GEOMETRIC OPTICS

This is the branch of physics that studies light as a wave phenomenon.

Light can be defined as the visible form of energy radiated outward from a source.

Light is an example of an electromagnetic wave because it does not require a material medium for its propagation (i.e. it can travel in a vacuum). It is also a typical example of a transverse wave.

SOURCES OF LIGHT

The energy associated with light is called **luminous energy**. Objects that can produce light are called **luminous objects**. Luminous objectS can be divided into two. They are

1. **Natural sources**: these include as the sun, stars, fireflies and glowing worms etc. These produce light without electrical or mechanical means.
2. **Artificial sources**: these include torches, bulb, candle, fluorescent lamp and photographer flash tube etc. They can only produce light by electrical or mechanical means.

Non-luminous objects do not produce light. They can only be seen when the rays of light from luminous objects fall on them and reflect into the eyes. Common examples of non-luminous objects include moons, concrete walls, books, humans etc.

TRANSMISSION OF LIGHT

Substances such as clean water and glass allow light to pass through and can be seen through easily. These types of objects are called **transparent objects**.

Substances such as moon, books and concrete walls don't allow light to pass through them. These types of objects are called opaque objects.

From experiments, we know that light travels in a straight line. This can be expressed by the ray model of light.

RAY MODEL OF LIGHT

This model is also called the **Rectilinear Propagation of Light**. This model simply explains how light travels in a straight line path called a light ray. This is the phenomenon that also defines light in a straight line. This model is used to explain concepts like reflection, refraction, mirrors and lenses. The two major effects of the rectilinear propagation are **Shadow** and **Eclipse**

RAY OF LIGHT

A ray of light can be defined as the direction or path along which light travels. A light ray is an imaginary straight line with arrows drawn in the direction in which the light is traveling. It is usually represented with a straight line having an arrow pointing in the direction of the light. The combination of two or more rays of light is known as a **beam of light**.

A train of light (or group of light rays) can be represented by a **wavefront**.

A wavefront is defined as the locus of points all of which are in the same phase. More often than not, we use ray diagrams instead of wave fronts to represent a train of light

TYPES OF BEAM OF LIGHT

1. **Parallel beam of light**: This is a collection of rays of light that travel parallel to each other. That is to say they meet at infinity.
2. **Convergent beam**: This is a collection of rays of light that meet at a point
3. **Divergent beam**: This is a collection of rays of light all starting from a particular point and leaving from that point.

HUYGEN'S PRINCIPLE

When light rays propagate from a point to another, they have shapes and it is important to determine the shape of the propagation. Huygen's principle is a geometrical method for finding what the shape of a wave front will be at particular instant in the wave's path.
Huygen's principle states that: Every point of a wave front may be considered as the source of small secondary wavelets, which spread out in all directions from the centers with a velocity equal to the velocity of propagation of the wave.

When wave fronts are spherical, the rays radiate from the center of the sphere. However, when wave fronts are plannar, the rays are perpendicular to the wave fronts and parallel to each other.

SHADOW

This can be defined as the region where rays of light do not reach due to the obstruction by an opaque object. In a shadow, two regions are usually defined. They are umbra and penumbra.

1. **Umbra**: This is the region of a shadow where rays of light do not reach at all. It is the dark part of a shadow
2. **Penumbra**: This is the region where rays of light slightly reach. That is the slightly brighter than the darkness.

ECLIPSE

This is another effect of rectilinear propagation of light. Eclipse occurs when the celestial bodies (The sun, moon and the earth) are collinear i.e. they are on a straight line

1. ECLIPSE OF THE SUN (SOLAR ECLIPSE): This occurs when the moon is between the sun and the earth. This occurs during the day.
2. ECLIPSE OF THE MOON (LUNAR ECLIPSE): This occurs when the earth is between the sun and the moon. This occurs at night.

PINHOLE CAMERA

This was the first type of camera produced in 1666. It works on the principle of rectilinear propagation of light. In consists of a box with a pin hole at one end and a wax paper which acts as a screen at the opposite. When a luminous object such as a lighted candle is placed in front of the pin hole, the image of the candle can be seen on the screen but inverted.

The smaller the hole, the smaller the image but is not bright. The bigger the hole, the bigger the image but it is brighter. From these statements, it can be seen that a brighter image is gotten from a bigger hole because more light is admitted into the camera.

Pinhole camera was used by the early artists to give correct perspective about drawing and painting. It is also used by the land surveyors for accurate land measurements.

The major disadvantage about this is that it cannot be used to take snapshots

MAGNIFICATION

This can be defined as the ratio of the size of the image to the size of real object.

