# TOPIC 13 Waves

## Waves

N.B. *Questions* **1, 2** *and* **3** *all refer to Fig. 1*

Fig. 1 represents the simple harmonic motion of a particle in a progressive wave travelling at a speed of 5.0 km $s^{-1}$.

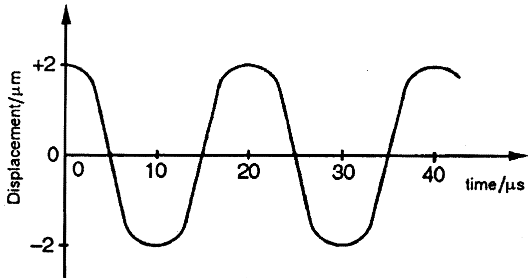



**Fig. 1**

**1** The frequency of vibration is

**A** 2.5 kHz
**B** 5.0 kHz
**C** 25 kHz
**D** 50 kHz
**E** 100 kHz N76/II/10

**2** The amplitude of vibration is

**A** $\sqrt{2}$ μm
**B** 2 μm
**C** $2\sqrt{2}$ μm
**D** 4 μm
**E** 20 μm N76/II/11

**3** The wavelength is

**A** 10 mm
**B** 15 mm
**C** 20 mm
**D** 50 mm
**E** 100 mm N76/II/12

**4** A circular bowl of diameter 400 mm contains water at rest. If its side is tapped gently, a completely circular pulse can be produced on the surface of the water which travels inwards with a speed of 250 mm $s^{-1}$. The radius of the pulse and its direction of travel, 1 second after the pulse is produced, are

**A** zero, stationary.
**B** 50 mm, outwards.
**C** 50 mm, inwards
**D** 150 mm, outwards
**E** 150 mm, inwards N77/II/12

**5** A wave motion has the equation

$$a = a_0 \sin(\omega t - kx).$$

The graph in Fig. 2 shows how the displacement $a$ at a fixed point varies with time $t$.

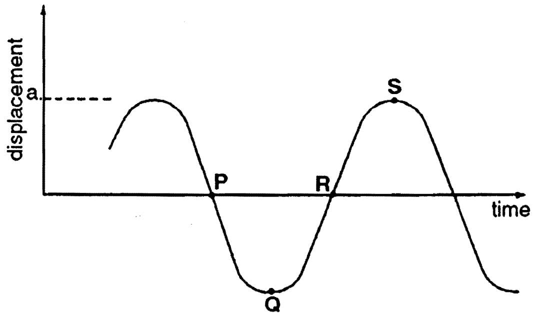



**Fig. 2**

Which one of the labelled points shows a displacement equal to that at the position $x = \pi/2k$ at time $t = 0$?

**A** P
**B** Q
**C** R
**D** S
**E** The point cannot be determined from the information given. N78/II/9

**6** 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?

**A** $\frac{\pi}{4}$ rad

**B** $\frac{\pi}{2}$ rad

**C** $\frac{2\pi}{5}$ rad

**D** $\frac{4\pi}{5}$ rad J79/II/13; N82/II/10; N90/I/13; J99/I/11

**7** The diagram below (Fig. 3) shows two sinusoidal curves R and S.

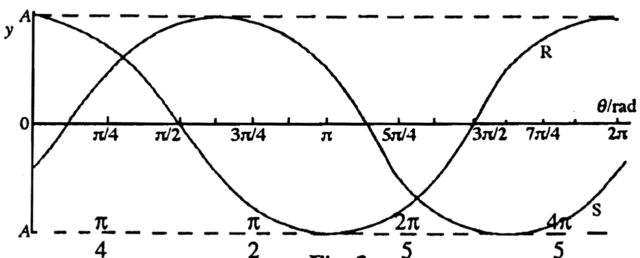



**Fig. 3**

Which one of the following pairs of equations represents the curves?

**A** $y_R = A\cos\theta$; $y_S = A\sin(\theta - \frac{5}{8}\pi)$
**B** $y_R = A\cos\theta$; $y_S = A\cos(\theta - \frac{5}{8}\pi)$
**C** $y_R = A\cos\theta$; $y_S = A\cos(\theta + \frac{5}{8}\pi)$
**D** $y_R = A\sin\theta$; $y_S = A\sin(\theta - \frac{5}{8}\pi)$
**E** $y_R = A\sin\theta$; $y_S = A\cos(\theta - \frac{5}{8}\pi)$ N80/II/13

**8** The diagram below (Fig. 4) shows an instantaneous position of a string as a transverse progressive wave travels along it from left to right.


**Fig. 4**

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** | ↑ | ↓ | ↑ |

N81/II/12

**9** Fig. 5 represents the simple harmonic motion of a particle in a progressive wave travelling at a speed of 5.0 km $s^{-1}$.

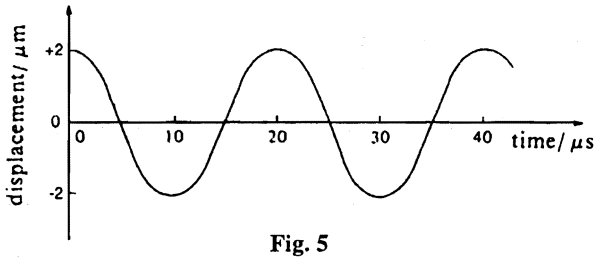



**Fig. 5**

What is the wavelength?

