Light

Light is produced when atoms within a material **absorb energy**. This puts the atoms into an "**excited state**" where electrons jump to a higher **energy level** (**orbit**). When these electrons **release the energy**, they return to their original orbit (**ground state**) and often give off **light**.

Light sources can be either direct or indirect.

Direct light – comes from **luminous objects** which are able to **produce their own light** (ex: **Sun, firefly**, etc…)

Indirect light – comes from **non-luminous** objects which **reflect light** and are not able to produce their own (ex: **Moon, bicycle reflectors** etc…)

Categories of Luminous Objects

Object	Description
Incandescent	Emit light because they are hot Ex. old school light bulb
Fluorescent	Emit light when excited by other radiation Ex. fluorescent light bulb
Phosphorescent	Emit light when excited and emission continues after input is removed Ex. glow-in-the-dark sticker
Chemiluminescent	Emit light because of a chemical reaction Ex. glow-stick
Bioluminescent	Living things that emit light because of a chemical reaction Ex. fire-fly
Triboluminecent	Light emitted when a material is crushed Ex. wintergreen lifesaver

Sunlight

- **Nuclear Fusion reactions** occur in the Sun's core (**hydrogen** atoms collide and fuse to form **helium**) and the energy produced is transferred to the gases near the Sun's surface.

- This excites the atoms near the surface (**photosphere**) and they release their energy in the form of light.

Incandescence

- Light is emitted by a **very hot object**.

- Older light bulbs pass an electric current through a **tiny tungsten wire**. The wire is **heated** (atoms are excited) and glows brightly to produce light.

- Incandescent bulbs are only **5% efficient** in producing light. **95%** of the energy used is **lost as heat**.

Electrical Discharge

- Current is passed through a **gas instead of a wire**.

- Bulb (tube) has an **electrode at either end** and is filled with a vapour (usually **mercury** or **sodium**). An electric current passes through the vapour and excites the atoms, which **emit this energy as light**.

- Each gas will emit a different wavelength of light (**colour**) when excited.

- **Fluorescent light bulbs** (ex. **CFL's**) contain **mercury** vapour and **argon**, an inert gas. The inside of the bulb is coated with a powder called **phosphor**.

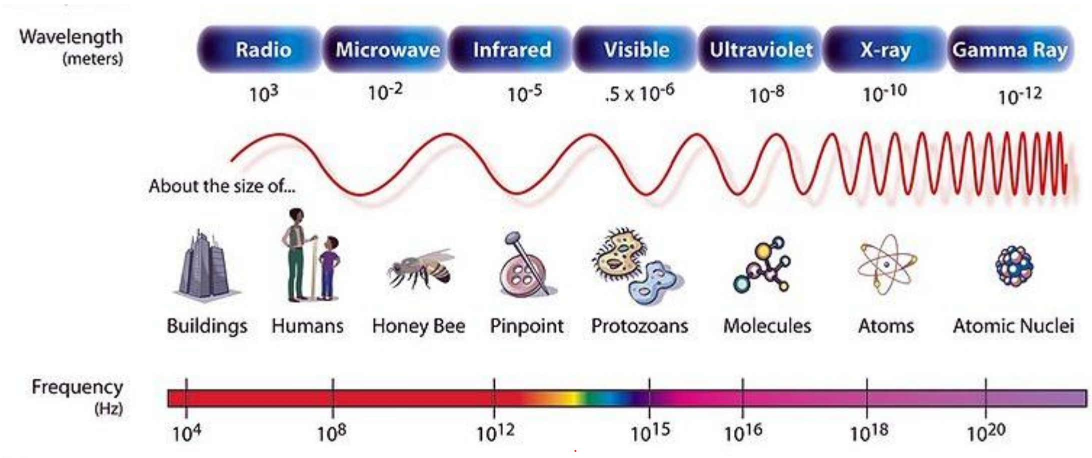
- When the mercury atoms are excited, they release **ultraviolet light**.

- The UV light is absorbed by the phosphor, which **emits visible light**. This kind of light emission is called "**fluorescence**"

- A CFL (Compact Fluorescent Lightbulb) is **20% efficient** so they use **less electricity**, and they **last much longer** than incandescent bulbs.

Properties of Light and Reflection

Using the example on page 409 as a guide, make a labeled diagram of the electromagnetic scale.



The electromagnetic spectrum shows all of the different forms of **energy** and their **wavelengths**, including visible light. Visible light is the only form of energy we can perceive with our **eyes**, but all the forms of energy can be used by or effect humans.

300 000 000 10.8 m/s

Light travels very fast (**3.00×10^{8} m/s**) and in **straight lines (rectilinear propagation)**.

Light will travel in a straight line as long as it is moving through the same **medium** (**substance**). Light waves **reflect** (**change direction**) when they reach a surface and bounce off of it.

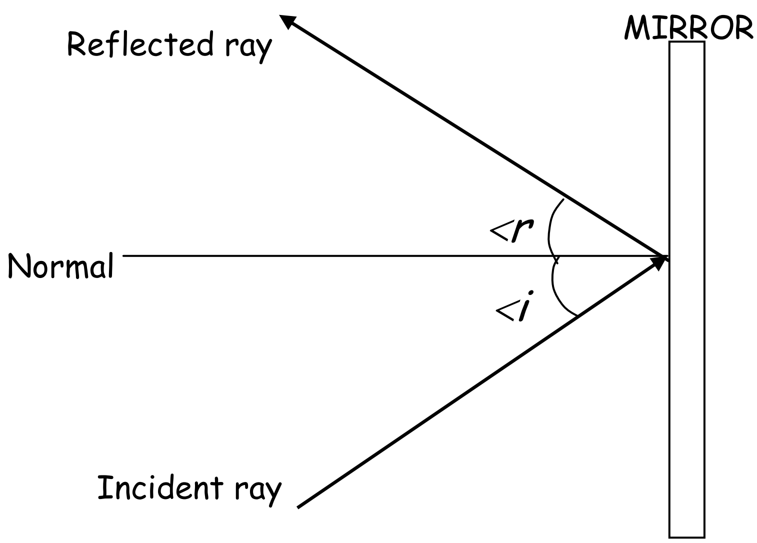
We can use a **ray** to model the **movement of a light wave**. A ray is a **straight line** with an **arrowhead** that shows the **direction** that light is traveling. We can use rays to predict how light **travels**, **creates shadows**, **reflects**, and **refracts**.

Fermat's Principle:

- Light follows the path that will take the **least time**.
- When light reflects off of a surface and remains in one medium, its speed is **constant**, so the path that takes the least time is the shortest path (**a straight line**). This principle leads to the **Laws of Reflection**.

Reflection Vocabulary:

- **Incident ray:** a ray of light coming toward a surface
- **Angle of incidence:** measured between the incident ray and the normal
- **Normal:** a perpendicular line drawn from the point of contact of the incident ray at the surface
- **Reflected ray:** a ray of light starting at the point of contact and moving away from the surface
- **Angle of reflection:** measured between the reflected ray and the normal



Laws of Reflection:

1. The incident ray, reflected ray, and the normal always lie on the **same plane**.
2. The angle of reflection (*<r*) is **equal** to the angle of incidence, (*<i).*

Images in Plane Mirrors

We can apply the laws of reflection to predict where an object's image will be and what the image will look like in a mirror (the **characteristics** of the image).

An image has 4 characteristics:

- **Location** (closer, farther, or same distance as the object to the mirror)
- **Orientation** (upright or inverted)
- **Size** (same size, larger, or smaller than the object)
- **Type** (real image or virtual image)

The image in a plane (flat) mirror is called a **virtual image**. We see the image of the object in the mirror, but there are **no actual light rays** coming from the image itself – it only appears that way. The rays behind the mirror **do not actually exist,** we only perceive that they exist because our **brain** assumes light travels in **straight lines**

We can predict the characteristics of an object's image by using a **ray diagram**

Characteristics of an image in a plane mirror:

- **Same distance**
- **Upright**
- **Same size**
- **Virtual image**
- Images in plane mirrors are also **laterally inverted**. For example, words in a mirror appear to be written **backwards**.

