CHAPTER 12: LIGHT

12.0 INTRODUCTION

Light is something that we are familiar with. We have learned to use light and have found many different ways to utilize it, some of which we now take for granted. For example, we have mirrors to reflect light. Another example of this would be people who use glasses or contact lenses to see better, telescopes to see farther and microscopes to see objects hundreds of times larger than they actually are. The light from lasers is used to perform a number of surgical techniques. Many telephone cables are now being replaced by fibre optics, which carry an enormous amount of information in a small space.

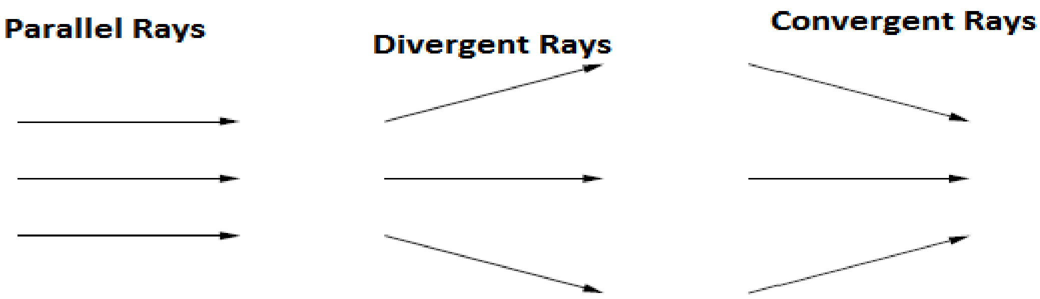
12.10 STRAIGHT PATH FOR LIGHT

In a dusty atmosphere it is sometimes possible to see light travelling and it does appear to be moving in a straight line.

Source: http://www.exo.net/~pauld/workshops/ScienceForMonks/shadows.html

Sunlight creates straight line shadows in the air.

Sunbeams streaming through the clouds suggest that light travels in straight lines. The direction of the path in which light is travelling is called a **ray** and is represented in diagrams by a straight line with an arrow on it. A **beam** is a stream of light and is shown by a number of rays; it may be parallel, diverging (spreading out) or converging (getting narrower).



All visible objects either emit light or reflect light. Some do both, most just reflect. The way that we "see" things is by responding to the light that is reflected off of them into our eyes.

When an object either emits light or reflects it, the light travels in all directions from the object. Only a tiny fraction of the light from the object gets into our eyes at one time .

Imagine a tree off in the distance. We may focus our eyes on the top branches of the tree but light from the trunk and the branches facing us is still traveling into our eyes. The rays have to travel through the tiny aperture in the iris - the pupil.

The same happens with a pinhole camera and the light source.

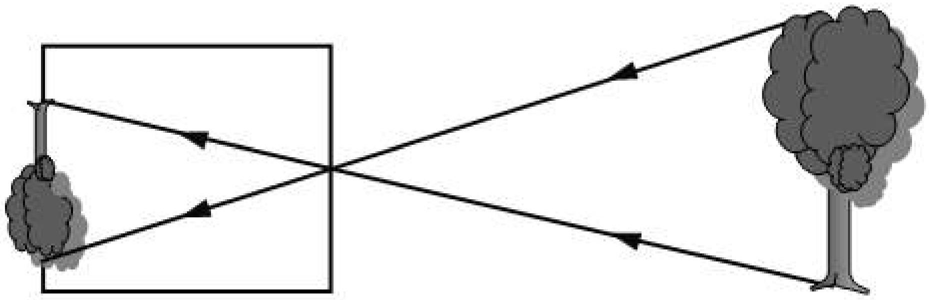
12.11 Pinhole Camera

Take a cardboard box (or an empty can - with the top taken off so that there are no sharp edges) and replace one side with a greaseproof paper screen.

Hold it so that you are pointing the pinhole end towards a brightly lit object (perhaps a sunlit tree through a window) and you will see the image formed on the screen.

The diagram shows why the image is upside down.

Since the pinhole is so small, only a tiny proportion of rays from top branch can pass through the hole. Their path is indicated by the line. These light rays haven't encountered any different media, so they travel in a straight path from the tree branch to the screen. The same is true for rays from the bottom of the tree.



Notice that the rays from the top branch and from the trunk have to cross at the pinhole in order to pass through. This is what causes the image of the tree (or light bulb, or any other object) to be upside down.

The retina cells at the top of your eye get image information from the lower part of an object you are looking at and the cells at the bottom from the top of the object.

12.12 Binocular Vision

In binocular vision, the visual axes of the eyes are arranged in such a manner that the images of the object viewed strike the identical portions of the retinas of both eyes. This produces a single stereoscopic image—a view of the world in relief. Binocular vision also makes it possible to determine visually the relative location of objects in space and to judge their distance from each other.

OPAQUE - An object that cannot be seen through and which does not allow light to enter. An example would be a brick wall.

TRANSLUCENT - An object that cannot be seen through, but allows light to enter. An example would be a stained-glass window.

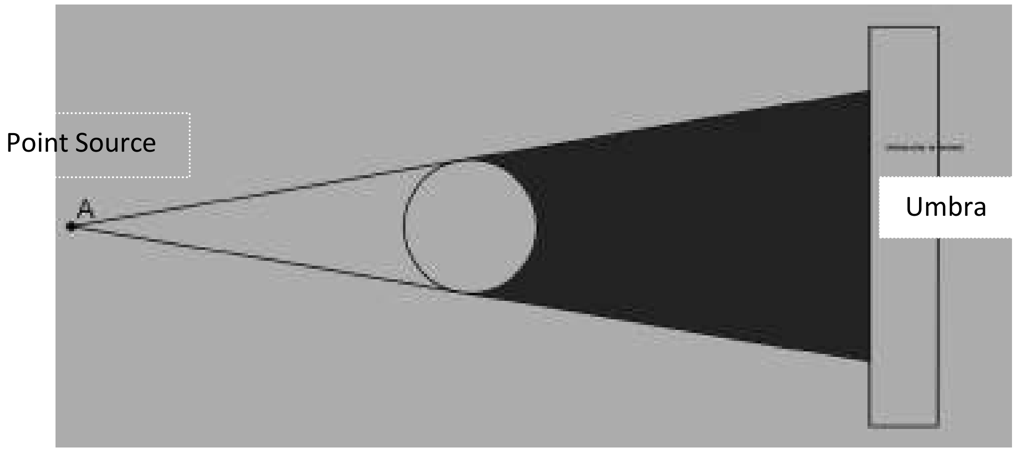
TRANSPARENT - An object that can be seen through. An example would be a normal window.

