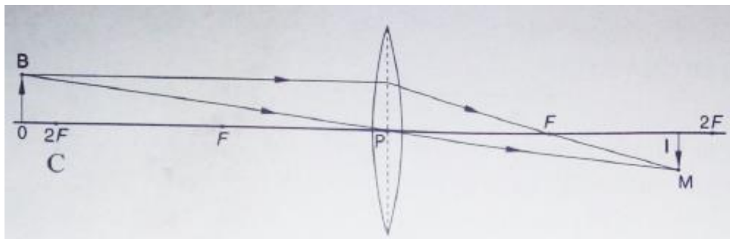


Figure 6: ray diagram

11

IMAGE FORMATION

Note:

- If the refracted rays **converge** a **real image** is formed, and if the rays **diverge,** a **virtual image** is formed.

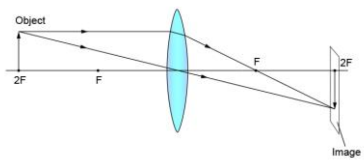
IMAGE FORMATION BY A CONVEX LENS

- In convex lenses we can have **three types** light rays namely:
- **Ray 1**: this is parallel and close to the principle axis and it passes through the principal focus (*F*) or focal point.
- **Ray 2**: this is a ray through the focal point *F* and emerges parallel to the principal axis after refraction (bending).
- **Ray 3**: this ray passes through the optical centre (P) and it is undeviated after refraction through the lens.

12

IMAGE FORMATION

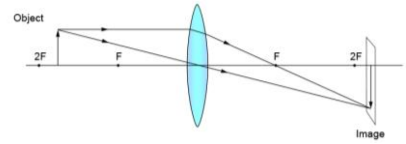
a. When object is at 2F



The formed image has the following **characteristics:**

- Inverted
- Real
- Same size as the object

b. When object is between 2F and F



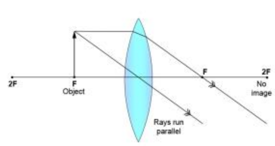
The formed image has the following **characteristics:**

- Inverted
- Real
- Magnified (larger than object)

13

IMAGE FORMATION

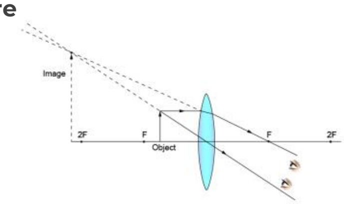
c. When object is at F



The formed image has the following **characteristics:**

- At infinity (no image)

d. When object is between F and optical centre



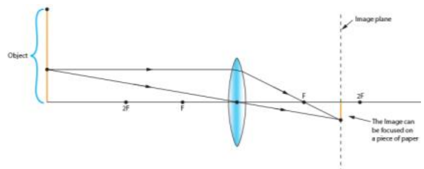
The formed image has the following **characteristics:**

- Upright
- Virtual
- Magnified (larger than object)

14

IMAGE FORMATION

e. When object is beyond 2F



The formed image has the following **characteristics:**

- Real
- Diminished (smaller that object)
- Inverted

f. When object is at infinity

The formed image has the following **characteristics:**

- Upright
- Virtual
- Magnified (larger than object)

Assignment:

Draw a ray diagram to represent the formation of an image whose object is at infinity. **(4 marks)**

15

IMAGE FORMATION - SUMMARY

The formed image at

- **2F** is of the same size as the object.
- **Before 2F from the optical centre** is larger in size than the object. (**magnified**)
- **Beyond 2F from the optical centre** is smaller in size than the object. (**diminished**)
- All images formed on the **negative** side of the lens are **upright and virtual**, while those formed on the **positive** side of the lens are **inverted and real**.

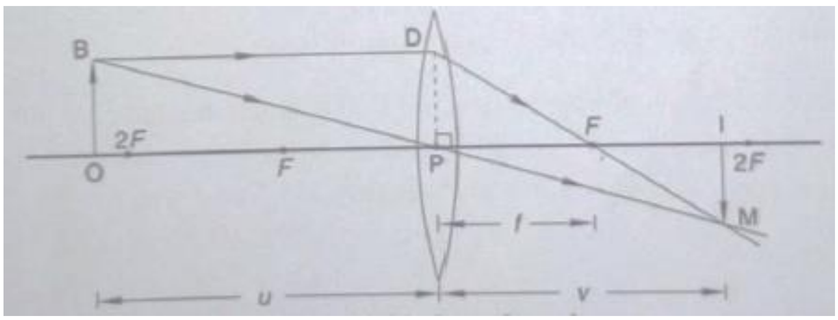
Symbols used to represent the distance between the lens and object and, image position.