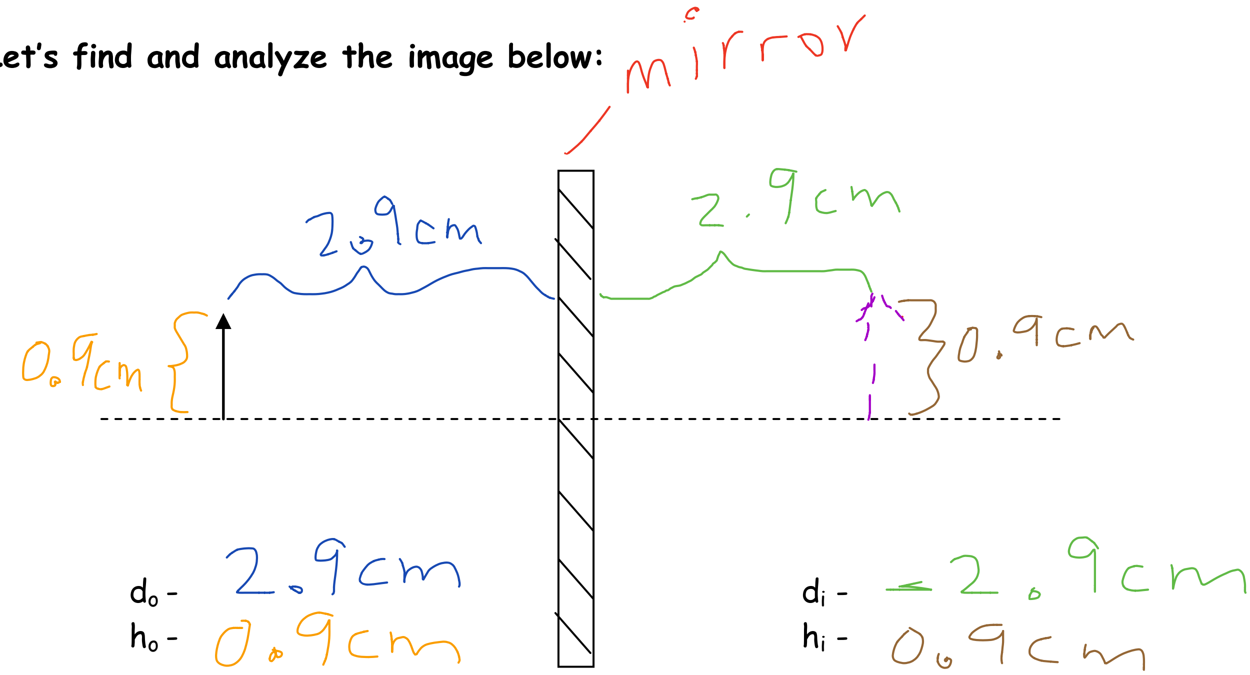
Steps in Locating Images in Plane Mirrors

1. Measure the **perpendicular** distance from the mirror to the object. The image will be located at the **same** distance **behind** the mirror.
2. Use another ray to demonstrate that images are formed where light rays **converge**. You may need to do this for more than one point on the object.

To Demonstrate How the Eye Perceives an Image

1. Draw lines from the **image** to the **eye**, using **dotted** lines behind mirror and **solid** lines in front. (**REFLECTED RAYS**)
2. Draw lines from the intersection of mirror and reflected rays to the object. (**INCIDENT RAYS**)

Let's find and analyze the image below:



d_o - 2.9cm

h_o - 0.9cm

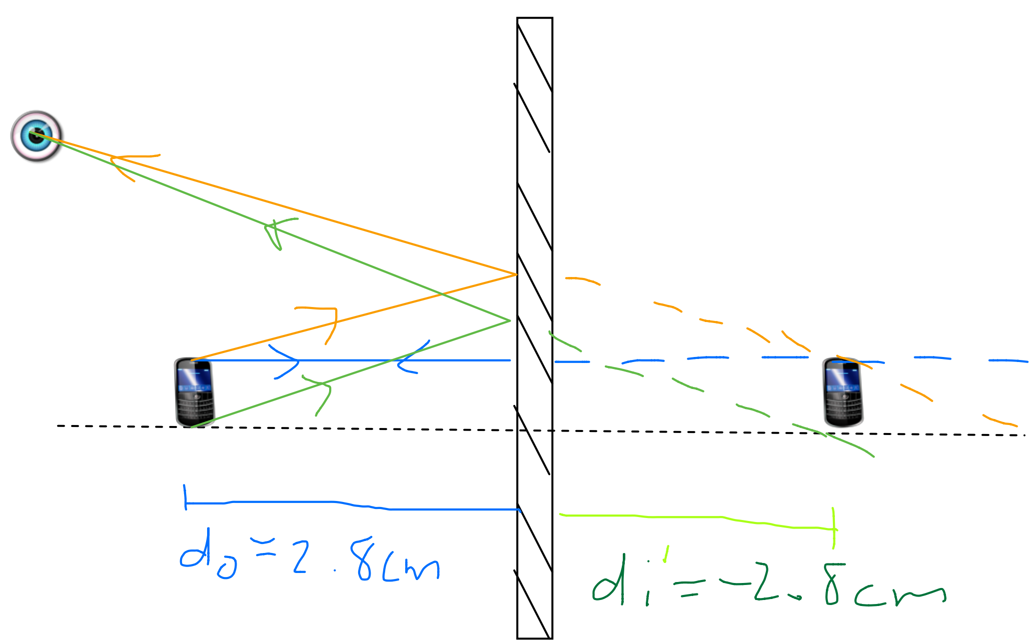
d_i - −2.9cm

h_i - 0.9cm

Characteristics of an image in a plane mirror:

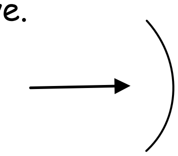
- L - same
- O - upright
- S - same
- T - virtual

How your eye perceives an image in a plane mirror

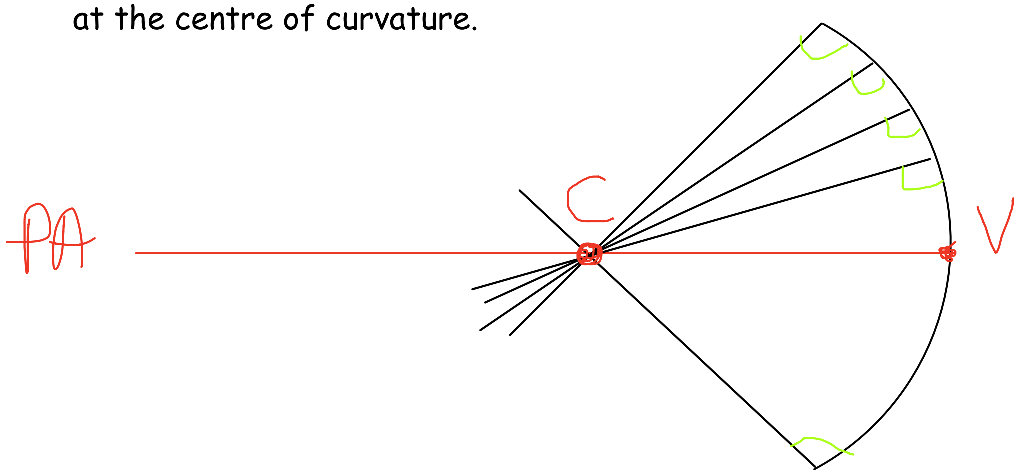


Properties of Concave Mirrors

Concave Mirror – A mirror whose reflecting surface curves inwards, like the inside surface of a basketball. You can remember it because the surface of the mirror forms a cave.



Centre of Curvature (C) – The centre of curvature is the centre of the circle formed by the surface of the mirror. If you took a **normal** line at each point on the mirror, they would meet at the centre of curvature.

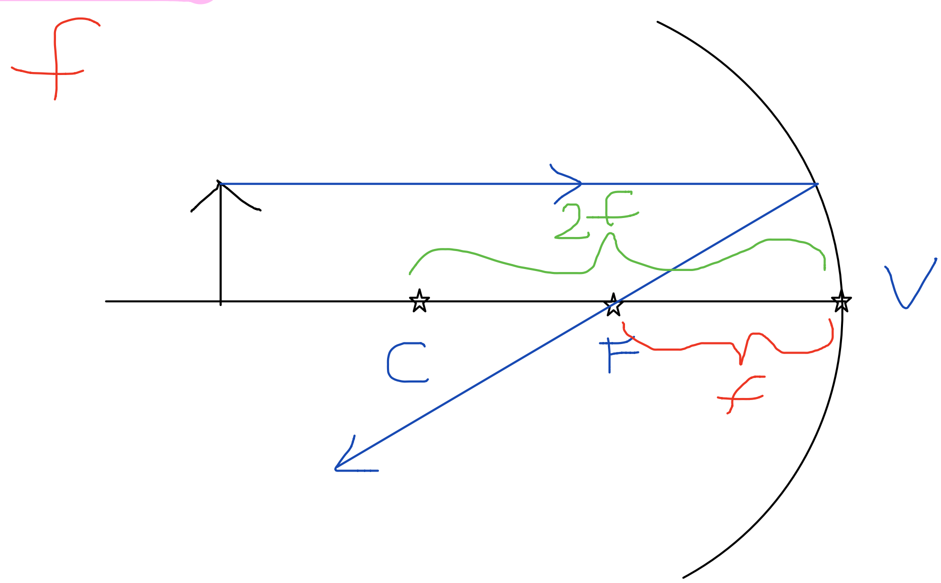


You can also find "C" because C = 2f or C = 2 x focal point

Principle Axis – With a concave mirror the principle axis is a line that passes from a point on the mirror through the centre of curvature. For our purposes we will always draw it in the middle of the mirror

