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"What one man calls God, another calls the laws of physics."

-Nikola Tesla

TOPIC 12: LIGHT

THE ABOUT

CHAPTER ANALYSIS

TIME

- 3 **big** concepts
- Reflection. Refraction, Lens
- 3 **difficult** concepts
- Principle of Reversibility, Total Internal Reflection, Ray Diagrams

EXAM

- Will always be tested
- Practicing and learning to draw ray diagrams will be very important

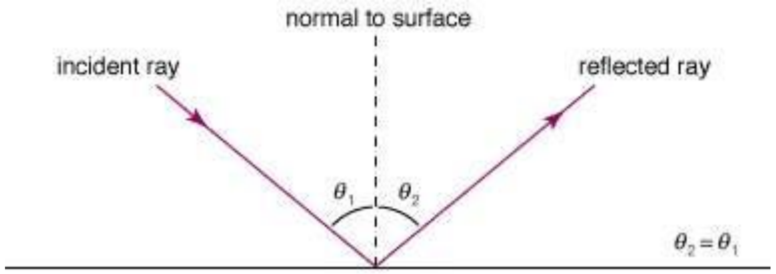
WEIGHTAGE

- Medium - Heavy overall weightage
- Constitute to around **5%** of marks for past 5 year papers

KEY CONCEPT

REFLECTION
LAW OF REFLECTION
RAY DIAGRAM & PLANE MIRROR IMAGE

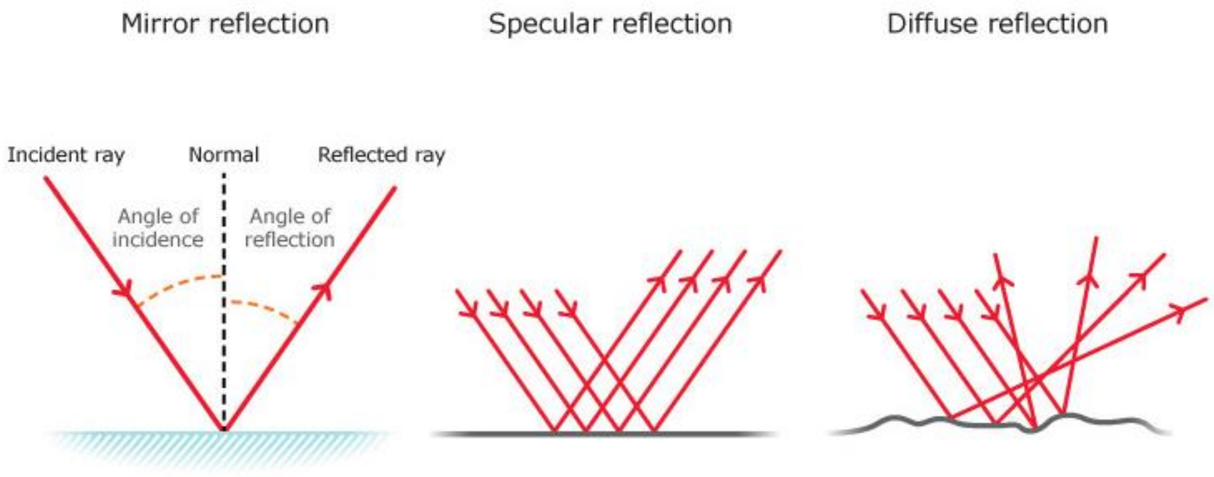
LAWS OF REFLECTION



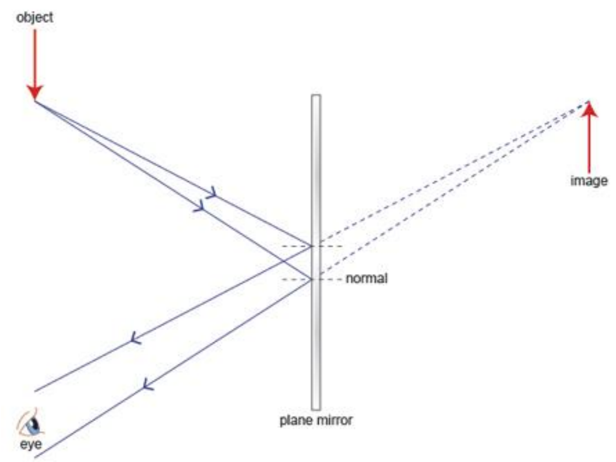
LAW OF REFLECTION

1) The incident ray, the reflected ray, and the normal at the point of incidence all lie on the same plane.

2) The angle of incidence, i, is equal to the angle of reflection, r.

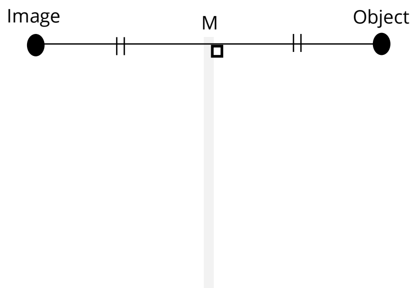


RAY DIAGRAM

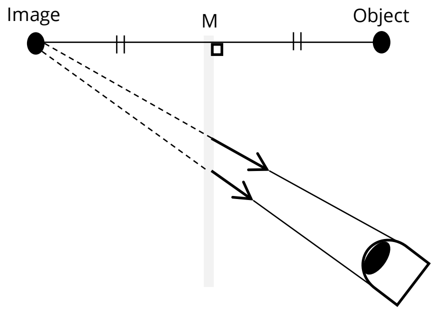


STEP BY STEP GUIDE FOR RAY DIAGRAM

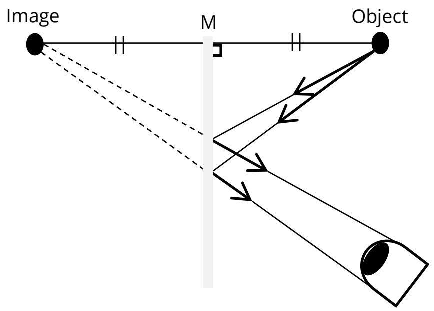
STEP 1
Locate the image. It will be the same distance from the mirror as the object's distance from mirror.



