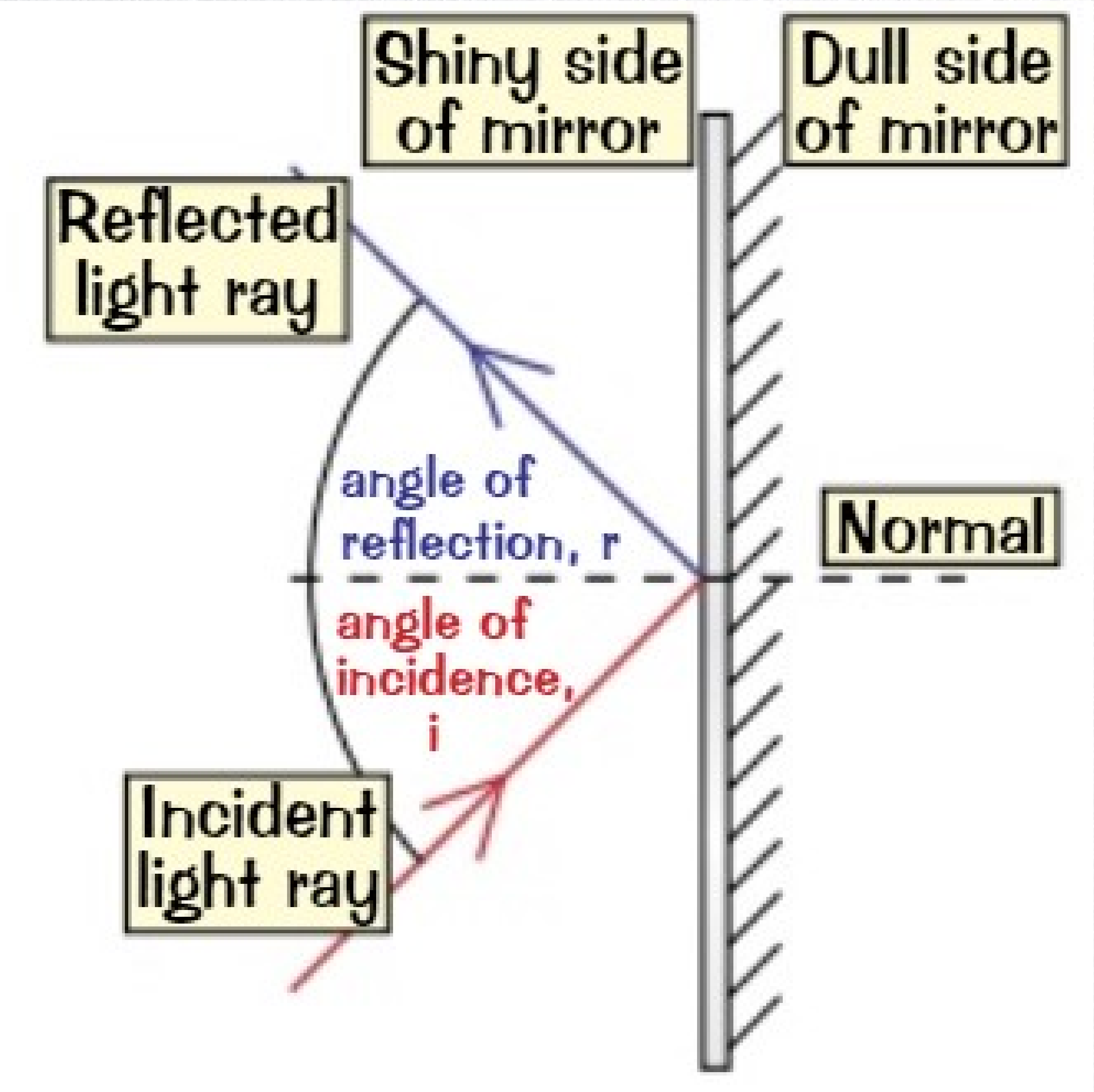
Light

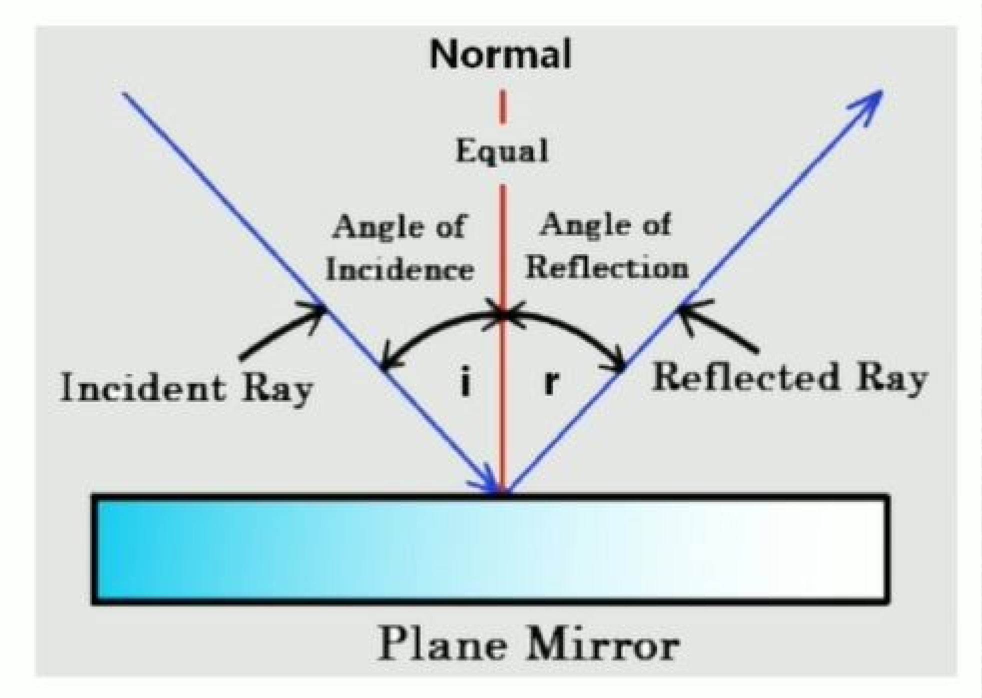
1. **Reflection of light**
2. Refraction of light
3. Thin lenses
4. Dispersion of light

Reflection



Shiny side of mirror
Dull side of mirror
Reflected light ray
angle of reflection, r
Normal
angle of incidence, i
Incident light ray

Reflection



A ray diagram is a diagram that traces the path that light takes in order for a person to view a point on the image of an object.

Reflection of light:

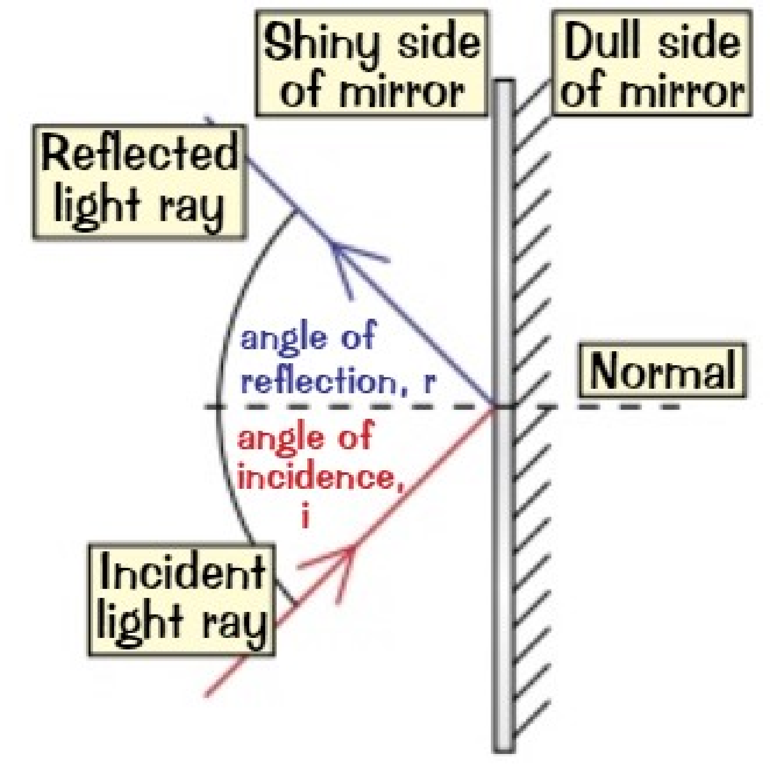
- **Incident ray**, **reflected ray**, and the **normal** are all on the same plane
- Angles of incidence and reflection are measured in relation to the normal

