Chapter 13. Light

Contents:

New word list:

Spectrum
Dispersion
Principle axis
Principle focus/principle point
Focal length
Converge
Diverge
Enlarged
Diminished
Upright
Short sight
Long sight
Retina
Magnifying glass
Chromatic
monochromatic

3.2 Light

3.2.1 Reflection of light

Core

1 Define and use the terms normal, angle of incidence and angle of reflection

2 Describe the formation of an optical image by a plane mirror, and give its characteristics, i.e. same size, same distance from mirror, virtual

3 State that for reflection, the angle of incidence is equal to the angle of reflection; recall and use this relationship

Supplement

4 Use simple constructions, measurements and calculations for reflection by plane mirrors

3.2 Light continued

3.2.2 Refraction of light

Core

1 Define and use the terms normal, angle of incidence and angle of refraction

2 Describe an experiment to show refraction of light by transparent blocks of different shapes

3 Describe the passage of light through a transparent material (limited to the boundaries between two media only)

4 State the meaning of critical angle

5 Describe internal reflection and total internal reflection using both experimental and everyday examples

Supplement

6 Define refractive index, n, as the ratio of the speeds of a wave in two different regions

7 Recall and use the equation

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

8 Recall and use the equation

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

9 Describe the use of optical fibres, particularly in telecommunications

3.2.3 Thin lenses

Core

1 Describe the action of thin converging and thin diverging lenses on a parallel beam of light

2 Define and use the terms focal length, principal axis and principal focus (focal point)

3 Draw and use ray diagrams for the formation of a real image by a converging lens

4 Describe the characteristics of an image using the terms enlarged/same size/diminished, upright/inverted and real/virtual

5 Know that a virtual image is formed when diverging rays are extrapolated backwards and does not form a visible projection on a screen

Supplement

6 Draw and use ray diagrams for the formation of a virtual image by a converging lens

7 Describe the use of a single lens as a magnifying glass

8 Describe the use of converging and diverging lenses to correct long-sightedness and short-sightedness

3.2.4 Dispersion of light

Core

1 Describe the dispersion of light as illustrated by the refraction of white light by a glass prism

2 Know the traditional seven colours of the visible spectrum in order of frequency and in order of wavelength

Supplement

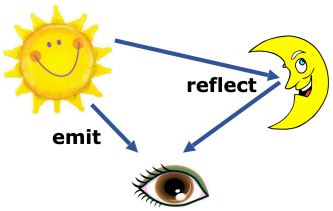
3 Recall that visible light of a single frequency is described as monochromatic

13.0 Nature of light

- Light ray travels in **straight lines**, changes its direction when hitting a shinny surface, like **particles** - [evidence: reflection, refraction]
- Light can also travel as **waves** - [evidence: diffraction]
- Can travel through empty space
- Speed of light in vacuum is the **fastest speed** in the universe
- Light is a form of radiation, transfers energy
- Light has visible and invisible region

"Wave-particle duality"

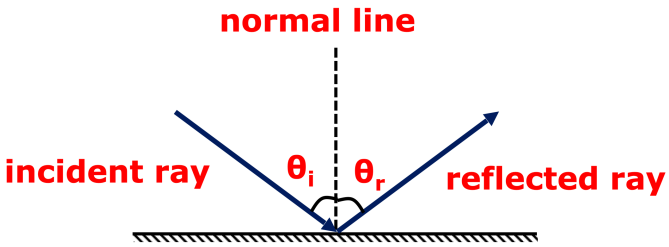
13.1 Reflection of light



- Def: the change of direction of a ray when it strikes a surface without passing through it

Reflection law: $\theta_i = \theta_r$

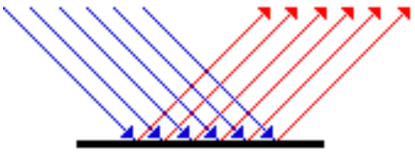
A ray of light strikes a plane mirror



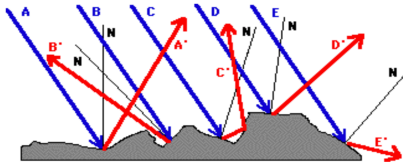
θ_i——angle of incidence

θ_r—— angle of reflection

Specular

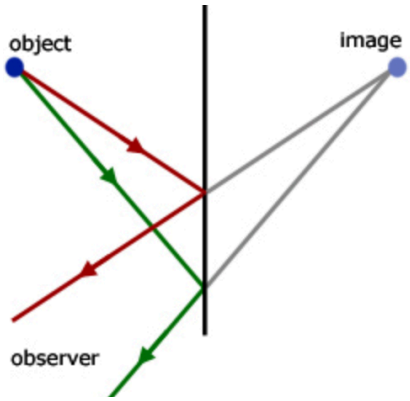


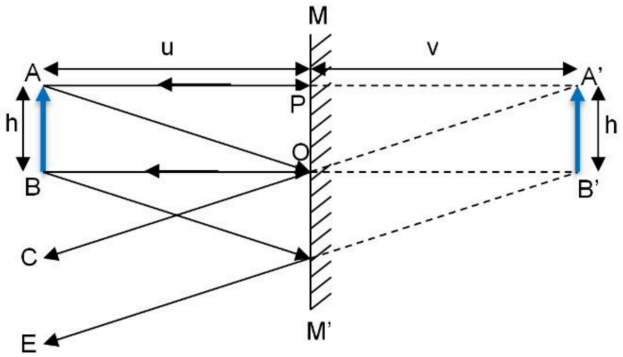
Diffuse Reflection

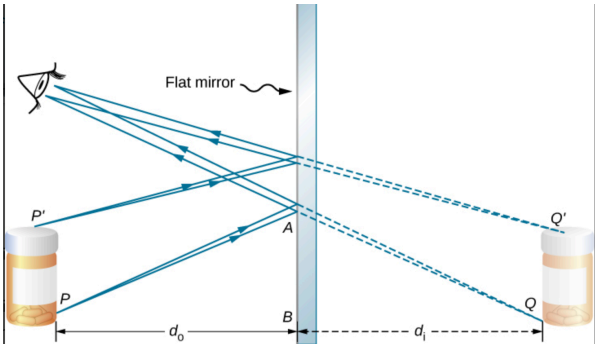


The Law of Reflection is Always Observed
(regardless of the orientation of the surface)

The image in a plane mirror







The image in a plane mirror

- The **same size** as object
- The **same distance** behind mirror as the object is in front of it
- **Laterally inverted**

