Unit 3: Thin Converging Lens

Learning Outcomes

Students should be able to:

1. Describe the action of a thin converging lens on a beam of light.
2. Define the term focal length
3. Draw ray diagrams to illustrate the formation of real and virtual images of an object by a lens
4. Define the term *linear magnification*
5. Draw scale diagrams to deduce the focal length needed for particular values of magnification.
6. Describe the use of a single lens as a magnifying glass and in a projector and draw ray diagrams to show how each forms an image.

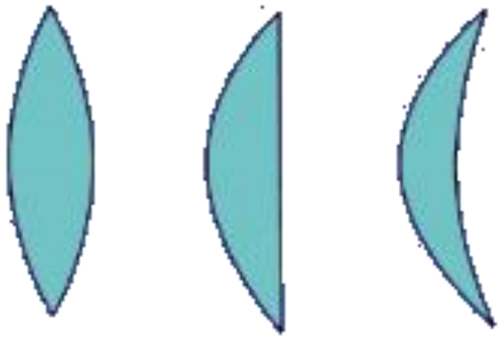
What is a lens?

- A lens is a piece of clear plastic or glass with curved surfaces.
- Lenses are widely used in spectacles, cameras, projectors and many other optical instruments.

lenses for spectacles

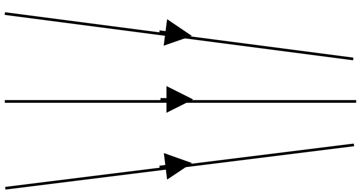
binoculars

Lenses can be classified into two categories.

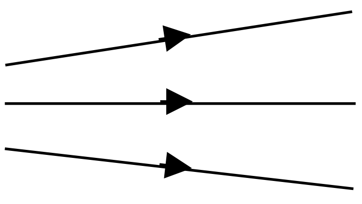


converging lens
(convex lens)

diverging lens
(concave lens)



converging
beams



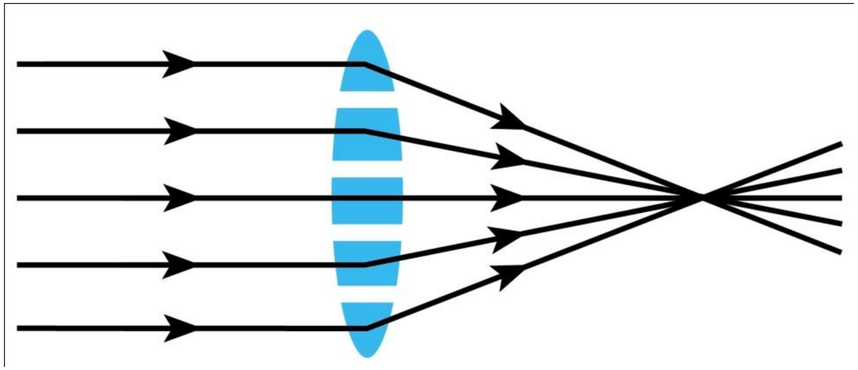
diverging
beams

Converging Lens and Diverging Lens

Lenses	Converging Lens	Diverging Lens
Structure	thicker in the middle	thinner in the middle
Use	converge: bring together to a point a parallel beam of light passing through it	diverge: spread out a parallel beam of light passing through it
Example	correct long-sightedness	correct short-sightedness

How does a converging lens converge light?

A converging lens can be thought of as a set of blocks and prisms



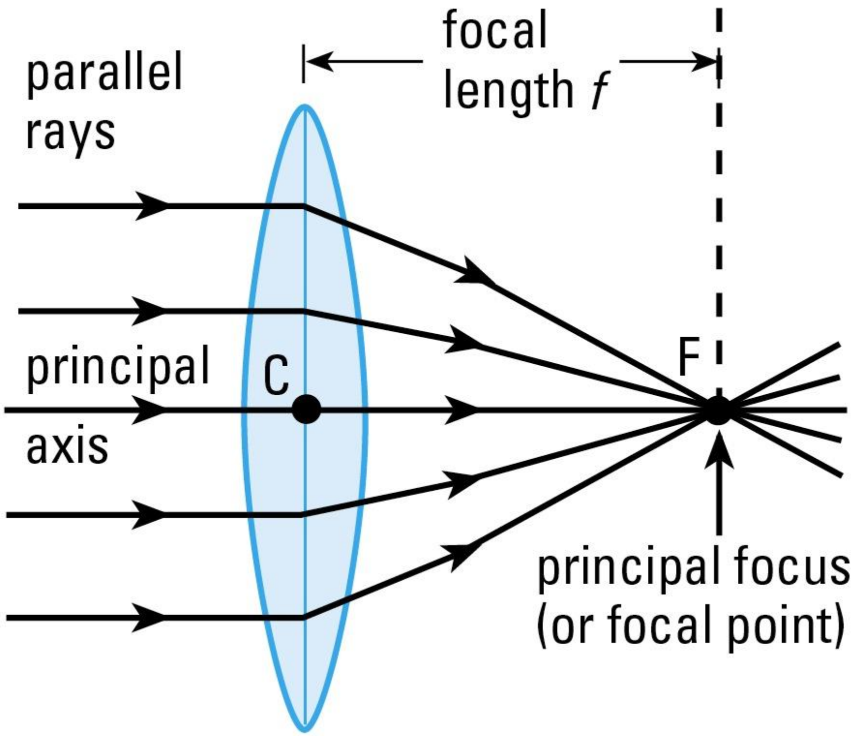
Parallel light rays will incident different parts of the lens at different incident angles.

Light rays refract the most at the outermost part of the lens, while less or no refraction occurs in the middle portion.

As a result, the light rays will converge behind the lens.

