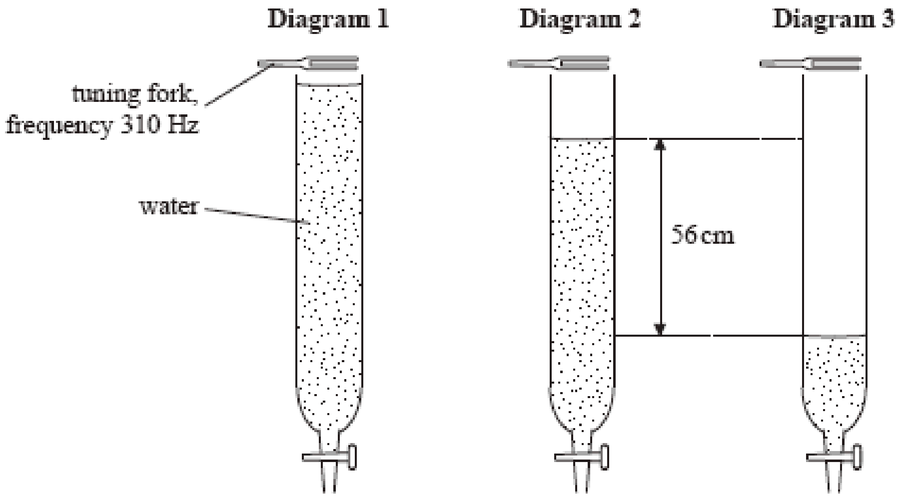
(c) A tube is filled with water and a tuning fork is sounded above the tube, as shown in diagram 1.



Water is allowed to run out of the tube and, at the position shown in diagram 2, a loud sound is heard for the first time. Water continues to run out of the tube and a loud sound is next heard at the position shown in diagram 3.

(i) A loud sound indicates that a standing (stationary) wave has been produced in the tube. Outline how the standing wave is formed. *[2]*

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(ii) On **diagram 3**, draw lines to represent the standing wave produced in the tube. Also, identify, with the letter N, the positions of the nodes of the standing wave. *[2]*

(iii) The change in height of the water surface between the positions shown in diagram 2 and diagram 3 is 56 cm. The frequency of the tuning fork is 310 Hz. Calculate the speed of sound in the tube. *[3]*

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(d) (i) State what is meant by the Doppler effect. *[2]*

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(ii) A source of sound has frequency f and is moving with constant speed v directly towards a stationary observer. The speed of sound in still air is c. Derive an expression for the frequency f_o of the sound heard by the observer. Explain your working. *[3]*

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(iii) A moving police car produces sound from its engine and from its siren. The car passes a stationary person. The person notices a Doppler shift as the car passes. When the police car, travelling at the same speed, next passes the person, its siren is not sounding. The Doppler shift is not as noticeable. Suggest **one** reason for this observation. *[2]*

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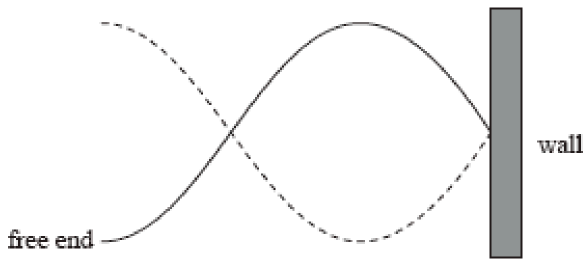
(d) The free end of the string in (c) is now made to oscillate with frequency f such that a standing wave is established on the string. The diagram below illustrates the standing wave.