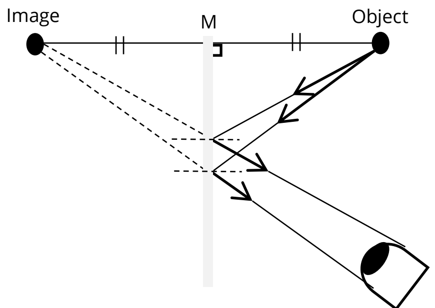
STEP 2
Draw light rays from image to the eyes. *(Dotted lines in virtual plane and solid lines in for outside mirror.)*



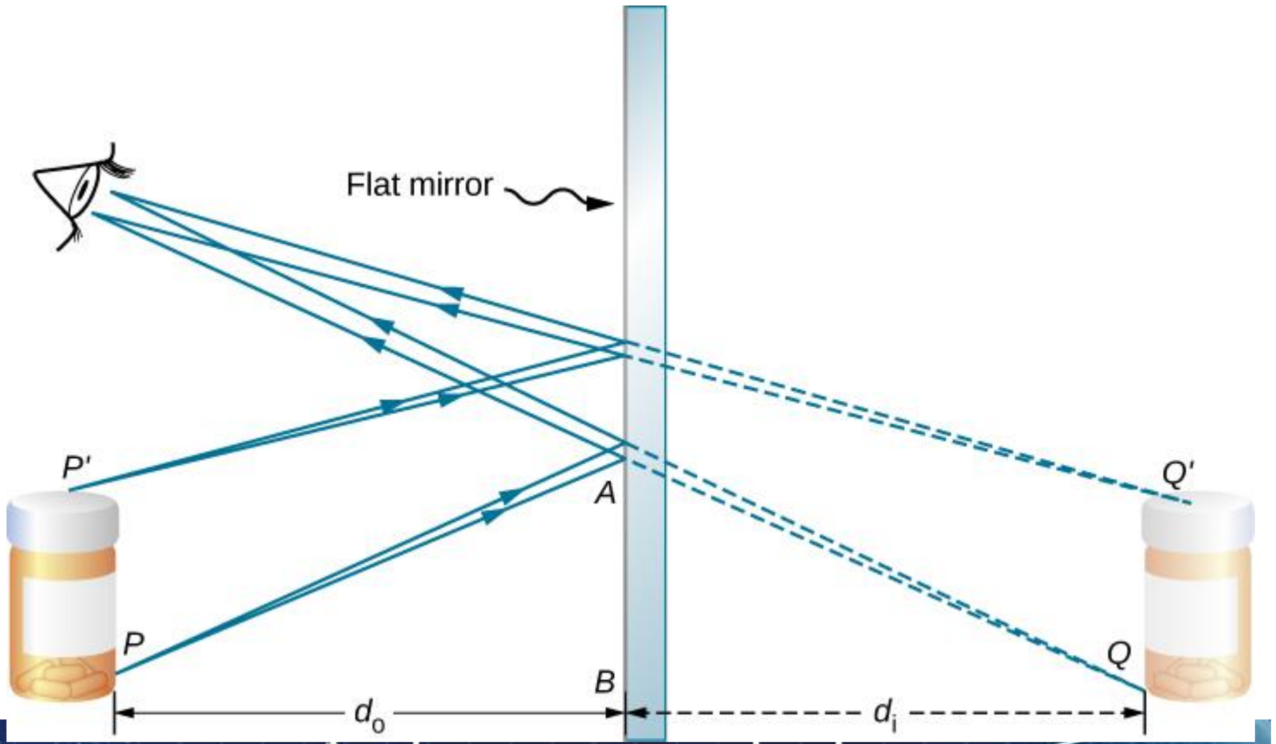
STEP 3
Draw light ray from object to mirror, meeting at the reflected rays.



STEP 4
Add in the arrows if you haven't & draw the normal at the point of reflection.



