TOPIC 15 Stationary Waves

1 An organ pipe of effective length 0·6 m is closed at one end. Given that the speed of sound in air is 300 m s^{-1}, the two lowest resonant frequencies are

A 125, 250 Hz
B 125, 375 Hz
C 250, 500 Hz
D 250, 750 Hz
E 500, 1000 Hz J76/II/11; N81/II/10

2 A resonance tube open at both ends and responding to a tuning fork

A always has a central node.
B always has a central antinode.
C always has an odd number of nodes.
D always has an even number of nodes.
E always has an odd number of nodes + antinodes.
N76/II/15

3 The frequency of the fundamental mode of transverse vibration of a stretched wire 1 m long is 250 Hz. When the wire is shortened to 0.4 m at the same tension, the fundamental frequency is

A 102 Hz
B 162 Hz
C 312 Hz
D 416 Hz
E 640 Hz J77/II/11; J89/I/11

4 A boy blows gently across the top of a piece of glass tubing the lower end of which is closed by his finger so that the tube gives its fundamental note of frequency, f. While blowing, he removes his finger from the lower end. The note he then hears will have a frequency of approximately

A $f/4$ **D** $2f$
B $f/2$ **E** $4f$
C f N77/II/13; N82/II/15

5 A string is stretched under constant tension between fixed points X and Y. They solid line in Fig. 1 below shows a standing (stationary) wave at an instant of greatest displacement. The broken line shows the other extreme displacement.

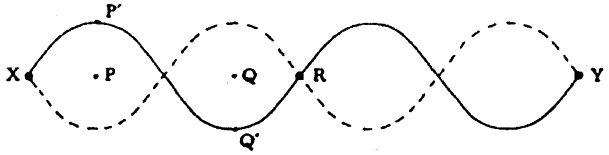


Fig. 1

Which one of the following statements is correct?

A The distance between P and Q is one wavelength.
B A short time later, the string at R will be displaced.
C The string at P' and the string at Q' will next move in opposite directions to one another.
D At the moment shown, the energy of the standing wave is all in the form of kinetic energy.
E The standing wave shown has the lowest possible frequency for this string stretched between X and Y under this tension. J78/II/13

6 A suspension bridge is to be built across a valley where it is known that the wind can gust at 5 s intervals. It is estimated that the speed of transverse waves along the span of the bridge would be 400 m s^{-1}. The danger of resonant motions in the bridge at its fundamental frequency would be greatest if the span had a length of

A 2000 m
B 1000 m
C 400 m
D 80 m
E 40 m N79/II/14; J85/I/12

7 A string fixed at both ends and of length L is plucked at its midpoint and emits its fundamental note of frequency f_1. When the string is plucked at a different point, the first overtone frequency f_2 is also produced. Which one of the following correctly gives both f_2/f_1 and v, where v is the speed of transverse waves in the string?

	f_2/f_1	v
A	2	f_1L
B	0.5	f_1L
C	2	f_2L
D	0.5	f_2L
E	2	$f_2L/2$

J81/II/13

8 A taut wire is clamped at two points 1.0 m apart. It is plucked near one end. Which are the three longest wavelengths present on the vibrating wire?

A 1.0 m, 0.50 m and 0.25 m
B 1.0 m, 0.67 m and 0.50 m
C 2.0 m, 0.67 m and 0.40 m
D 2.0 m, 1.0 m and 0.50 m
E 2.0 m, 1.0 m and 0.67 m J83/II/12

9 Which one of the following pairs correctly describes the amplitudes of displacement and pressure change at a displacement node in a stationary sound wave?

	displacement amplitude	*pressure change amplitude*
A	zero	maximum
B	maximum	minimum
C	maximum	maximum
D	zero	minimum
E	zero	zero

N83/II/12

10 Which one of the following correctly compares characteristics of travelling and stationary plane waves?

	travelling wave	*stationary wave*
A	no medium required	requires a material medium
B	separation between two adjacent points of corresponding phase is one wavelength	separation between a node and the adjacent antinode is half a wavelength
C	the amplitude of vibration is the same at all points	amplitude of vibration varies with position
D	energy at any point is always kinetic	energy at any point changes from kinetic to potential and back again
E	energy is transported at a speed given by the frequency divided by the wavelength	no net transport of energy