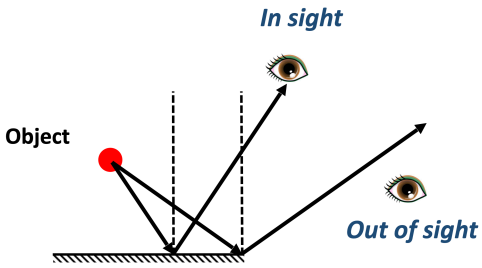
Actual Time
3:20

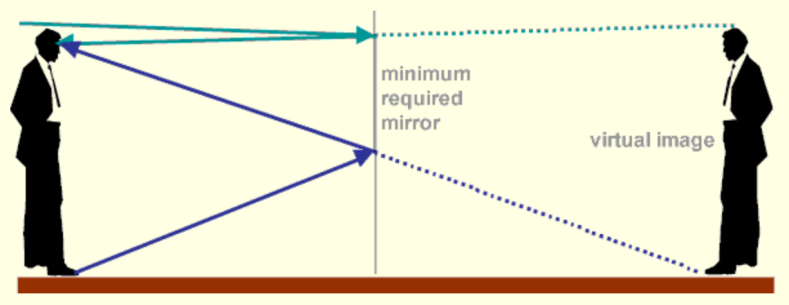
Time shown in the mirror
8:40

The actual time

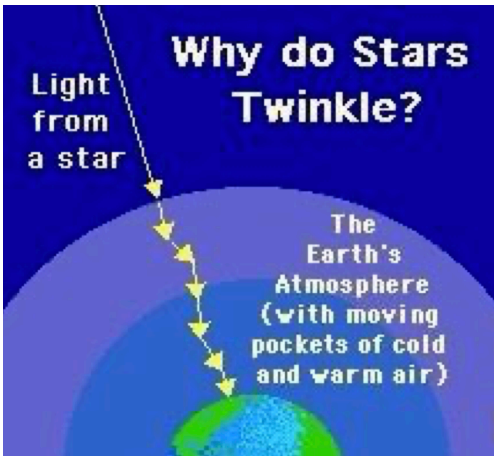
Time shown in the mirror

In/out of sight:

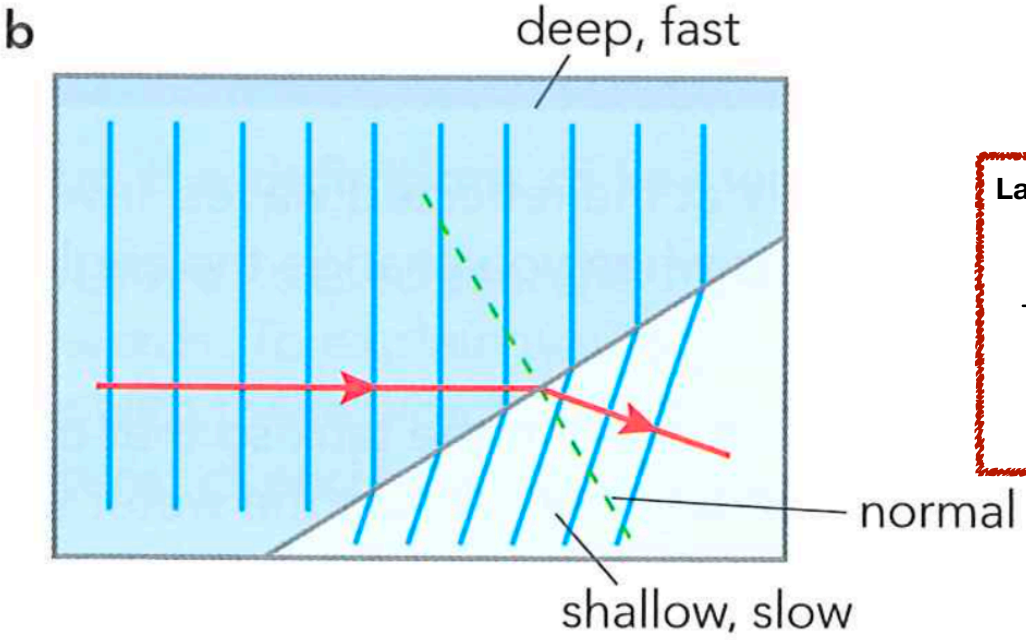




13.2 Refraction of light



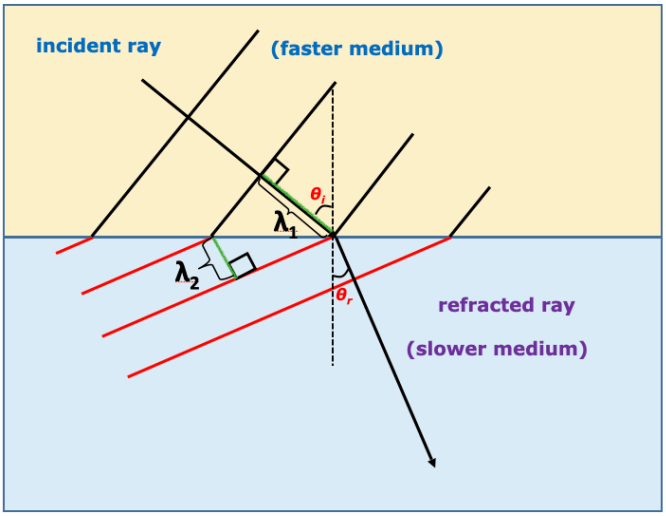
def: Refraction is the bending of the path of a light wave as it passes from one material to another material. (Incident angle = 0 => No bending)



Law of refraction:

$$\frac{\sin\theta_i}{\sin\theta_r} = \frac{n_2}{n_1}$$

Derivation of law of refraction:



$\lambda_1 = L \times \sin\theta_i$

$\lambda_2 = L \times \sin\theta_r$

$\lambda_1/\lambda_2 = \sin\theta_i / \sin\theta_r$

$\frac{\lambda_1}{\lambda_2} = \frac{\sin\theta_i}{\sin\theta_r}$ $\quad v_1 = \lambda_1 f$ $\quad v_2 = \lambda_2 f$ $\quad \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{\sin\theta_i}{\sin\theta_r}$

refractive index of medium(n) —— $n = \frac{c}{v} = \frac{\text{Speed of light in vacuum}}{\text{Speed of light in medium}}$