**A** 10 mm
**B** 15 mm
**C** 20 mm
**D** 50 mm
**E** 100 mm

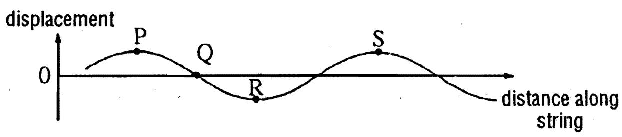
N83/II/10

**10** A point source of sound emits energy equally in all directions at a constant rate and a person 8 m from the source listens. After a while, the intensity of the source is halved. If the person wishes the sound to seem as loud as before, how far should he be now from the source?

**A** 2 m
**B** $2\sqrt{2}$ m
**C** 4 m
**D** $4\sqrt{2}$ m
**E** $8\sqrt{2}$ m

J84/II/11

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

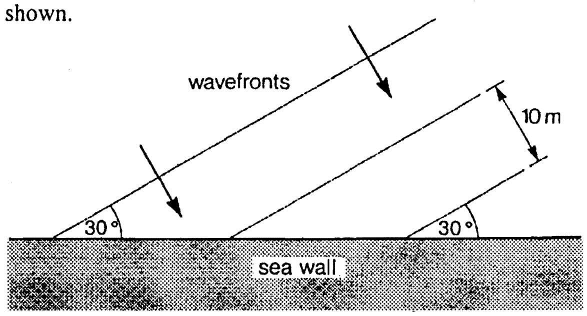



Which statement about the motion of elements of the string is correct?

**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.

N84/II/11; J96/I/10

**12** Parallel water waves of wavelength 10m strike a straight sea wall. The wavefronts make an angle of 30° with the wall as shown.

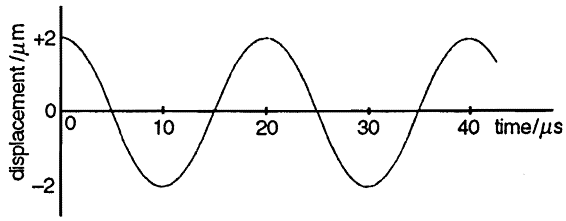



What is the difference in phase at any instant between the waves at two points 5 m apart along the wall?

**A** 45°
**B** 55°
**C** 90°
**D** 180°

J85/I/8; N95/I/10

**13** The diagram below represents the displacement of a particle caused by a progressive wave travelling at a speed 5.0 km $s^{-1}$.

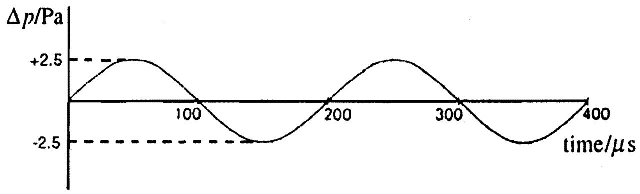



What is the frequency of vibration of the particle?

**A** 2.5 kHz
**B** 5.0 kHz
**C** 25 kHz
**D** 50 kHz
**E** 100 kHz

J85/I/9

**14** The diagram below represents the variation with time of pressure at a point in air through which a sound wave is travelling at 340 m $s^{-1}$.




What is the frequency of the wave?

**A** 1.7 Hz
**B** $5.0 \times 10^3$ Hz
**C** $1.0 \times 10^4$ Hz
**D** $3.1 \times 10^4$ Hz
**E** $1.7 \times 10^6$ Hz

N85/I/8

**15** Visible light has wavelengths between 400 nm and 700 nm, and its speed in a vacuum is $3.0 \times 10^8$ m $s^{-1}$. What is the maximum frequency of visible light?

A $1.2 \times 10^{11}$ Hz
B $4.3 \times 10^{11}$ Hz
C $4.3 \times 10^{14}$ Hz
D $7.5 \times 10^{14}$ Hz
E $7.5 \times 10^{17}$ Hz

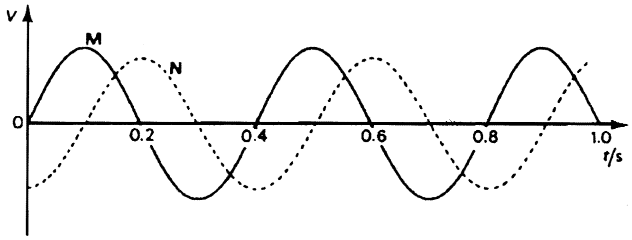
J87/I/11

**16** Transverse progressive sinusoidal waves of wavelength $\lambda$ are passing vertically along a horizontal rope. $P$ and $Q$ are points on the rope $5\lambda/4$ apart and the waves are travelling from $P$ to $Q$. Which one of the following correctly describes $Q$ at an instant when $P$ is displaced upwards but is moving downwards?

| | *displacement of Q* | *movement of Q* |
|---|---|---|
| A | upwards | downwards |
| B | upwards | upwards |
| C | downwards | upwards |
| D | downwards | downwards |
| E | downwards | stationary |

N87/I/8

**17** Two sinusoidal voltages of the same frequency are shown in the diagram.

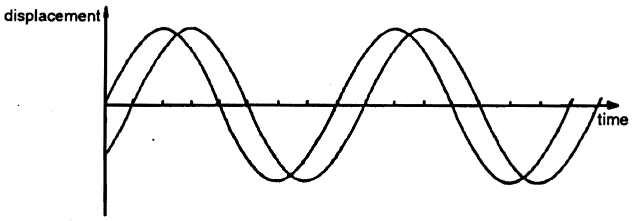



What is the frequency, and the phase relationship between the voltages?

| | *frequency*/Hz | *phase lead of* N *over* M/rad |
|---|---|---|
| A | 0.4 | $-\frac{\pi}{4}$ |
| B | 2.5 | $-\frac{\pi}{2}$ |
| C | 2.5 | $+\frac{\pi}{2}$ |
| D | 2.5 | $-\frac{\pi}{4}$ |
| E | 2.5 | $+\frac{\pi}{4}$ |

N89/I/21

**18** The diagram shows two oscillations.

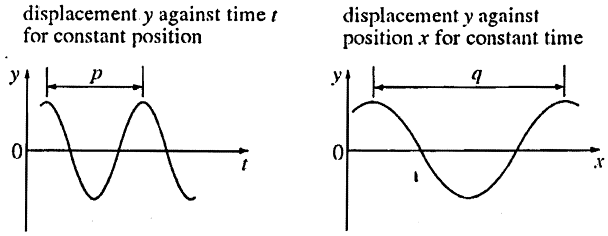



What is the phase difference between the oscillations?

