Oscillations & Waves

Waves

Marline Kurishingal

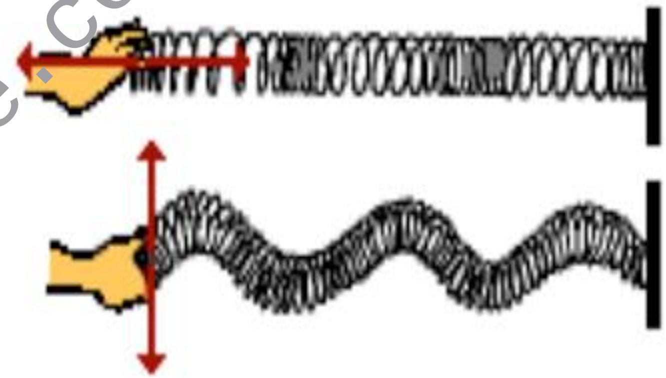
Introducing Waves

- Waves carry energy.
- For Example, during an earthquake, the seismic waves produced can cause great damage to buildings and the surroundings.
- What is a wave?
- Wave is a method of propagation of energy.

For example, when we drop a pebble into a pond of still water, a few circular ripples move outwards, on the surface of the water. As these circular ripples spread out, energy is being carried with them.

Sources of Waves

- The source of any wave is a ***vibration*** or ***oscillation***.
- For example, the forming of the slinky waves as shown.
- Wave motion provides a mechanism for the **transfer of energy** from one point to another ***without*** the physical transfer of the medium between the two points.



Slinky waves can be made by vibrating the first coil back and forth in either a horizontal or a vertical direction.

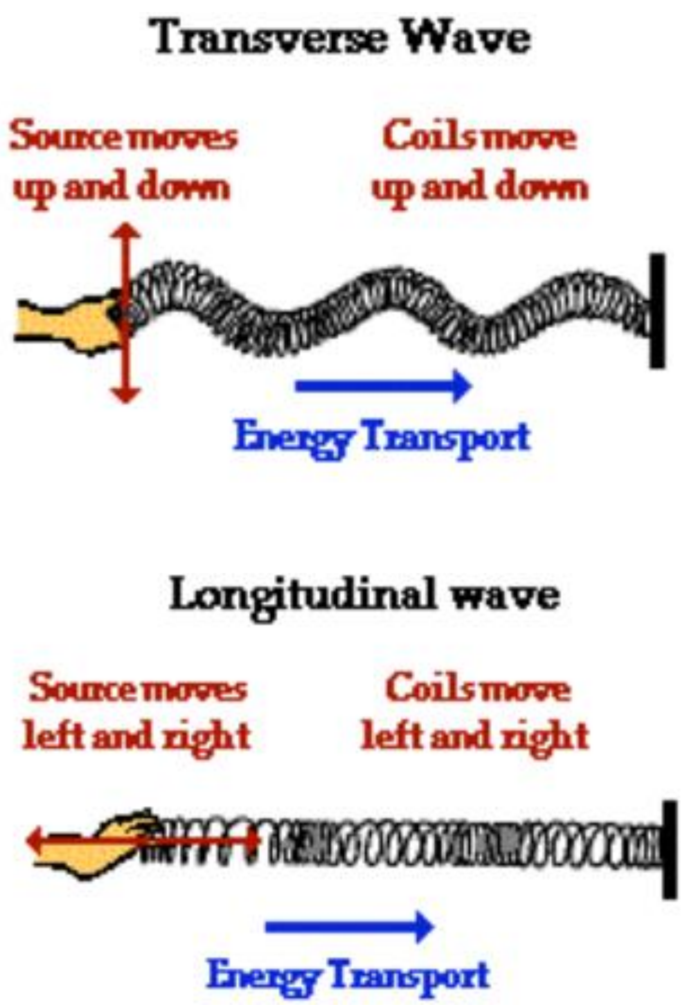
Two Types of Waves

- Transverse Wave

Rope waves, Water waves, Light waves, Radio waves, Electromagnetic waves.

- Longitudinal Wave

Sound waves and waves produced in a vertical oscillating spring under tension.



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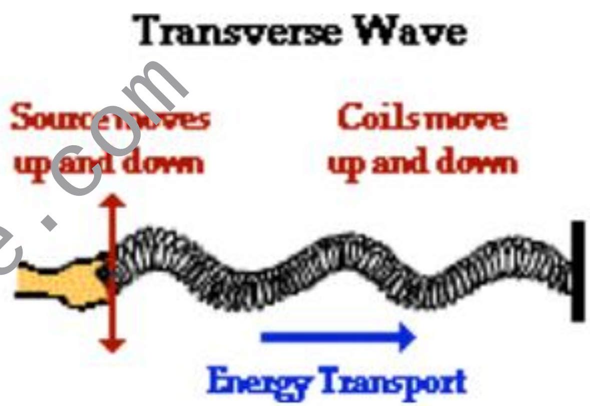
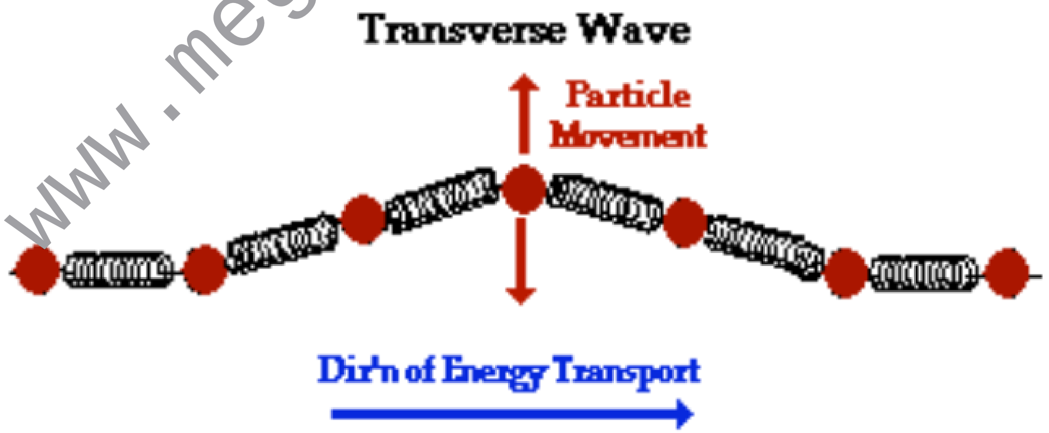
Transverse Waves

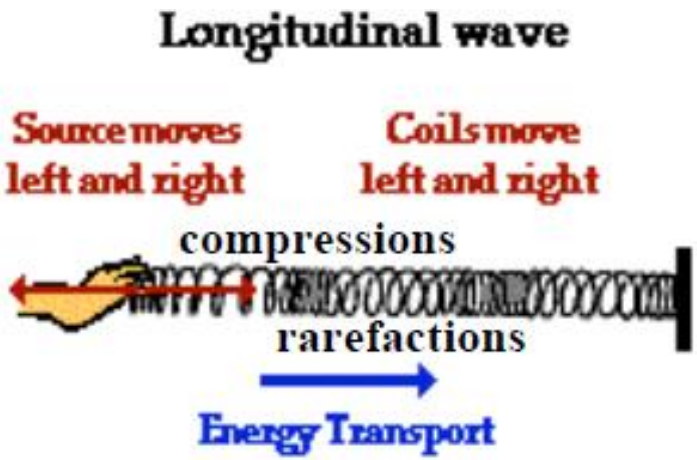
- *Transverse waves* propagate in a direction ***perpendicular*** to the direction of vibration.

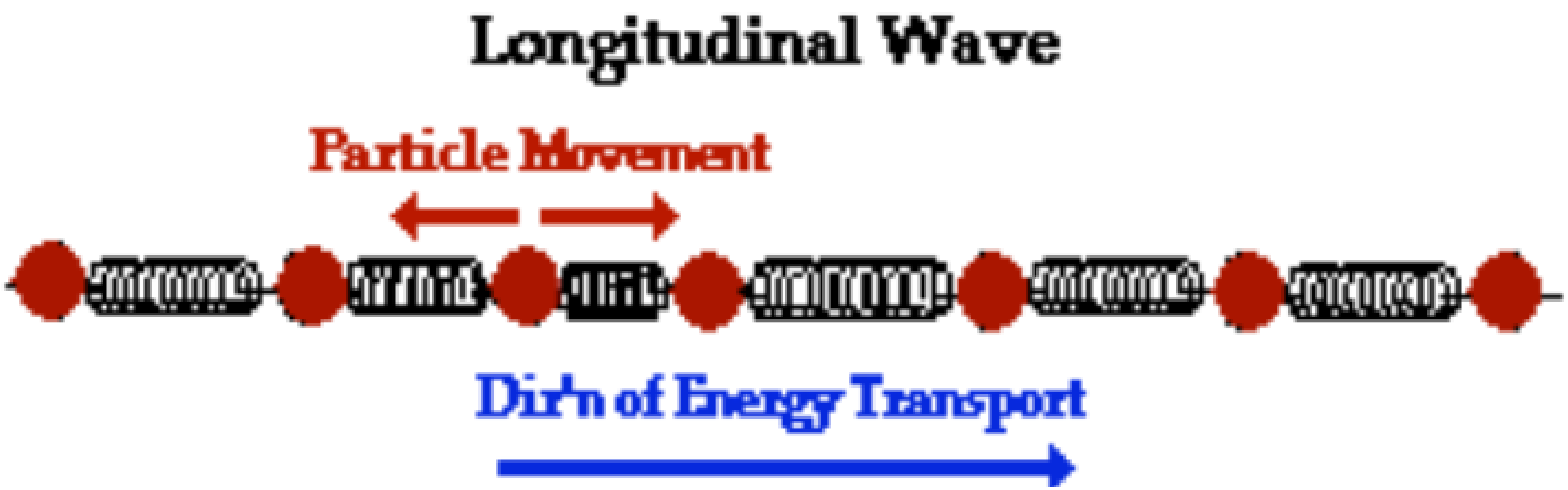




Longitudinal Waves

- *Longitudinal waves* propagate in a direction ***parallel*** to the direction of vibration.

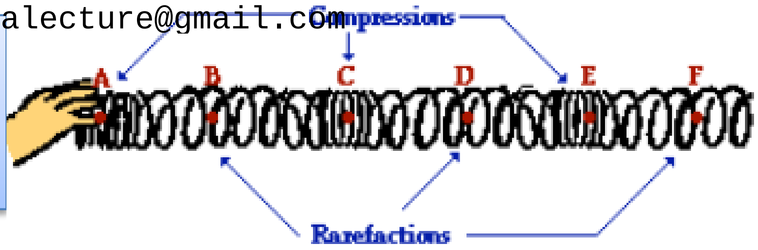




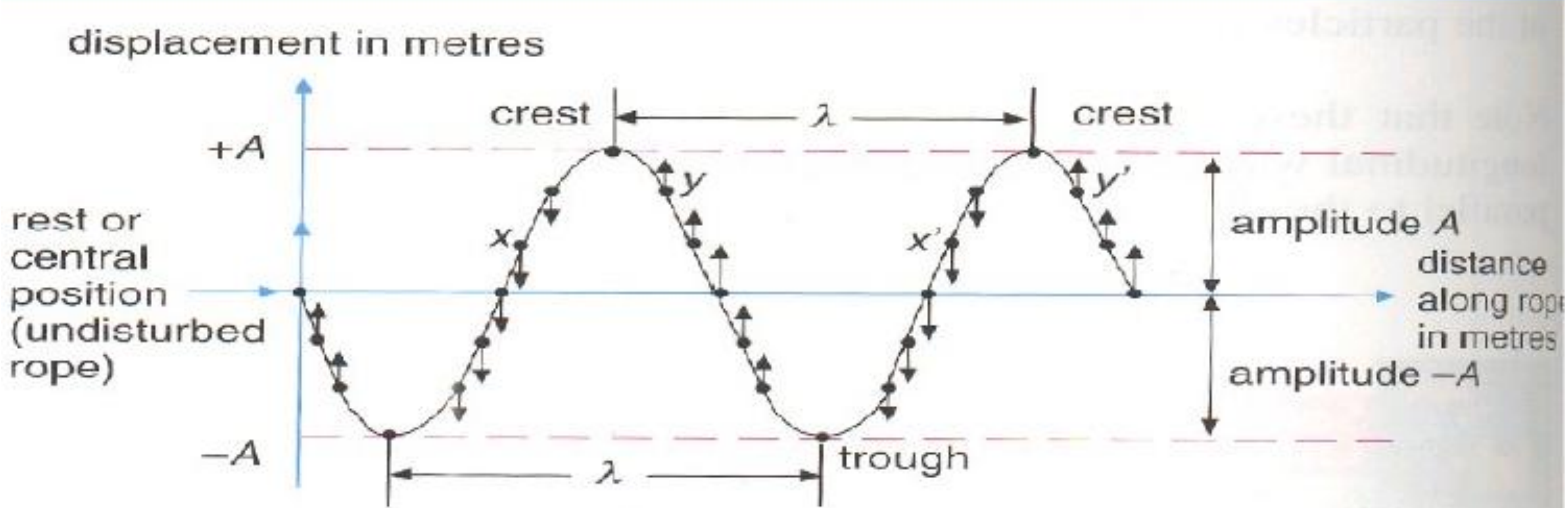
Reference link for Demonstration of waves

http://www.acs.psu.edu/drussell/demos/waves/wavemotion.html

Describing Waves



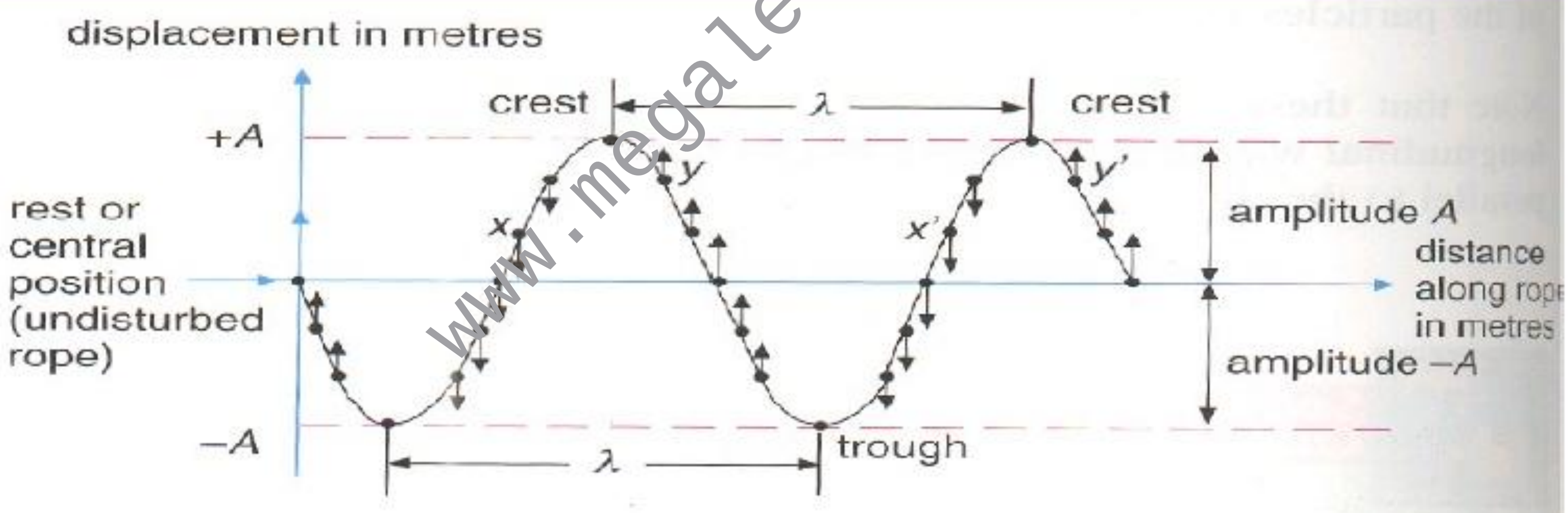
- **Crests and troughs**
  - High points and low points that characterise transverse waves only. For longitudinal waves, compressions and rarefactions are used.
- **Amplitude, A, SI Unit: metre (m)**
  - The value of the maximum displacement from the rest of central position in either direction.