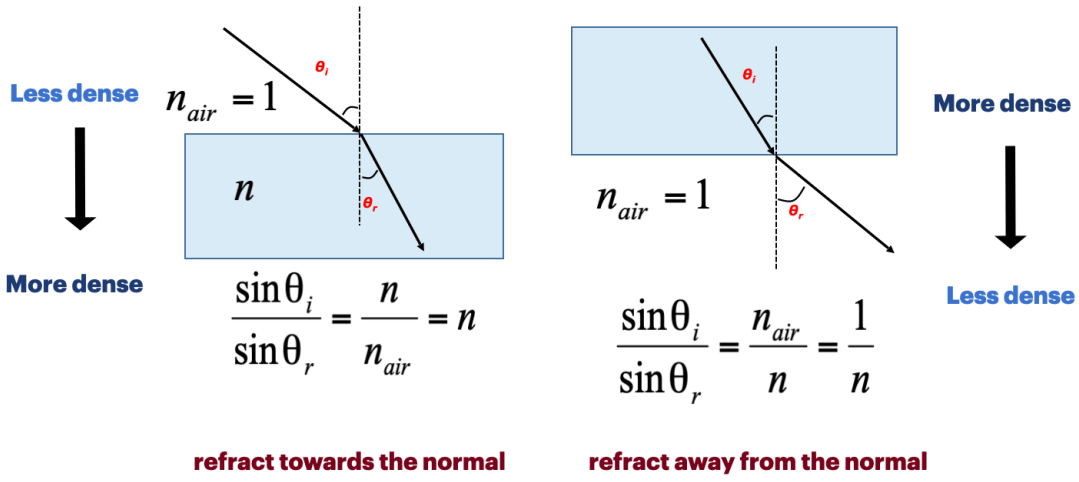
$n_1 = \frac{c}{v_1}$ $\quad n_2 = \frac{c}{v_2}$

$$\frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{\sin\theta_i}{\sin\theta_r} \longrightarrow \frac{v_1}{v_2} = \frac{\sin\theta_i}{\sin\theta_r} = \frac{n_2}{n_1}$$

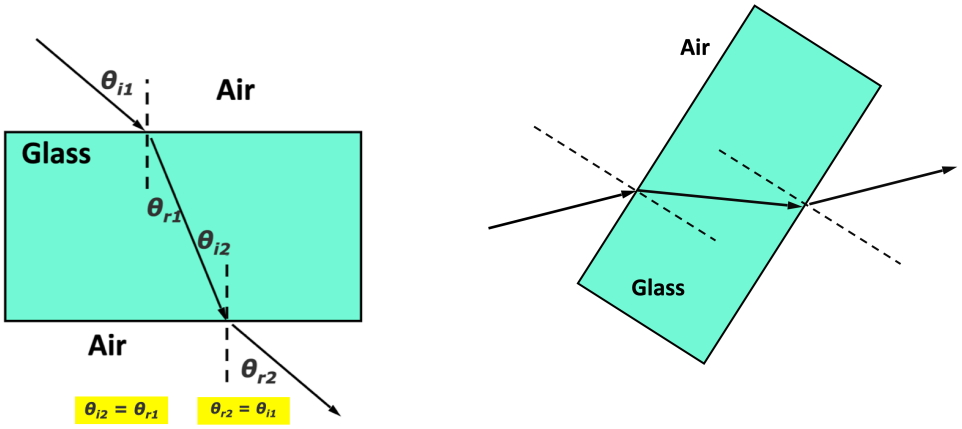
Refractive index of vacuum: $n_{vacuum} = c/c = 1$ $\qquad n_{air} \approx n_{vacuum} = 1$

n of all other materials >

Material	Speed of light / m/s	$\frac{\text{speed in vacuum}}{\text{speed in material}}$
vacuum	2.998×10^8	1 exactly
air	2.997×10^8	1.0003
water	2.308×10^8	1.33
Perspex®	2.000×10^8	1.5
glass	$(1.800–2.000) \times 10^8$	1.5–1.7
diamond	1.250×10^8	2.4

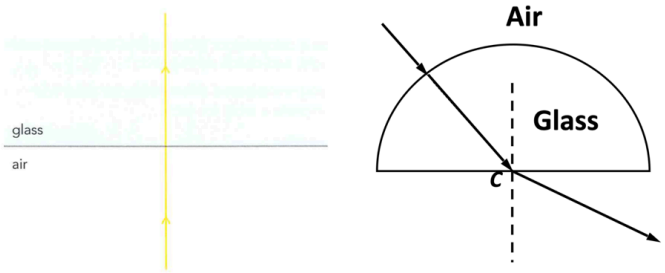


refraction though block



Refracted ray will return to its original direction, only **shifted**

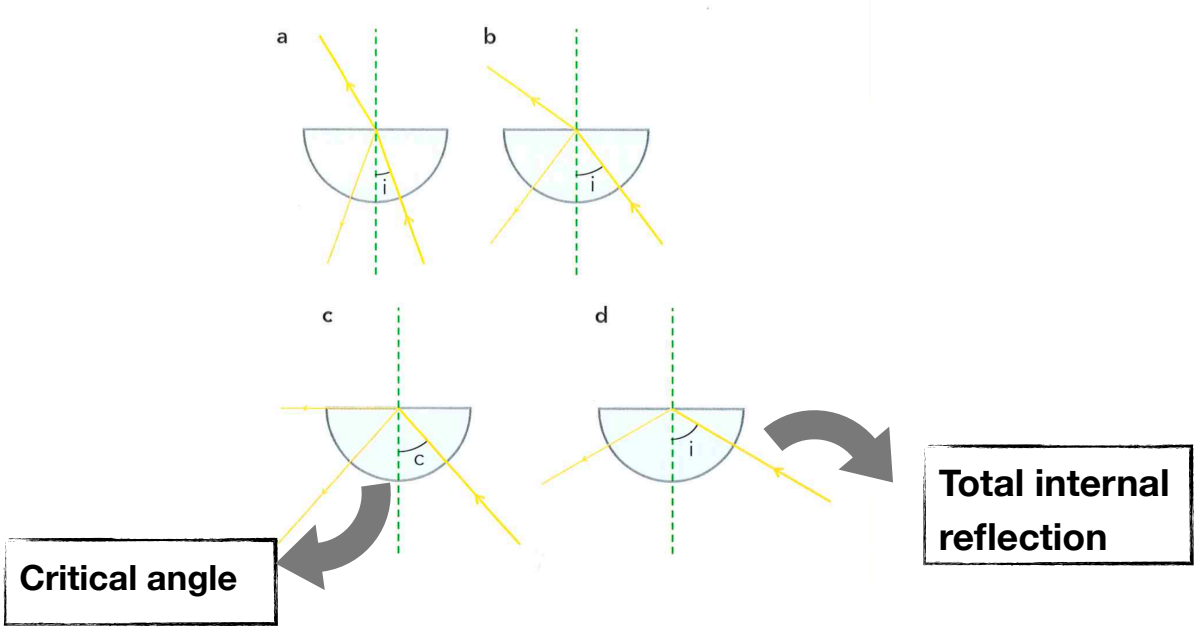
When incident angle = 0 ==> refracted angle =0