12.13 Shadows

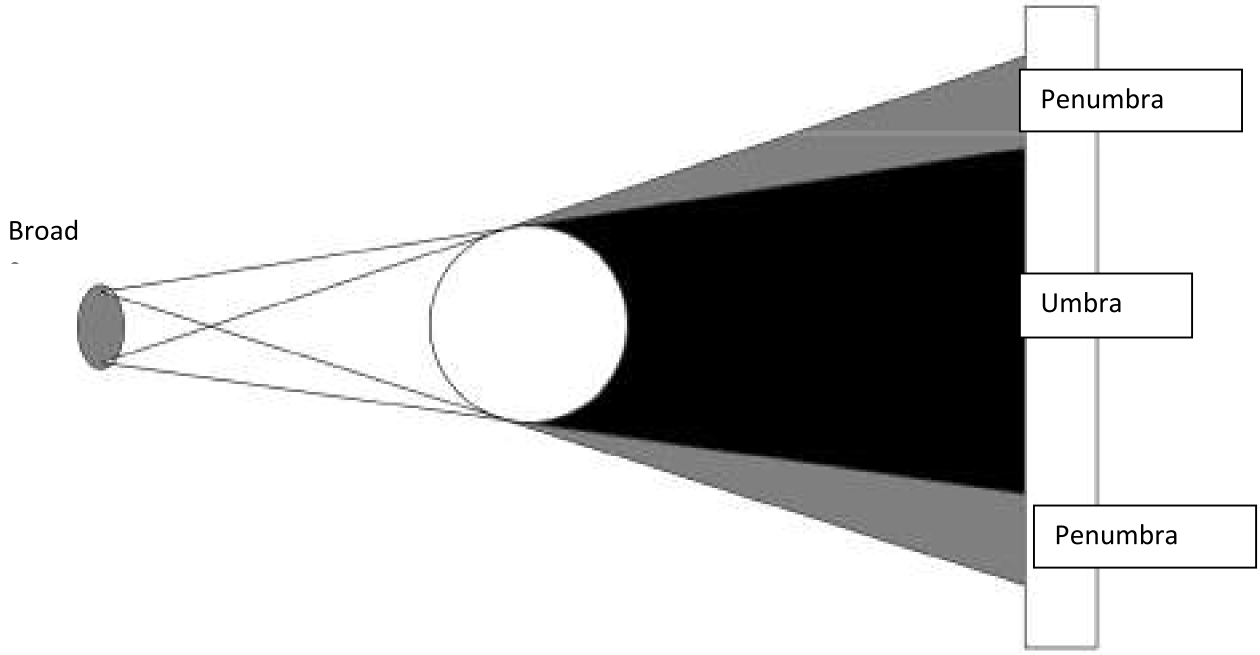
Where there is no light there is darkness, we call this a shadow. In fact at night we are in the shadow of the Earth.

A shadow is formed where light is 'missing'. A dark shadow (umbra) is formed where no light falls and a light shadow (penumbra) is formed where some light falls, but some is blocked.

If the light source is very tiny and concentrated in one place (a point source) only a sharp shadow is formed.



If the source is broader light from the top of the source causes a lower shadow than that from the top. You therefore get partial shadow or penumbra as well as umbra.



The region of deep, total shadow is called the **UMBRA** and the region of partial shadow is called the **PENUMBRA**. The umbra is a region where no light can get to while the penumbra is a region where some light can reach.

12.14 Eclipses

When the Sun, Moon and the Earth come into a straight line an **ECLIPSE** occurs. This does not happen very often because the Moon's orbit is inclined to that of the Earth. A **TOTAL** eclipse occurs when all the Moon or Sun is blotted out. A **PARTIAL** eclipse is when only part of the Sun or Moon is covered.

Lunar Eclipse

When the Earth comes between the Sun and the Moon we get a 'Lunar eclipse' or eclipse of the Moon.

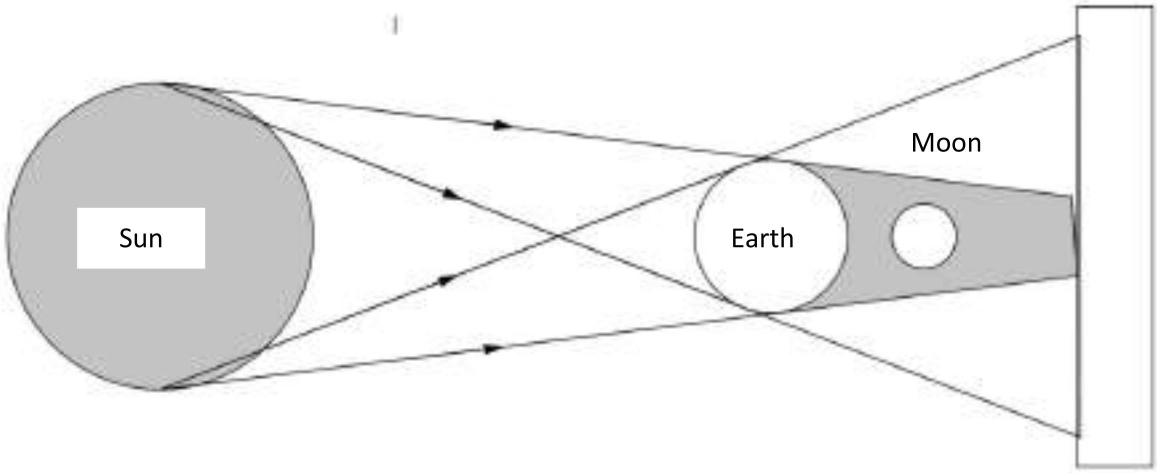


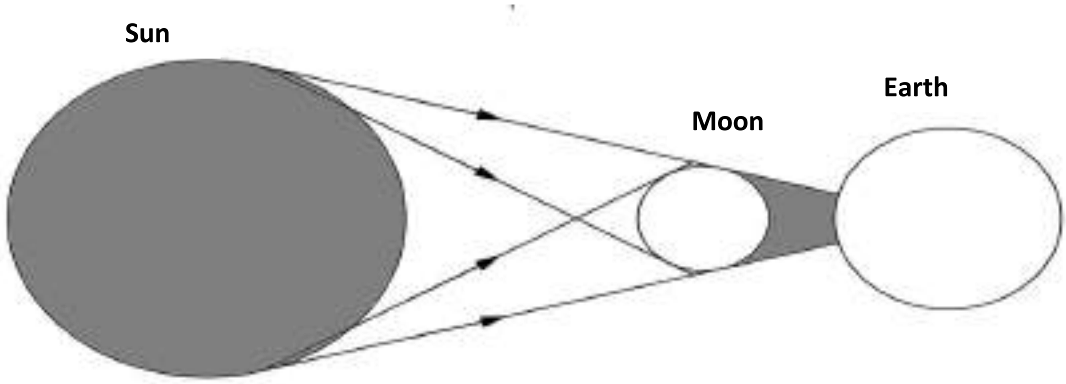
Figure 1

The Moon passes into the shadow of the Earth, it ever completely disappears because a small amount of the Sun's light is refracted by the Earth's atmosphere and falls on the Moon during the eclipse. This light gives the Moon a reddish appearance.

You can see form Figure 1 that at the distance of the Moon the Earth's shadow is much bigger than the Moon and so the Moon takes some time to pass through it.

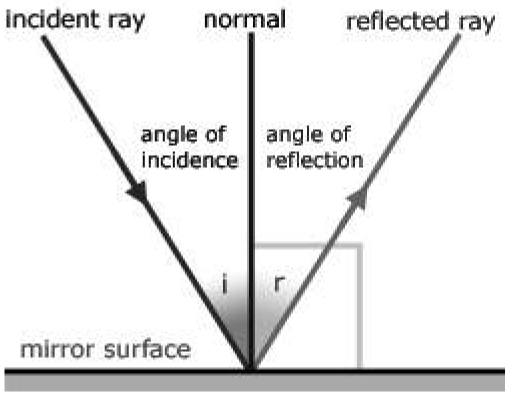
Solar Eclipse

It’s much more impressive when the Moon comes between the Sun and the Earth. The shadow of the Moon falls on part of the Earth and this is a Solar eclipse or eclipse of the Sun. When seen from the Earth the Moon and Sun look almost exactly the same size and so in a total eclipse the Moon just covers the Sun.



Eclipses do not occur as often as you might expect. This is due to the tilt of the Moon's orbit around then Earth compared with the plane of the Earth's orbit around the Sun. An eclipse, of the Sun or the Moon, will only occur if all three bodies – Sun, Earth and Moon are in a line.

12.20 REFLECTION



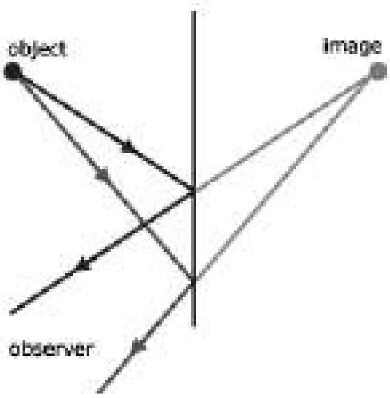
Source: http://www.a-levelphysicstutor.com/optics-plane-mirrs.php

The diagram shows a ray of light hitting a plane mirror.

