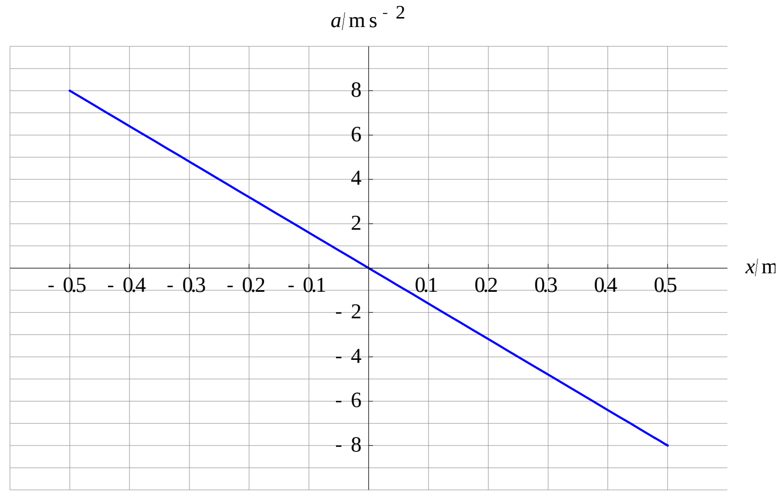
TOPIC C

Paper 2 Exam Questions

1.

The graph shows how the acceleration of a particle varies with displacement from a fixed equilibrium position.



(a) Use the graph to explain why the particle is performing simple harmonic oscillations. [2]

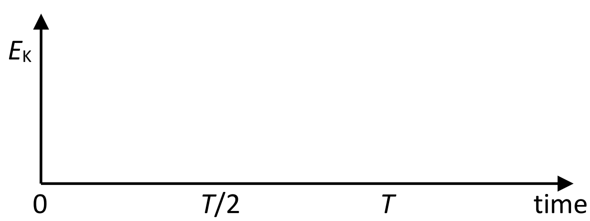
(b) Determine:

(i) the amplitude of oscillations, [1]

(ii) the angular frequency of the motion, [2]

(iii) the maximum velocity of the particle. [2]

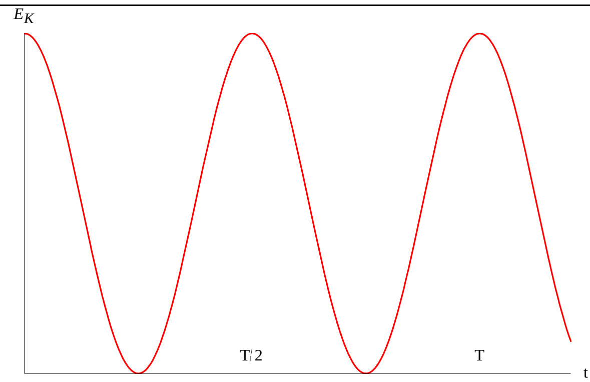
(c) At t = 0 the particle is going through the equilibrium position. Draw a graph on the axes to show how the kinetic energy of the particle varies with time. T is the period of the motion. No numbers are required. [2]



The mass of the particle is 0.20 kg.

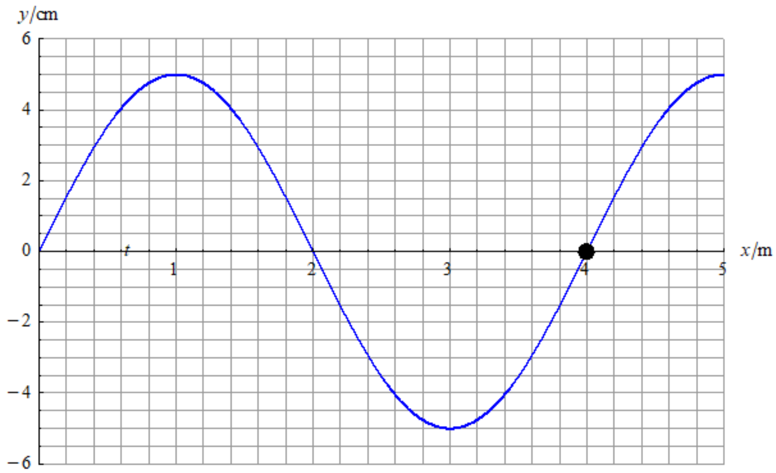
(d) (i) Calculate the maximum kinetic energy of the particle. [2]

(ii) Determine the displacement of the particle when its kinetic energy is 75% of the total energy. [3]

Question 1		Answers	Marks
a		The acceleration is proportional and opposite to the displacement✓ I.e. the defining SHM equation $a = -\omega^2 x$ is satisfied✓	2
b	i	0.50 m✓	1
b	ii	Gradient is $-\omega^2$ and from graph gradient is − 16 s^{-2}✓ So $\omega = 4.0\ \text{s}^{-1}$ ✓	2
b	iii	$v_{\max} = \omega x_0$ ✓ $v_{\max} = 4.0 \times 0.50 = 2.0\ \text{m s}^{-1}$ ✓	2
c		 Shape at t = 0✓ Period✓	2
d	i	$E_{\max} = \frac{1}{2} m\omega^2 x_0^2 = \frac{1}{2} \times 0.20 \times 4.0^2 \times 0.50^2$ ✓ $E_{\max} = 0.40\ \text{J}$ ✓	2
d	ii	$\frac{1}{2} m\omega^2 (x_0^2 - x^2) = 0.75 \times \frac{1}{2} m\omega^2 x_0^2 = \frac{3}{8} m\omega^2 x_0^2$ ✓ $x_0^2 - x^2 = \frac{3}{4} x_0^2$ ✓ $x = \frac{x_0}{2} = 0.25\ \text{m}$ ✓	3

