

7

Waves

Waves (AS Level 22)

An understanding of colour from Cambridge IGCSE/O Level Physics or equivalent is assumed.

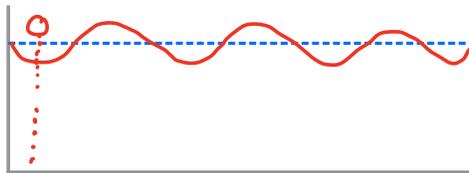
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7.1 Progressive waves

Candidates should be able to:

- 1 describe what is meant by wave motion as illustrated by vibration in ropes, springs and ripple tanks
- 2 understand and use the terms displacement, amplitude, phase difference, period, frequency, wavelength and speed
- 3 understand the use of the time-base and y-gain of a cathode-ray oscilloscope (CRO) to determine frequency and amplitude
- 4 derive, using the definitions of speed, frequency and wavelength, the wave equation $v = f\lambda$
- 5 recall and use $v = f\lambda$
- 6 understand that energy is transferred by a progressive wave
- 7 recall and use $intensity = power/area$ and $intensity \propto (amplitude)^2$ for a progressive wave

WAVE :-

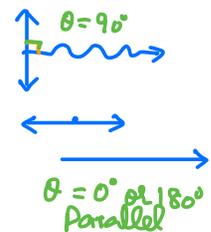
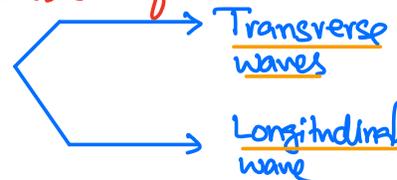


This is a disturbance in a medium.

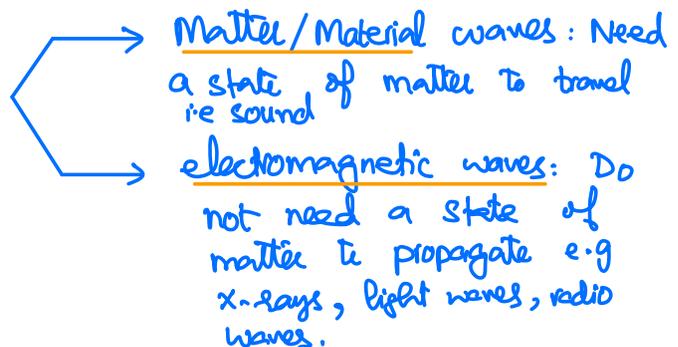
Classification of waves:

on the basis of

(i) Vibration / displacement of particle



(ii) material medium

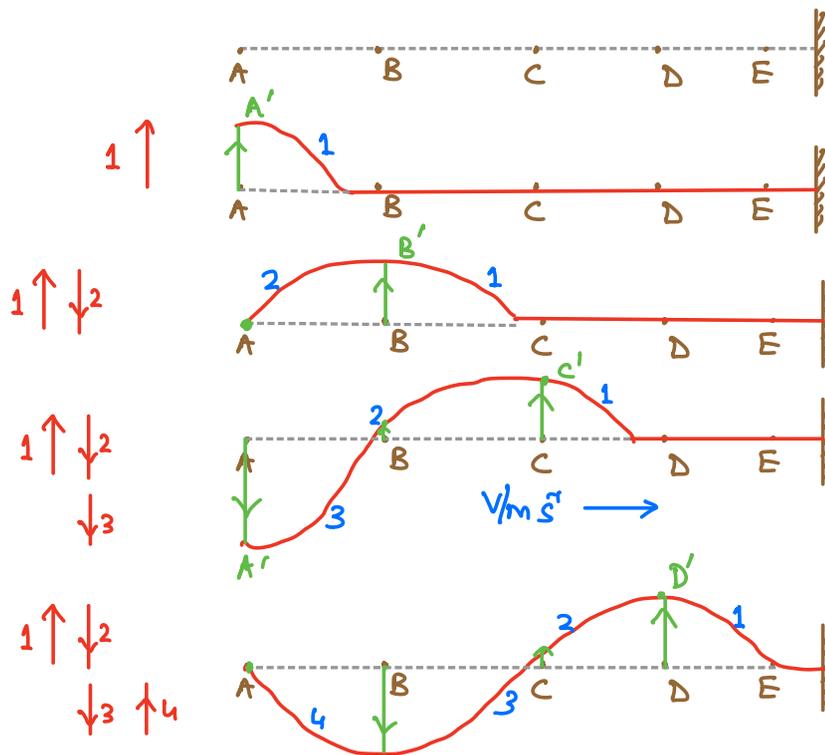


(iii) energy transfer

- Progressive waves : Energy is transferred along the wave
- Stationary waves : No energy is transferred along the wave.

Important terms :-

(i) Displacement :-



Def. Straight directed distance of a particle on wave from its mean/equilibrium position.

Symbol : s, x

Units : metre (m)

P.S. : Vector

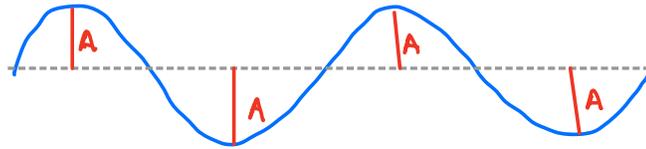
Direction : Always away from mean position.

(ii) Amplitude:

Def. Maximum value of displacement is amplitude.

Symbol: A

P.S. Scalar



(iii) Time period:-

Def. Time taken to complete one wave.

Symbol: T

P.S. Scalar

Unit: second (s)

(iv) Frequency:

Def. No. of complete waves generated by a source per unit time.

Symbol: f

Formula: $f = \frac{n}{t}$

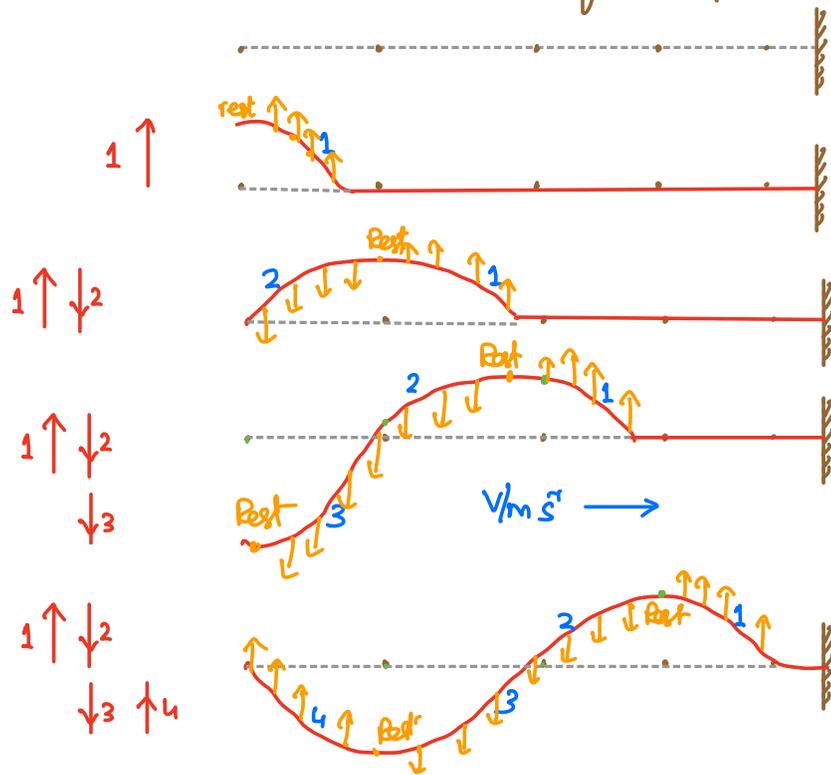
For one wave, $n=1$ and $t=T$

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

Units: s^{-1} or Hertz (Hz)

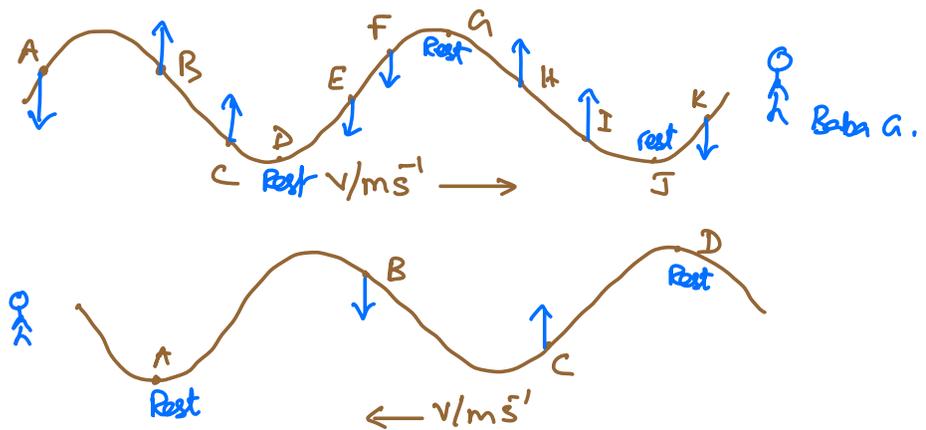
P.S: Scalar

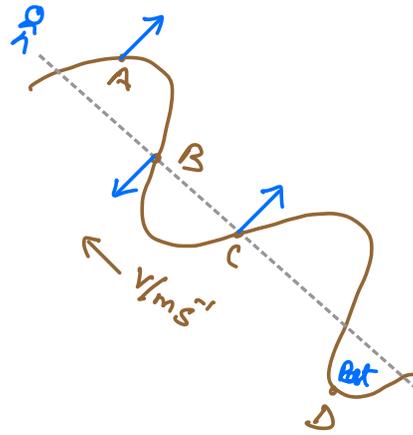
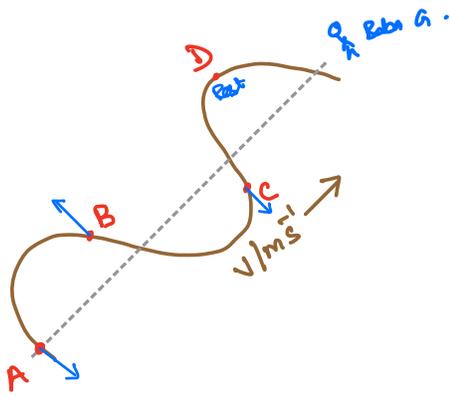
(v) Instantaneous motion of a particle on wave:-



Hint :: Study the motion a Baba G against the motion of wave. The motion of Baba G perpendicular to the motion of wave defines the instantaneous motion of a particle on transverse wave.

