GEOMETRIC OPTICS

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 model is used to explain concepts like reflection, refraction, mirrors and lenses.

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

So what is a light ray? A light ray is an imaginary straight line with arrows drawn in the direction in which the light is traveling.

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 equat 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.

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 is defined as the angle makes with the normal (perpendicular) to the surface and the angle of reflection, , is the angle the reflected ray also makes with the normal. We can also define the glancing angle as the angle between the reflected ray and the reflecting surface.

The law of reflection states that:

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

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 object can be divided into two. They are

Natural sources: these include as the sun, stars, fireflies and glowing worms etc. These produce light without electrical or mechanical means.

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.

Objects

RAY OF LIGHT

A ray of light can be defined as the direction or path along which light travels. 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.

TYPES OF BEAM OF LIGHT

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.

Convergent beam: This is a collection of rays of light that meet at a point

Divergent beam: This is a collection of rays of light all starting from a particular point and leaving from that point.

RECTILINEAR PROPAGATION

This is the phenomenon that defines light in a straight line. The two major effects of the rectilinear propagation are Shadow and Eclipse

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.

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

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

ECLIPSE OF THE SUN (SOLAR ECLIPSE)

This occurs when the moon is between the sun and the earth. This occurs during the day

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

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 OF LIGHT ON PLANE SURFACES

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

There are two types of reflection

Regular Reflection: This is the reflection that occurs on a smooth surface such as a (plane) mirror

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. 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.

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

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, 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

LAWS OF REFLECTION

First law: The incident ray (i), the reflected ray (r) and the normal all lie on the same point

Second law: The angle of incidence is equal to the angle of reflection

ROTATION OF A MIRRORR

This slightly defies the laws of reflection of light on a plane surface

When a plane mirror is rotated through an angle, 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 in the direction of the rotation of the mirror.

That means if a mirror is rotated through an angle, the new reflected ray will be 60 (i.e.

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 while the angle between the reflected ray and the normal is the angle of reflection.

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

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

But

Also,

We can say

Similarly,

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

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.
8. Convex Mirror: 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

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

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

A ray of light (or ray of an object) is first reflected.

The reflected ray then converges at the principal focus (and passes through it)

Then a line is drawn from the (top of the) object and passes through the center of curvature.

The lines that pass through the center of curvature and the principal focus then meet at a point.

RAY DIAGRAMS

For an object placed behind the center of curvature, the image is:

Diminished (of smaller size)

Inverted

Real

For an object placed exactly on the center of curvature, the image is:

Same size

Inverted

Real

For an object placed between the center of curvature (c) and the principal focus (f), the image is:

Magnified

Inverted

Real

For an object placed exactly on the principal focus, the image is:

At infinity (i.e. it will not be seen)

For an object placed between the principal focus and the pole, the image is:

Magnified

Upright (Erect)

Virtual

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

FORMATION OF IMAGES IN A CONVEX MIRROR

In a convex mirror, the image formed is always diminished, erect and virtual no matter the position of the object in relation to the mirror.

MIRROR FORMULAE

These formulae are used in solving most questions pertaining to mirrors

For the following

SIGN CONVENTION

For all mirrors, the object distance is always positive

For a concave mirror,

For a convex mirror,

For a real or inverted image,

For a virtual or upright image,

DISTANCE BETWEEN THE OBJECT AND THE IMAGE IN MIRRORS

For a virtual image,

For a real image,

In the graph of against, 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

REFRACTION OF LIGHT ON PLANE SURFACE

Refraction is defined as the apparent change in the direction of a (light) wave when it travels from one medium to another.

During refraction, frequency remains unchanged but the direction, velocity and wavelength all change. Optical density increases from gases (air) to liquid (water) and to solids (glasses)

The following equation shows the optical densities relation of the following objects

When light travels from a less dense medium to a denser medium, like from gas to liquid or liquid to solid or gas to solid, the light bends towards the normal. However, if the light travels from a denser medium to a less dense medium, it bends away from the normal.

