UNIT G482	Module 4	2.4.1	Wave Motion

- ***Candidates should be able to*** :

  - *Describe and distinguish between **progressive longitudinal** and **transverse** waves.*

  - *Define and use the terms **displacement, amplitude, wavelength, period, phase difference, frequency and speed of a wave.***

  - ***Derive** from the definitions of speed, frequency and wavelength, the wave equation :*

    $$\boxed{v = f\lambda}$$

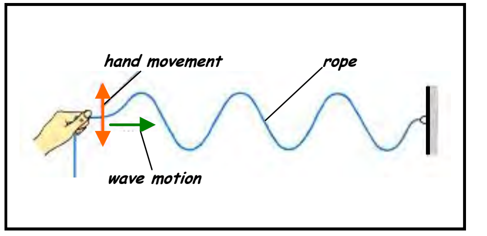
  - *Select and use the wave equation :* $\boxed{v = f\lambda}$

  - *Explain what is meant by **reflection, refraction** and **diffraction** of waves such as sound and light.*

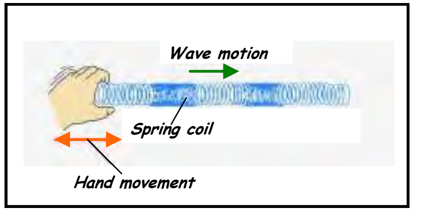
- *PROGRESSIVE WAVES*

- *With the exception of electromagnetic waves, which do not need a material substance for their transmission, all other wave motions (e.g. sound waves, water waves etc.) are disturbances which pass through a substance.*

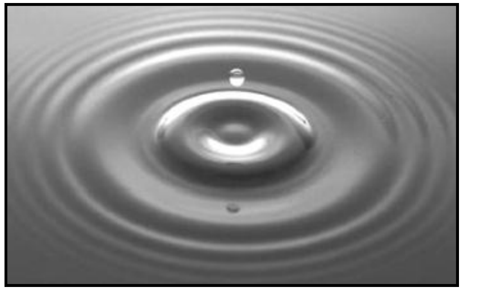
- *A series of waves (similar to those produced on a water surface) can be generated in a long piece of rope which is fixed at one end and moved repeatedly at right angles to its length (as shown in the diagram opposite).*



- *Waves (similar to sound waves) are produced in a spring coil which is fixed at one end while the other end is repeatedly moved as shown in the diagram opposite.*



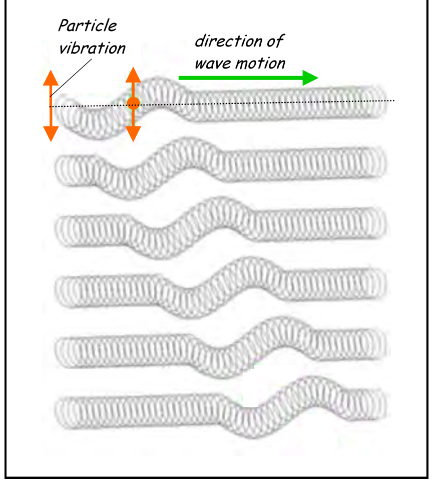
- *A pebble dropped onto a still water surface causes a vibration which produces concentric, circular waves which spread outwards across the water surface.*



- *In each of the wave examples considered, the wave disturbance is initiated at a particular point and this sets the particles of the substance at that point into vibration. This causes neighbouring particles to vibrate in the same way and so the wave progresses through the substance.*

In the case of a single wave pulse initiated by an up and down movement of the end of a springy coil, the motion of the first ring causes the next ring to move and so on.

In this way, the wave travels from one end of the coil to the other as shown in the diagram opposite.



- *All the waves considered so far are :*

PROGRESSIVE WAVES

Waves which travel through a material or through a vacuum and transfer energy from one point to another.

- *CLASSIFICATION OF WAVES*

- *Waves can be :*

MECHANICAL — OR — **ELECTROMAGNETIC**

MECHANICAL

Waves which need a substance for their transmission.