J84/II/12

11 A stationary wave in the gas in a resonance tube can be described in terms either of the amplitude Δx of oscillation of the particles of the gas from their mean positions or of the fluctuation of pressure Δp above and below the average. Which one of the following correctly describes the situation at resonance in a tube which is closed at one end? (Neglect the end correction at the open end.)

	at closed end		at open end	
	Δx	Δp	Δx	Δp
A	zero	maximum	zero	maximum
B	zero	maximum	maximum	zero
C	maximum	zero	maximum	zero
D	maximum	zero	zero	maximum
E	zero	zero	maximum	maximum

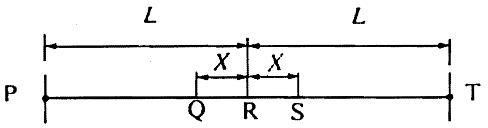
N84/II/12

12 A string of length L is stretched between two fixed points and is set into transverse vibration. The two lowest resonant frequencies are f_1 (the fundamental) and f_2. Which one of the following correctly gives both f_2 / f_1 and v, where v is the speed of the transverse waves in the string?

	f_2 / f_1	v
A	2	$f_1 L$
B	3	$3 f_1 L$
C	2	$f_2 L$
D	0.5	$f_2 L$
E	3	$f_2 L / 3$

J86/I/12

13 The diagram below shows a string with ends P and T fixed. The string is made to vibrate transversely so that P, R and T are the only points on the string which are nodes.



The vibrations of the two points Q and S, shown on the string, have

A the same amplitude and are in phase.
B different amplitudes and are in phase.
C the same amplitudes and differ in phase by 90°.
D different amplitudes and differ in phase by 180°.
E the same amplitudes and differ in phase by 180°.

N87/I/12

14 A vertical tube is completely filled with water. A small sound source of constant frequency is held a little above the open upper end and water is run out from the lower end.

A number of resonance positions are detected. The first of these occurs when the water surface is 7 cm below the top of the tube and another occurs at 39 cm.

At which of the following distances should resonance also be detected?

A 14 cm
B 15 cm
C 23 cm
D 31 cm
E 47 cm

N88/I/10

15 A standing wave is set up on a stretched string **XY** as shown in the diagram.

At which point(s) will be oscillation be exactly in phase with that at P?

A 1, 2 and 3
B 1 and 2 only
C 2 and 3 only
D 2 only
E 3 only

J89/I/9

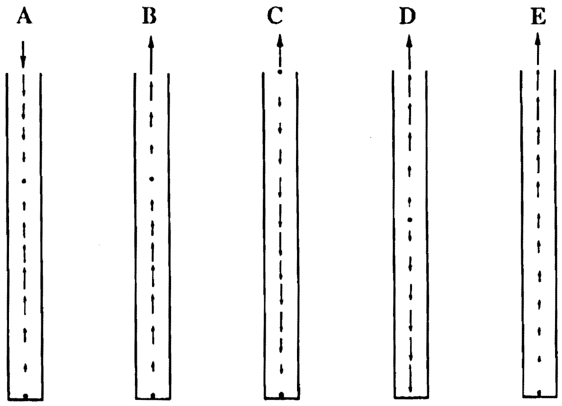
16 Progressive waves of frequency 300 Hz are superimposed to produce a system of stationary waves in which adjacent nodes are 1.5 m apart. What is the speed of the progressive waves?

A 100 ms^{-1}
B 200 ms^{-1}
C 450 ms^{-1}
D 900 ms^{-1}
E 1800 ms^{-1}

J90/I/13

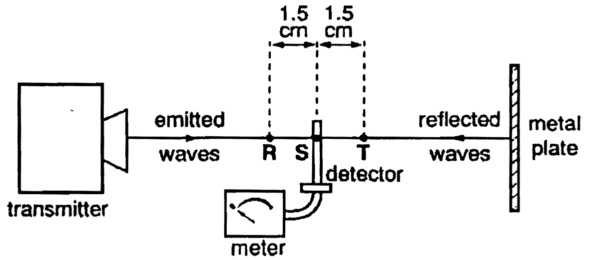
17 The arrows on the diagrams represent the movement of the air molecules in a pipe in which a stationary longitudinal wave has been set up. The length of each arrow represents the amplitude of the motion, and the arrow head shows the direction of motion at a particular instant.