LAWS OF REFRACTION

The incident ray, refracted ray and the normal all lie on a common point

Second Law: The ratio of the sine of the incident ray to the sine of the refraction angle is equal to the ratio of the refractive indices of the materials at the interface and is constant for any given pair of media. This statement is known as Snell’s law

The angle that the incident ray makes with the normal is called the angle of incidence

Let the refractive index of medium A be and let the refractive index of medium “B” be

If the light is incident at medium A and is refracted at medium B, let the angle of incident (at medium A) be and the angle of refraction be

From Snell’s law,

Let n be a constant known as the refractive index (of the second medium with respect to the first)

We have

Therefore,

The refractive index (n) of a medium can also be defined as the ratio of the velocity of light in air to the velocity in that medium

But

Since in refraction, frequency remains unchanged, that means it is constant

Therefore,

REFRACTIVE INDEX OF A LIQUID

When a metallic coin is in a beaker of water, the coin appears to be (displaced) above its normal level when viewed vertically from above (the beaker of water). Similarly, a swimming pool appears to be shallow when viewed from vertically above the pool. All these effects are due to the refraction of light in the water.

The distance between the top of the liquid (water) and the real position of object (in the liquid) is called the Real depth (R). The distance between the top of the liquid and the where it appears to be (i.e. its apparent position) is called the apparent depth (A). The distance between the real depth and the apparent depth is called the displacement (d).

The refractive index of the liquid is defined as the ratio of the real depth to the apparent depth

Since

CRITICAL ANGLE AND TOTAL INTERNAL REFLECTION

When a ray of light travels from a denser medium to a less dense medium, the ray bends away from the normal; as the angle of incidence increases, there is also an increase in the angle of refraction.

The largest angle of incidence that will give a maximum angle of refraction is called the critical angle. The largest angle of refraction is 90 degrees

Critical angle can now be defined as the highest incident angle (which produces the highest angle of refraction) below which light rays can escape from an optically denser medium to a less dense medium.

If the angle of incidence becomes greater than the critical angle, there will be no more refraction but a strong reflection call Total Internal Reflection

CONDITIONS FOR TOTAL INTERNAL REFLECTION

Light must travel from an optically denser medium to a less dense medium

The incident angle must be greater than the critical angle.

The relationship between the critical angle (c) and the refractive index (n) is expressed as

MIRAGE

This happens when the ground is very hot and the air is cool. The hot ground warms a layer of air just above the ground and makes it optically less dense than the cool air above it. When light moves through the cold air into the layer of hot air it is refracted. A layer of very warm air near the ground refracts the light from the sky nearly into a U-shaped bend.

Mirage is caused by the total internal reflection of light at layers of air of different densities and the sky which looks like a pool of water when viewed from a distance is produced.

LENSES

A lens can be defined as a piece of glass or other transparent material with curved sides for concentrating or dispersing light rays, used singly (as in a simple magnifying glass) or with other lenses (as in a telescope)

There are two major types of lenses

Convex lenses: These have a lot of similarities with concave mirrors. They are called converging lenses. When (parallel) rays of light pass through a convex lens, they are refracted and they converge at a point called the principal focus. These lenses are thicker at the center than at the rim

USES

1. Convex lenses are used in making magnifying glasses
2. They are also used to make eyeglasses
3. They are used in cameras
4. They are used in multi-junction star cells
5. They are used in telescopes
6. They are used in projectors
7. They are also used in making side-view mirrors

Concave lenses: These have a lot of similarities with convex mirrors. They are called diverging lenses. They are thinner at the center than at the rims.