Example:





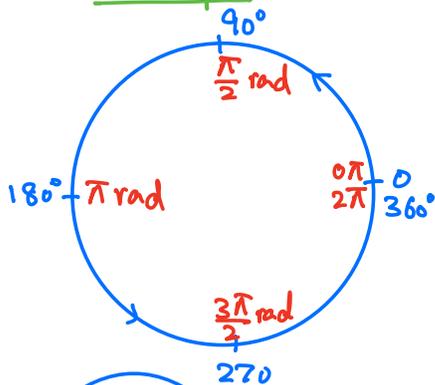
(vi) Phase angle / difference:

Symbol: ϕ

Units: degree ($^\circ$) or radian (rad)

Relationship: $\pi \text{ rad} = 180^\circ$

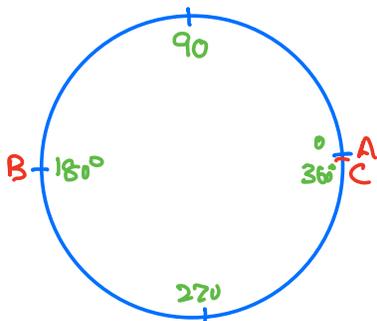
Concept:



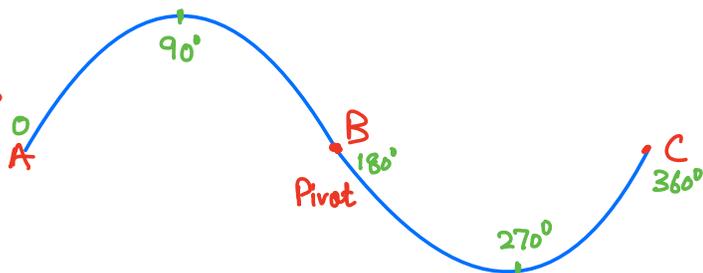
Single rotation transverse a 360° or 2π radian.



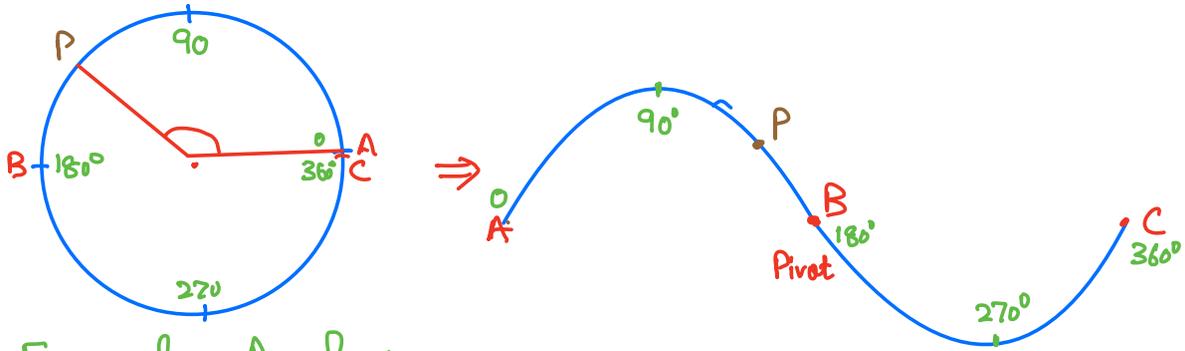
Exert force at end A, so that it rotate about pivot B and A makes contact with point C. Now we get a circle which represents 360° or 2π rad.



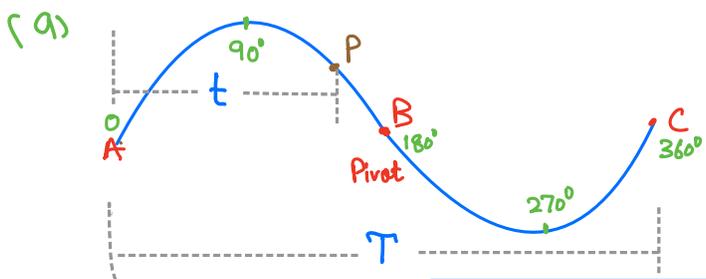
\Rightarrow



A waveform also represents a 360° or 2π rad.



Formula Analysis:

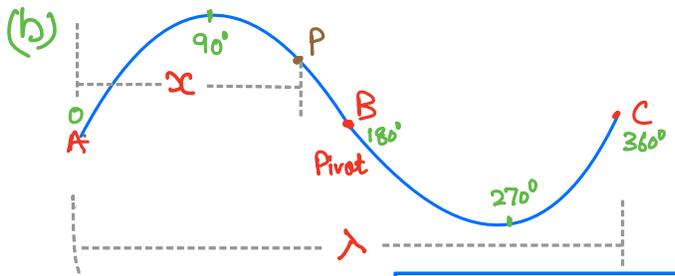


$$360^\circ \text{ --- } T$$

$$(\phi = ?) \text{ --- } t$$

$$\frac{\phi}{360} = \frac{t}{T}$$

$$\phi = \left(\frac{t}{T}\right) 360^\circ \quad \text{or} \quad \phi = \left(\frac{t}{T}\right) 2\pi$$



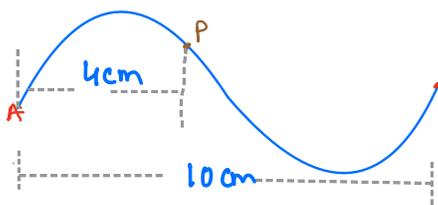
$$360^\circ \text{ --- } \lambda$$

$$(\phi = ?) \text{ --- } x$$

$$\frac{\phi}{360} = \frac{x}{\lambda}$$

$$\phi = \left(\frac{x}{\lambda}\right) 360^\circ \quad \text{or} \quad \phi = \left(\frac{x}{\lambda}\right) 2\pi$$

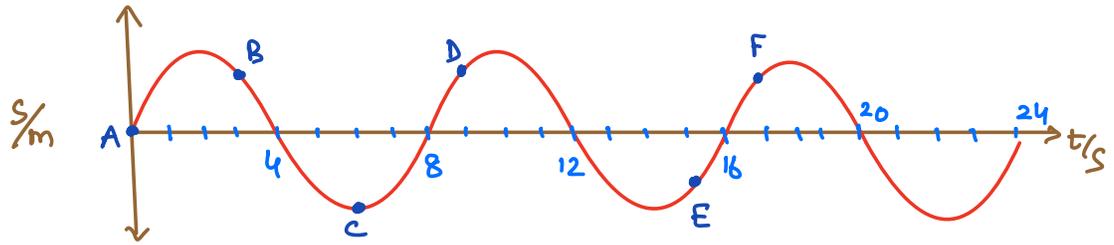
Example:



$$\phi_{AP} = \left(\frac{x}{\lambda}\right) 360^\circ$$

$$= \left(\frac{4}{10}\right) (360^\circ) = 144^\circ$$

Q)



Calculate phase angle b/w

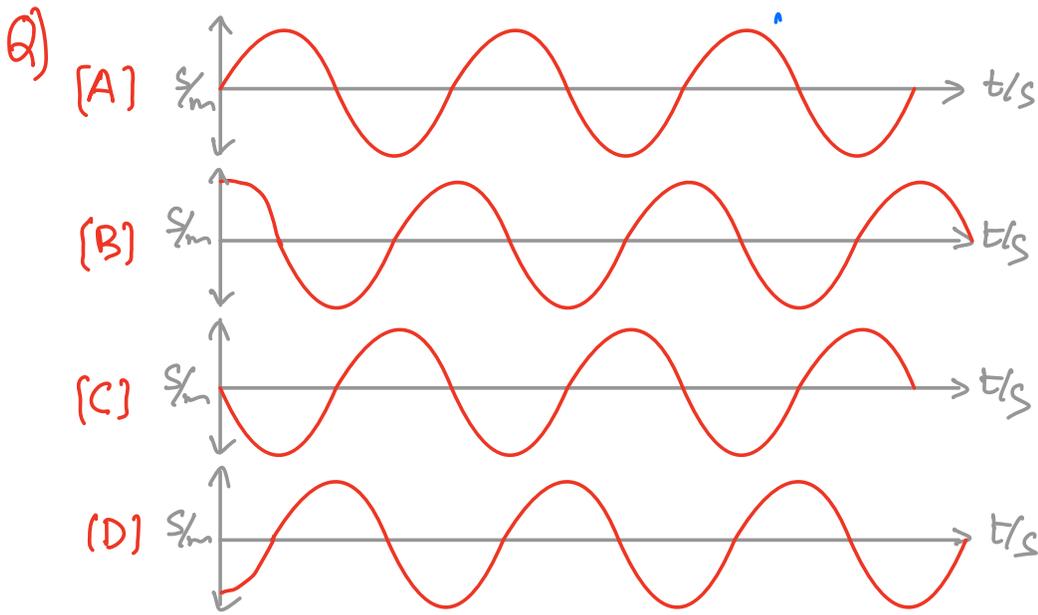
(i) AB $\phi_{AB} = \left(\frac{t_{AB}}{T}\right) 360^\circ \Rightarrow \phi = \left(\frac{3-0}{8}\right) (360^\circ) = 135^\circ$