(i) Explain, by reference to the principle of superposition, the formation of a standing wave. *[3]*

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(ii) The length of the string is 3.0 m. Using your answer for the speed of the wave in (a)(iii) calculate the frequency f. *[2]*

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Stationary (standing) waves and resonance

(a) State **two** ways in which a standing wave differs from a continuous wave. *[2]*

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(b) State the principle of superposition as applied to waves. *[2]*

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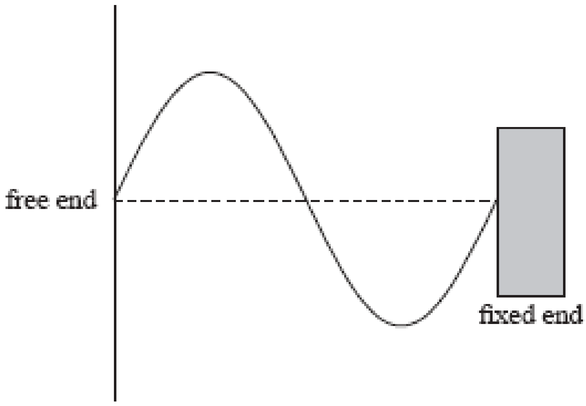
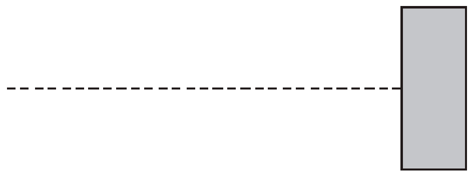
(c) A stretched string is fixed at one end. The other end is vibrated continuously to produce a wave along the string. The wave is reflected at the fixed end and as a result a standing wave is set up in the string.

The diagram below shows the displacement of the string at time $t=0$. The dotted line shows the equilibrium position of the string.

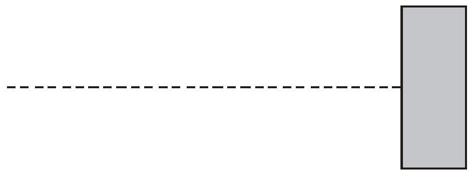


(i) The period of oscillation of the string is T. On the diagrams below, draw sketches of the displacement of the string at time $t = \frac{T}{4}$ and at time $t = \frac{T}{2}$. *[2]*

$t = \frac{T}{4}$



$t = \frac{T}{2}$



(ii) Use your sketches in (i) to explain why the wave in the string appears to be stationary. *[2]*

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(d) Stationary waves are often associated with the phenomenon of resonance.

(i) Describe what is meant by *resonance*. *[2]*

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(ii) On 19 September 1985 an earthquake occurred in Mexico City. Many buildings that were about 80 m tall collapsed whereas buildings that were taller or shorter than this remained undamaged. Use the data below to suggest a reason for this. *[3]*

period of oscillation of an 80 m tall building $= 2.0\,\text{s}$
speed of earthquake waves $= 6.0 \times 10^3\,\text{m s}^{-1}$
average wavelength of the waves $= 1.2 \times 10^4\,\text{m}$