(e.g. sound waves can be transmitted Through air, water and steel, but not Through a vacuum).

EXAMPLES

- *Water waves*
- *Sound waves*
- *Waves along a spring coil or rope*
- *Seismic waves*

ELECTROMAGNETIC

Waves which ***DO NOT*** *need a substance for their transmission*

(e.g. light waves travel from stars and galaxies travel through empty space to reach us here on Earth).

EXAMPLES

- *Gamma-rays*
- *X-rays*
- *Ultra-violet (UV)*
- *Visible light*
- *Infra-red (IR)*
- *Microwaves*
- *Radio waves*

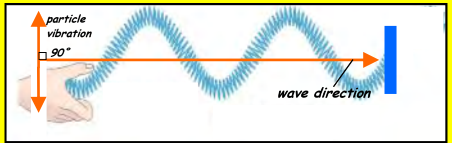
UNIT G482	Module 4	2.4.1	Wave Motion

- Waves can be :

TRANSVERSE OR **LONGITUDINAL**

TRANSVERSE

Waves in which the particles of the medium in which a wave is moving vibrate **perpendicular** To the direction of wave travel.



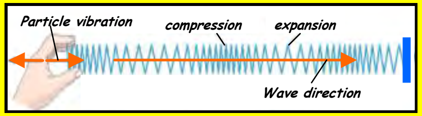
A spring coil can be used as shown above to observe **TRANSVERSE** wave motion. The coil is fixed at one end and the free end is continuously vibrated in a direction **PERPENDICULAR** to the axis of the coil.

<u>TRANSVERSE WAVE EXAMPLES</u>

- **Water waves**
- **Secondary seismic waves**
- **All electromagnetic waves**

LONGITUDINAL

Waves in which the particles of the medium in which a wave is moving vibrate **parallel** to the direction of wave travel.

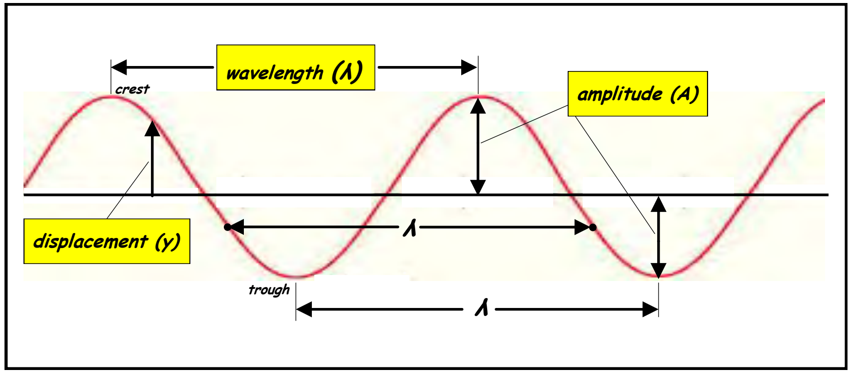


A spring coil can be used as shown above to observe **LONGITUDINAL** wave motion. The coil is fixed at one end and the free end is continuously vibrated in a direction **PARALLEL** to the axis of the coil.

<u>LONGITUDINAL WAVE EXAMPLES</u>

- **Sound waves**
- **Primary seismic waves**

- TERMS ASSOCIATED WITH WAVES



DISPLACEMENT (y) / metre (m)

The **distance** and **direction** of a vibrating particle in a wave from its undisturbed position.

AMPLITUDE (A) / metre (m)

The **maximum displacement** of any particle in a wave from its undisturbed position.

WAVELENGTH (λ) / metre (m)

The distance between two **consecutive points** on a wave which are **in phase** with each other (i.e. the vibrating particles at these points have the same displacement and velocity).
It is the distance between two consecutive **crests** or **troughs.**

PERIOD (T) / second (s)

The time taken for one complete wave to pass a fixed point.