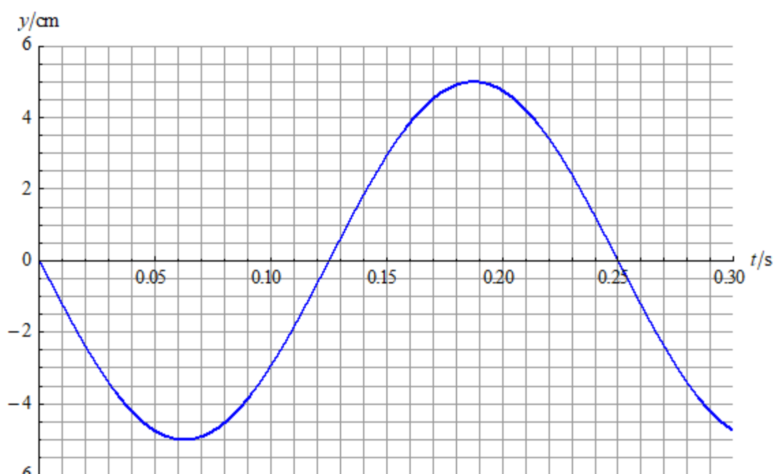
2.

Graph 1 shows, at $t = 0$, the variation with distance of the displacement y, of particles in a medium in which a transverse wave is travelling.



Graph 1

The equilibrium position of a particle in the medium has been marked. Graph 2 shows the variation with time t of the displacement y of this particle.



Graph 2

(a) (i) Calculate the speed of the wave. [2]

(ii) Determine the direction of propagation of the wave. [2]

(b) Calculate the **average** speed of the marked particle during one period of oscillation. [2]

(c) The variation of the displacement y of the marked particle with time t, is given by the equation $y = y_0 \sin(\omega t + \phi)$.

State the values of

(i) y_0 [1]

(ii) ω [1]

(iii) φ [1]

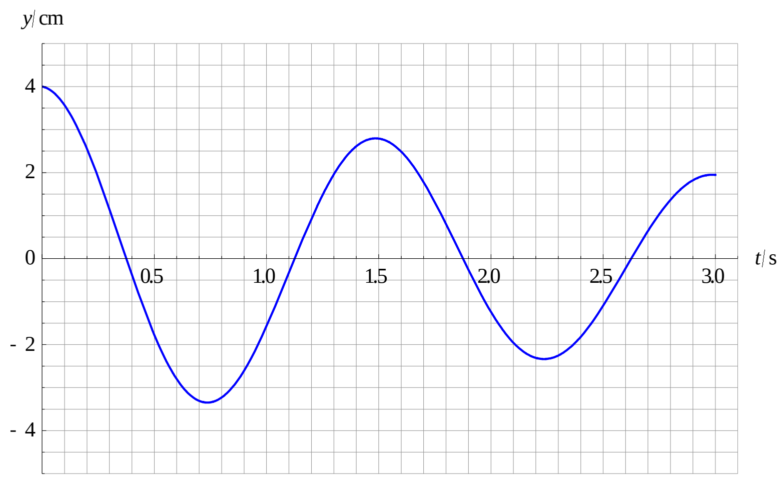
(d) (i) Calculate the velocity of the particle at $t = 0$. [2]

(ii) Calculate the potential energy of the particle at $t = 0.60$ s. The mass of the particle is 0.050 kg. [3]

Question 2		Answers	Marks
a	**i**	Wavelength is 4.0 m and period is 0.25 s✓ $v=\frac{\lambda}{T}=\frac{4.0}{0.25}=16\text{ m s}^{-1}$ ✓	**2**
a	**ii**	Immediately after t = 0, marked particle has negative displacement✓ Hence wave moves to the right✓	**2**
b		In one period marked point moves a distance of 4×5.0 = 20 cm✓ So $v=\frac{0.20}{0.25}=0.80\text{ m s}^{-1}$ ✓	**2**
c	**i**	5.0 cm✓	**1**
c	**ii**	$\omega=\frac{2\pi}{0.25}=25.1\approx 25\text{ s}^{-1}$ ✓	**1**
c	**iii**	π✓	**1**
d	**i**	$v=\omega x_0\cos(0+\pi)=-25.1\times 0.050$ ✓ $v=-1.3\text{ m s}^{-1}$ ✓	**2**
d	**ii**	$x=5.0\times\sin(25.1\times 0.60+\pi)=-3.0\text{ cm}$ ✓ $E_P=\frac{1}{2}m\omega^2x^2=\frac{1}{2}\times 0.050\times 25.1^2\times(-3.0\times 10^{-2})^2=0.28\text{ J}$ ✓	**2**

3.

A body of mass 0.020 kg is performing oscillations. The graph shows the variation with time *t* of the displacement *y* of the body from equilibrium.