(ii) AC $\phi_{AC} = \left(\frac{t_{AC}}{T}\right) (360^\circ) \Rightarrow \phi = \left(\frac{6-0}{8}\right) (360) = 270^\circ$

(iii) AE $\phi_{AE} = \left(\frac{t_{AE}}{T}\right) 360^\circ \Rightarrow \phi_{AE} = \left(\frac{15-0}{8}\right) (360^\circ) = 675^\circ$
 $\phi_{AE} = 675 - 360 = 315^\circ$

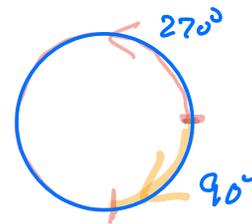
(iv) CE $\phi_{CE} = \left(\frac{t_{CE}}{T}\right) (360^\circ) = \left(\frac{15-6}{8}\right) (360^\circ) = 405^\circ$
 $\phi_{CE} = 405 - 360 = 45^\circ$

(v) BF $\phi_{BF} = \left(\frac{t_{BF}}{T}\right) (360^\circ) = \left(\frac{17-3}{8}\right) (360^\circ) = 630^\circ$
 $\phi_{BF} = 630 - 360 = 270^\circ$

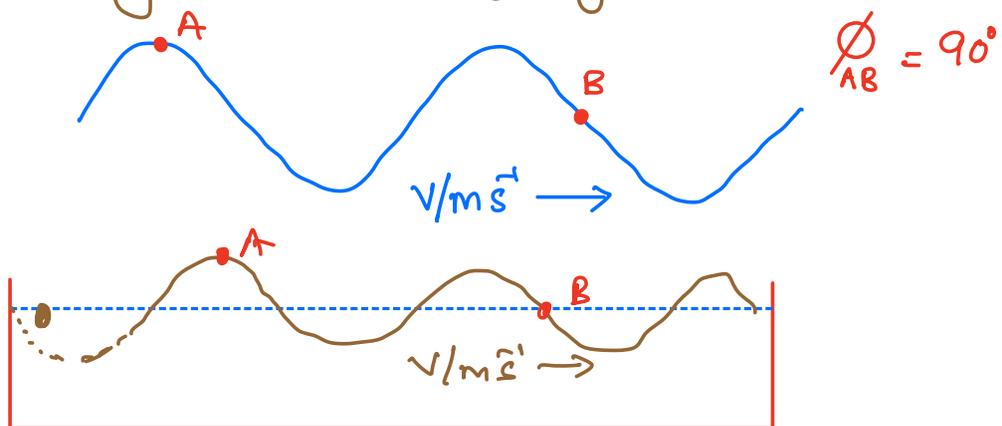


State phase angle b/w

- (i) AB 90° or 270°
- (ii) AC 180°
- (iii) AD 270° or 90°
- (iv) BC 90° or 270°
- (v) BD 180°
- (vi) CD 90° or 270°



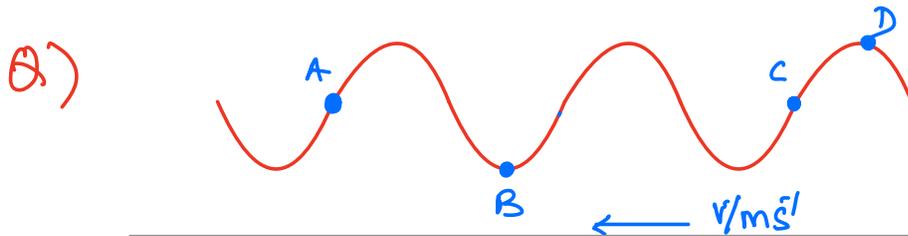
(vii) Leading and Lagging Concept:



Hint: Always consider the source of waveform as an enemy. The particle on wave closer to disturbance level/energy is leading while the other behind this particle is lagging

So

A leads B by a phase angle of 90°
 or B lags A " " " " " "



	Lead	Lag	ϕ
AB	B	A	270
BC	C	B	90
CD	D	C	90
AC	C	A	0 or 360
BD	D	B	180
AD	D	A	90

- 5 The variation with time t of the displacement x of a point in a transverse wave T_1 is shown in Fig. 5.1.

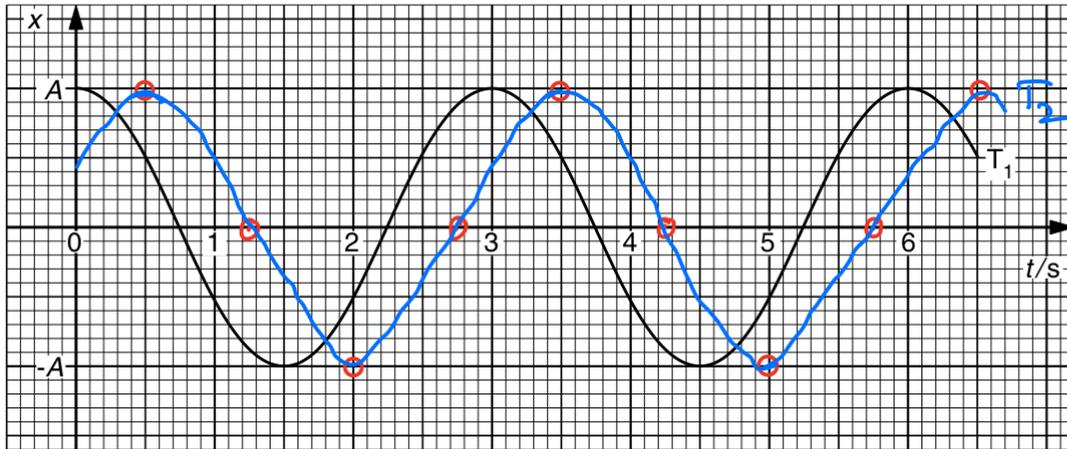


Fig. 5.1

$$\phi = \left(\frac{t}{T}\right) 360^\circ$$

$$60 = \left(\frac{t}{3.0}\right) (360^\circ) \Rightarrow t = 0.50 \text{ s}$$

- (a) By reference to displacement and direction of travel of wave energy, explain what is meant by a *transverse* wave.

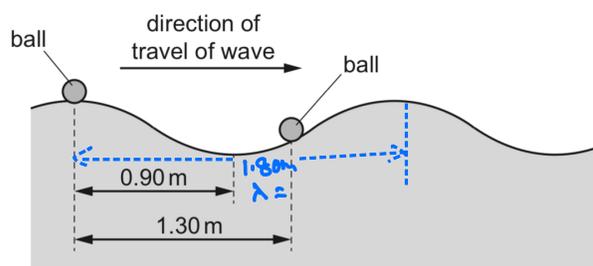
Wave in which displacement of particle is 90° to the direction of travel of wave energy. [1]

- (b) A second transverse wave T_2 , of amplitude A has the same waveform as wave T_1 but lags behind T_1 by a phase angle of 60° . The two waves T_1 and T_2 pass through the same point. $\phi = 60^\circ$

- (i) On Fig. 5.1, draw the variation with time t of the displacement x of the point in wave T_2 . [2]

Q. no. 21
N 21/21 Two balls float on the surface of the sea. The balls are separated by a distance of 1.30 m.

A wave travels on the surface of the sea so that the balls move vertically up and down.



$$\phi = \left(\frac{x}{\lambda}\right) 360^\circ$$

$$= \left(\frac{1.30}{1.80}\right) 360$$

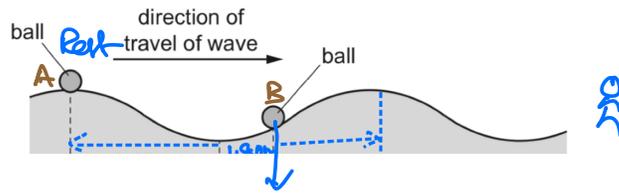
$$= 260^\circ$$

NOT TO SCALE

The distance between a crest and an adjacent trough of the wave is 0.90 m.

What is the phase difference between the two balls?

- A 55° B 110° C 160° **D 260°**



Source as energy concept { Leading ball : A
Lagging ball : B

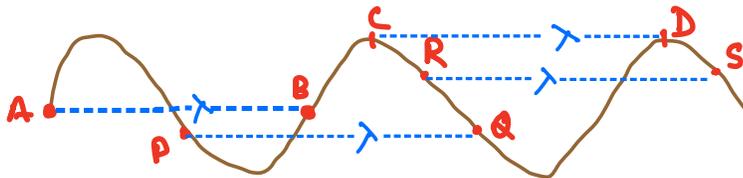
Ball's concept { Direction of velocity of ball A: Rest
Direction of velocity of ball B: Downward

(viii) Wavelength :-

Def Distance b/w two consecutive inphase particles is wavelength.

Symbol: λ

Waveform:



P.S: Scalar

(ix) Speed :-

Def Distance travelled by a wave per unit time.