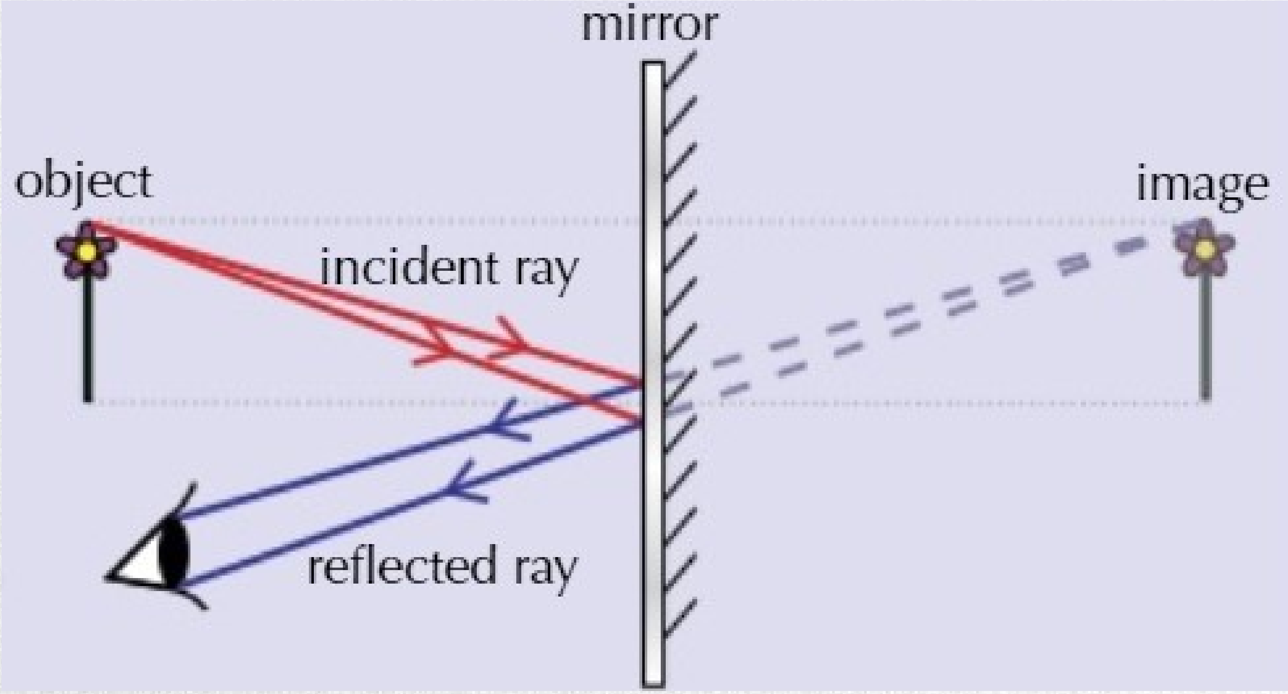
The law of reflection:

$$\text{Angle of incidence} = \text{Angle of reflection}$$

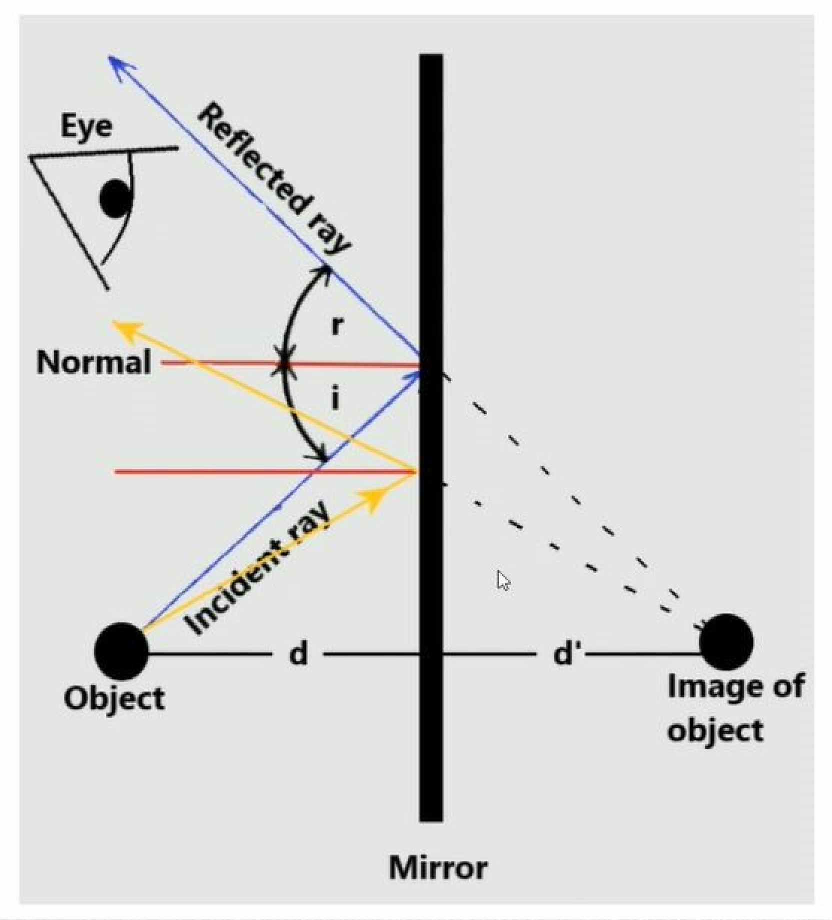
Reflection

Mirror reflection





Reflection



Mirror reflection:

- Mirrors reflect light coming from objects which then enter our eyes
- Ray diagrams can demonstrate how an image of an object is formed inside the mirror:
  - Trace 2 incident rays from object
  - Trace the reflected rays
  - Trace back the rays into the mirror
  - The point of intersection between two rays behind the mirror is where the image formed

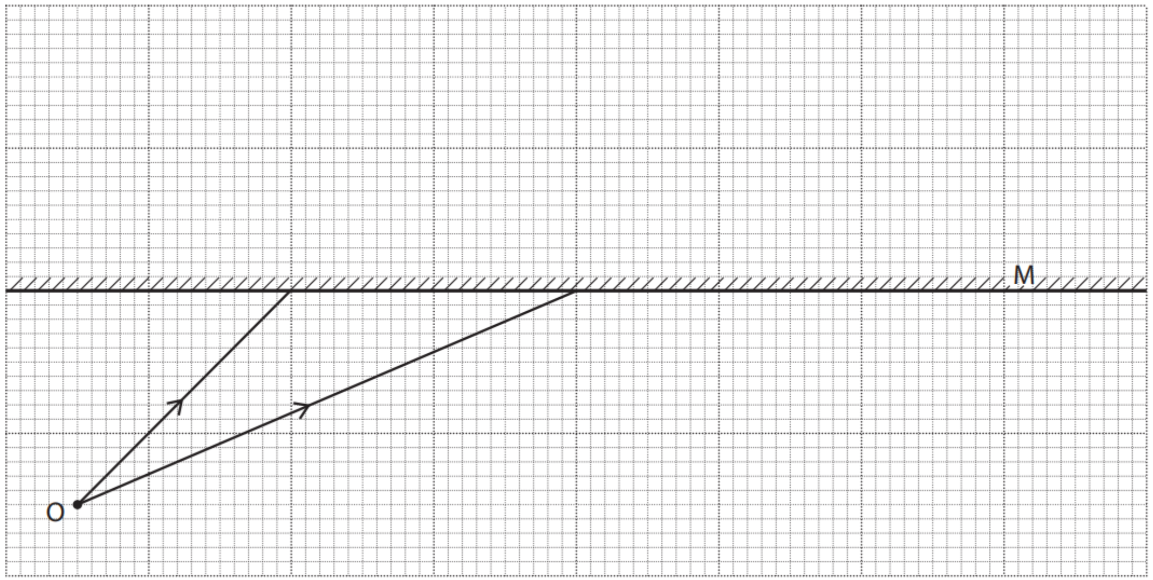
Reflection

Properties of mirror reflection:

- Mirror images are **virtual** images
- **Virtual images** are formed when light **appears** to converge in a location which forms an image
- **Real images** are formed when light **actually** convergences in a location which forms an image
- **Same size** as the actual object
- **Same distance** away from the mirror as the actual object
- **Laterally inverted**

Reflection

The figure shows an object O placed in front of a plane mirror M. Two rays from the object to the mirror are shown.



(a) On the figure, for **one** of the rays shown,

1. draw the normal to the mirror,

2. mark the angle of incidence. Label this angle X. [2]

(b) On the figure, draw

1. the reflected rays for both incident rays,

2. construction lines to locate the image of O. Label this image I. [2]

[Total: 4]

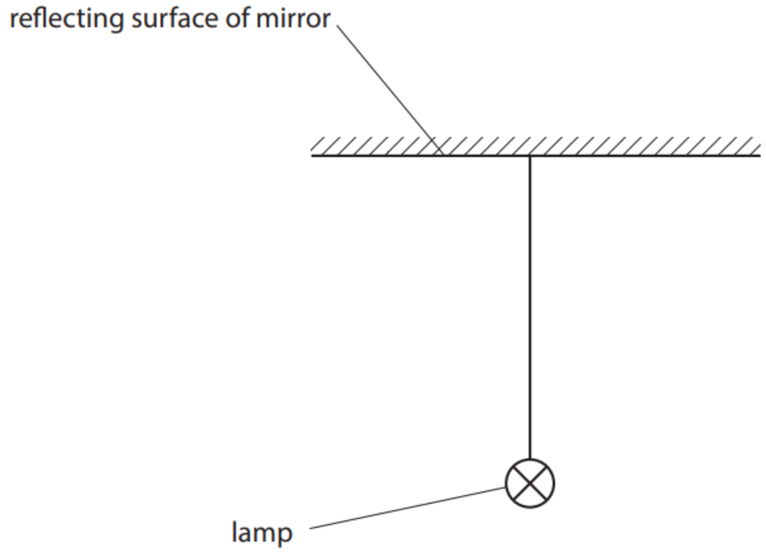
Reflection

3(a)	**1.** one normal to mirror drawn	**B1**			
	2. angle of incidence, labelled X	**B1**			

- Mark Scheme /

Question	Answer	Marks	AO Element	Notes	Guidance
3(b)	**1.** both reflected rays drawn	**B1**			
	2 . construction lines to locate image, marked I	**B1**			

4 A lamp in a large room is suspended below a horizontal mirror that is fixed to the ceiling. The figure is a scale diagram of the lamp and mirror.



An image of the lamp is formed by the mirror.

(a) On the figure, draw two rays from the centre of the lamp that strike the mirror. Use these rays to locate the image. Label the image I. [3]

(b) State **two** characteristics of this image.

1. ....