OR

The time taken for one complete oscillation of a particle in the wave.

FREQUENCY (f) / hertz (Hz)

The number of complete waves passing a fixed point per second.

OR

The number of complete oscillations per second of a particle in the wave.

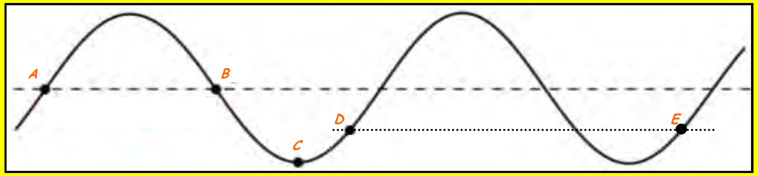
1 Hz = 1 vibration per second.
1kHz = 10^3 Hz **1 MHz** = 10^6 Hz.

PHASE DIFFERENCE (Φ) / degrees or radians

The phase difference between two vibrating particles in a wave is the fraction of a cycle between the vibrations of the two particles.

*Phase difference is measured in **DEGREES** or **RADIANS**.*

1 cycle = 360° = 2π radians



- *In the diagram above, particles at points **D** and **E** which are one wavelength apart, vibrate **in phase** with each other. The **phase difference** between the partcles at these two points is **360° (=2π rads)** (which is the same as **0°**).*
- *Particles at points **A** and **B** which are ½ a wavelength apart, vibrate in **antiphase.** The **phase difference** between the particles at these two points is **180° (π rads).***
- *What is the **phase difference** between :*

  *(a) Particles at points **A** and **C** ?*

  *(b) Particles at points **C** and **D** ?*

UNIT G482	Module 4	2.4.1	Wave Motion

WAVE SPEED (v or c) / metre per sec (m s^{-1})

This is the speed with which energy is transmitted by a wave.

WAVE SPEED EQUATION

*Consider a wave having **wavelength (λ), period (T), frequency (f)** and moving with **speed (v)***

In time (T) the wave will travel a distance (λ).

wave speed, $v = \dfrac{\text{distance travelled}}{\text{time taken}} = \dfrac{\lambda}{T}$

And since, $T = 1/f$, $\quad v = \dfrac{\lambda}{1/f}$

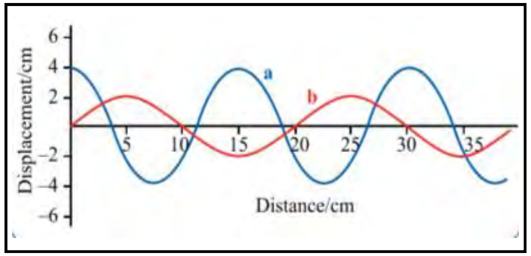
Therefore :

$$\boxed{v = f\,\lambda}$$

v (m s^{-1}) $\quad f$ (Hz) $\quad \lambda$ (m)

- **PRACTICE QUESTIONS**

1 Determine the **amplitude** and **wavelength** of waves **a** and **b** shown in the diagram opposite.



2 (a) Sound waves travel at a speed of **340 m s^{-1}** in air at **20°C**. If the frequency of these waves **is 2.5 kHz**, what is their **wavelength ?** *5*

(b) Infra-red electromagnetic waves travel at a speed of **3.0 x 10^8 m s^{-1}**. Calculate the **frequency** of these waves if their wavelength is **1.2 x 10^{-6} m.**

3 A wave of frequency **2.5 Hz** travels along a stretched cable at a speed of **20 m s^{-1}.** Calculate the **phase difference** between two points on the cable which are **2.0 m** apart.

Express your answers in : (a) **Degrees**, (b**) Radians** and (c) **Fractions of a wavelength.**

4 Calculate the **speed** of a progressive wave of frequency **350 Hz**, if the least distance between two points on the wave having a phase difference of **π/6 rad** is **0.08 m.**

5 A laser emits a single burst of light which lasts for a time of **0.02 μs.** If the wavelength of the light is **500 nm,** calculate the **number of complete waves emitted** by the laser.