Formula: $Speed = \frac{Distance}{Time}$

For one wave,

Distance moved = Wavelength (λ)

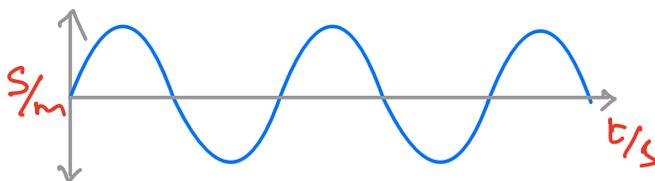
Time taken = Time period (T)

$$v = \frac{\lambda}{T} \Rightarrow v = \left(\frac{1}{T}\right) \lambda$$

$$v = f \lambda$$

(x) Difference b/w displacement-time and displacement distance graph:

Displacement-time graph

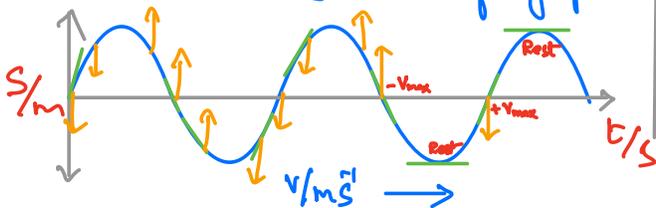


Results:

- (i) Time period \rightarrow x-axis
- (ii) Frequency $\rightarrow f = \frac{1}{T}$
- (iii) Instantaneous displacement \rightarrow Y-axis

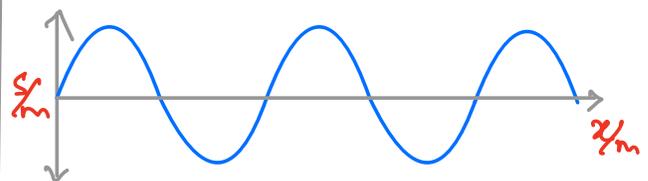
(iv) Amplitude \rightarrow Y-axis

(v) velocity of a particle on wave (Baba's?) \rightarrow Gradient of graph



speed of a wave ($v = f \lambda$)

Displacement-distance graph



Results:

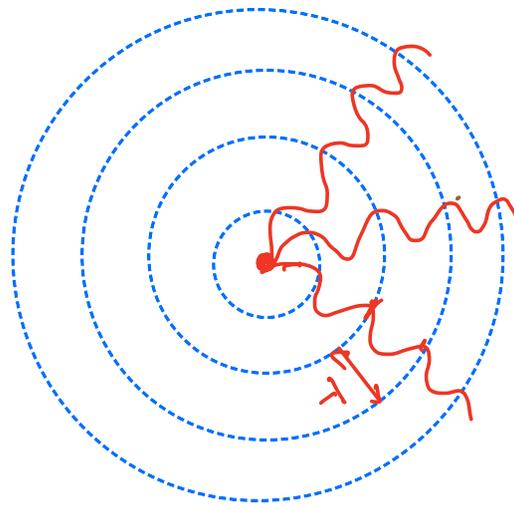
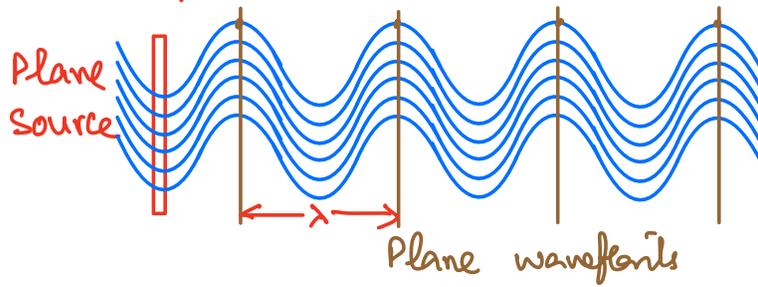
- (i) Wavelength \rightarrow x-axis
- (ii) Instantaneous displacement \rightarrow Y-axis

(iii) Amplitude \rightarrow Y-axis

obtained using both graphs.

(xi) Wavefronts:-

Concept:-



Spherical / Circular wavefronts.

(xii) Monochromatic light source:-
Single colour

Def. Source which emits light having single frequency or wavelength or colour.

Example: LASER, Sodium source which emit light of yellow colour. Filters can be used to make light having single colours.

(xiii) Intensity:-

V.V. Samp

Def. Energy per unit time per unit perpendicular area is Intensity.

Symbol: I

Formula: $I = \frac{E}{tA} \Rightarrow I = \frac{E}{tA} \Rightarrow I = \frac{P}{A}$

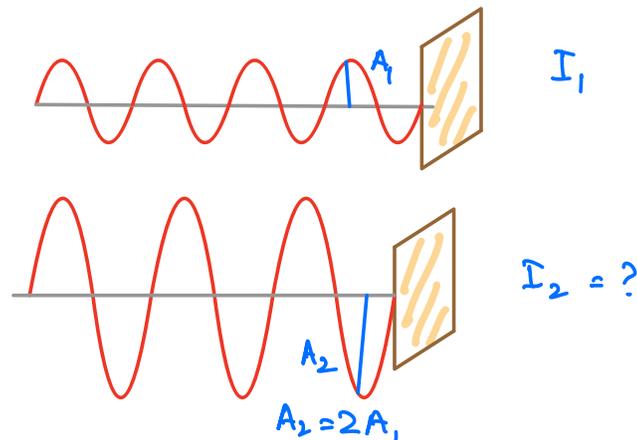
Units: $J s^{-1} m^{-2} = W m^{-2} = kg s^{-3}$

P.S: Scalar

Smp Dependance:

(i) Square of Amplitude:

Intensity \propto (Amplitude)²



$$I \propto A^2$$
$$\frac{I_2}{I_1} = \frac{A_2^2}{A_1^2} \Rightarrow \frac{I_2}{I_1} = \frac{(2A_1)^2}{A_1^2}$$

$$I_2 = 4I_1$$

(ii) Square of frequency

Intensity \propto (frequency)²

Energy of a wave/oscillating object

$$E = \frac{1}{2} m \omega^2 x_0^2$$
$$= \frac{1}{2} m (2\pi f)^2 x_0^2$$
$$= 2\pi^2 m f^2 x_0^2$$

(iii) Inverse square of distance b/w source and perpendicular area:-

$$\text{Intensity} \propto \frac{1}{(\text{distance})^2}$$

Study of waveforms using CRO:-

Note:

1. The Scale associated with x-plates is called time-base control or x-plate sensitivity and represent time in terms of no. of divisions ie 4ms/cm

2. The Scale associated with Y-plates is called Gain control or Y-plate sensitivity and represent voltage in terms of no. of divisions ie 2V/cm

Formulae:

(1) Time period:

$$T = \left(\begin{array}{l} \text{no. of divisions to} \\ \text{represent a waveform} \end{array} \right) \left(\begin{array}{l} \text{x-plate} \\ \text{sensitivity} \end{array} \right)$$

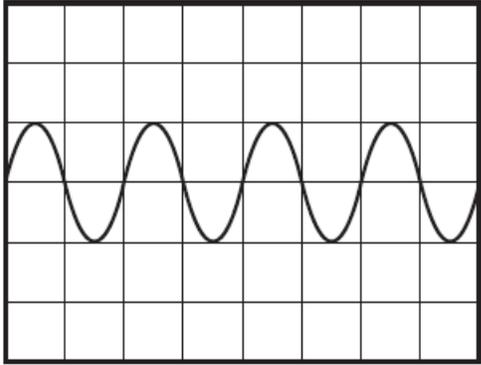
(2) Frequency: $f = \frac{1}{T}$

(3) Amplitude:

$$A = \left(\begin{array}{l} \text{no. of divisions to} \\ \text{represent the peak} \\ \text{value} \end{array} \right) \left(\begin{array}{l} \text{Y-plate} \\ \text{sensitivity} \end{array} \right)$$

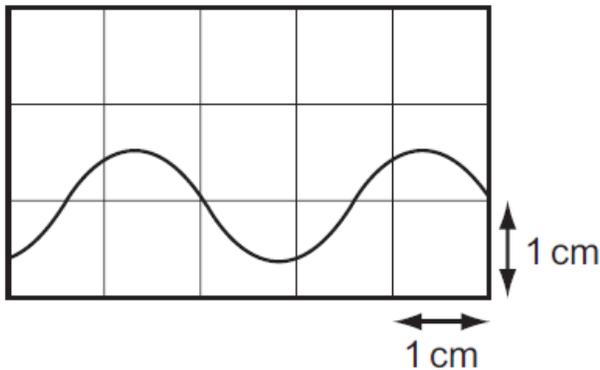
Measurements using CRO

1. A whale produces sound waves of frequency 5 Hz. The waves are detected by a microphone and displayed on an oscilloscope.



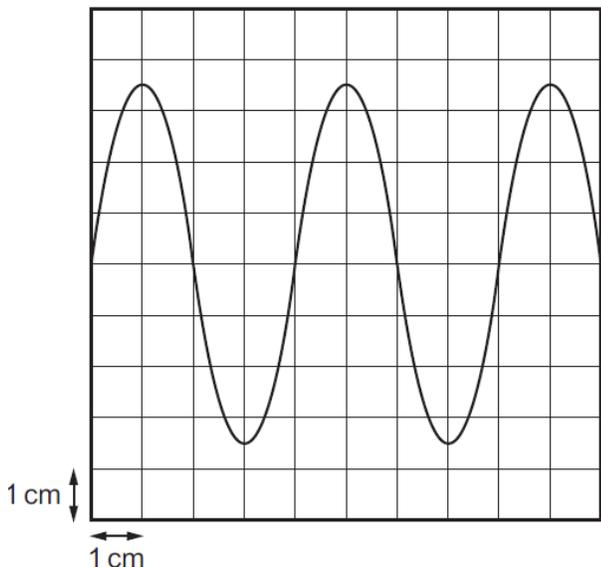
What is the time-base setting on the oscilloscope?
A 0.1 ms div^{-1} **B** 1 ms div^{-1}
C 10 ms div^{-1} **D** 100 ms div^{-1}
 {Q.4/June 15/11}

2. A cathode-ray oscilloscope (c.r.o.) is used to display the trace from a sound wave. The time-base is set at $5 \mu\text{s mm}^{-1}$



What is the frequency of the sound wave?
A 6.7 Hz **B** 67 Hz
C 6.7 kHz **D** 67 kHz.
 {Q25/June 15/13}

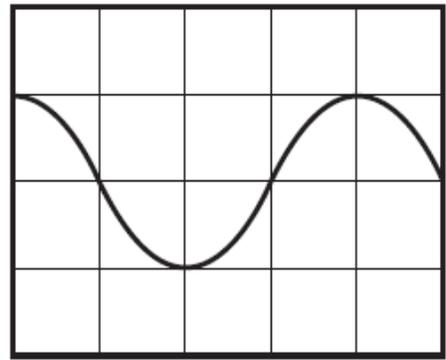
3. A cathode-ray oscilloscope (c.r.o.) is connected to an alternating voltage. The following trace is produced on the screen.