- A line drawn at right angles to the mirror where the light hits it is called the NORMAL to the surface at that point.
- The **angle of incidence** is the angle between the normal and the incident ray.
- The **angle of reflection** is the angle between the normal and the reflected ray.
- The **Law of reflection** states that the angle of incidence equals the angle of reflection. The incident ray and the reflected ray and the normal are all in the same plane.

12.21 The Image in a Plane Mirror

The image in a plane mirror seems to be somewhere in space behind the mirror, this type of image is called a virtual image. It is actually the same distance from the mirror as the object is in front of the mirror.



Source: http://www.a-levelphysicstutor.com/optics-plane-mirrs.php

You can see the image but you can't actually touch it or focus it on a surface. The light rays from the object spread out, hit the mirror and then reflect – they seem to have come from a point behind the mirror. This is the image of the object.

The image in a plane mirror also looks as though it is reversed from left to right. This property is called **LATERAL INVERSION**.

12.22 Real and Virtual Images

A **real** image is one which can be produced on a screen (as in a pinhole camera) and is formed by rays that actually pass through it.

A **virtual** image cannot be formed on a screen and is produced by rays which seem to come from it but do not pass through it. The image in a plane mirror is virtual. Rays from a point on an object are reflected at the mirror and appear to come from the point behind the mirror where the eye imagines the rays intersect when produced backwards.

12.30 CURVED MIRRORS

When you look into the two sides of the bowl of a spoon you are actually using two simple curved mirrors. The side that curves inwards is called CONCAVE and the side that curves outwards is called **CONVEX**.

It is the same with mirrors, if the reflecting surface curves inwards you have a **CONCAVE** mirror and if the reflecting surface curves outwards you have a **CONVEX** mirror.

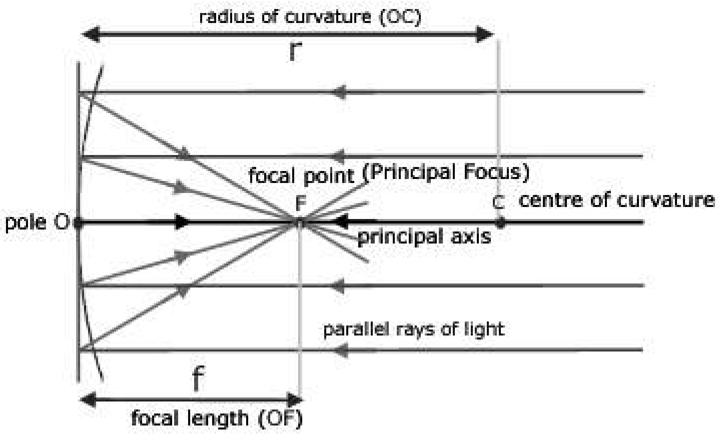
Curved mirrors are parts of a sphere and so are known as **SPHERICAL MIRRORS**. The center of this sphere is called the **CENTRE OF CURVATURE (C)** of the mirror and its radius the **RADIUS OF CURVATURE (R)** of the mirror.

The distance from the pole (P) to the principal focus (F) is called the **FOCAL LENGTH** of the mirror. The principal focus and focal length of a concave mirror are real but those of a convex mirror are virtual.

The effect of the two types of curved mirror on a parallel beam of light is shown by the two diagrams.

12.31 Concave Mirrors

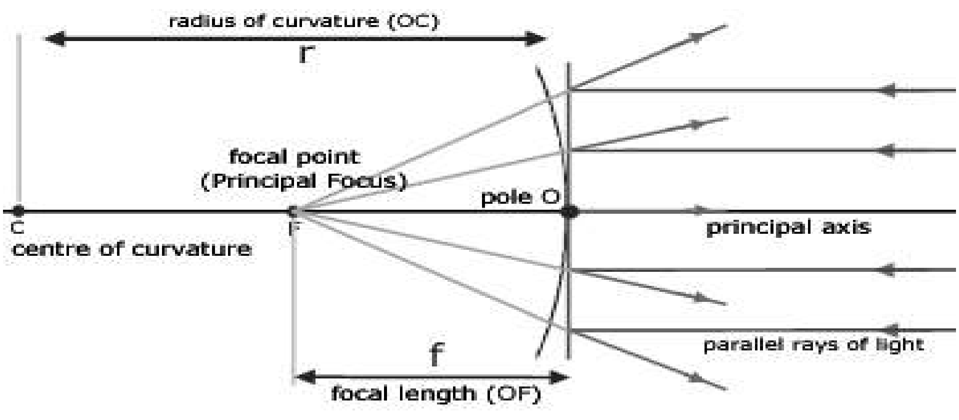
A concave mirror will converge a beam of light and it gives a real image. However, if the object is closer to the mirror than its focal length the image is virtual.
The focal length and radius of curvature of a concave mirror are real.
The image produced is up the right way, virtual and magnified if the object is closer to the mirror than its focal length but inverted and real if it is further away.



Source: http://www.a-levelphysicstutor.com/optics-concav-mirrs.php

12.32 Convex Mirror

A convex mirror will diverge a beam of light and it gives a virtual image. The focal length and radius of curvature of a convex mirror are virtual. The image produced is always up the right way and smaller than the object, the convex mirror gives a wide field of view because of this and thus used as rear view mirrors in cars and other motor vehicles.



Source: http://www.a-levelphysicstutor.com/optics-convex-mirrs.php

12.33 Ray Diagrams

Ray diagrams are scale drawings which can be used to find details of the images formed by curved mirrors or lenses. The usual details required from a ray diagram are the size, position and nature of the image. The nature of the image refers to whether the image is *inverted* (or *upright*), *virtual* (or *real*) or whether it is *enlarged* (or *diminished*).

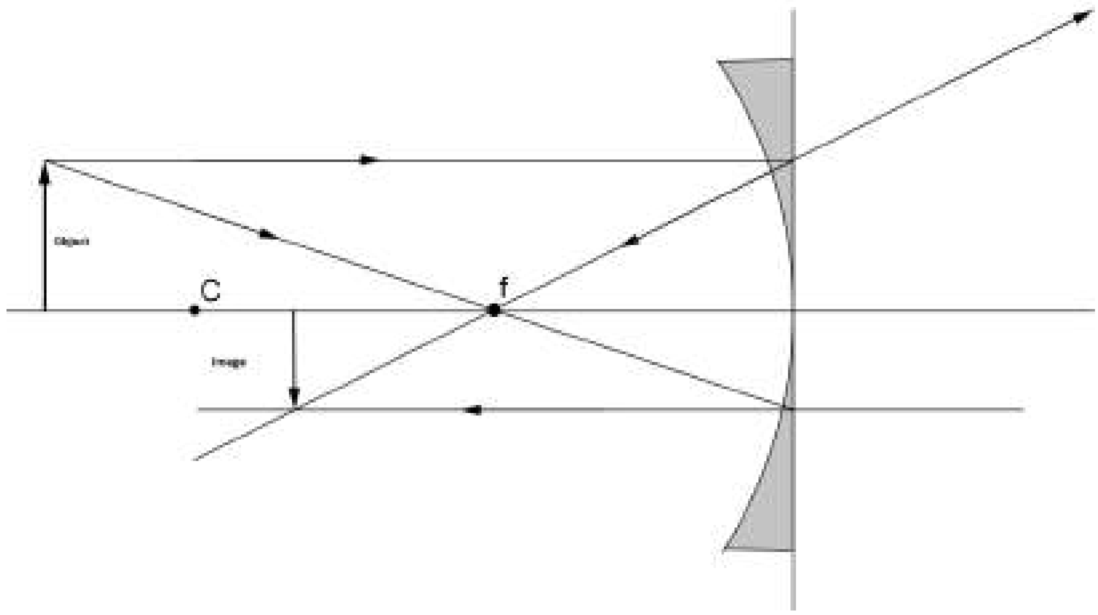
From the top of the object draw *two* of the following rays and where the reflected rays meets or appear to come from is the top of the image.