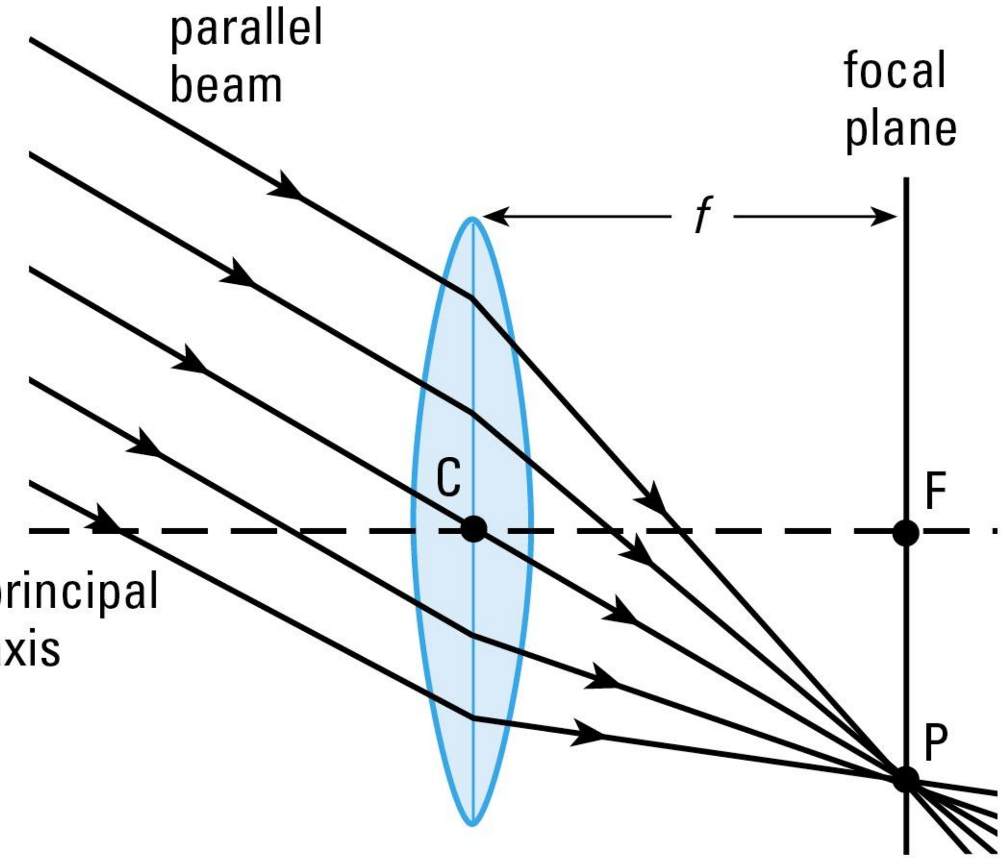
Thin converging lens and its main features

1. C is the Optical centre - for a symmetrical lens, this is the point midway between the lens surfaces on its principal axis.
2. Principal axis
3. F is the Principal Focus – all parallel rays to the principal axis converge at the focal point F.
4. Focal length, f – The distance between the optical centre C and the focal point F.



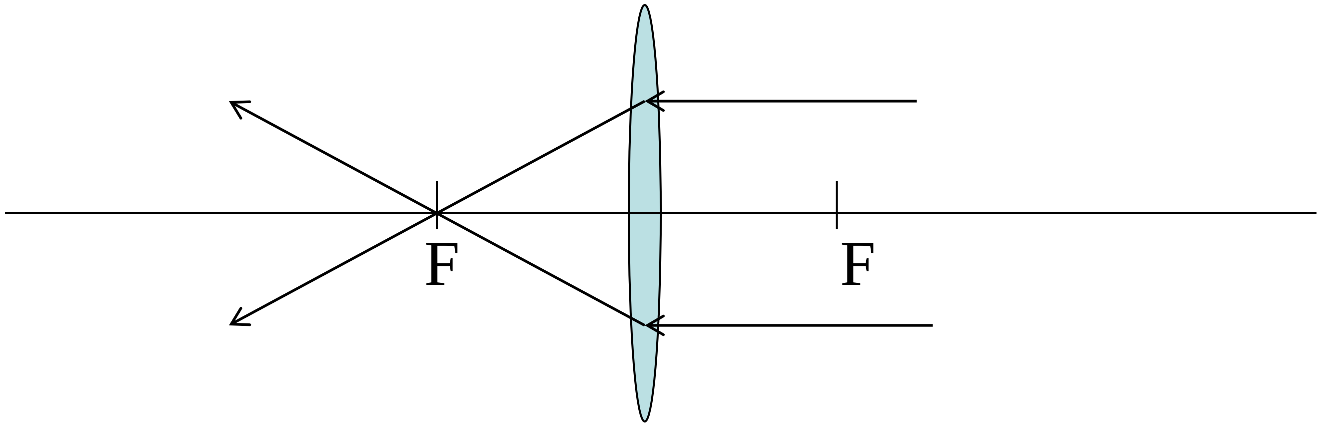
Thin converging lens and its main features

5. Focal plane

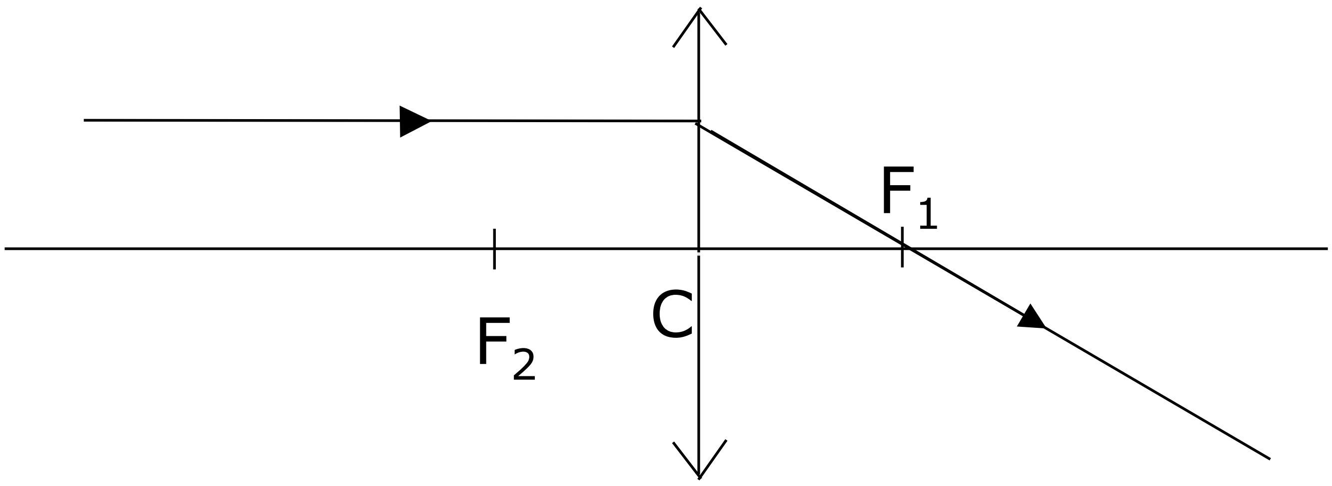


Thin converging lens and its main features

- Light may pass through a lens in either direction (from left or right). Therefore, a lens has 2 focal points at equal distance from optical center, one on each side.