A transverse rope wave

Describing Waves

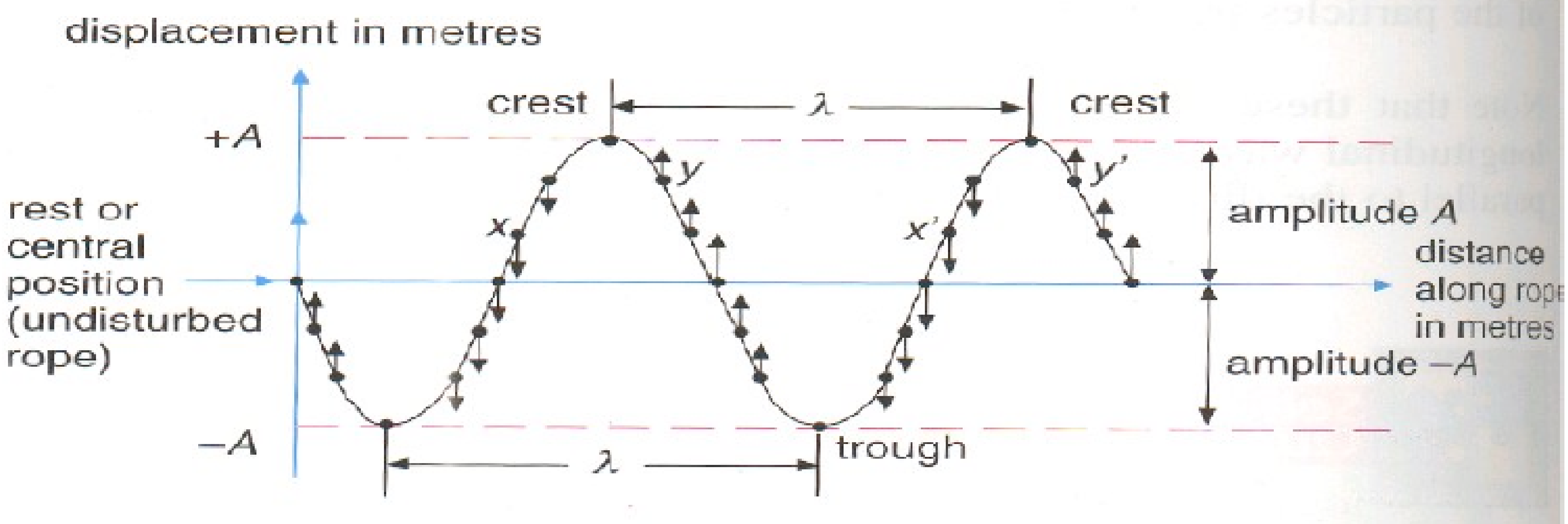
- **Wavelength, λ, SI Unit : metre (m)**
  - The shortest distance between any two points on a wave that are in phase. The two easiest points to choose for a distance of one wavelength are two successive crests or troughs.



A transverse rope wave

Describing Waves

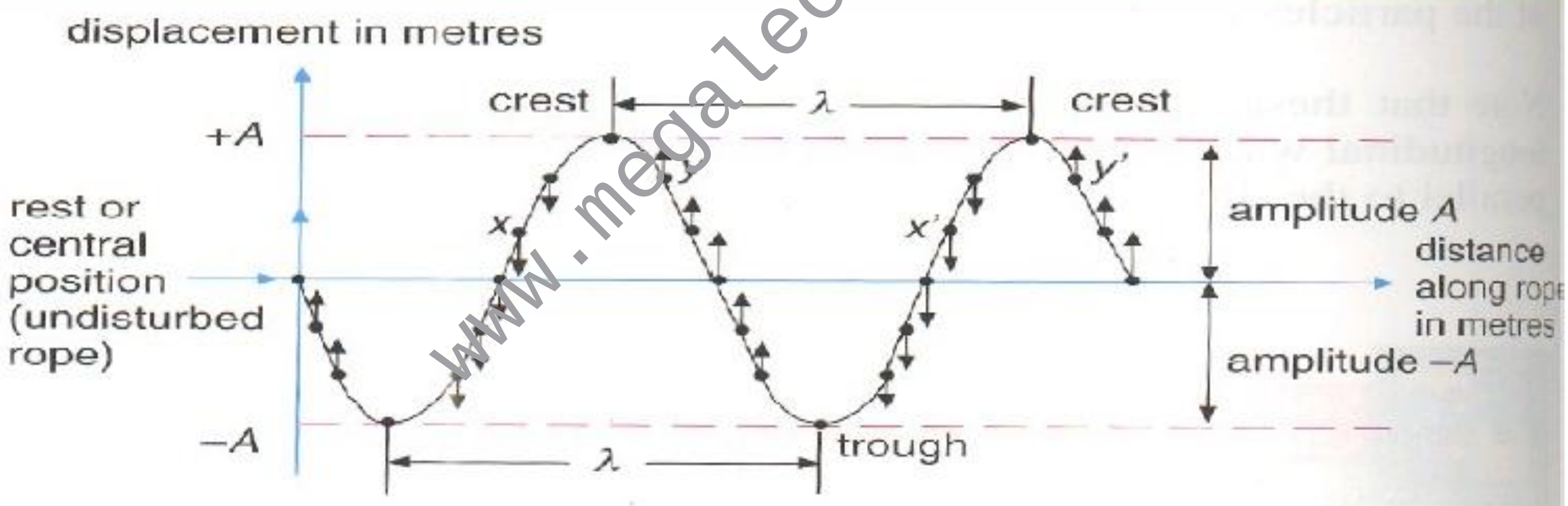
- **Frequency, *f*, SI Unit: hertz (Hz)**
  - The number of complete waves produced per second. The figure shows two complete waves and if they are produced in one second, then the frequency of this wave is two waves per second or 2 hertz.
- **Period, *T*, SI Unit: second (s)**
  - The time taken to produce one complete wave. $T = 1/f$



A transverse rope wave

Describing Waves

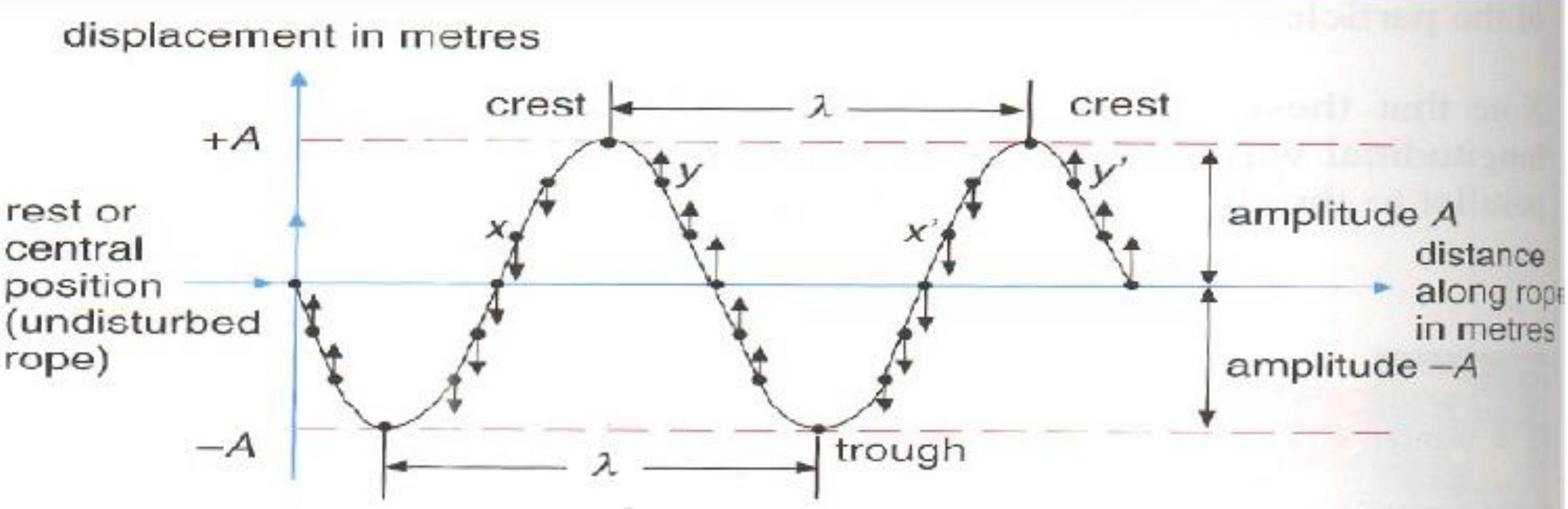
- **Wave Speed, *v*, SI Unit : metre per s (m/s)**
  - The distance travelled by a wave in one second.
- **Wave Front**
  - An imaginergy line on a wave that join all points which are in phase of vibration.



A transverse rope wave

Describing Waves

- **Phase**
  - Two points (such as x &x', and y & y') are said to be in phase because that are moving in the same direction with the same speed and having the same displacement from the rest position. Any two crests or trough are in phases.



A transverse rope wave

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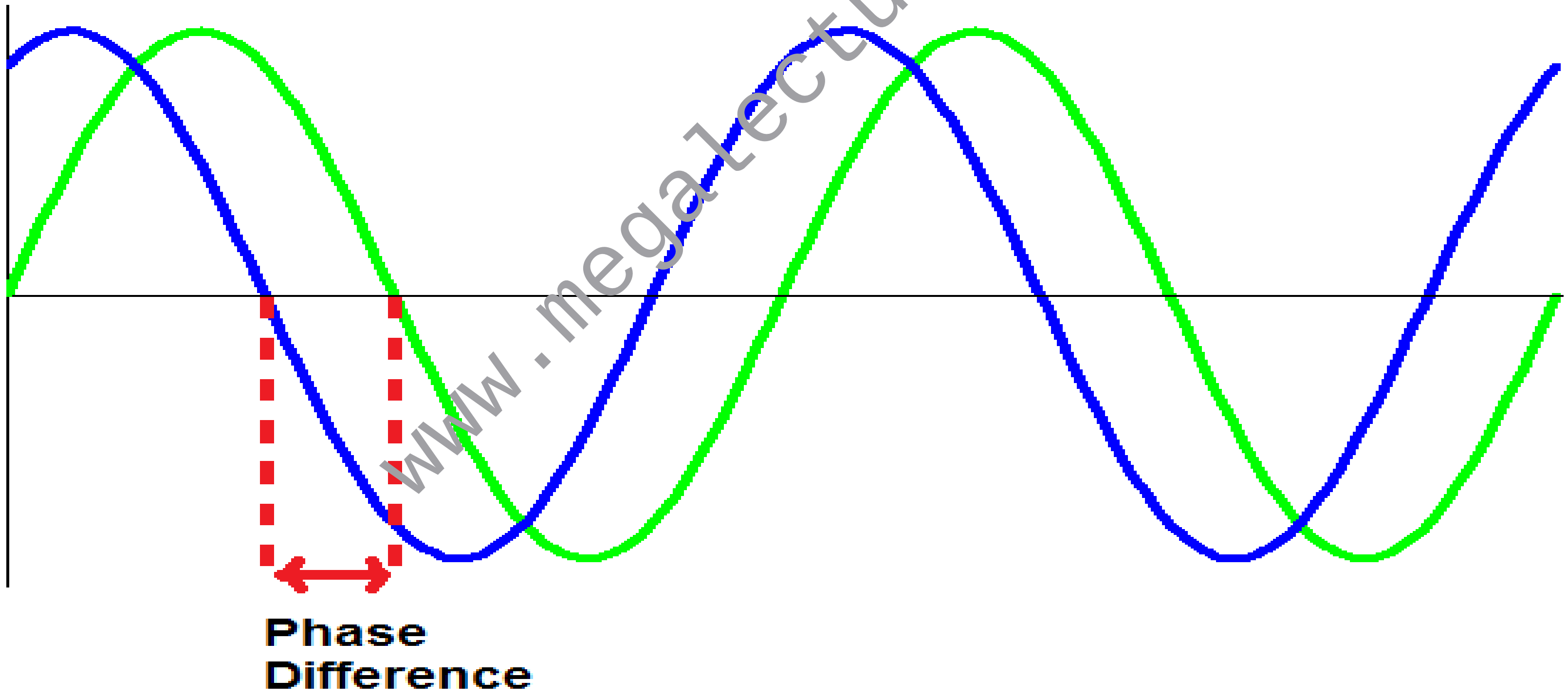
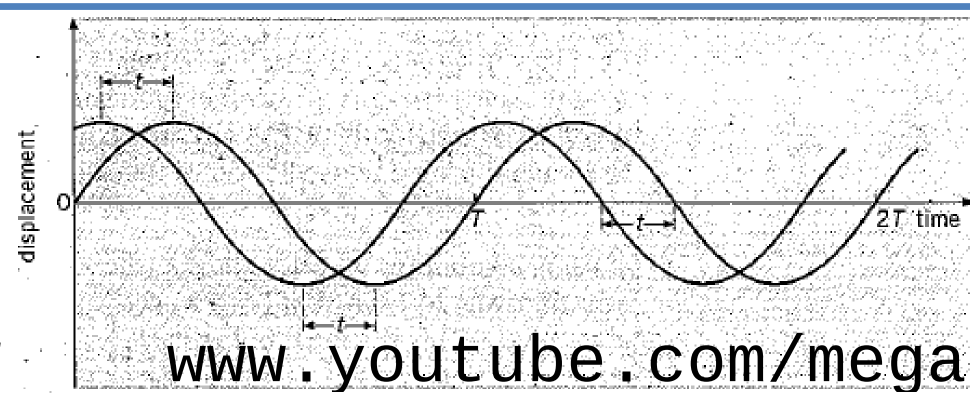
Describing Waves – Phase difference



Describing Waves – Phase difference

A term used to describe the relative positions of the crests or troughs of two waves of the same frequency is **phase**. When the crests and troughs of the two waves are aligned, the waves are said to be **in phase**. When a crest is aligned with a trough, the waves are **out of phase**. When used as a quantitative measure, phase has the unit of angle (radians or degrees). Thus, when waves are out of phase, one wave is half a cycle behind the other. Since one cycle is equivalent to 2π radians or 360°, the **phase difference** between waves that are exactly out of phase is π radians or 180°.