RAY DIAGRAM



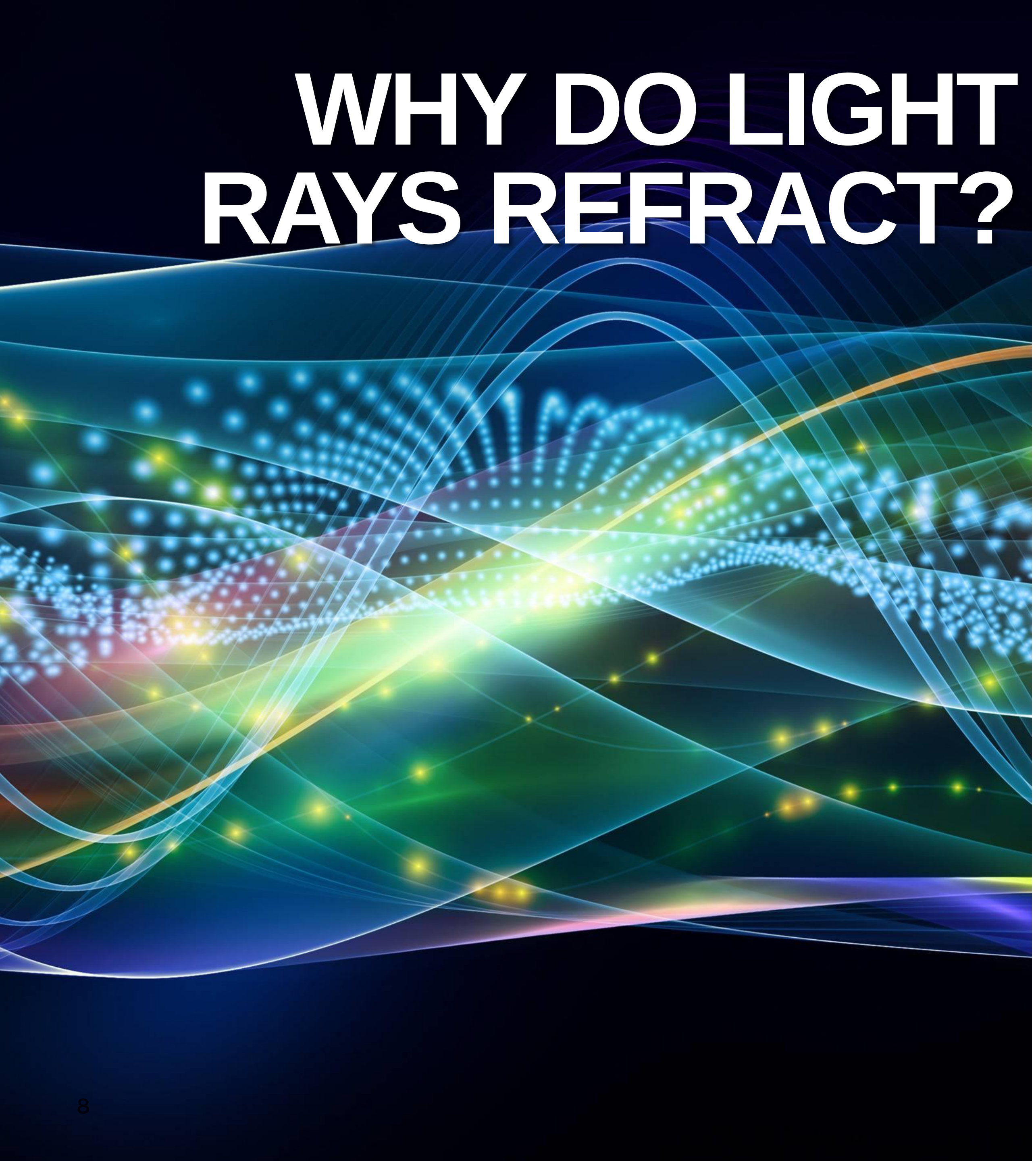
CHARACTERISTICS OF PLANE MIRROR IMAGE

Images in a plane mirror are:

- Image is **virtua**l.
- Image is **upright**.
- Image is **same size** as object.
- Image is **laterally inverted**.
- Image will be **same distance** from the mirror as the object is from the mirror.

KEY CONCEPT

REFRACTION
LAW OF REFRACTION
REFRACTIVE INDEX



WHY DO LIGHT RAYS REFRACT?

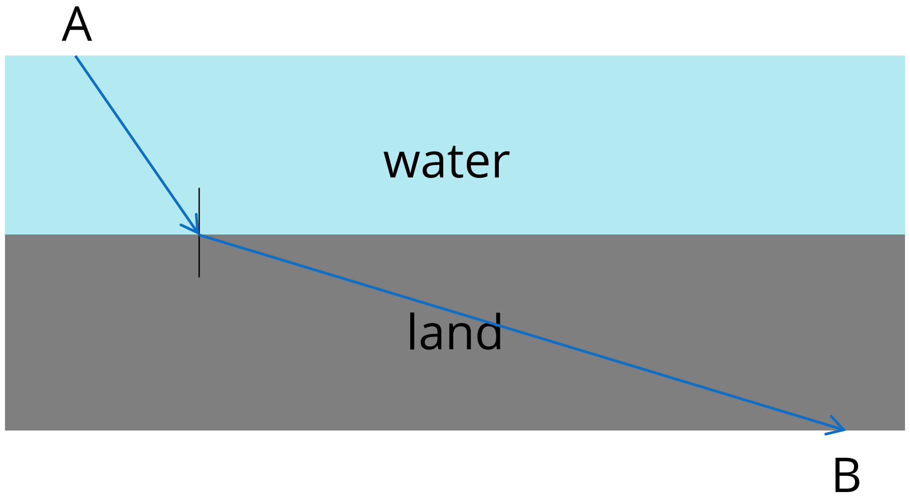
WHY DO LIGHT RAYS UNDERGO REFRACTION?

Light rays bend due to the **difference in speed of light** in different optical mediums.

IMAGINE THIS SCENARIO

You are trying to get from point A to point B. You walk faster on land than swim in water.

What path will allow you to reach point B in the shortest amount of time?



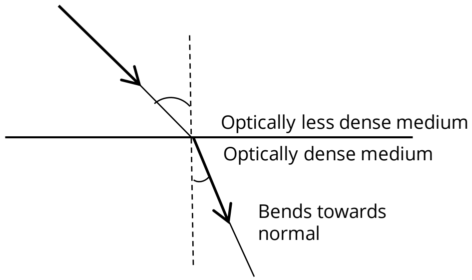
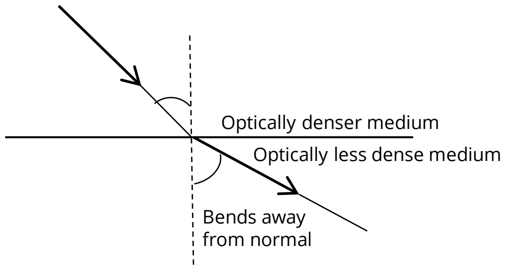
You will not just simply travel in a straight line because that means spending an equal amount of time in water and on land when you travel faster on land.

Given that you walk faster on land, you would cut short the distance you swim in water and attempt to get on land as soon as possible. You will probably travel in a path as shown above.

Light behaves in the same way, taking the fastest path.

Light rays bend due to the difference in speed of light in different mediums.

LAW OF REFRACTION

	Less dense to denser medium	Denser to less dense medium
Speed of light	Decreases	Increases
Light ray	Towards normal	Away from normal
Diagram		

*See if you are able to visualise the example from the previous page to the 2 refraction diagrams shown here. *(Strongly suggest you understand this instead of memorizing.)*

LAW OF REFRACTION

1) The incident ray, the refracted ray and the normal at the point of incidence all lie in the same plane.