1. A ray parallel to the principal axis reflects through (or from in convex mirrors) the principal focus F.
2. A ray through the center of curvature C which hits the mirror normally, is reflected back along its own path (the radius of a sphere is perpendicular to the surface where it meets the surface)
3. A ray through the principal focus F is reflected parallel to the principal axis.

12.34 Images Formed By A Concave Mirror

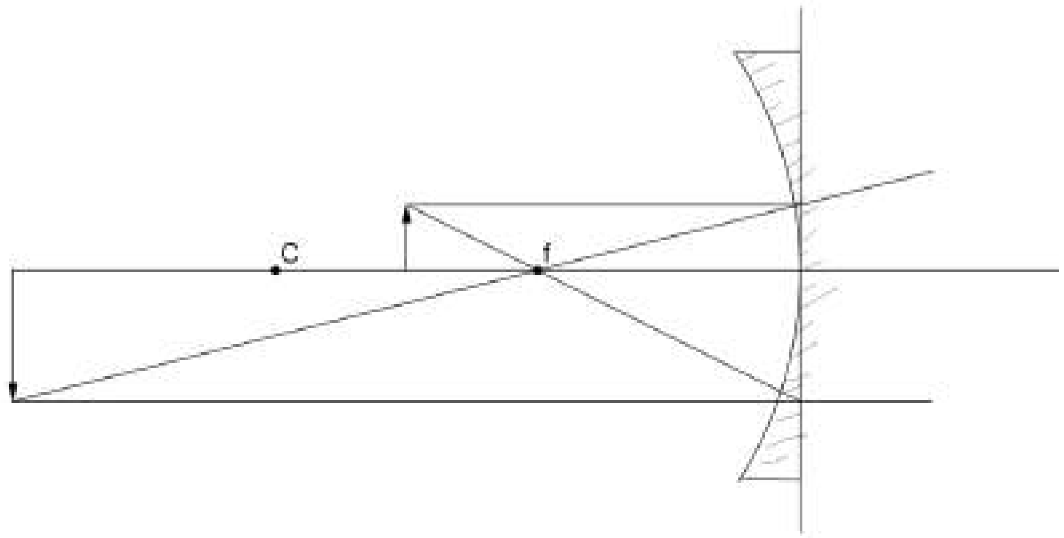
The ray diagrams in the Figure shown below show the images for four object positions. In each case rays are drawn from the top of an object and where they intersect after reflection gives the top of the image.

(a) Objects beyond C



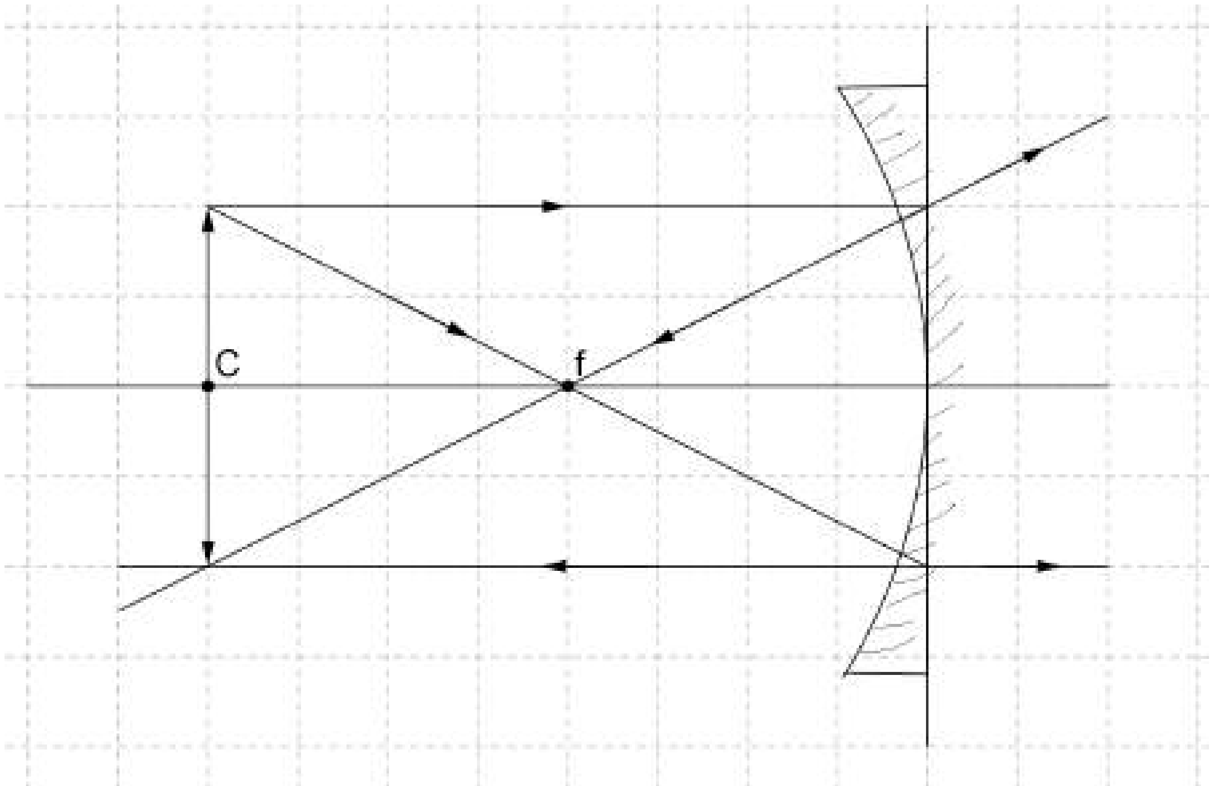
nature of the image : real, diminished and inverted.

(b) Objects between C and F



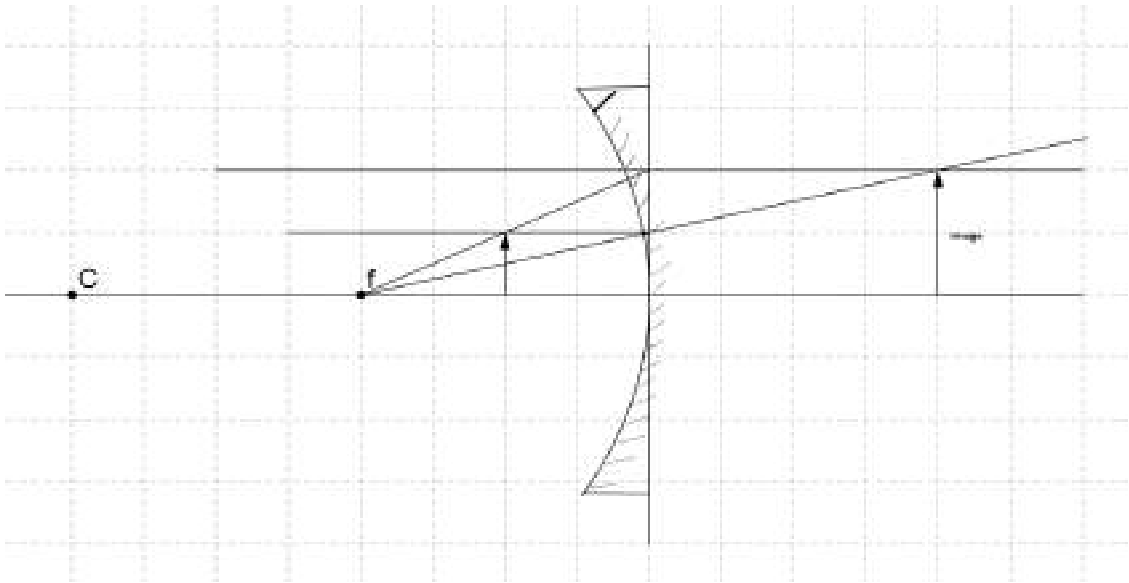
nature of the image : real, enlarged and inverted

