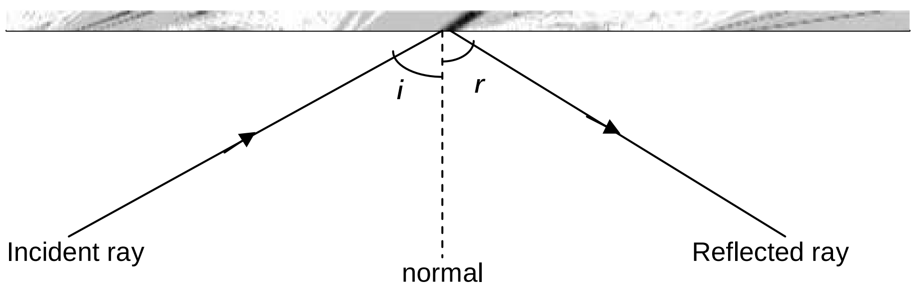
CHAPTER 5: LIGHT AND VISION

5.1 Light Reflection

5.1.1 Plane mirrors



Law of light reflection:

- The reflected angle is always the **same** as the incident angle.
- The incident ray, reflected ray, and normal line are in the **same plane**.

Characteristics of an image formed by a plane mirror:	
Size	Same
Direction	Upright, laterally inverted
Type	Virtual
Distance	Distance of an image from the plane mirror is the same as the distance of the object from the mirror

Image characteristics are commonly explained using the following three categories:

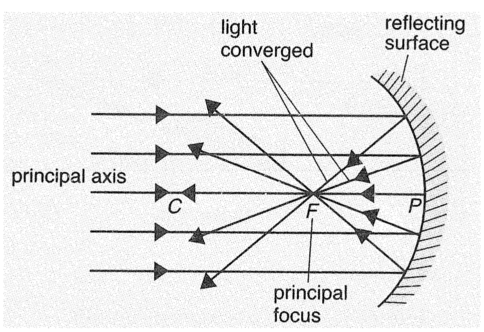
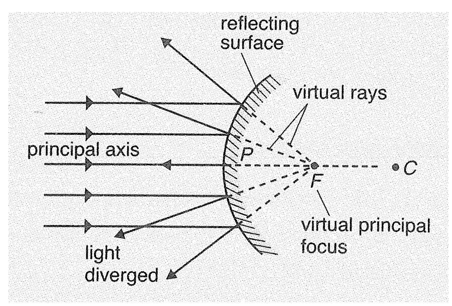
Size	Same	Image is exactly the same size as the object
	Magnified	Image appears bigger than the object
	Diminished	Image appears smaller than the object
Direction	Upright	Image appears to be in the same direction as the object
	Inverted	Image appears upside down compared to object
Type	Real	Image formed is on the same side of the mirror as the object. *Real images mean you can capture the image on a screen.*
	Virtual	Image formed is on the opposite side of the mirror from the object *Virtual images can only be seen; they cannot be captured on a screen.*

5.1.2 Curved Mirrors

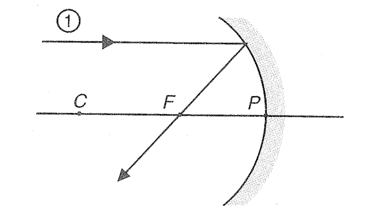
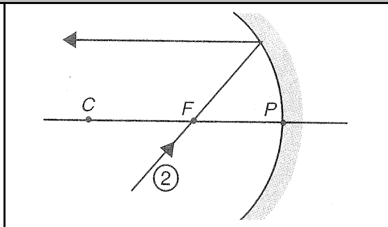
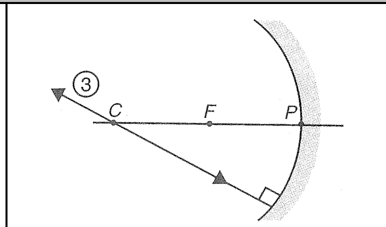
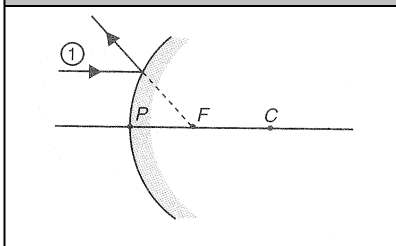
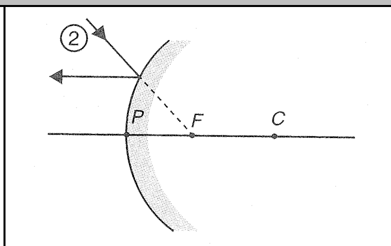
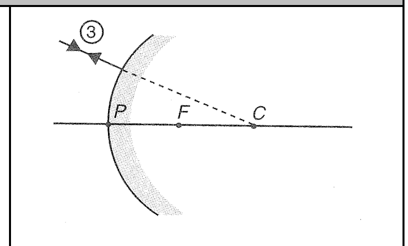
Common terminology of curved mirrors:

Centre of curvature, *C*	The geometric centre of a hollow sphere of which the concave or convex mirror is a part
Pole of mirror, *P*	The centre point on the curved mirror
Principal axis	A line which passes through the centre of curvature, *C* and the pole of a curved mirror, *P*
Radius of curvature, *r* (=*CP*)	Distance between the pole, *P* and the centre of curvature, *C*
Principal focus, *F*	A point through which all rays traveling parallel to the principal axis converge to or appear to diverge from after reflection by the mirror
Focal length, *f*	The distance between the principal focus, *F* and the pole of the curved mirror, *P*
Aperture of mirror	The portion of the surface of the mirror that reflects light
Object distance, *u*	Distance of object from the pole of the mirror, *P*
Image distance, *v*	Distance of image from the pole of the mirror, *P*

For both concave and convex mirrors, the focal length is half the radius; i.e. $CF = FP$.

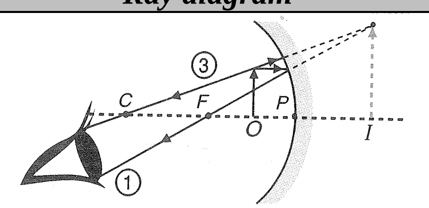
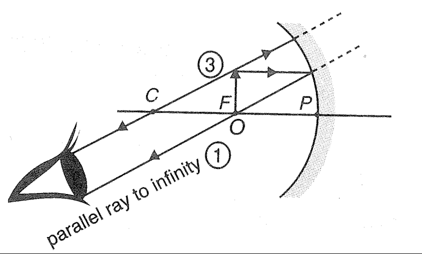
Concave mirror	Convex mirror
 Rays traveling parallel to the principal axis **converge** to a point, called the **real principal focus**, on the principal axis. Focal lengths are written in positive. E.g. f = +20cm.	 Rays traveling parallel to the principal axis appear to **diverge** from a point behind the mirror which lies on the principal axis, called the **virtual principal axis**. Focal lengths are written in negative. E.g. f = -20cm.

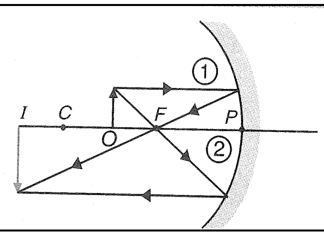
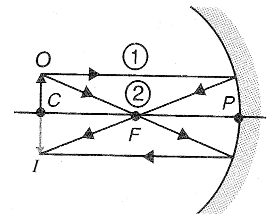
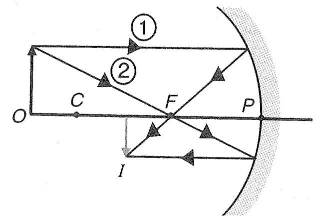
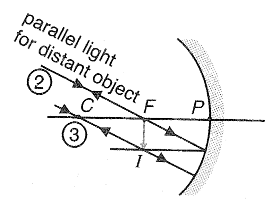
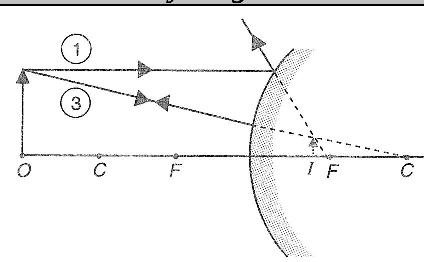
Determining the Position and Characteristics of an Image with a Ray Diagram

Concave mirror		
		
① A ray parallel to the principal axis is reflected to pass through *F*	② A ray through *F* is reflected parallel to the principal axis	③ A ray through *C* is reflected back along its own path
Concave mirror		
		
① A ray parallel to the principal axis is reflected as if it came from *F*	② A ray towards *F* is reflected parallel to the principal axis	③ A ray towards *C* is reflected back along its own path

To determine the position and characteristics of an image using a ray diagram:

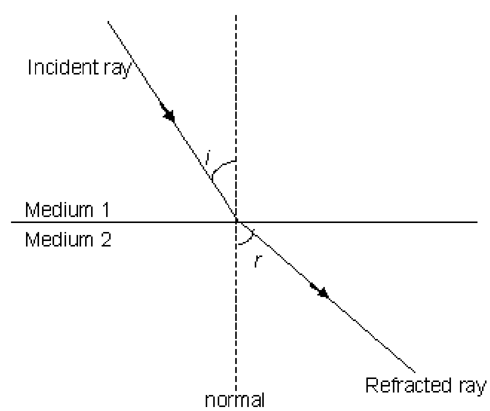
1. Draw rays emanating from the top of the object to the mirror, and using the guide in the table above, draw their reflected paths. Use any of the two of the rays in the above guide.
2. A point on the image is produced at the intersection of two rays originating from the point on the object.

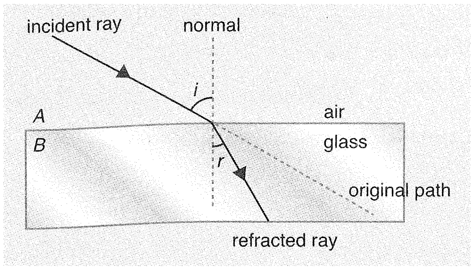
Images formed by a Concave Mirror		
Position of object	***Ray diagram***	***Characteristics of image***
O between *F* and *P*		• Virtual • Upright • Magnified
O at *F*		• Virtual • Upright • Magnified • At infinity

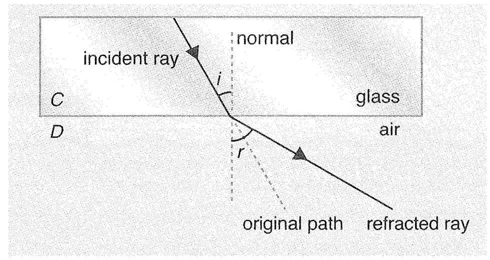
O between *F* and *C*		• Real • Inverted • Magnified
O at *C*		• Real • Inverted • Same size
O beyond *C*		• Real • Inverted • Diminished
O at infinity		• Real • Inverted • Diminished
Images formed by a Convex Mirror		
Position of object	***Ray diagram***	***Characteristics of image***
Anywhere in front of the mirror		• Virtual • Upright • Diminished

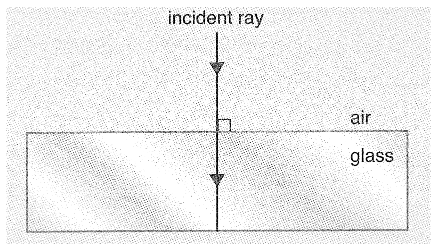
5.2 Light Refraction

Light refraction is a phenomenon where the direction of light is changed when it crosses the boundary between two materials of different optical densities. It occurs as a result of a change in the velocity of light as it passes from one medium to another.



<table>
<tr>
<td>When a light ray travels from medium A to medium B which is optically denser than A


The ray of light will refract towards normal; $r < i$</td>
<td>When a light ray travels from medium C to medium D which is optically denser than C


The ray of light will refract away from normal; $r > i$</td>
</tr>
<tr>
<td colspan="2">When a light ray crosses the boundary between two different mediums at a right angle


$i = 0°, r = 0°$</td>
</tr>
</table>

5.2.1 Laws of Refraction

When a light ray travels from one medium to another,

1) the incident ray and the refracted ray are on the opposite sides of the normal at the point of incidence, and all three lie in the same plane.
2) the value of $\frac{\sin i}{\sin r}$ is a constant (**Snell's Law**)

5.2.2 Refractive Index

$$\eta = \frac{\sin i}{\sin r}$$

where η = refractive index / index of refraction

The higher the refractive index, the greater the optical density.

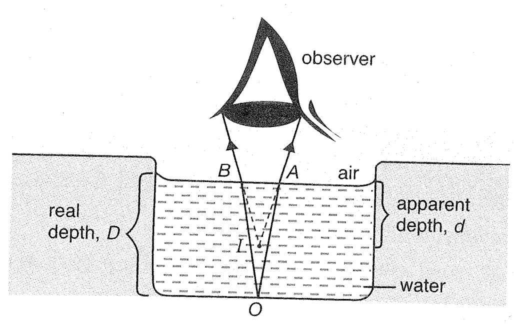
Note: A material with greater density may not necessarily have greater optical density.