(a) (i) Suggest why the oscillations are damped. [1]

(ii) State whether the damping is light, critical or heavy. [1]

(b) Estimate the average rate at which energy is lost from the system from $t = 0$ to $t = 3.0$ s. [4]

(c) A periodic force is applied to the oscillating system. State and explain the frequency *f* of the force that would give rise to large amplitude oscillations. [2]

(d) Suggest what happens to the amplitude of oscillations as the frequency of the driving force becomes very much

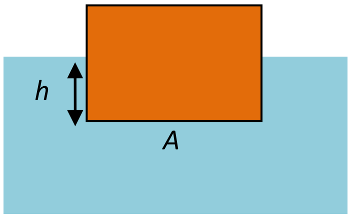
(i) smaller than *f*. [1]

(ii) larger than *f*. [1]

Question 3		Answers	Marks
a	i	The amplitude is decreasing✓	1
a	ii	Light✓	1
b		$\omega = \frac{2\pi}{1.5} = 4.189\ \text{s}^{-1}$ ✓ Initial energy $E = \frac{1}{2} m\omega^2 x_0^{\ 2} = \frac{1}{2} \times 0.020 \times 4.189^2 \times (4.0\times10^{-2})^2 = 2.81\times10^{-4}$ J ✓ Final energy $E = \frac{1}{2} m\omega^2 x_0^{\ 2} = \frac{1}{2} \times 0.020 \times 4.189^2 \times (2.0\times10^{-2})^2 = 0.702\times10^{-4}$ J ✓ Rate of loss $\frac{(2.81 - 0.702)\times10^{-4}}{3.0} = 70\ \mu\text{W}$ ✓	4
c		Damping is light so frequency is close to the natural frequency✓ So 0.67 Hz✓	2
d	i	Becomes small and constant✓	1
d	ii	Goes to zero✓	1

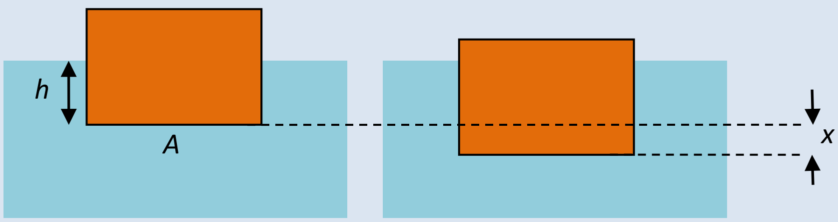
4.

A rectangular block floats in a liquid of density ρ. The cross sectional area of the block is A. The length of the side immersed in the liquid is h.



(a) Show that $Mg = \rho Ahg$. [2]

(b) The block is pushed vertically downwards by a distance x and is then released.



(i) Show that the acceleration of the block is given by $a = -\dfrac{\rho Ag}{M}x$. [3]

(ii) Hence describe the motion of the block. [2]

(c) The cross-sectional area is 0.048 m^2 and the mass of the block is 22 kg. The period of oscillations is 1.5 s.

(i) Calculate the angular frequency of the oscillations. [1]

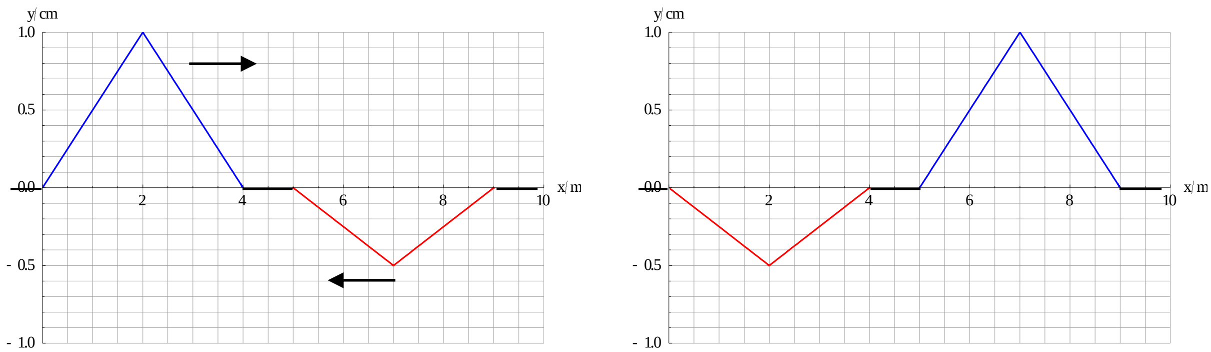
(ii) Determine the density of the liquid. [3]

(d) The maximum distance by which the block is pushed downwards is 5.0 cm. Calculate the maximum speed of the block. [2]

Question 4		Answers	Marks
a		$Mg = \rho V_{imm} g$ ✓ $Mg = \rho(Ah)g$ ✓	2
b	i	Magnitude of net force is $F_{\text{net}} = \rho A(h+\lvert x\rvert)g - Mg$ (x is negative)✓ $F_{\text{net}} = -\rho Axg$ since $Mg = \rho(Ah)g$ ✓ $a = \frac{F_{\text{net}}}{M} = -\frac{\rho Ag}{M}x$ ✓	3
b	ii	The acceleration is proportional and opposite to the displacement✓ I.e. the defining SHM equation $a = -\omega^2 x$ is satisfied✓	2
c	i	$\omega = \frac{2\pi}{1.5} = 4.189\ \text{s}^{-1}$ ✓	1
c	ii	$\omega = \sqrt{\frac{\rho Ag}{M}}$ ✓ $\rho = \frac{M\omega^2}{Ag}$ ✓ $\rho = \frac{22\times 4.189^2}{0.048\times 9.81} = 820\ \text{kg m}^{-3}$ ✓	3
d		$v_{\text{max}} = \omega x_0$ ✓ $v_{\text{max}} = 4.189\times 0.050 = 0.21\ \text{m s}^{-1}$ ✓	2

5.

Two pulses travel towards each other on the same taut rope. The two graphs show the pulses before and after the collision. The left diagram shows the pulses at t = 0 and the right diagram at t = 0.20 s.