Consider Figure (, in which there are two waves of the same frequency, but with a phase difference between them. The period T corresponds to a phase angle of 2π rad or 360°. The two waves are out of step by a time t. Thus, phase difference is equal to $2\pi(t/T)$ rad = $360(t/T)°$. A similar argument may be used for waves of wavelength λ which are out of step by a distance x. In this case the phase difference is $2\pi(x/\lambda)$ rad = $360(x/\lambda)°$.



$\Phi = 2\Pi\frac{x}{\lambda}$ OR $\Phi = 360°\frac{x}{\lambda}$

Where ϕ is phase difference, x is distance, λ is the wavelength.

The wave equation and principle

- Speed = distance/time
- Wavelength is the distance moved by the wave in one cycle i.e distance
- Time = period = 1/frequency
- So speed = wavelength/period

Speed = wavelength x frequency, i.e $v = \lambda f$

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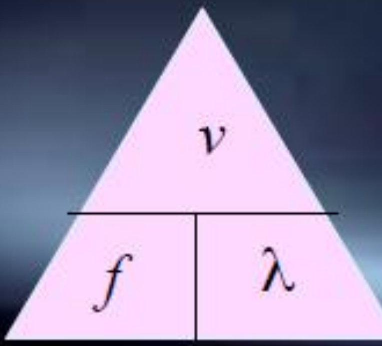
The Wave Equation

The relationship of v, λ & f

$$v = f\lambda$$

$v = f\lambda$
$f = v/\lambda$
$\lambda = v/f$

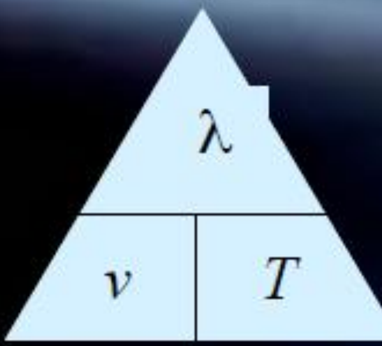


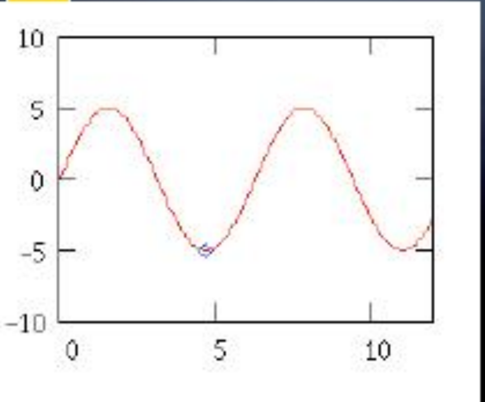
The relationship of v, λ & T

Since $T = 1/f$

$$v = \frac{\lambda}{T}$$

$f = 1/T$
$v = \lambda/T$
$\lambda = vT$
$T = 1/f$
$T = \lambda/v$





Example 1

Visible light has wavelengths between 400 nm and 700 nm, and its speed in a vacuum is 3.0×10^8 m s^{-1}.

What is the maximum frequency of visible light?

Solution:

From $v = f\lambda$, the frequency $f = \frac{v}{\lambda}$, i.e. f is inversely proportional to λ.

For maximum frequency, minimum wavelength should be used.

Hence, $f_{max} = \frac{v}{\lambda_{min}} = \frac{3 \times 10^8 \text{ m s}^{-1}}{400 \times 10^{-9} \text{ m}} = \mathbf{7.5 \times 10^{14}}$ **Hz**

Example 2

A sound wave of frequency 400 Hz is travelling in a gas at a speed of 320 m s^{-1}.

What is the phase difference between two points 0.2 m apart in the direction of travel?

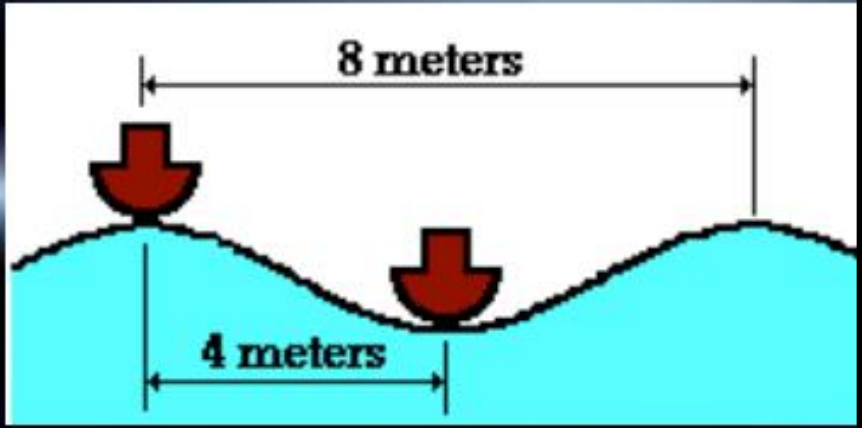
Solution:

Wavelength, $\lambda = \frac{v}{f} = \frac{320 \text{ m s}^{-1}}{400 \text{ Hz}} = 0.80$ m

$$\frac{\phi}{2\pi} = \frac{x}{\lambda} = \frac{0.2 \text{ m}}{0.8 \text{ m}} = \frac{1}{4} \rightarrow \phi = \frac{\pi}{2} \text{ rad}$$

Example 4

Two boats are anchored 4 metres apart. They bob up and down every 3 seconds, but when one is up the other is down. There are never any wave crests between the boats. Calculate the speed of the waves.



Solution:

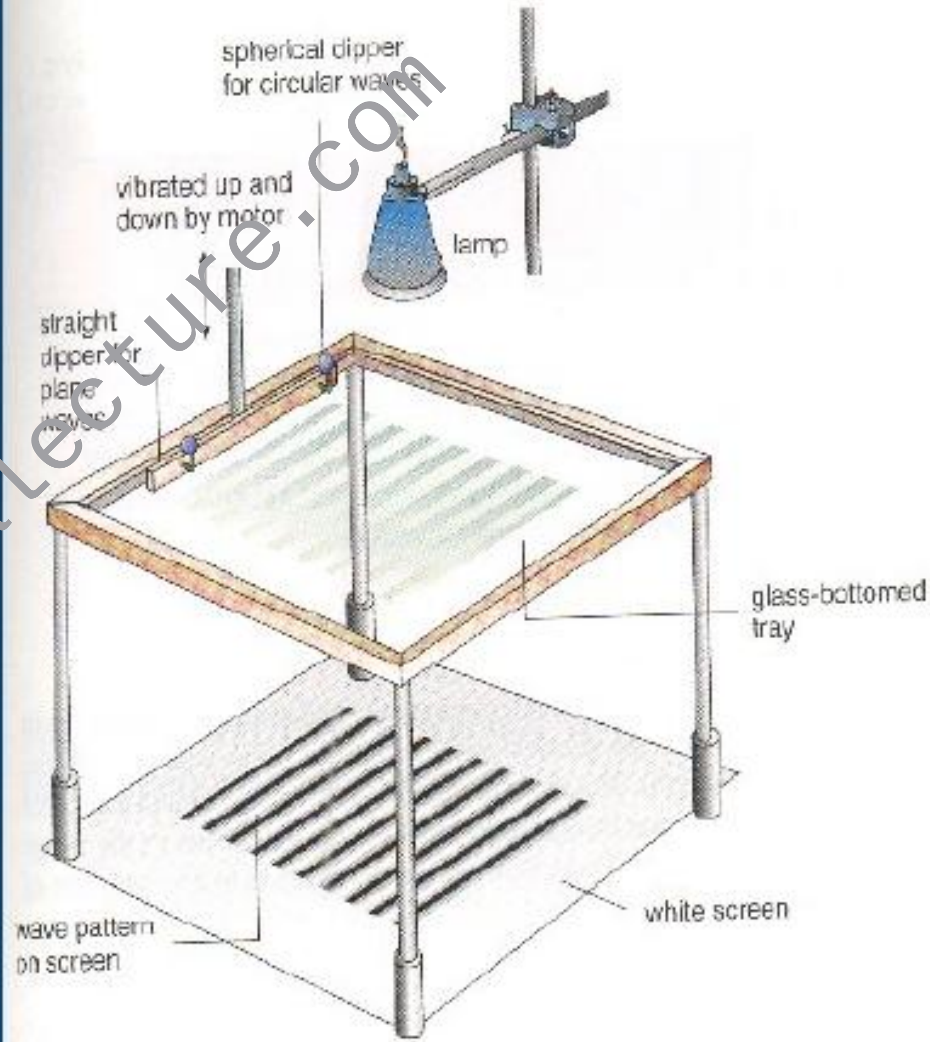
Period, $T = (3 \times 2)\ \text{s} = 6\ \text{s}$

Wavelength, $\lambda = 8\ \text{m}$

Speed, $v = \lambda/T = (8/6)\ \text{m/s} = 1.33\ \text{m/s}$

Ripple Tank (Wave production)

- The Structure
  - A shallow glass-bottomed tray;
  - A light source directly above the tray; and
  - A white screen beneath the tray used to capture the shadows formed when water waves traverse the tray.
- Production of waves
  - Plane waves by using the straight dipper
  - Circular waves by spherical dipper



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Energy is transferred by a progressive wave

Wave Motion

- There are also two other ways to classify waves - by their motion. A wave in which energy is transferred from one place to another as a result of its motion is called a **progressive** wave.

- For example : An ultraviolet light wave, which transfers energy from the sun to the skin of people lying on the beach, for instance, is a progressive wave. In general, waves that move from one point to another transfer some kind of energy.
- In a progressive wave, the shape of the wave itself, is what is transferred, not the actual components of the medium.

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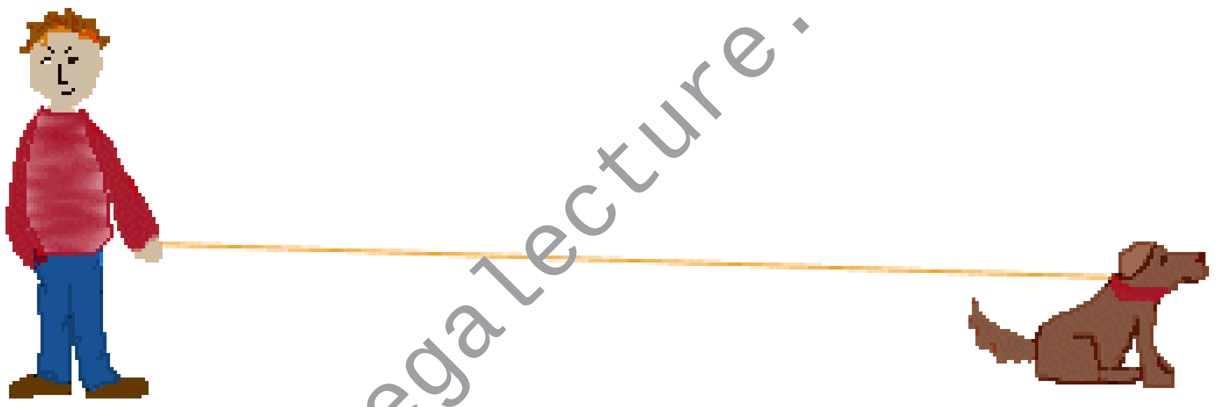
Look at this animated example

- http://library.thinkquest.org/15433/unit5/5-3.htm



- This animation of a dog on a leash shows a progressive wave transferring energy from the boy to the dog, which end up getting flipped through the air.

Show an understanding that energy is transferred due to a progressive wave.

- **Oscillation** (or oscillatory motion) refers to the to-and-fro motion of **a particle** about an equilibrium position.

  The oscillatory motion of the particle is a continuous exchange of potential and kinetic energy of the particle.

- **Wave** refers to the combined motion of **a series of linked-particles**, each of which is originally at rest at its respective equilibrium position.
  Starting from the *oscillation* of the *first particle* about its equilibrium position, the **energy** of the oscillation is passed to the *second particle*, which in turn is passed to the *third particle* and subsequent particles in the series of linked-particles.

So ***wave motion* is the motion of *energy*** passed from one particle to the next in a series, through oscillatory motion of these particles, in sequence.

