S3 New Curriculum Physics

Theme: waves

Chapter 4 – General wave properties

WAVES

Waves are **disturbances that transfer energy** from one place to another without apparent movement of particles of the medium.

Types of Waves:

- **Mechanical waves**: Need a medium (like air, water, or a rope) to travel through. Examples: sound waves, water waves.
- **Electromagnetic waves**: Don't need a medium—they can move through the vacuum of space. Examples: light, X-rays, radio waves.
- **Matter waves**: Found in quantum physics, where particles like electrons behave like waves.

Differences between mechanical and electromagnetic waves

Mechanical Waves	Electromagnetic waves
Need a medium for transmission.	Do not need a medium for transmission.
Cannot travel through vacuum.	Can travel through a vacuum.
Relatively slow	Very fast

Characteristic of wave motion

(i) In a wave motion, the energy is transmitted through a medium by repeated periodic oscillations of particles of the medium about their mean or equilibrium position.

(ii) Energy and momentum are transferred from one point to another without any actual transfer of the particles of the medium.

(iii) The velocity with which wave travel is different from the velocity with which the particles in the wave vibrate about their mean or equilibrium position.

(iv) For a given medium, the velocity of wave motion remains constant but the velocity of the particles about their equilibrium position in the wave changes continuously during their vibrations.

(v) The velocity of the particles is maximum at the mean position and become zero at th extreme position

Kinds/shapes of waves

There are two kinds/ shapes of waves namely:

(i) Longitudinal waves.

(ii) Transverse waves.

Longitudinal waves

A longitudinal wave is one in which the direction of the wave motion in the same direction as the vibration.

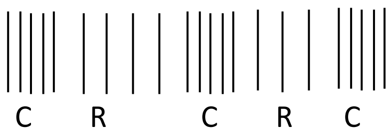
OR

A longitudinal wave is a mechanical wave in which particles vibrate in direction parallel to wave motion.

Examples of longitudinal waves are sound waves, waves produced by pipes and string instruments.

A longitudinal wave has two regions namely: compression and rare faction regions.

Diagram showing motion of particles for longitudinal wave.



C is compression region, **R** is rare faction region.

Compression region

Compression region is a region in the longitudinal wave where the vibrating particles are very close together. A particle at the centre of compression region moves from the rest position in same direction as the wave.

Rare-faction region

Rare-faction region is a region in the longitudinal wave where the vibrating particles are further apart. A particle at the centre of rare-faction moves from rest position in the opposite direction to that of the wave.

Differences between compression and rare faction regions of longitudinal wave.

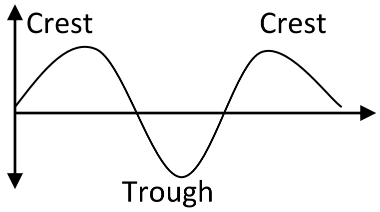
Compression	**Rare-faction**
Vibrating particles are very close together.	Vibrating particles are further apart.
A particle at the centre moves from rest position in a direction the same as that of the wave motion.	A particle al the centre moves from rest position in opposite direction to that of the wave motion.

Transverse waves

Transverse wave is either mechanical or electromagnetic wave in which particles vibrate perpendicular to the direction of wave motion.

Example: Water waves, light waves, all electromagnet waves.

A transverse wave has two main regions namely: Crest and Trough.



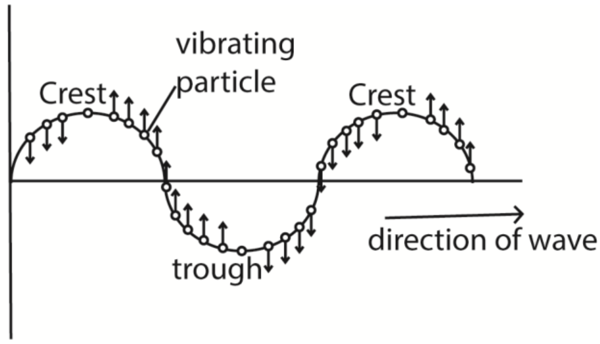
Crest is a region of maximum upward displacement of particles in a transverse wave.

Trough is a region of maximum downward displacement of particles in a transverse wave.