A light ray which travels through a medium with higher optical density will have its speed reduced.

$$\eta = \frac{\text{speed of light in vacuum, } c}{\text{speed of light in the medium, } v}$$

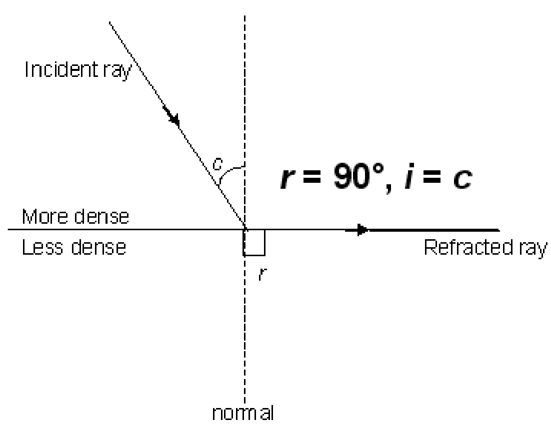
where $c = 3 \times 10^8$ m s^{-1}

5.2.3 Actual depth and Apparent depth

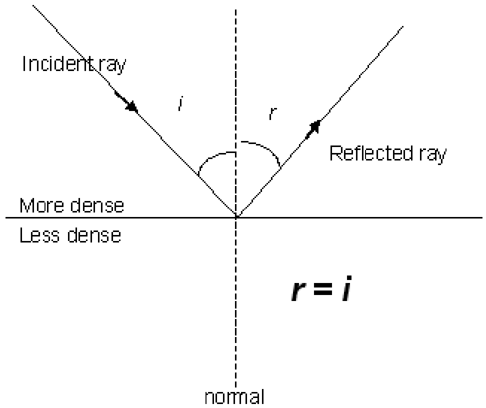


$$\eta = \frac{\text{actual depth, } D}{\text{apparent depth, } d}$$

5.3 Total Internal Reflection



Critical angle, c is the value of the incident angle when the refracted angle is 90°.



- When i is increased to be greater than c, the light will be complete reflected back into the material. No light will be refracted.
- This phenomenon is known as **total internal reflection**.

Conditions for total internal reflection:

1. Light must be traveling from an optically denser medium to a less dense medium.
2. The incident angle must be greater than the critical angle.

SUMMARY OF FORMULA FOR INDEX OF REFRACTION:

$$n = \frac{\sin i}{\sin r}$$

$$n = \frac{\text{speed of light in air}}{\text{speed of light in medium}}$$

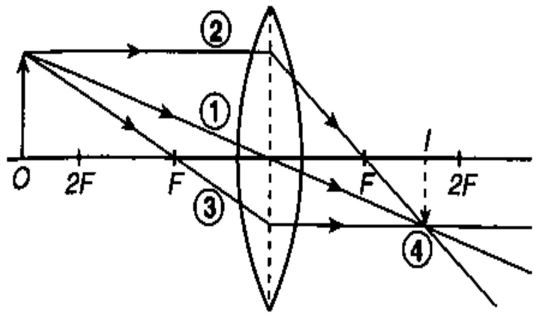
$$n = \frac{1}{\sin c}$$

$$n = \frac{\text{actual depth}}{\text{apparent depth}}$$

Hint:
The index of refraction for any medium when compared to air ***must be greater than 1****.*

5.4 Lenses

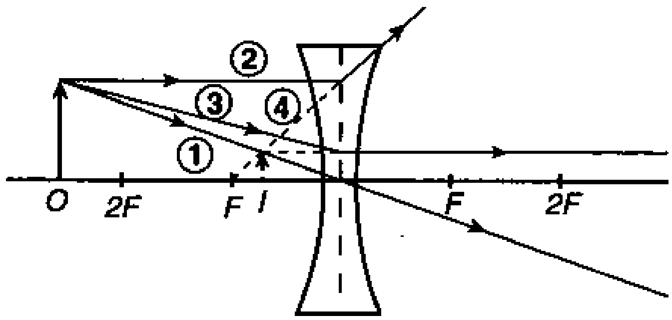
5.4.1 Convex lenses



Focal length +ve

Object distance	Image characteristics
Infinity (Light rays enter at parallel) $u = \infty$	• Image at focal point ($v = f$) • Real • Inverted • Diminished
$u > 2f$	• Real • Inverted • Diminished
$u = 2f$	• Real • Inverted • Same size
$f < u < 2f$	• Real • Inverted • Magnified
$u = f$	• Image at infinity ($v = \infty$) • Virtual • Upright • Magnified
$u < f$	• Virtual • Upright • Magnified