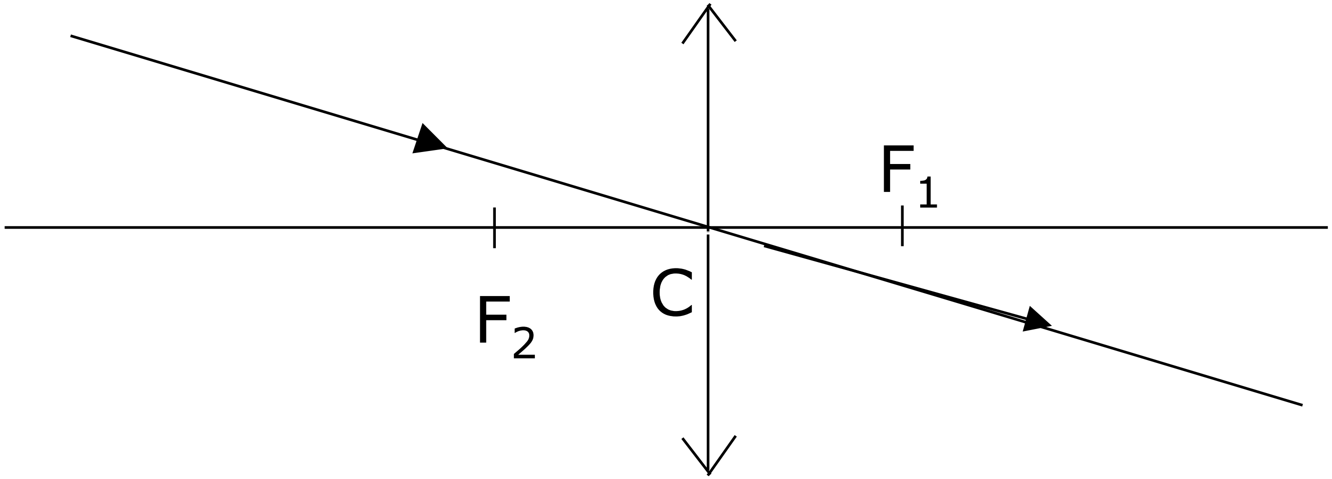


Tracing path of light through a thin converging lens



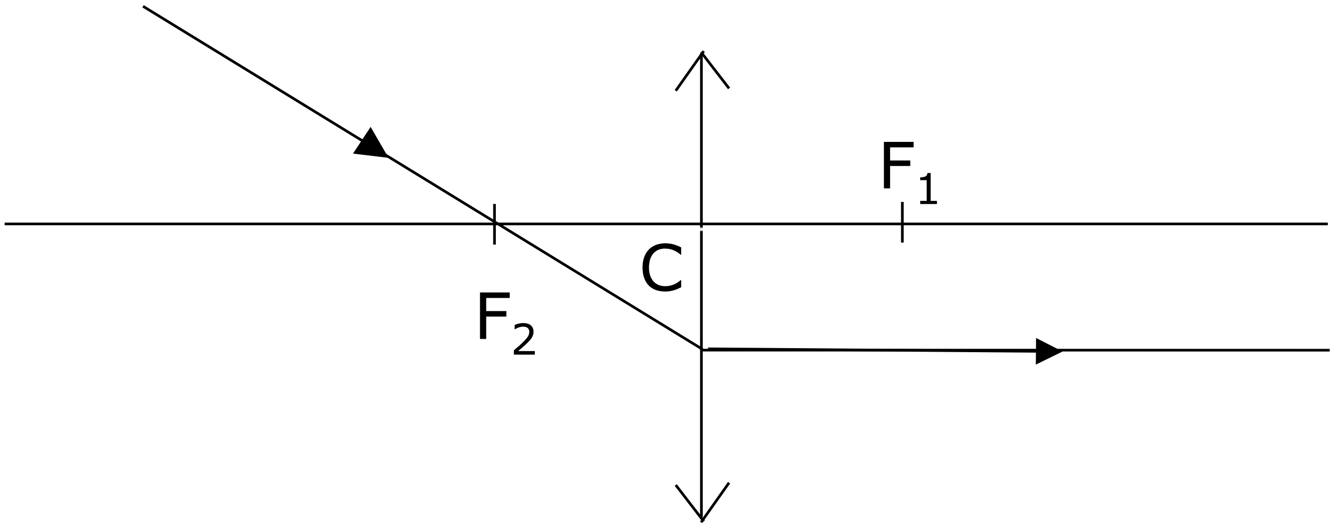
the incident ray parallel to the principal axis passes through the focal point, F_1

Tracing path of light through a thin converging lens



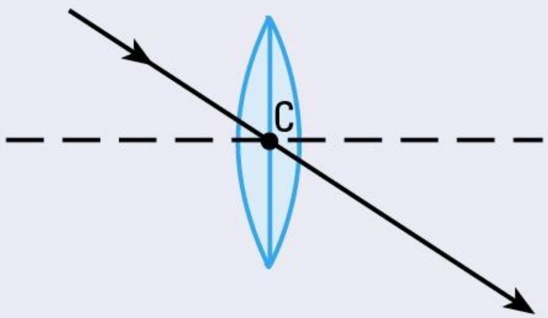
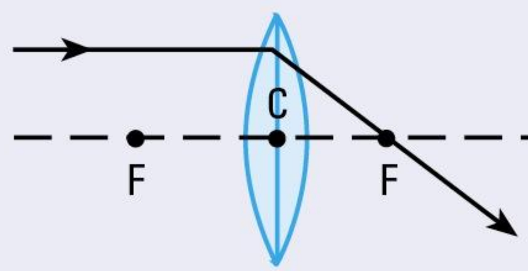
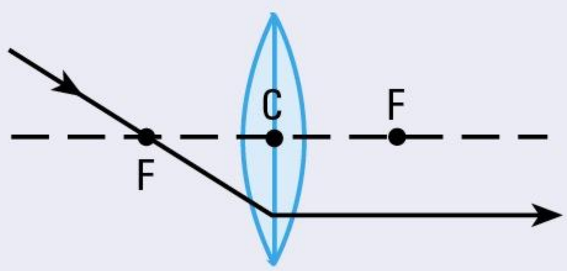
the incident ray which passes through the optical centre, C, is not deviated

Tracing path of light through a thin converging lens



the incident ray passing through F_2 becomes parallel to the principal axis

Tracing path of light through a thin converging lens

Path 1: Ray passing through the optical centre C	Path 2: Ray parallel to the principal axis	Path 3: Ray passing through the focal point F
		
An incident ray through the optical centre C passes without bending.	An incident ray parallel to the principal axis is refracted to pass through F.	An incident ray passing through the focal point F is refracted parallel to the principal axis after passing through the lens.