Differences between a transverse wave and longitudinal wave

Transverse	**Longitudinal wave**
Is one in which particles vibrate perpendicular to the direction of wave motion	is one in which particles vibrate in a direction parallel to wave motion
Has 2 regions crest and trough	It has 2 regions, compression region and rare faction

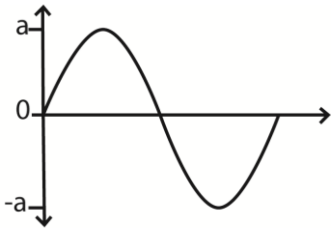
General presentation of a transverse wave



Definition of terms

Amplitude is a maximum displacement of a particle from its rest position on a wave.

S.I unit of amplitude is metre (m).

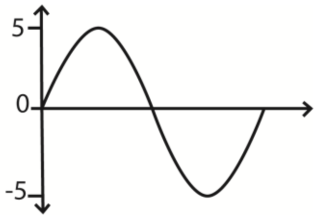


In the diagram above:

Amplitude = a-0 = a or Amplitude = 0-(-a) = a

Example 1:

Find the amplitude of the wave below

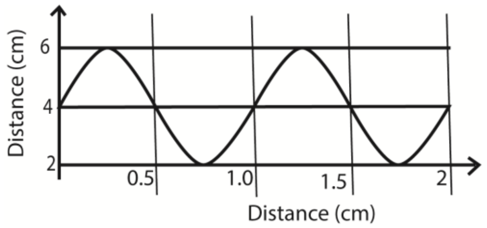


Amplitude = 5 -0

= 5m

Example 2

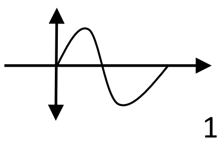
Find amplitude of the wave below



Amplitude = 6 - 4=2m

A cycle of a wave

Cycle is one complete to and from motion of a wave.

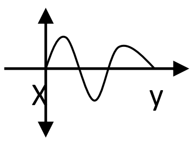


1 cycle

Example 3

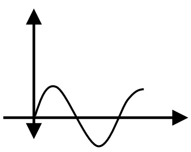
For each of the following find the number of cycles

(a)



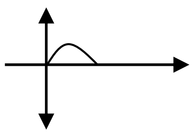
1 ½ cycle

(b)



1 ¼ cycle

(c)



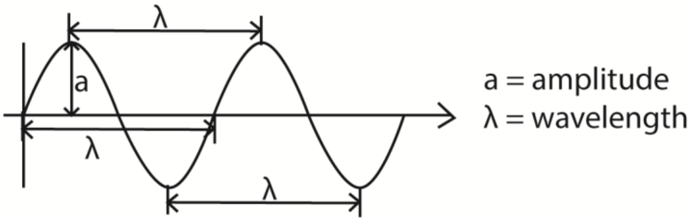
½ cycle

Wave length (λ)

Wave length is the distance between successive particles of the medium that are in phase.

For transverse waves, **wave length** is the distance between two successive crests or troughs. For longitudinal waves, **wave length** is the distance between two successive compressions or rare-factions.

The S.I unit of wave length is metre **(m)**



The Period

A Period of a wave is the time to taken to complete one cycle of wave or time taken for a wave to travel a distance of wave length. S. I unit is seconds.

In general for n cycles completed in time t

Period $T = \frac{t}{n}$

Example 4

Find the period of a wave which makes 10cycles in 40s

n = 10cycles

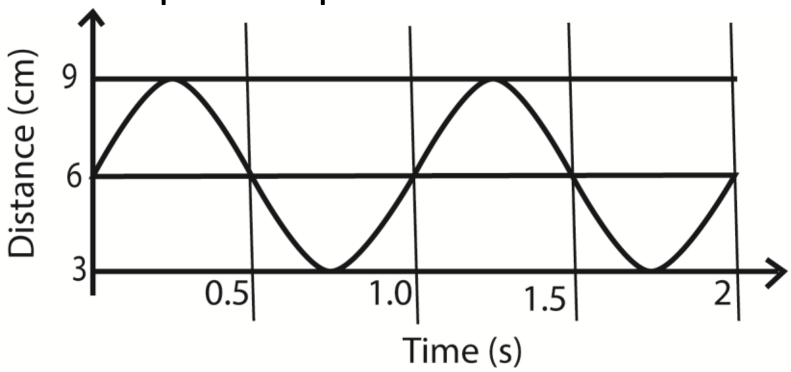
t = 40s

$T = \frac{t}{n}$

$T = \frac{40}{10} = 4s$

Example 5

Find the amplitude and period of wave below



Amplitude = 9 – 3 = 3cm

Period = 1.0s

Frequency

Frequency is the number of vibrations per second.