2. .... [2]

[Total: 5]

Reflection

4(a)	two rays from lamp to mirror **AND** one good (i ≈ r) reflected ray	**B1**			
	two good reflected rays **AND** rays traced back above mirror	**B1**			
	labelled / clear image located at intersection **AND** in correct position	**B1**			
4(b)	any two from: virtual (longitudinally) inverted same size (as lamp) **OR** same distance (from mirror)	**B2**			

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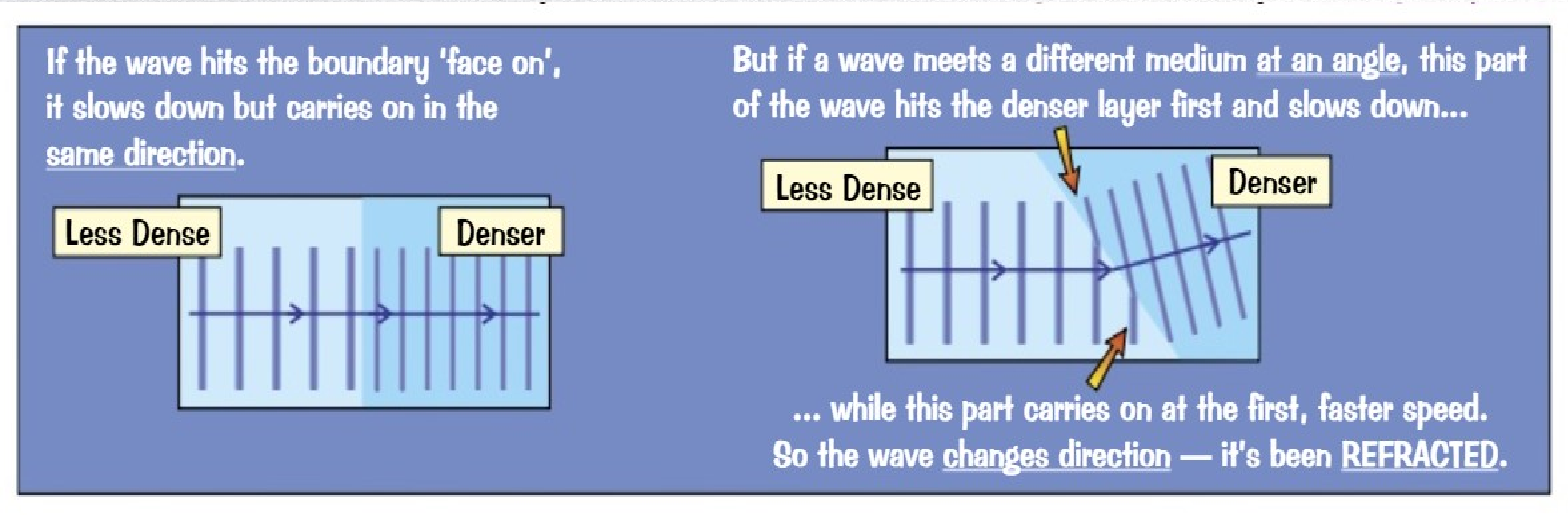
Refraction

Refraction

Refraction:

- Waves travel at **different speeds** in substances which have **different densities**.
  - ✓ EM waves travel more slowly in denser substances.
  - ✓ Sound waves travel faster in denser substances.
- When a wave cross a boundary between substances, e.x. from glass to air, it changes speed.
- If a wave is travelling along (or parallel to) the normal when it crosses a boundary between materials, it doesn't refract.

Refraction



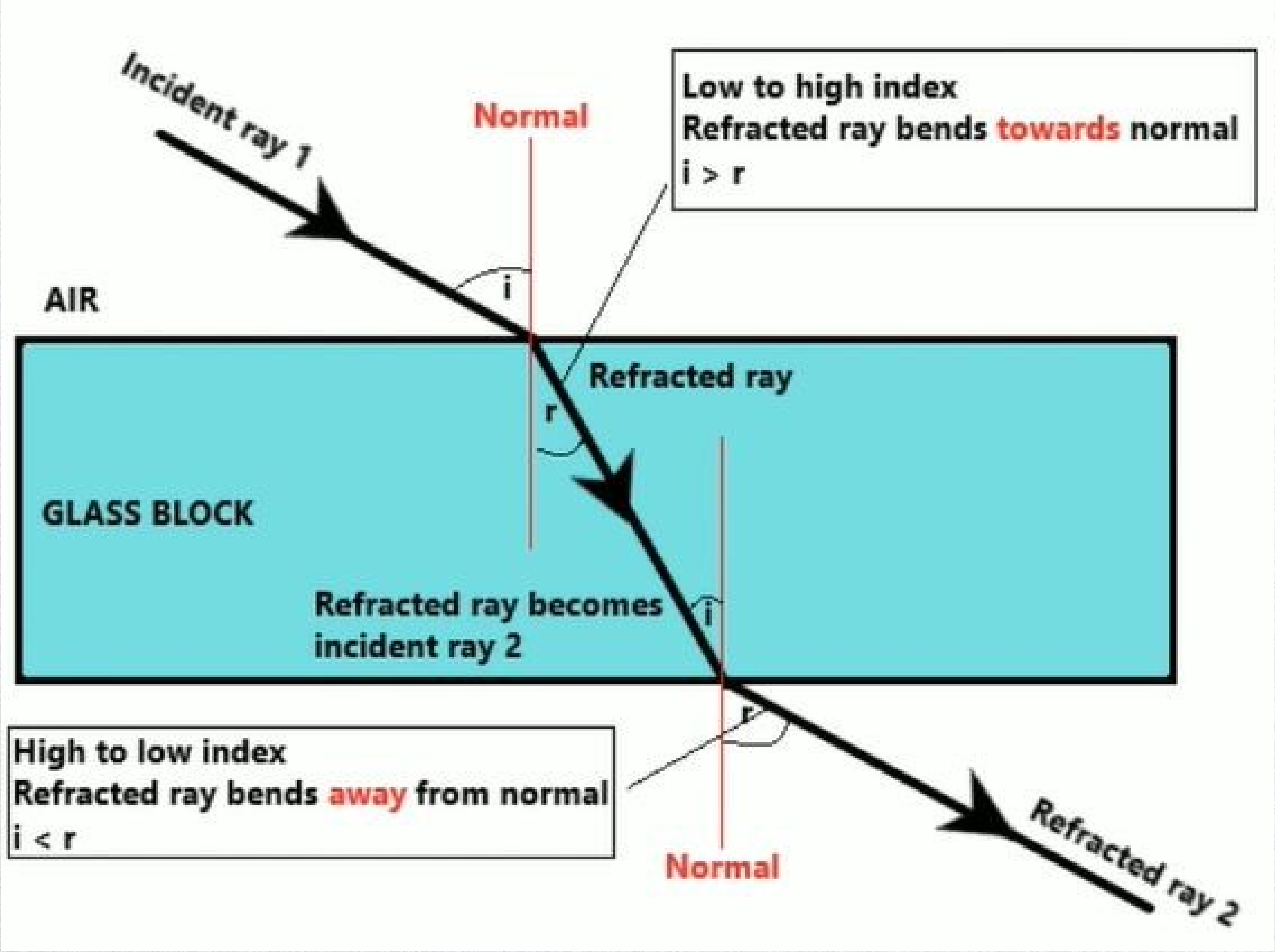
If the wave hits the boundary 'face on', it slows down but carries on in the same direction.
Less Dense
Denser
But if a wave meets a different medium at an angle, this part of the wave hits the denser layer first and slows down...
Less Dense
Denser
... while this part carries on at the first, faster speed.
So the wave changes direction — it's been REFRACTED.

Refraction

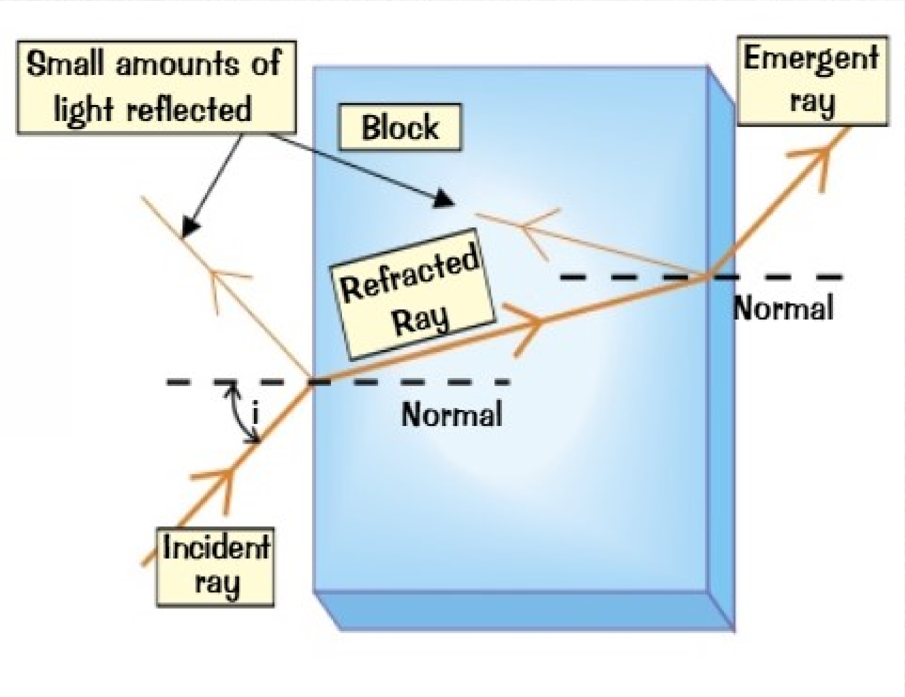
A ray diagram for a refracted wave:

- Draw the **boundary** between two materials
- Sketch the **normal**: a line that is at 90◦ to the boundary
- Draw an **incident ray** that meets the normal at the boundary
- Draw the angle of incidence, i
- Draw the **refracted ray** on the other side of the boundary:
  - ✓ If the 2nd material is denser than the 1st → the refracted ray **bends towards** the normal → $i > r$
  - ✓ If the 2nd material is less dense than the 1st → the refracted ray **bends away** the normal → $i < r$

Refracted twice



Refracted twice



As the light passes **from air into the block** (a denser medium), it **bends towards the normal**. This is because it **slows down**.