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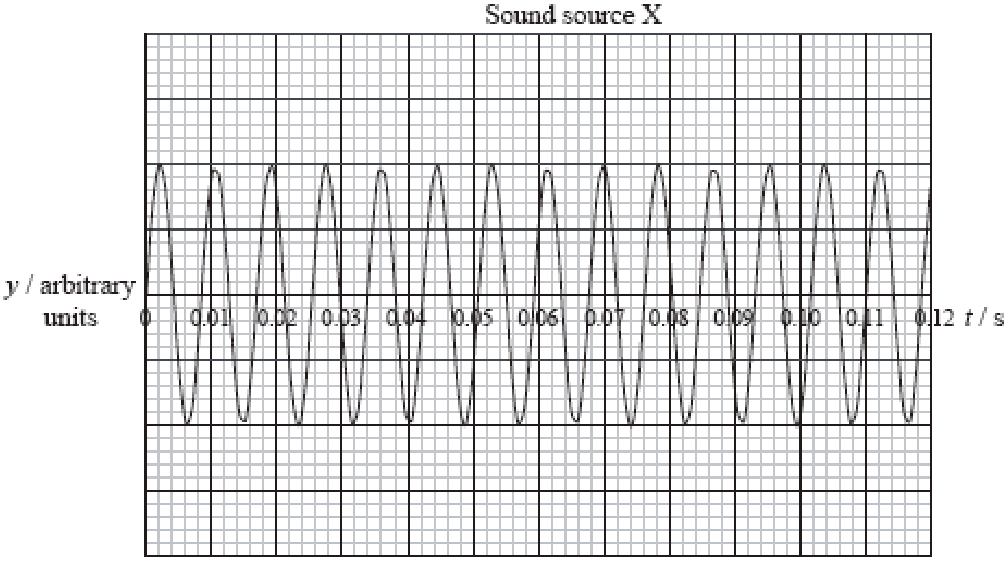
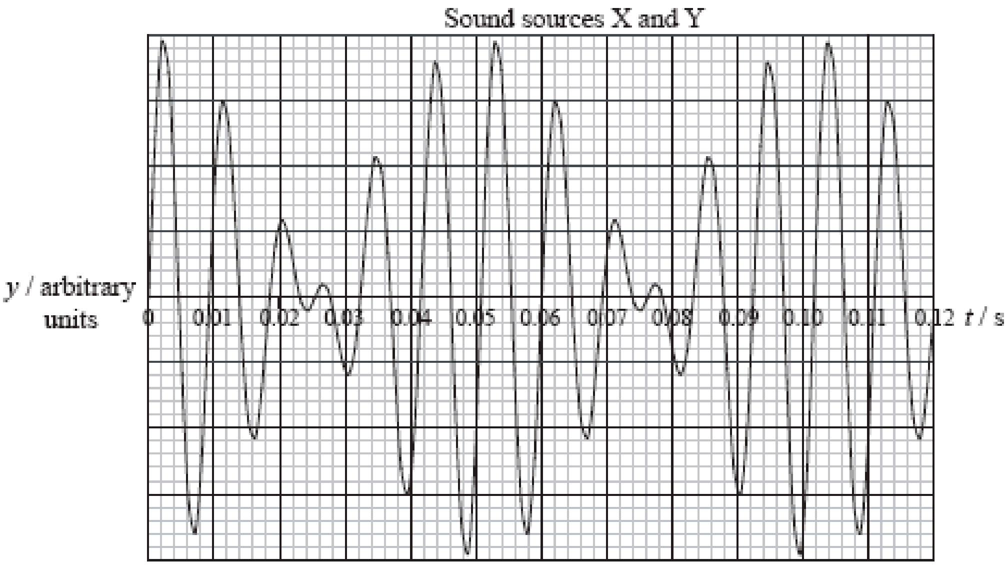
(e) Two sound sources X and Y have the same intensity but different frequencies. The graph below shows the variation with time t of the displacement y of the air at point P when source X is sounded alone.



The graph below shows the variation with time t of the displacement y of the air at point P when source X and source Y are sounded together.



Use data from the graphs

(i) to explain what is heard by an observer at point P. *[2]*

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(ii) to calculate the beat frequency and the frequency of the sound source X. *[4]*

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(f) State **one** of the possible values for the frequency of sound source Y. *[1]*

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(a) State two differences between a travelling wave and a standing (stationary) wave. *[2]*

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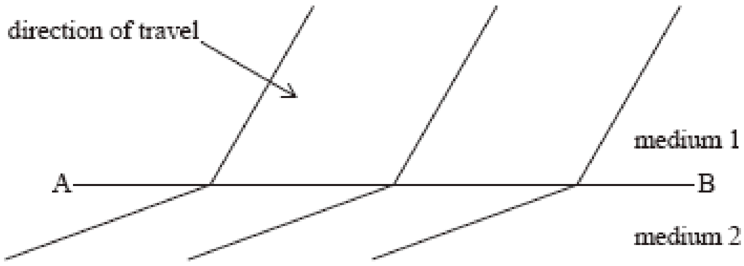
(b) In the scale diagram below, plane wavefronts travel from medium 1 to medium 2 across the boundary AB.