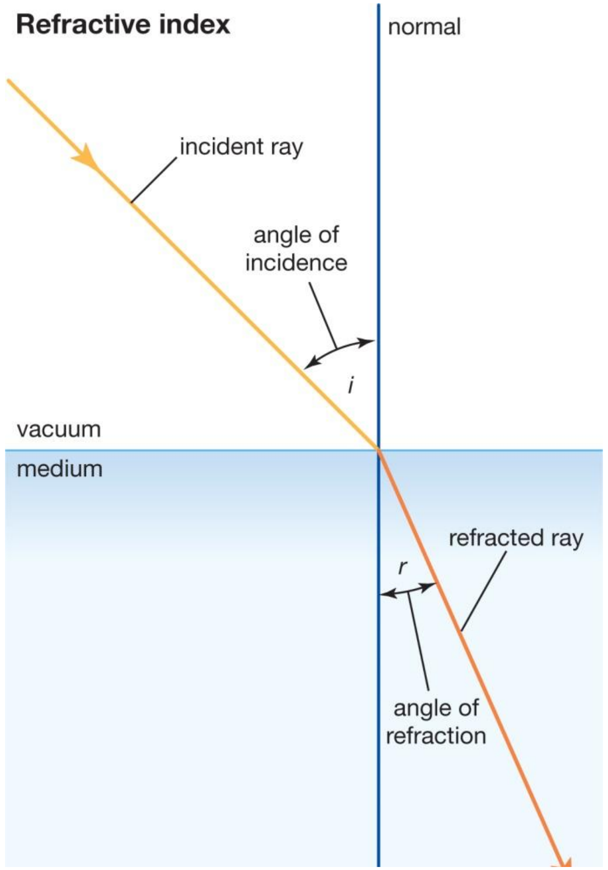
2) For light passing through any two mediums, the ratio of **sin i / sin r** is a constant (refractive index).

BENDING OF LIGHT RAYS

When light travel from a **less dense** medium to a **denser** medium, the refracted ray will **bend towards** the normal.

When light travel from a **denser** medium to a **less dense** medium, the refracted ray will **bend away** from the normal.

REFRACTIVE INDEX



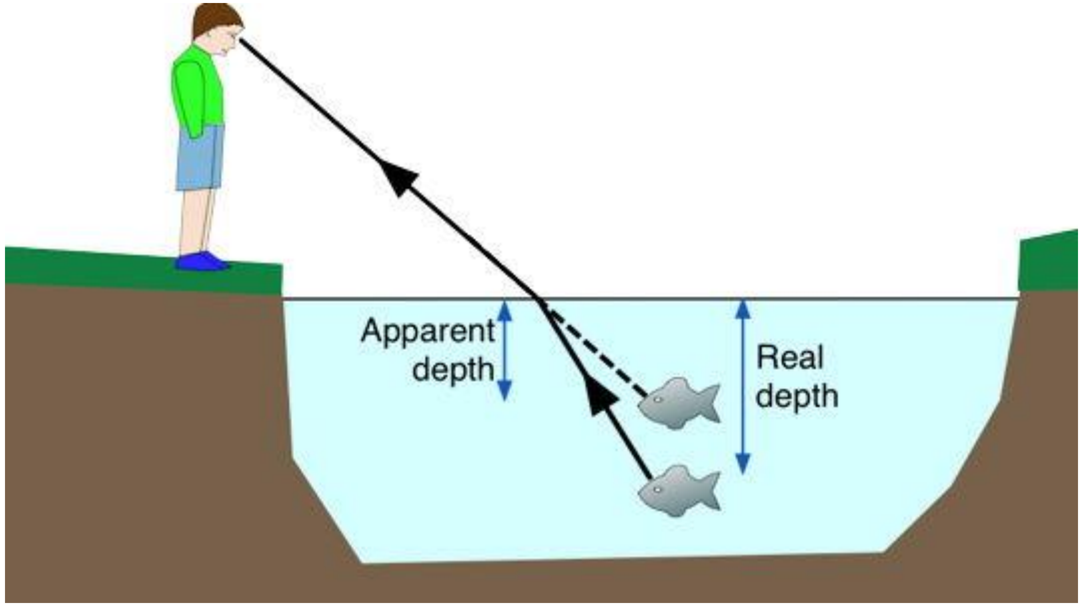
Medium	Refractive index, n
Vacuum	1.00
Air	1.003
Water	1.33
Glass	1.50
Diamond	2.42

FORMULAS FOR REFRACTIVE INDEX

n = sin i / sin r, where i is angle of incidence & r is angle of refraction.

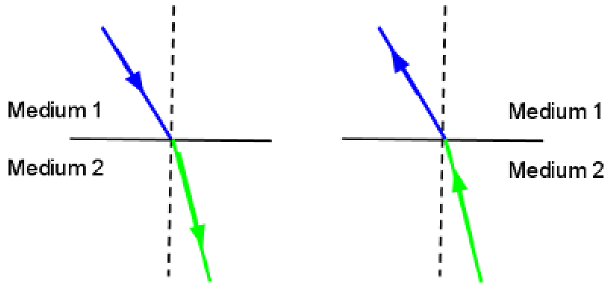
n = speed of light in vacuum* (c) / speed of light in medium (v)

*speed of light in vacuum is 3×10^8 ms^{-1}



Note that refractive index, n, should never be smaller than value 1.

PRINCIPLE OF REVERSIBILITY



Please note that this for ‘O’ Levels without using Snell’s Law (as it is not within syllabus).

PRINCIPLE OF REVERSIBILITY

The principle of reversibility states that **light will follow the same path even if its direction of travel is reversed.**

Given that,

n = sin i / sin r

But if we reverse the light’s direction,

n = sin r / sin i

(due to principle of reversibility)

The **rule of thumb** is to make sure **value of n is always bigger than 1**.