When the light reaches the boundary on the other side of the block, it's passing into a less dense medium. So it **speeds up and bends away from the normal**. (some of the light is also reflected at this boundary.)

The light ray that emerges on the other side of the block is now travelling **in the same direction** it was to begin with – **it's been refracted towards the normal and then back again by the same amount**.

Refractive Index (Index of Refraction)

- Light travels at different speeds depending on the refractive index of the material.
- Every material (medium) has a different refractive index
  - ✓ The higher the refractive index (n), the slower light travels (v)
  - ✓ The lower the refractive index (n), the faster light travels (v)
- In general, the denser the material the higher the refractive index

Refractive Index (Index of Refraction)

In optics, the **refractive index** (also known as index of refraction, n) of a material is a *dimensionless* number that describes how fast light travels through the material.

Material	$\boldsymbol{n}$
vacuum	1
air	$1.000293 \approx 1.00$
water	1.33
glass	1.52

Refractive Index

- Every transparent material has a refractive index
- The refractive index of a transparent material tells you how fast light travels in that material.

$$refractive\ index, n = \frac{speed\ of\ light\ in\ a\ vacuum, c}{speed\ of\ light\ in\ that\ material, v}$$

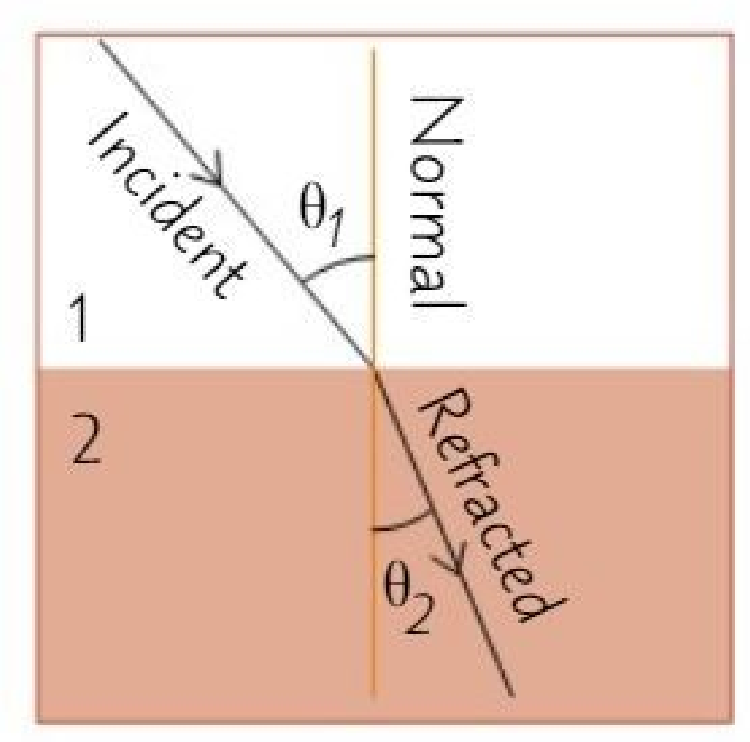
$$\boldsymbol{n = \frac{c}{v}}$$

✓ The speed of light in air is about the same as in a vacuum, so the refractive index of air is 1.00 (to 2 d.p.).

Snell's law

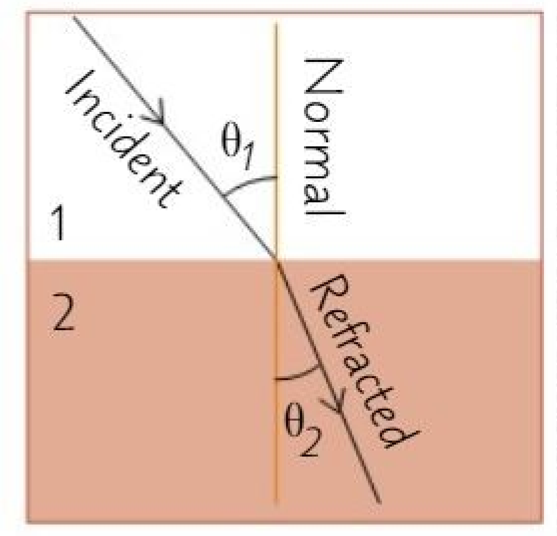
$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

Where
n_1 is the refractive index in medium 1;
n_2 is the refractive index in medium 2;
θ_1 is the angle of incidence;
θ_2 is the angle of refraction.



Snell's law

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$



Where
n_1 is the refractive index in medium 1;
n_2 is the refractive index in medium 2;
θ_1 is the angle of incidence;
θ_2 is the angle of refraction.

In the case if medium 1 is air, and it is known that the refractive index of air is 1; the formula above could be arranged as :

$$1 \times \sin \theta_1 = n_2 \sin \theta_2$$

Now θ_1 is the angle of incidence (i) , θ_2 is the angle of refraction (r), n_2 can be simply written as n. Thus, the formula can be simplified as $\boldsymbol{n = \frac{\sin i}{\sin r}}$

Refractive Index

Study question:

A ray of light passes into a glass block from the air. The angle of incidence is 34°. If the speed of light in the block is 1.9×10^8 m/s, calculate the angle of refraction of the ray. Use $c = 3.0 \times 10^8$ m/s.

Refractive Index

Study question:

A ray of light passes into a glass block from the air. The angle of incidence is 34◦. If the speed of light in the block is 1.9 × 10^8 m/s, calculate the angle of refraction of the ray. Use c = 3.0 × 10^8 m/s.

Calculate n:

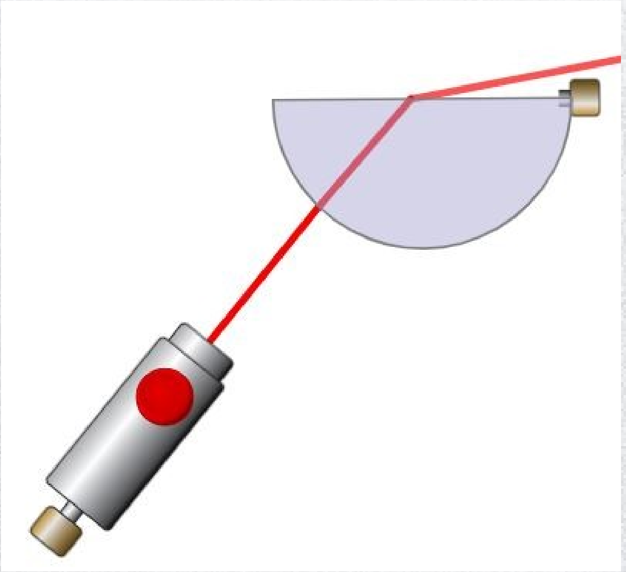
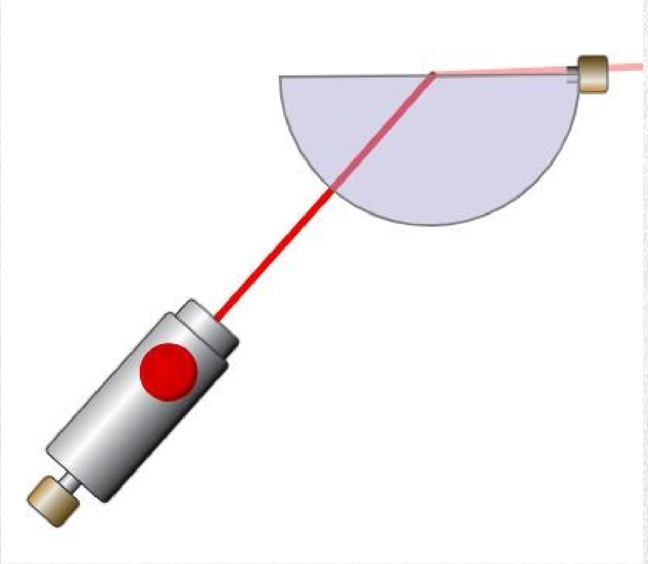
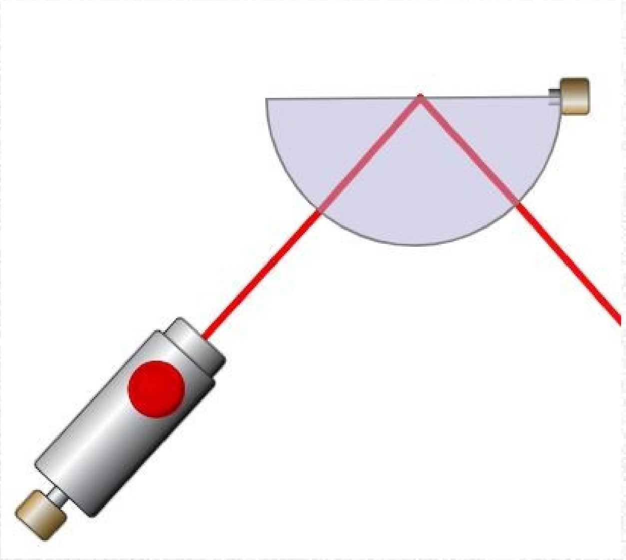
$$n = \frac{c}{v} = \frac{3.0 \times 10^8}{1.9 \times 10^8} = 1.578$$