The oscilloscope time-base setting is 0.5 ms cm^{-1} and the Y-plate sensitivity is 2 V cm^{-1} . Which statement about the alternating voltage is correct?
A The amplitude is 3.5 cm.
B The frequency is 0.5 kHz.
C The period is 1 ms.
D The wavelength is 4 cm.
 {Q3/June 14/12}

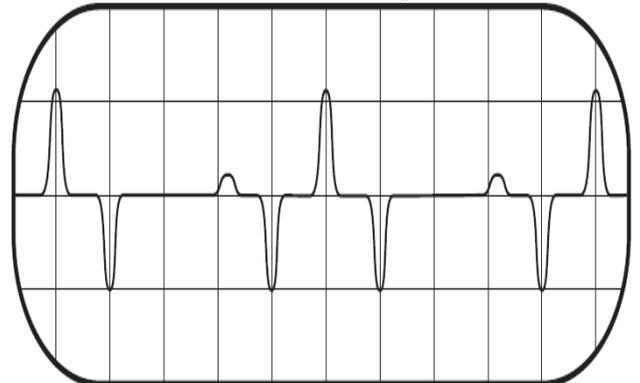
4. The display on a cathode-ray oscilloscope shows the signal produced by an electronic circuit. The time-base is set at $5.0 \text{ ns per division}$ and the Y-

gain at $10 \text{ V per division}$.



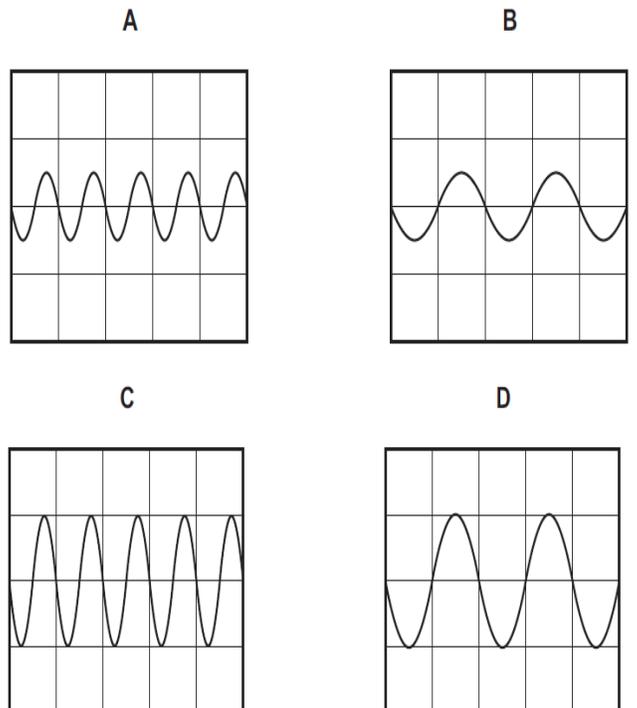
What is the frequency of the signal?
A $2.0 \times 10^{-8} \text{ Hz}$ **B** $2.5 \times 10^{-2} \text{ Hz}$
C $5.0 \times 10^7 \text{ Hz}$ **D** $3.1 \times 10^8 \text{ Hz}$
 {Q.5/June 14/13}

5. A signal that repeats periodically is displayed on the screen of a cathode-ray oscilloscope.



The screen has 1 cm squares and the time base is set at 2.00 ms cm^{-1} . What is the frequency of this periodic signal?
A 50 Hz **B** 100 Hz **C** 125 Hz **D** 200 Hz
 {Q.4/Nov 13/11,12}

6. The Y-input terminals of a cathode-ray oscilloscope (c.r.o.) are connected to a supply of amplitude 5.0 V and frequency 50 Hz . The time-base is set at $10 \text{ ms per division}$ and the Y-gain at $5.0 \text{ V per division}$. Which trace is obtained?

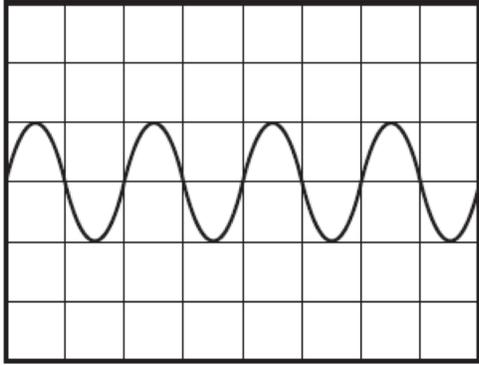


{Q6/June 13/11 & Q4/Nov 06}

Answer Grid:

Q. No.	1	2	3	4	5	6
Answer	D	C	B	C	B	D

A whale produces sound waves of frequency 5 Hz. The waves are detected by a microphone and displayed on an oscilloscope.



What is the time-base setting on the oscilloscope?

- A 0.1 ms div⁻¹
C 10 ms div⁻¹

B 1 ms div⁻¹

D 100 ms div⁻¹ = $\frac{100}{1000} = 0.10$

$$T = \frac{1}{f} = \frac{1}{5} = 0.20 \text{ s}$$

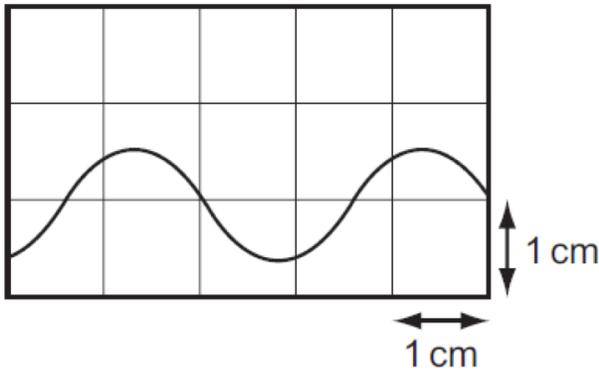
$$T = (n_x)(\text{Time base setting})$$

$$0.20 = (2)(\text{Time base setting})$$

$$(\text{Time base setting}) = \frac{0.20}{2} = 0.10 \text{ s/div}$$

2.

A cathode-ray oscilloscope (c.r.o.) is used to display the trace from a sound wave. The time-base is set at 5 μs mm⁻¹



What is the frequency of the sound wave?

- A 6.7 Hz
 C 6.7 kHz

- B 67 Hz
D 67 kHz.

$$T = (n_x)(\text{Time base setting})$$

$$T = (3)\left(\frac{5 \times 10^{-6}}{10^{-1}}\right) = 1.5 \times 10^{-4} \text{ s}$$

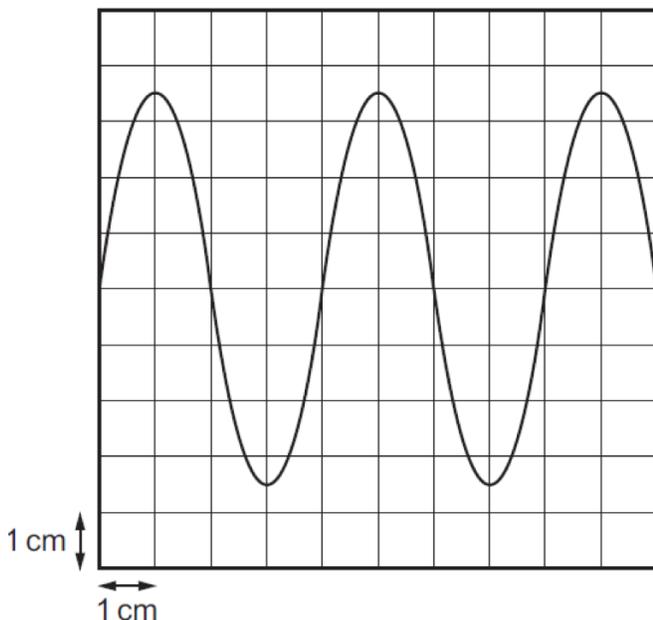
$$f = \frac{1}{T} = \frac{1}{1.5 \times 10^{-4}}$$

$$6666.7 \text{ Hz} = 6.67 \times 10^3 \text{ Hz}$$

$$6.7 \text{ kHz}$$

3.

A cathode-ray oscilloscope (c.r.o.) is connected to an alternating voltage. The following trace is produced on the screen.



The oscilloscope time-base setting is 0.5 ms cm⁻¹ and the Y-plate sensitivity is 2 V cm⁻¹.

Which statement about the alternating voltage is correct?