*You can see Path 2 and Path 3 are the reverse of each other.

Ray Diagram for Lenses

How to locate the position of an image?

3 steps to locate the image:

Step 1: Set up the lens and the ray diagram.

Step 2: Placing the object.

Step 3: Trace the light rays using paths 1, 2 or 3

http://www3.moe.edu.sg/edsoftware/ir/files/physics-thin-converging-lens/index.htm

Ray Diagram for Lenses

How to locate the position of an image?

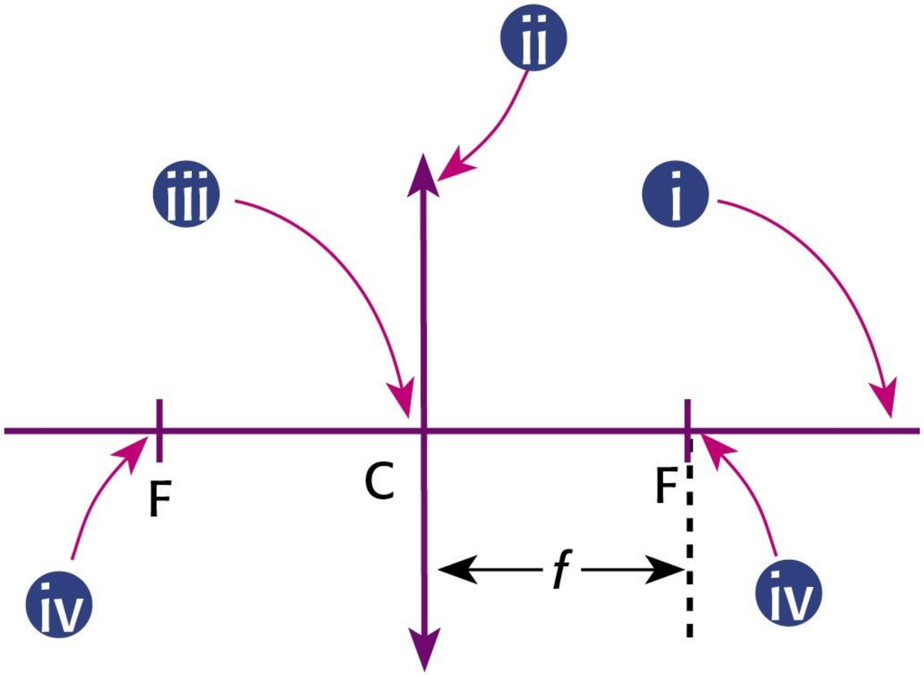
Step 1: Set up the lens and the ray diagram

i. Draw principal axis

ii. Draw the lens

iii. Mark optical centre C

iv. Mark the focal point F

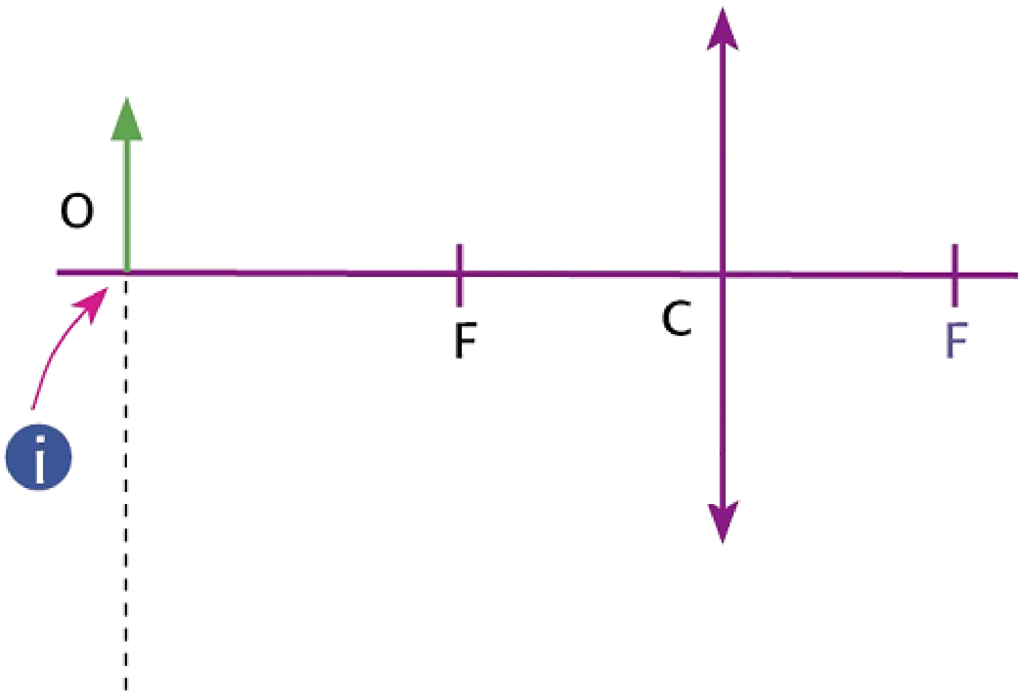


Ray Diagram for Lenses

How to locate the position of an image?

Step 2: Placing the object.

i. Place the object O to the left of the lens according to the given object distance.