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

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

$$r = \sin^{-1}\left(\frac{\sin i}{n}\right) = \sin^{-1}\left(\frac{\sin 34\ \circ}{1.578}\right) = 20.74\ \circ = 21\ \circ$$

Simulation

https://phet.colorado.edu/sims/html/bending-light/latest/bending-light_en.html

The critical angle & Total internal reflection

- Consider light rays going **from a medium of higher to lower refractive index (*density from low to high*)**
- Light bends away from the normal
- As the angle of incidence (i) increases, angle of refraction (r) increases as well
- If the angle of refraction (r) is larger than 90°, the entire light is reflected back into the medium (total internal reflection)
- The critical angle is this limit – It is the angle of incidence that causes **an angle of refraction of 90°**
- When **the angle of incidence (i) is larger than the critical angle (C)**, then we get **total internal reflection**

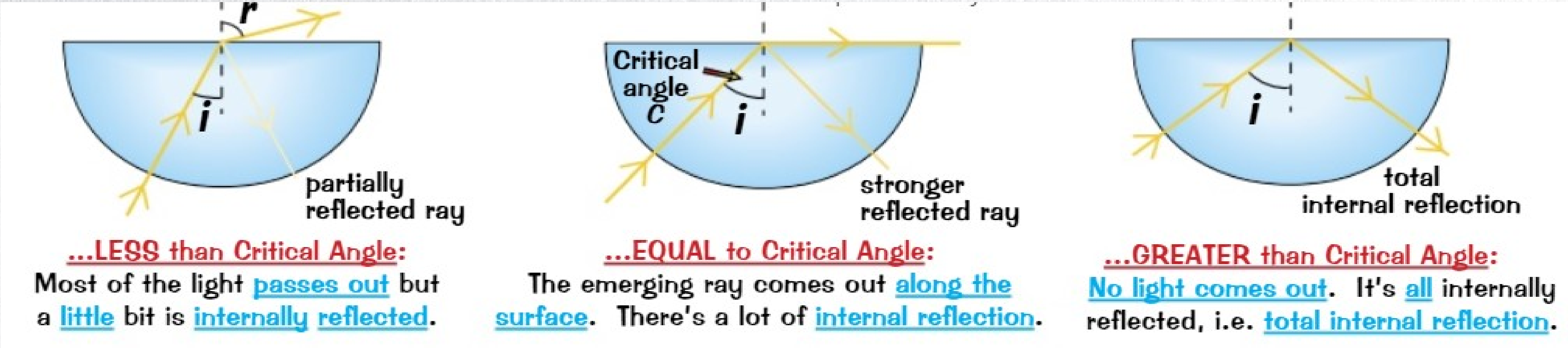
The critical angle & Total internal reflection

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

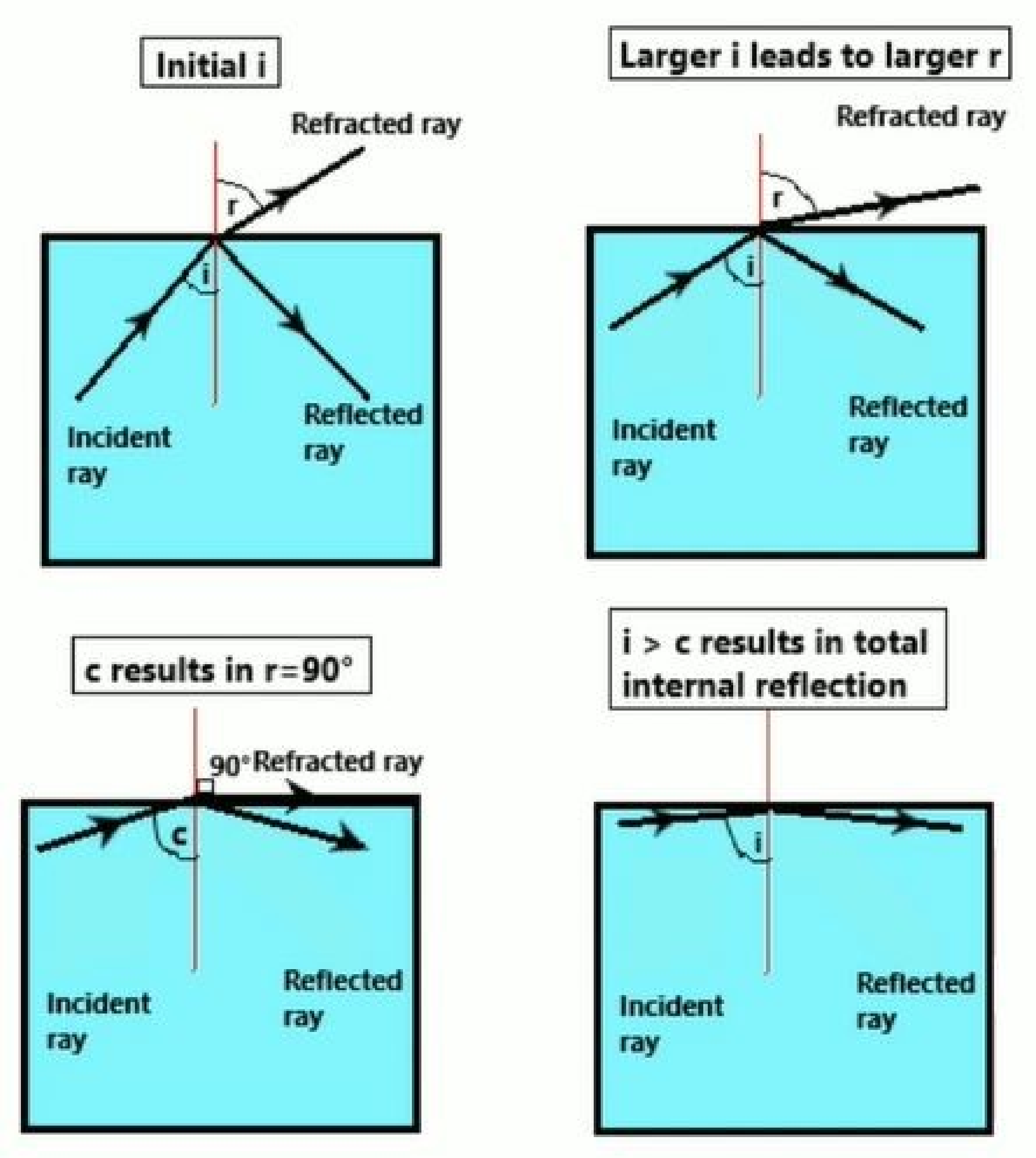
where i is the angle of incidence ***in air****, when total internal reflection happens, the angle of refraction = 90°*

Therefore, $n = \frac{\sin 90^\circ}{\sin C}$ *which gives* $\boldsymbol{n = \frac{1}{\sin C}}$ *where* ***C is the critical angle****.*

The critical angle & Total internal reflection



The critical angle & Total internal reflection



Critical Angles

Study question:

Calculate the critical angle for a material with a refractive index of 1.4.

Critical Angles

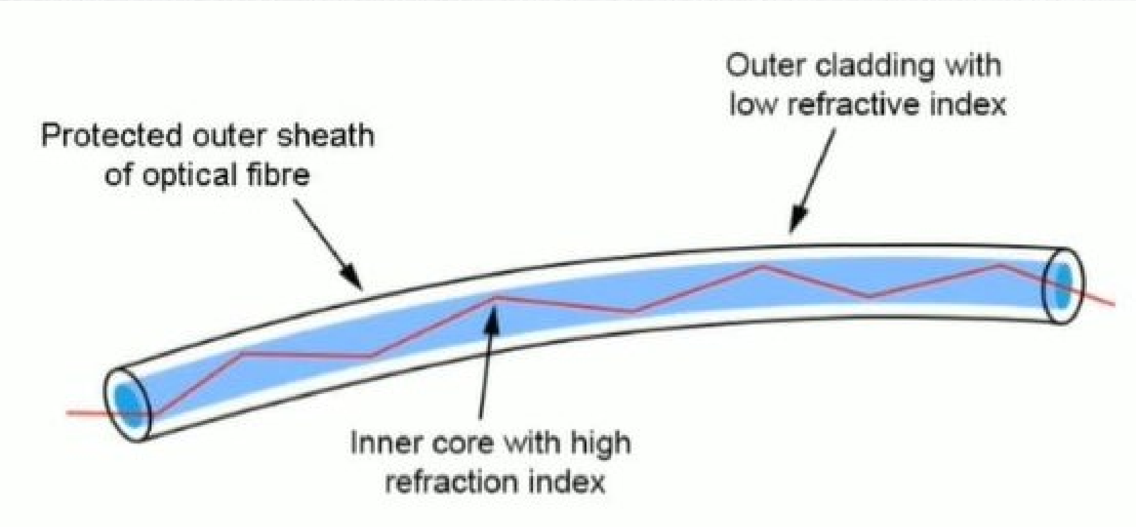
Study question:

Calculate the critical angle for a material with a refractive index of 1.4.