6 Using graph paper, draw two waves, **X** and **Y**, such that **Y** has **twice the wavelength** and **a quarter of the amplitude** of **X.**

7 Use the data given below to calculate the **frequency range of light** detectable by the human eye.

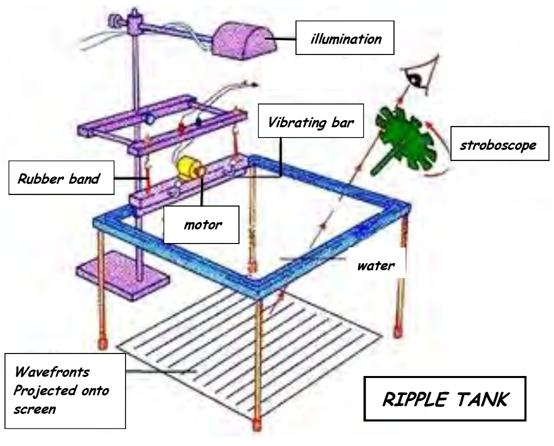
Speed of light in air = **3.0 x 10^8 m s^{-1}**.

Approximate range of visible light wavelengths is **400 nm (violet)** to **700 nm (red).**

• ***REFLECTION, REFRACTION AND DIFFRACTION OF WAVES***

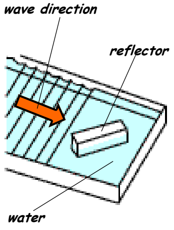
• *A ripple tank as shown opposite may be used to demonstrate reflection, refraction and diffraction of water waves.*

The waves, produced by a vibrating, straight-edged bar, can be viewed from above or projected onto a screen. The straight lines observed on the screen show the positions of the wavefronts (i.e. the crests of the wave).

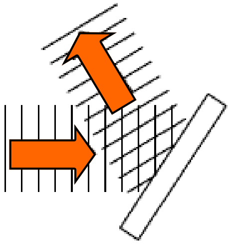


Obstacles are placed in the path of the waves to see what effects are produced.

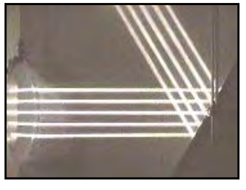
REFLECTION



The waves are sent at an angle to a straight Reflector.



The angle between the Reflected wavefronts and the surface = the angle between the incident wavefronts and the surface. So the direction of the reflected wave is at the same angle to the reflector as the direction of the incident wave.

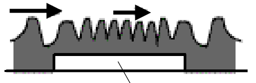


When a ray of light is directed at a plane mirror, the angle between the reflected ray and the mirror = the angle between the incident ray and the mirror.

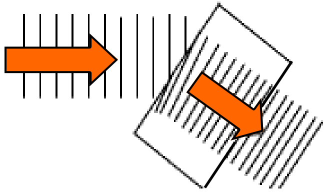
Sound waves are reflected in The same way.

REFRACTION

Refraction occurs when waves change their speed. Water waves slow down when they pass from deep into shallower water.

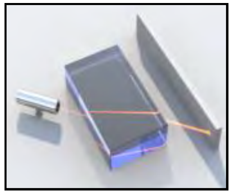


A flat, rectangular piece of perspex placed in the tray, makes the water shallower and as the waves pass over it they are slowed down



*When the water waves are incident at the **DEEP-SHALLOW** boundary at an angle, they change direction and their wavelength (λ) decreases.*

*This is because **$v = f\lambda$** and since **v increases** and **f stays the same, λ must decrease.***



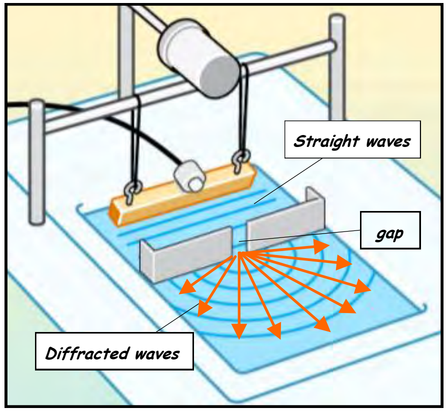
When a ray of light is directed at a parallel-sided glass block at an angle, it is also refracted.