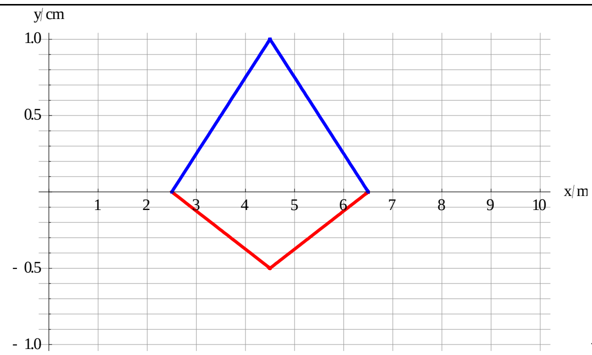
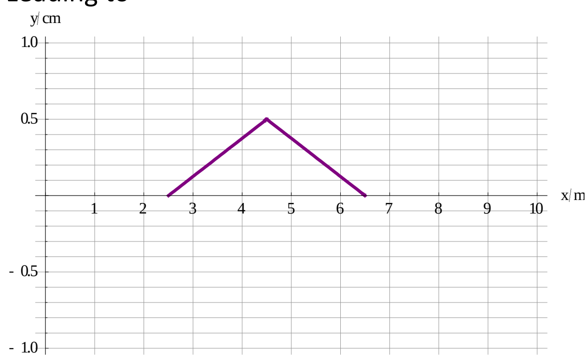


(a) State the *principle of superposition*. [1]

(b) Determine the speed of each pulse. [2]

(c) (i) Determine the time at which the two pulses completely overlap. [1]

(ii) Draw the shape of the rope at the time of complete overlap. [2]

Question 5		Answers	Marks
a		When two waves or pulses meet the resultant displacement is the algebraic sum of the individual displacements✓	1
b		Distance travelled by both pulses is 5.0 m✓ $v=\frac{5.0}{0.20}=25\text{ m s}^{-1}$ ✓	2
c	i	$t=\frac{5.0}{50}=0.10\text{ s}$ ✓	1
c	ii	 ✓ Leading to  ✓	2

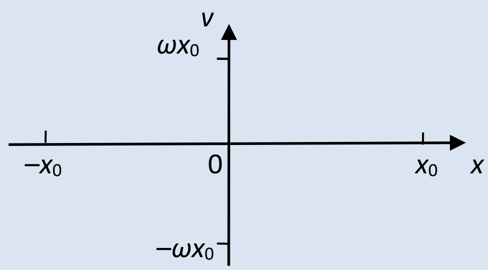
6.

A particle is performing simple harmonic oscillations with angular frequency ω and amplitude x_0.

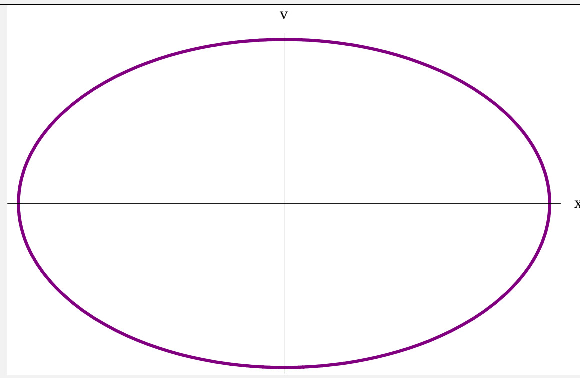
(a) Show that the velocity of the particle when the displacement is x is given by

$$v = \pm\omega\sqrt{x_0^2 - x^2}$$ [3]

(b) On the axes draw a graph to show the variation with displacement x of the velocity v. [2]

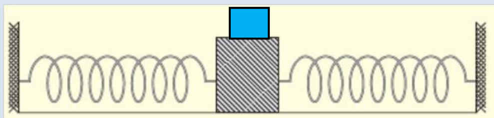


(c) Determine, in terms of x_0, the displacement of the particle when its kinetic energy is equal to its potential energy. [3]

Question 6	Answers	Marks
a	From $x = x_0 \sin(\omega t + \phi)$ and $v = \omega x_0 \cos(\omega t + \phi)$ we get $\sin(\omega t + \phi) = \frac{x}{x_0}$ and $\cos(\omega t + \phi) = \frac{v}{\omega x_0}$ ✓ $\sin^2(\omega t + \phi) + \cos^2(\omega t + \phi) = 1 = \left(\frac{v}{\omega x_0}\right)^2 + \left(\frac{x}{x_0}\right)^2$ ✓ $v^2 = (\omega x_0)^2 - (\omega x)^2$ ✓ Result follows.	3
b	 Overall shape ✓ Ellipse ✓	2
c	$E_K = \frac{1}{2} m\omega^2 x_0^2 - \frac{1}{2} m\omega^2 x^2$ and $E_P = \frac{1}{2} m\omega^2 x^2$ ✓ $\frac{1}{2} m\omega^2 x_0^2 - \frac{1}{2} m\omega^2 x^2 = \frac{1}{2} m\omega^2 x^2$ ✓ $x = \frac{x_0}{\sqrt{2}}$ ✓	3

7.

Two identical springs, each of spring constant k = 240 N m^{-1} are attached to a block of mass M = 25 kg as shown in the diagram. On top of this block is a second block of mass m = 5.0 kg. There is friction between the two blocks. When the blocks are displaced to the right and released the blocks move together without sliding on each other.



The blocks are displaced by a distance x to the right.