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

$$C = \sin^{-1}\left(\frac{1}{n}\right) = \sin^{-1}\left(\frac{1}{1.4}\right) = 45.58 = 46\ ^\circ$$

Optical Fibers

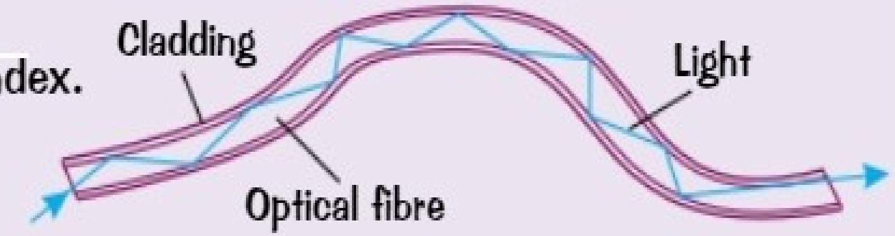


- Total internal reflection is used in optical fibers
- Optical fibers have a thin glass core with an outer cladding that has a lower refractive index (n)
- Total internal reflection occurs for all rays that hit the boundary between core and cladding at an angle larger than the critical angle (C)

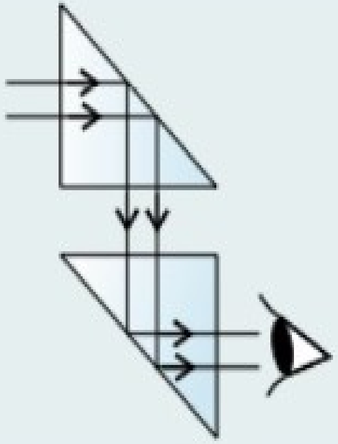
Optical Fibers

Optical Fibres and *Prisms* Use *Total Internal Reflection*

1) Optical fibres made of plastic or glass consist of a central core surrounded by cladding with a lower refractive index.
2) The core of the fibre is so narrow that light signals passing through it always hit the core-cladding boundary at angles higher than C — so the light is always totally internally reflected. It only stops working if the fibre is bent too sharply.



1) Total internal reflection also allows us to use prisms to see objects that aren't in our direct line of sight. This is how a periscope works.
2) The ray of light travels into one prism where it is totally internally reflected by 90°.
3) It then travels to another prism lower down and is totally internally reflected by another 90°.
4) The ray is now travelling parallel to its initial path but at a different height.



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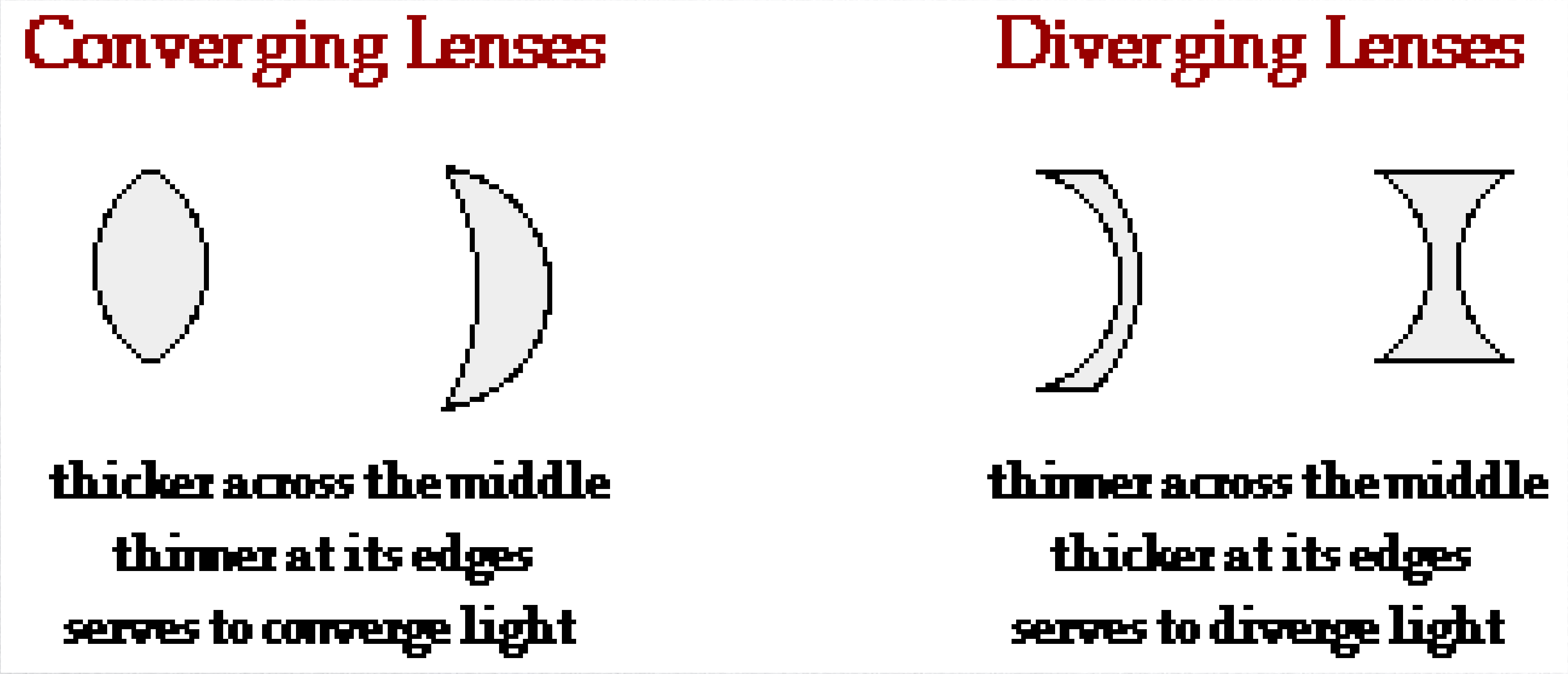
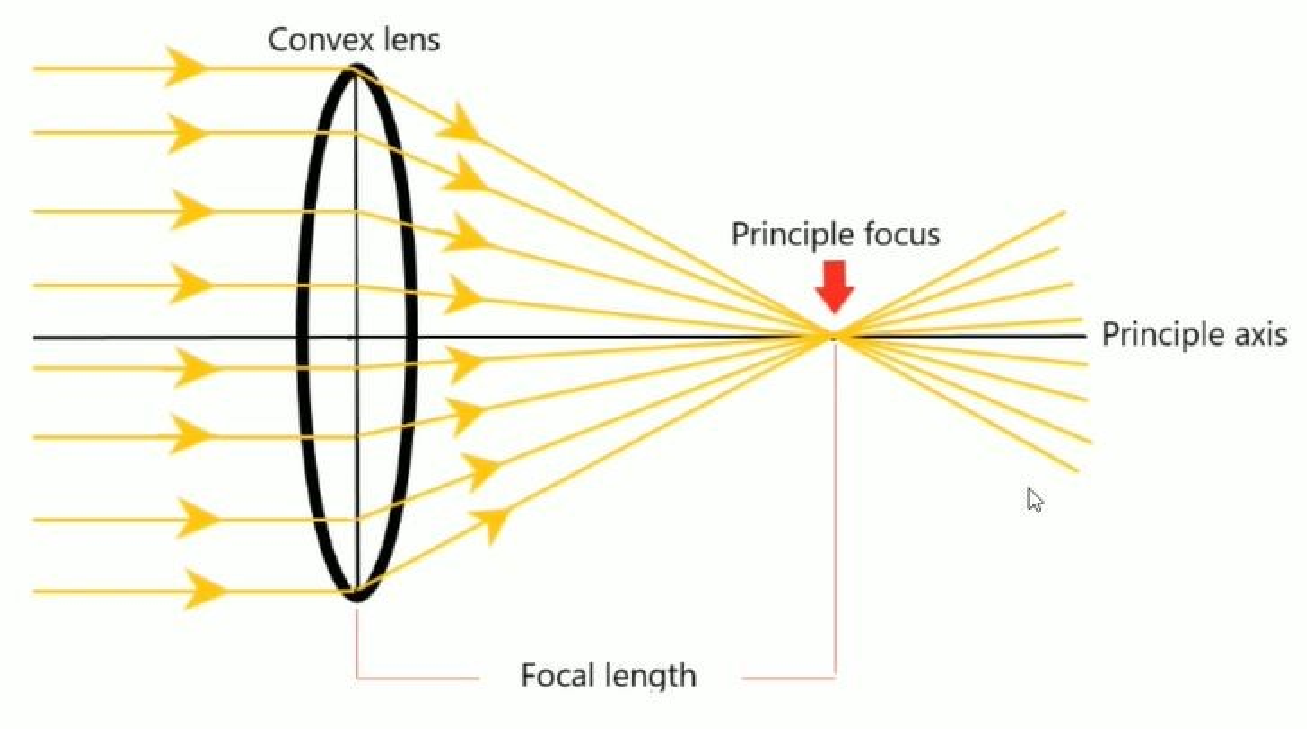
2. Refraction of light
3. **Thin lenses**
4. Dispersion of light

Lenses


Converging Lenses
thicker across the middle
thinner at its edges
serves to converge light
Diverging Lenses
thinner across the middle
thicker at its edges
serves to diverge light

Thin Converging Lenses



- Light coming from **a very distance** object are considered **parallel rays**
- When parallel rays pass a **convex (converging)** lens, light rays are focused at a single point called the **principle focus** (or **focal point**).
- The **imaginary horizontal line** at right angles to the lens is the **principle axis.**
- The distance from **the lens center to the principle focus** is the **focal length**

Ray diagrams

- Light travels from an object, passes through a convex lens, and form an image
- All convex lenses have a focal point (or principle focus)
  - ✓ The focal point and focal length is the same on either side of the lens
- To determine the size and position of the image, tracing the light rays are essentials.
- Consider an object being placed on the left hand side:
  - ✓ There are 5 positions for the object