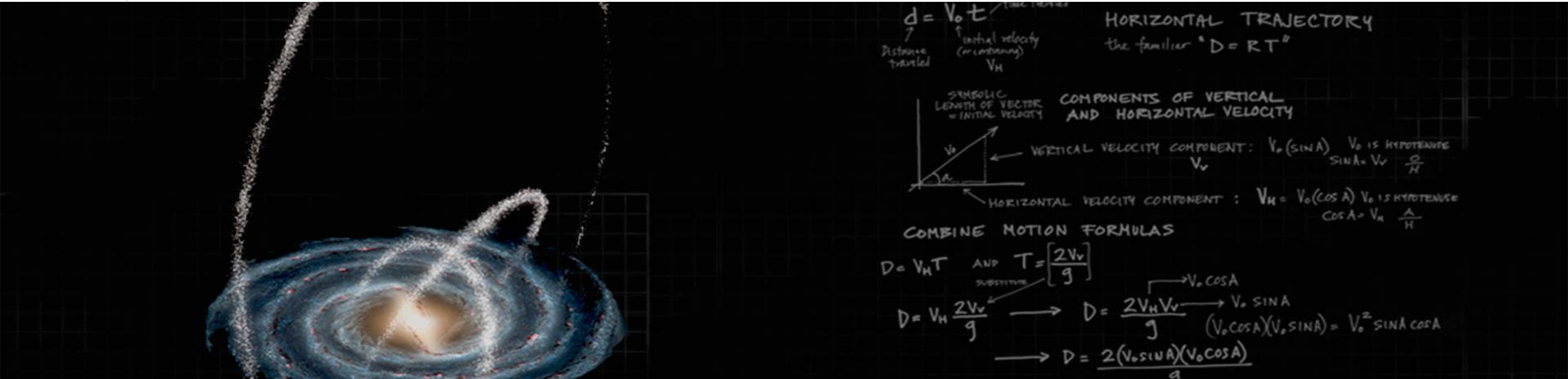
Use **n = sin r / sin i (principle of reversibility)** if the light ray is traveling from denser to less dense medium.

The best way to approach this is:

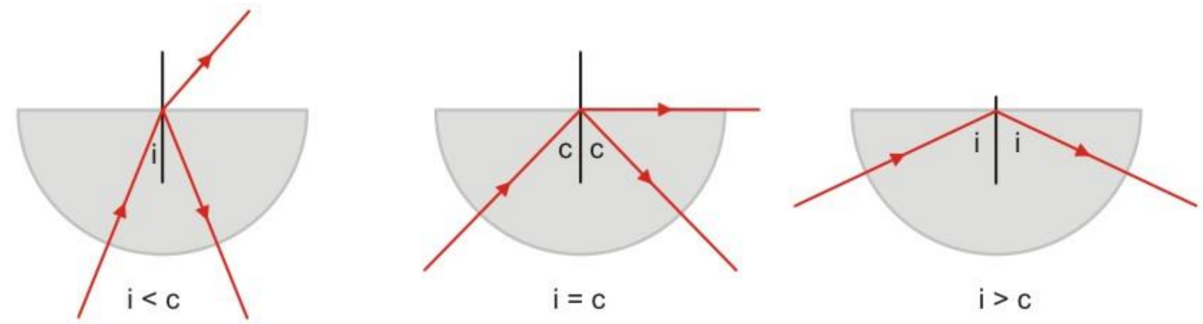
n = sin (angle in air) / sin (angle in medium)

KEY CONCEPT

TOTAL INTERNAL REFLECTION
CRITICAL ANGLE



TOTAL INTERNAL REFLECTION



Light ray is travelling from optically denser medium to optically less dense medium.

Light ray bends away from normal.

Light ray bends away from normal until it at a refraction of 90°.

This is your critical angle.

Now that the angle of incidence exceeds the critical angle, light ray bend inwards.

Total internal reflection occurs.

TOTAL INTERNAL REFLECTION

As angle of incidence increases, the angle of refraction also increases.

Total internal reflection occurs once the angle of incidence exceeds the **critical angle**, causing the light ray to not leave the optically denser medium and instead, reflect internally.

Critical angle, c, is defined as the angle of incidence in the optically denser medium for which angle of refraction in the optically less dense medium is exactly 90°.

FORMULA:

$$\sin c = 1 / n$$

where n is refractive index.

Hence the 2 conditions for total internal reflections are:

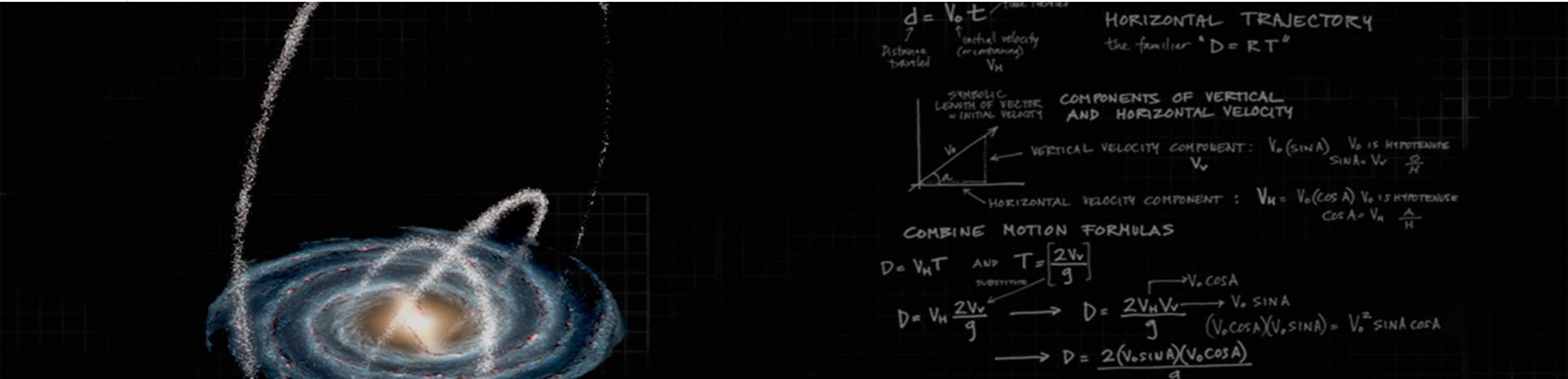
1) Light ray must be travelling from optically denser medium to an optically less dense medium (so that it bends away from the normal until it hits 90°)