(a) (i) Show that the expression for the acceleration of the blocks is $a = -\dfrac{2kx}{M+m}$. [2]

(ii) Deduce that the blocks will oscillate in simple harmonic motion. [1]

(b) The amplitude of oscillations is 0.15 m. Calculate

(i) the period of the oscillations. [2]

(ii) the maximum acceleration of the blocks. [1]

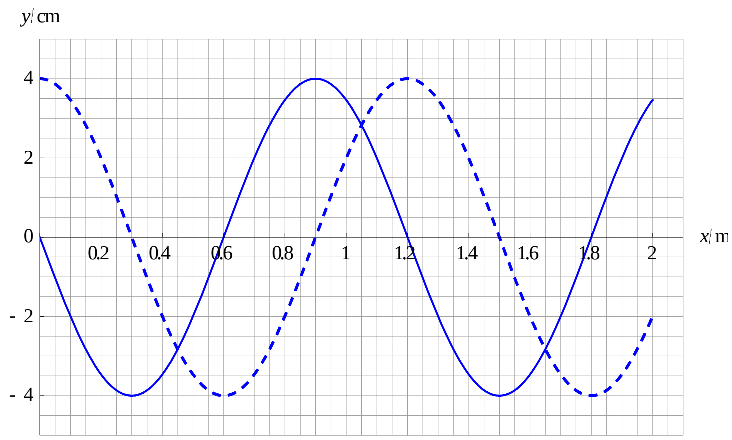
(c) (i) The static coefficient of friction between the two blocks is 0.30. Explain why there was no sliding between them during the oscillations. [3]

(ii) Deduce the maximum amplitude of oscillations so that the blocks would not slide over each other. [2]

Question 7		Answers	Notes	Marks
a	i	Displace blocks to the right by x then net force is to the left and equal to $F=-2kx$ ✓ $F=(M+m)a$ ✓ Result follows.		2
a	ii	We have the defining equation for SHM relating acceleration to displacement✓		1
b	i	$\omega=\sqrt{\frac{2k}{M+m}}=\sqrt{\frac{2\times 240}{25+5.0}}=4.0\ \text{s}^{-1}$ ✓ $T=\frac{2\pi}{\omega}=\frac{2\pi}{4.0}=1.6\ \text{s}^{-1}$ ✓		2
b	ii	$a_{\text{max}}=\omega^2 x_0=16\times 0.15=2.4\ \text{m s}^{-2}$ ✓		1
c	i	The net force on the top block is $F_{\text{max}}=ma_{\text{max}}=5.0\times 2.4=12\ \text{N}$ ✓ The maximum possible frictional force is $f_{\text{max}}=\mu mg=0.30\times 5.0\times 9.8=14.7\approx 15\ \text{N}$ ✓ so friction can provide necessary force✓		3
c	ii	$m\omega^2 x_0=\mu mg$ ✓ $x_0=\frac{\mu g}{\omega^2}=\frac{0.30\times 9.8}{16}=0.18\text{m}$ ✓		2

8.

The graph shows the variation of the displacement *y* with distance *x* for a wave travelling to the right in a medium. The solid line shows the wave at *t* = 0 and the dotted line shows the same wave at *t* = 1.25 ms. The period of the wave is longer than 1.25 ms.

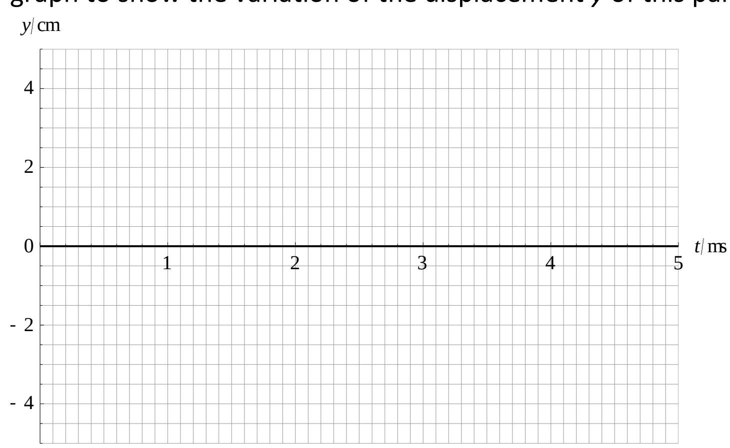


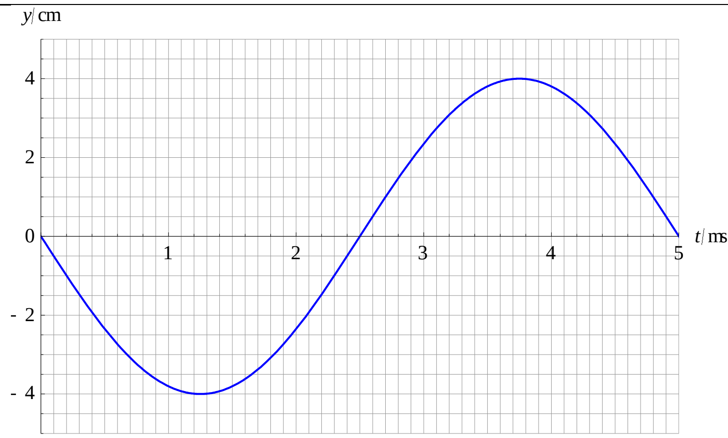
(a) State the wavelength of this wave. [1]

(b) Suggest why the question specified that the period of the wave is longer than 1.25 ms. [1]

(c) Calculate the frequency of the wave. [3]

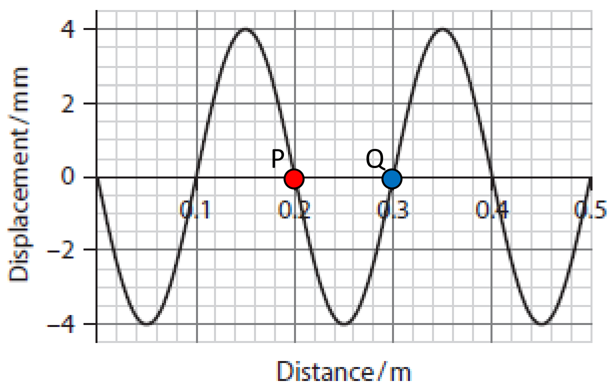
(d) The equilibrium position of a particle in the medium is at *x* = 0.60 m. On the axes draw a graph to show the variation of the displacement *y* of this particle with time. [2]