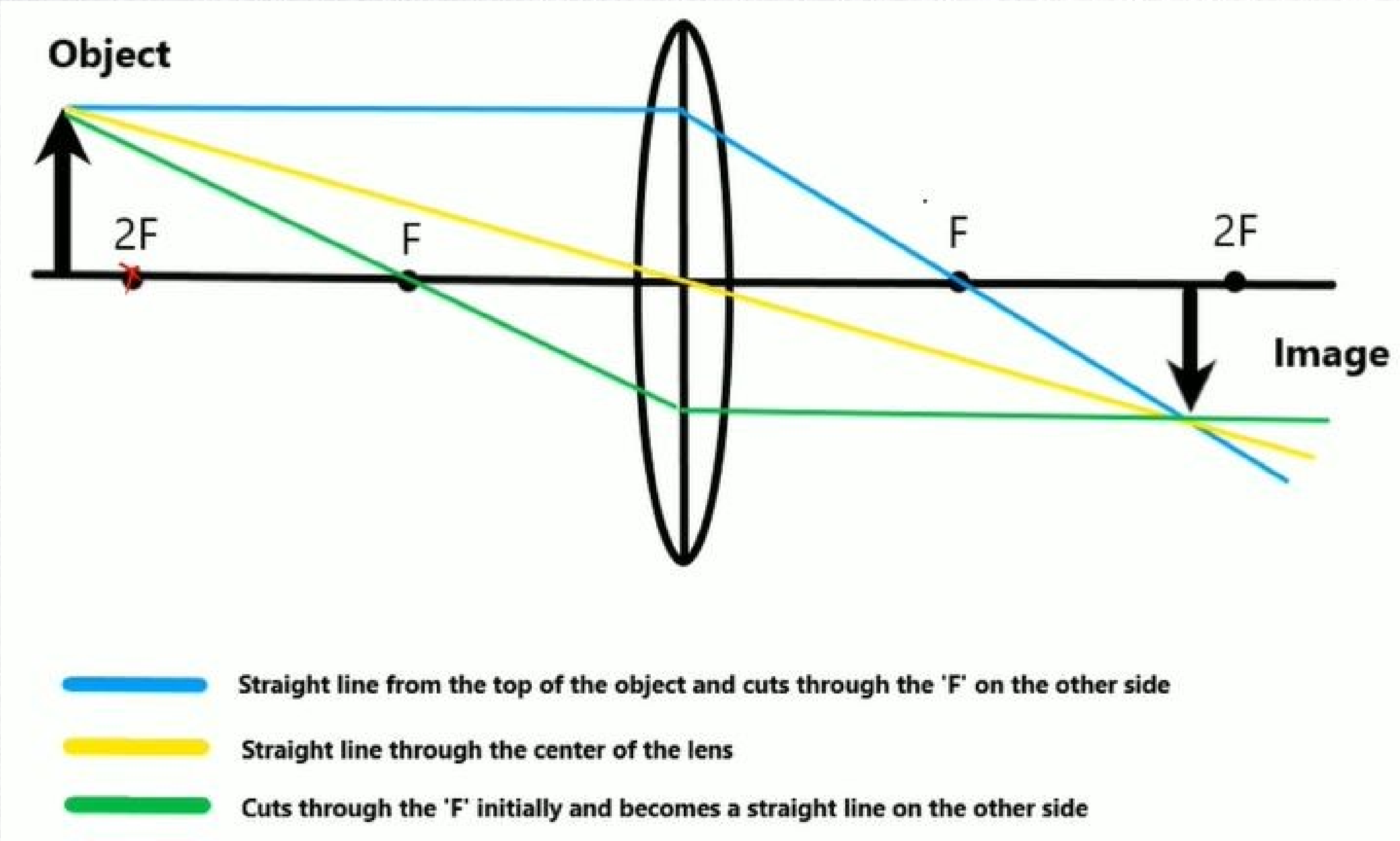
    - 2F & beyond
    - Between 2F & F
    - Between F & the lens
    - at F
    - at 2F

  - ✓ The resulting image of the object will be depending on these positions

Rules of Ray tracing

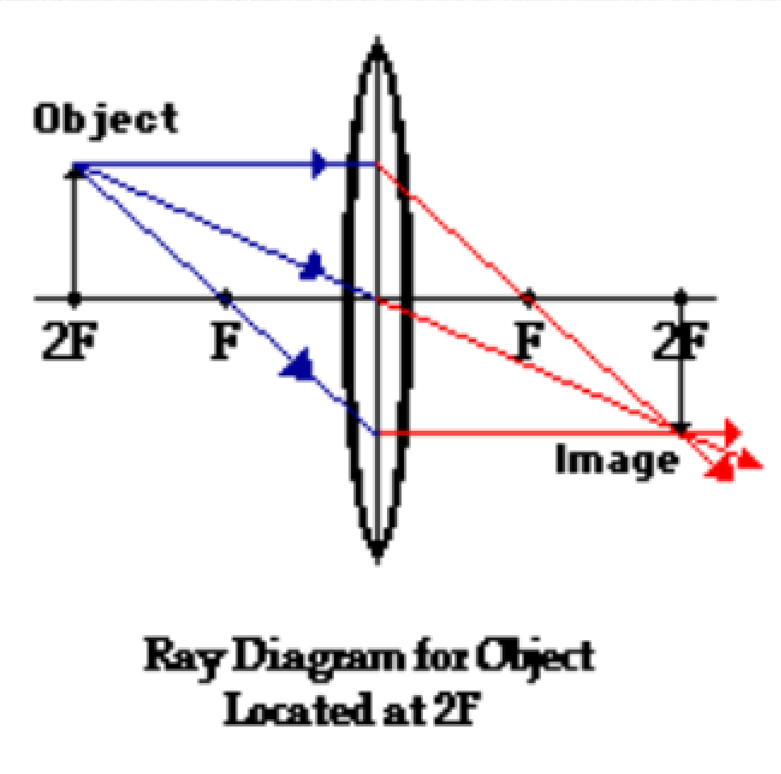
- The three rules of refraction for a thin convex lens:
  - Any incident ray traveling parallel to the principal axis of a converging lens will refract through the lens and travel through the focal point on the opposite side of the lens. (Light rays that travel parallel to the principle axis travel through the lens to the focus)
  - Any incident ray traveling through the focal point on the way to the lens will refract through the lens and travel parallel to the principal axis.
  - An incident ray that passes through the center of the lens will in effect continue in the same direction that it had when it entered the lens. (Light rays that travel through the optical centre continue on in a straight line).

Ray tracing: object beyond 2F



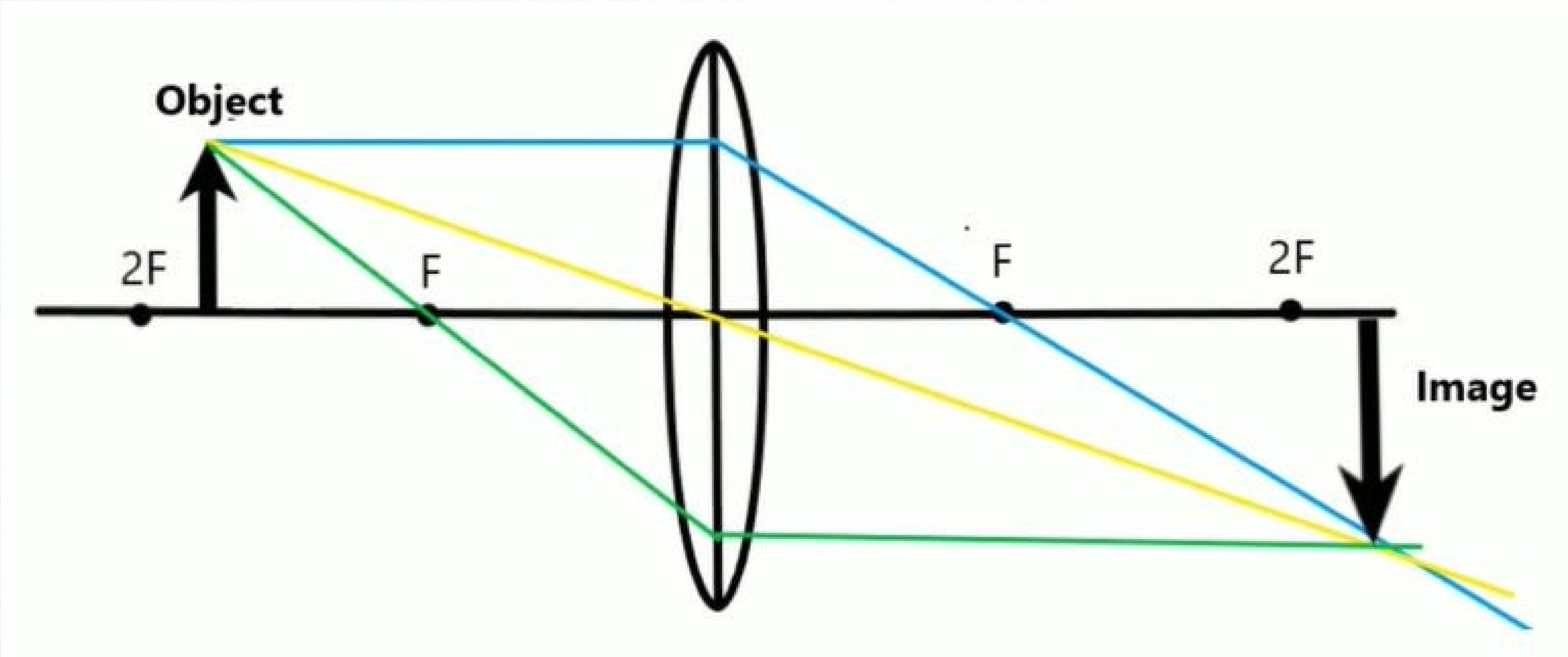
- From the top of the object, draw 3 rays as shown
- The point at which these 3 lines meet is where the image is positioned
- This results in an image that is **real, inverted, and diminished (smaller)**