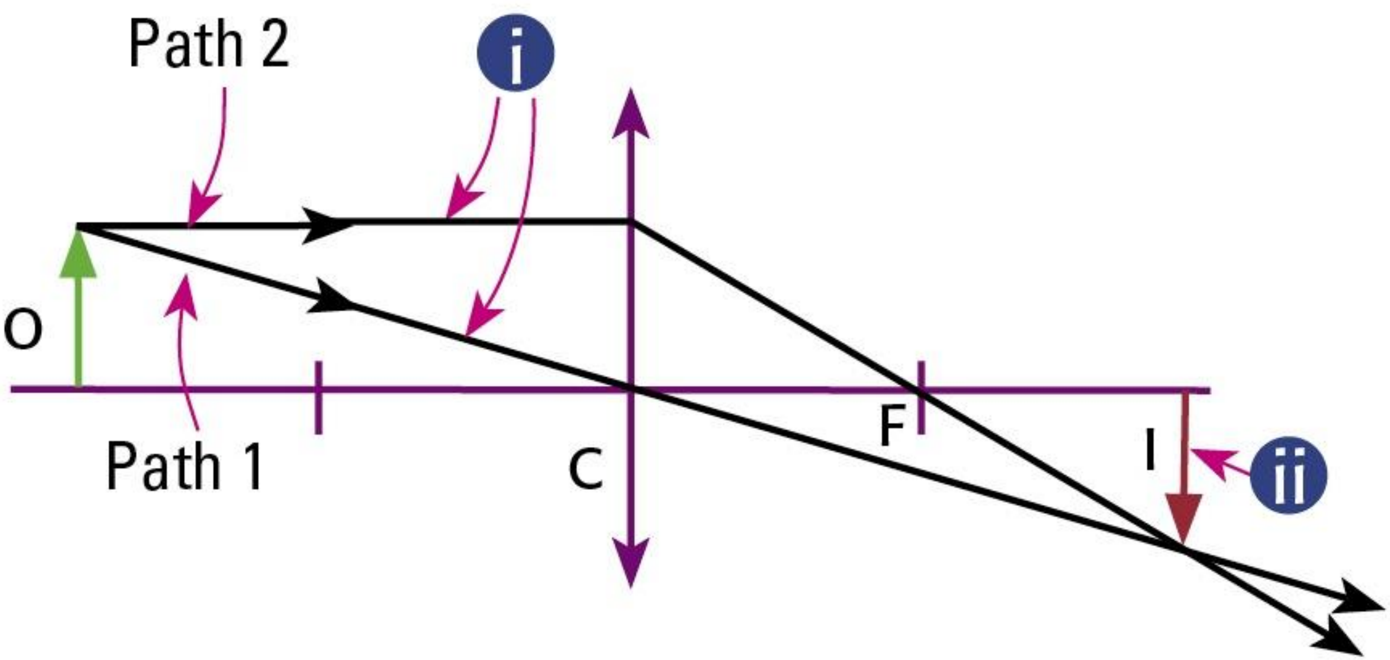
Ray Diagram for Lenses

How to locate the position of an image?

Step 3: Trace the light rays and draw the image.

i. Draw 2 of the 3 definite paths eg. Path 1 and 2.

ii. The point where the two light paths intersect is the position of the image.

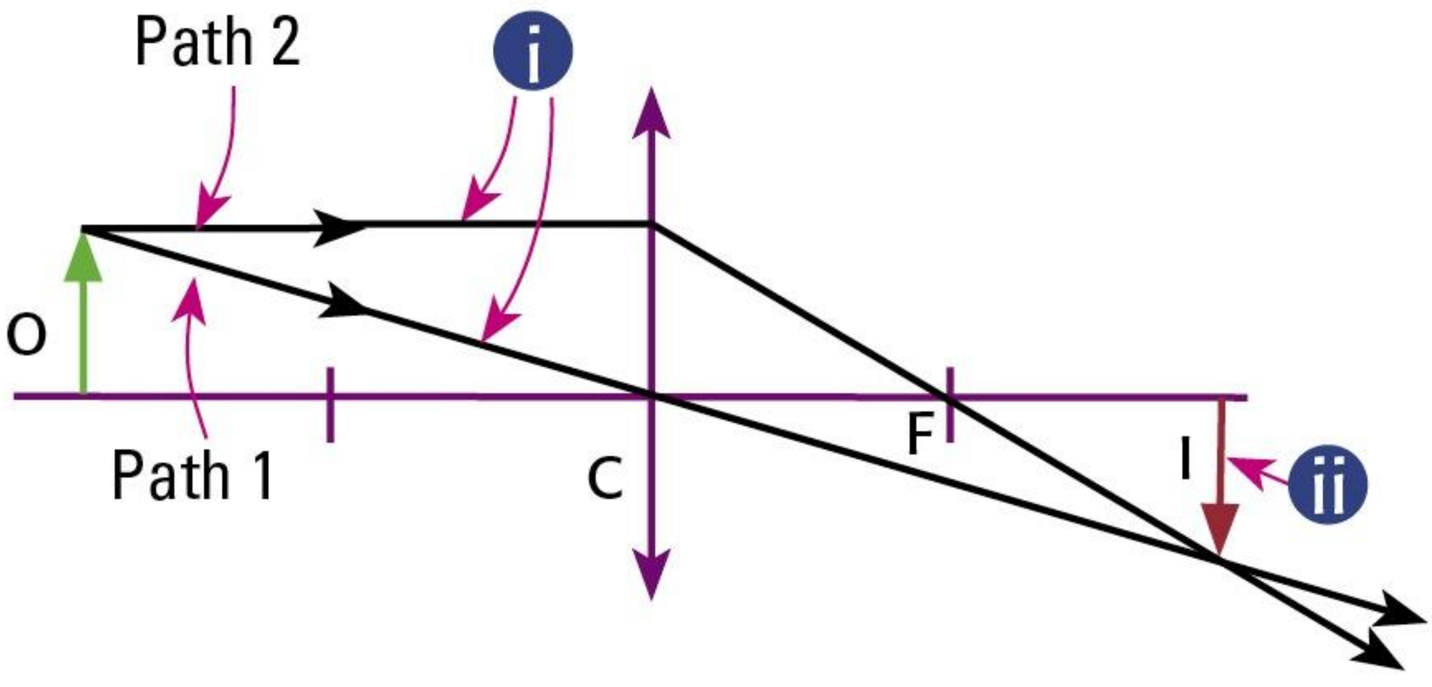


Ray Diagram for Lenses

How to locate the position of an image?

In this example, the image is said to be a **real image**.

A real image is formed when the light rays converge at the point of the image. If a screen is place at this position, the image will be captured clearly on screen.



What is the difference between: Real and Virtual Image?

Real Image: It is an image which can be captured by a screen.

i.e. we are able to see an image casted by the original object if a screen (or paper) is placed at a desired location.