Which diagram shows a possible stationary wave in which there are two displacement nodes and two displacement antinodes?



J92/I/10

18 A microwave transmitter emits waves which are reflected from a metal plate, as shown in the diagram. A detector responds to the stationary waves produced. **R**, **S** and **T** are three successive points at which the meter shows zero intensity.

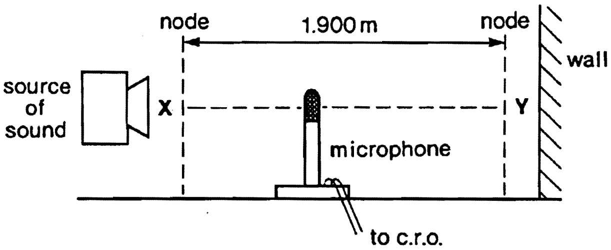


What is the frequency of the waves?

A	9.0×10^6 Hz	**C**	1.0×10^{10} Hz
B	1.0×10^8 Hz	**D**	2.0×10^{10} Hz

N92/I/10; J96/I/11

19 A source of sound of frequency 2500 Hz is placed several metres from a plane reflecting wall in a large chamber containing a gas. A microphone, connected to a cathode-ray oscilloscope, is used to detect nodes and antinodes along the line **XY** between the source and the wall.



The microphone is moved from one node through 20 antinodes to another node, a distance of 1.900 m.

What is the speed of sound in the gas?

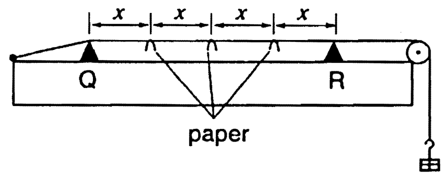
A 238 m s^{-1}
B 250 m s^{-1}
C 330 m s^{-1}
D 475 m s^{-1} N89/I/7; J95/I/10

20 An organ pipe of length l has one end closed but the other end open.

What is the wavelength of the fundamental note emitted?

A slightly smaller than $4l$
B slightly larger than $4l$
C roughly equal to $3l/2$
D slightly larger than $2l$ N96/I/11

21 A wire is stretched over two supports, Q and R, a distance $4x$ apart. Three light pieces of paper rest on the wire, as shown.



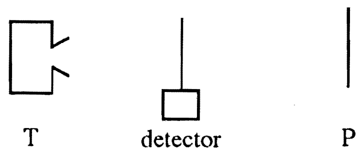
When the wire is made to vibrate at one particular frequency, the middle piece of paper stays on, but the others fall off the wire.

What is the wavelength of the vibration produced on the wire?

A	$2x$	**C**	$4x$
B	$3x$	**D**	$8x$

J97/I/12

22 In the diagram, T represents a transmitter of microwaves and P represents a metal plate.

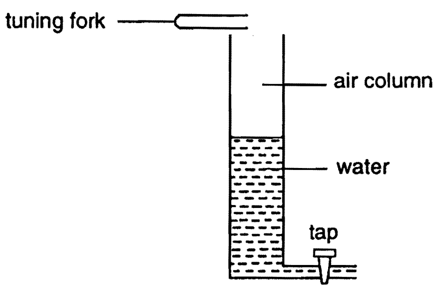


The detector is connected to a galvanometer. The distance TP is much greater than the wavelength of the microwaves.

As the detector is moved between T and P, what happens to the galvanometer reading?

A It decreases steadily.
B It reaches a maximum at P.
C It reaches a maximum midway between T and P.
D It increases and decreases regularly. J98/I/11

23 The diagram shows an experiment to produce a stationary wave in an air column. A tuning fork, placed above the column, vibrates and produces a sound wave. The length of the air column can be varied by altering the volume of the water in the tube.



The tube is filled and then water is allowed to run out of it. The first two resonances occur when the air column lengths are 0.14 m and 0.46 m.

What is the wavelength of the sound wave?

A 0.32 m
B 0.56 m
C 0.60 m
D 0.64 m N2000/I/10

24 Two radio transmitters emit vertically polarised electromagnetic waves of frequency 9×10^7 Hz. The speed of the waves is 3×10^8 m s^{-1}.

(a) Calculate the internodal distance in the standing wave set up along the line joining the transmitters.