Ray tracing: at 2F



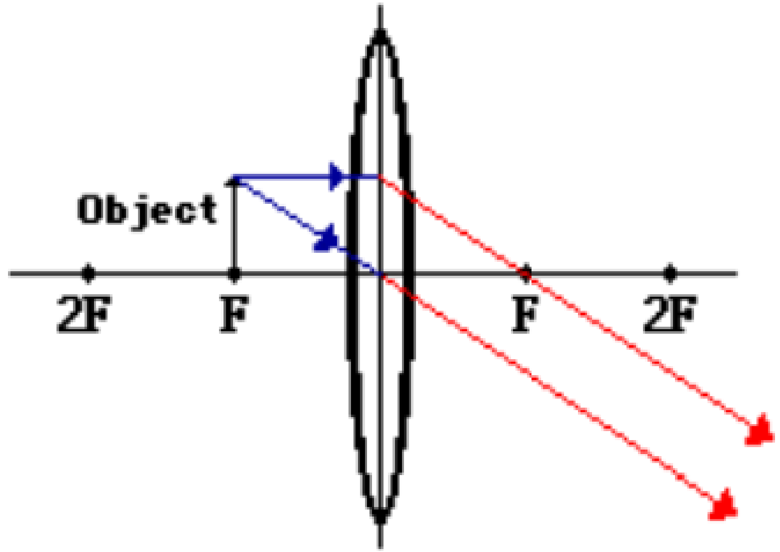
- From the top of the object, draw 3 rays as shown
- The point at which these 3 lines meet is where the image is positioned
- This results in an image that is **real, inverted, and same size**

Ray tracing: Between 2F & F



- From the top of the object, draw 3 rays as shown
- The point at which these 3 lines meet is where the image is positioned
- This results in an image that is **real, inverted, and magnified (larger)**

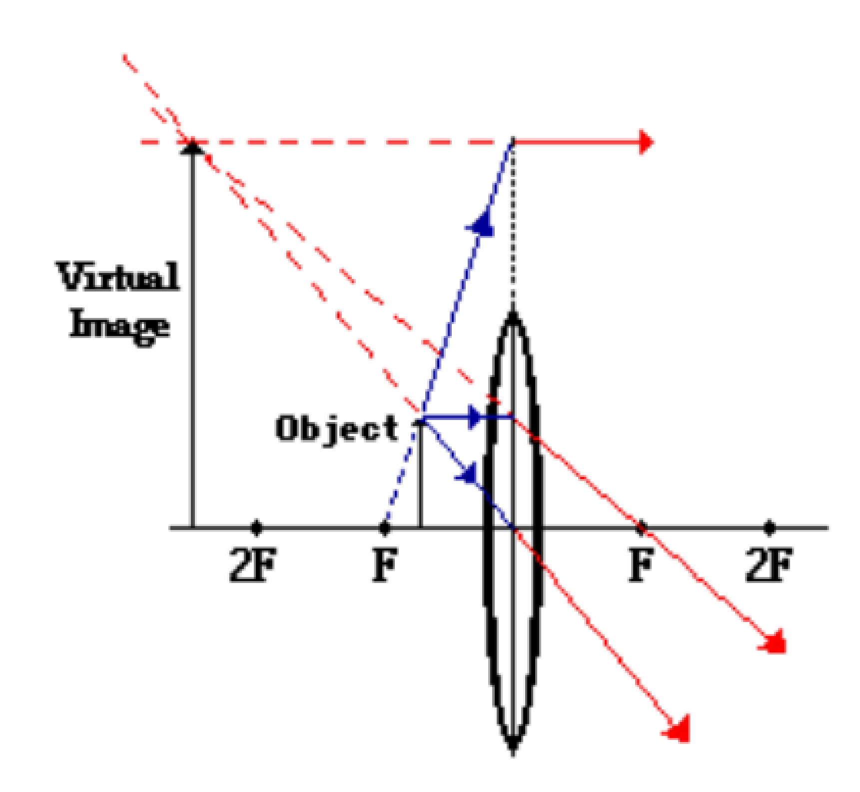
Ray tracing: at F



Ray Diagram for Object Located at F
(an image is <u>not</u> formed)

- From the top of the object, draw 2 rays as shown
- The two refracted rays are never across (i.e. parallel)
- This results in **no image**

Ray tracing: between F and the lens



Ray Diagram for Object Located in Front of F

- Light rays that travel parallel to the principal axis reflect off the mirror through the focus
- Light rays that travel through the centre of curvature reflect back through the centre of curvature
- This results in a **larger, upright, virtual image.**

Ray tracing: Between F & the lens

Position	Description of images
beyond 2F	real, inverted, and diminished (smaller)
at 2F	real, inverted, and same size
between 2F and F	real, inverted, and magnified (larger)
at F	no image
between F and the lens	virtual, upright, beyond 2F, larger

Real vs. Virtual images

- The real images are always formed by actual intersection of light rays, just like intersection of two straight lines. They are formed at the intersection point. When you place a screen at this position you can see the image.
- Virtual images are not 'formed’, they appear to be formed.

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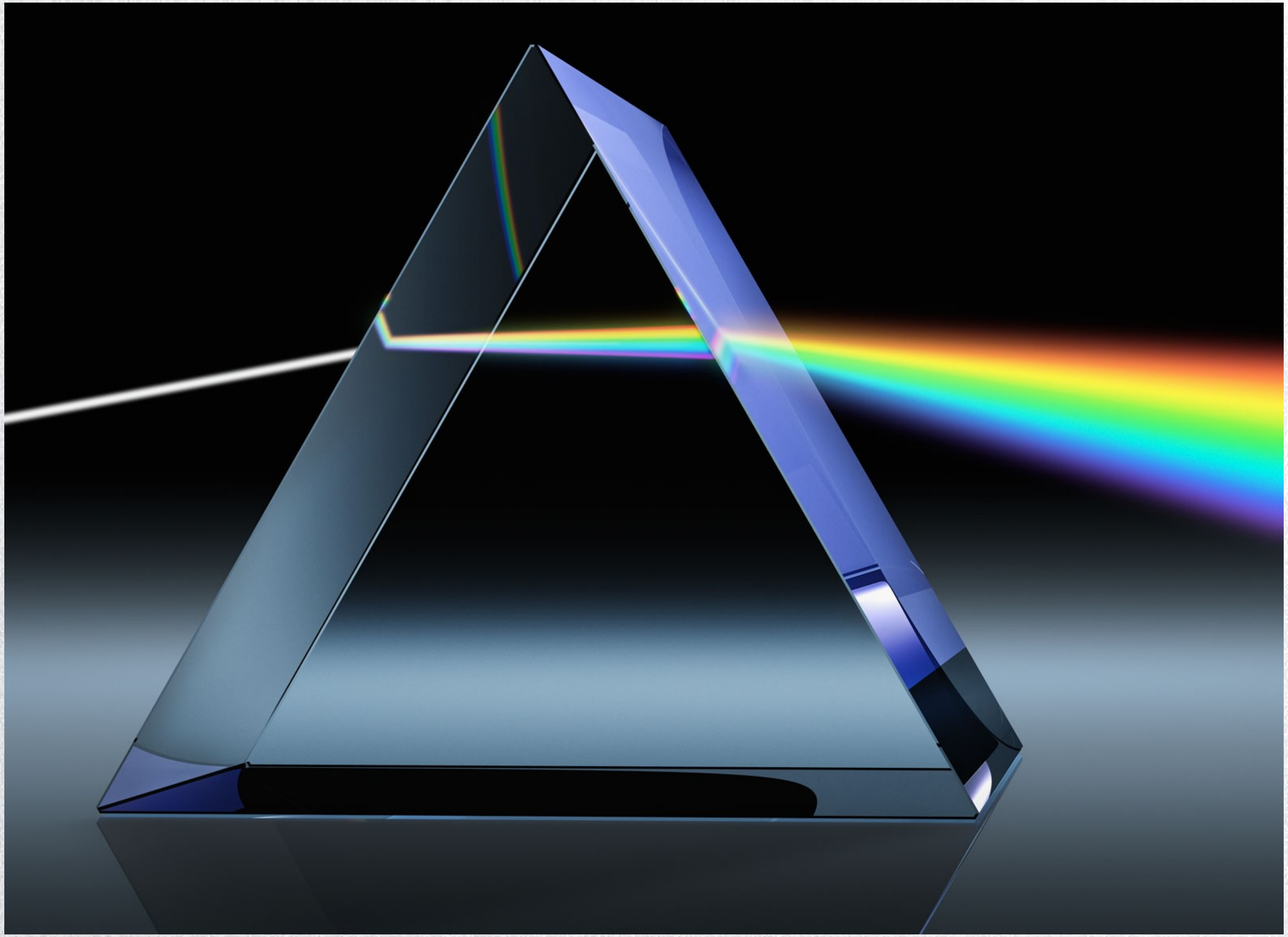
White light & Dispersion



White light & Dispersion

- White light is a complex **combination of all the different wavelengths of the visible spectrum**
- Each of the wavelengths have a different colour, i.e. green has a wavelength of 500 nm and red has a wavelength of 700 nm
- Light of single frequency is called **monochromatic light**
- Combining all monochromatic light results in "**white light**"
- We can separate out the different wavelengths by using a prism, which is called **dispersion**

White light & Dispersion

- **Different wavelengths of light refract by different amounts**, so white light (which is a mixture of all visible frequencies) disperses into different colours as it enters a prism, and the different wavelengths are refracted by different amounts. A similar effect happens as the light leaves the prism.
- Seven colours of the visible spectrum are in order of frequency and in order of wavelength.