A $\pi/4$ rad
B $\pi/2$ rad
C $3/4\ \pi$ rad
D $\pi$ rad
E $3/2\pi$ rad

J90/I/12

**19** The same progressive wave is represented by the following graphs.




Which of the following gives the speed of the wave?

A $pq$  B $\frac{p}{q}$  C $\frac{q}{p}$  D $\frac{1}{pq}$

N91/I/11; J98/I/10

**20** 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?

A 4.2 W $m^{-2}$
B 6.0 W $m^{-2}$
C 9.0 W $m^{-2}$
D 12 W $m^{-2}$

N94/I/10

**21** What happens to the speed, frequency and wavelength of light when it enters glass from air?

| | *speed* | *frequency* | *wavelength* |
|---|---|---|---|
| A | decreases | increases | unchanged |
| B | increases | unchanged | increases |
| C | unchanged | decreases | decreases |
| D | decreases | unchanged | decreases |

J97/I/10

**22** A plane wave of amplitude $A$ is incident on a surface of area $S$ placed so that it is perpendicular to the direction of travel of the wave. The energy per unit time intercepted by the surface is $E$.

The amplitude of the wave is increased to $2A$ and the area of the surface is reduced to $S/2$.

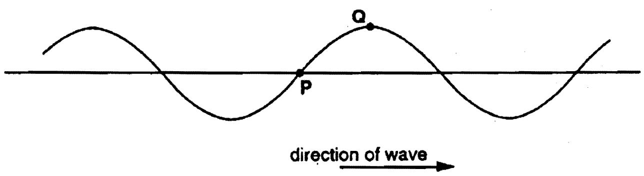
How much energy per unit time is intercepted by this smaller surface?

A $4E$
B $2E$
C $E$
D $E/2$

N97/I/10

**23** The diagram shows a transverse wave on a rope. The wave is travelling from left to right.

At the instant shown, the points **P** and **Q** on the rope have zero displacement and maximum displacement respectively.



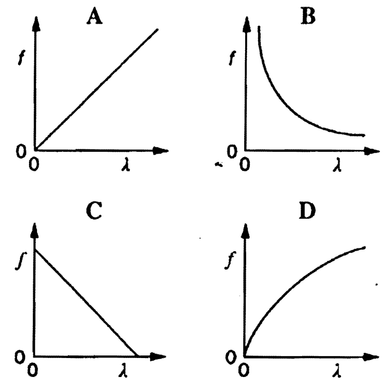
Which of the following describes the direction of motion, if any, of the points **P** and **Q** at this instant?

| | *point* **P** | *point* **Q** |
|---|---|---|
| **A** | downwards | stationary |
| **B** | stationary | downwards |
| **C** | stationary | upwards |
| **D** | upwards | stationary |

N98/I/10

**24** A sound wave of frequency $f$ and wavelength $\lambda$ travels through air. It may be assumed that its speed is independent of the frequency.

Which graph correctly shows the variation of $f$ with $\lambda$?




N99/I/10

**25** A small source of sound radiates energy equally in all directions. At a particular frequency, the intensity of the sound 1.0 m from the source is $1.0 \times 10^{-5}$ W m$^{-2}$, corresponding to an amplitude of oscillation of the air molecules of 70 μm. Assuming that the sound is propagated without energy loss, what will be *(a)* the intensity of the sound, *(b)* the amplitude of oscillation of the air molecules, at a distance of 5.0 m from the source? J83/I/4

**26** A point source of sound radiates energy uniformly in all directions. At a distance of 3.0 m from the source, the amplitude of vibration of air molecules is $1.0 \times 10^{-7}$ m. Assuming that no sound energy is absorbed, calculate the amplitude of vibration 5.0 m from the source. N85/III/2

**27** *(a)* Explain what is meant by the *frequency* of a wave. [1]

*(b)* A certain wave has wavelength 1.00 m. What is the distance between two points on this wave with a phase diffefence of $\pi/4$ rad? [2]

*(c)* **Figure 6** represents the variation with time $t$ of the displacement $y$ of a point in a sinusoidal wave of frequency 100 Hz.

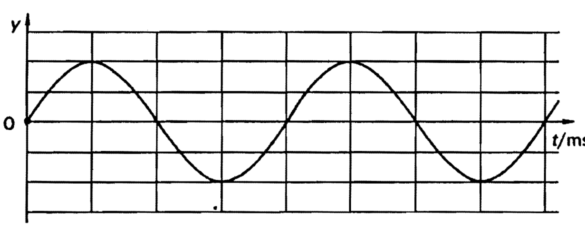



**Fig. 6**

(i) Mark the $t$-axis of **Fig. 6** with values of time measured in milliseconds.

(ii) On the axes of **Fig. 7**, and using the same scales as in **Fig. 6**, draw a second curve representing the displacement of a point in a second wave of twice the frequency and half the amplitude.