2) angle of incidence must be greater than the critical angle

Applications:
- Glass Prisms
- Optic Fibre

KEY CONCEPT

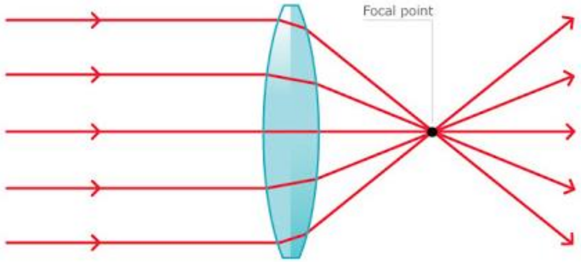
LENS
CONVERGING & DIVERGING LENS
RAY DIAGRAMS



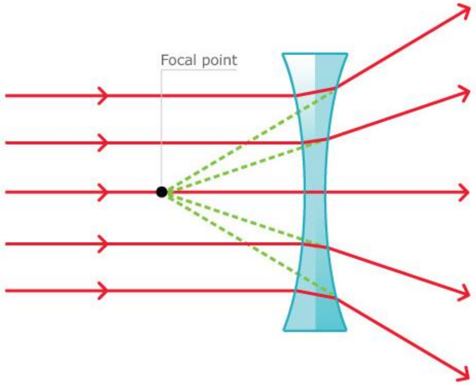
LENSES

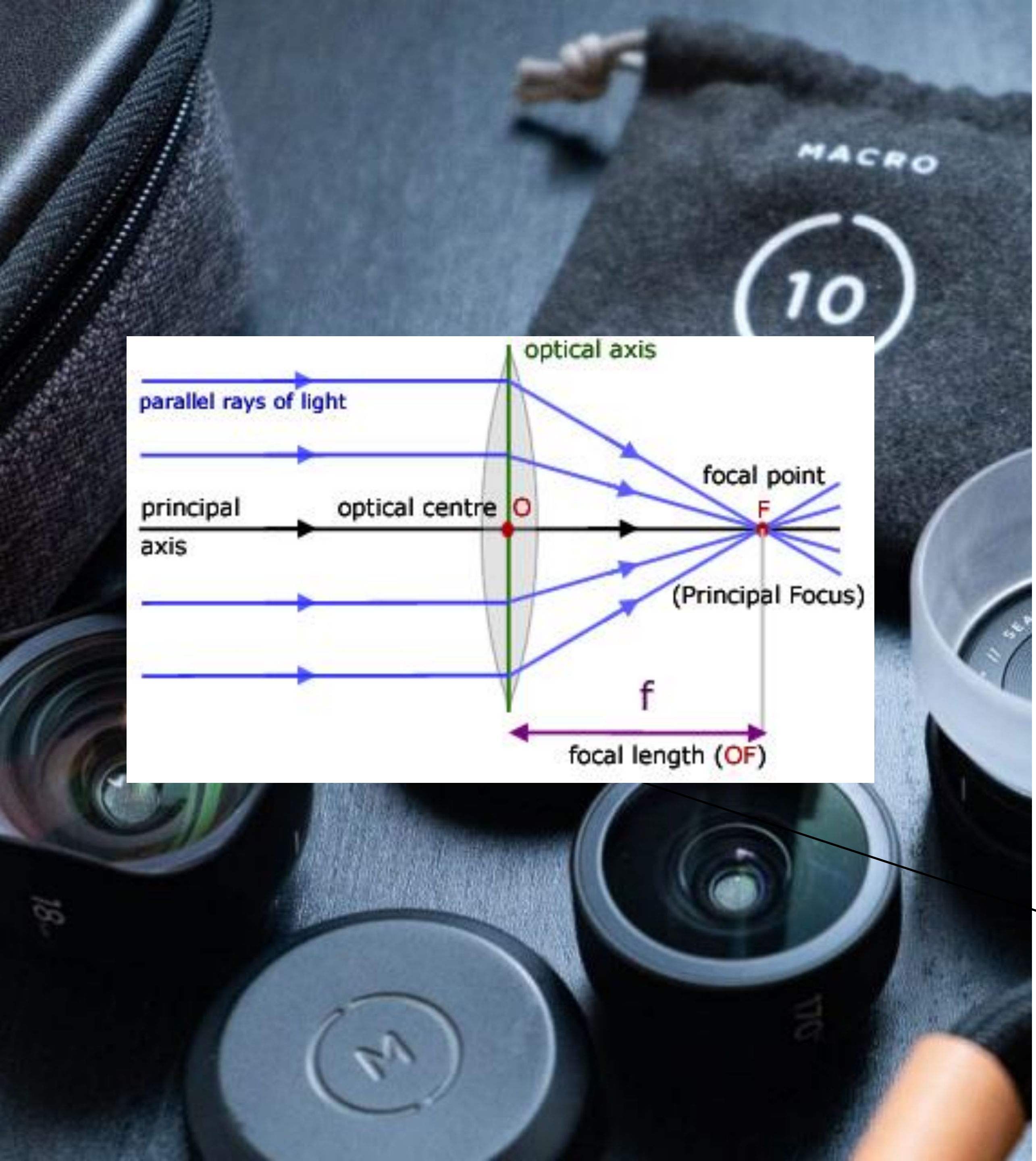
A lens is a piece of transparent glass that have a curved surface.