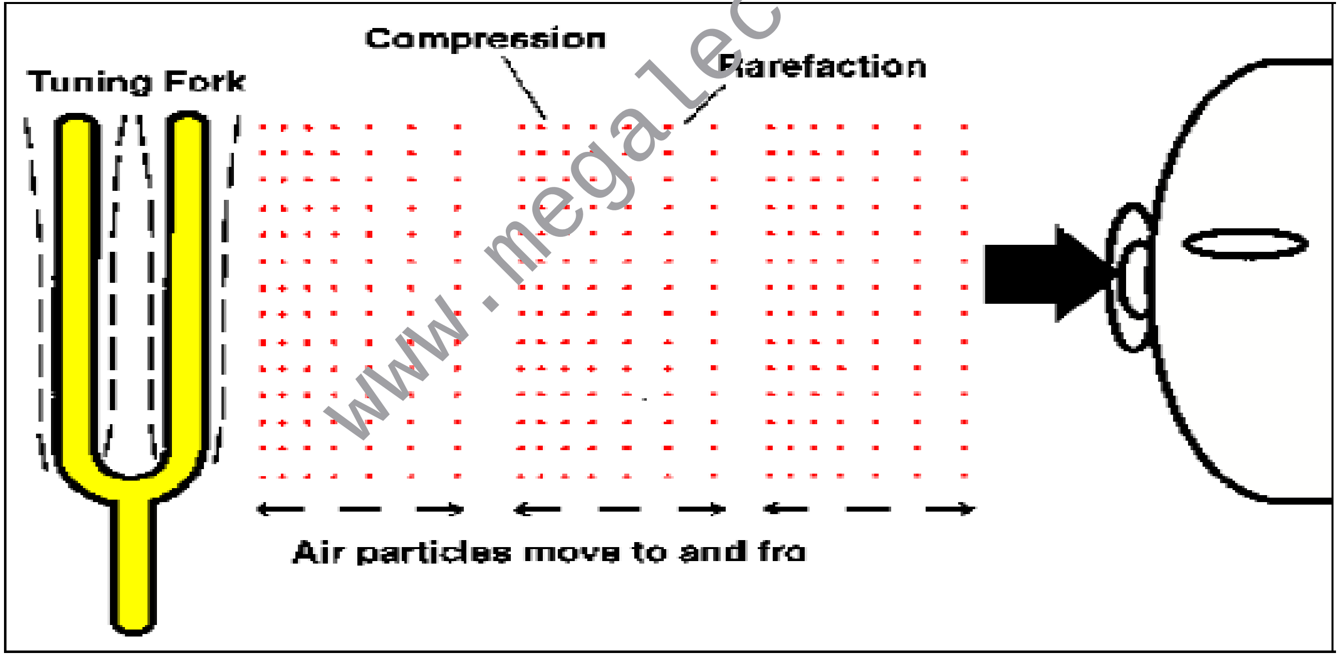
Examples:

(1) Sound wave:

When a sound wave is propagated from a tuning fork to an ear of a person some distance away, the vibration of the fork sets the air layer next to it into vibration.

The second layer of air is then set into vibration by the transfer of energy from the first layer.

This transfer of energy continues for subsequent layers until the layer of air next to the ear is also set into vibration, which in turn vibrates the ear-drum of the ear, enabling the person to hear the sound originated from the tuning fork.



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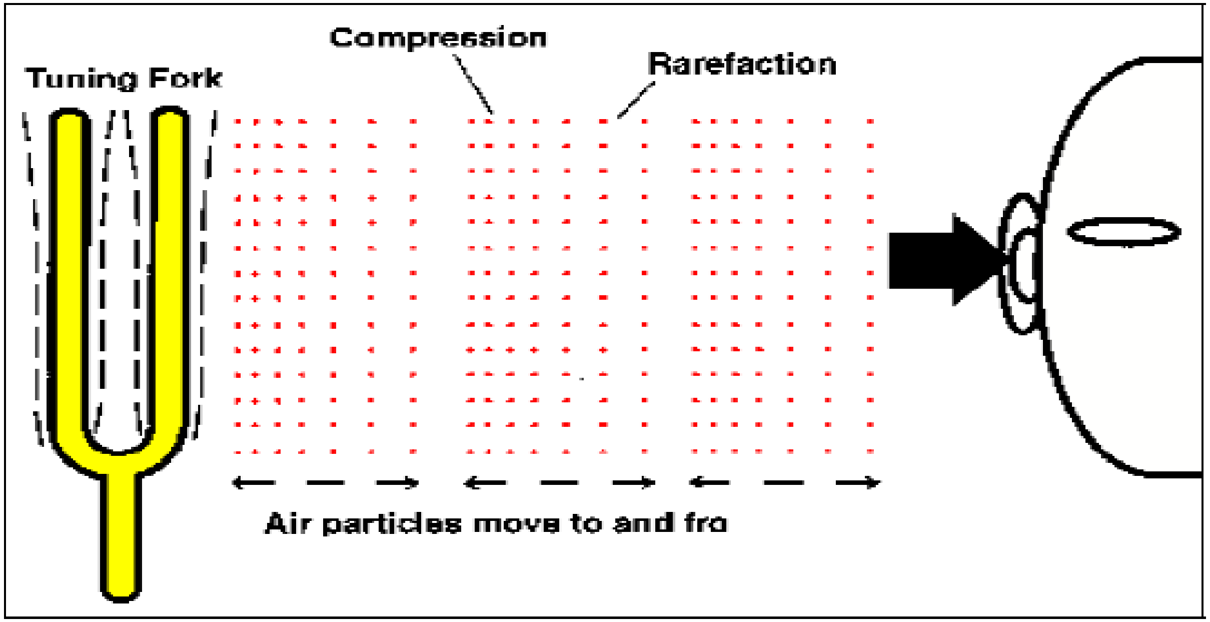


There is no net transfer of air particles from the tuning fork to the ear. The ear-drum in the ear can vibrate because energy has been transferred to it from the tuning fork, through the sequential vibration of the layers of air between the tuning fork and the ear. (Diagram above)

This sequential vibration of the layers of air forms regions of **compression** (where air layers are closer to each other) and regions of **rarefaction** (where air layers are further apart). The one-way movement of such regions from the tuning fork to the ear signifies the propagation of sound wave energy.

(2) Wave in a rope:

The wave travelling in a rope may originate from the vibration of the first particle at one end of the rope.
The energy of the vibrating first particle is transferred to the second particle, setting it into vibration.
This transfer of energy continues to subsequent particles in the rope until it reaches the other end of the rope.

(3) Water wave:

The energy of the vibrating water molecules is transferred to subsequent molecules along the surface of water, causing these molecules further from the vibrating source to be set into up-down motion.

The examples (1), (2) and (3) are examples of **progressive waves**, where energy is transferred from one region to another region through sequential vibration of a series of linked-particles.

The energy of a first vibrating particle is propagated along a series of linked-particles to another region. Sound energy is propagated from the tuning fork to the ear, energy from one end of a rope is propagated to the other end, and energy from one region of water surface next to a vibrating source is propagated to another region in the ripple tank.

Intensity of the Wave

One of the characteristics of a progressive wave is that it carries energy. The amount of energy passing through unit area per unit time is called the **intensity** of the wave. The intensity is proportional to the square of the amplitude of a wave. Thus, doubling the amplitude of a wave increases the intensity of the wave by a factor of four. The intensity also depends on the frequency: intensity is proportional to the square of the frequency.

For a wave of amplitude A and frequency f, the intensity I is proportional to A^2f^2.

If the waves from a point source spread out equally in all directions, we have what is called a **spherical wave**. As the wave travels further from the source, the energy it carries passes through an increasingly large area. Since the surface area of a sphere is $4\pi r^2$, the intensity is $W/4\pi r^2$, where W is the power of the source. The intensity of the wave thus decreases with increasing distance from the source. The intensity I is proportional to $1/r^2$, where r is the distance from the source.

This relationship assumes that there is no absorption of wave energy.

Recall and use the relationship, intensity ∝ (amplitude)^2.

Intensity, ***I***, is the **rate of incidence of energy per unit area normal to the direction of incidence.**

The rate of incidence of energy can be regarded as power.

The plane of the area, which the wave energy is incident onto, has to be normal (perpendicular) to the direction of the incidence of the wave energy.

The **unit** of intensity is **W m^{-2}**.

Intensity on an area *A* can be expressed as

$$I = \frac{P}{A}$$

where *P* is the power incident on the area normally.

Intensity ∝ (amplitude)^2

A sound wave of amplitude 0.20 mm has an intensity of 3.0 W m^{-2}.

What will be the intensity of a sound wave of the same frequency which has an amplitude of 0.40 mm?

Solution:

The relation $I \propto (\text{amplitude})^2$

can be expressed as $I = k(\text{amplitude})^2$

where k is the constant of proportionality.

Substituting,

$$3.0 \text{ W m}^{-2} = k(0.20 \text{ mm})^2 \quad \text{- - - - - (1)}$$

New intensity, $I = k(0.40 \text{ mm})^2$ - - - - - (2)

$\frac{(2)}{(1)}$: $\frac{I}{3.0 \text{ W m}^{-2}} = 4 \rightarrow I = 12.0 \text{ W m}^{-2}$.

- For sound waves, **intensity** is a measure of **loudness**.
- For light waves, **intensity** is a measure of **brightness**.

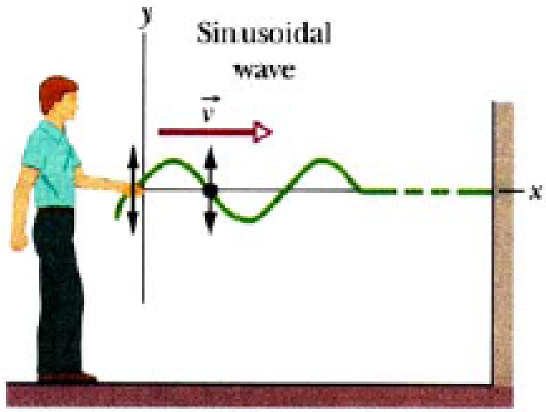
Analyse and interpret graphical representations of transverse and longitudinal waves.

- In a wave, there are ***two directions of motions:***

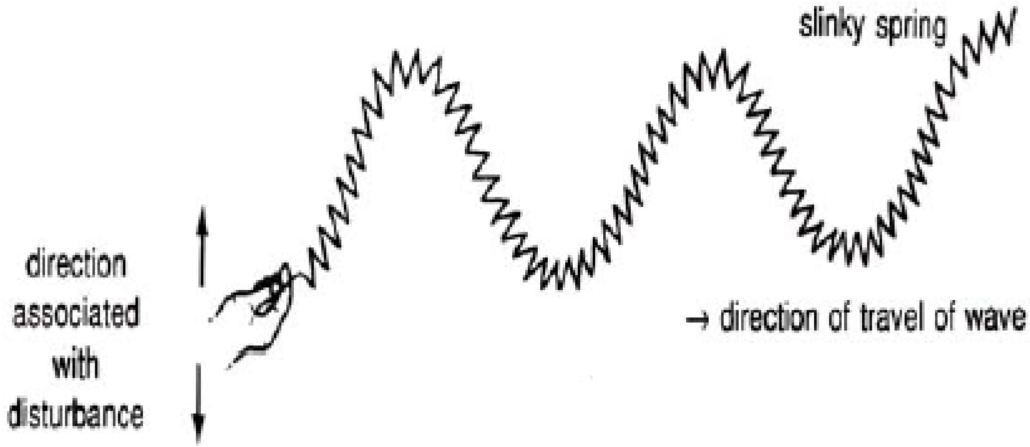
➢ direction of propagation of energy (which is the direction of *motion of the wave)*

➢ direction of oscillation of the particles in the wave.

A **transverse wave** is one in which the direction of propagation of energy is **perpendicular** to the direction of oscillation of the particles in the wave.

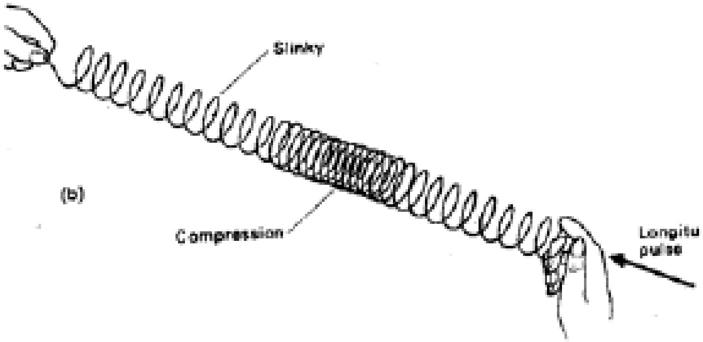


The string element's motion is ***perpendicular*** *to the wave's direction of travel. This is a transverse wave.*



In the example of a wave travelling along a string (or a wave travelling along a slinky diagrams above, the direction of propagation of the wave is along the string. If the wave is started from one end of the string by the oscillation of the first element in the direction *perpendicular* to the string, then this wave travelling along the string is an example of a *transverse wave*.

A **longitudinal wave** is one in which the direction of propagation of energy is **parallel** to the direction of oscillation of the particles in the wave.



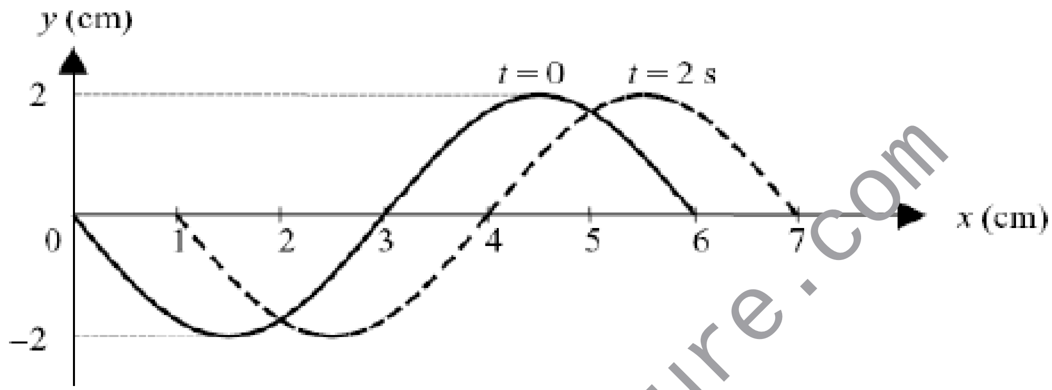
A visual demonstration of a longitudinal wave.

When a sound wave set up by the vibrating piston propagates along the pipe of air, the direction of propagation of sound energy is along the pipe to the right. The direction of oscillation of the air layers is back and forth, *parallel* to this direction. Hence sound wave is an example of a *longitudinal wave*.

Graphs representing waves

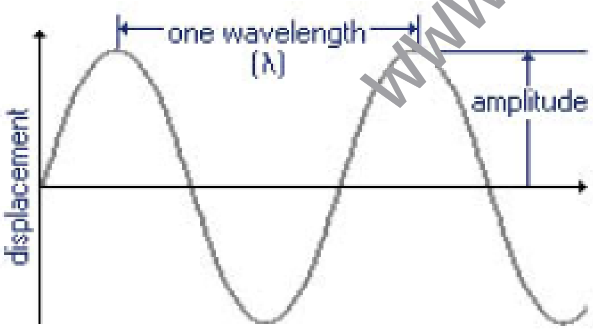
Graph 1 : Displacement vs. Position graphs

These are plotted with displacement, *y*, **against distance or position, *x***.