Frequency is also the number of complete cycles made by a wave in 1 second.

Frequency is also the number of wave length that passes a fixed point per second.

The S.I unit for frequency is Hertz (Hz).

Hertz is one complete oscillation per second e.g. 60Hertz means 60 oscillations per second or 60 vibrations per second.
Note: 1Hz = 1s^{-1}
Bigger units
1 kHz = 1000 Hz
E.g. 4 kHz = 4 x 1000
= 4000Hz
1 MHz = 10^6 = 1000000Hz

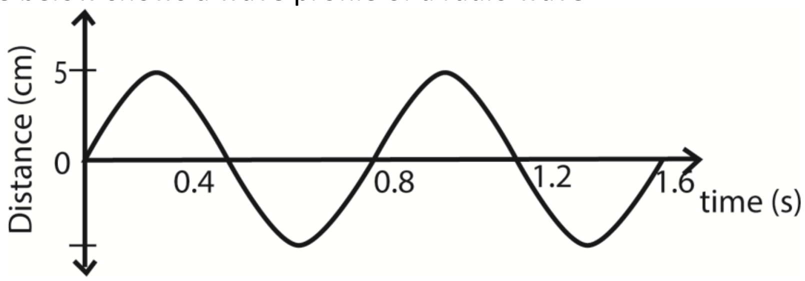
In general for calculation
Frequency (f) = $\frac{\textbf{number of oscillation (n)}}{\textbf{time taken (t)}}$

Where **n** is the number of oscillation or cycles or vibrations made in time **t**.

Example 5:
A vibrator produces 10 vibrations in 4 seconds, find the frequency
n= 10 oscillations
t = 4s
f = $\frac{n}{t}$ = $\frac{10}{4}$
= 2.5Hz

Example 6
A vibrate vibrating at 10Hz for 4s, find the no of vibrations made
f = $\frac{n}{t}$ f = 10 Hzt = 4s
10 = $\frac{n}{4}$
n= 40 vibrations

Example 7
The figure below shows a wave profile of a radio wave



(i) Determine the amplitude of the wave
5 -0 = 5cm
(ii) Find the frequency of the wave
0.8 seconds are required for 1wave cycle
1.0 second are equal to $\frac{1.0}{0.8}$ = 1.25Hz

Wave velocity (V)

Wave velocity is the distance a wave travels in 1 second.

Or

Velocity, v = wavelength in meters x number of cycles per second

= wavelength in meters x frequency of a wave

= fλ

S.I unit is $\mathbf{ms^{-1}}$

For calculations

If a wave covers a distance **X** in time **t**, then wave velocity $\mathbf{V = \frac{x}{t}}$

Example 8

A vibrator produces wave which travels a distance of 35m in 2 seconds

Calculate the wave velocity

X = 35m   t = 2s

$V = \frac{x}{t} = \frac{35}{2} = \mathbf{17.5ms^{-1}}$

Example 9

A vibrator produces waves which travel 60m in 0.1minutes if the frequency of vibration is 5 vibrations per second. Find the wave length

X = 60m

t= 0.1 minute = 0.1 x 60 = **6s**

f = 5 vibrations per second = **5Hz**

$V = \frac{x}{t} = \frac{60}{6} = 10ms^{-1}$

V= λf

10 = λ x 5

$\lambda = \frac{10}{5} = \mathbf{2m}$

Example 10

A wave of wave length 0.5m moves at $5ms^{-1}$. Find

(i) Frequency

Frequency, $f = \frac{velocity}{wave\ length} = \frac{5}{0.5} = 10Hz$

(ii) Period

$T = \frac{I}{f} = \frac{1}{10} = \mathbf{0.1s}$

Example 11

A wave vibrating at 10Hz makes 4cycles covering 20cm. calculate a wave velocity.

f = 10Hzn= 4 cycles   X = 20m

$\lambda = \frac{x}{n} = \frac{20}{4} = 5m$

V= λf=5x10 = $\mathbf{50ms^{-1}}$

Note: for electromagnetic waves which include Gamma rays, x-rays, light, radio waves all move at a speed of $\mathbf{3x\ 10^8 ms^{-1}}$. When handling calculations involving electromagnetic waves, speed of $\mathbf{3x\ 10^8 ms^{-1}}$ should be used.