This is because the light waves slow down and so change direction when they pass from air into glass.

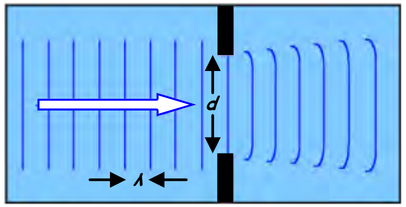
DIFFRACTION

Diffraction is the spreading of waves when they pass through a gap or around an obstacle.

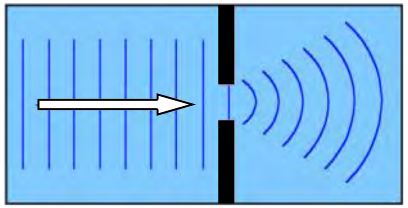
In a ripple tank, plane waves directed at a gapped barrier are seen to spread out as they pass through the gap.



*By varying the **gap width (d)** and the **wavelength (λ)** of the waves, it is seen that the extent of **the diffraction effect depends on both (λ) and (d).***

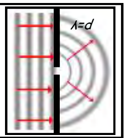


When the gap width (d) is LARGE compared to the wavelength (λ) of the incident waves, the diffraction effect is SMALL.



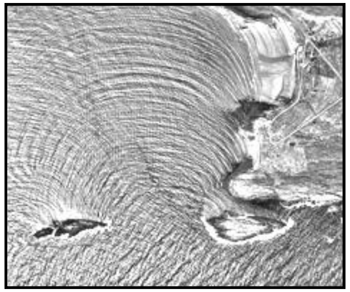
As the gap width (d) is decreased (with the wavelength (λ) kept the same), the diffraction effect becomes GREATER.

The diffraction effect is ***GREATEST*** when the ***WAVELENGTH (λ)*** of the waves is ***EQUAL*** to the gap ***WIDTH (d).***



The fact that the diffraction effect is more significant when the gap width is comparable to the wavelength of the incident waves enables us to explain why, in everyday life, We can observe diffraction for some types of wave but not for others.

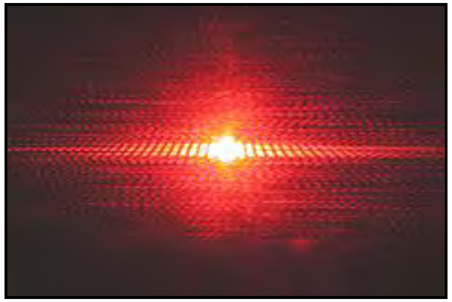
***Sound waves**, for example, diffract as they pass through open doorways because their wavelengths are comparable to the size of the opening. This is why a person speaking in a corridor can be overheard in an adjoining room, in spite of the fact that there is a thick wall in the way.*



*In the aerial photograph shown opposite, **sea waves** are greatly diffracted as they pass through the gap between two large rocks. Again, the effect is observable because the wavelength is of the same order of magnitude as the gap width.*

***Light wave** diffraction, on the other hand, is rarely observable in normal circumstances. This is because visible light wavelengths (400 - 700 nm) are tiny in comparison to the size of the gaps and objects we normally encounter.*

When light from a laser is directed at a very narrow slit, it diffracts into the space beyond the slit to give the type of image shown in the photograph opposite.