For a **transverse** wave moving from left to right along the *x*-axis, displacement of the particles in the wave, *y*, may be given a **+ve** sign for displacement **upwards**, and a **–ve** sign for displacement **downwards**.

For a **longitudinal** wave moving from left to right along the *x*-axis, displacement of the particles in the wave, *y*, may be given a **+ve** sign for displacement **to the right**, and a **–ve** sign for displacement **to the left**.

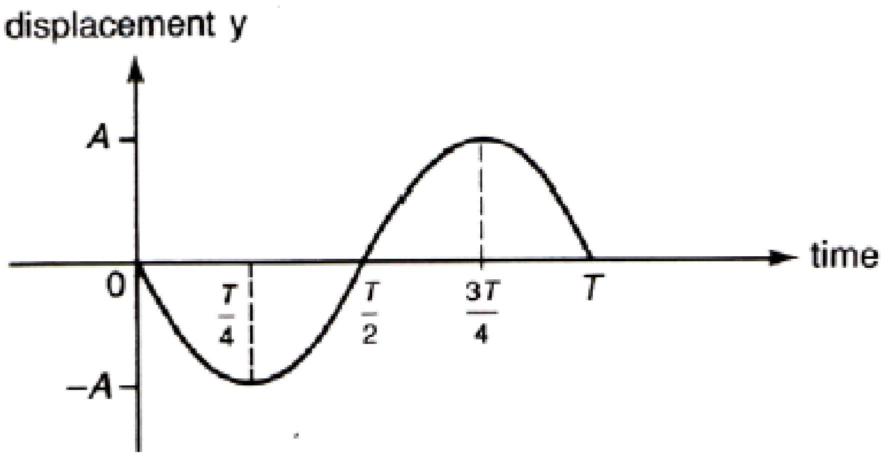


In Displacement vs. Position graphs,

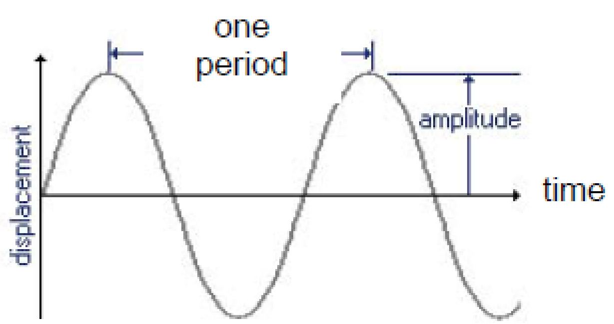
- the graph represents the actual wave at an instant in time
- the distance between consecutive crests or consecutive troughs is **one wavelength**
- The maximum height of the vertical axis = amplitude of <u>wave</u>

Graph 2 : Displacement vs. Time graphs

In contrast, graphs used to represent an **oscillation of a particle** are plotted with displacement, *y*, **against time, *t***.



In the graph above, we are tracking the displacement of **one particle only** as time goes by. This does NOT represent the wave.



In Displacement vs. Time graphs,

- The graph represents the oscillation of one particle on the wave with time.
- the "distance" between consecutive crests or consecutive troughs is **one period**
- The maximum height of the vertical axis = amplitude of **oscillation**

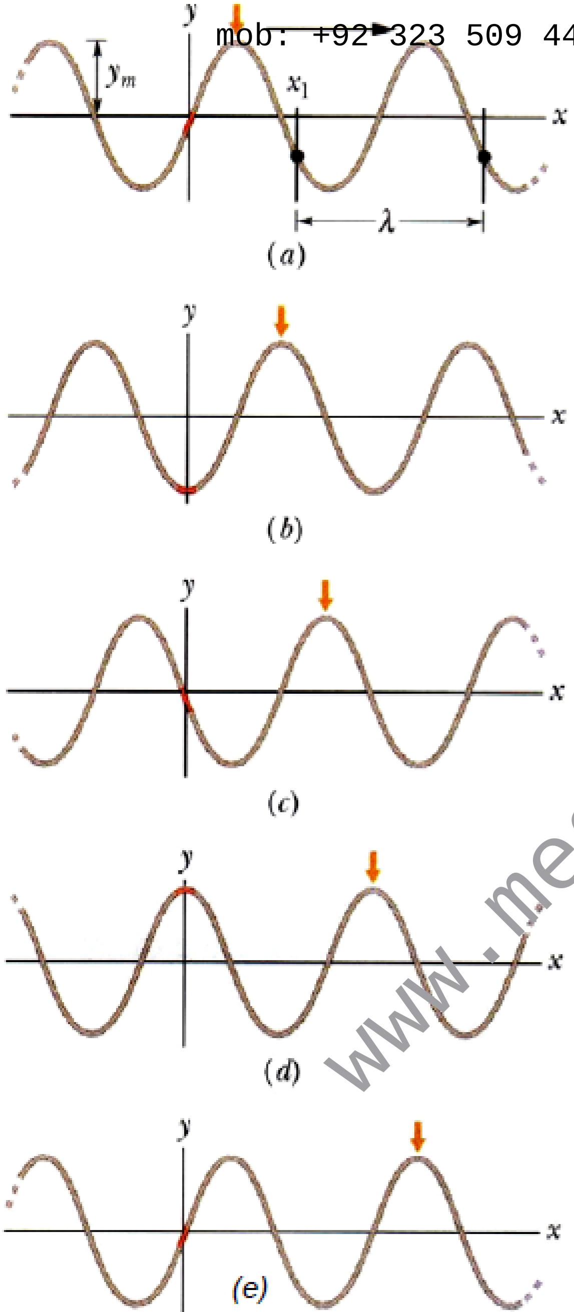


Fig.2

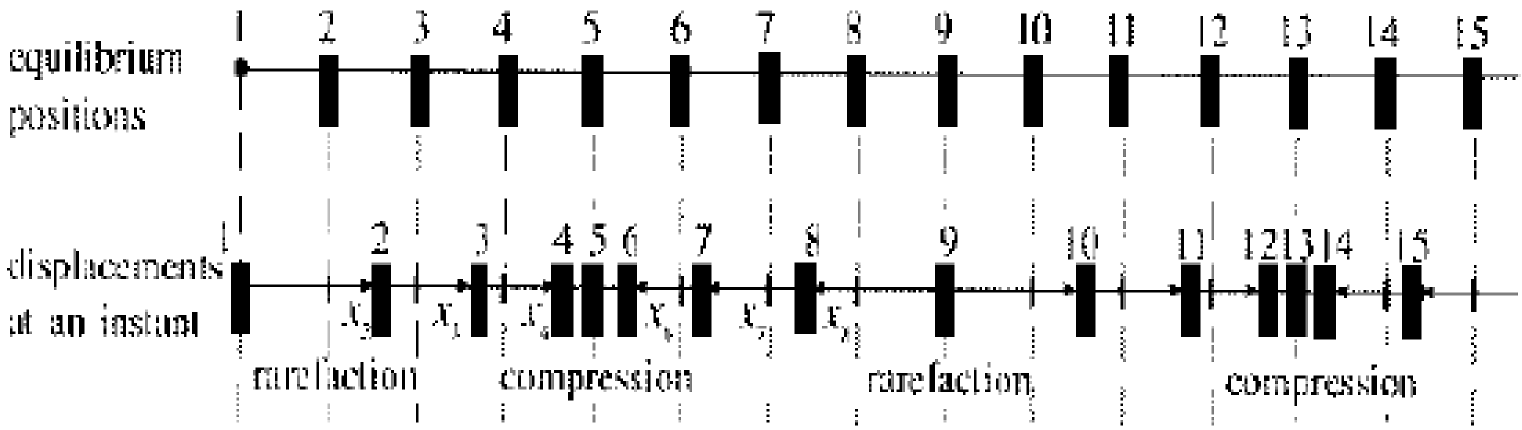
- **Fig.2** shows 5 snapshots of a transverse wave in a string, travelling in the +ve direction of an *x*-axis (left to right).

- The movement of the wave is indicated by the right-ward progress of the short down-pointing arrow, pointing at the middle 'crest' of the wave in snapshot (a).

- From snapshots (a) to (e), the short arrow moves to the right with the wave, but each particle in the string moves parallel to the *y*-axis (up and down). An example of such a particle is along the *y*-axis (shown darkened).

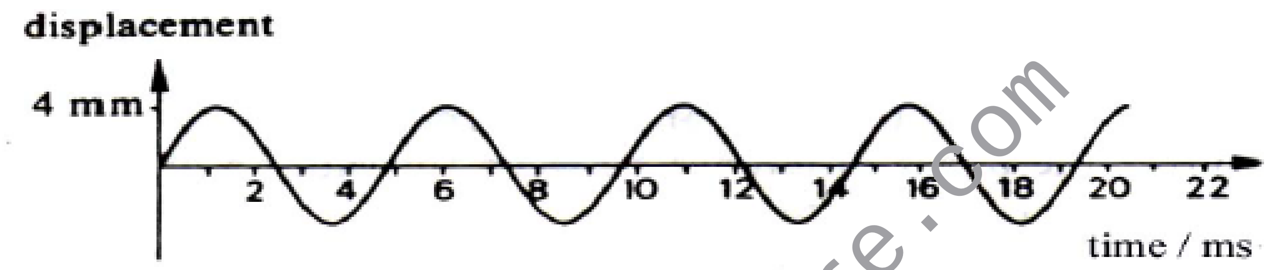
- Each snapshot is taken at an interval of ¼ period. One full oscillation takes place from (a) to (e).

Actual positions of layers within the longitudinal wave



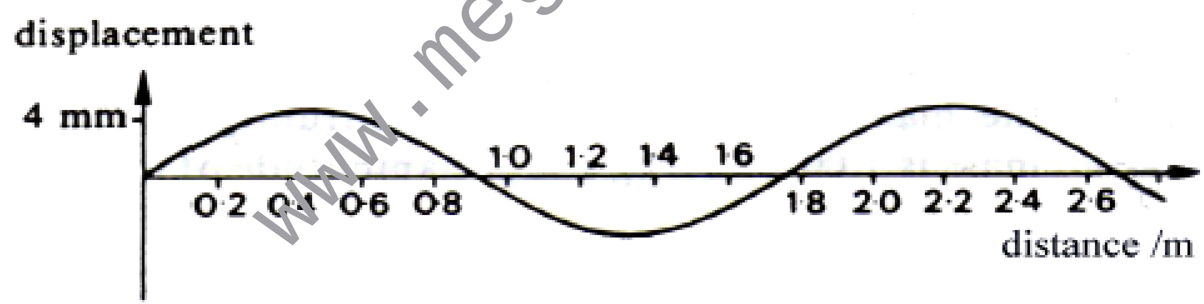
Summary For Part (f):

(1) **Displacement-time graph** is for the **oscillation of a particle** in the wave.



The graph above shows an element oscillating with an amplitude of 4 mm.
Its **period** of oscillation is about 5 ms.

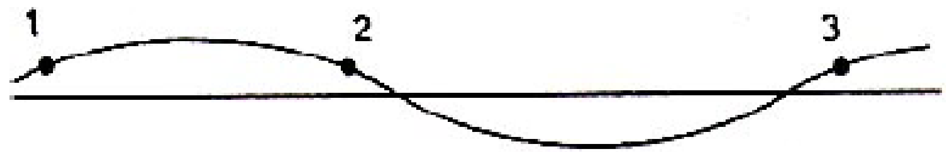
(2) **Displacement-distance graph** is for a **snapshot of a wave motion at an instant**.



The graph above shows an instant of a wave with an amplitude of 4 mm.
Its **wavelength** is about 1.8 m.

Example 7

The diagram below shows an instantaneous position of a string as a transverse progressive wave travels along it from left to right.



Which one of the following correctly shows the directions of the velocities of the points 1, 2 and 3 on the string?

	1	*2*	*3*
A	→	→	→
B	→	←	→
C	↓	↓	↓
D	↓	↑	↓
E	↑	↓	↑

Solution

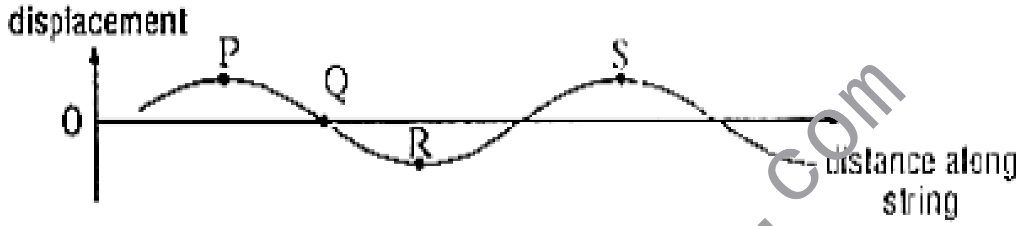
Knowing that the wave is traveling from LEFT to RIGHT, sketch how the wave would look like just an instant after:

Then look at the points concerned.
Since it is a TRANSVERSE wave, the particles only oscillates perpendicular to the wave direction.
This eliminates Answers A & B.

Ans D

Example 8

The graph shows the shape **at a particular instant** of part of a transverse wave travelling along a string.



Which statement about the motion of elements of the string is correct?

A The speed of the element at P is a maximum
B The displacement of the element at Q is always zero
C The energy of the element at R is entirely kinetic
D The acceleration of the element at S is a maximum

Solution:
Although the graph represents the whole wave at an instant in time, the question requires you to **analyse the motion of the individual particles** within the wave at this instant.