Example 12

The wavelength of electromagnetic wave is 10m. Calculate frequency and period.

$V = 3 \times 10^8 ms^{-1}$ $\lambda = 10m$

(i) $V = \lambda f$

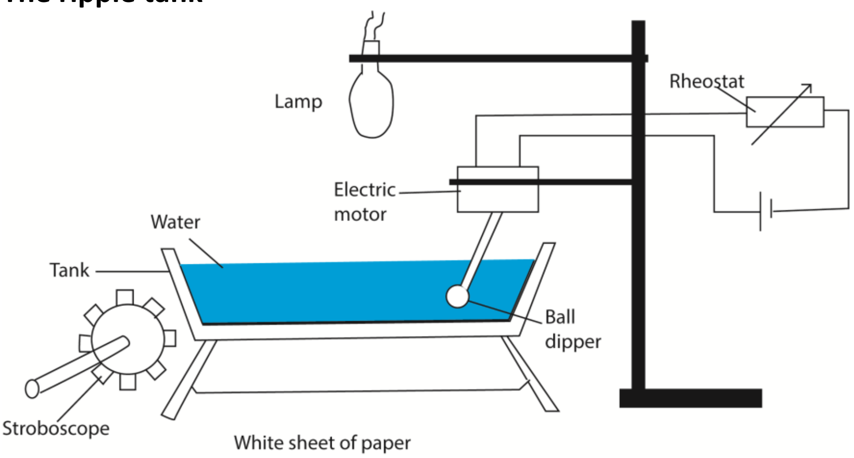
$\mathbf{3 \times 10^8 = 10 \times f}$

$\frac{3 \times 10^8}{10} = \frac{10}{10} \times f$

$\mathbf{f = 3 \times 10^7 Hz}$

(ii). Period $T = \frac{1}{f} = \frac{1}{3 \times 10^7} \cong \mathbf{3.3 \times 10^{-8} s}$

The ripple tank



The properties of waves can be obtained by studying the behaviour of water waves in the ripple tank.
The ripple tank consists of a tray whose bottom is transparent so that light can shine upwards or downwards.
The sides are sloppy and lined with a sheet of sponge in order to:

(i) Absorb the energy of the ripples.
(ii) Prevent reflection by the sides.

The lamp above the tank casts the shadow of the wave on the white sheet of paper placed underneath.

How waves are produced on the ripple tank?

Straight waves

These are produced by dipping a straight edged object like ruler in the water surface.
Continuous straight waves are produced when a straight edged object is attached to a bar using vibrations generated by an electric motor.

Circular waves

These are produced by dipping a small spherical balls attached to bars using
Vibrations generated by an electric motor.

Stroboscope
This is used in the making of waves to appear stationary so that they can be studied. Stroboscope is a disc with equally spaced slits.

How the Stroboscope is used to freeze or slow down movement of water waves set up in the ripple tank
This is done by varying the speed of rotation of the Stroboscope until the waves appear to be stationary when viewed on the screen through the discs of the stroboscope.

How frequency may be measured by ripple tank?
In short the frequency can be measured by the following ways:
Varying speed of rotation
The speed of rotation of the Stroboscope is varied until the waves appear stationary on viewing through the slits of the Stroboscope.

Measuring the periodic T
When the waves appear stationary, the time taken for successive slits to cross the line of sight is measured. This is the period "T" of the wave. So frequency f = 1/T

Description of how the wave length may be measured from ripple tank experiment
Varying the speed of rotation
The speed of rotation of the stroboscope is varied until the waves appear stationary on viewing through the slits.

Casting the shadow
Then the lamp above casts the shadow of the waves on the white paper below the tray. The wavelength is measured directly.

Progressive and stationary or standing waves
A **progressive wave**—also called a *traveling wave*—is a wave that moves through a medium, carrying energy from one point to another **without transporting matter**.

A **standing wave**, also called a *stationary wave*, is a special type of wave that appears to be “standing still” rather than traveling through space. It forms when **two identical waves** move through the same medium in **opposite directions** and interfere with each other.