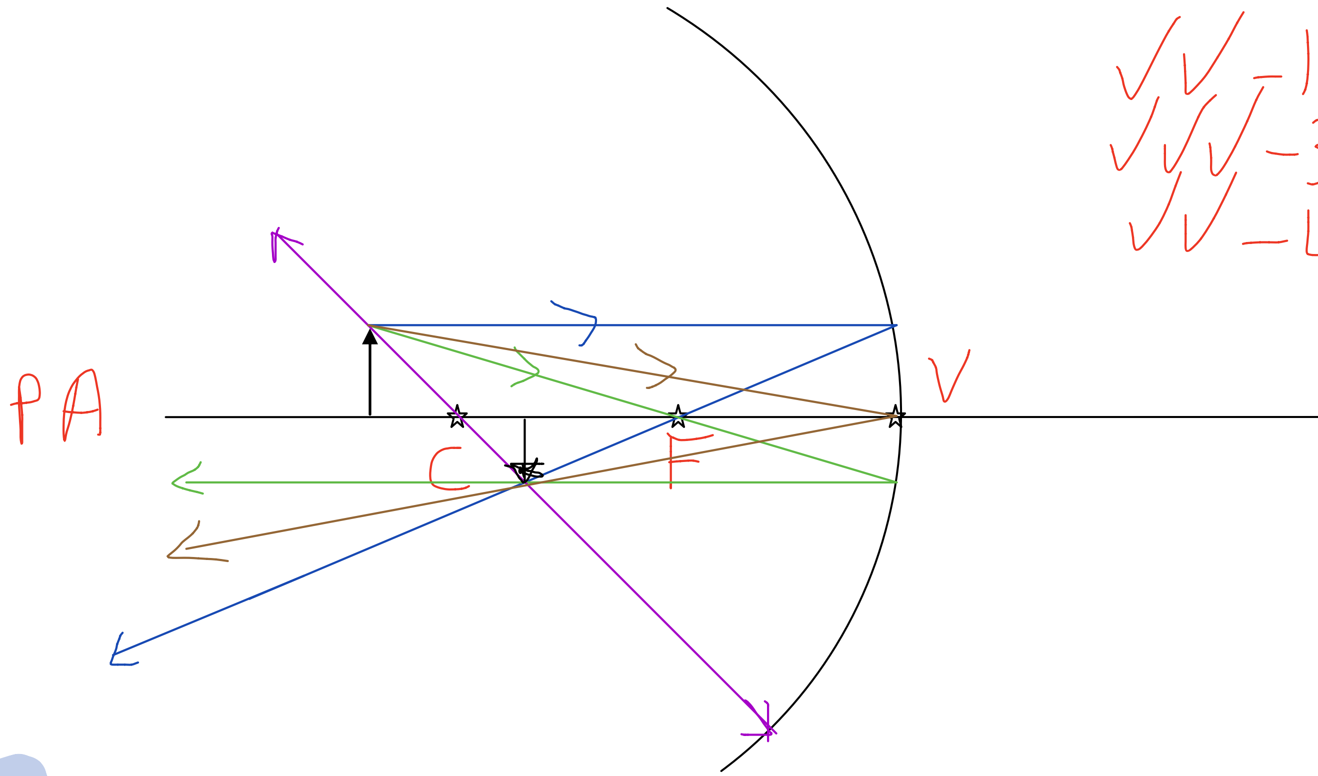
Vertex – The Vertex is where the principle axis strikes the mirror.

Focal Point – When a ray travels parallel to the principle axis, it is always reflected through the focal point of the mirror. The distance between the focal point and the surface of the mirror is the **focal length**. This length is ½ the distance to the centre of curvature.



Images always form where **reflected rays** from the object **meet**.

√√ – label
√√√ – 3 rays
√√ – LOST



1. Draw a ray parallel to the **principle axis** and the point on the object. It will reflect through the **focal point**.
2. Draw a line through the **focal point** and the point on the object. It will reflect parallel to the **principle axis**.
3. Draw a line through the **centre of curvature** and the point on the object. It will reflect back on itself.
4. Draw a line through the **vertex** and the point on the object. Its **angle of reflection** will be the **same** as the **angle of incidence**.

Don't forget: you can always extend your reflected rays behind the mirror as **Virtual Rays**.

You must always report the L.O.S.T. characteristics of every image you form. For the image we just created:

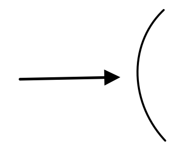
L: closer
O: inverted
S: smaller
T: real

You will notice that the image has formed with **Real Rays**, as opposed to **Virtual Rays**. This means the image formed is **Real Image**. Real images can be projected onto a screen.

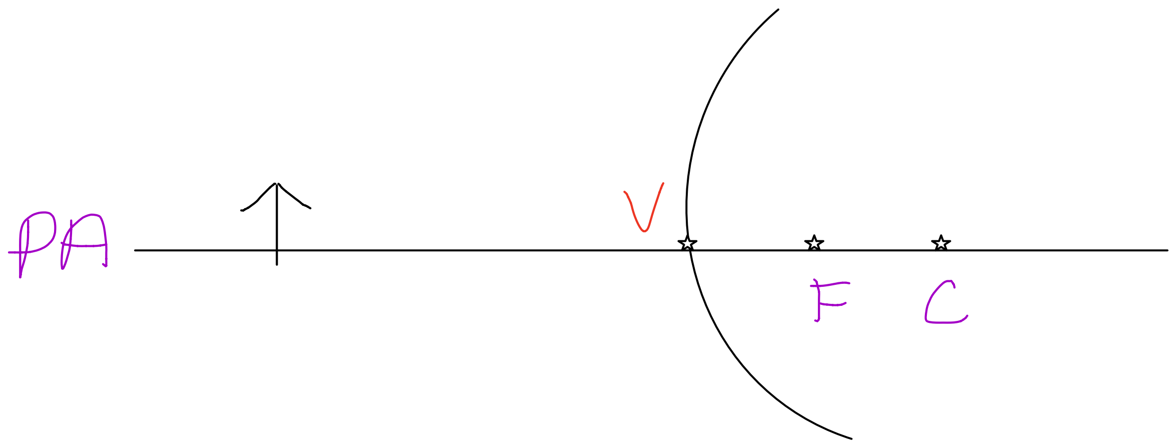
Concave mirrors will create **different images** depending on the location of the object.

Properties of Convex Mirrors

Convex Mirror – A convex mirror has a reflecting surface that curves outwards like the **outside** surface of a ball or sphere.



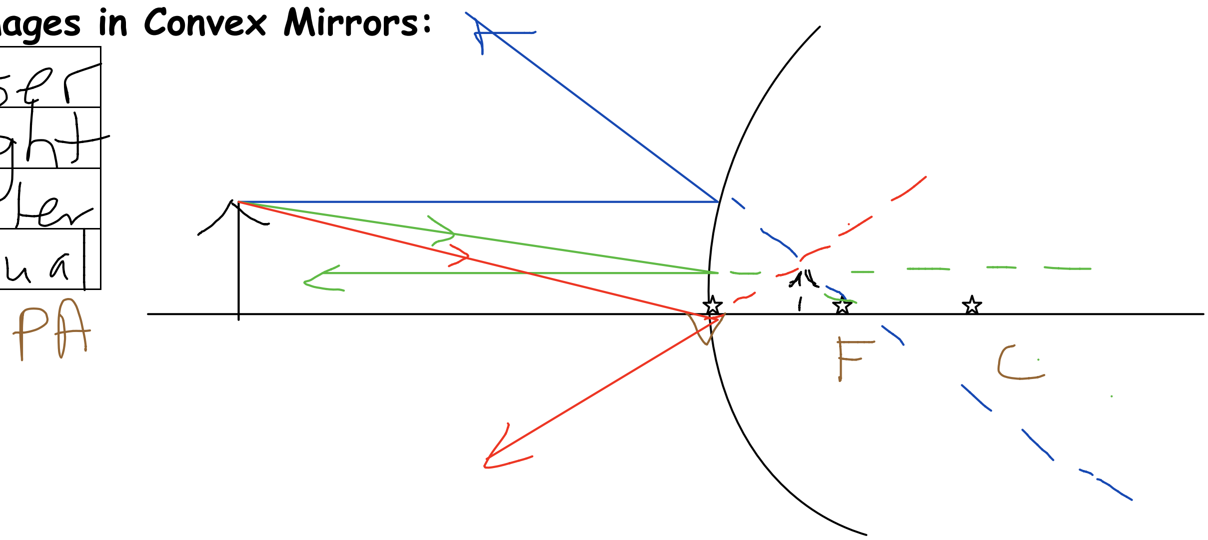
Like concave mirrors, convex mirrors have a focal point and centre of curvature. However, they are both found on the **non-reflecting** side of the mirror.



In the case of a convex mirror, rays that enter parallel to the principal axis are scattered, with their **virtual reflected rays** passing through the focal point.

Finding Images in Convex Mirrors:

L	closer
O	upright
S	smaller
T	virtual

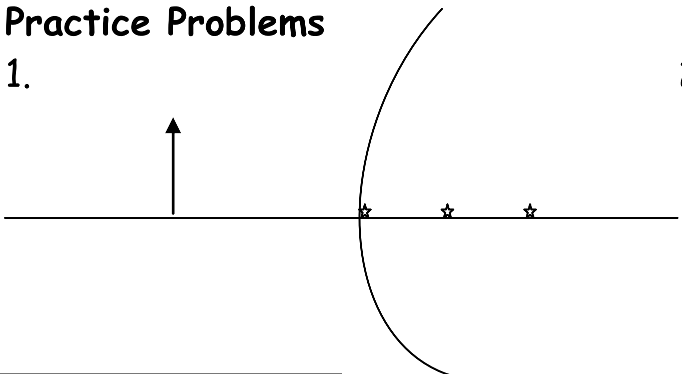


Follow the 4 Rules:

1. Draw a ray parallel to the **principal axis** and the point on the object. It will reflect through the **focal point**.
2. Draw a line through the **focal point** and the point on the object. It will reflect parallel to the **principal axis**.
3. Draw a line through the **centre of curvature** and the point on the object. It will reflect back on itself.
4. Draw a line through the **vertex** and the point on the object. Its **angle of reflection** will be the **same** as the **angle of incidence**.