Magnification has no unit i.e. it has no dimension

$$magnification = i\,mage\,object$$

$$magnification = \frac{image\,height}{object}$$

$$m = \frac{H_i}{H_o}$$

$$magnification = \frac{Image\,distance}{Object\,distance}$$

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

If m > 1: Image size > Object size: That means that the object has been magnified

If m < 1: Image size < Object size: That means that the image has been diminished

If m = 1: Image size = Objet size:

REFLECTION

When a narrow beam of light wave strikes a flat surface, the wave is in general partly reflected and partly refracted into the medium that received the incident light. The angle of incidence $(\theta_i)$is defined as the angle makes with the normal (perpendicular) to the surface and the angle of reflection, (θ_r), is the angle the reflected ray also makes with the normal. We can also define the glancing angle (θ_g)as the angle between the reflected ray and the reflecting surface.

When a ray of light is incident on a plane surface, the light is either absorbed, transmitted (refracted) or it is reflected.

LAWS OF REFLECTION

i. The incident and reflected rays lie on the same plane with the normal to the surface

ii. The angle of incidence is equal to the angle of reflection, for all wavelengths and for any pair of materials. That is

TYPES OF REFLECTION ON PLANE SURFACES

1. Regular Reflection: This is the reflection that occurs on a smooth surface such as a (plane) mirror
2. Irregular Reflection: This is the reflection that happens on a rough surface such as paper or cloth. It is also called scattered or diffused reflection.

TYPES OF IMAGES

1. **Real Images**: These are the ones in which the rays of light and can be obtained on a screen. A real image is that image which is formed when the light rays coming from an object actually meet each other after reflection or refraction. A real image is most times inverted. Typical examples of real images are the ones formed in pin hole cameras and the one in cinemas. It can also be defined as a collection of focus points actually made by converging rays.
2. **Virtual Images**: This is the one in which the rays of light do not reach yet visible to the eye. It can be said that this is an image formed if the rays of light do not actually pass through the image point. The ray of light touches the object, and then reflected into the mirror where the image is formed. A virtual image cannot be viewed on a screen (or a sheet of paper) and is usually erect. A virtual image is the collection of focus points made by extensions of diverging rays. In other words, it is an image

which is located in the plane of convergence of the light rays that originate from a given object (divergent rays).
The image formed on a plane mirror is an example of a virtual image.

PLANE MIRRORS

CHARACTERISTICS OF THE IMAGE FORMED ON A PLANE MIRROR

1. The image is virtual
2. The image is upright
3. The magnification is equal to one
4. The distance of the image from the mirror is the distance of the objet from the mirror
5. The image is laterally inverted (i.e. the left of the object is the right of the image and vice versa)

INCLINATION OF A (PLANE) MIRROR

When two plane mirrors are inclined at an angle(θ), a number of images will be formed. The number of images formed depends on the angle. The formula for calculating the number of images is given by

$$n=\frac{360}{\theta}-1$$

ROTATION OF A MIRROR

This slightly defies the laws of reflection of light on a plane surface
When a plane mirror is rotated through an angle(θ), the incident ray and the normal remain unchanged (i.e. they stay at the same point). However, the reflected ray will move through an angle that is twice the angle of rotation (2θ) in the direction of the rotation of the mirror.
That means if a mirror is rotated through an angle$30°$, the new reflected ray will be 60 (i.e. (2×30)

USES OF PLANE MIRRORS

1. They are used as common looking glasses.
2. They are used to construct sextants (devices used to measure the angle of elevation of the sun)
3. They are used to create periscopes (A device used to view objects above you without being seen. They are used a lot in submarines)

4. They can be used to construct kaleidoscopes (A toy which produces beautiful pattens.This is done by inclining two mirrors at 60 degrees)

5. They are used to make solar cookers

6. They are also used in various scientific instruments

DEVIATION OF LIGHT

When a ray of light is incident on a plane mirror, the angle between the incident ray and the normal is called the angle of incidence$(\hat{i})$ while the angle between the reflected ray and the normal is the angle of reflection$(\hat{r})$.

The angle the incident ray makes with the surface of the reflecting material (not the angle with the normal) is called the **glancing angle** (g). This is also equal to the angle the reflected ray makes with the glass (since the incident angle and the reflected angle are the same) and it is also called the glancing angle.