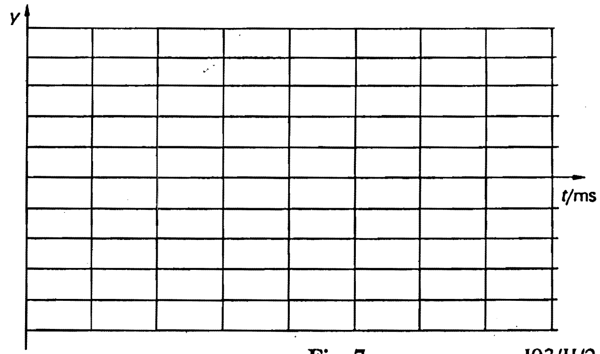



**Fig. 7** J93/II/2

**28** A water wave of amplitude 0.50 m is travelling in water which is 2.0 m deep, as illustrated in Fig. 8.

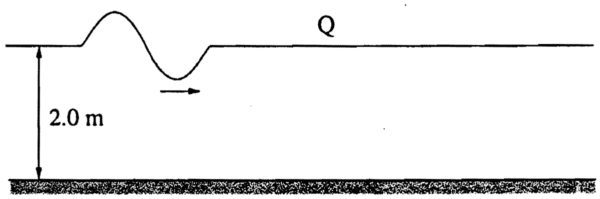



**Fig. 8**

Water waves travel with a speed $v$ which is dependent on the depth of water $h$ and is given by the equation

$$v = \sqrt{gh}$$

where $g$ is the acceleration of free fall. As there is a greater depth of water beneath the crest of a water wave than beneath the trough, wave crests will travel faster than wave troughs.

*(a)* Determine the depth of water beneath the crest of the wave.

depth = ................ m [1]

*(b)* For the wave illustrated in Fig. 8, calculate the speed of travel of

(i) the crest,

speed of crest = ........... m s$^{-1}$

(ii) the trough.

speed of trough = .......... m s$^{-1}$ [3]

*(c)* On Fig. 8, draw a suggested shape of the wave a little later as it passes Q. [2]

J99/II/2

## *Long Questions*

**29** A ship's siren vibrates with displacement $y$, where $y = a \sin 200\pi t$.

This sound causes vibration of the diaphragm of an eardrum of an observer 500 m away. The speed of sound is 335 m $s^{-1}$. Calculate

(i) the frequency of the sound,

(ii) the number of wavelengths of this sound there are between the siren and the eardrum,

(iii) the phase difference between the motion of the siren and the eardrum.

(Ignore any possible phase differences between vibrating surfaces and adjacent air.)

Calculate also

(iv) the maximum energy of the eardrum given that its mass is $1.0 \times 10^{-5}$ kg and the amplitude of its motion is $1.00 \times 10^{-8}$ m.

If the speed and distance data were reliable only to three significant figures, little confidence could be placed in your answer to (iii). Explain this. J82/III/1 (part)

**30** Define *wavelength* and *frequency*. Deduce a relation between these quantities and the speed of propagation of a wave.

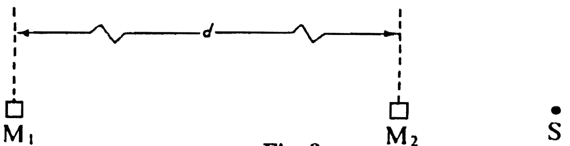



**Fig. 9**

Two microphones, $M_1$ and $M_2$, are positioned at a distance $d$ apart in still air. A source S of sound of fixed frequency is placed on the line $M_1M_2$ but beyond $M_2$ as shown in Fig. 9. The outputs of the two microphones are monitored using a cathode ray oscilloscope.

*(a)* What connections would you make and how would you adjust the cathode ray oscilloscope in order to measure the phase difference between the signals from the microphones?

*(b)* Draw diagrams to illustrate the traces observed when the phase angle between the two signals is

(i) 0, (ii) $\pi$ rad.

*(c)* Describe how the apparatus could be used to measure the speed of sound in air by moving $M_1$ along the line $M_1M_2$.

The speed $v_S$ of sound waves in air varies with thermodynamic temperature $T$ according to the relation

$$v_S = bT^{-1/2},$$

where $b$ is a constant. If the temperature of the air changes from 18 °C to 20 °C, what is the resulting fractional change in $v_S$? Discuss whether this change could be measured by this method if the wavelength at 18 °C were 500 mm.

J86/III/9

**31** Name one physical example of a *longitudinal* wave motion.

What features do longitudinal waves have in common with transverse waves? N86/III/8 (part)

**32** What is meant by the *period* $T$ and the *wavelength* $\lambda$ of a wave? [2]

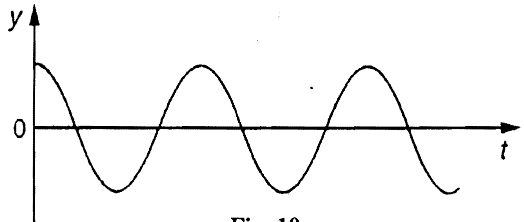



**Fig. 10**

Fig. 10 shows the displacement $y$ of a particle in a sinusoidal wave as a function of time $t$. Write an equation that represents the displacement of the particle in terms of $t$ and $T$, explaining any other symbols used. [2]

A second particle is situated a distance $\lambda/4$ from the first, measured in the direction in which the wave is travelling. What is the phase angle between the vibrations of the two particles? Draw a sketch graph to illustrate the variation with time of the displacement of the second particle. Give an equation to represent this displacement. [4]

Two continuous sound waves, each of amplitude $A$ and wavelength $\lambda$, meet at a point such that their phase difference is $\pi/3$. Show, by means of a phasor diagram or otherwise, that the amplitude of the resultant wave is approximately $1.7A$. Hence find the ratio of the intensity of the resultant wave to the sum of the intensities of the component waves. [6]

Discuss your result with reference to the principle of conservation of energy. [3]