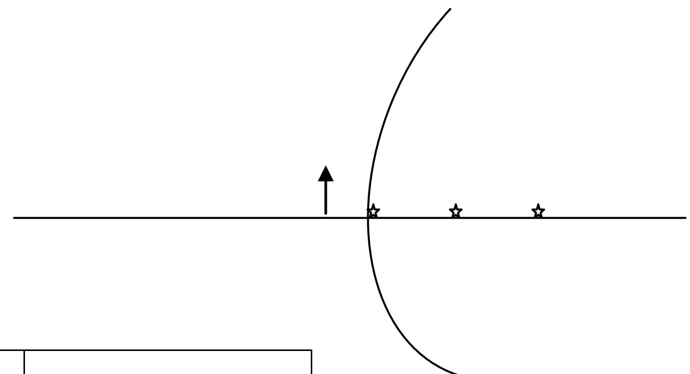
Practice Problems

1.



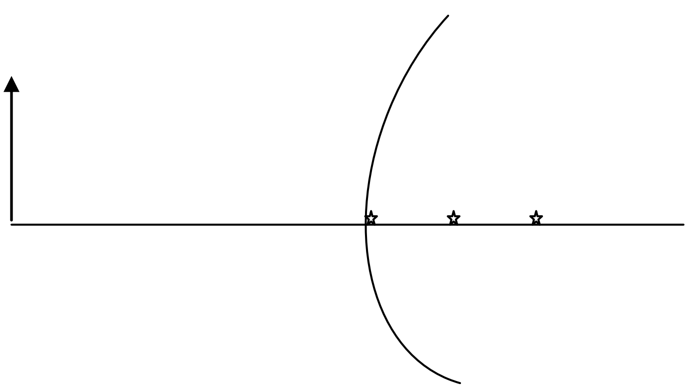
L	
O	
S	
T	

2.



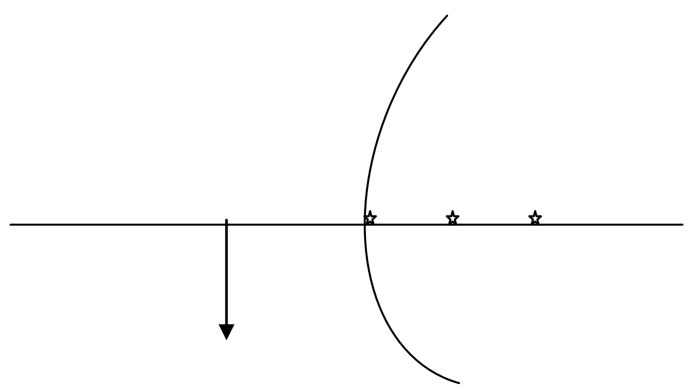
L	
O	
S	
T	

3.



L	
O	
S	
T	

4.

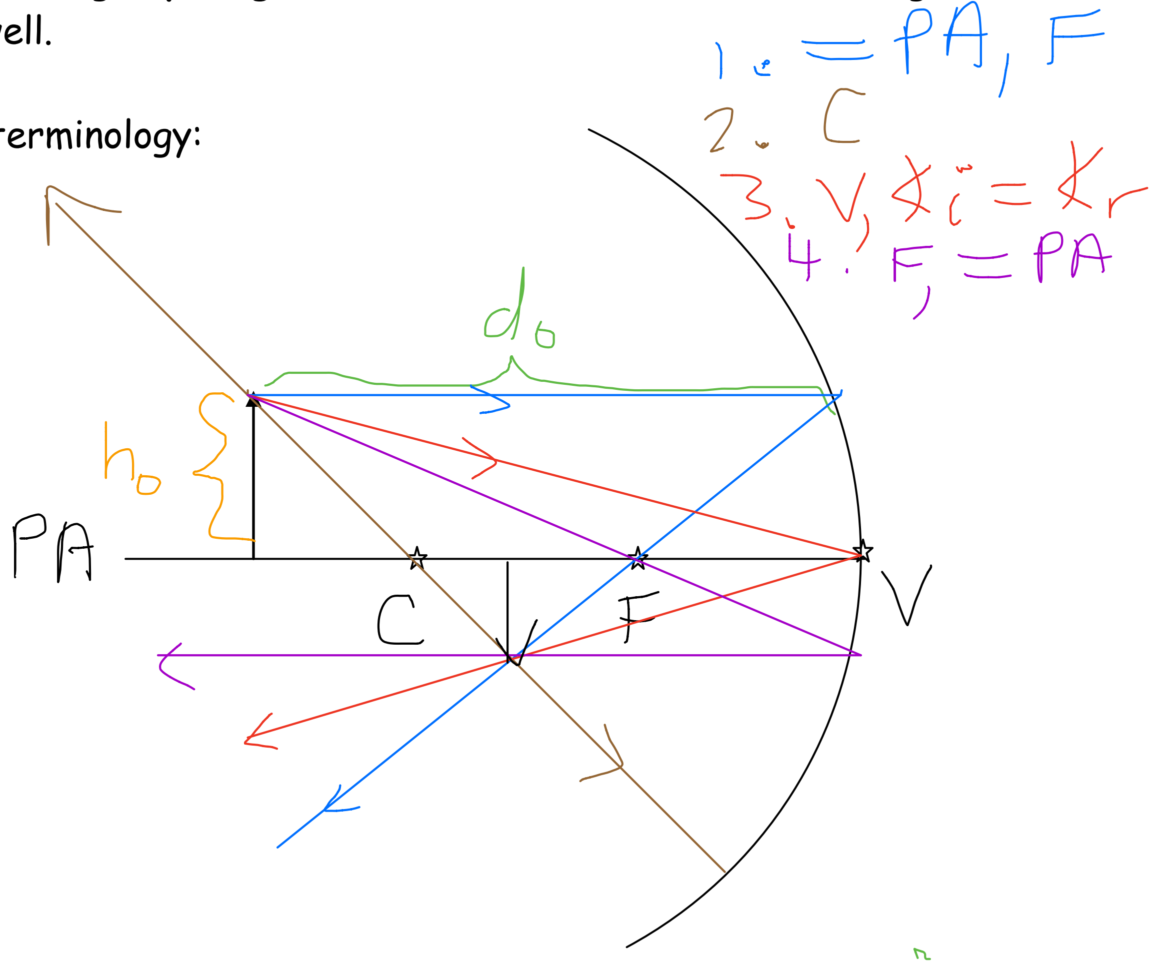


L	
O	
S	
T	

Magnification and Curved Mirror Equations

Figuring out the characteristics of an image in a curved mirror can be accomplished by making **ray diagrams**, but can also be achieved through the use of **equations** as well.

Let's review our terminology:



We can also measure these properties:

h_o = **height of object** d_o = **distance of object**

h_i = **height of image** d_i = **distance of image**

Remember **above** the PA is "+" height and **below** the PA is "-" height

To the **left** of V is "+" distance to the **right** of V is "-" distance

Magnification Equation

$$m = \frac{hi}{ho} = \frac{-di}{do}$$

Curved Mirror Equation

$$\frac{1}{f} = \frac{1}{do} + \frac{1}{di}$$

1. You are told that an object's image is magnified 1.5 times. You also know that the image is 6 cm high.
Given Required Analysis Solve Summary

a) What is the height of the object? Is the image upright or inverted?

G: $h_i = 6cm$, $m = 1.5x$

R: $h_o = ?$

A: $h_o = \frac{h_i}{m}$

S: $h_o = \frac{6}{1.5}$ → $h_o = 4cm$

S: $\therefore$ the h_o is 4cm, upright

b) If the object is 8 cm from the mirror where is the image? Is it real or virtual?