- **Object distance** (**u**) – this is the distance between the object and the optical centre.
- **Image distance** (**v**) – this is the distance between the image and the optical centre.
- The relationship between the image distance, object distance and focal length is described in a **lens formula**.

16

LENS FORMULA

Consider the ray diagram below:



17

LENS FORMULA

From the ray diagram above:

Δ**OBP** is similar to Δ**IMP**, therefore:

$\frac{OB}{IM} = \frac{OP}{IP}$ (i)

Constructing line **DP** perpendicular to **PF** and equal to **OB**, we note that:

Δ**PDF** is similar to Δ**IMF**, therefore:

$\frac{DP}{IM} = \frac{PF}{IF}$ (ii)

But **DP = OB**, substituting this in equation (i) we get:

$\frac{DP}{IM} = \frac{PF}{IP}$ (iii)

Using equation (ii) we also note that:

$\frac{OP}{IP} = \frac{PF}{IF}$ (iv)

From equation (iv) we see that: **OP = u**, **IP = v**, **PF = *f*,** and **IF = v-*f***

18

LENS FORMULA

Substituting this into the equation (iv) we get:

$\frac{OP}{IP} = \frac{PF}{IF} \rightarrow \frac{u}{v} = \frac{f}{(v-f)}$

Thus: **uv – uf = vf**

Dividing both sides by **uvf**, we get:

$\frac{uv}{uvf} - \frac{uf}{uvf} = \frac{vf}{uvf} \rightarrow \frac{1}{f} - \frac{1}{v} = \frac{1}{u}$

Therefore the **lens formula** is:

$$\frac{1}{f} - \frac{1}{v} = \frac{1}{u}$$

19

WORKED EXAMPLES LENS FORMULA

Example 1

Calculate the position of an image formed by a convex lens of focal length 15 cm for an object placed 20 cm from the lens.

Solution

$\frac{1}{f} - \frac{1}{v} = \frac{1}{u}$

Given: f = 15 cm, u = 20 cm, v = ?

$\frac{1}{15cm} - \frac{1}{v} = \frac{1}{20cm} \rightarrow \frac{1}{15} - \frac{1}{20} = \frac{1}{v}$

$\frac{1}{v} = \frac{1}{60} \rightarrow$ v = 60cm

The image formed can be described as:

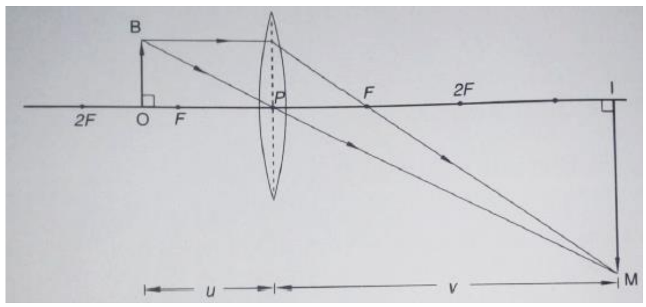
- Magnified if **m** >1
- Diminished if **m** < 1
- Same as object if **m** = 1

Where **m** is magnification.

20

MAGNIFICATION FORMULA

- Magnification refers to the ratio of the size of an image produced by a lens to the size of the actual object.
- Consider the ray diagram below:



21

MAGNIFICATION FORMULA

From the ray diagram we note that:

Δs **OBP** and **IMP** are similar, so we have:

$$\frac{IM}{OB} = \frac{IP}{OP}$$

Let **IM** = $\mathbf{h_2}$, **OB** = $\mathbf{h_1}$, **IP** = **v** and **OP** = **u**

Thus:

$$\frac{\mathbf{h_2}}{\mathbf{h_1}} = \frac{v}{u}$$

Since Magnification = $\frac{size\ of\ I}{size\ of\ O} \rightarrow \frac{\mathbf{h_2}}{\mathbf{h_1}}$

But $\frac{\mathbf{h_2}}{\mathbf{h_1}} = \frac{v}{u}$, therefore:

Magnification = $\frac{v}{u}$

Where:

- v = Image distance
- U = object distance

Thus:

$$\mathbf{m} = \frac{\mathbf{h_2}}{\mathbf{h_1}} = \frac{v}{u}$$

22