A mobile receiver moves along the straight line joining the transmitters at a speed of 6×10^2 m s^{-1}.

(b) Calculate the rate at which nodes in this standing wave are passed by the moving receiver. J76/I/4

25 An organ pipe is 0.33 m long, open at one end and closed at the other. The speed of sound is 330 ms^{-1}. Assuming that end corrections are negligible, calculate

(a) the frequencies of the fundamental and the first overtone,

(b) the length of a pipe which is open at both ends and which has a fundamental frequency equal to the difference of those calculated in *(a)*. N76/II/3

26 Draw clearly-labelled diagrams to show how a stationary wave is produced. What is stationary about such a wave? N78/I/4

27 A source of sound of frequency 250 Hz is used with a resonance tube, closed at one end, to measure the speed of sound in air. Strong resonance is obtained at tube lengths of 0·30 m and 0·96 m. Find *(a)* the speed of sound, *(b)* the end-correction of the tube. N79/I/4

28 A string is stretched between two points a distance L apart. Sketch the two lowest frequency modes of transverse vibration of the string, and write down expressions for their frequencies in terms of L and of c, the speed of propagation of transverse waves on the string. J80/I/3

29 Stationary waves are set up in the space between a microwave transmitter and a plane reflector. Successive minima are spaced 15 mm apart. What is the frequency of the microwave oscillator? N81/I/3

30 A sound wave is generated by means of a tuning fork held near the end Q of the tube QR. As the piston P is moved from Q towards R, a loud sound is first heard when PQ is 0.15 m, and next when PQ is 0.47 m (Fig. 2). For this second resonance position, draw a graph showing the way in which the amplitude a of vibration of the air particles in the tube depends on the distance x from P.

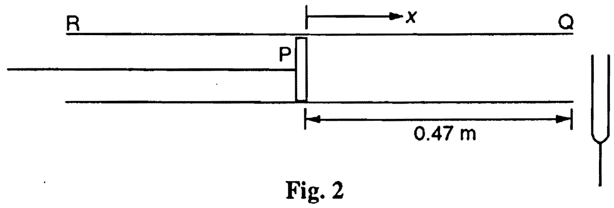


Fig. 2

Explain why the relationship between the two lengths measured for PQ is not a simple ratio. J84/I/4

31 A wire 1.20 m long is fixed at each end under tension. A transverse wave of speed 300 m s^{-1} is propagated along the wire and forms a standing wave pattern by reflection at the ends. In a certain mode of vibration, it is found that the nodes are 0.40 m apart. What is the frequency of this mode? What lower resonant frequencies are possible? N84/I/4

32 The lowest resonant frequency of a guitar string of length 0.75 m is 400 Hz. Calculate the speed of transverse waves on the string. N86/III/1

33 A stretched wire is fixed at both ends and plucked at its centre. Draw a diagram to represent the mode of vibration which gives rise to the lowest possible frequency. Draw a second diagram to represent another mode of vibration of the wire. Write down the relationship between the frequencies of the two modes. [3] N87/III/1

34 A wire 1.8 m long is fixed at both ends. The tension is such that when the wire is plucked, a transverse wave of speed 300 m s^{-1} is propagated along the wire and forms a standing wave by reflection at the ends. Three antinodes are formed. Sketch the appearance of the vibrating wire. What is its frequency of vibration? [4] J88/III/2

35 A ripple tank containing shallow water of constant depth has some fine sand sprinkled into it. Plane waves are incident normally on a straight barrier as shown in Fig. 3.

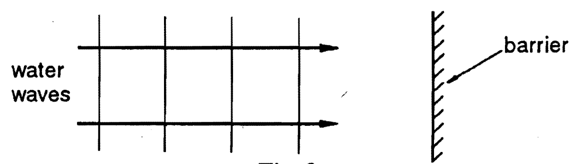


Fig. 3

The sand is observed to settle into regularly spaced ridges parallel to the barrier.

(a) Briefly explain why this occurs.

(b) Calculate the speed of the water waves if the separation of the ridges is 0.05 m and the frequency of the waves is 3 Hz. [6] J89/III/2

36 *(a)* Sound waves are longitudinal waves. What is meant by *longitudinal*? [2]

(b) Two sources of sound waves S_1 and S_2 are placed a distance of 3.0 m apart at either end of a narrow pipe. Both sources are emitting waves of wavelength 1.2 m and of similar amplitude, which travel along the pipe. (Fig. 4 is not to scale.)