Electromagnetic waves

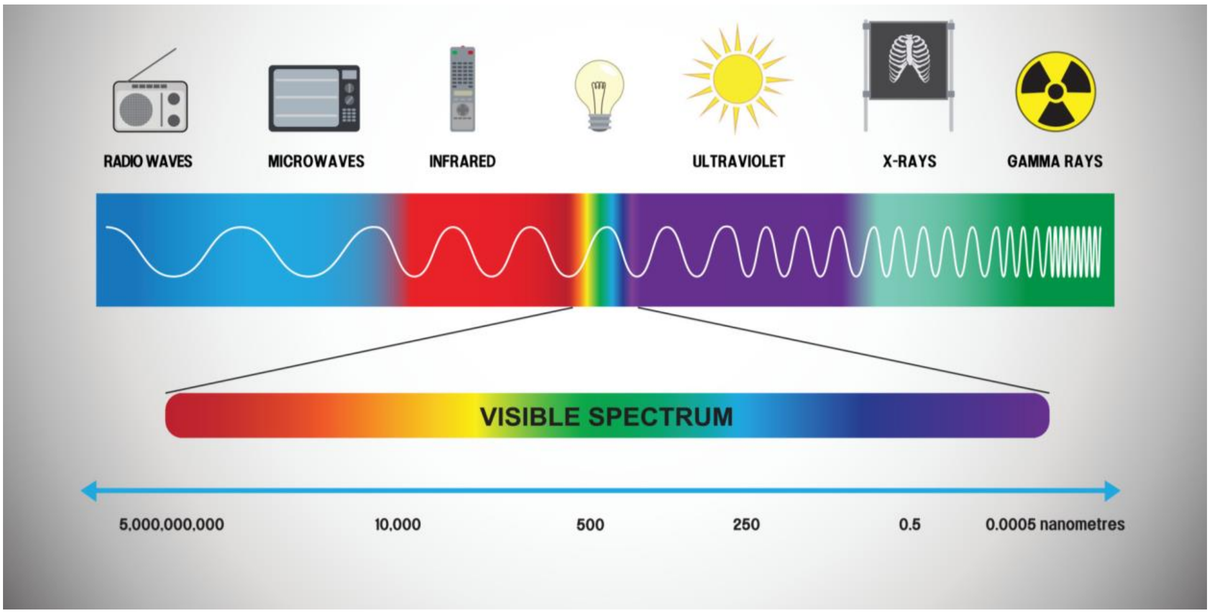
Electromagnetic waves are a type of energy wave that can travel through space—even a vacuum—without needing a medium like air or water. They’re created when **electric and magnetic fields oscillate together**, at right angles to each other and to the direction the wave is moving.

Key Characteristics:

- **Transverse in nature**: The electric and magnetic fields are perpendicular to each other and to the direction of wave travel.

- **Travel at the speed of light** in a vacuum: about 300,000 km/s (or 3×10^8 m/s).
- **Don't need a medium**: Unlike sound or water waves, electromagnetic (EM) waves can move through empty space.

The Electromagnetic Spectrum:

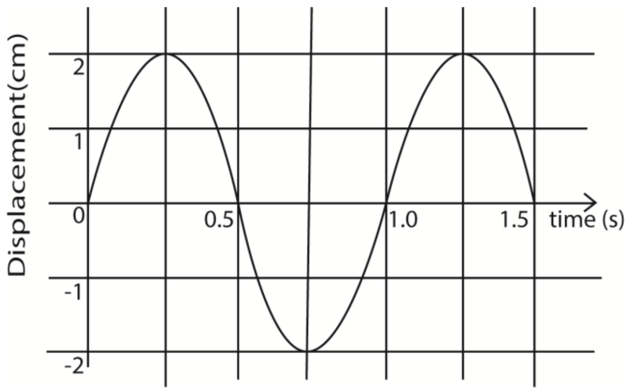


EM waves come in a wide range of wavelengths and frequencies, forming the **electromagnetic spectrum**. From longest to shortest wavelength (and lowest to highest energy), the types include:

1. **Radio waves** – used in communication (TV, radio, phones)
2. **Microwaves** – for cooking and radar
3. **Infrared** – felt as heat
4. **Visible light** – the only part we can see
5. **Ultraviolet (UV)** – causes sunburn
6. **X-rays** – used in medical imaging
7. **Gamma rays** – emitted by radioactive materials and cosmic events

Revision questions

1.



The diagram above shows a section of a transverse wave of wavelength 4.0cm

Find its

(i) Frequency

Frequency = $\frac{1}{T} = \frac{1}{1} = 1Hz$

(ii) Amplitude

2cm

(iii) Velocity

Velocity = fλ = 1 x $\frac{4}{100} = 0.04ms^{-1}$

2. (a) What is meant by standing wave?