Virtual Image: It is an image which **cannot** be captured by a screen.

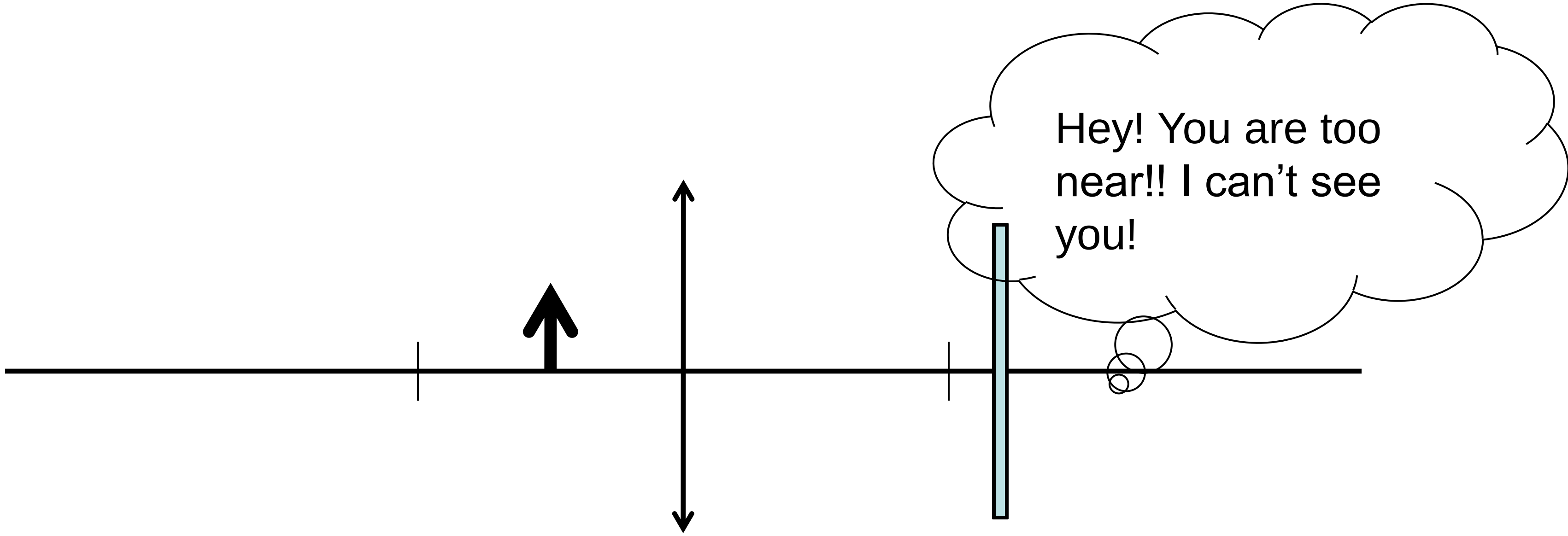
i.e. no matter where we place the screen now on earth, this image cannot be formed on that screen. It can only be seen using our own eyes.

Convex Lens can produce real and virtual images

- Convex lenses can produce both real and virtual images.
- We can determine whether the object is real or virtual by observing the **distance between the object and the lens**.
- If the distance > focal length = Real
- If the distance < focal length = Virtual.

Convex Lens can produce real and virtual images

- To remember this well, we just have to know that the object cannot be too near the lens; it will not be formed on a screen.