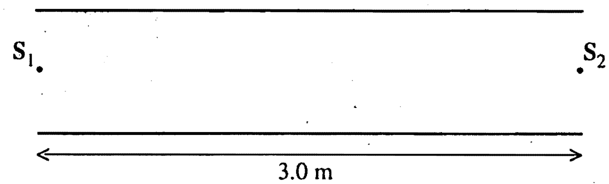


Fig. 4

By drawing on Fig. 4 above, show how the amplitude of the resultant wave will vary along the line S_1S_2. [3]

(c) In what two ways would the resultant wave in (b) be different if the sources were replaced with sources of microwaves? [2]

N91/II/2

Long Questions

37 S_1 and S_2 are loudspeakers emitting continuous sound waves of frequency 1100 Hz. M is a small microphone which runs on a straight track between S_1 and S_2 at a speed of 30 m s^{-1}. The sound received by M fluctuates regularly. Explain this.

If the speed of sound is 330 m s^{-1}, calculate the frequency of the fluctuations in the sound received by M.

N79/III/2 (part)

38 State the conditions for the establishment of a well-defined stationary wave using two separate sound sources. Compare and contrast the motions of the air molecules in such a stationary wave with those in a progressive wave. Consider especially the amplitudes, phases, frequencies and kinetic energies of the wave motions.

A tuning fork produces a stationary wave in a tube that is closed at one end. Explain this with reference to the conditions you have previously stated. Such a tube resonates to the same fork for a number of different tube lengths. Explain this, with the aid of suitable diagrams. Deduce a general expression for these length l_n in terms of the fork frequency f, the speed of sound v and any other relevant quantities.

A fork resonates with a tube closed at one end. The two shortest resonant lengths l_1, l_2 were each measured at two different temperatures t. The results were

t/°C	l_1/cm	l_2/cm
0	31.0	97.0
20.0	32.2	100.6

Calculate the end correction of the tube. Examine how well these data support the conclusion that the speed of sound is proportional to the square root of thermodynamic temperature.

J83/III/1

39 A monochromatic beam of light of wavelength λ is directed normally on to a front-silvered plane mirror where it is reflected. The incident and reflected beams interfere with each other. Explain how the spacing of the resultant pattern of nodes and antinodes is related to λ.

J87/III/10 (part)

40

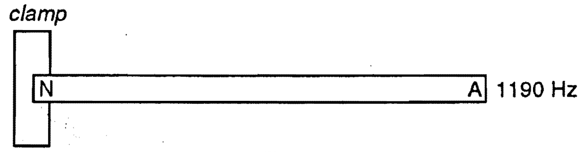


Fig. 5

A thin copper rod, 800 mm long , is clamped at one end. It is made to vibrate by an oscillator of variable frequency. This produces *longitudinal* waves in the rod. As the frequency is varied it is found that the rod resonates: the two lowest resonant frequencies are 1190 Hz and 3570 Hz. In all resonant modes the clamped end is a displacement node and the free end is an antinode. Fig. 5 illustrates the position of the node (N) and the antinode (A) for the resonant frequency of 1190 Hz.

(a) Draw a labelled sketch showing the positions of the displacement nodes and antinodes for the resonant frequency of 3570 Hz. (Indicate clearly which end of the rod is clamped.) [1]

(b) Find two frequencies *higher* than 3570 Hz at which the rod might also be expected to resonate. [2]

N87/II/13 (part)

41 (c) (i) Distinguish between *progressive* and *stationary* waves.

(ii) Figure 6 shows a stationary wave on a string stretched between two points **A** and **F** which are a distance L apart.

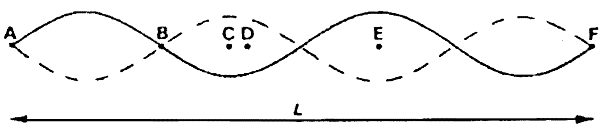


Fig. 6

Describe the oscillations of the points **B, C, D** and **E.** Compare these oscillations in terms of their relative phases and amplitudes.