(c) Objects at C



nature of the image : real, same size and inverted

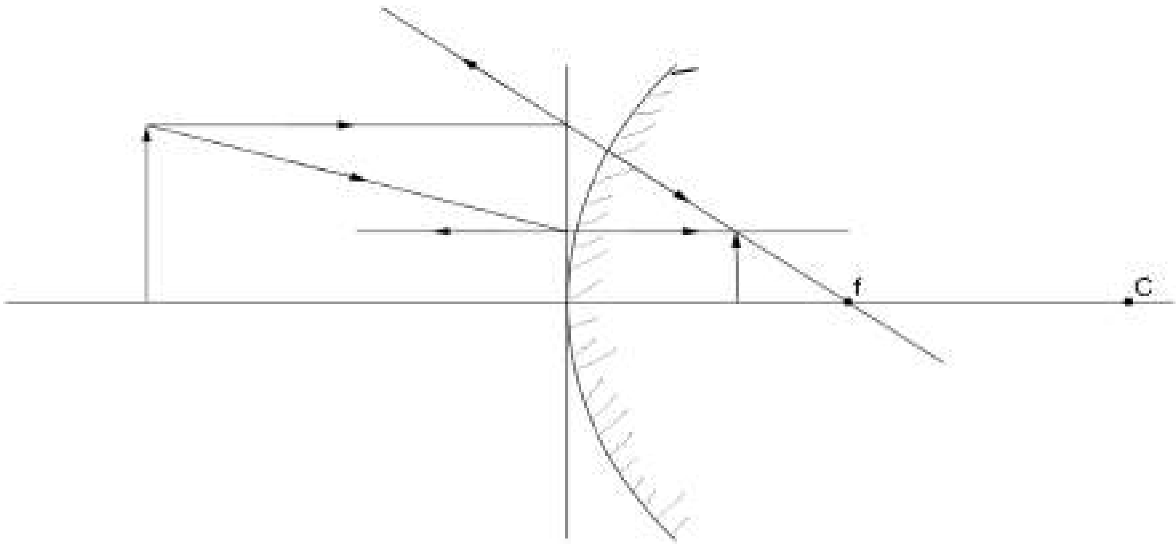
(d) Objects between F and P



nature of the image : virtual, enlarged and upright.

12.35 Images Formed By A Convex Mirror

A convex mirror produces only virtual images which are always upright and smaller than the object.



nature of the image : virtual, diminished and upright.

12.40 REFRACTION OF LIGHT

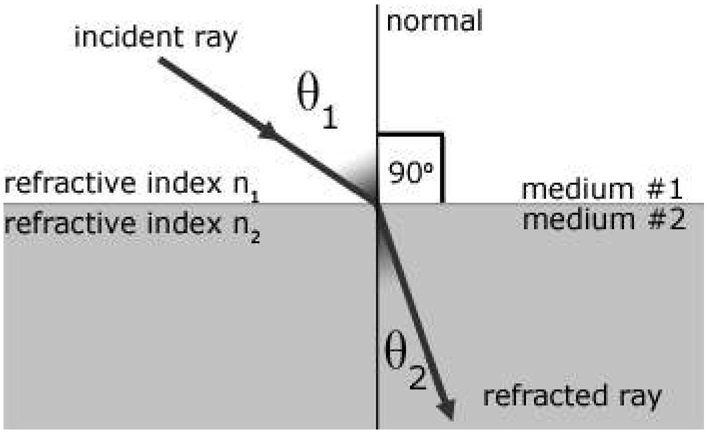
If you place a coin in an empty cup and move back until you just cannot see it, the result is surprising if someone gently pours water.

Although light travels in straight lines in one transparent material, e.g. air, if it passes into a different material, e.g. water to air, it changes direction at the boundary between the two, i.e. it is bent. The bending of light when it passes from one medium to another is called refraction.

12.41 The Laws of Refraction

Consider a single light ray travelling through a low density material and being refracted at the surface of a transparent material with higher density.

- The normal is a line drawn at right angles to the material's surface at the ray's point of entry.
- The angle of incidence is the angle the light ray makes with the normal.
- The angle of refraction is the angle the refracted light ray makes with the normal inside the material.



Source: http://www.a-levelphysicstutor.com/optics-refract.php

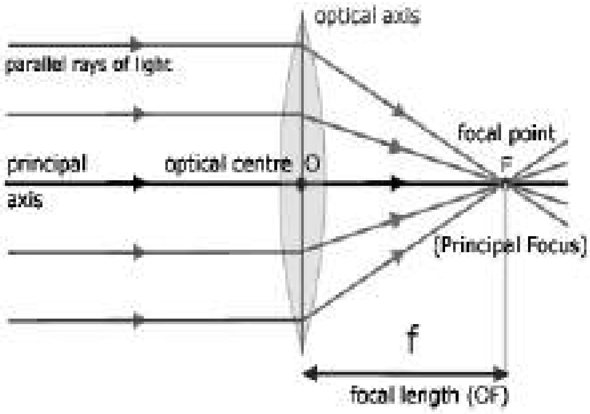
Note

1. A ray of light bent towards the normal when it enters a more denser medium.
2. A ray of light bent away from the normal when it enters a less dense medium

12.50 LENSES

Lenses are used in many optical instruments; they have spherical surfaces and there are two types.

A convex lens is thickest in the center and is also a converging lens because it bends light inwards. You may have used one as a magnifying glass.

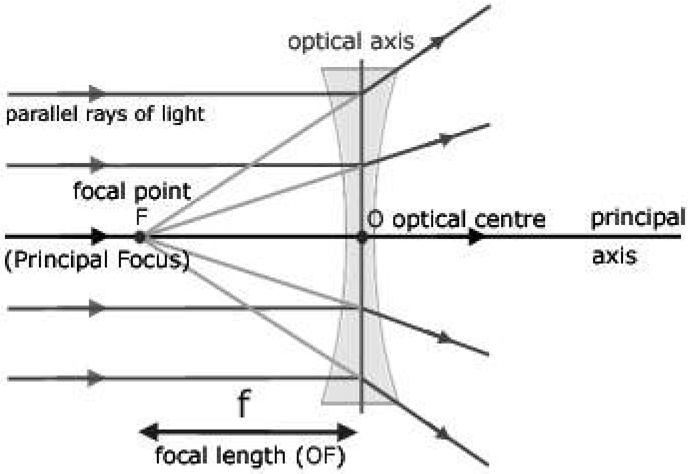


Source: http://www.a-levelphysicstutor.com/optics-convx-lnss.php

- The pole of the lens is the centre of the lens. Rays drawn passing through this point are not diverted, they continue in a straight line.
- The focal length of a lens is the distance between the pole of the lens and the focal point OR the perpendicular distance between the axis of the lens and the focal plane.
- The focal point or principal focus of a convex lens is point through which rays of light travelling near to and parallel to the principal axis pass after refraction by the lens. (The point all emerging rays pass through).

A concave or diverging lens is thinnest in the center and spreads light out. It always gives a diminished image.

The focal point or principal focus of a concave lens is point from which rays of light travelling near to and parallel to the principal axis seem to emerge from after refraction by the lens. (The point all emerging rays can be 'traced back' through).