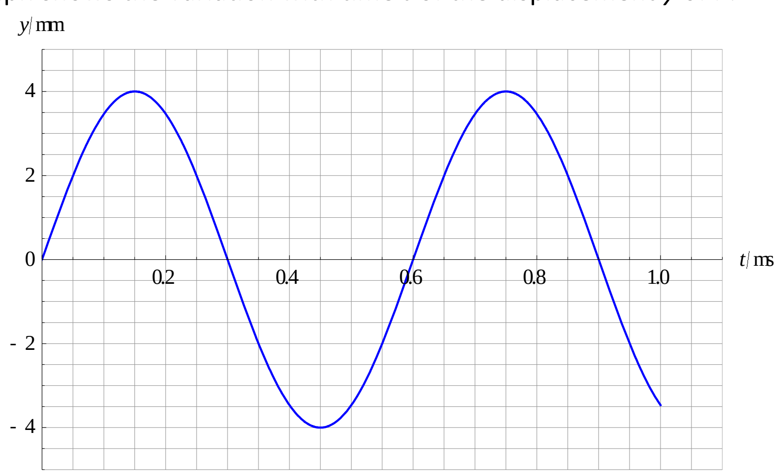
Question 8		Answers	Marks
a		1.2 m✓	1
b		If the period were much smaller than 1.25 ms we could not decide what distance the wave travelled in this time✓	1
c		Distance travelled is 0.30 m✓ $v = \frac{0.30}{1.25 \times 10^{-3}} = 240 \text{ m s}^{-1}$ ✓ $f = \frac{240}{1.2} = 200 \text{ Hz}$ ✓	3
d		 Negative sine function✓ With correct period✓	2

9.

A longitudinal wave is travelling through a medium. The graph shows the variation of the displacement of particles in the medium with distance at t = 0. Positive displacements are directed to the right. Two points in the medium, P and Q, have been marked.



The graph shows the variation with time t of the displacement y of P.



(a) Distinguish a *longitudinal* from a *transverse* wave. [2]

(b) State, for this wave:

(i) the amplitude [1]

(ii) the wavelength [1]

(iii) the frequency. [1]

(c) Calculate the speed of the wave. [1]

(d) Suggest whether the wave is travelling to the right or to the left. [2]

(e) (i) Calculate the phase difference between P and Q. [2]

(ii) Draw the variation of the displacement of Q with time. [2]

(f) The travelling wave in parts (a)–(d) is directed towards a pipe that has both ends open.

(i) Calculate the length of the pipe so that a standing wave in its first harmonic is established within the pipe. [2]

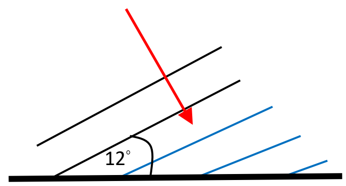
(ii) State two differences between a standing wave and a travelling wave. [2]

(iii) In the context of a standing wave state the meaning of the term *wave speed*. [2]

Question 9		Answers	Marks
a		In a longitudinal wave the displacement of the particles of the medium is parallel to the direction of energy transfer✓ In a transverse wave the displacement is perpendicular to the direction of energy transfer✓	**2**
b	**i**	4.0 mm✓	**1**
b	**ii**	0.20 m✓	**1**
b	**iii**	$f=\frac{1}{0.60\times 10^{-3}}=1667\approx 1700\ \text{Hz}$ ✓	**1**
c		$v=1667\times 0.20=333\approx 330\ \text{m s}^{-1}$ ✓	**1**
d		The displacement of P is zero at time zero and becomes positive immediately afterwards✓ This can happen if we shift the first graph *to the right*; this means the wave is going to the right✓	**2**
e	**i**	P and Q differ by a half wavelength✓ $\Delta\phi=\frac{2\pi}{\lambda}\Delta x=\frac{2\pi}{\lambda}\frac{\lambda}{2}=\pi$ ✓	**2**
e	**ii**	Negative sine function✓ With correct period and amplitude✓	**2**
f	**i**	The wavelength of the first harmonic is 2L✓ The wavelength is 0.20 m so L = 0.10 m✓	**2**
f	**ii**	All points in a travelling wave have the same amplitude; in a standing wave they do not✓ A travelling wave transfers energy; a standing wave does not✓	**2**
f	**iii**	A standing wave is the supperposition of two identical travelling waves moving in opposite drections✓ The speed refers to the speed of these travelling waves ✓	**2**

10.

(a)Sound waves travelling in air approach an air-water boundary. The speed of sound in air is 340 m s^{-1} and in water it is 1500 m s^{-1}. The wavefronts make an angle of 12° with the boundary.