Standing waves is one which is formed as a result of the two waves moving in opposite direction with the same speed, amplitude and superpose on each other.

(b) State three differences between sound and light waves

Sound wave	Light waves
- Need material medium for propagation - Propagate at relatively low speed - Have longer wavelength - Particles vibrate in direction is same direction as that of a wave	- Can propagate in vacuum - Propagate as very high speed - Shorter wavelength - Particles vibrate perpendicular to the direction of travel of the wave.

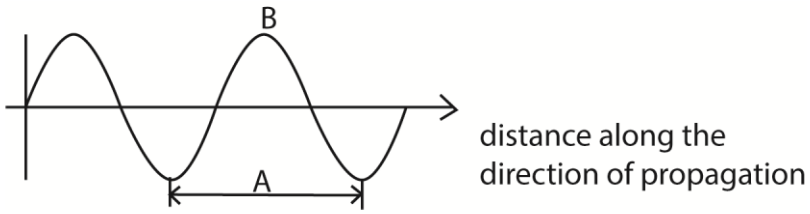
(c) By use of a diagram, explain what is you understand by the term amplitude and wavelength as applied in wave motion.

Amplitude is the maximum displacement of a particle from its equilibrium position while wavelength is the distance covered by a wave after one complete oscillation or it is the distance between two successive crests or troughs.

3. (a) What is meant by a transverse wave?

Is one in which particles in a medium vibrate perpendicular to the direction of travel of the wave.

(b) the diagram below represents a wave travelling in water



(i) Name part labelled B

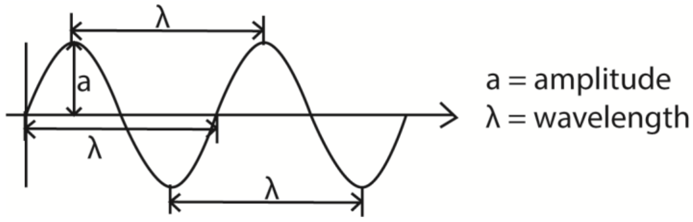
crest

(ii) If distance represented by A is 20cm and the speed of the wave is $8.0ms^{-1}$.

What is the speed of a wave?

f = $\frac{v}{\lambda} = \frac{8}{0.2} = 40Hz$

4.



(b) Derive an equation relating velocity, V, frequency, F, and wavelength, W, of a wave.

Wave speed, V = $\frac{wavelength}{periodic\ time} = \frac{W}{T}$

But T = $\frac{1}{F}$

Thus, V = $\frac{W}{\frac{1}{F}}$ = FW

(c) A radio wave is transmitted at a frequency of 150MHz. calculate its wavelength; velocity of electromagnetic wave is 3 x $10^8 ms^{-1}$.

V = fλ

λ = $\frac{v}{f} = \frac{3 \; x \; 10^8}{150 \; x \; 10^6}$ =2m

(d) (i) List four properties of electromagnetic waves.

They undergo

- Reflection
- Refraction
- Interference
- Diffraction
- Travel in straight

5. (a) (i) How can the speed of waves in ripple tank be reduced

By placing (or dipping) thin glass in the tank making water shallower.

(ii) What is the effect of decreasing the speed of waves in the ripple tank above on frequency?

No change in frequency since frequency depends on the vibrator not depth.

(b) What is the effect of the size of a gap on diffraction of a wave?

When the gap is small the diffracted wave are more circular than when the gap is big

(c) (i) Give two reasons why sound is louder at night than during the day?

- At night air has lower temperature and thus denser increasing speed of sound
- also the air above the earth is less dense causing refraction of sound towards the earth
- Less ambient noise: During the day, background sounds from traffic, people, and machines mask quieter noises. At night, the environment is generally quieter, so even soft sounds stand out more clearly.

(ii) An echo sounding equipment on a ship receives sound pulse reflected from sea bed 0.03s after they have sent out from it. Is the speed of sound in water is 1450ms^{-1}. Calculate the depth of water under the ship.

Depth = velocity x time/2 = $\frac{1450\ x\ 0.03}{2}$ = 21.75m

(d) Give the differences between water and sound waves

Water waves	Sound waves
Particles vibrate perpendicular to the direction of wave/transverse	Particles vibrate in the same direction as that of a wave/longitudinal
Slow	Fast
Polarized	Unpolarized

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Thanks

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