5.4.2 Concave lenses



Focal length –ve

Image Characteristics:
- Virtual
- Upright
- Diminished

5.4.3 Lens Equation

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

where u = object distance [cm]
v = image distance [cm]
f = focal length of lens [cm]

5.4.4 Lens Power

Lens power is defined as the inverse of the focus length in meters.

$$P=\frac{1}{f}$$

where P = lens power [D]
f = focal length [m]

5.4.5 Linear Magnification

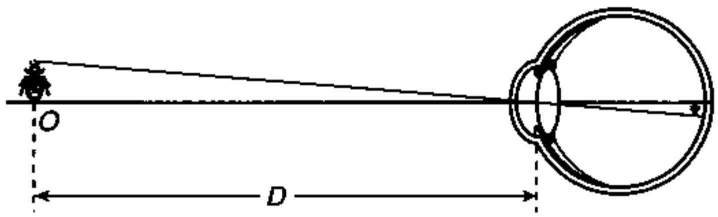
Linear magnification is the ratio of the image size to the object size.

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

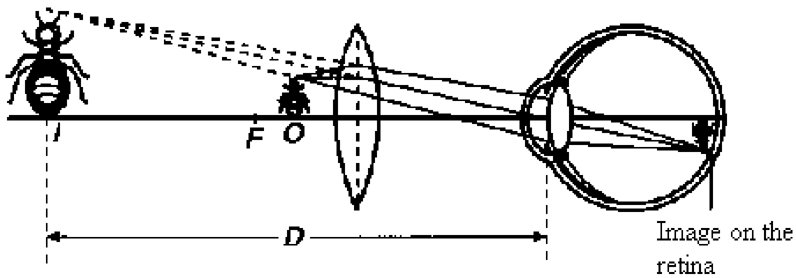
where m = linear magnification
h_i = height of image
h_o = height of object

5.5 Applications of Lenses

5.5.1 Magnifying Glass

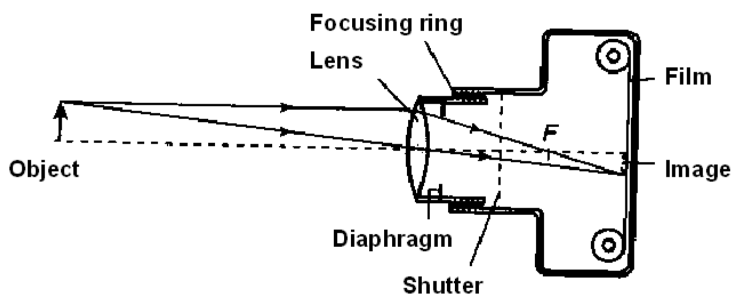


An object observed with the naked eye

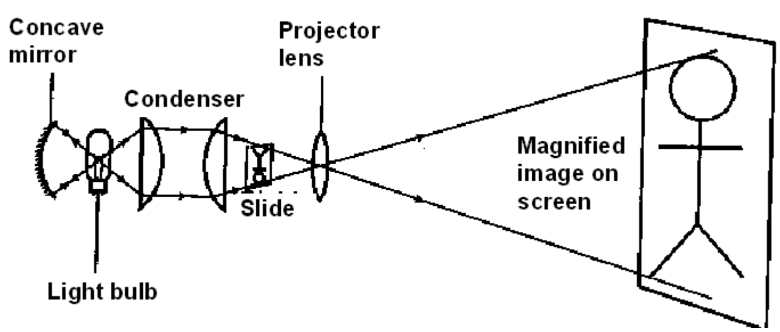


The image formed by the object is a lot bigger with the magnifying glass at the same position