Element P: At extreme end of oscillation → stationary
Element Q: At equilibrium position → moving fastest
Element R: At extreme end of oscillation → stationary, no kinetic energy
Element S: At extreme end of oscillation → max displacement, max acceleration

Ans: D

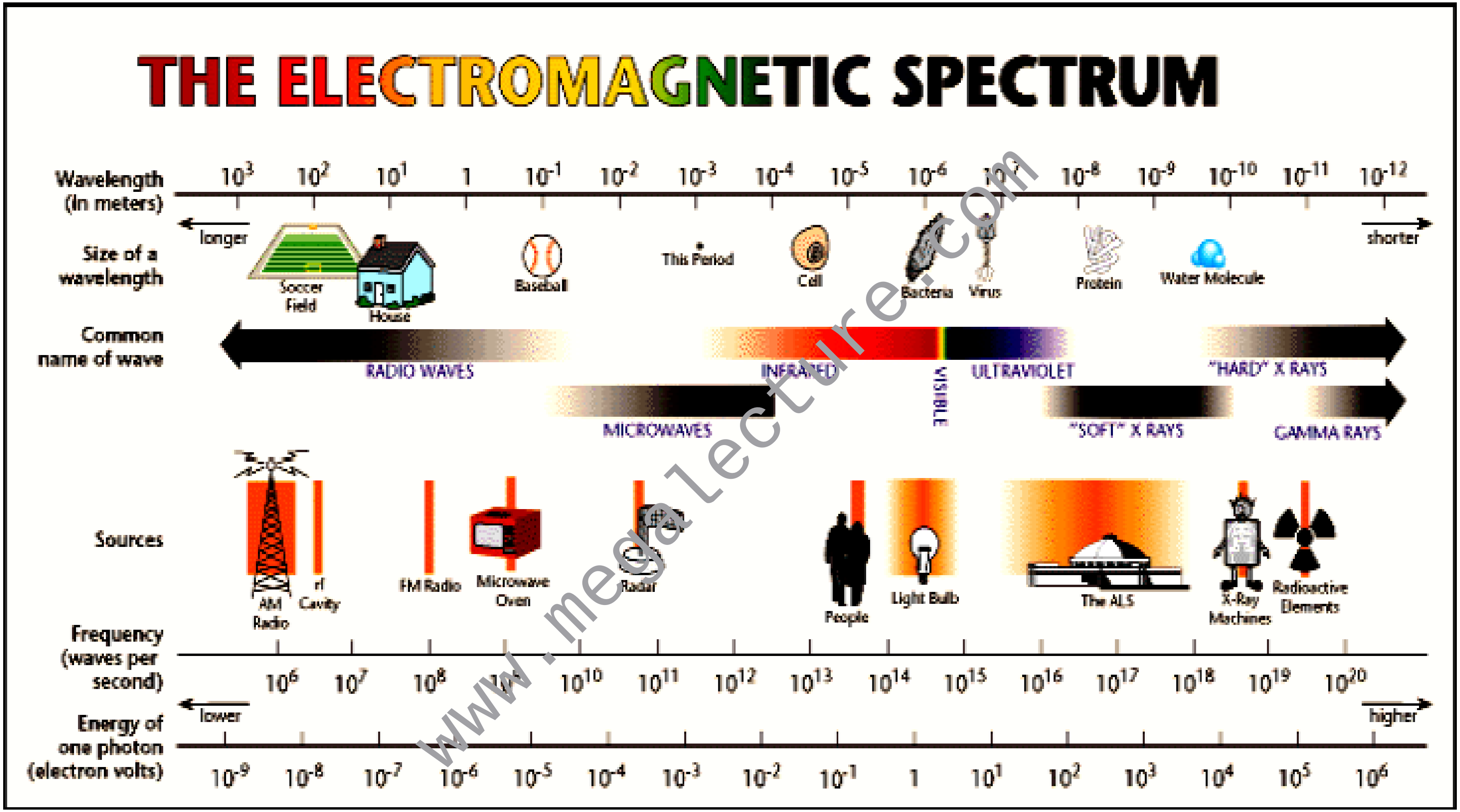
Electromagnetic Waves

James Clerk Maxwell's (1831 – 1879) crowning achievement was to show that a beam of light is a travelling wave of electric and magnetic field, an *electro-magnetic* wave.

In Maxwell's time, the *visible*, *infrared* and *ultraviolet* form of light were the only electromagnetic waves known. *Heinrich Hertz* then discovered what we now call *radio waves* and verified that they move through the laboratory at the same speed as visible light.

We now know a wide spectrum of electromagnetic waves. The Sun, being the dominant source of these waves, continually bathes us with electromagnetic waves throughout this spectrum.

Reference : * This is a very useful video
http://www.youtube.com/watch?v=pYE8UHcL_gU


THE ELECTROMAGNETIC SPECTRUM
Wavelength (in meters)
10^3 10^2 10^1 1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12}
longer
shorter
Size of a wavelength
Soccer Field
House
Baseball
This Period
Cell
Bacteria
Virus
Protein
Water Molecule
Common name of wave
RADIO WAVES
INFRARED
VISIBLE
ULTRAVIOLET
"HARD" X RAYS
MICROWAVES
"SOFT" X RAYS
GAMMA RAYS
Sources
AM Radio
rf Cavity
FM Radio
Microwave Oven
Radar
People
Light Bulb
The ALS
X-Ray Machines
Radioactive Elements
Frequency (waves per second)
10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20}
lower
higher
Energy of one photon (electron volts)
10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10^1 10^2 10^3 10^4 10^5 10^6

Type of EM wave	Typical Wavelengths λ and its corresponding frequency, f.	Orders of magnitude for wavelength, λ / m
Gamma (γ) rays	λ = 1 pm = 10^{-12} m f = 3×10^{20} Hz	**10^{-12}**
x-rays	λ = 100 pm = 10^{-10} m f = 3×10^{18} Hz	**10^{-10}**
UV ultraviolet	λ = 10 nm = 10^{-8} m f = 3×10^{16} Hz	**10^{-8}**
Visible light	**λ_{red} = 700 nm** λ_{green} = 600 nm = 0.6 μm **λ_{violet} = 400 nm** f_{green} = 5×10^{14} Hz	**10^{-6}**
IR (infra-red)	λ = 100 μm = 10^{-4} m f = 3×10^{12} Hz	**10^{-4}**
Radio wave (*includes microwaves, UHF, VHF etc*)	λ = 3 m f = 10^{8} Hz	**$10^{0} \sim 10^{-2}$**

Properties of Electromagnetic Waves

1) EM waves have the same **speed, *c*, in vacuum** ($c \approx 3 \times 10^{8}$ m s^{-1}).
2) EM waves consist of oscillating **electric and magnetic fields** that are perpendicular to each other.
3) EM waves are all **transverse waves**.

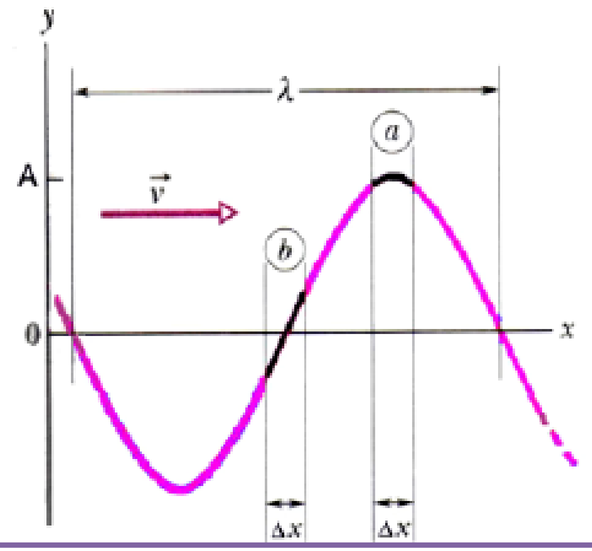
Energy (*E*) and Intensity (*I*) of a Progressive Wave

When we set up a wave on a stretched string, we provide energy for the motion of the string. As the wave moves away from us, it transports that energy as both kinetic energy and elastic potential energy.

Kinetic Energy

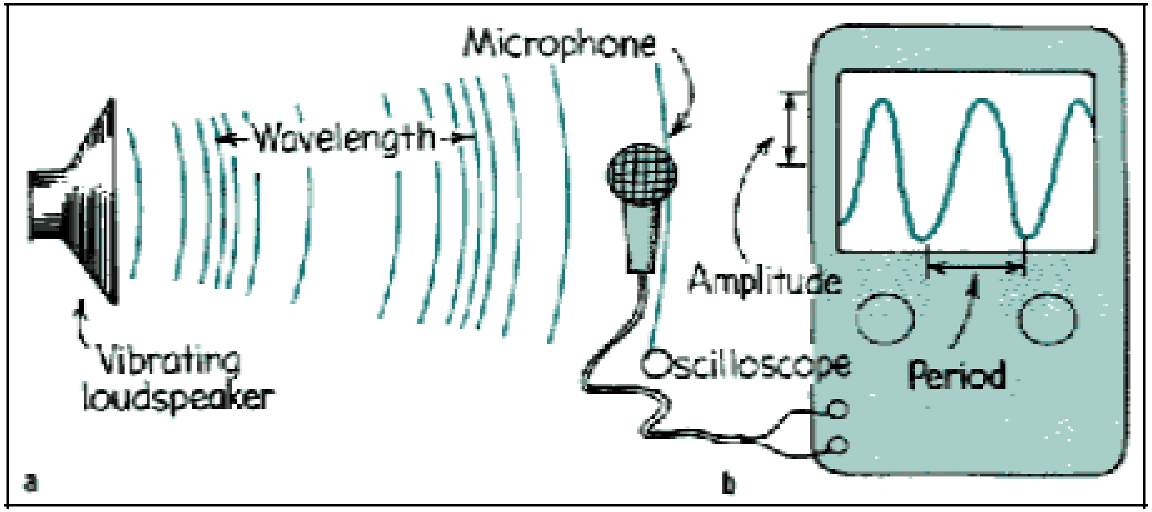
An element of the string of mass Δm, oscillating transversely in simple harmonic motion as the wave passes through it, has KE associated with its transverse velocity $\vec{u}$.

- When the element is rushing through its $y = 0$ position (element *b* in the diagram), its transverse velocity – and thus its KE - is a maximum.
- When the element is at its extreme position $y = A$ (element *a*), its transverse velocity – and thus its KE – is zero.



The frequency of sound using a calibrated CRO

(This topic was done in Second chapter : Measurement & Techniques)



A calibrated c.r.o. (cathode-ray oscilloscope) implies that the time-base is set such that the period, T, of oscillations of the air layers detected by the microphone may be read.

Using the relation

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

the frequency, f, of sound produced by the vibrating loudspeaker may be determined.

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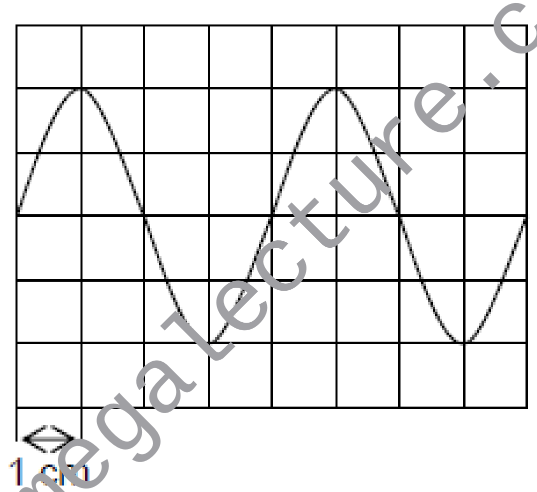
Sample problem

(This topic was done in Second chapter : Measurement & Techniques)

The trace shown appeared on an oscilloscope screen with the time-base set to 2.0 ms cm^{-1}.



What is the frequency of the signal?

A 40 Hz **B** 125 Hz **C** 250 Hz **D** 500 Hz

Solution

Period, $T = 2.0\text{ ms cm}^{-1} \times 4\text{ cm} = 8.0\text{ ms}$

Frequency, $f = \frac{1}{T} = \frac{1}{8 \times 10^{-3}\text{ s}} = 125\text{ Hz}$

Ans: B

The wavelength of sound using stationary waves

- This topic would be studied in detail in next chapter ‘Superposition’.
- Please refer to notes on Stationary Waves in the topic Superposition.

POLARISATION

Electromagnetic Wave : Electric Field & Magnetic Field

- A light wave is an electromagnetic wave that travels through the vacuum of outer space.
- Electromagnetic wave is a transverse wave that has both an electric and a magnetic component.

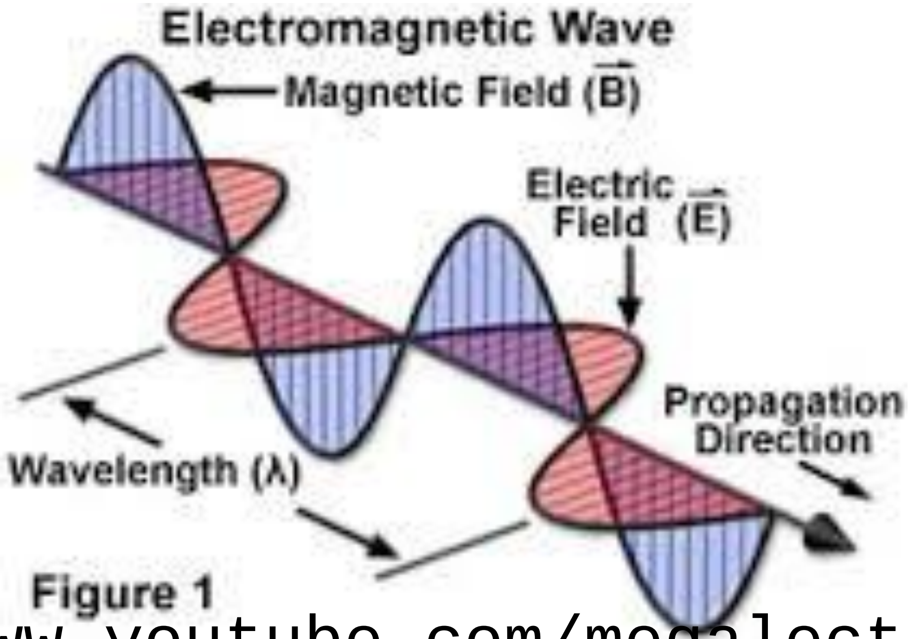


Figure 1

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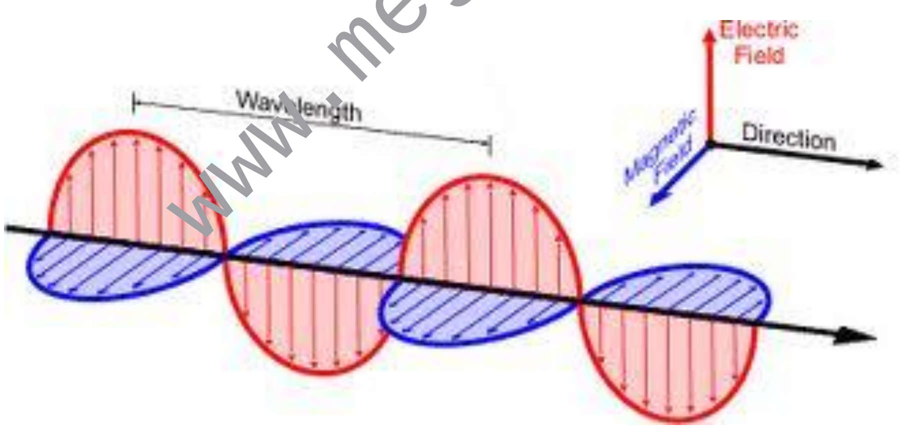
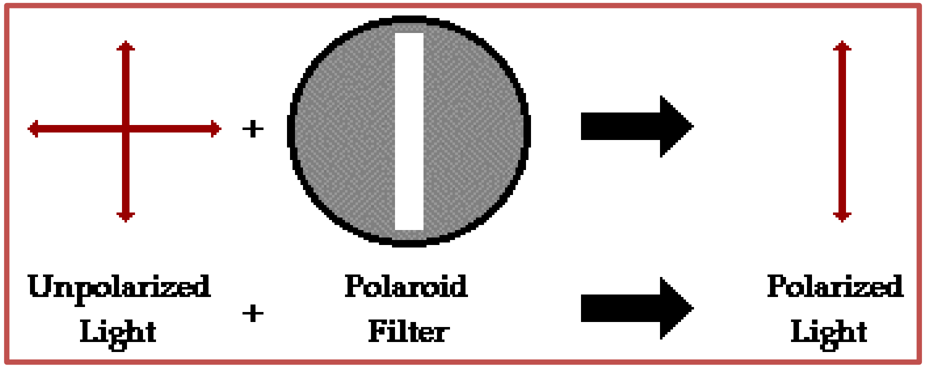
Electromagnetic Wave : Electric Field & Magnetic Field