State and explain in which medium the wavefronts have the greater speed. *[3]*

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(c) By taking measurements from the diagram, determine the ratio

$$\frac{\text{speed of wave in medium 1}}{\text{speed of wave in medium 2}}.$$ *[3]*

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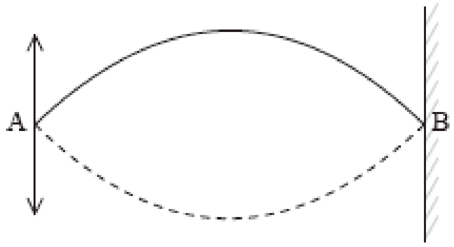
(d) To demonstrate the production of a standing wave, Samantha attaches the end B of a length AB of rubber tubing to a rigid support. She holds the other end A of the tubing, pulls on it slightly and then shakes the end A in a direction at right angles to AB. At a certain frequency of shaking, the tubing is seen to form the standing wave pattern shown below.



Explain how this pattern is formed. *[5]*

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(e) The speed v with which energy is propagated in the tubing by a travelling wave depends on the tension T in the tubing. The relationship between these quantities is

$$v = k\sqrt{T}$$

where k is a constant.

In an experiment to verify this relationship, the fundamental (first harmonic) frequency f was measured for different values of tension T.

(i) Explain how the results of this experiment, represented graphically, can be used to verify the relationship $v = k\sqrt{T}$. *[4]*

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(ii) In the experiment, the length of the tubing was kept constant at 2.4 m. The fundamental frequency for a tension of 9.0 N in the tubing was 1.8 Hz. Calculate the numerical value of the constant k. *[3]*

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(f) A source S emits sound waves at constant frequency. In the diagram below, S is moving at constant speed in the direction shown, along a straight-line between two stationary observers A and B.

(i) Draw, on the above diagram, **three** wavefronts representing the waves emitted by S. *[2]*

(ii) Use your sketch to explain any difference in the frequency of the sound as heard by observer A and by observer B. *[2]*

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(g) Some speed detectors make use of the Doppler effect and the beat frequency between a transmitted wave and a reflected wave.

(i) Explain, with reference to sound waves, the term *beat frequency*. *[2]*

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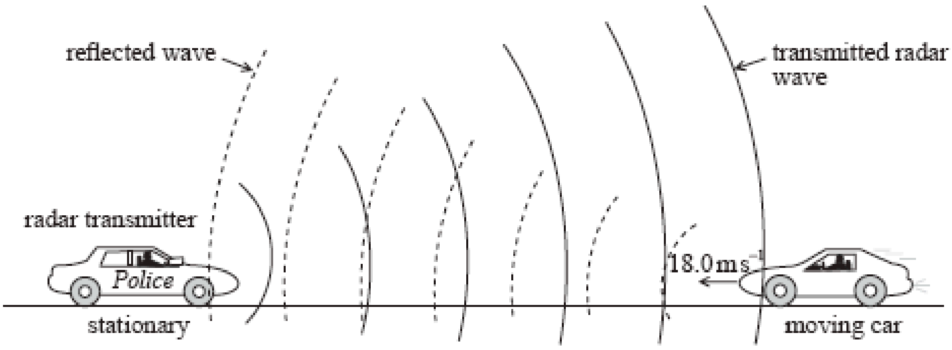
(ii) Some speed detectors transmit microwaves rather than sound. In this situation, the Doppler equations that apply to sound can also be assumed to apply to microwaves.

In the diagram below, a speed detector in a stationary police car emits microwaves of frequency 10.6 GHz. The waves are reflected off an approaching car.



The car is travelling in a direct line towards the police car with a speed $18.0\,\text{m s}^{-1}$. The reflected waves are Doppler shifted and interfere with the transmitted waves to produce beats. The speed of the microwaves is $3.00 \times 10^{8}\,\text{m s}^{-1}$.

Calculate the beat frequency measured at the speed detector. *[4]*

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