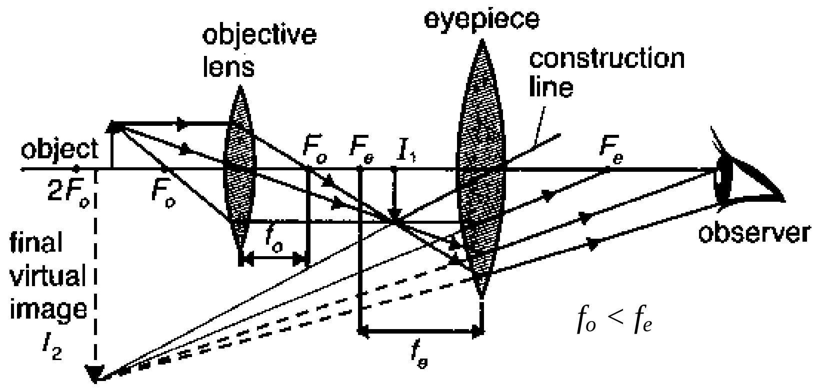
5.5.2 Camera



5.5.3 Slide Projector

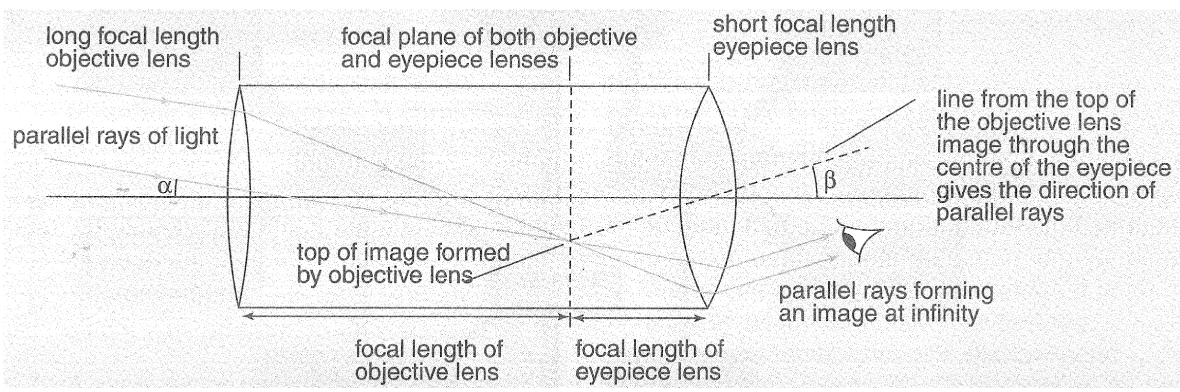


5.5.4 Complex Microscope



$f_o < f_e$

5.5.5 Astronomical Telescope



$f_o > f_e$

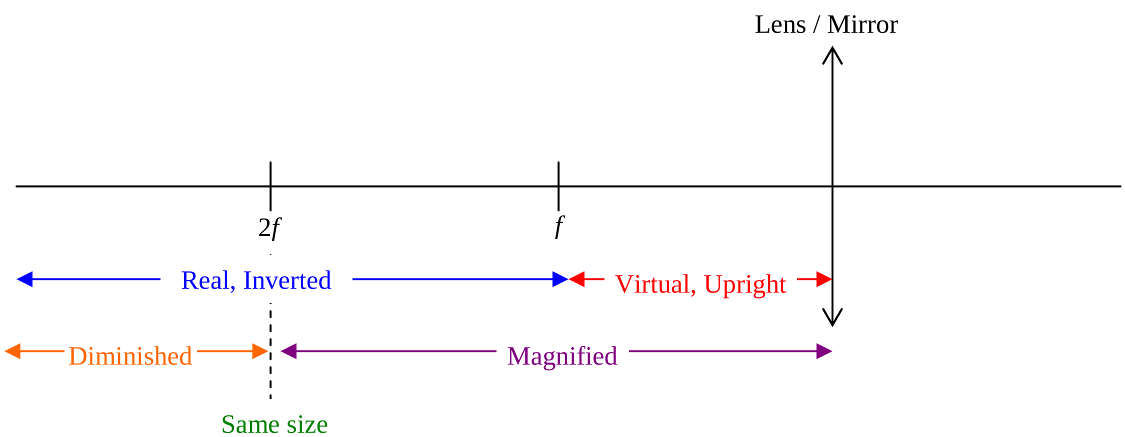
Magnification = $\dfrac{f_o}{f_e}$

<u>Normal setting:</u>

Length between lenses = $f_o + f_e$

SUMMARY OF COMPARISON OF IMAGE CHARACTERISTICS

Characteristics of **concave mirrors** are the same as **convex lenses**:



Object distance	Image characteristics		
$u = \infty$	Real	Inverted	Diminished
$u > 2f$	Real	Inverted	Diminished
$u = 2f$	Real	Inverted	Same Size
$f < u < 2f$	Real	Inverted	Magnified
$u = f$	Virtual	Upright	Magnified
$u < f$	Virtual	Upright	Magnified

Characteristics of **convex mirrors** are the same as **concave lenses**:

Virtual, Upright, Diminished