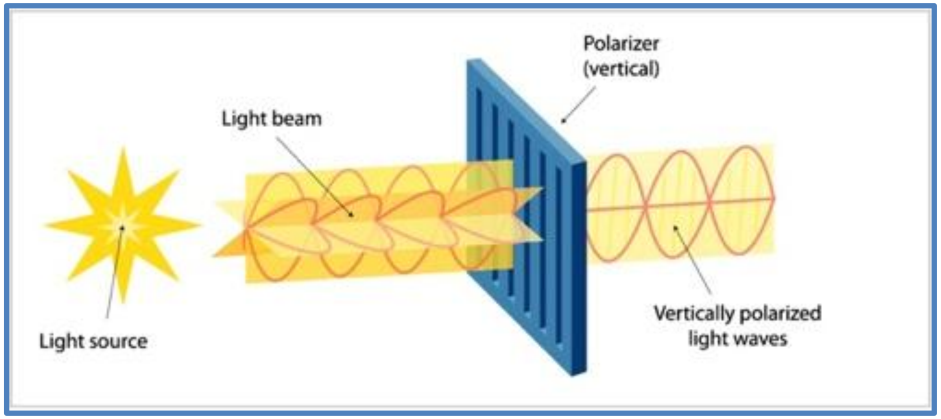
- A light wave that is vibrating in more than one plane is referred to as **unpolarized light**.
- Light emitted by the sun, by a lamp in the classroom or by a candle flame are examples of unpolarized light.
- Such light waves are created by electric charges and vibrate in a variety of directions.



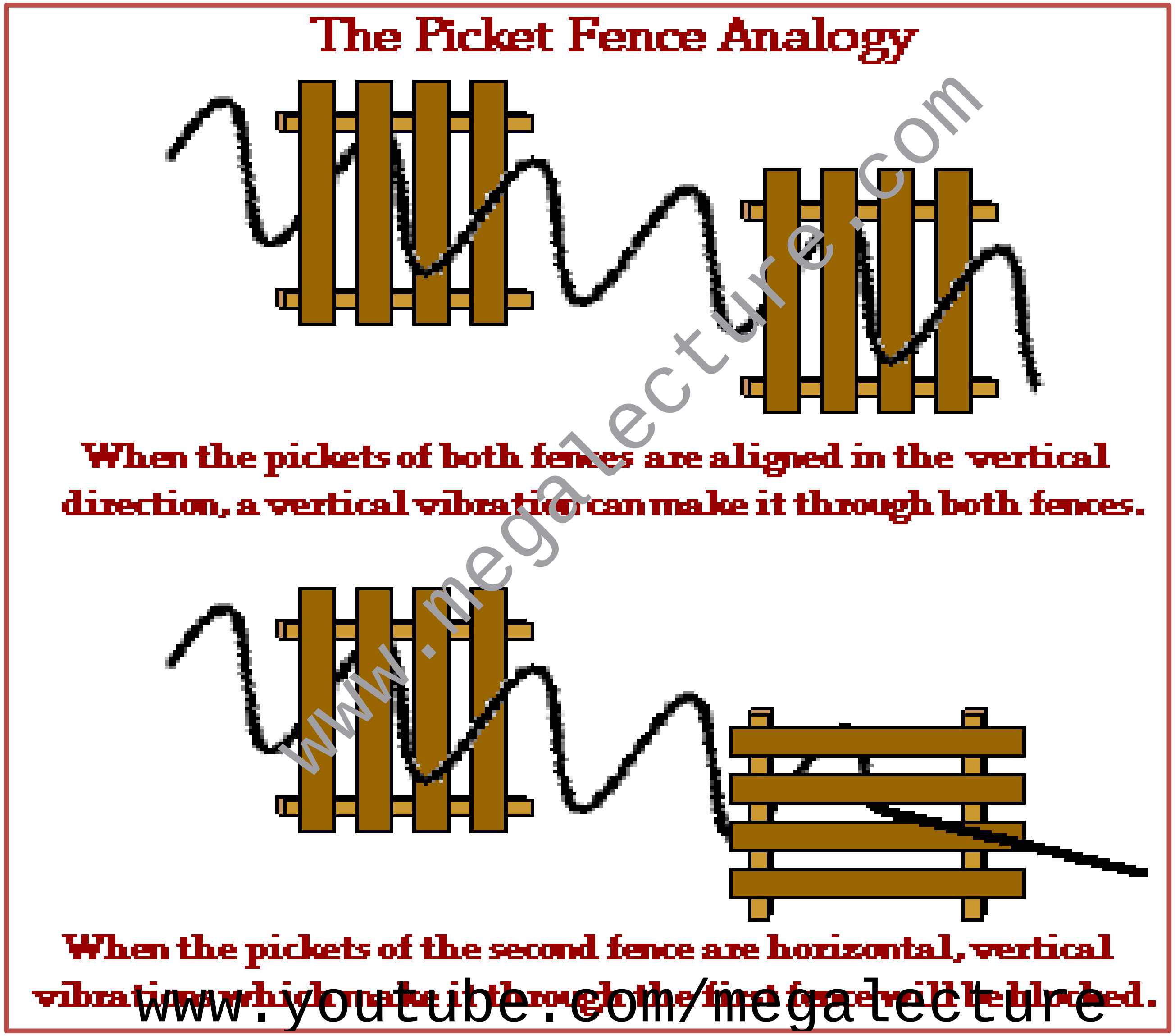
Polarization is a phenomenon associated with transverse waves

- Process by which a wave's oscillations are made to occur in ***one plane*** only.
- Associated with ***transverse waves*** only.





Note : Here, Polarization of light is analogous to that shown in the diagrams.

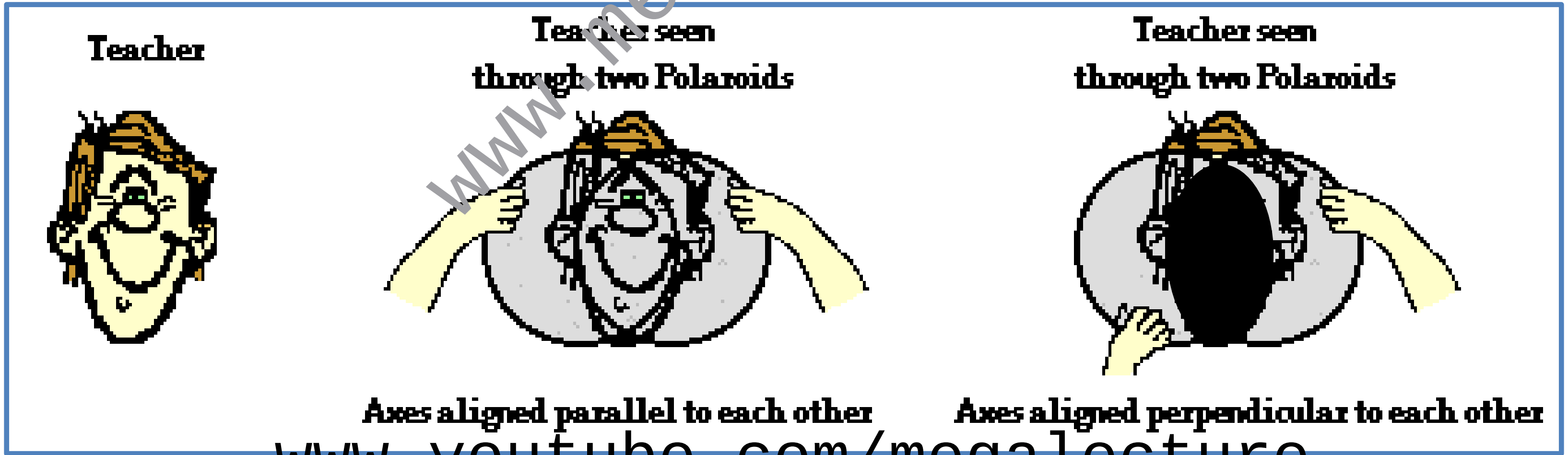


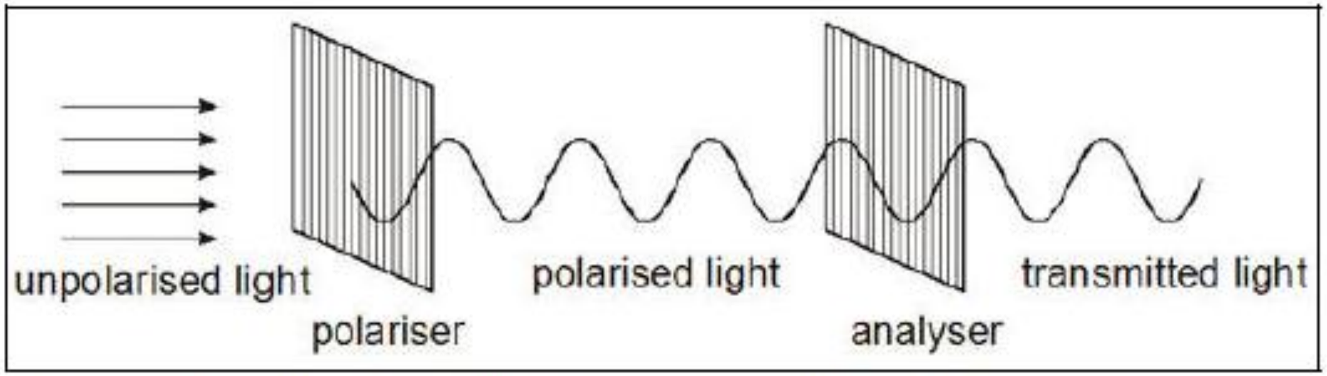
Show an understanding that **Polarisation** is a phenomenon associated with transverse waves

Reference link : http://www.youtube.com/watch?v=e8aYoLj2rO8

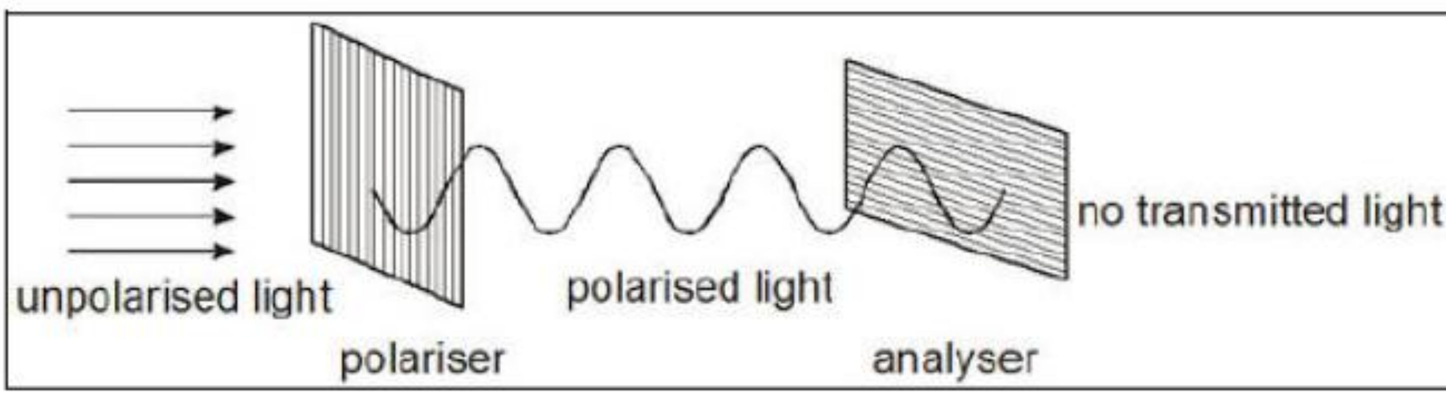
Polarization by Use of a Polaroid Filter

- The most common method of polarization involves the use of a **Polaroid filter**.
- Polaroid filters are made of a special material that is capable of blocking one of the two planes of vibration of an electromagnetic wave.
- In this sense, a Polaroid serves as a device that filters out one-half of the vibrations upon transmission of the light through the filter. When unpolarized light is transmitted through a Polaroid filter, it emerges with one-half the intensity and with vibrations in a single plane; it emerges as polarized light.





Light travelling *parallel* to polariser → the transmitted light has (almost) the same intensity as the polarised light (i.e. the amplitude of the light wave is identical).



When the 2nd polariser, or the Analyser is *perpendicular* to polariser, no transmitted light is observed. Hence, intensity is zero. (i.e. the amplitude of the light wave is zero).

A longitudinal waves cannot be Polarised. Why?

A longitudinal waves cannot be polarised because the particles in the wave oscillate parallel to the wave direction and cannot be restricted to vibrate in any plane.

Applications of Polarizations

1) Polaroid sunglasses

- The glare from reflecting surfaces can be diminished with the use of Polaroid sunglasses.
- The polarization axes of the lens are vertical, as most glare reflects from horizontal surfaces.