(iii) What is the wavelength in terms of L? [8]

(d) Describe an experiment by which the frequency of such a wave can be accurately determined. [5]

N90/III/3 (part)

42 This question is about the superposition of waves.

(a) (i) What is meant by the term *stationary wave*? [2]

(ii) Describe an experiment to show how a stationary wave may be set up. [3]

J93/III/2 (part)

43 *(a)* What is meant by the term *interference*? Explain your answer by reference to

(i) a stationary wave on a stretched string,

(ii) the fringe pattern observed when a narrow beam of monochromatic light (for example, from a laser) has passed through a double slit. [7]

(b) In order to investigate stationary waves on a stretched string, a student set up the apparatus illustrated in Fig. 7.

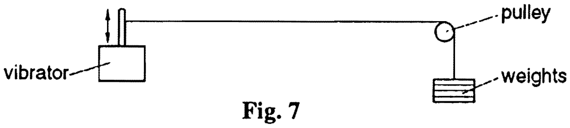


Fig. 7

(i) Explain why it is usually necessary to adjust either the vibrating length of the string or the frequency of the vibrator in order to obtain observable stationary waves on the string.

(ii) What is meant by a *node*? Explain why a node must exist at the pulley.

(iii) The distance between successive nodes on the string is 16.0 cm when the frequency of the vibrator is 75 Hz. Calculate the speed of the wave on the string. [7] N95/III/3 (part)

44 *(d)* One end of a horizontal string is now attached to the oscillating plate. The string passes over a pulley and the string is kept under tension by means of a weight, as illustrated in Fig. 8.

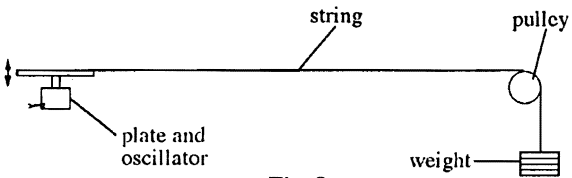


Fig. 8

The frequency of oscillation of the plate is increased and at certain frequencies, stationary waves are produced on the string.

(i) Copy Fig. 8 and on your diagram show the stationary wave on the string when the frequency is such that the distance between the plate and the pulley corresponds to two wavelengths of the wave on the string.

(ii) On your diagram, label the position of a node on the string.

(iii) Briefly explain why a stationary wave is observed on the string only at particular frequencies of vibration of the plate. [4]

(e) Some musical instruments rely on stationary waves on strings in order to produce sound.

Suggest why strings made of different materials or with different diameters are sometimes used. [2]

J99/III/4 (part)

45 *(b)* A horizontal steel wire is fixed at one end and is kept under tension by means of weights suspended over a pulley, as shown in Fig. 9.

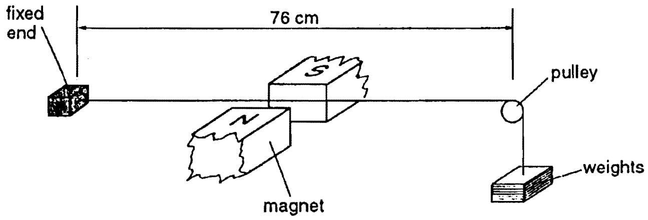


Fig. 9

A low-voltage alternating supply of frequency 50 Hz is connected to the wire between the fixed end and the pulley. Magnets are placed near to the centre of the horizontal section of the wire in order to produce a magnetic field at right angles to the wire.

The tension in the wire is gradually increased from a small value, thereby changing the speed with which waves may travel along the wire. Suddenly, the amplitude of vibration of the wire increases to a maximum and then becomes small once more.

(i) Explain why

1. the wire vibrates,

2. the amplitude of vibration is a maximum at one value of the tension. [6]

(ii) The distance between the fixed point and the pulley is 76 cm. For the wire vibrating with maximum amplitude,

1. sketch the shape of the stationary wave on the wire,

2. calculate the wavelength of this stationary wave. [2]

******(c)* The low-voltage power supply in *(b)* is removed and the ends of the wire are connected to the Y-plates of a cathode-ray oscilloscope (c.r.o.). The wire is plucked at its centre and a sinusoidal trace is observed on the screen of the c.r.o.

By reference to laws of electromagnetic induction, explain why

(i) an e.m.f. is induced between the ends of the wire,

(ii) the e.m.f. is alternating. [5]

J2000/III/3 (part)