Converging lens:



Diverging Lens:





THIN CONVERGING LENS

Key Terminologies:

Optical Centre, C

Midway point between the lens surfaces on its principal axis - rays passing through optical centre do not deviate.

Principal Axis

Line passing through the optical centre of the lens and perpendicular to the plane of the lens.

Principal Focus, Focal point F

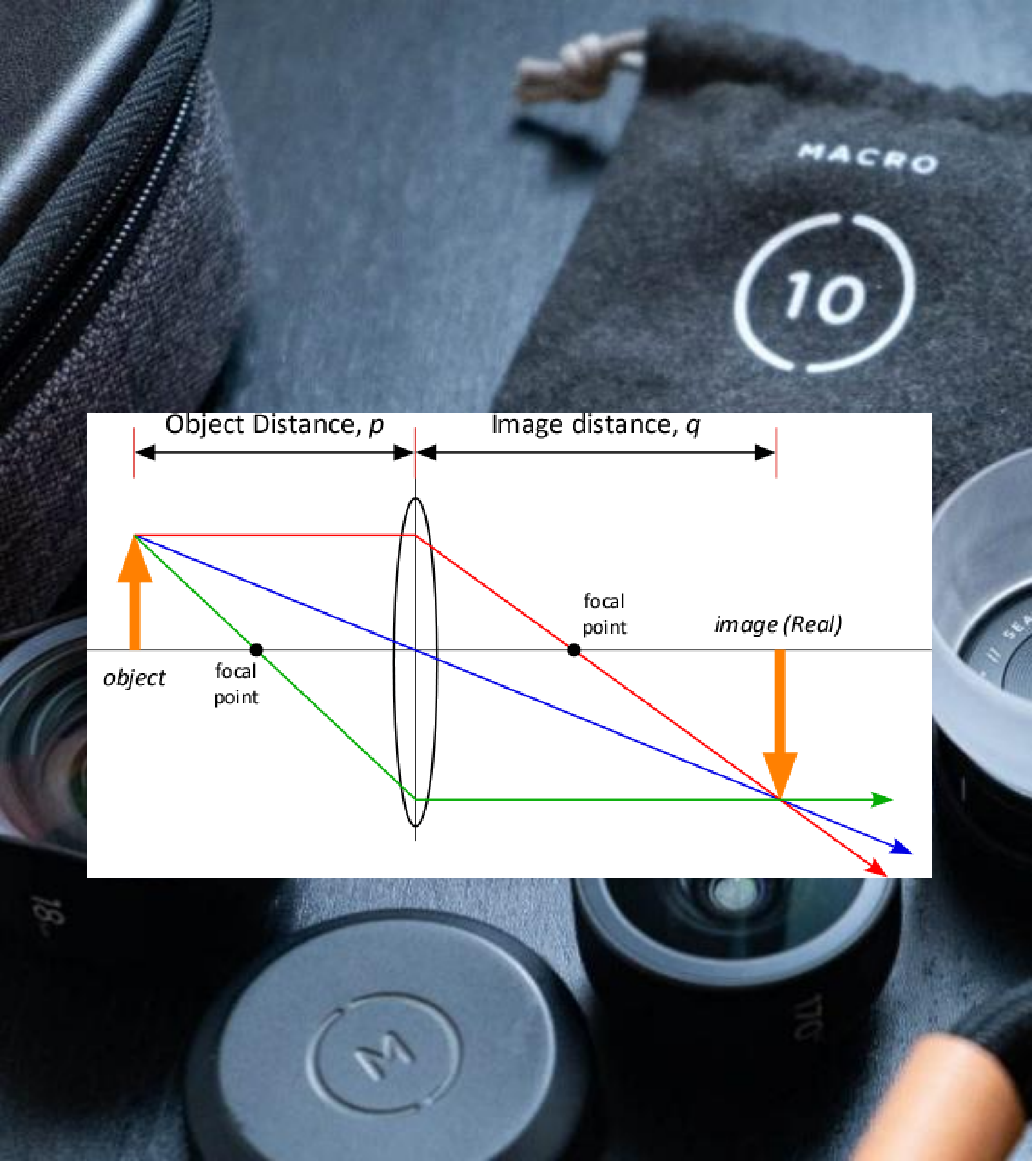
Point on the principal axis to which an incident beam parallel to the principal axis converges to.

Focal Length, f

Distance between its optical centre and principal focus

Focal Plane

Vertical plane which passes through the principal focus and is perpendicular to the principal axis.



THIN CONVERGING LENS

How to locate image using ray diagrams

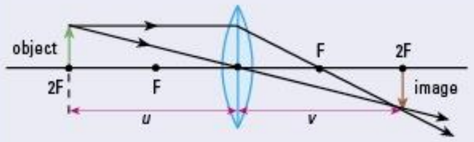
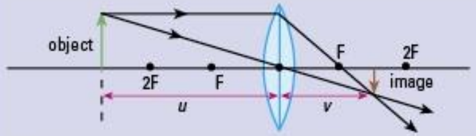
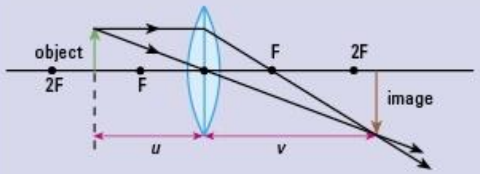
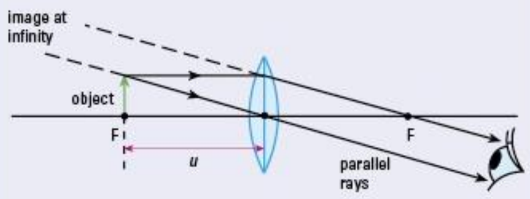
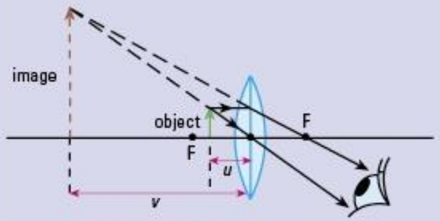
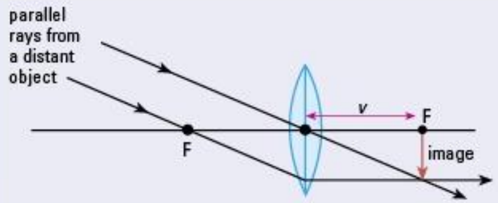
The spot where **2 light rays intersect** is where the image will be formed.