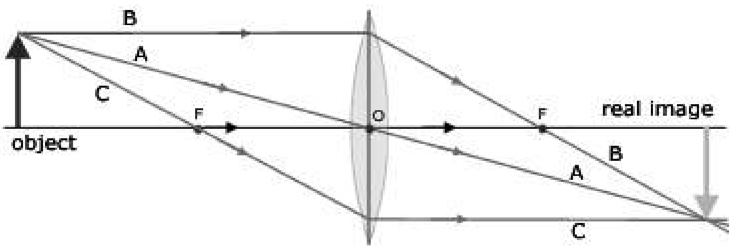
Source: http://www.a-levelphysicstutor.com/optics-concv-lnss.php

12.51 Ray Diagrams for a Convex Lens

Convex lenses converge light thus behaving similarly to a concave mirror.

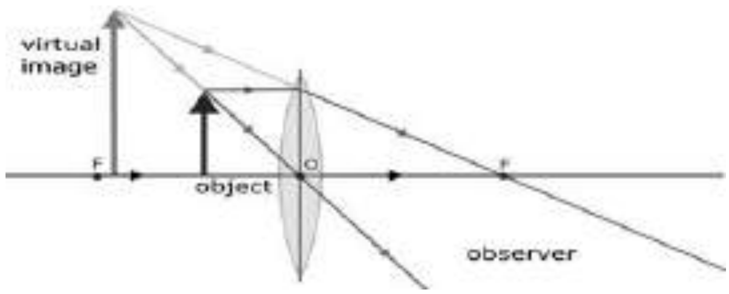
From the top of the object draw any *two* of the following rays:

1. A ray passing through the principal focus (on the same side as the object) and being refracted through the lens, emerging parallel to the principal axis.
2. A ray passing through the optical centre of the lens.
3. A ray parallel to the principal axis, which refracts through the lens, passing through the principal focus.



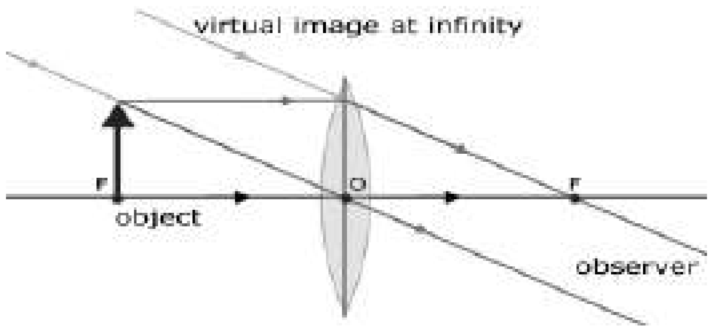
The drawings displayed below depict the various cases for convex (converging) lenses.

Object between *f* and the lens



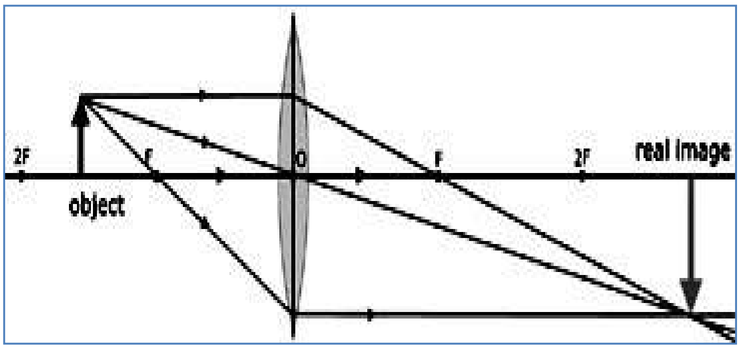
The image is the same side of the lens as the object and is upright, virtual and magnified.

Object at f



The image is formed at infinity from parallel rays that do not converge. Therefore no image is formed.

Objects between F and 2F

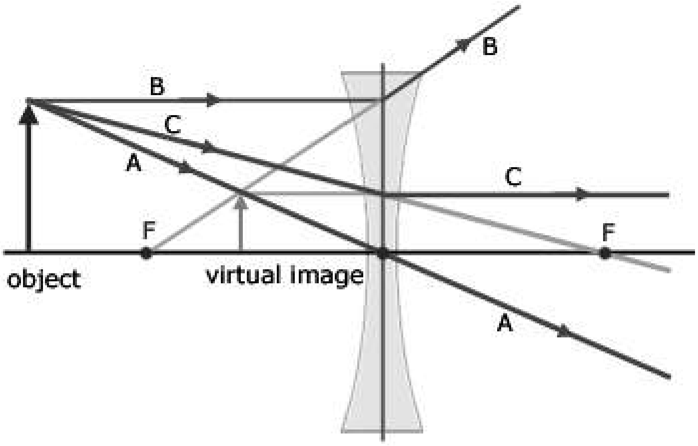


The image is on the opposite side of the lens than the object. It is real, inverted and magnified.

12.52 Ray Diagrams For A Concave Lens

From the top of the object draw any ***two*** of the following rays:

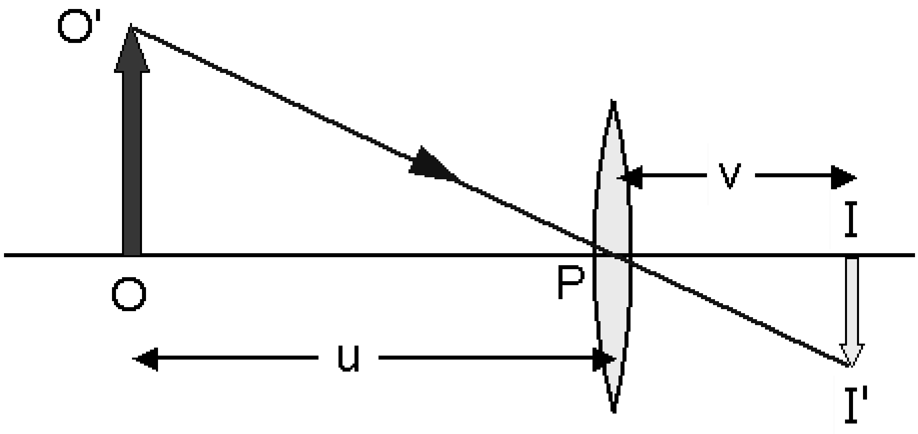
1. A ray through the principal focus (on the opposite side of the lens) and being refracted through the lens, emerging parallel to the principal axis.
2. A ray passing through the optical centre of the lens.
3. A ray parallel to the principal axis, which refracts through the lens and appears to have come from the principal focus.



The image produced is always virtual, upright, diminished and on the same side of the lens as the object.

12.53 Magnification of a Lens

Lenses give an image of the object. The size of the image compared with the object depends on the magnification of the lens.



Magnification = image height (II')/object height (OO')

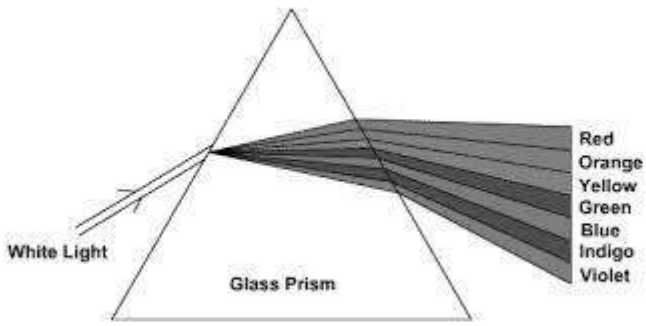
The magnification is also equal to image distance/object distance or v/u.
Magnifications don't always have to be bigger than one. For example in a camera and in your eyes the image is smaller than the object.

For a convex lens with an object distance of 15 cm and an image distance of 7.5 cm the magnification would be 7.5/15 or 0.5, the image is real and half the size of the object.

12.60 COLOURS

In 1665, during his investigation on optics, Isaac Newton discovered that by placing a triangular prism in the path of a beam of white light, he was able to split the beam into seven bands of colour, namely red, orange, yellow, green, blue, indigo, violet. The process of separating white light into its constituent coloured lights is known as the dispersion of white light.