USES OF CONCAVE LENSES

1. They are used in lasers
2. They are also used in cameras
3. They are used in flashlights
4. They are used in peepholes
5. They are also used in making eyeglasses

TERMS USED IN LENSES

1. Pole (p): This is the center of the lens
2. Principal focus (x): This is where parallel rays of light converge (at the back of the lens for convex lenses) and diverge (for concave lenses).
3. Center of curvature (2f)
4. Principal axis (x): This is an imaginary line that joins the pole to the center of curvature.
5. The focal length of a lens depends on the refractive index of the lens and the radius of curvature of the lens/

FORMING IMAGES IN CONVEX LENSES

Similar to mirrors, images formed can also be represented with ray diagrams

The following rules should be followed when drawing ray diagrams for convex lenses

The rays of the object parallel to the principal axis pass through the lens and are refracted

The refracted rays then pass through the principal focus (i.e. they converge there)

Then a line is drawn from the top of the object which passes through the exact center (pole) of the lens and it intercepts the line that passed the principal focus.

Finally a line is drawn perpendicularly to the principal axis to meet the point of intersection.

For an object before 2f (or at infinity), the image is:

Inverted

Real

Diminished

For an object on 2f exactly, the image is:

The same size

Inverted

Real

For an object between 2f and f, the image is

Magnified

Inverted

Real

For an object at f, the image is:

At infinity

For an object between f and p, the image is

Magnified

Erect

Virtual

RAY DIAGRAM FOR A CONCAVE LENS

LENS FORMULAE

These formulae are used in solving most questions pertaining to mirrors

For the following,

If we multiply through by u

But

Therefore,

If we multiply through by v

But

SIGN CONVENTION

For all mirrors, the object distance is always positive

For a convex lens,

For a concave lens,

For a real or inverted image,

For a virtual or upright image,

DISTANCE BETWEEN THE OBJECT AND THE IMAGE

For a virtual image,

For a real image,

POWER OF A LENS

This is defined mathematically as the reciprocal of the focal length of the lens.

If the focal length is in meters

If it is in centimeters

COMPOSITE LENSES

A composite lens is the combination of two or more lenses. The average focal length of the lens can be obtained from

That formula is called the lens maker equation.

The power of composite lenses (or lenses in close contact) is expressed as

OPTICAL INSTRUMENT

1. Simple microscope: This consists of just a single lens. The object to be magnified is placed between the principal focus and the pole of the lens.

The image formed is Magnified, Erect and Virtual

1. Slide projector: This also consists of a simple convex lens. The object to be magnified is placed between the principal focus and the center of curvature.

The image formed will be magnified, inverted and real.

1. Compound Microscope: This comprises 2 convex lenses. The first is called the objective lens (because it is close to the object) and it has a shorter focal length than the second which is called the eyepiece (because it’s close to the eye) with a longer focal length.

The object to be magnified is placed between f and 2f of the objective lens. The image produced by the objective lens serves as the object of the eyepiece which produces a final Virtual, Inverted and magnified image (VIM image).

1. Telescope: This device is used for viewing distant objects. It comprises two lenses. The first is the objective lens with a longer focal length and the eyepiece with a shorter focal length

Under normal adjustment, the distance between the lenses is the sum of the focal lengths of the two lenses.

The angular magnification (M) of the image formed is

An object at infinity then forms a final magnified image also at infinity. When adjusted to produce an image (at the near point), the final image is magnified, inverted and virtual.

In a terrestrial telescope, an extra convex lens is inserted between the objective lens and the eyepiece in order to produce a final erect image.

If you look at the galaxy from earth, we see things in the past. If we look at the sun, what we actually see the sun how it was 8mins ago.

1. Camera: The camera also consists of a convex lens which focuses a real inverted image on a film. The aperture is the hole through which light enters the camera and the size of the aperture is controlled by an adjustable diaphragm in order to control the amount of light that comes into the camera and reaches the film.
2. The human eye: Although this is a biological organ, it has a natural convex lens which has a flexible focal length that can be controlled by the ciliary muscles. The lens focuses the image of the object on the retina. The retina is the most sensitive part of the eye. The retina is located at the back of the eye and it is the site of image formation.