Applications of Polarizations

2) Polarization is also used in the entertainment industry to produce and show 3-D movies.

Reference link : http://www.youtube.com/watch?v=qIKzPgo2rNw

HOW 3D WORKS (not in syllabus, just for your information only)

- Three-dimensional movies are actually two movies being shown at the same time through two projectors.
- The two movies are filmed from two slightly different camera locations. Each individual movie is then projected from different sides of the audience onto a metal screen.
- The movies are projected through a polarizing filter. The polarizing filter used for the projector on the left may have its polarization axis aligned horizontally while the polarizing filter used for the projector on the right would have its polarization axis aligned vertically.
- Consequently, there are two slightly different movies being projected onto a screen. Each movie is cast by light that is polarized with an orientation perpendicular to the other movie. The audience then wears glasses that have two Polaroid filters. Each filter has a different polarization axis - one is horizontal and the other is vertical. The result of this arrangement of projectors and filters is that the left eye sees the movie that is projected from the right projector while the right eye sees the movie that is projected from the left projector. This gives the viewer a perception of depth.

QUESTION TIME !

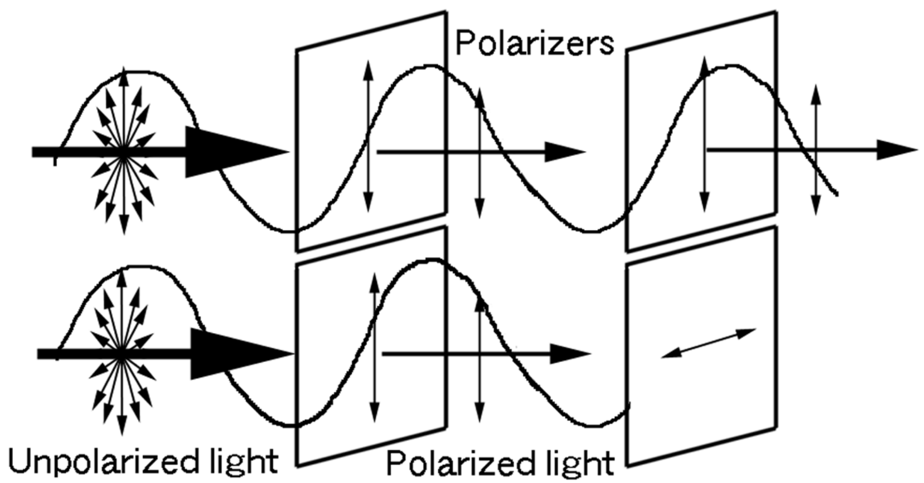
Check your understanding on Polarization

Question No.1

1. Suppose that light passes through two Polaroid filters whose polarization axes are parallel to each other. What would be the result?

Answer - Question No.1

The first filter will polarize the light, blocking one-half of its vibrations. The second filter will have no affect on the light. Being aligned parallel to the first filter, the second filter will let the same light waves through.



Question No.2

2. Which of the following **cannot** be polarised?

A-infrared waves

B-microwaves

C-sound waves

D- ultraviolet waves

Answer - Question No.2

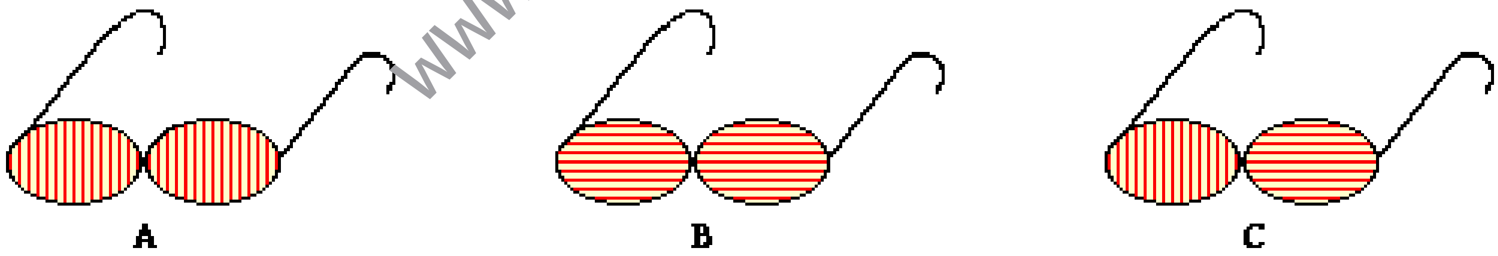
- Answer: **C – Sound waves**

A longitudinal waves cannot be polarised because the particles in the wave oscillate parallel to the wave direction and cannot be restricted to vibrate in any plane.

Question No.3

3. Consider the three pairs of sunglasses below. Identify the pair of glasses which is capable of eliminating the glare resulting from sunlight reflecting off the calm waters of a lake? ___________ Explain.

(The polarization axes are shown by the lines.)



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Answer - Question No.3

- Answer: **A**
- The glare is the result of a large concentration of light aligned parallel to the water surface. To block such plane-polarized light, a filter with a vertically aligned polarization axis must be used.

The Doppler effect

You may have noticed a change in pitch of the note heard when an emergency vehicle passes you while sounding its siren. The pitch is higher as it approaches you, and lower as it recedes into the distance. This is an example of the Doppler effect; you can hear the same thing if a train passes at speed while sounding its whistle.

Figure 13.11 shows why this change in frequency is observed. It shows a source of sound emitting waves with a constant frequency f_s, together with two observers A and B.

- If the source is stationary (Figure 13.11a), waves arrive at A and B at the same rate, and so both observers hear sounds of the same frequency f_s.
- If the source is moving towards A and away from B (Figure 13.11b), the situation is different. From the diagram you can see that the waves are squashed together in the direction of A and spread apart in the direction of B.

Observer A will observe waves whose wavelength is shortened. More waves per second arrive at A, and so A observes a sound of higher frequency than f_s. Similarly, the waves arriving at B have been stretched out and B will observe a frequency lower than f_s.

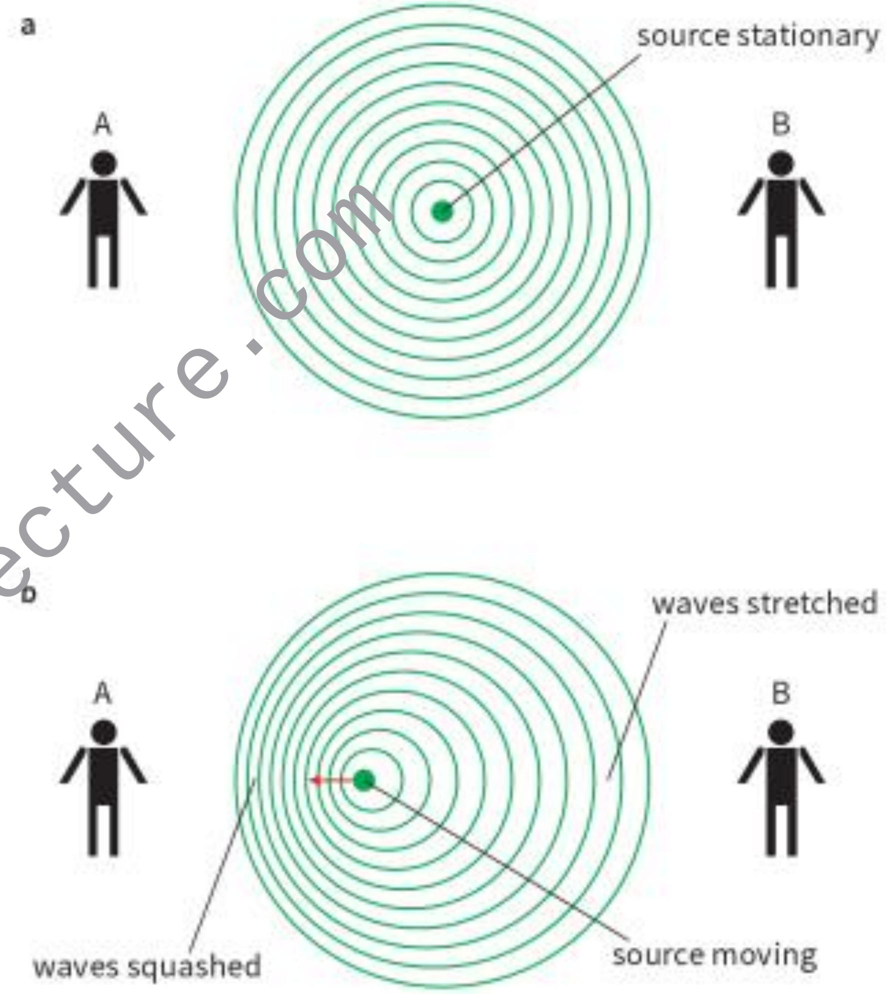

Figure 13.11 Sound waves, represented by wavefronts, emitted at constant frequency by **a** a stationary source, and **b** a source moving with speed v_s.

An equation for observed frequency

There are two different speeds involved in this situation. The source is moving with speed v_s. The sound waves travel through the air with speed v, which is unaffected by the speed of the source. (Remember, the speed of a wave depends only on the medium it is travelling through.)

The frequency and wavelength observed by an observer will change according to the speed v_s at which the source is moving. Figure 13.12 shows how we can calculate the observed wavelength λ_o and the observed frequency f_o.

The wave trains shown in Figure 13.12 represent the f_s waves emitted by the source in 1 s. Provided the source is stationary (Figure 13.12a), the length of this train is equal to the wave speed v since this is the distance the first wave travels away from the source in 1 s. The wavelength observed by the observer is simply $\lambda_o = \frac{v}{f_s}$.

The situation is different when the source is moving away from the observer (Figure 13.12b). In 1 s, the source moves a distance v_s. Now the train of f_s waves will have a length equal to $v + v_s$.

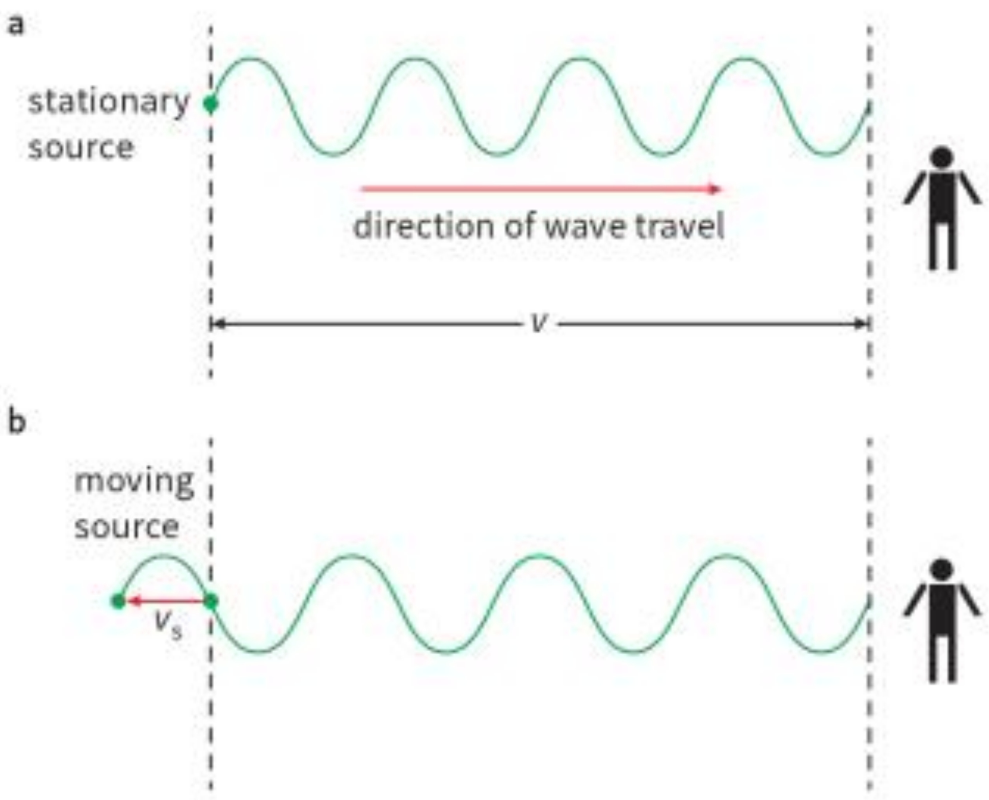

Figure 13.12 Sound waves, emitted at constant frequency by **a** a stationary source, and **b** a source moving with speed v_s away from the observer.

The observed wavelength is now given by $\lambda_o = \frac{(v + v_s)}{f_s}$.
The observed frequency is given by:

$$f_o = \frac{v}{\lambda_o} = \frac{f_s \times v}{(v + v_s)}$$

This tells us how to calculate the observed frequency when the source is moving away from the observer. If the source is moving towards the observer, the train of f_s waves will be compressed into a shorter length equal to $v - v_s$, and the observed frequency will be given by:

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

We can combine these two equations to give a single equation for the Doppler shift in frequency due to a moving source:

$$\text{observed frequency } f_o = \frac{f_s \times v}{(v \pm v_s)}$$

where the plus sign applies to a receding source and the minus sign to an approaching source. Note these important points:

- The frequency f_s of the source is not affected by the movement of the source – it still emits f_s waves per second.
- The speed v of the waves as they travel through the air (or other medium) is also unaffected by the movement of the source.

Note that a Doppler effect can also be heard when an observer is moving relative to a stationary source, and also when both source and observer are moving.

WORKED EXAMPLE

3 A train with a whistle that emits a note of frequency 800 Hz is approaching an observer at a speed of 60 m s^{-1}. What frequency of note will the observer hear? (Speed of sound in air = 330 m s^{-1}.)

Step 1 Select the appropriate form of the Doppler equation. Here the source is approaching the observer so we choose the minus sign:

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

Step 2 Substitute values from the question and solve:

$$f_o = \frac{800 \times 330}{(330 - 60)} = \frac{800 \times 330}{270}$$

$$= 978 \text{ Hz}$$

So the observer hears a note whose pitch is raised significantly, because the train is travelling at a speed which is an appreciable fraction of the speed of sound.

Light waves show the Doppler effect in the same way that sound waves do. So, for example, if an astronomer looks at the light from a distant star which is receding from Earth at speed v_s, its wavelength will be increased and its frequency will be decreased. The change in wavelength $\Delta\lambda$ is simply given by $\Delta\lambda/\lambda = v_s/c$.


Q&A