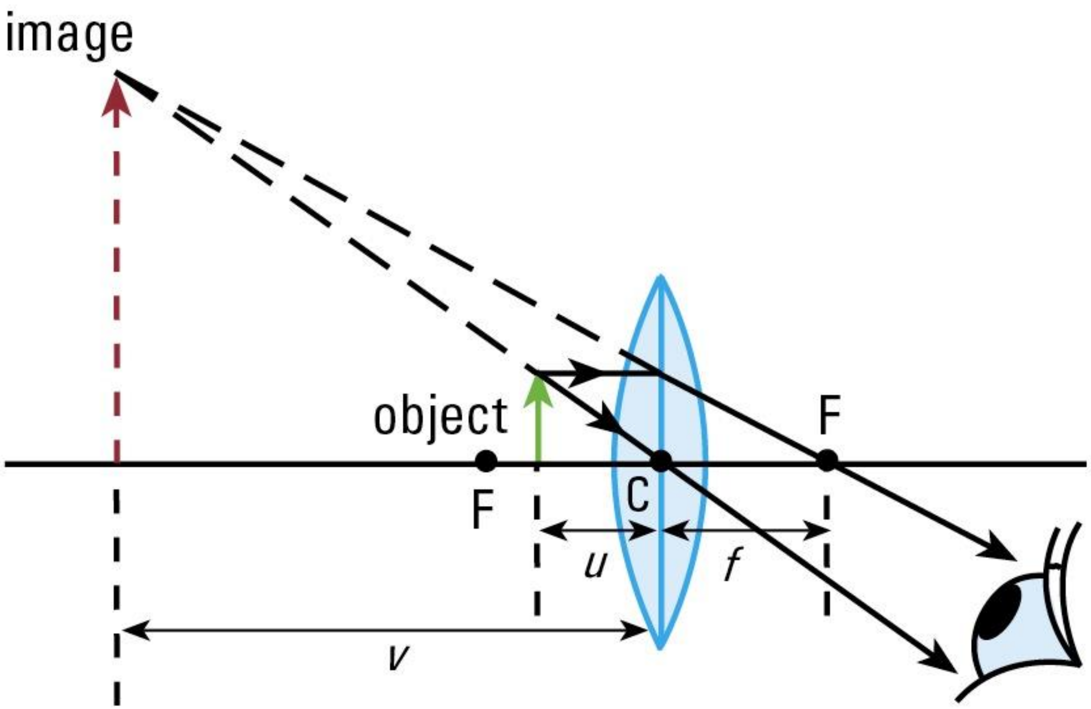


Ray Diagram for Lenses

Virtual image formed by a converging lens

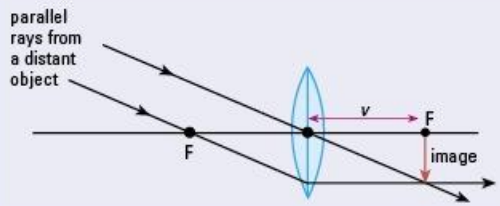
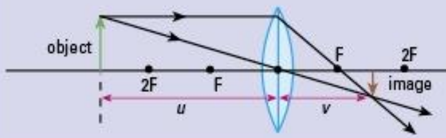
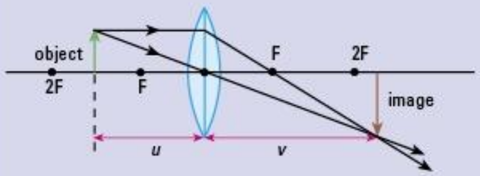
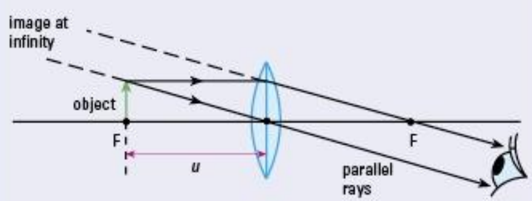
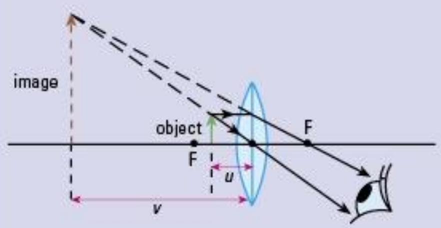
When the object O is placed near to the lens such that the object distance u is less that the focal length f, then a virtual image is formed.

A **virtual image** cannot be captured on screen.



Virtual image is formed when $u < f$

Types of images formed by a converging lens with different values of object distances u.

Object distance (u)	Ray diagram	Type of image	Image distance (v)	Uses
$u = \infty$		- inverted - real - diminished	$v = f$ - opposite side of the lens	- object lens of a telescope
$u > 2f$		- inverted - real - diminished	$f < v < 2f$ - opposite side of the lens	- camera - eye
$u = 2f$		- inverted - real - same size	$v = 2f$ - opposite side of the lens	- photocopier making same-sized copy
$f < u < 2f$		- inverted - real - magnified	$v > 2f$ - opposite side of the lens	- projector - photograph enlarger
$u = f$		- upright - virtual - magnified	- image at infinity - same side of the lens	- to produce a parallel beam of light, e.g. a spotlight
$u < f$		- upright - virtual - magnified	- image is behind the object - same side of the lens	- magnifying glass

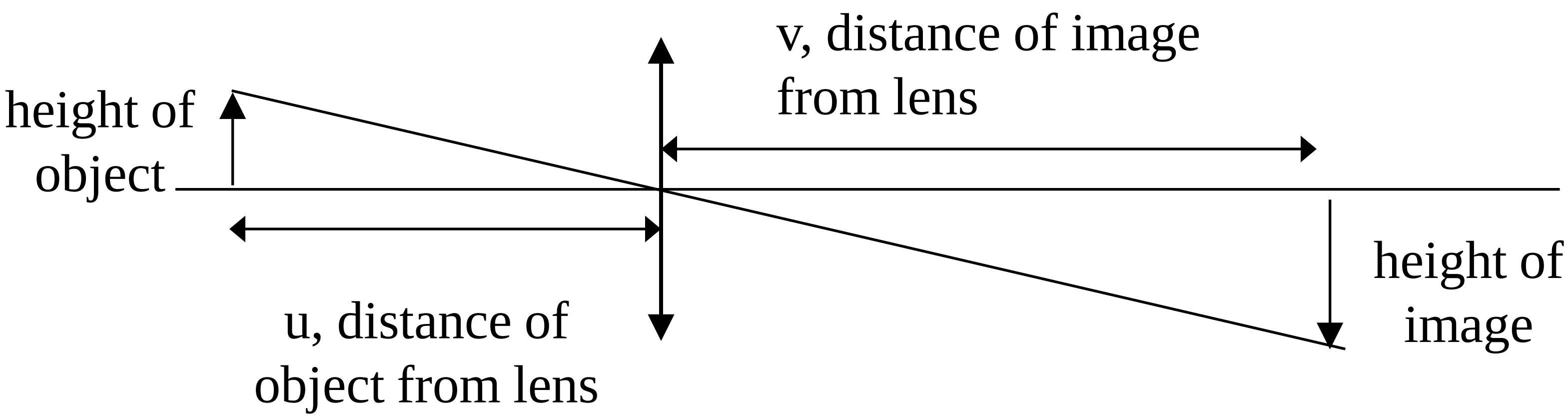
Linear Magnification

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

$$m = \frac{\text{height of image}}{\text{height of object}}$$

Linear Magnification

By the method of similar triangles,



$$m = \frac{\text{distance of image from lens}}{\text{distance of object from lens}} = \frac{v}{u}$$

Use of Converging Lens

When the object is placed such that $u < f$, image is magnified, virtual and upright.