The dispersion of white light depends on the wavelength of each colour of light. Since red light has the longest wavelength of 700 nm, it travels the fastest in glass and is refracted the least. On the other hand, violet light has the shortest wavelength of 400 nm. It travels the slowest in glass and is refracted the most.



12.70 NATURAL REFRACTION PHENOMENA

1. Mirages

We often see what appears like water on a dry road on sunny, hot days. However, when we get to the water-like area that produces the reflection, the road is perfectly dry. This is an optical effect called a mirage. It appears not only on roads and pavement, but also on deserts or any open area subject to heating by sunlight.

These mirages are caused not by any water on the surface, but by warm air immediately above the road. The sunlight beating on the road warms the road significantly above the ambient air temperature. The warm road in turn warms a layer of air immediately above it.
Because warm air is less dense than cool air, it has a lower refractive index. Consider light originating in the cold air above the boundary. When the light strikes the boundary to traverse into the region of less refractive index it bends. If light strikes the boundary at a shallow grazing angle, it is totally reflected by the boundary. This is called "Total Internal Reflection" which in this case gives rise to mirage.

2. Rainbow

Rainbows are caused by the splitting of white sunlight into it component colours by raindrops. Some of the light that falls on a water drop enters it. As it enters the drop, the colour components of the sunlight are refracted (bent) by different amounts depending upon their wavelength.

Then, the different colours reflect off the back of the inside of the drop, and when they pass through the front of the drop again, they are refracted once again.

A rainbow is always directly opposite the sun from the observer's perspective. This explains why rainbows are only seen when the sun is low in the sky, usually in the late afternoon.

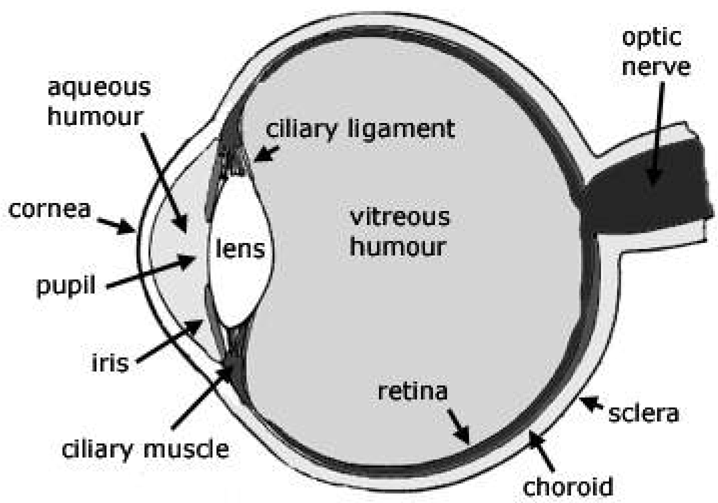
12.80 THE EYE

The human eye has been called the most complex organ in our body. It's amazing that something so small can have so many working parts. But when you consider how difficult the task of providing vision really is, perhaps it's no wonder after all.

In a number of ways, the human eye works much like a digital camera:

1. Light is focused primarily by the cornea — the clear front surface of the eye, which acts like a camera lens.
2. The iris of the eye functions like the diaphragm of a camera, controlling the amount of light reaching the back of the eye by automatically adjusting the size of the pupil (aperture).
3. The eye's crystalline lens is located directly behind the pupil and further focuses light. Through a process called accommodation, this lens helps the eye automatically focus on near and approaching objects, like an autofocus camera lens.
4. Light focused by the cornea and crystalline lens (and limited by the iris and pupil) then reaches the retina — the light-sensitive inner lining of the back of the eye. The retina acts like an electronic image sensor of a digital camera, converting optical images into electronic signals. The optic nerve then transmits these signals to the visual cortex — the part of the brain that controls our sense of sight.

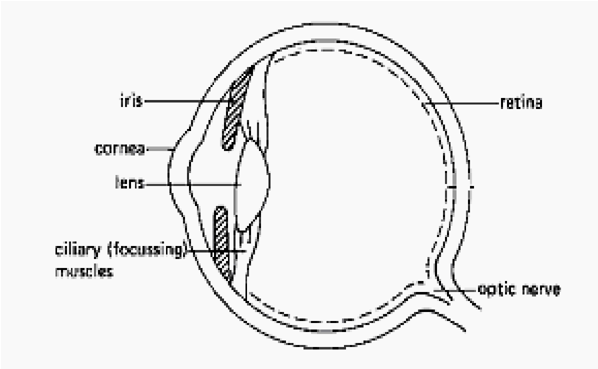
Parts of the Eye,



Source: http://www.a-levelphysicstutor.com/optics-eye.php

12.90 EXERCISES

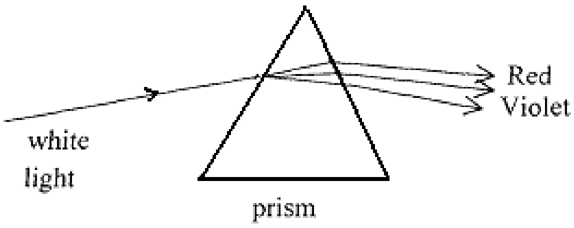
1. The diagram below shows parts of an eye.



2. Which part shown above controls the amount of light entering the eye?

A. iris B. retina C. cornea & lens D. ciliary muscles

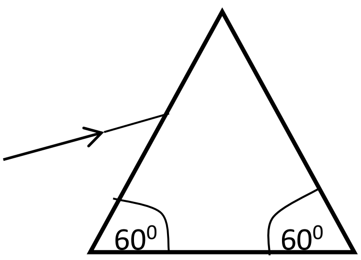
3. A beam of white light, incident on a glass prism is spread into a spectrum of colors.



This phenomenon is called:

A. reflection. B. dispersion. C. diffraction. D. interference.

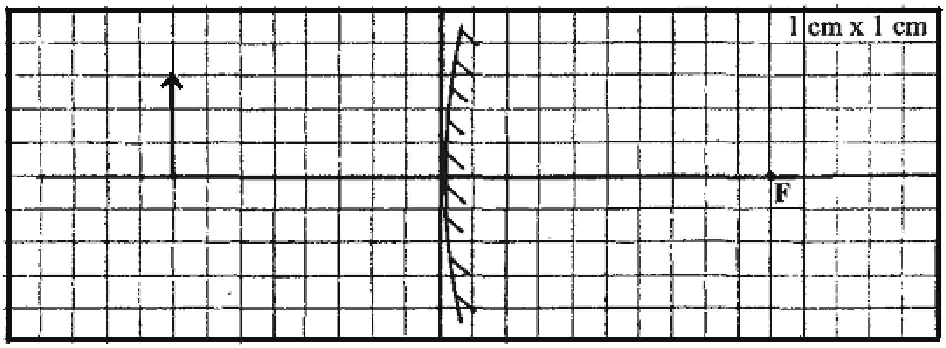
4. The diagram below shows a ray of red light incident on a glass prism.



(i) Complete the diagram to show the path of the light through and out of the prism.

(ii) If white light was used instead of red light, what difference, if any would you notice?