The divergence (d) of that setup is twice the glancing angle

$$d=2g$$

Since the incident ray, reflected ray and the glancing angles are all on a straight line,

$$g+i+r+g=180\left(\sum of\ angles\ on\ a\ straight\ line\right)$$

$$i+r+2g=180$$

But

$$d=2g$$

$$i+r+d=180$$

Also,

$$i=r$$

We can say

$$i+i+d=180$$

$$2i+d=180$$

$$d=180-2i$$

Similarly,

$$d=180-2r$$

REFLECTION OF LIGHT ON CURVED SURFACES (MIRRORS)

Rays of light can also be reflected from curved mirrors. There are two types of curved mirrors:

1. Concave mirrors
2. Convex mirrors

TERMS USED IN CURVED MIRRORS

1. Pole (p): The pole of a mirror is the (approximate) center of the mirror
2. Center of curvature (c): This can be defined as the point at which the mirror forms a path
3. Radius of curvature (r): This can be defined as the distance between the pole and the center of curvature
4. Principal axis (x): This can be defined as an imaginary line that joins the pole to the center of curvature. The length of the principal axis is the radius of curvature.
5. Principal focus (f): This can be defined as the point at which rays of light that are parallel and close to the principal axis converge (for a concave mirror) or diverge from (for a convex mirror) after the rays have been reflected

Concave Mirrors

In this type of mirror, rays of light converge at the center. They are also known as converging mirrors.

FORMATION OF IMAGES BY A CONCAVE MIRROR

A ray diagram is used to show (or determine) the nature and type of image formed by a concave mirror. The nature of the image formed depends on the distance and position of the object in relation to the mirror.

The following rules should be taken when drawing a ray diagram

RULES FOR DRAWING RAY DIAGRAMS

1. A ray of light (or ray of an object) parallel to the principal axis is first reflected.
2. The reflected ray then converges at the principal focus (f) [and passes through it]
3. Then a line is drawn from the (top of the) object and passes through the center of curvature (c).
4. The lines that pass through the center of curvature and the principal focus then meet at a point.

RAY DIAGRAMS OF CONCAVE MIRRORS

1. For an object placed behind the center of curvature, the image is:
    - Diminished (of smaller size)
    - Inverted
    - Real
2. For an object placed exactly on the center of curvature, the image is:
    - Same size
    - Inverted
    - Real
3. For an object placed between the center of curvature (c) and the principal focus (f), the image is:
    - Magnified
    - Inverted
    - Real
4. For an object placed exactly on the principal focus, the image is:
    - At infinity (i.e. it will not be seen)
5. For an object placed between the principal focus and the pole, the image is:
    - Magnified
    - Upright (Erect)
    - Virtual

NB: For a concave mirror to be used as a shaving mirror, the object has to be placed between the principal focus and the pole of the mirror

USES OF CONCAVE MIRRORS

1. Concave mirrors are used as shaving mirrors
2. They can also be used as head mirrors
3. Ophthalmoscope
4. They are also used in astronomical telescopes
5. They are also used by dentists to magnify the image of a hole present in the teeth
6. They are used in headlights
7. They are also used to start fires and in solar furnaces.

Convex Mirrors

In this type of mirror, rays of light diverge from the center. They are also known as diverging mirrors

USES OF A CONVEX MIRROR

They are used to make sunglasses

1. They are also used for security purposes
2. They are used as street light reflectors
3. They are also used as driving mirrors because it usually forms an erect image and gives a wide field view.
4. In curved mirrors, a virtual image is usually formed behind the mirror while a real image is formed in front of the mirror

MIRROR FORMULAE

These formulae are used in solving most questions pertaining to mirrors

For the following

$$u = object\ distance\ (mirror)$$

$$v = image\ distance$$

$$f = focal\ length\ (length\ of\ the\ principal\ focus \mid the\ pole)$$

$$m = magnification$$

$$r = radius\ of\ curvature$$

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

$$f = \frac{uv}{u+v}$$

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

$$f = \frac{r}{2}$$

$$r = 2f$$

$$u = f\left(1 + \frac{1}{m}\right)$$

$$v = f\,(1+m)$$

SIGN CONVENTION

For all mirrors, the object distance is always positive

For a concave mirror,

$$f = +ve$$

For a convex mirror,

$$f = -ve$$

$$v = -ve$$

For a real or inverted image,

$$m = +ve$$

$$v = +ve$$

For a virtual or upright image,

$$m = -ve$$

$$v = -ve$$

<u>DISTANCE BETWEEN THE OBJECT AND THE IMAGE IN MIRRORS</u>

For a virtual image,

$$d = |v| + u$$

For a real image,

$$d = |v| - u$$

In the graph of $\frac{1}{u}$ against $\frac{1}{v}$, the focal length can be found by

First adding the intercepts of the y axis and the x-axis then finding the reciprocal of the sum