N87/III/9

**33** *(a)* What is meant by the *amplitude* of a wave? *Intensity* is defined as the rate of transfer of energy per unit area normal to the direction of propagation of the wave. Given that intensity $I$ is related to amplitude $A$ by

$$I = cA^2,$$

show that the constant $c$ may have the units W $m^{-4}$ [5]

*(b)* A wave of amplitude $A$ and intensity $I$ is coincident with a second wave of amplitude $3A$. Both waves have the same frequency. Calculate, in terms of $A$ and $c$, the resultant amplitude and intensity when the phase difference is

(i) zero,

(ii) $\pi$ rad. [4]

*(c)* A radar transmitter produces pulses of microwaves each with a mean power $P$ which are emitted uniformly in all directions. A small spherical target of effective area $S$ is placed at a distance $d$ from the transmitter. The target reflects a fraction $k$ of the energy incident on it uniformly in all directions as shown in Fig. 11.

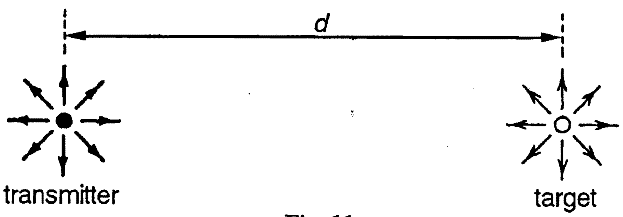



**Fig. 11**

Show that the mean intensity $I_r$ of the reflected pulse when it is received back at the transmitter is given by

$$I_r = \frac{PkS}{16\pi^2 d^4}. \qquad [6]$$

[The surface area of a sphere of radius $r$ is $4\pi r^2$.]

If the mean power $P$ is 2MW and the pulse duration is 3μs, calculate

(i) the energy in each emitted pulse,

(ii) the mean intensity of the emitted pulse at a range of 50 km,

(iii) the mean intensity of the reflected pulse when received back at the transmitter if the range is 50 km and the product $kS = 1\ m^2$. [5]

Briefly discuss the effect on your answer to (iii) if the pulses were emitted in an almost parallel beam. [2]

J88/III/8

**34** *(a)* Distinguish between *longitudinal* and *transverse* progressive waves. [3]

*(b)* Fig. 12 shows the variation with time $t$ of $\Delta p$, the excess pressure at a point in a progressive sinusoidal wave in air. The speed of the wave is 340 m s$^{-1}$.

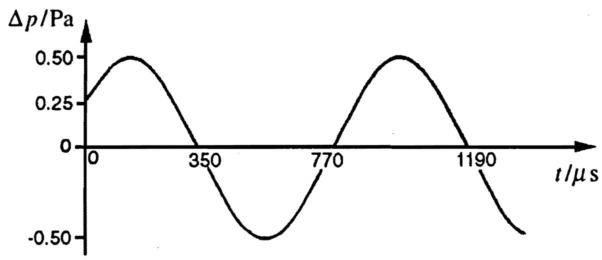



**Fig. 12**

Determine

(i) the amplitude,

(ii) the frequency,

(iii) the wavelength. [4]

J89/III/8 (part)

**35** *(a)* (i) Distinguish between *longitudinal* and *transverse* waves.

(ii) What phenomenon associated with transverse waves is not observed with longitudinal waves? [3]

*(b)* Figure 13 shows two graphs which refer to the same wave.

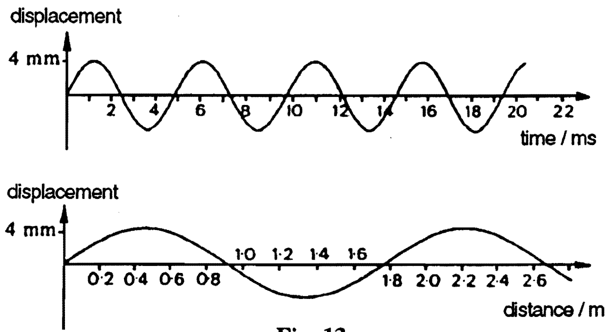



**Fig. 13**

Calculate the speed of the wave. [4] N90/III/3 (part)

**36** *(a)* Explain, using diagrams where necessary, the meaning of the terms *displacement, amplitude, frequency, wavelength* and *period* of a transverse wave. [5]

*(b)* Deduce the relationship between the wavelength, the period and the speed of a wave. [2]

*(c)* Fig. 14 is a full-scale diagram showing the rest positions and the actual positions of a series of particles through which a sinusoidal longitudinal wave is passing.

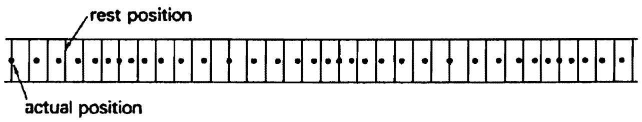



**Fig. 14**

Describe the movement of a single particle. Describe how the compressions and rarefactions move. Measure the wavelength from the diagram. [3] J91/III/2 (part)

**37** *(a)* What do you understand by a *progressive* wave? Illustrate your answer by reference to a transverse progressive wave. [4] J92/III/2 (part)

**38** *(a)* Explain what is meant by the term *progressive* as applied to a wave. [2]

*(b)* Starting with the definition of speed, show that the speed of a wave is given by the equation

speed = frequency × wavelength. [3]

*(c)* A progressive wave moves past two points P and Q, separated by a distance of 0.90 m. A graph showing how the displacement $y$ at P varies with time $t$ is shown in Fig. 15. Another graph, Fig. 16, shows how the displacement of the wave at time $t$ = 0 varies with distance $x$ from point P.