No bending when incident angle = 0

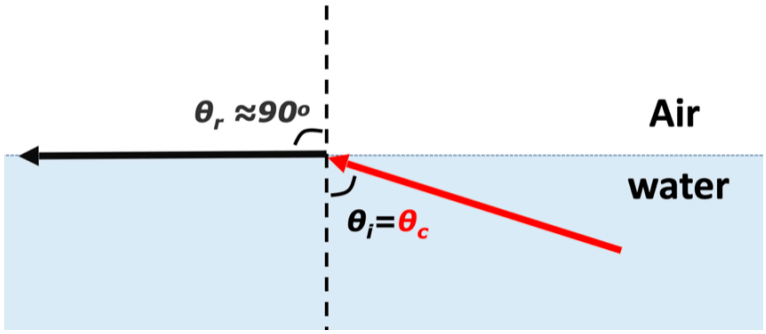
13.3 Total internal reflection

If we slowly increase incident angle, what would happen?



Critical angle: When angle of incidence is critical angle θc, refracted ray will be along the surface(θr is 90 degrees)

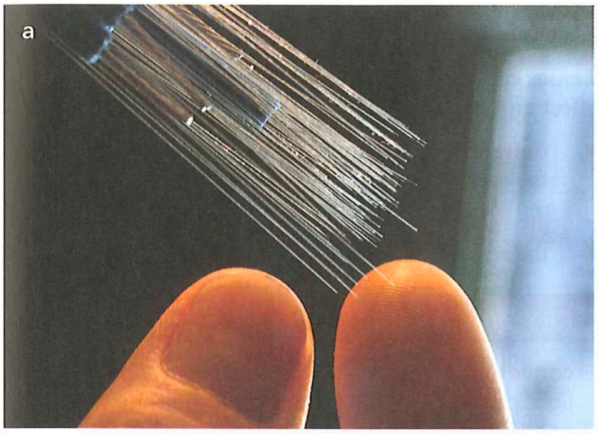
Total internal reflection (TIR): When light travels from more dense material to a less material and angle of incidence is larger than critical angle θc, all light is reflected, no light refracted.

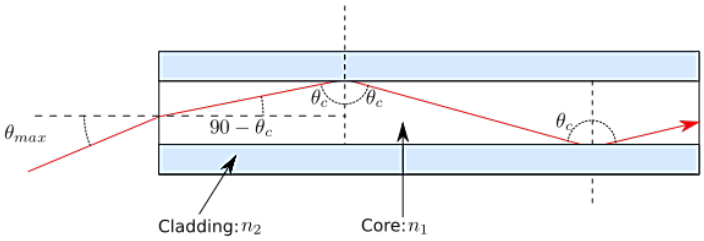


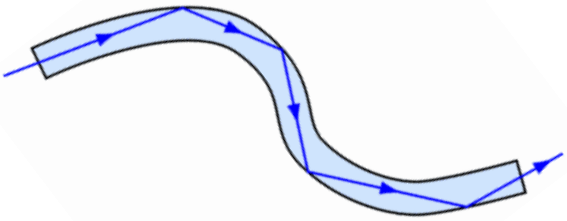
$$\frac{\sin\theta_i}{\sin\theta_r} = \frac{\sin\theta_c}{\sin 90^o} = \sin\theta_c = \frac{1}{n}$$

Conditions for TIR to happen:
1. the light is in the **more dense** medium and approaching the **less dense** medium.
2. the angle of incidence is **greater** than the critical angle.