You will only need **2 out of 3 light rays** to locate the image.

Ray 1:
Travel parallel to principal axis → hits the lens → cuts through focal point, F

Ray 2:
Straight line that cuts through optical centre, C

Ray 3:
Passes through principal focus F → hit the lens → travel parallel to principle axis

Object distance (u)	Ray diagram	Type of image	Image distance (v)	Uses
$u = 2f$		- inverted - real - same size	$v = 2f$ - opposite side of the lens	- photocopier making same-sized copy
$u > 2f$		- inverted - real - diminished	$f < v < 2f$ - opposite side of the lens	- camera - eye
$f < u < 2f$		- 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
$u = \infty$		- inverted - real - diminished	$v = f$ - opposite side of the lens	- object lens of a telescope

THIN CONVERGING LENS

TIPS:

The easiest diagram to start with is when ***u* =2*f*.**

→ **The object is at the perfect distance from the lens to produce a same size image.**

If you shift the object further to the left, you will get ***u* > 2*f*.**

→ **Notice how the entire ray diagram has shifted to the left. The image is now formed closer to the lens and is diminished.**

If we shift the object to the right instead, we get ***f* < *u* < 2*f*.**

→ **Notice how the entire ray diagram has shifted to the right. The image formed is now further from the lens and magnified.**

If we shift the object even more to the right, we get ***u* = *f*.**

→ **Notice how the entire ray diagram has shifted even further to the right. This forces the light rays to open up so much until Ray 1 & Ray 2 are parallel. Image is at infinity because the light rays will never converge.**

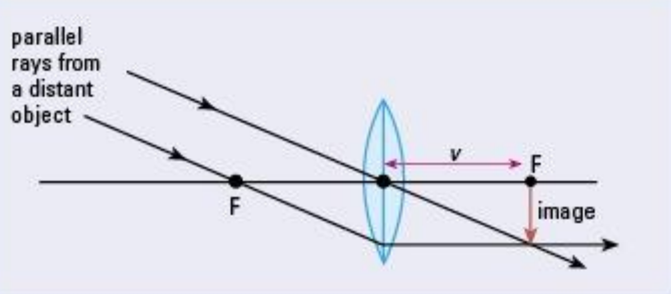
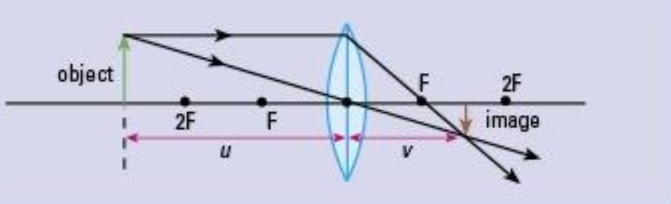
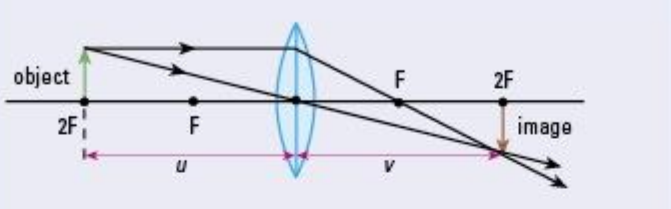
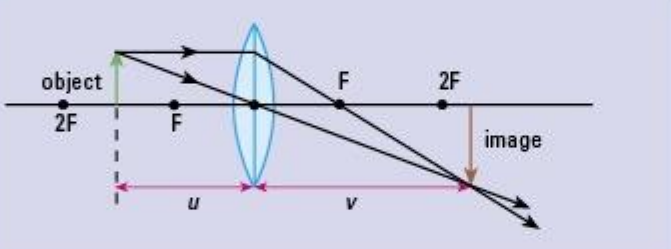
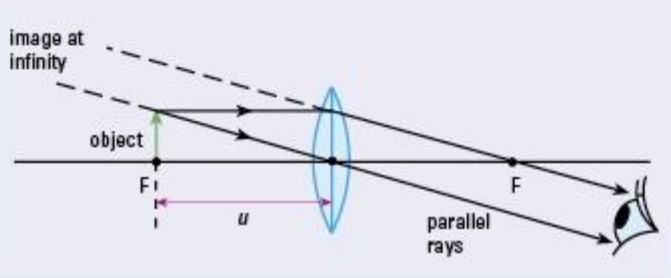
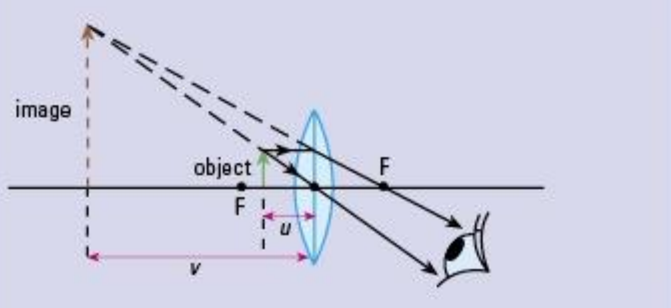
If we shift the object right next to the lens, we get ***u* < *f*.**

→ **The object is so close to the lens, image formed is behind the object are we have to trace the rays backwards to locate the image.**

If the image is far away and enters the lens as parallel rays, u = ∞.

→ **Parallel rays easily converges at focal point F to form an image.**

*I've rearrange the sequence of the ray diagrams, original textbook version is on the next page!

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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