Accomodation is the ability of the eye to focus on objects clearly at various distances. Far point is the maximum distance at which the eye can focus objects clearly and the near point is the minimum distance. For a normal eye (i.e. eyes without glasses), the near point is 25cm while the far point is an infinity.

EYE DEFECTS

1. Hypermetropia (Long sightedness): A long sighted person can only distant objects clearly but can’t see near objects clearly (i.e. they are blurred). This is due to a small eyeball and then the image is formed behind the retina. It can be corrected using a convex lens
2. Myopia (Short sightedness): A short sighted person can only see near objects clearly but distant objects remain blurred. This is due to a large eyeball and the image is formed in front of the retina. This can be corrected using a concave lens.
3. Presbyopia: This is known as loss of accommodation (i.e. the inability of the eye to focus objects at various distances. It is usually due to old age and weakening of the ciliary muscles and making the lens weak. It can be corrected lens using a bi-focal lens (i.e. a concave and convex lens)
4. Astigmatism: This is due to the uneven curvature of the cornea. A person suffering from astigmatism will not see equally clearly. It can be corrected by using a cylindrical lens (i.e. a lens that allows light to pass in one direction).

The camera has similar features with the human eye and a comparison between the camera and the human eye.

|  |  |
| --- | --- |
| The eye | Camera |
| Flexible lens | Rigid lens |
| Retina | Film |
| Pupil | Aperture |
| Iris | Diaphragm |
| Biological organ | Mechanical Instrument/ Device |

GLASS PRISMS

USES OF RECTANGULAR PRISMS

1. Glass prisms are the most commonly used prisms in real life especially in packaging, from cereal boxes to cartons and parcels delivered by mail.
2. In a rectangular glass block (rectangular prism) (also known as a parallel sided glass block), the angle of deviation of the emergent ray is always zero no matter the angle of incidence given in the question.

TRIANGULAR PRISM

A triangular prism is made up of glass or plastic having internal angles of 60, 6h0 and 60 (An equilateral triangular prism) or 90, 45 and 45.

When a ray of light incidents on one phase of the triangular prism it is refracted through the prism and comes out from the other side of the prism the angle of deviation (D) is the angular difference between the incident ray and the emergent ray. Generally, the refractive index of a triangular prism is given as

DISPERSION OF LIGHT BY A TRIANGULAR PRISM

White light is a mixture of several colors which include

Red, Orange, Yellow, Green, Blue, Indigo and Violet popular in the acronym ROYGBIV

As you move from red down to indigo, the wavelength decreases while the frequency increases.

If a beam of light is incident on a triangular prism, it is refracted through the prism. The emergent rays split into various colors which make up the spectrum of white light. This phenomenon is known as dispersion. The various components of light travel at different speeds in the glass and refract along different directions.

Red light which has the fastest speed is the least deviated while violet with the least speed is the most deviated.

COLOR MIXTURE

When two different colors of the spectrum are superimposed, a third color is produced.

TYPES OF COLORS (IN PHYSICS AND LIGHT NOT PERTAINING TO PAINTING)

1. Primary colors: These are colors (or lights) that can’t be gotten from other colors. These colors are Red, Green and Blue

Secondary Colors: These are produced by mixing two other colors

1. Complementary colors: These are colors that will produce white when mixed together. The combination of all three primary colors gives white.

A color triangle is used for quick remembrance of the color mixture

A corner of the triangle represents primary colors

The side of the triangle represents secondary colors

A mixture of a primary color and the side opposite it produces a white circle. Also, the circle in the center represents white.

A transparent object is seen by the color it transmits while an opaque object is seen by the color it reflects.

|  |  |  |
| --- | --- | --- |
| Object Color | Reflected Color | Absorbed Color |
| Red | Red | Blue and Green |
| Blue | Blue | Red and Green |
| Green | Green | Red and Blue |
| Yellow | Red and Green | Blue |
| Magenta | Red and Blue | Green |
| Cyan | Blue and Green | Red |