Applications of TIR: Optical fibres

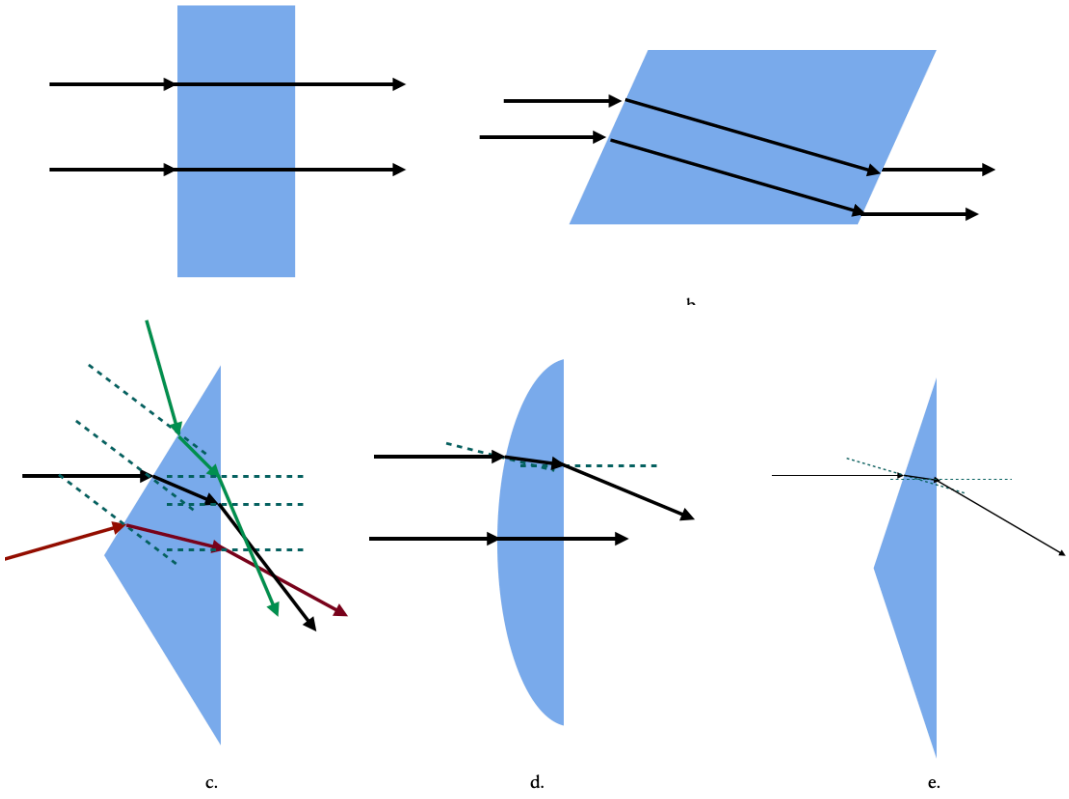






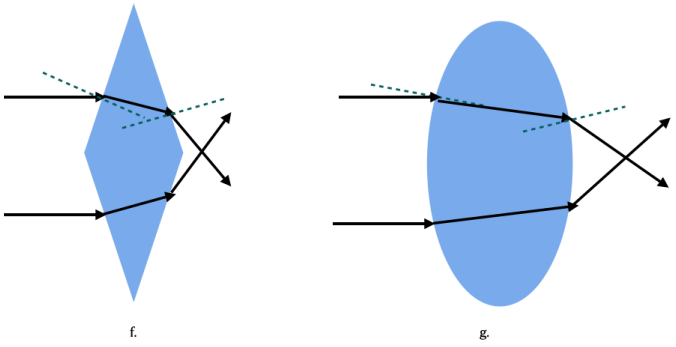
13.4 Lenses

Can you draw the continuation of the light ray through the each shape of glass block?



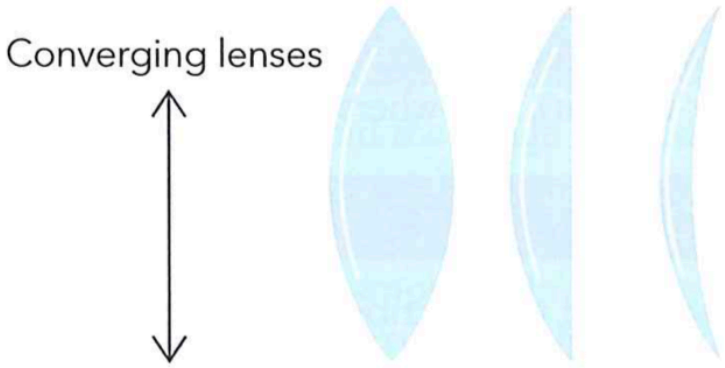
c. d. e.

light from all direction are **converged!**

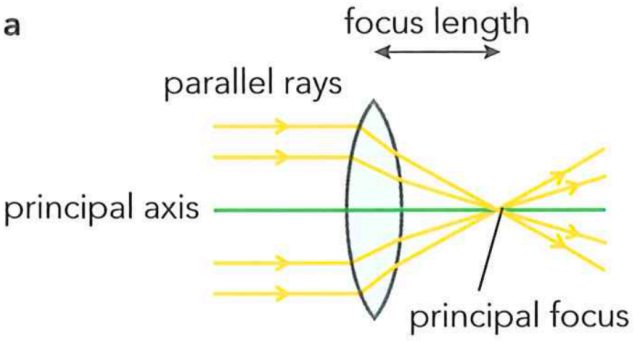


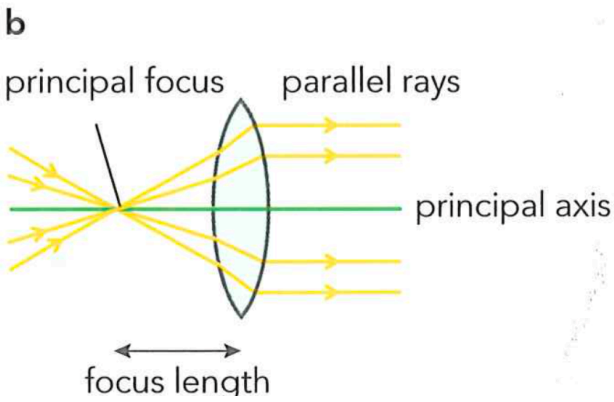
f. g.

converging lens: fatter in the middle => bring light together

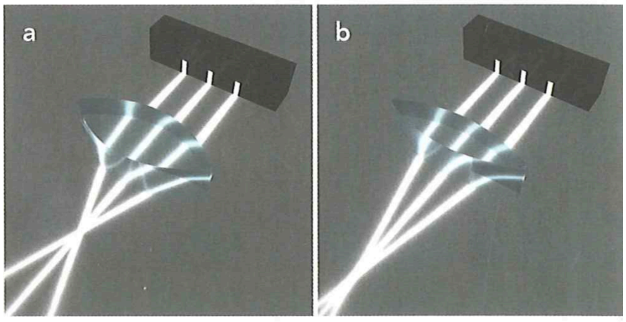


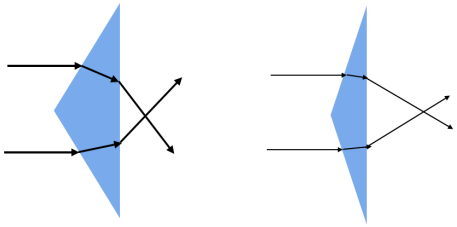
Parallel rays: Light comes from distant stars can be seen as parallel rays





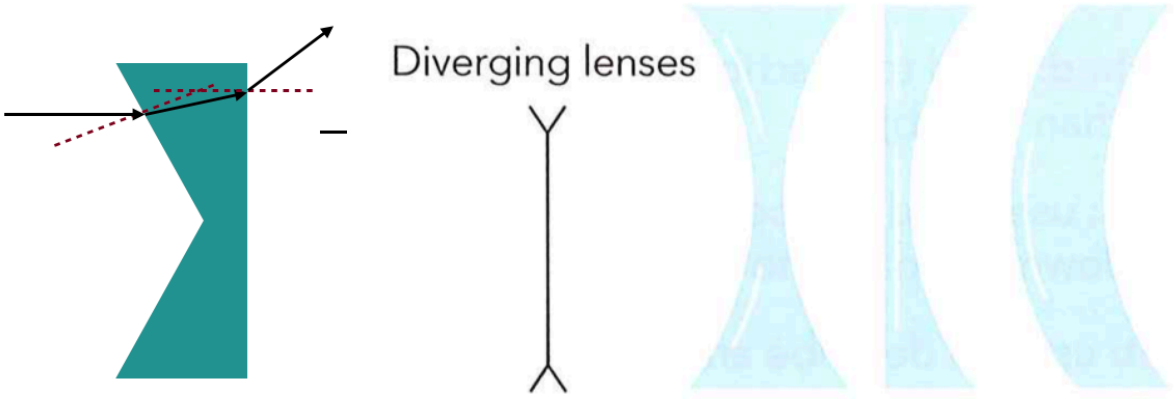
Principle axis: the line passing through the center of a lens perpendicular to its surface, denoted by dashed line
Focal point/principle focus: the point at which rays of light parallel to the principle axis converge after passing through a converging lens, denoted by F
Focal length: the distance from the center of the lens to its principle focus, denoted by f