G: $d_o = 8cm$, $m = 1.5x$

R: $d_i = ?$

A: $d_i = -m d_o$

S: $= -(1.5)(8)$
$= -12cm$

S: $\therefore$ $d_i = -12cm$, virtual

2. A convex security mirror has a focal length of -0.25 m. A person with a height of 1.5 m is 4.0 m from the mirror.

a) Calculate the image distance

G: $f = -0.25m$, $h_o = 1.5m$, $d_o = 4.0m$

R: $d_i = ?$

A: $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$

S: $\frac{1}{d_i} = \frac{1}{-0.25} - \frac{1}{4}$

$= -4.25$

$d_i = -0.24m$

S: $\therefore$ d_i is $-0.24m$

b) Calculate the image height

A: $h_i = \frac{-d_i h_o}{d_o}$

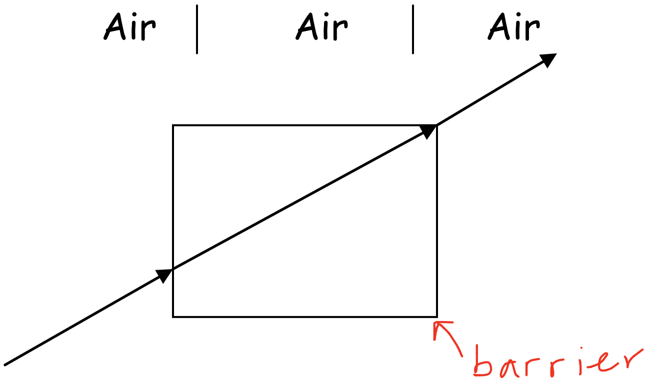
S: $h_i = -\frac{(-0.24)(1.5)}{(4.0)}$

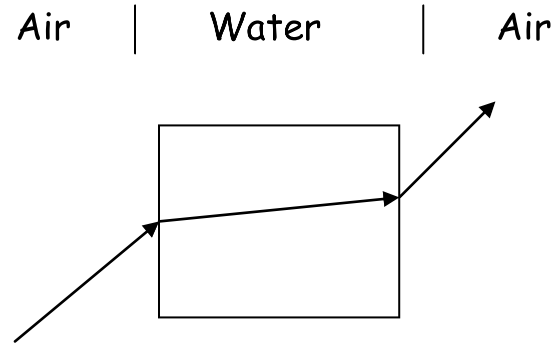
S: $\therefore$ h_i is 0.09m

= 0.09m

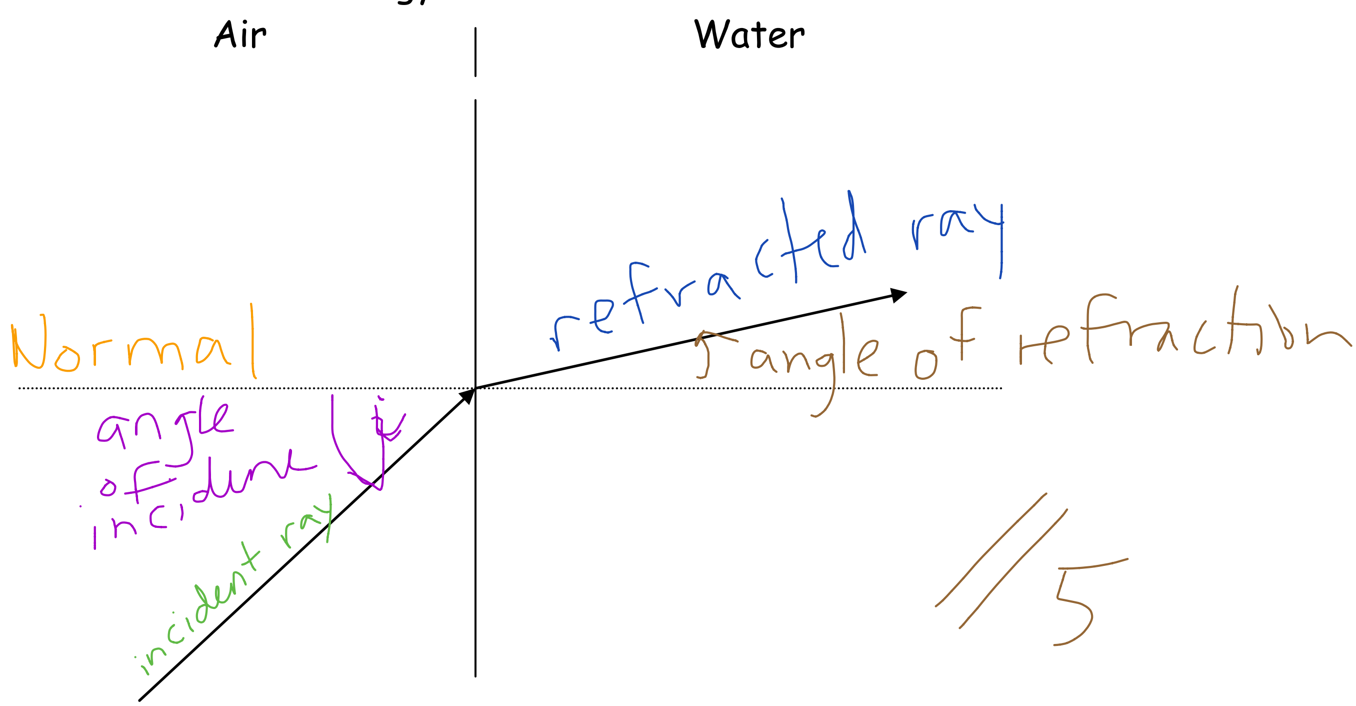
Refraction

We have discussed how light travels in a straight line as long as it stays in the same medium. But what happens when light moves into a new medium?



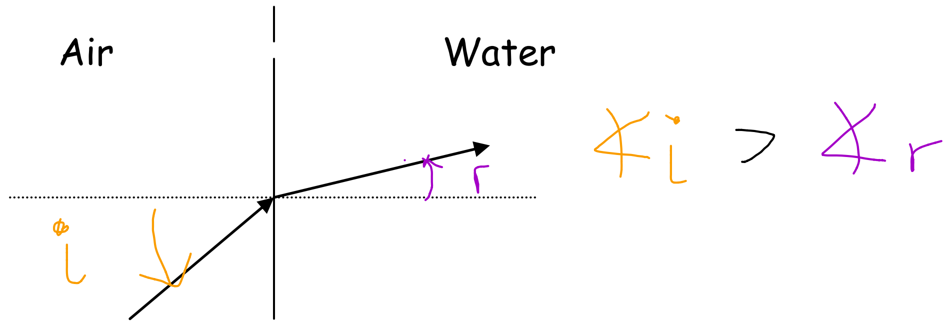


When light crosses a **barrier** into a new medium it bends, changing the ray's direction. When a light ray **bends** it is called **refraction**.
Light refracts because when travelling through a more **optically dense** medium it **slows down**. Optical density is a measurement of how much light is slowed down by a medium. Light travels the fastest in a vacuum like in space. The speed of light in a vacuum is **3.0×10^{8} m/s.** In all other mediums it is slower.
9.76 m/s
First let's review some terminology:

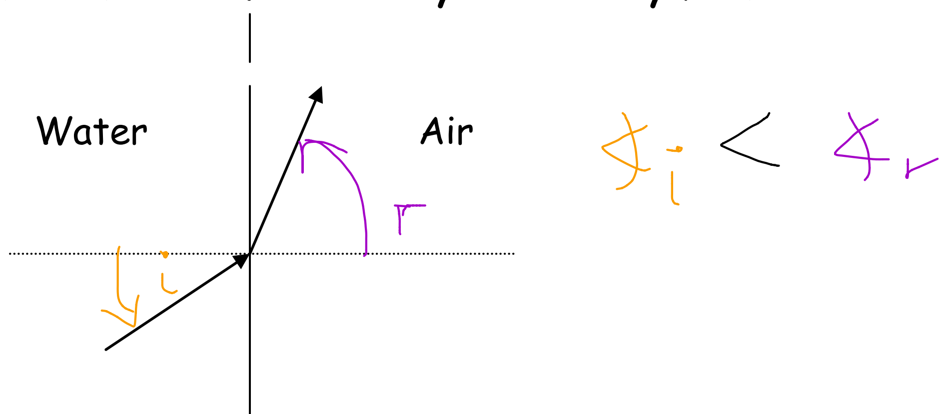


Rules of Refraction

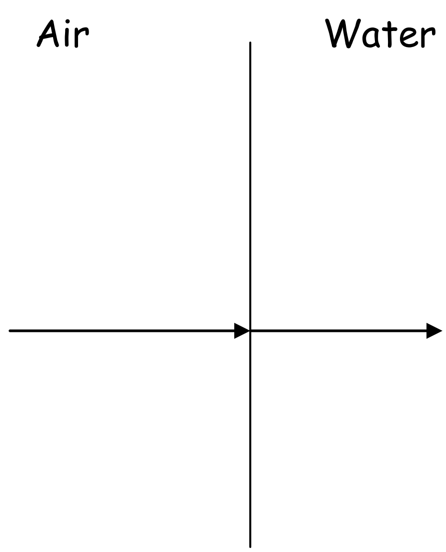
1. When light travels from a less **optically** dense medium to a more optically dense medium the refracted ray bends **towards** the **normal**.