(i) Calculate the angle the wavefronts in the water make with the boundary. [2]

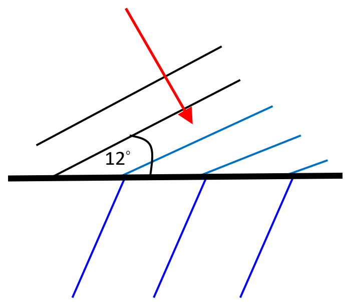
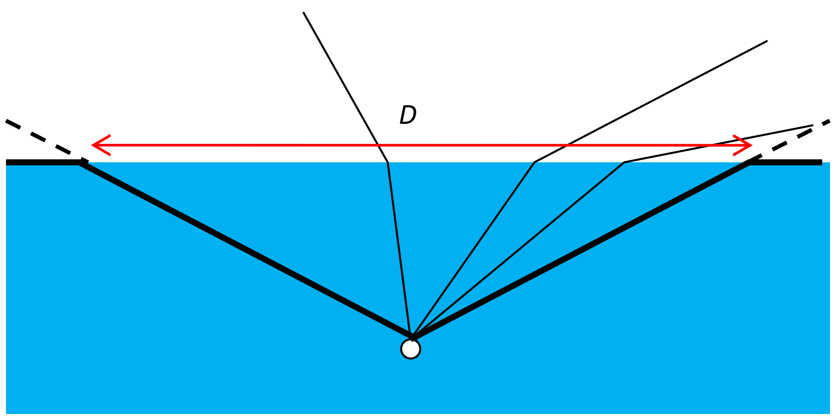
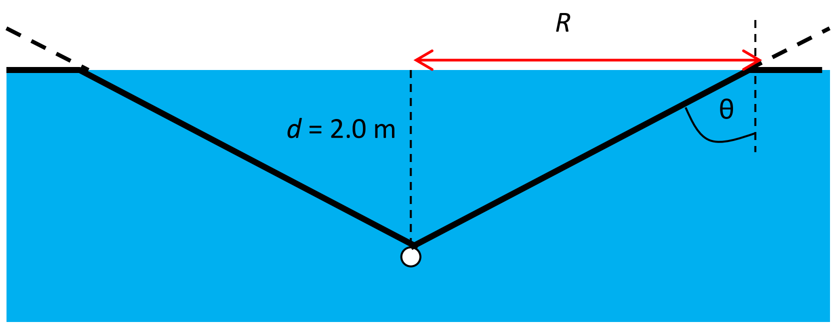
(ii) Draw lines to extend the three blue wavefronts in water. [2]

A man is swimming underwater at a depth of d = 2.0 m. The man looks upwards.

(b) Explain, with the help of a diagram, why he can see the world outside the water only through a circle on the surface of the water. [2]

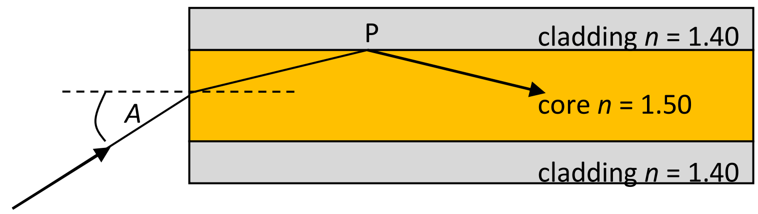
(c) (i) The refractive index of water is 1.33. Calculate the diameter of the circle in (b). [2]

(ii) Discuss how the answer to (c) (i) changes (if at all) if he looks up from a greater depth. [2]

Question 10		Answers	Marks
a	i	$\frac{\sin 12^\circ}{340}=\frac{\sin\theta}{1500}$ ✓ $\theta = 66.5^\circ$ ✓	2
a	ii	 Angle with boundary consistent with answer in (a) (i) ✓ Larger spacing✓	2
b		 Only the rays bounded by the thick lines that correspond to an angle of incidence of 90° can enter his eye✓ He can only see rays entering through a circle of diameter *D*✓	2
c	i	 $1.00\times\sin 90^\circ = 1.33\sin\theta \Rightarrow \theta = 48.753^\circ$ ✓ $R = d\tan\theta = 2.0\times\tan 48.753^\circ = 2.28$ m so *D* = 4.5 = 4.6 m to 2 s.f. ✓	2
c	ii	The depth *d* is greater and θ is the same✓ so the diameter of the circle is greater, $D = 2d\tan\theta$ ✓	2

11.

In an optic fibre, a ray of light enters the core of refractive index 1.50. The core is surrounded by cladding of refractive index 1.40. The angle of incidence in air is *A*.



(a) (i) State what is meant by the *critical angle*. [1]

(ii) Calculate the critical angle at the core-cladding boundary. [2]

(iii) Explain why total internal reflection cannot happen to a ray entering the core from the cladding. [1]

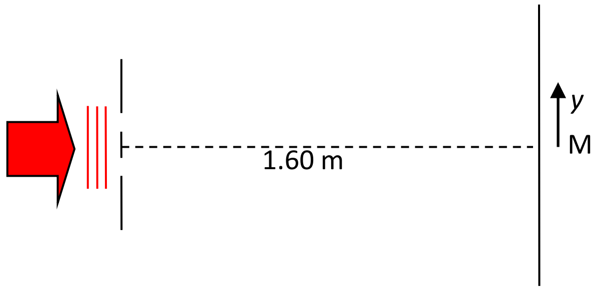
(b) Determine A_{max}, the largest value of the angle *A*, such that the ray suffers total internal reflection at P. [2]

(c) The length of the optic fibre is 8.0 km. Calculate the time of travel of a ray that enters the core at an angle of incidence equal to A_{max}. [3]

Question 11		Answers	Marks
a	i	The angle of incidence for which the angle of refraction is 90° ✓	1
a	ii	$1.50\times\sin\theta_c = 1.40\times\sin 90^\circ$ ✓ $\theta_c = 68.96^\circ \approx 69.0^\circ$ ✓	2
a	iii	Solving $1.40\times\sin\theta_c = 1.50\times\sin 90^\circ$ is impossible ✓	1
b	i	The angle of refraction at the air-core boundary must be $90^\circ - 68.96^\circ = 21.039^\circ$ ✓ $1.0\times\sin A_{max} = 1.50\times\sin 21.039^\circ \Rightarrow A_{max} = 32.583^\circ \approx 32.6^\circ$ ✓	2
c		Speed of light in core $\dfrac{3.0\times10^8}{1.50} = 2.0\times10^8$ m s^{-1} ✓ Actual distance covered $\dfrac{8.0\times10^3}{\sin 68.96^\circ} = 8.571\times10^3$ m ✓ Time taken $\dfrac{8.571\times10^3}{2.0\times10^8} = 42.9$ μs ✓	3

12.