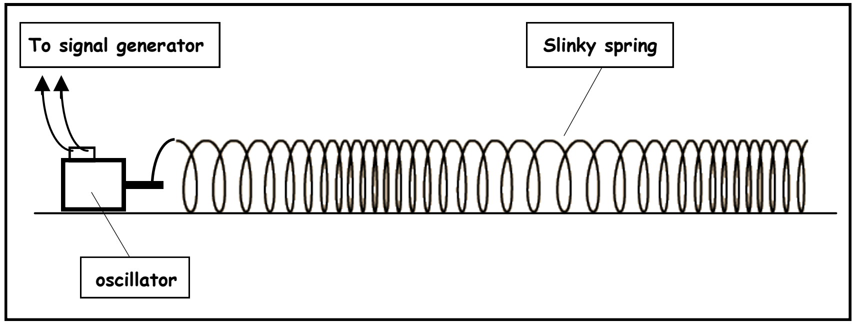
With an adjustable gap, the effect of narrowing the gap can be investigated.

UNIT G482	Module 4	2.4.1	Wave Motion

- **HOMEWORK QUESTIONS**

1 (a) Describe the differences between **transverse** and **longitudinal** waves.

(b) The diagram below shows a **progressive** longitudinal wave formed in a slinky spring by an oscillator connected to a signal generator.



(i) Draw arrows to show the direction of the vibrations produced by the oscillator - Label these **'V'**.

(ii) Label with a **'C'** the centre of a compression on the slinky.

(iii) Show the **wavelength** of the wave and label this **'λ'**.

(c) **State** and **explain** the effect on the wavelength of increasing the frequency of the oscillator.

(OCR AS Physics - Module 2823 - June 2005)

2 (a) **State** what is meant by the **DIFFRACTION** of waves.

(b) Draw diagrams to illustrate how plane water waves are diffracted when they pass through a gap : (i) About 2 wavelengths wide,
(ii) About 10 wavelengths wide.

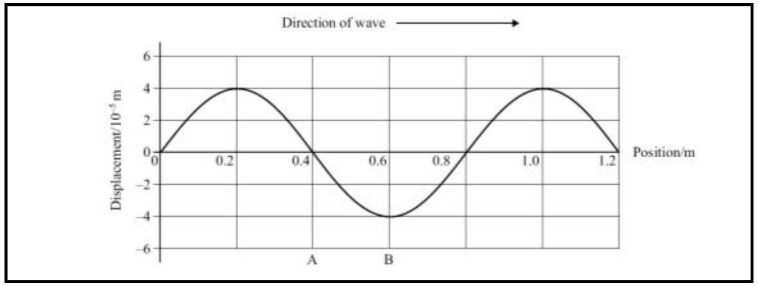
(c) Suggest why the diffraction of **light waves** cannot usually be observed, except under laboratory conditions.

(OCR AS Physics - Module 2823 - June 2004)

3 (a) All waves are either **longitudinal** or **transverse.** State **one** example of each.

(b) Define : (i) The **FREQUENCY** of a wave.
(ii) The **PERIOD** of a wave.

(c) The diagram below shows the variation of displacement with position at a particular instant for a progressive wave travelling in air.

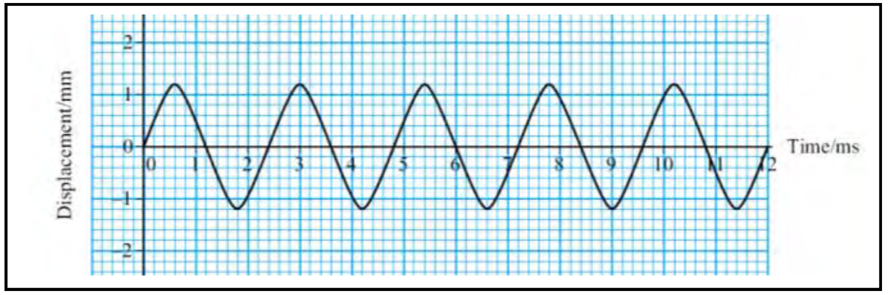


(i) State the **amplitude** of the wave shown in the diagram.
(ii) Describe the motion of an air particle at **position A** as one full cycle of the wave passes.
(iii) State **one** way in which the motion of an air particle at **position B** is similar to, and **one** way in which it is different from, the motion of an air particle **at A** as the wave passes.
(iv) Use the diagram to determine the **wavelength** of the sound wave.
(v) The speed of the sound wave is **340 m s^{-1}.** Calculate the **frequency** of the sound.