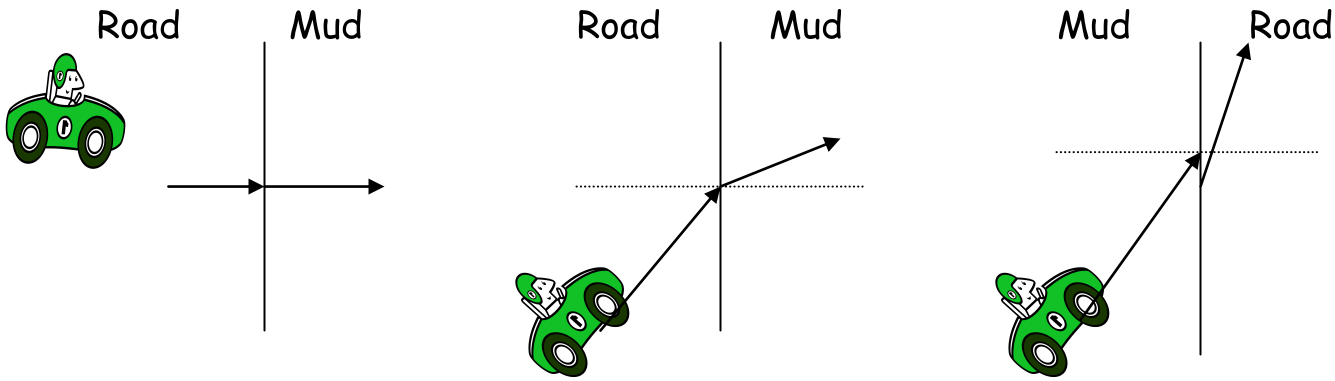
2. When light travels from a more optically dense medium to a less optically dense medium the **refracted ray** bends **away** from the **normal**.



3. When the angle of incidence is 0, no **refraction** occurs.



Light refracts because of its **wave-like** properties but refracting light can be thought of like a car.



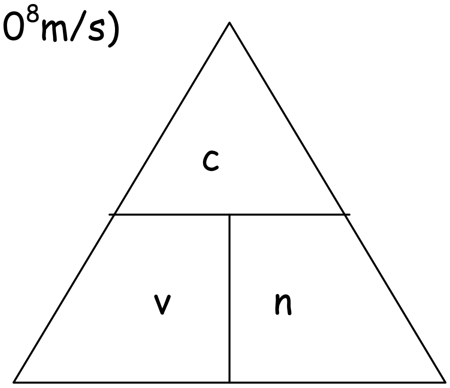
Think of your car as a beam of light. When it comes to a barrier with mud if there is **no** angle it will **not** affect the direction of the car.
If you approach mud on an angle, the tires contacting the mud will **slow down** while the tires on the road will keep going the same space. This will turn the car into the mud. The opposite will be true for leaving the mud.

Index of refraction

The index of refraction is a measurement of the difference between the speed of light in a medium and the speed of light in a vacuum.

$$n = c/v$$

n = **the index of refraction**
c = **the speed of light in a vacuum** (3.0×10^{8}m/s)
v = **the speed of light in a given medium**



Some common indices of refraction

Substance	Index of Refraction
Glass	1.5-1.9
Diamond	2.42
Fused quartz	1.46
Quartz crystal	1.54
Glycerin	1.47
Water	1.33

Notice they are all greater than 1.

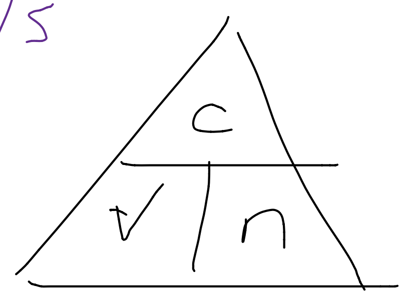
Let's do a practice problem together.

You are told that the index of refraction for glass is 1.5. What is the speed of light in glass? (use the G.R.A.S.S. method)

G: $n = 1.5$, $c = 3.0 \times 10^8$ m/s

R: $v = ?$

A: $v = \frac{c}{n}$



S: $v = \frac{3.0 \times 10^8}{1.5}$

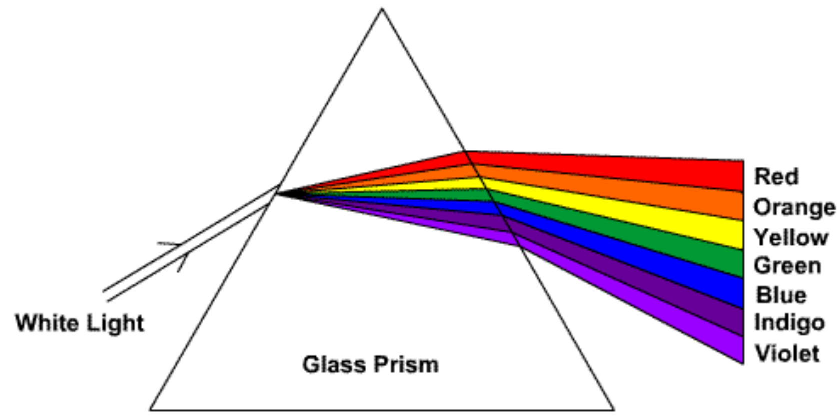
$= 2.0 \times 10^8$ m/s

S: ∴ the speed of light in glass is 2.0×10^8 m/s.

Optical Phenomena in Nature

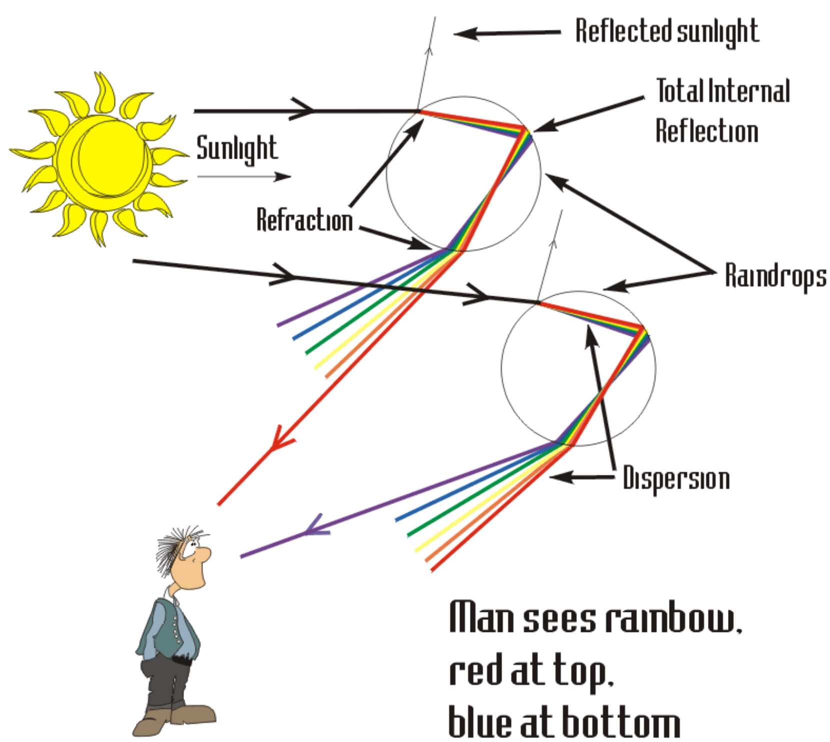
White light is a combination of all the **wavelengths** of visible light. When this light is separated into its **spectrum** of colours it is called **dispersion**. The colours of visible light in a spectrum can be remembered by **ROYGBIV** (red, orange, yellow, green, blue, indigo and violet).

When white light **enters** into a **prism** it is **refracted**. It is then **refracted** a second time when it **leaves** the prism. Since each colour of light travels at a different **speed**, each colour of light refracts a **different amount** creating the separation of coloured **bands**.



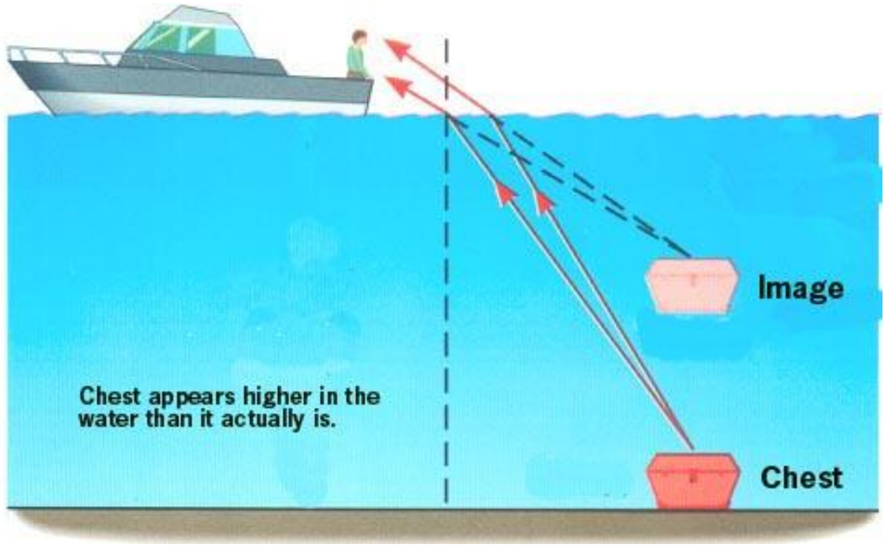
Rainbows

A rainbow is an arc of colours of the visible spectrum appearing opposite the Sun, caused by **reflection**, **refraction** and **dispersion** of the Sun's rays as they pass through **raindrops**.



A rainbow forms when sunlight enters a water droplet and **refracts**, then **reflects** off the inners surface of the raindrop and then **refracts** again when leaving the droplet. The two refractions result in the **dispersion** of light. The different colour layers in a rainbow are created by water droplets at different **heights** in the sky.