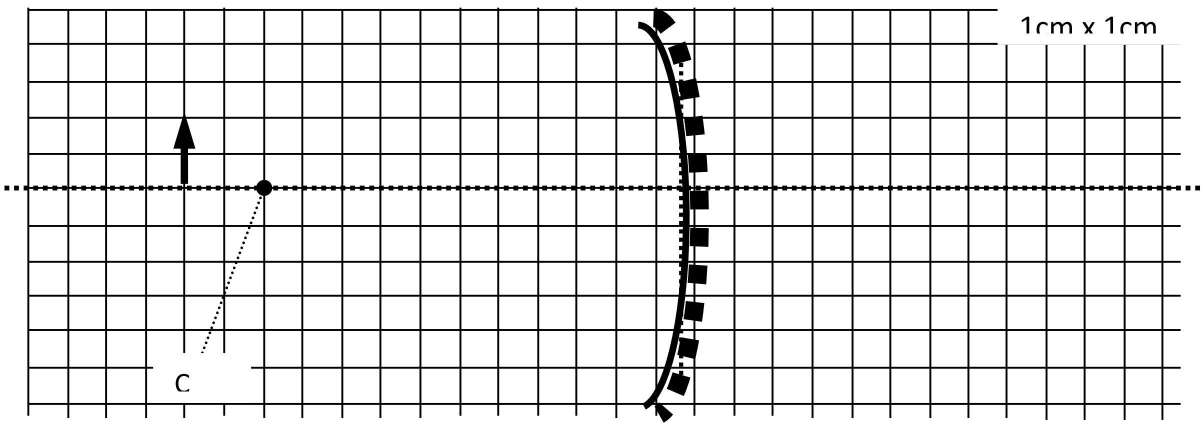
5. An object 3 cm tall is placed 8 cm in front of a convex mirror of focal length 10 cm.



(i) Dray ray diagrams to locate the image formed.

(ii) What is the magnification of the image formed?

6. An object 2 cm high is placed perpendicular to the principle axis of a concave mirror. The radius of curvature of the mirror is 10 cm and the object is 12 cm from the pole of the mirror as shown in the diagram given below.

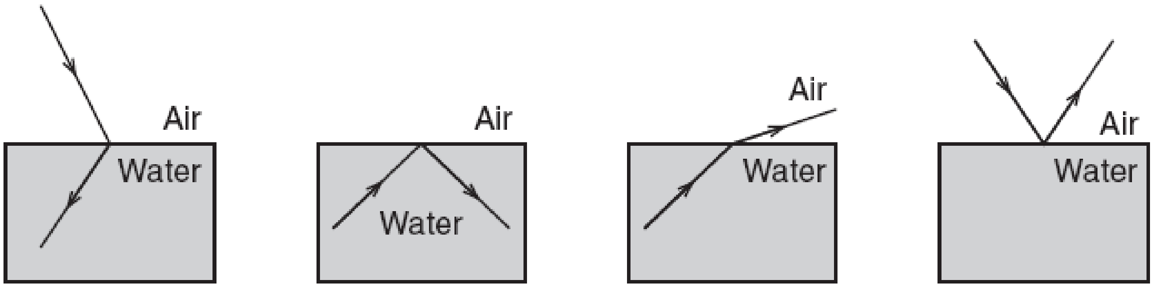


i) Draw suitable construction rays to find the position of the image.

ii) Determine the nature of the image.

7. Which ray diagram best represents the phenomenon of refraction?

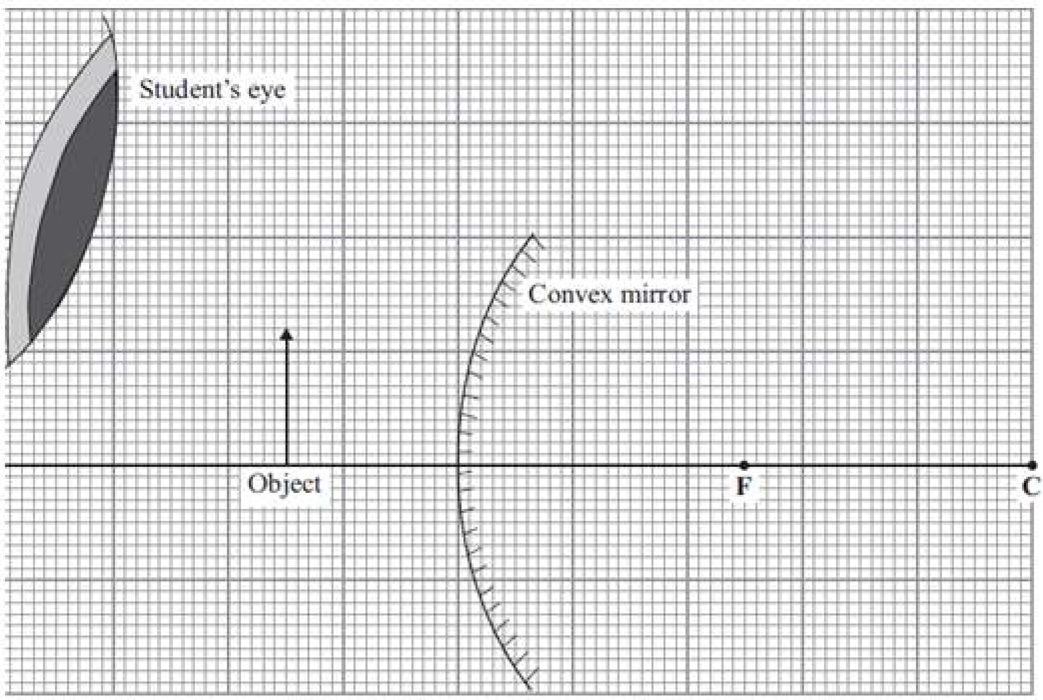
A. B. C. D.



8. A student investigates the formation of images by a convex mirror. In the mirror, she can see the image of an object placed in front of the mirror. In the diagram, F is the principal focus of the mirror and C is the centre of curvature of the mirror.

(a) Use a ruler to draw two rays from the top of the object which show the position of the image and how the student sees the image.

Mark the direction of the rays at each stage.



(b) The image is a virtual image.

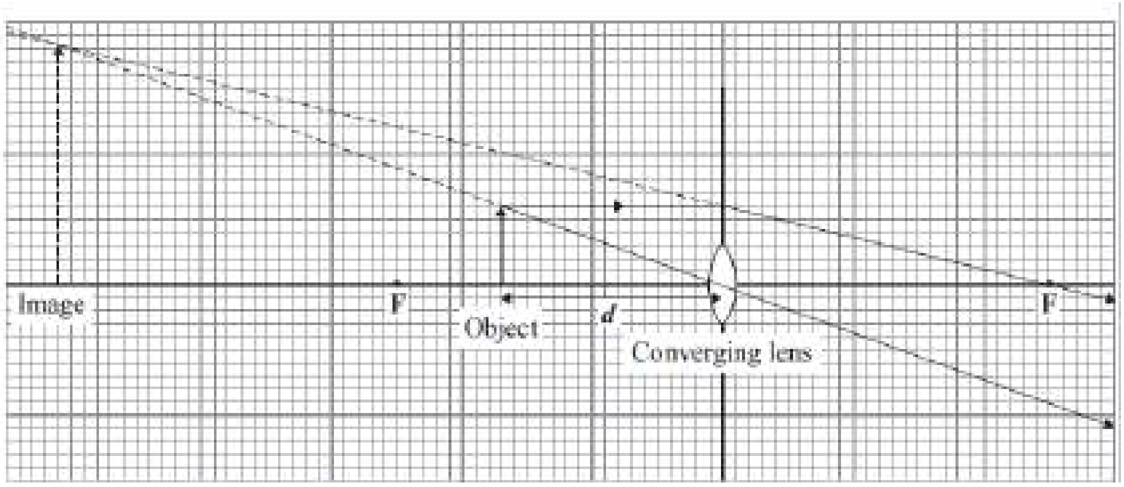
How can you tell from the rays you have drawn that the image is a virtual image?

9. A student investigates how the magnification of an object changes at different distances from a converging lens.

The diagram shows an object at distance *d* from a converging lens.

(i) The points F are at equal distances on either side of the centre of the lens. State the name of these points.

(ii) Explain how you can tell, from the diagram, that the image is virtual.



(iii) The height of the object and the height of its image are drawn to scale. Use the equation in the box to calculate the magnification produced by the lens shown in the diagram.

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