Magnifying glass

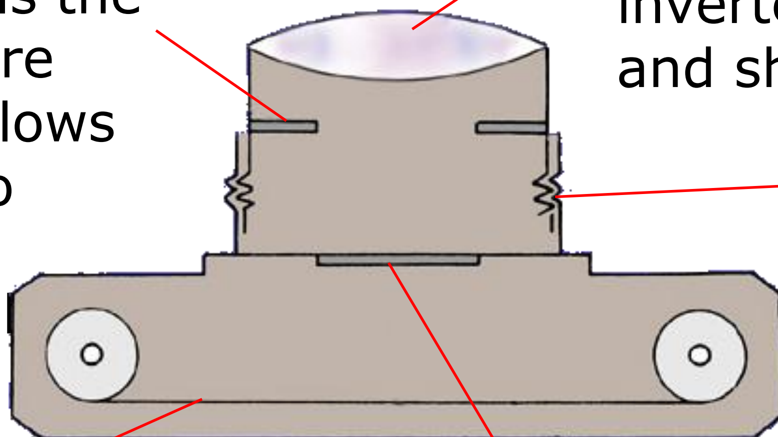
Use of Converging Lens

variable aperture diaphragm

controls the aperture that allows light to pass throug

converging lens

converge light from objects into a real, inverted, diminished and sharp image



focussing ring

moves the lens to and fro

light sensitive film

captures the image

shutter

controls the length of time that the film is exposed to light

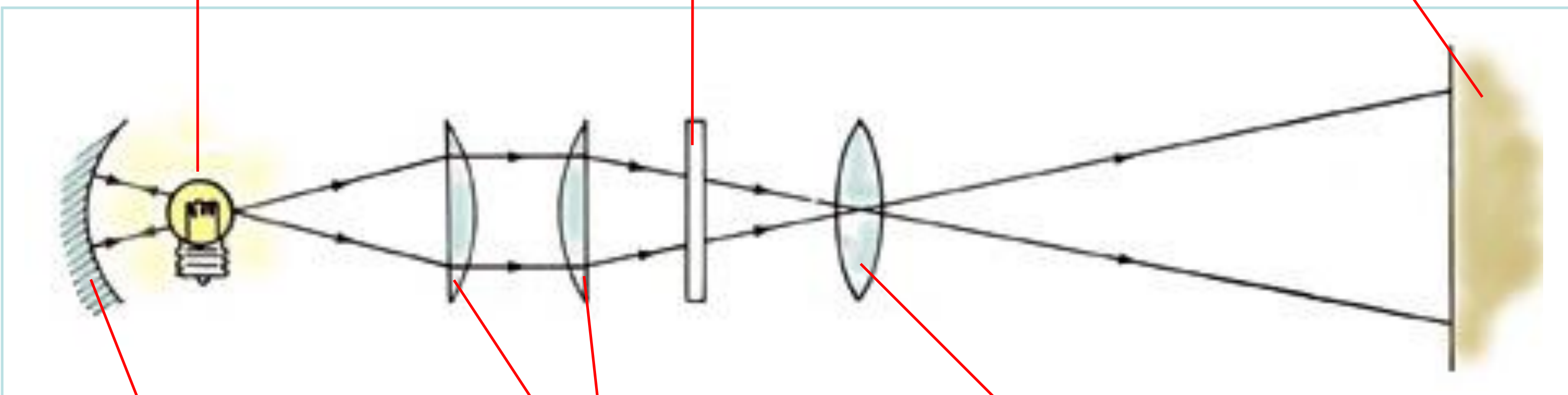
simple camera

Use of Converging Lens

lamp

slide
put upside down and turned left to right

screen
image formed is inverted laterally and vertically



concave mirror
reflects light from a quartz iodine lamp back onto a pair of condenser lenses

condenser lenses
direct the light through the slide to a projection lens

projection lens
moves to and fro until a sharp magnified image is focused on the screen

slide projector

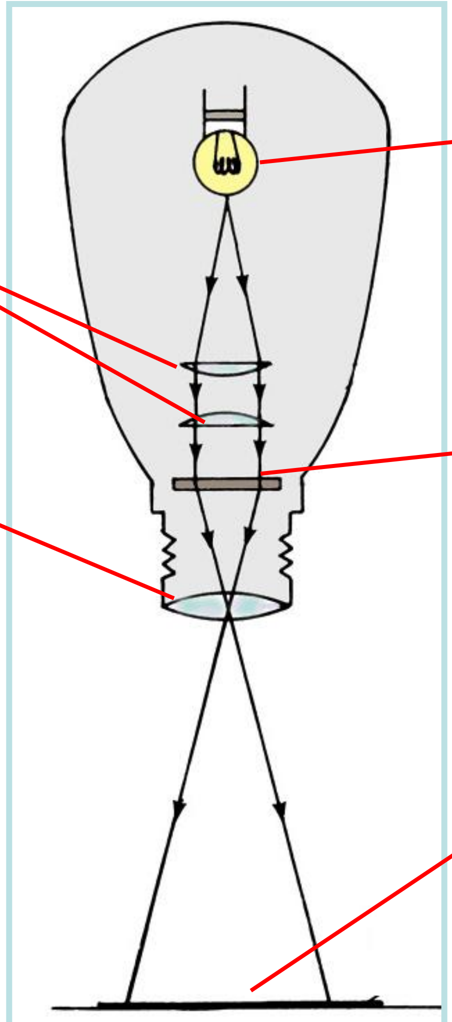
Use of Converging Lens

condenser lenses

direct the light through the slide to a projection lens

projection lens

moves to and fro until a sharp magnified image is focused on the screen



lamp

negative film

placed upside-down and back to front in the film holder

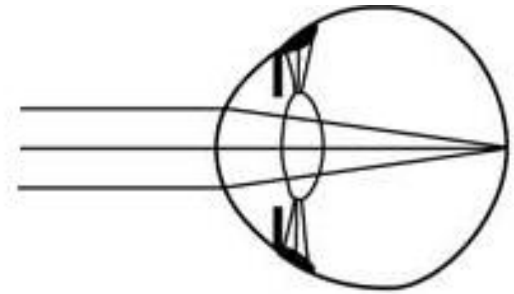
photographic paper

image formed is inverted laterally and vertically

photographical enlarger

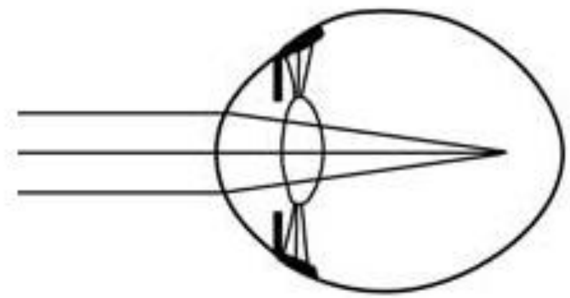
Use of Diverging Lens

- The spectacles we wear daily is made up of diverging lenses.
- When we look at images, the muscle will pull the lens and form a sharp image at the back of the eyeball called 'retina'.
- After wear and tear, some far images cannot be seen.
- We call it 'shortsightedness' because the focal length of our eyeball lenses cannot reach that far anymore because our muscles can't pull further to lengthen the focal length.
- So we use a diverging lens to lengthen the focal length of our eyeball lens to get a clearer image.

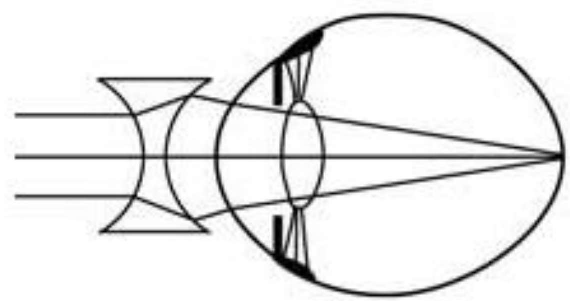


Normal eye

Myopia



Light focused in front of retina



Corrected with concave lens