Apparent Depth



Just as real and virtual images can be created by reflected light from a mirror, images are created by refracted rays as well.

For example, an object at the bottom of a lake or pond will create an optical effect in which the image of the object appears **closer** than the object. This is called **apparent depth**.

Some animals such as the **pelican** or the **archer fish** have found ways to account for the illusion of apparent depth.

Shimmering and Mirages

Shimmering and mirages are caused by the **refraction** of light in **unevenly heated air**. When light travels through air at different temperatures, it refracts because hot air is **less** dense than cooler air. Since there is no distinct **boundary** between sections of air and the fact that air is constantly **moving** the location and amount of **bending** is constantly **changing**.

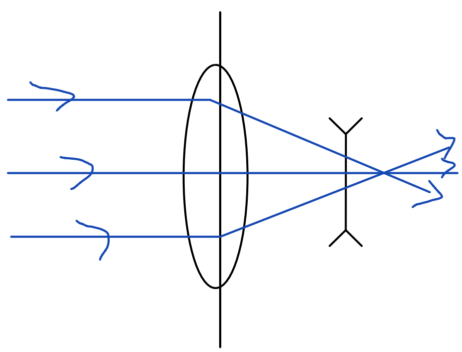
Shimmering is the apparent movement of objects over **hot surfaces**. Metallic surfaces or any other material, like asphalt, that tend to **heat-up more rapidly than air** will display shimmering.

A mirage occurs on a much larger scale than shimmering and is typically seen over **large**, **hot**, **land masses** like the desert. The air over the desert heats up faster than the surrounding air. When sunlight reaches the hot air, the sunlight is **refracted upward**. You will interpret the origin of the light as being on the **ground**. An object that appears to be on the ground but is not really there is called a **mirage**.

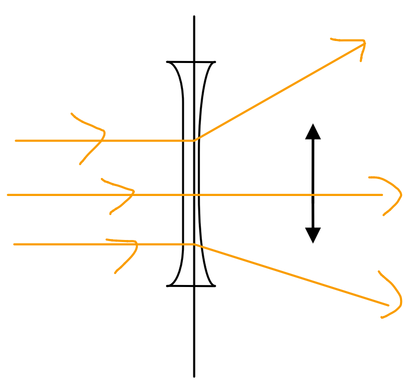
The opposite type of mirage can happen when **wind** brings **warm air** over a very **cold ocean** or land mass. This condition is known as a **temperature inversion**. When this type of mirage occurs, people will think they are seeing an object in the **air**.

Lenses

A lens is a device that **bends** light. Lenses come in all **sizes** and **shapes**.



Converging lens (Biconvex)
- focuses light onto a single point (focal point)

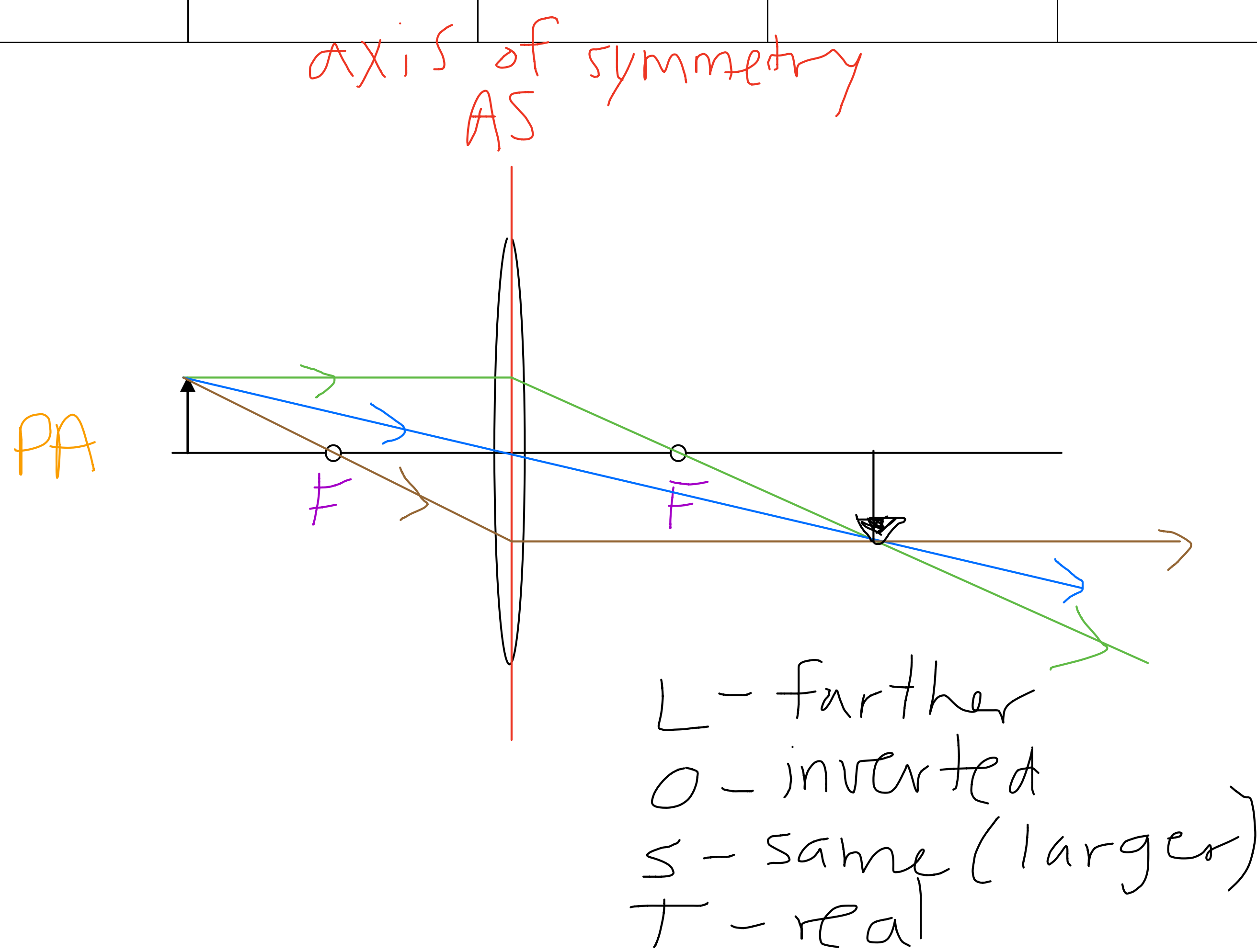


Diverging Lens (Biconcave)
- spreads light out (appears to come from a focal point)

Ray Diagrams for Converging Lenses

RULES FOR DRAWING RAY DIAGRAMS FOR CONVERGING LENSES:

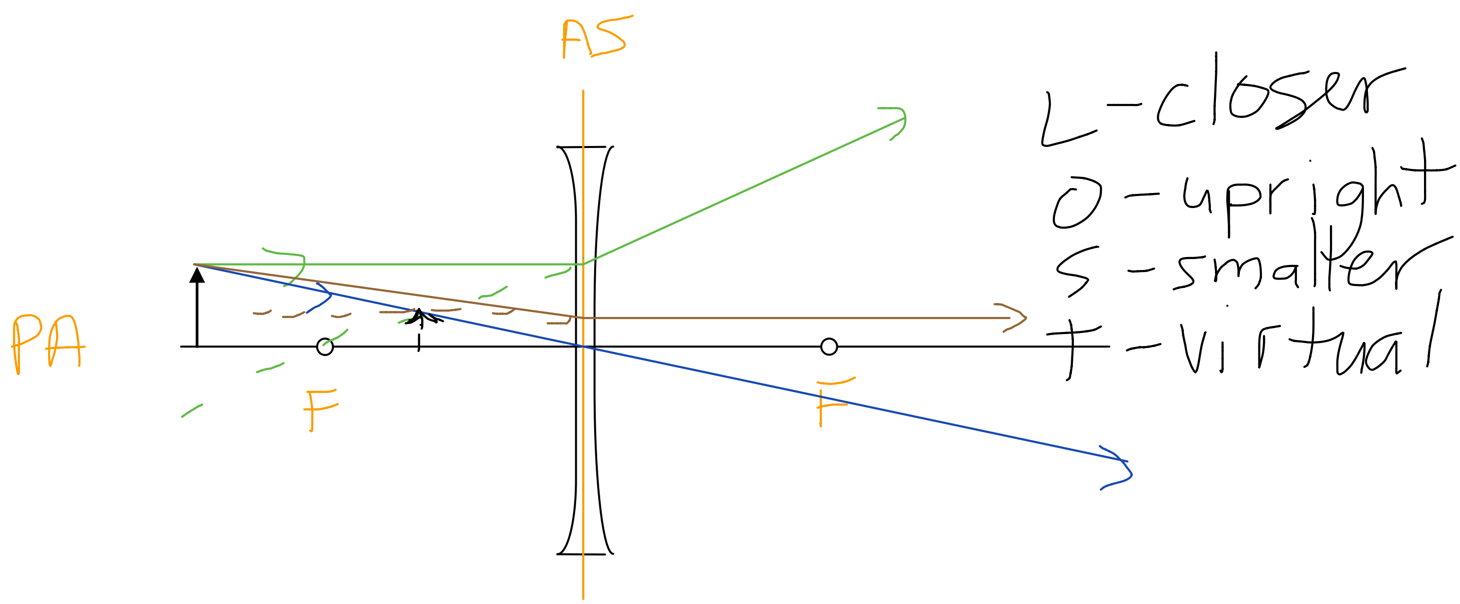
Step 1	Step 2	Step 3	Step 4	Step 5
· Draw principal axis and vertical line through lens · Draw focal points on both sides of the lens at the same distance of the lens · Add an object that is farther from the lens than the focal point	· Draw the 1st ray parallel to the principal axis until it reaches the axis of symmetry · From the principal axis the ray goes through the focal point on the opposite side	· Draw the 2nd ray from the top of the object through the centre of the lens	· Draw the 3rd ray through the focal point on the same side of the lens as the object to the axis of symmetry · From the axis of symmetry, continue ray until it meets the other 2 rays.	· Draw the real image · The top of the image is at the point where the three rays meet · The bottom of the image is on the principal axis