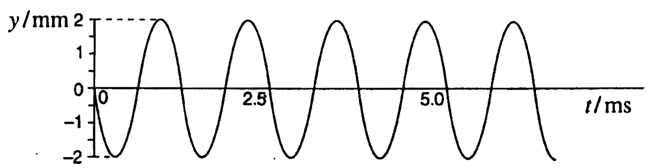



**Fig. 15**

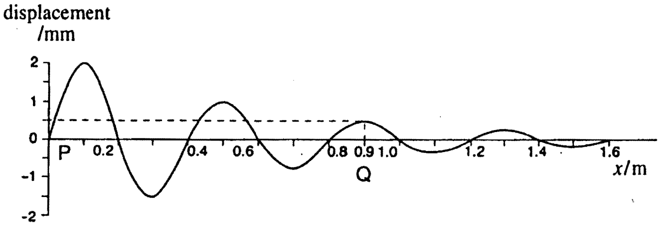



**Fig. 16**

Using data from the graphs, deduce for this wave

(i) the wavelength,

(ii) the frequency,

(iii) the speed,

(iv) the phase difference between the oscillations at P and those at Q,

(v) the ratio $\frac{\text{amplitude at P}}{\text{amplitude at Q}}$,

(vi) the ratio $\frac{\text{intensity at P}}{\text{intensity at Q}}$

*(d)* Light waves, sound waves in air and surface water waves are different forms of waves. Suggest, with a reason, which of these might be the wave being considered in *(c)*. [2]

*(e)* (i) Suggest an experimental method for obtaining the graph shown in Fig. 15.

(ii) Discuss whether the same method could be used for the graph in Fig. 16. [6]

N96/III/2

**39** *(a)* Distinguish between a progressive wave and a stationary wave by making reference to

(i) energy transfer,

(ii) amplitude of vibration of neighbouring particles,

(iii) phase angle between particles. [7]

J2000/III/3 (part)

**40** *(a)* State the meaning of *wavelength* and *frequency* as applied to wave motion. [2]

*(b)* Deduce, from the definition of speed, the equation for the speed of a wave in terms of its wavelength and frequency. [2]

*(c)* Describe, using labelled sketches where appropriate, the motion and phase of particles in

(i) a progressive longitudinal wave,

(ii) a stationary longitudinal wave. [6]

*(d)* State, for each type of wave described in *(c)*, a particular example of such a wave. [2]

N2000/III/3 (part)

## Polarisation

**41** Which effect provides direct experimental evidence that light is a transverse, rather than a longitudinal, wave motion?

**A** Light can be diffracted.
**B** Two coherent light waves can be made to interfere.
**C** The intensity of light from a point source falls off inversely as the square of the distance from the source.
**D** Light can be polarised.

J78/I/11; J94/I/10

**42** Plane-polarised radio-waves are transmitted by a vertical aerial. The amplitude of the waves is $A$ when they reach a receiving aerial which is tilted from the vertical at an angle $\theta$ in the plane perpendicular to the direction of arrival. The power delivered by the aerial to the receiver is proportional to

**A** $A^2 \cos^2 \theta$
**B** $A \cos \theta$
**C** zero
**D** $A \sin \theta$
**E** $A^2 \sin^2 \theta$

J80/II/16; J83/II/13

**43** In which one of the following instances are the waves plane-polarised?

**A** infra-red radiation from a hot electric iron
**B** compression waves caused by an earthquake
**C** electromagnetic waves from a dipole aerial
**D** ultra-sonic waves from an echo sounder
**E** radiation from a hydrogen discharge tube

J81/II/11; N84/II/13

**44** Fig. 17 below shows a beam of initially unpolarised light passing through three polaroids $P_1$, $P_2$ and $P_3$. The polarising axis of each polaroid is shown by an arrow. Polaroids $P_1$ and $P_2$ are fixed, with their polarising axes at 30° to one another, and $P_3$ can be set with its polarising axis at a variable angle $\theta$ to that of $P_1$.

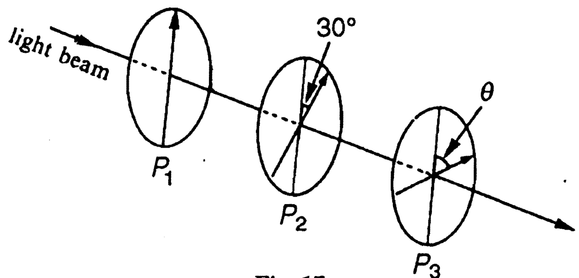



**Fig. 17**

For what values of $\theta$ do intensity minima of the emergent light occur?

**A** 30°, 120°, 210°, 300°
**B** 90°, 120°, 270°, 300°
**C** 60°, 240°
**D** 90°, 270°
**E** 120°, 300°

J82/II/13

**45** A beam of plane-polarised light of intensity $I$ falls normally on to a thin sheet of polaroid. If the transmitted beam has an intensity of $I$ / 4, what is the angle $\theta$ between the plane of incident polarisation and the polarising direction of the polaroid

A $22\frac{1}{2}°$
B $30°$
C $45°$
D $60°$
E $67\frac{1}{2}°$ N82/II/13

**46** If a wave can be polarised, it **must** be

A an electromagnetic wave.
B a longitudinal wave.
C a sound wave.
D a stationary wave.
E a transverse wave. J87/I/2; J91/I/10

**47** Is it possible to polarise *(a)* sound wave, *(b)* radio waves? Explain briefly why it is or is not possible in each case. J77/I/3