fatter lens bends light more => **shorter** focal length

Diverging lens: <u>thinner</u> in the middle => spread light apart



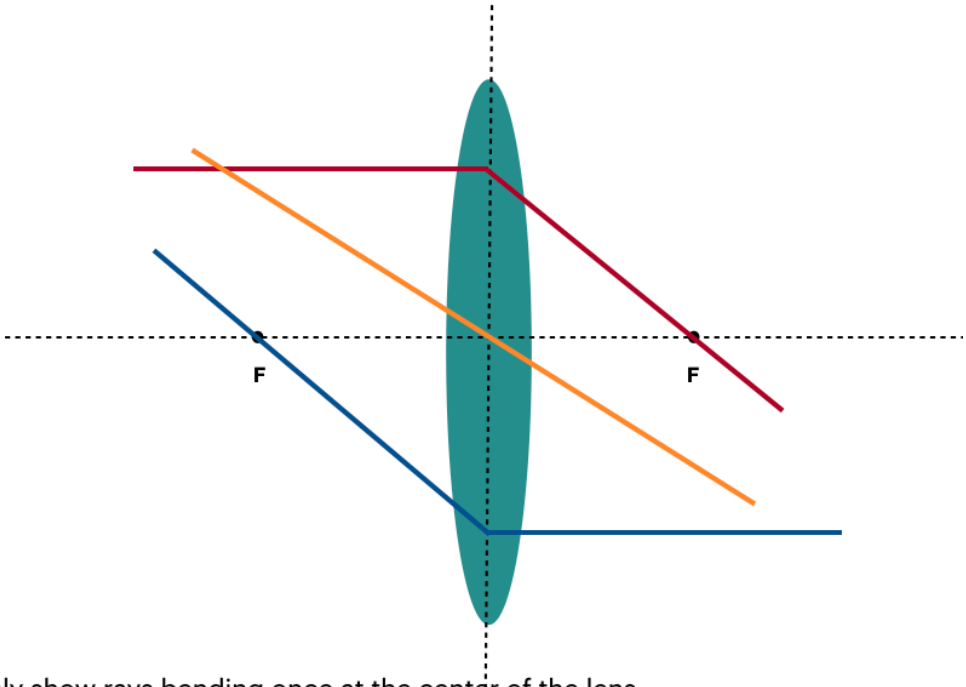
Drawing ray diagrams for lenses

Rays can be drawn:

1. central ray: unrefracted through the center of the lens

2. principle ray: parallel to the axis and then refracted through the principle focus

3. focal ray: through the focus and then parallel to the axis



To make things easier, we only show rays bending once at the center of the lens.

★ **Example:** draw a ray diagram to find the image formed of 3cm tall object placed 12cm from a converging lens which has a focal length of 5cm

Step 1: Draw the lens with a horizontal axis through the middle of it

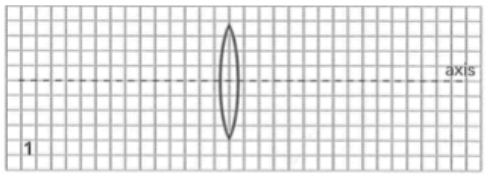


Figure 13.37a

Step 2: mark the positions of the principle focus(F) on either side , at 5cm from the center of the lens, mark the position of the object, O, along with a 3cm arrow standing on the axis. Place the arrow 12 cm from the lens.

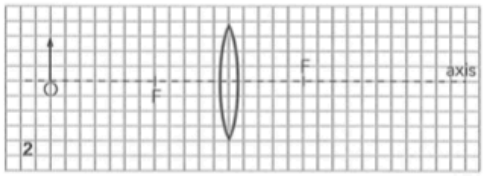


Figure 13.37b

Step 3: Draw ray 1(central ray), a straight line from the top of the object arrow which principle ray passes undeflected through the middle foe of of the lens

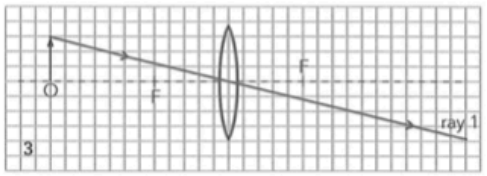
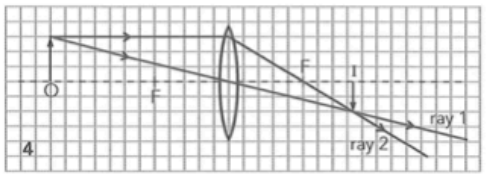


Figure 13.37c

Step 4: Draw ray 2 (principle ray) from the top of the object arrow parallel to the principle axis. As it passes through the lens, it is refracted through the principle focus.

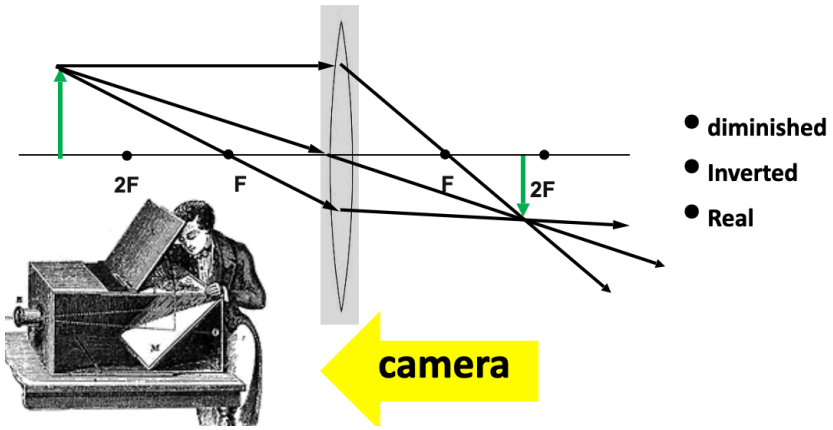


Images formed by lens could be described as:

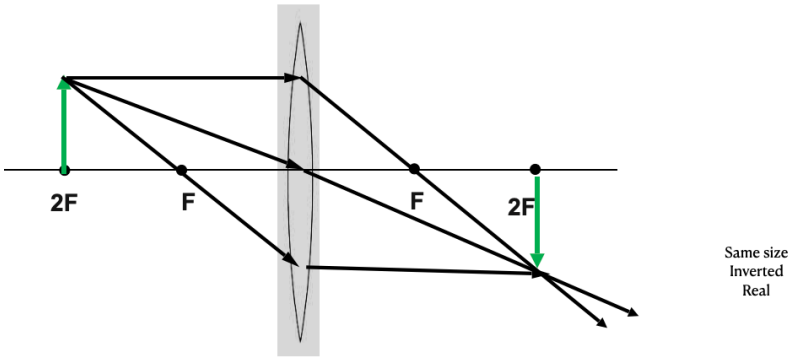
1. **Enlarged or diminished**
2. **Upright or Inverted**
3. **Real or virtual**
4. **Nearer or further to the lens than the object**

Images formed by converging lens

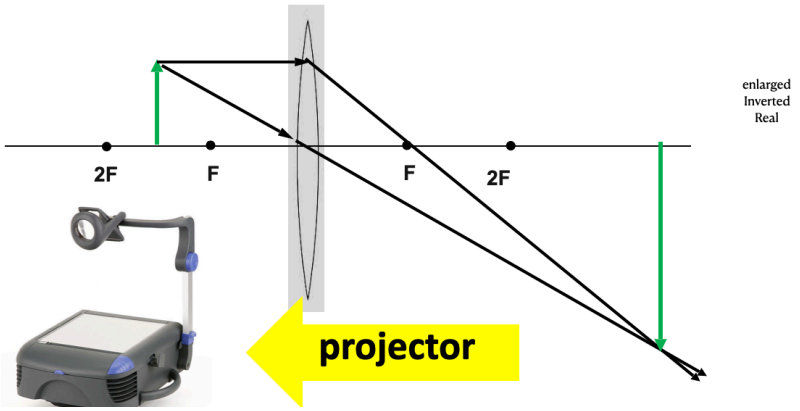
1. object is placed beyond 2F



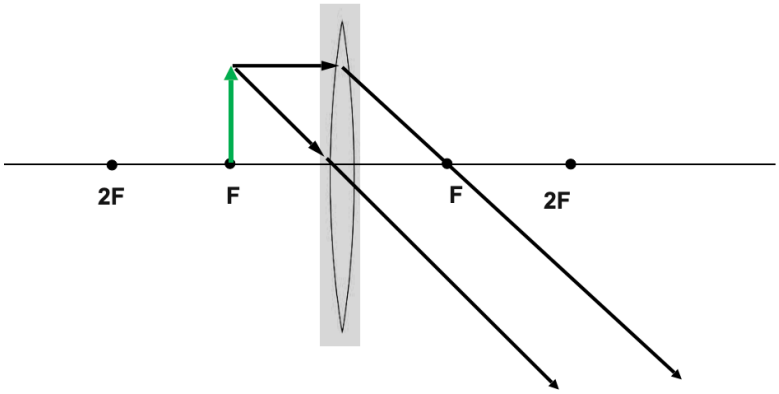
2. Object is placed at 2F



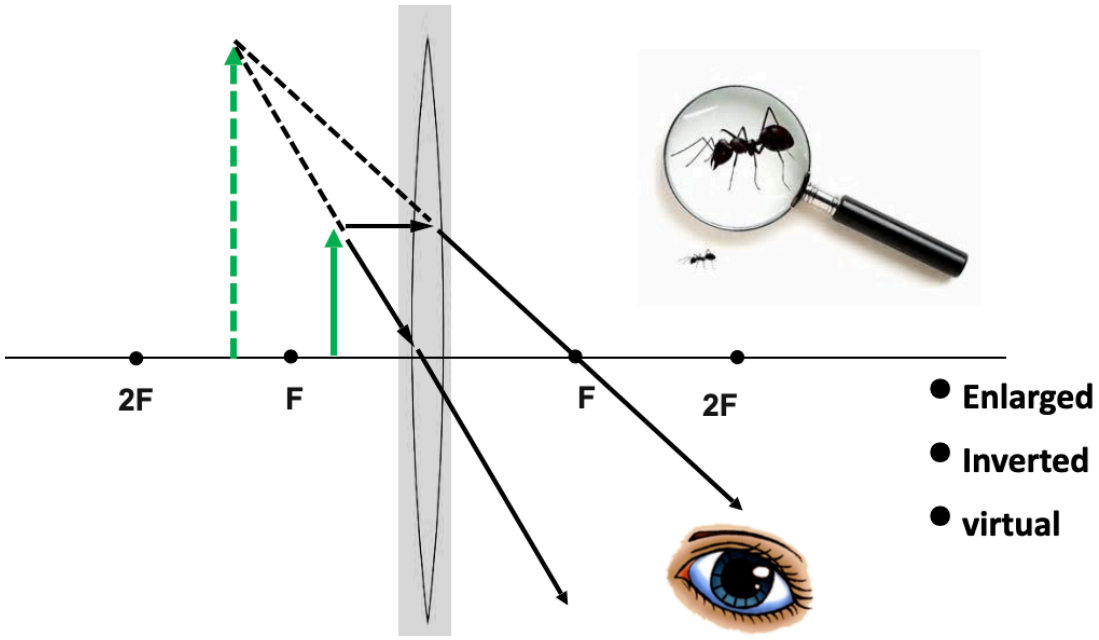
3. Object is placed between F and 2F



4. Object is placed at F

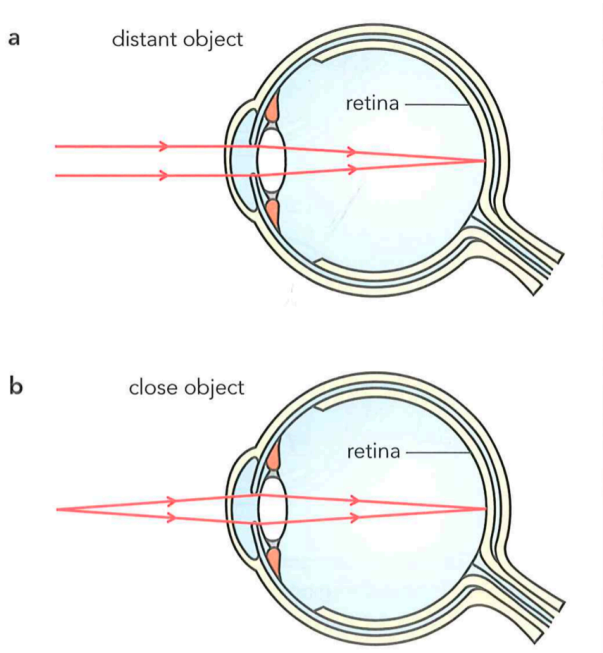


5. Object is placed within F

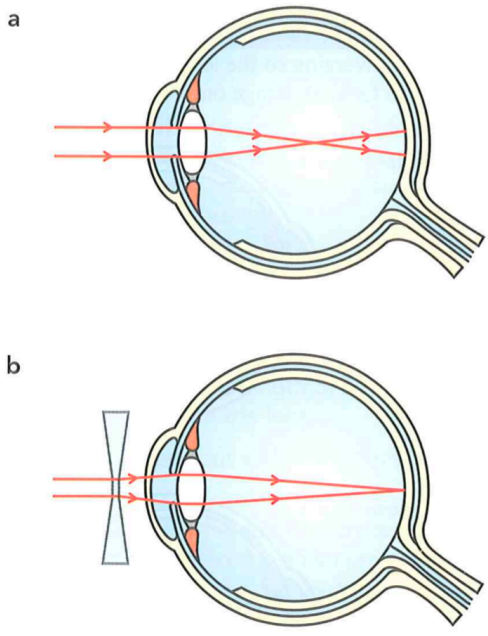


Using lenses to correct poor eyesight

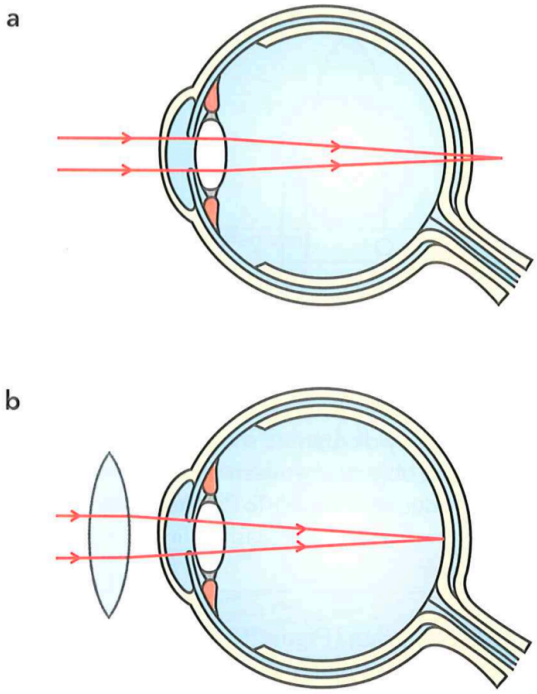
Normal eyes:



Short sight:

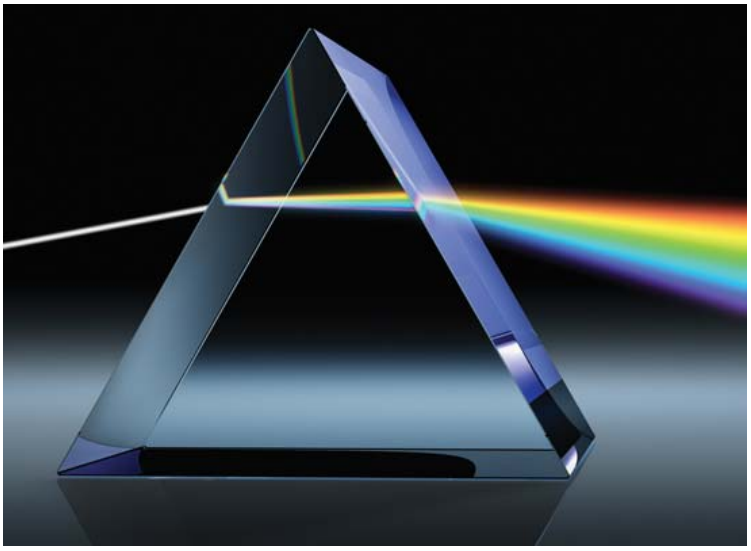


Long sight:



13.5 Dispersion of light

White light passing through a prism, form a spectrum. => dispersion.
How does this happen? What determines color?



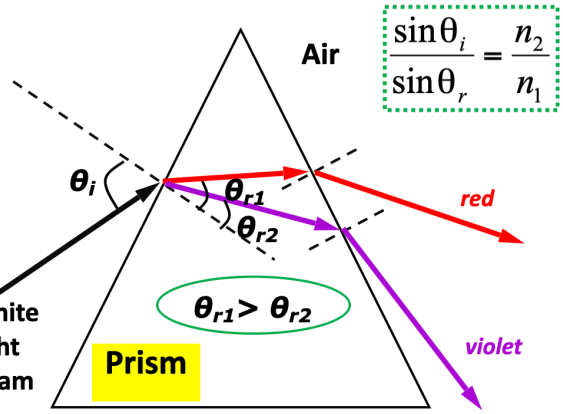
	Wavelength	Frequenzy
Red	~ 625 – 740 nm	~ 480 – 405 THz
Orange	~ 590 – 625 nm	~ 510 – 480 THz
Yellow	~ 565 – 590 nm	~ 530 – 510 THz
Green	~ 520 – 565 nm	~ 580 – 530 THz
Blue	~ 445 – 520 nm	~ 675 – 580 THz
Indigo	~ 425 – 445 nm	~ 700 – 675 THz
Violet	~ 380 – 425 nm	~ 790 – 700 THz

Def of dispersion: the separation of different wavelengths of light because they are refracted through different angles

Monochromatic light: Light of a single frequency

Explaining dispersion:

- The speed of light in **vacuum** is a constant **c ≈ 3×108 m/s**
- In a medium (not vacuum), light with higher the frequency travels slower.
- **Red** light travels the **fastest**
  Violet light travels the **slowest**.



$$\text{refractive index } (n) \longrightarrow n = \frac{c}{v} = \frac{\text{Speed of light in vacuum}}{\text{Speed of light in medium}}$$

$$n_{red} = \frac{c}{v_{red}} < n_{violet} = \frac{c}{v_{violet}}$$

One medium has different refractive index of different frequency of light

$$n_{red} < n_{yellow} < n_{green} < n_{blue} < n_{violet}$$