Ray Diagrams for Diverging Lenses

RULES FOR DRAWING RAY DIAGRAMS FOR DIVERGING LENSES:

Step 1	Step 2	Step 3	Step 4	Step 5
· Draw principal axis and vertical line through lens · Draw focal points on both sides of the lens at the same distance of the lens · Add an object that is farther from the lens than the focal point	· Draw the 1st ray parallel to the principal axis until it reaches the axis of symmetry · From the principal axis the ray leaves as though it were coming from the virtual focal point on the object side	· Draw the 2nd ray from the top of the object through the centre of the lens	· Draw the 3rd ray going from the top of the object to the focal point on the opposite side of the lens. STOP at the axis of symmetry and then draw it PARALLEL to the principal axis	· Because the rays do NOT meet, extend RAY 2 and RAY 3 · The top of the image is at the point where the three rays meet · The bottom of the image is on the principal axis



Images created by lenses can also be determined mathematically.

Thin Lens Equation

$$\frac{1}{f} = \frac{1}{di} + \frac{1}{do}$$

Magnification Equation

$$m = \frac{hi}{ho} = \frac{-di}{do}$$

An object is 8.5 cm high is placed 28 cm from a converging lens. The focal length is 12 cm. GRASS

a. Calculate the image distance, di

G: $h_o = 8.5 cm$, $f = 12 cm$, $d_o = 28 cm$

R: $d_i = ?$

A: $\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$

S: $\frac{1}{d_i} = \frac{1}{12} - \frac{1}{28}$

$d_i = 21 cm$

∴ d_i is 21 cm

b. Calculate the image height, hi.

R: $h_i =$

A: $h_i = -\frac{d_i h_o}{d_o}$

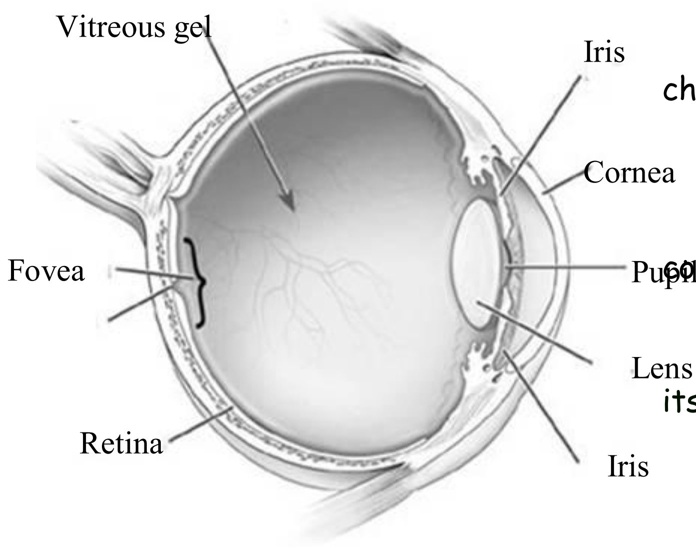
S: $h_i = -\frac{(21)(8.5)}{28}$

$= -6.4 cm$

S: ∴ h_i is $-6.4 cm$

<u>The Human Eye</u>

Parts of the Eye



Lens: directs light to the retina. It changes **shape** to allow clear vision.

Aqueous Humour: a **watery liquid** important for nourishing the lens and cornea.

Vitreous Humour: a **jelly-like** substance that fills the eye and helps keep its shape.

Ciliary Muscles & Suspensory Ligaments: control the **curvature** of the lens.

Cornea: **protective**, **transparent** structure at the front of the eye that allows light to enter the eye.

Sclera: the **tough** outer layer of the eyeball; forms the **whites** of your eyes.

Iris: the **coloured** part of the eye; **opens** and **closes** to let light in.

Pupil: the **black area** in the centre of the iris through which **light enters** the eye.

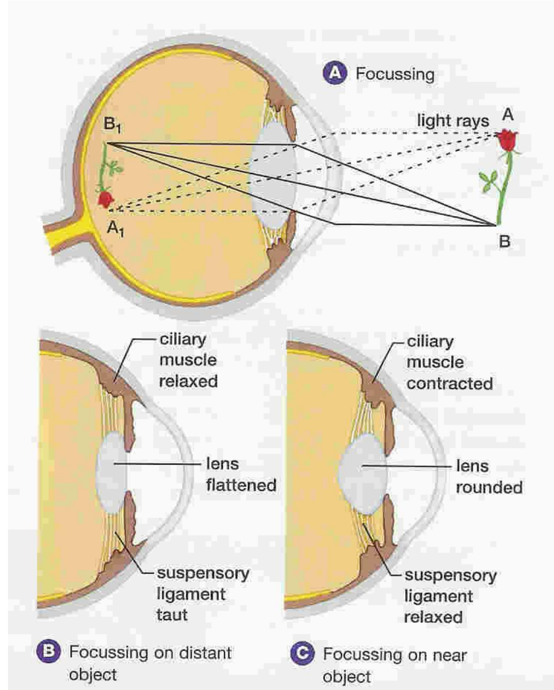
Retina: a thin film of tissue where images are brought into **focus**, it lines the **inside surface** of the eyeball and is covered by specialized cells called **rods** (**dark** and **light**) and **cones** (**colour**).

Fovea: located on the retina and is responsible for **sharp central** vision, cones are concentrated here.

Blind spot: the place in the visual field where there is **no** light-detecting photoreceptor cells due to the **optic nerve** passing through it.

Optic Nerve: transmits visual information from the **retina** to the **brain** via **electrical impulses**.

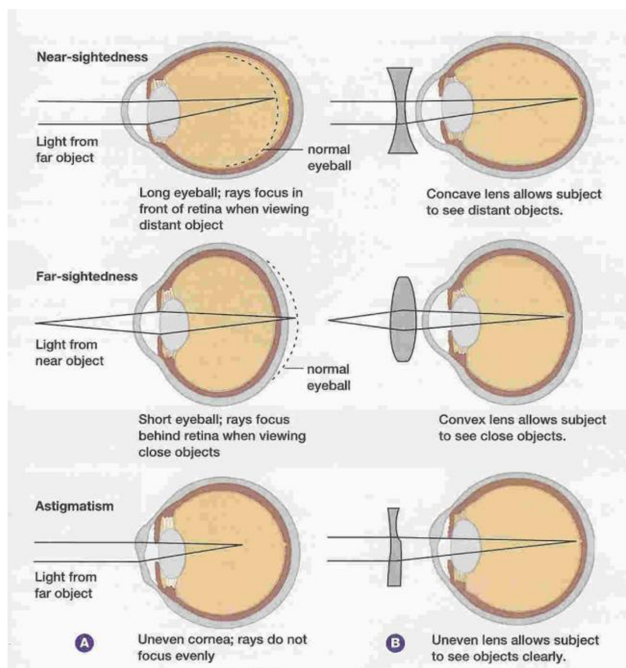
How the eye Functions



As light enters the eye, the **pupil dilates** if there is **insufficient** light or **constricts** if there is **too much** light; this action is controlled by the **iris**. The shape of the **lens** can be altered as the **distance** from the object being viewed changes; this action is controlled by the **ciliary muscle** and **suspensory ligament**.

When focusing on **distant** objects, the lens is **flat** because the ciliary muscle is **relaxed** and the suspensory ligament is **tight**. When focusing on a **near** object, the lens becomes **rounded** because the ciliary muscles **contract**, thus causing the suspensory ligament to **relax**. These adjustments are referred to as **accommodation**. When light rays enter the eyes, the object's rays are **refracted** by the **cornea** and the **lens** in such a way that an **inverted** and **reversed** image of the object forms.

Disorders of the Visual System



Near-sightedness (myopia) is a condition in which the person has difficulty seeing things that are **far** away. It usually occurs when the eyeball is **too long** or the ciliary muscle is **too strong**. When this occurs, the image is focused **in front** of the retina.

Far-sightedness (hyperopia) is a condition in which a person has difficulty seeing things **close up**. It usually occurs when the eyeball is **too short** or the ciliary muscle is **too weak**. When this occurs, the image is focused **behind** the retina.

Astigmatism is when there is an abnormal shape of the **cornea** or **lens** that results in **uneven focus**.