**48**

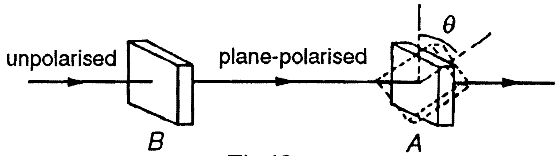



**Fig 18**

A beam of unpolarised light is incident normally on a polariser $P$ (Fig. 18). The plane-polarised light thus formed is incident normally on a second polariser $A$. $A$ is arranged so that the intensity of light transmitted by it is a maximum, and it is then rotated through 360° about the direction of the incident light beam. Draw a labelled graph showing how the intensity of the light transmitted by $A$ depends on the angle of rotation $\theta$. N80/I/4

**49**

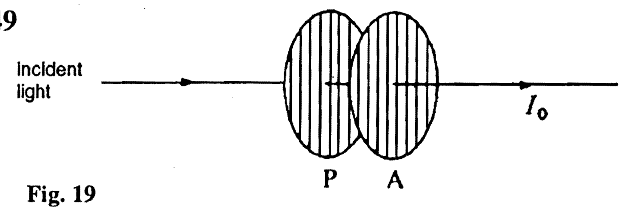



**Fig. 19**

Two sheets of polaroid, P and A, are placed so that their polarising directions are parallel and vertical, as shown in Fig. 19, the intensity of the emergent beam is then $I_0$. Through what angle should A be turned for the intensity of the emergent beam to be reduced to $\frac{1}{2}I_0$? Describe the polarisation of the emergent beam when this operation is carried out. N83/I/4

**50** A beam of plane-polarised microwaves is incident upon an aerial which is initially positioned to give maximum response. In a storm, the aerial is rotated about the direction of the incident waves until it makes an angle of 30° to the plane of polarisation, as shown in Fig. 20.

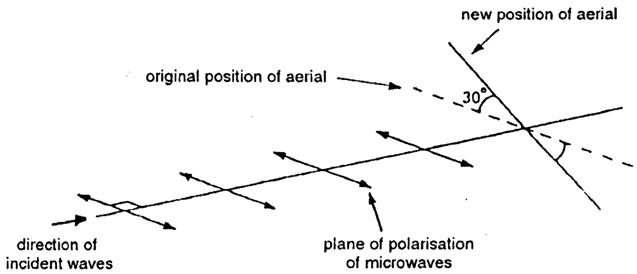



**Fig. 20**

Calculate the percentage reduction in the amplitude of the signal now received from the aerial. J86/III/2

**51** When two polarisers P and Q are placed so that their polarising directions are parallel, the amplitude of the emergent beam is $A$ (see Fig. 21)

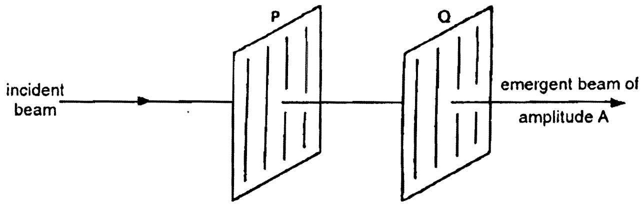



**Fig. 21**

Through what angle must Q be rotated so that amplitude of the emergent beam is reduced to $A/2$?

What will be the corresponding fractional reduction in the intensity of the emergent beam? [5]
N88/III/2

## *Long Questions*

**52** Thin parallel wires are stretched across a wooden frame. Explain why vertically polarised microwaves are transmitted through the frame most strongly when the wires are horizontal. N80/III/1 (part)

**53** Explain what is meant by a *plane-polarised* wave. Describe an experiment to investigate the state of polarisation of a beam either of light or of microwaves.

In some crystals, light waves with different planes of particular quartz crystal has a refractive index of 1.553 for one plane of polarisation but 1.544 for the perpendicular plane of polarisation. For light of wavelength 500 nm (in a vacuum), what is the minimum thickness of quartz which will introduce a phase difference of $\pi$ radians between the two polarisations?

Explain why it is not possible to observe interference fringes between light beams which are plane-polarised in perpendicular planes. N86/III/8 (part)

## Electromagnetic Spectrum

**54** Which group of electromagnetic waves is arranged in order of increasing frequency?

| | lowest ⟶ highest |
|---|---|
| **A** | $\gamma$-rays, ultraviolet, radio |
| **B** | microwaves, ultraviolet, X-rays |
| **C** | radio, visible light, infra-red |
| **D** | visible light, infra-red, microwaves |

N76/II/14; J81/II/10; J95/I/11; N97/I/12; N99/I/12

**55** The range of wavelengths of infra-red radiation is approximately

**A** $10^{-9}$ m to $10^{-7}$ m
**B** $10^{-7}$ m to $10^{-6}$ m
**C** $10^{-6}$ m to $10^{-3}$ m
**D** $10^{-4}$ m to $10^{-1}$ m
**E** $10^{-1}$ m to $10^{+2}$ m N76/II/32

**56** Which one of the following summarises the change in wave characteristics on going from infra-red to X-rays in the electromagnetic spectrum?

| | *frequency* | *wavelength (in a vacuum)* | *speed (in a vacuum)* |
|---|---|---|---|
| **A** | decreases | increases | decreases |
| **B** | decreases | increases | remains constant |
| **C** | remains constant | decreases | decreases |
| **D** | increase | decreases | remains constant |
| **E** | increases | increases | increases |

J78/II/12; N82/II/11; J86/I/13

***57** Three energies are listed below

1 the energy of a photon of a 3 m wavelength radio wave

2 the energy of an X-ray photon

3 the energy of a photon of yellow light from a sodium lamp

Which of the following puts these energies in order of increasing magnitude?

| | | | |
|---|---|---|---|
| **A** | 1 | 2 | 3 |
| **B** | 1 | 3 | 2 |
| **C** | 2 | 1 | 3 |
| **D** | 2 | 3 | 1 |
| **E** | 3 | 2 | 1 |

J78/II/33; N92/I/27

***58** The natural frequency of oscillation of the ions in a crystal of sodium chloride is of the order of $10^{13}$ Hz. Which one of the following radiations would be needed to excite ionic motion of large amplitude?