- A The amplitude is 3.5 cm.
 B The frequency is 0.5 kHz.
C The period is 1 ms.
D The wavelength is 4 cm.

$$\begin{aligned} \text{Amplitude} &= (n_y)(\text{Gain control}) \\ &= (3.5)(2) \\ &= 7 \text{ V} \end{aligned}$$

$$\begin{aligned} T &= (n_x)(\text{time base control}) \\ &= (4)(0.5 \times 10^{-3}) \\ &= 2 \times 10^{-3} \text{ s} \end{aligned}$$

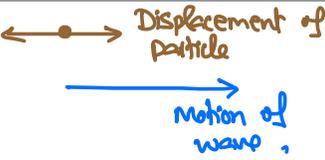
$$f = \frac{1}{T} = \frac{1}{2 \times 10^{-3}} = 500 \text{ Hz}$$

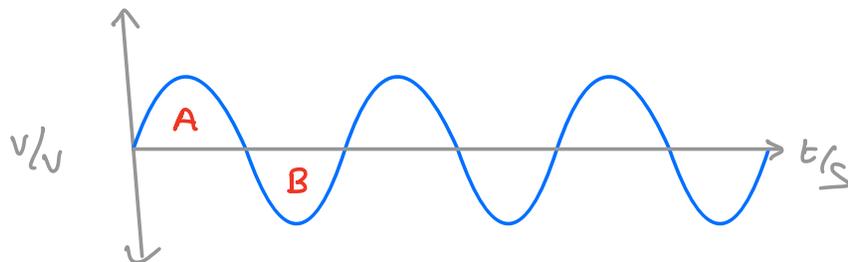
$$f = 0.5 \text{ kHz}$$

7.2 Transverse and longitudinal waves

Candidates should be able to:

- 1 compare transverse and longitudinal waves
- 2 analyse and interpret graphical representations of transverse and longitudinal waves

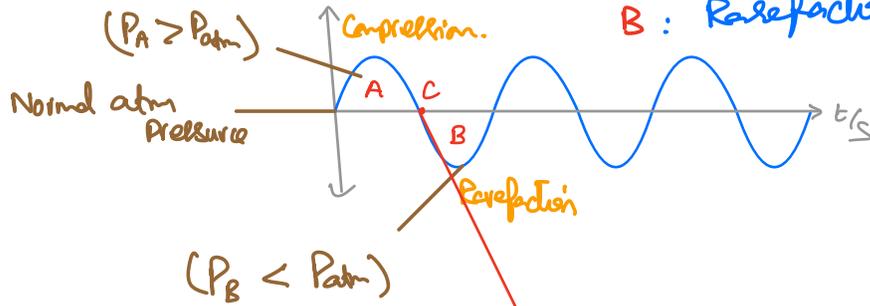
		Transverse waves	Longitudinal waves
1.	Def.	Waves in which displacement/vibration of particle is <u>perpendicular</u> to motion of wave energy.	Waves in which displacement/vibration of particle is <u>parallel</u> to motion of wave energy.
	Composition	Crest and trough	Compression and rarefaction
	Geometrical form.		
	Examples	Water waves, wave along a rope/string, e.m. waves	Sound wave
	Polarisation	can be polarised	can not be polarised



Above wave form can be transverse or longitudinal.

of transverse \rightarrow A : crest
B : Trough

of Longitudinal \rightarrow A : Compression
B : Rarefaction



Region of maximum compression because particles at region move towards right and particles at region B move towards left. So greatest compression is produced at region C.

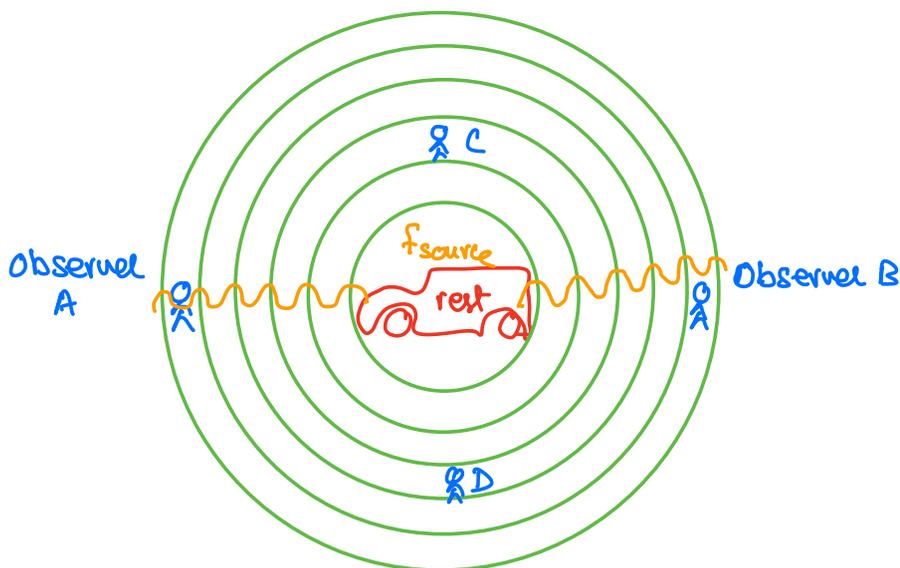
7.3 Doppler effect for sound waves

Candidates should be able to:

- 1 understand that when a source of sound waves moves relative to a stationary observer, the observed frequency is different from the source frequency (understanding of the Doppler effect for a stationary source and a moving observer is not required)
- 2 use the expression $f_o = f_s v / (v \pm v_s)$ for the observed frequency when a source of sound waves moves relative to a stationary observer

Doppler effect:

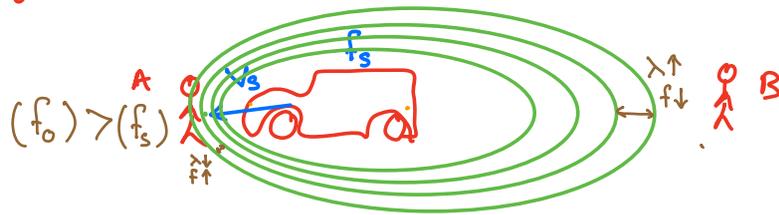
Statement: The apparent change in frequency (observed frequency) of a sound due to motion of a source relative to an observer.



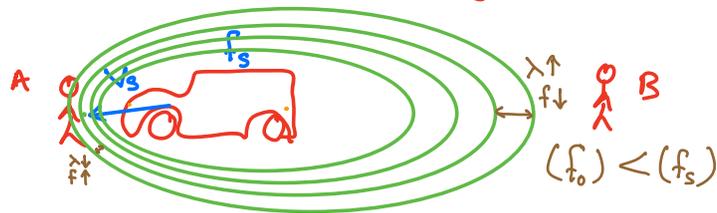
$$(f_A = f_B = f_C = f_D) = f_{\text{source}} = f_{\text{wave}}$$

$$\lambda_{\text{source}} = \lambda_{\text{waves}} = \lambda_{\text{observed}}$$

Case 1: If a source move towards observer:



Case 2: If a source move away from observer:



Formula :-
$$f_o = \frac{(f_s)(v)}{v \pm v_s}$$

Here f_o - observed frequency
 f_s - Frequency of source
 v - velocity / speed of wave
 v_s - velocity / speed of source

Case 1: If source and sound wave move in same direction i.e source move toward observer

Relative speed :

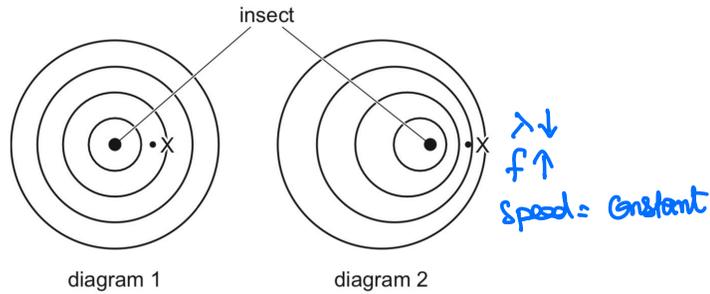
$$f_o = \frac{(f_s)(v)}{v - v_s} \Rightarrow (f_o > f_s)$$

Case 2: If source and sound wave move in opposite directions: i.e source move away from observer

Relative speed : $v + v_s$

$$f_o = \frac{(f_s)(v)}{v + v_s} \Rightarrow (f_o < f_s)$$

- 25 A stationary insect on the surface of water creates circular waves with its legs, as shown in diagram 1. The insect begins to travel to the right as shown in diagram 2.



Which row describes the change to the waves at X caused by the movement of the insect?

	frequency	wave speed
A	decreases	increases
B	decreases	stays the same
C	increases	increases
D	increases	stays the same

- 26 In one of the first experiments to demonstrate the Doppler effect, a train was filled with trumpeters all playing a note of frequency 440 Hz. The difference in observed frequency of the note as the train directly approached a stationary observer was 22 Hz. The speed of sound was 340 m s⁻¹.

At which speed was the train moving?

- A** 15.4 m s⁻¹ **B** 16.2 m s⁻¹ **C** 17.0 m s⁻¹ **D** 17.9 m s⁻¹

$$f_o = \frac{(f_s)(v)}{v - v_s}$$

$$462 = \frac{(440)(340)}{340 - v_s} \Rightarrow v_s = 16.19 \text{ m s}^{-1}$$

$$f_s = 440 \text{ Hz}$$

$$f_o = 440 + 22 = 462 \text{ Hz}$$

$$v = 340 \text{ m s}^{-1}$$

$$v_s = ?$$

- 24 The siren of a moving police car emits a sound wave with a frequency of 440 Hz. A stationary observer hears sound of frequency 494 Hz. The speed of sound in the air is 340 m s⁻¹.

What could be the speed and the direction of movement of the car?