(OCR AS Physics - Module 2823 - January 2003)

UNIT G482	Module 4	2.4.1	Wave Motion

4 The diagram below shows the displacement-time graph for a particle in a medium as a **progressive** wave passes through the medium.



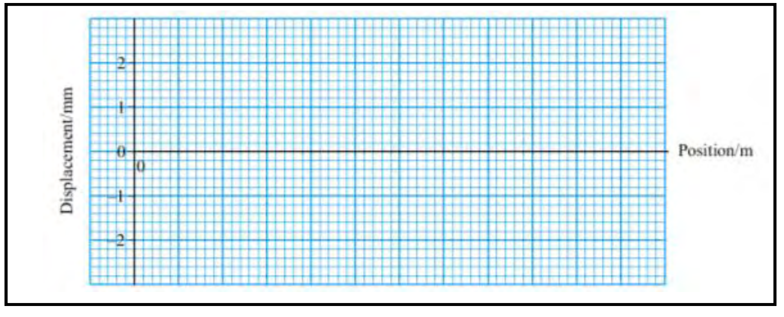
(a) Determine from the graph :

(i) The **AMPLITUDE** of the wave.
(ii) The **PERIOD** of the wave.

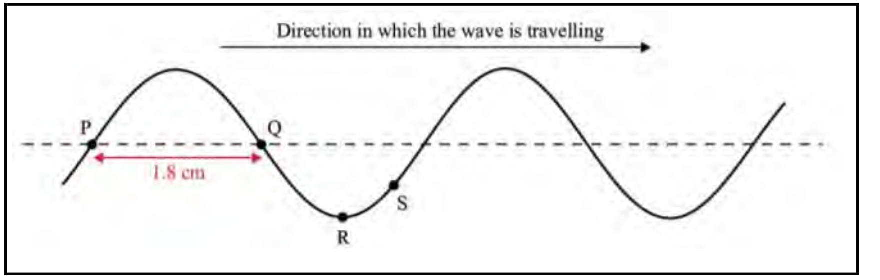
(b) (i) What is the **FREQUENCY** of the wave ?

(ii) The speed of the wave is **1500 m s^{-1}**.
Calculate its **WAVELENGTH**.

(iii) Use the grid in the diagram shown below to sketch the displacement-position graph for the wave at a particular instant. Mark the scale on the position axis and draw at least **two full cycles**. *(OCR AS Physics - Module 2823 - June 2004)*



5 The diagram below shows, at a given instant, the surface of the water in a ripple tank when plane water waves are travelling from left to right. 9



(a) Copy the diagram and on your copy show :
(i) The **AMPLITUDE** of the wave - Label this **'A'**.
(ii) The **WAVELENGTH** of the wave - Label this **'λ'**.

(b) On your copy of the diagram :
(i) Draw the position of the wave a short time, about **1/10th of a period**, later.
(ii) Draw arrows to show the **directions** in which the particles at **Q** and **S** are moving during this short time.

(c) State the **PHASE DIFFERENCE** between the movement of particles at **P** and **Q**.

(d) The frequency of the wave is **25 Hz** and the distance between **P** and **Q** is **1.8 cm**. Calculate :
(i) The **PERIOD** of the wave.
(ii) The **SPEED** of the wave.

(e) (i) Suggest how the **speed** of the waves in the ripple tank could be changed.
(ii) The frequency of the wave source is **kept constant** and the **wave speed is halved**. State what change occurs to the **wavelength**.

(OCR AS Physics - Module 2823 - January 2005)