**A** X-rays
**B** radio waves
**C** ultraviolet radiation
**D** green light
**E** infrared radiation J83/II/33

**59** Ultra-violet rays differ from X-rays in that ultra-violet rays

**A** cannot be diffracted.
**B** cannot be polarised.
**C** do not affect a photographic plate.
**D** have a lower frequency.
**E** are deviated when they pass through a magnetic field.

N85/I/12; J93/I/11

**60** Which one of the following could be the frequency of ultraviolet radiation?

**A** $1.0 \times 10^{6}$ Hz
**B** $1.0 \times 10^{9}$ Hz
**C** $1.0 \times 10^{12}$ Hz
**D** $1.0 \times 10^{15}$ Hz
**E** $1.0 \times 10^{18}$ Hz N86/I/11

**61** Data transmitted along glass-fibre cables is in the form of pulses of monochromatic red light each of duration 2.5 ns. Which of the following is the best estimate of the number of wavelengths in each pulse?

**A** $10^3$ **B** $10^6$ **C** $10^9$ **D** $10^{12}$ **E** $10^{15}$

N88/I/11

**62** In which part of the electromagnetic spectrum does a wave of frequency 500 MHz occur?

**A** infra-red
**B** radio
**C** ultra-violet
**D** visible
**E** X-ray N89/I/8

**63** Which of the following frequency ranges includes most of the electromagnetic waves emitted by the ultra-violet tubes used in a sunbed?

**A** $5 \times 10^{5}$ to $5 \times 10^{8}$ Hz
**B** $5 \times 10^{8}$ to $5 \times 10^{11}$ Hz
**C** $5 \times 10^{11}$ to $5 \times 10^{14}$ Hz
**D** $5 \times 10^{14}$ to $5 \times 10^{17}$ Hz
**E** $5 \times 10^{17}$ to $5 \times 10^{20}$ Hz J91/I/12

**64** The wavelengths of a radio wave and that of an X-ray are in the ratio $10^m : 1$.

Which of the following is a possible value for $m$?

**A** +24 **B** +12 **C** –12 **D** –24

N91/I/13; N98/I/12

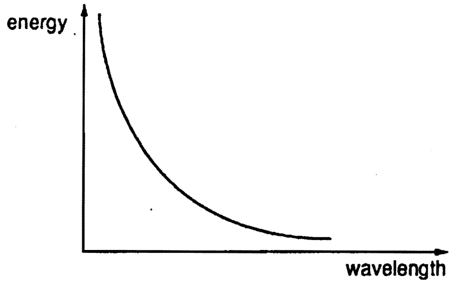
**65** An electromagnetic radiation has a frequency of $10^8$ Hz. In which region of the spectrum would such radiation occur?

**A** infrared
**B** radio
**C** ultraviolet
**D** visible
**E** X-ray J92/I/12

**66** What is the approximate range of frequencies of infra-red radiation?

**A** $1 \times 10^{3}$ Hz to $1 \times 10^{9}$ Hz
**B** $1 \times 10^{9}$ Hz to $3 \times 10^{11}$ Hz
**C** $3 \times 10^{11}$ Hz to $4 \times 10^{14}$ Hz
**D** $4 \times 10^{14}$ Hz to $7 \times 10^{14}$ Hz J94/I/12

67 The diagram shows the relationship between the energy of electromagnetic radiation and the wavelength of the waves.




Which of the following has the lowest energy?

| | | | | |
|---|---|---|---|---|
| A | infra-red | C | ultra-violet | |
| B | microwaves | D | X-rays | N94/I/12 |

68 The metre was defined in terms of the wavelength λ of the orange spectral line emitted by excited atoms of Krypton-86. Thus 1 metre = $n\lambda$, where $n$ is the number of wavelengths in 1 metre of vacuum.

What is the best value for $n$?

| | | | | |
|---|---|---|---|---|
| A | $1.43 \times 10^4$ | C | $2.00 \times 10^8$ | |
| B | $1.65 \times 10^6$ | D | $3.33 \times 10^{12}$ | N95/I/11 |

69 The table shows the wavelengths of electromagnetic waves in various parts of the spectrum.

For which line in the table is **X** in the ultraviolet region and **Y** in the microwave region of the spectrum?

| | X | Y |
|---|---|---|
| A | $1 \times 10^{-7}$ m | $1 \times 10^{-2}$ m |
| B | $1 \times 10^{-7}$ m | $1 \times 10^{-6}$ m |
| C | $1 \times 10^{-10}$ m | $1 \times 10^{-2}$ m |
| D | $1 \times 10^{-10}$ m | $1 \times 10^{-6}$ m |

J96/I/12; N2000/I/12

70 Which of the following gives three regions of the electromagnetic spectrum in order of increasing wavelength?

- **A** gamma rays, microwaves, visible radiation
- **B** radio waves, ultraviolet, X-rays
- **C** ultraviolet, infra-red, microwaves
- **D** visible radiation, gamma rays, radio waves J2000/I/12

71 Give one typical wavelength in each of the following regions of the electromagnetic spectrum:

*(a)* radio,

*(b)* ultra-violet,

*(c)* visible. N80/I/5

## *Long Questions*

72 Place the radio, visible, infra-red and ultra-violet regions of the electromagnetic spectrum in order of increasing wavelength and give a typical wavelength for each region.

J85/III/10 (part)