- A** 37 m s⁻¹ directly towards the observer
B 37 m s⁻¹ directly away from the observer
C 42 m s⁻¹ directly towards the observer
D 42 m s⁻¹ directly away from the observer

$$f_s = 440 \text{ Hz}$$

$$f_o = 494 \text{ Hz}$$

$$v = 340 \text{ m s}^{-1}$$

$$v_s = ?$$

Since ($f_o > f_s$) so source move towards observer

$$f_o = \frac{(f_s)(v)}{v - v_s} \Rightarrow 494 = \frac{(440)(340)}{340 - v_s} \Rightarrow v_s = \underline{\hspace{2cm}}$$

- 23 A loudspeaker emitting a constant frequency of 2000 Hz is swung in a horizontal circle with a speed of $15.0 \text{ m s}^{-1} = v_s$ $f_s =$

A stationary observer is level with the loudspeaker and situated a long distance from the loudspeaker. The observer hears a sound of varying frequency. The maximum frequency heard is 2097 Hz. $= f_o$ i.e. ($f_o > f_s$) i.e. loudspeaker is moving towards observer

What is the speed of the sound in the air?

$$f_o = \frac{(f_s)(v)}{v - v_s}$$

- A 294 m s^{-1} B 309 m s^{-1} C 324 m s^{-1} D 330 m s^{-1}

$$2097 = \frac{(2000)(v)}{v - 15.0}$$

$$v = \text{m s}^{-1}$$

- 25 A train travels in a straight line at a constant speed of $30 \text{ m s}^{-1} = v_s$. The train's horn continuously emits sound of frequency 2400 Hz. $= f_s$

$$f_o = \frac{(f_s)(v)}{v \pm v_s}$$

A stationary observer stands next to the train track. The train approaches the stationary observer, passes him and then moves away. When train approaches an observer: When train recedes an observer:

The speed of sound is $340 \text{ m s}^{-1} = v$. $f_o = \frac{(f_s)(v)}{v - v_s} = \frac{(2400)(340)}{340 - 30} = 2632$ $f_o = \frac{(f_s)(v)}{v + v_s} = \frac{(2400)(340)}{340 + 30} = 2205$

What is the maximum difference in the frequencies of the sound heard by the stationary observer?

$$\Delta f = 2632 - 2205 = 427 \text{ Hz}$$

- A 190 Hz B 230 Hz C 430 Hz D 460 Hz

- I An ambulance has a siren that emits sound of a constant frequency. The ambulance is moving directly towards a stationary observer. $f_o \uparrow$

The ambulance decelerates as it is approaching the observer and then accelerates after it has passed the observer.

How does the frequency of the sound heard by the observer change as the ambulance is approaching and as it is moving away from the observer?

	approaching observer	moving away from observer
A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

Approaching: $f_o = \frac{(f_s)(v)}{v - v_s}$

decelerates means v_s decreases, so $(v - v_s) \uparrow$. Hence $f_o \downarrow$

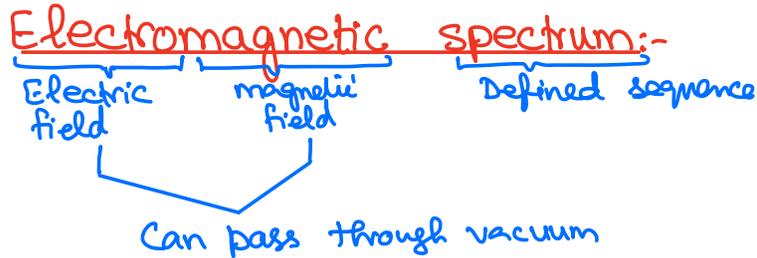
Receding: $f_o = \frac{(f_s)(v)}{v + v_s}$

Accelerate means v_s increases, so $(v + v_s) \uparrow$. Hence $f_o \downarrow$

7.4 Electromagnetic spectrum

Candidates should be able to:

- 1 state that all electromagnetic waves are transverse waves that travel with the same speed c in free space
- 2 recall the approximate range of wavelengths in free space of the principal regions of the electromagnetic spectrum from radio waves to γ -rays
- 3 recall that wavelengths in the range 400–700 nm in free space are visible to the human eye



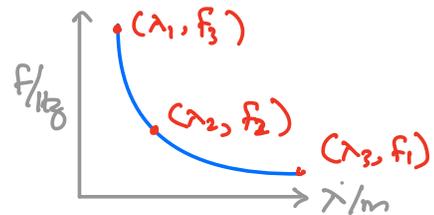
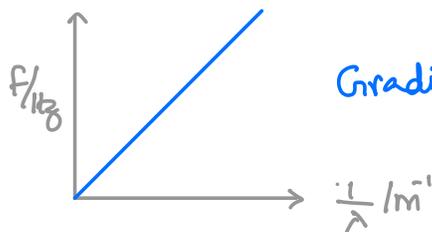
Def. Defined sequence of all transverse waves which do not need a state of matter to propagate (travel).

Relative order: Since $v = f\lambda$

For e.m. waves, $v = c = 3.00 \times 10^8 \text{ m s}^{-1}$

$$c = f\lambda \Rightarrow f = \frac{c}{\lambda} \Rightarrow f = \frac{\text{constant}}{\lambda}$$

$$f \propto \frac{1}{\lambda}$$



$$\lambda_1 f_1 = \lambda_2 f_2 = \lambda_3 f_3 = \text{speed}$$

frequency	← f/Hz						
Order	Gamma rays	X-rays	Ultra violet	Visible light	Infrared	Micro-wave	Radio waves
order of λ/m	10^{-12}	10^{-10}	10^{-8}	10^{-6}	10^{-4}	10^{-2}	$10^0 = 1$
Wavelength	→ λ/m						

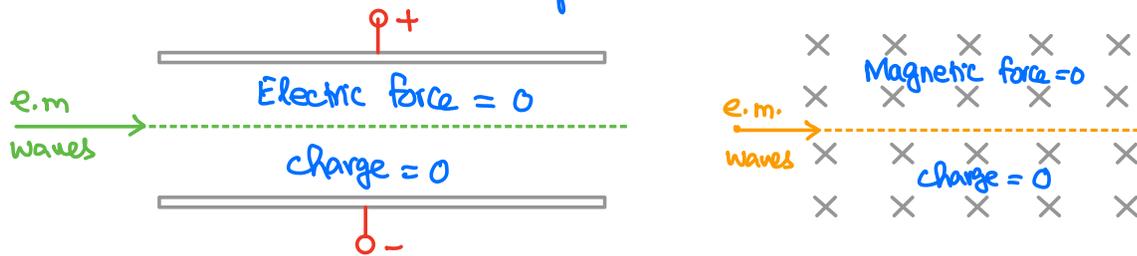
To calculate frequency: $f = \frac{c}{\lambda} = \frac{\times 10^8}{\square}$

Visible spectrum:

Order	V	I	B	G	Y	O	R
$\lambda/10^{-9}\text{m}$	400	450	500	550	600	650	700
Wavelength	$\lambda/\text{nm} \longrightarrow$						

Common properties of e.m. waves: All e.m. waves

- 1- are transverse in nature and therefore can be polarised.
- 2- do not need a state of matter to travel i.e. they can pass through vacuum.
- 3- do not carry an charge because they do not show any deflection in a perpendicular electric or magnetic field.



4- move with the same speed of $3.00 \times 10^8 \text{ m s}^{-1}$ in air or vacuum.

5- can exhibit

Reflection, diffraction and interference properties

Note: Reflection is not a common property due to deviation behaviours of absorption and emission on

dark rough surfaces.

Type of electromagnetic waves	Wavelength range / m
radio waves	$>10^6$ to 10^{-1}
microwaves	10^{-1} to 10^{-3}
infrared	10^{-3} to 7×10^{-7}
visible	7×10^{-7} (red) to 4×10^{-7} (violet)
ultraviolet	4×10^{-7} to 10^{-8}
X-rays	10^{-8} to 10^{-13}
γ -rays	10^{-10} to 10^{-16}

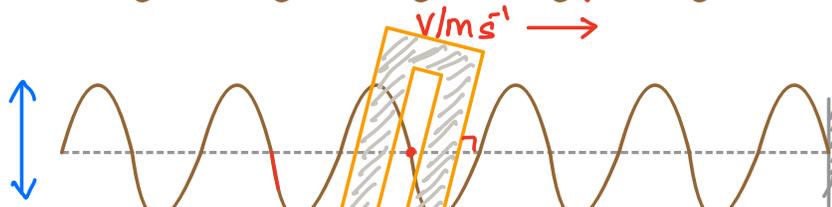
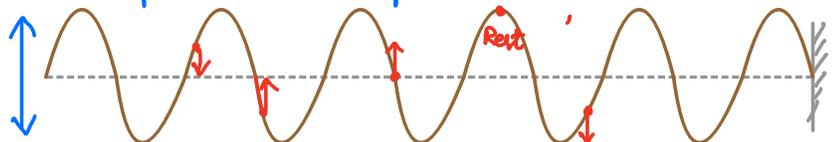
7.5 Polarisation

Candidates should be able to:

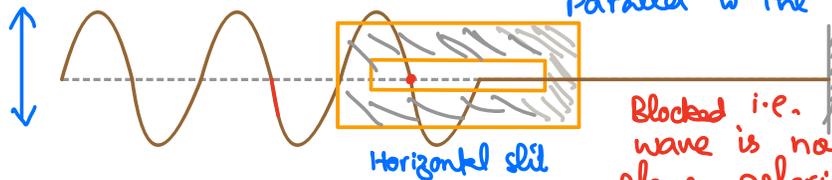
- 1 understand that polarisation is a phenomenon associated with transverse waves
- 2 recall and use Malus's law ($I = I_0 \cos^2\theta$) to calculate the intensity of a plane polarised electromagnetic wave after transmission through a polarising filter or a series of polarising filters

Polarisation:-

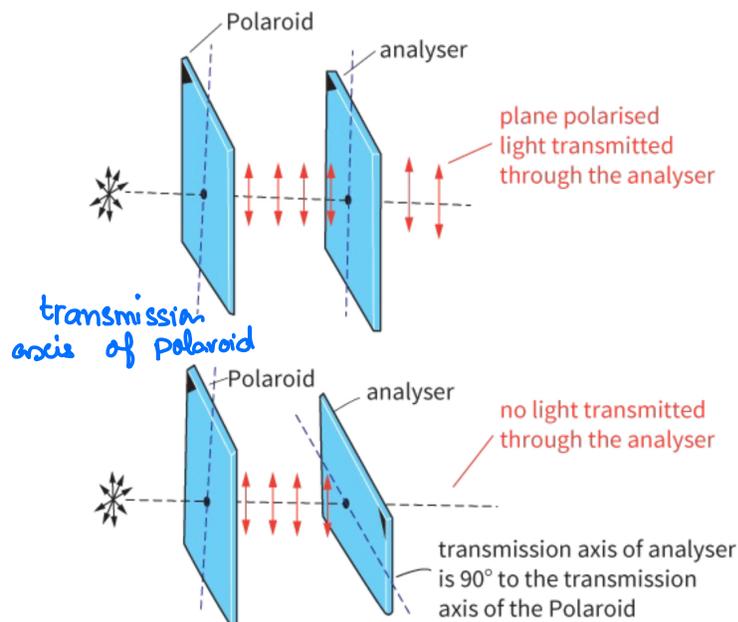
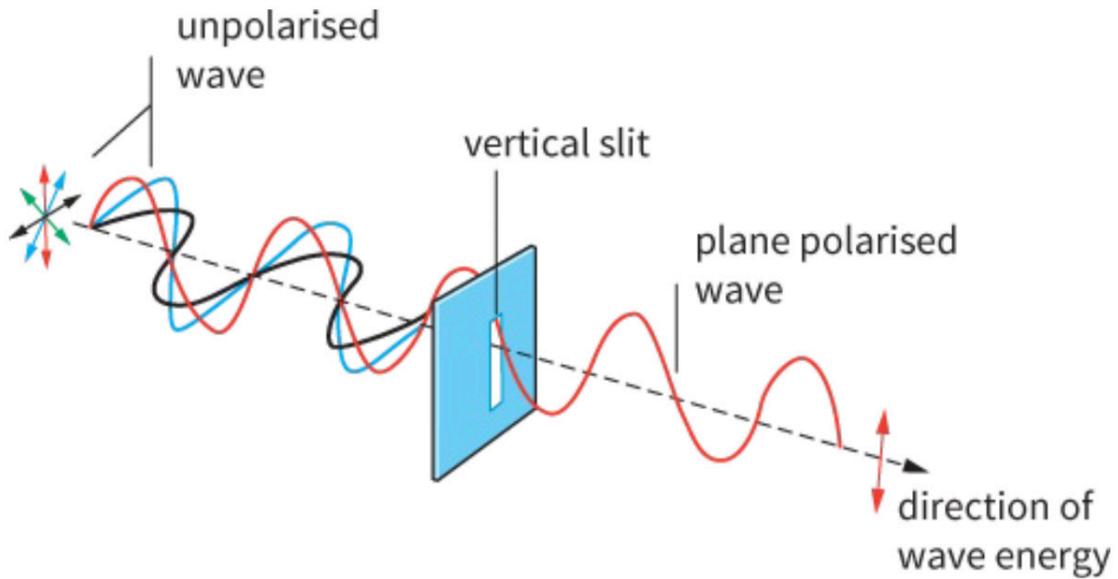
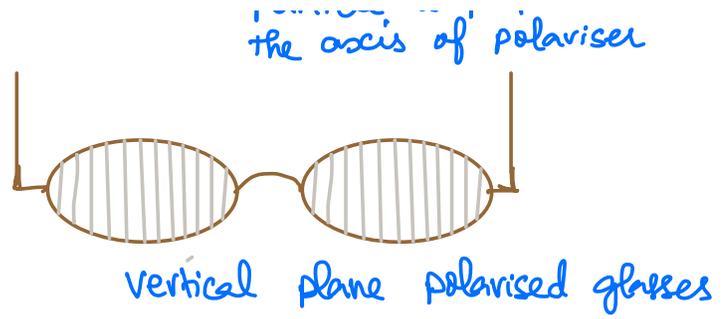
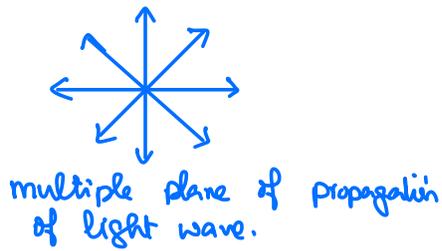
Process to confine a wave to pass through in one plane is polarisation.



vertical plane polarised wave because vibrations/displacement of particles is parallel to the axis of polariser



Blocked i.e. wave is not a horizontal plane polarised wave because vibrations/displacement of particle is perpendicular to



The light is blocked by the analyser when its transmission axis is 90° to the plane of the incident light. The dashed lines are transmission axes of the Polaroid and the analyser.

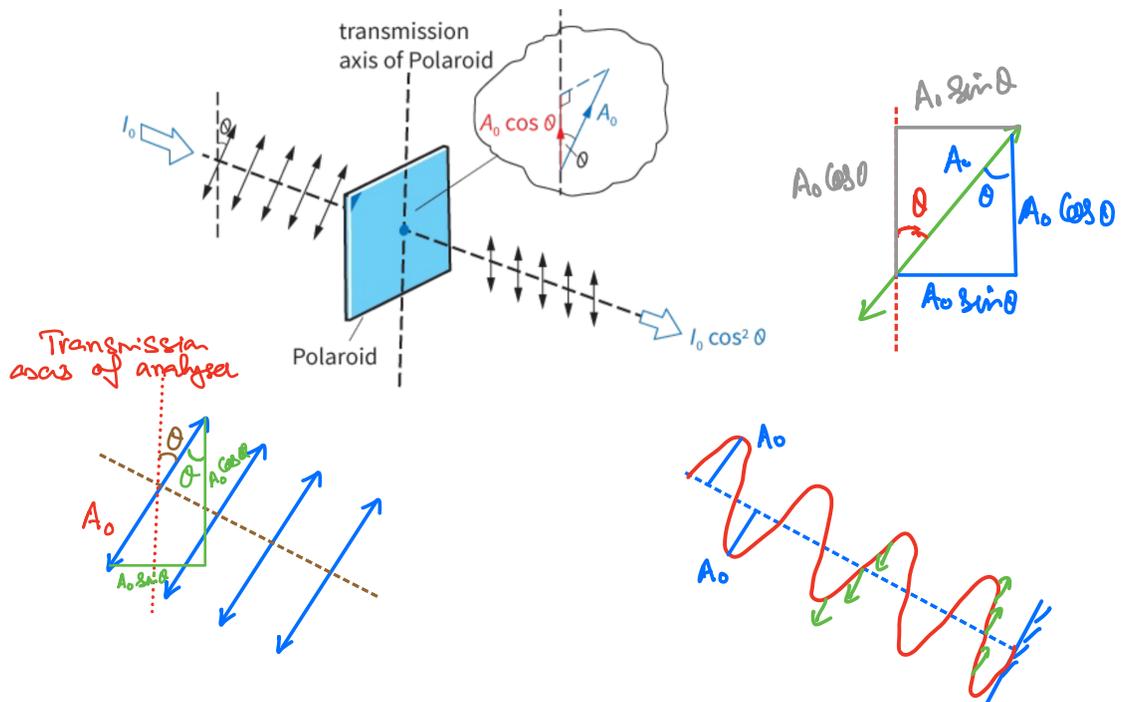
Note: Only transverse waves can be polarised and is a major property which differentiates transverse waves from longitudinal waves.

Malus's Law:

Concept:

- If transmission axis of Polaroid and analyser is
- (i) parallel to each other, then polarised wave can pass through analyser.
 - (ii) perpendicular to each other, then polarised wave is blocked by analyser.

If transmission axis of an analyser is at an angle ' θ ' to the polarised wave.



Component of maximum value of displacement (Amplitude) transmitted through the polaroid along its transmission axis is $A_0 \cos \theta$.

$$(\text{Intensity}) \propto (\text{Amplitude})^2$$

So incident Intensity $\propto (A_0)^2 \Rightarrow I_0 \propto A_0^2 \dots \text{--- (1)}$

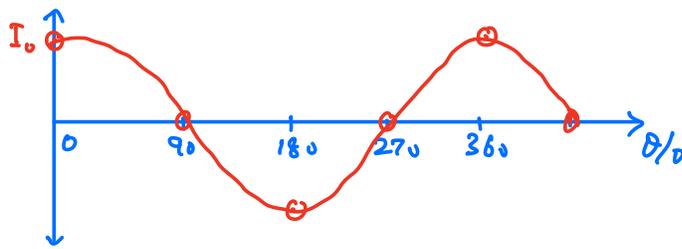
Plane polarised intensity $\propto (A_0 \cos \theta)^2 \Rightarrow I \propto (A_0 \cos \theta)^2$ (2)

Divide (2) by (1)

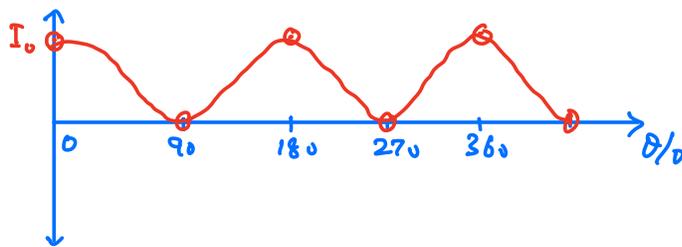
$$\frac{I}{I_0} = \frac{(A_0 \cos \theta)^2}{(A_0)^2} \Rightarrow \frac{I}{I_0} = \frac{\cancel{A_0}^2 \cos^2 \theta}{\cancel{A_0}^2}$$

$$I = I_0 \cos^2 \theta \quad \text{--- Malus's Law}$$

$$I = I_0 \cos \theta$$



$$I = I_0 \cos^2 \theta$$



$\theta/^\circ$	$\cos(\theta/^\circ)$
0	1
90	0
180	-1
270	0
360	1