In a Young two-slit experiment, planar wavefronts of light are incident on two very narrow slits that are a distance 0.120 mm apart. Bright and dark fringes are observed on a screen 1.60 m from the slits. M is the middle of the screen.

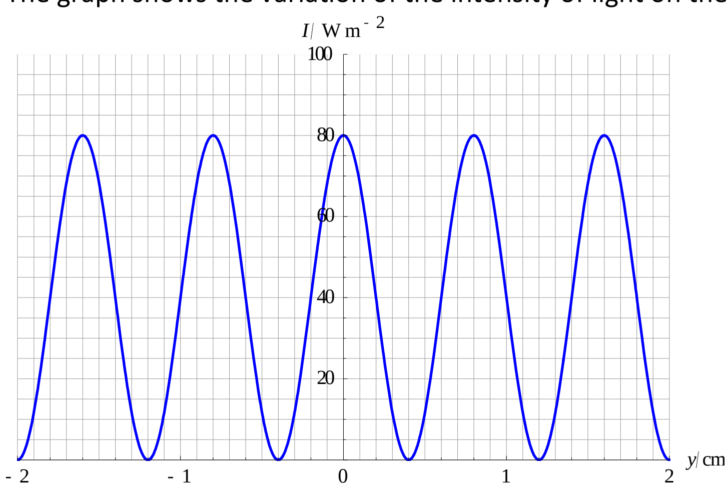


(a)

(i) Explain why in two-source interference no fringes will be observed if the sources are incoherent. [2]

(ii) The two slits in the figure above act as the two sources. Suggest why they are coherent. [1]

The graph shows the variation of the intensity of light on the screen with distance *y* from M.



(b) (i) Explain how the bright fringes are formed. [2]

(ii) Determine the wavelength of light. [3]

(c) Describe the changes, if any, to the graph when the following separate changes are made:

(i) the separation of the slits is increased, [1]

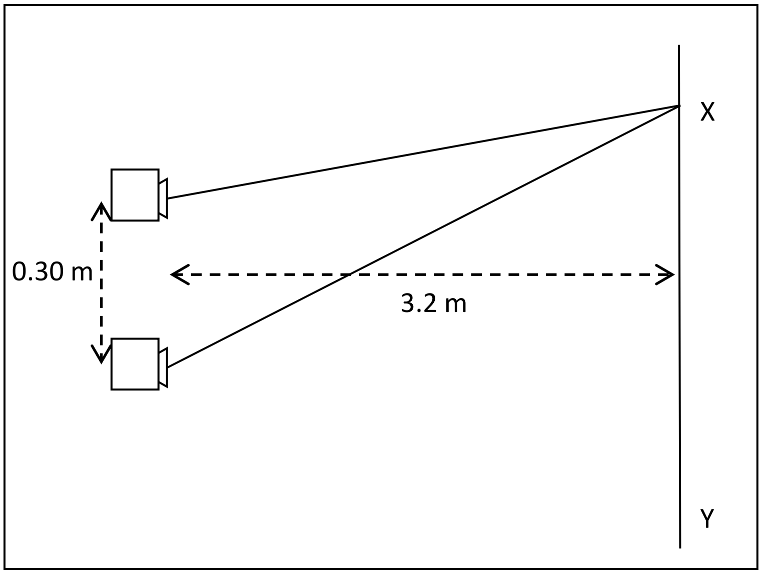
(ii) the wavelength of light is increased. [1]

(d) The intensity of light is proportional to the square of the amplitude. Estimate the intensity of the light at M when one of the slits is closed. [3]

Question 12		Answers	Marks
a	**i**	If the light is not coherent, the phase difference between the light leaving one source and the light leaving the other will be constantly changing✓ This means that the positions where maxima and minima will be observed are switching places very quickly, erasing any interference pattern✓	**2**
a	**ii**	They are coherent because they belong to the same wavefront ✓	**1**
b	**i**	Light from one slit interferes with light from the other slit✓ Bright fringes are formed when the path difference is an integer multiple of the wavelength/when phase difference is 0 in which case the waves add peak to peak✓	**2**
b	**ii**	The fringe separation is 0.80 cm✓ $s=\frac{\lambda D}{d}\Rightarrow\lambda=\frac{sd}{D}$ ✓ $\lambda=\frac{0.80\times10^{-2}\times0.120\times10^{-3}}{1.60}=6.0\times10^{-7}$ m ✓	**3**
c	**i**	The separation of the fringes decreases✓	**1**
c	**ii**	The separation of the fringes increases✓	**1**
d		The amplitude at the central maximum is 2*A*, where *A* is the amplitude of the light from one slit✓ 80 = $k(2A)^2$✓ So, kA^2=20 W m^{-2}✓	**3**

13.

Two speakers 0.30 cm apart emit identical sound waves in phase in an enclosed space.



A person walks along the line from X to Y. The line is a distance 3.2 m from the speakers.

(a) The person hears maxima and minima in the intensity of sound as he walks along the line. Explain this observation. [3]

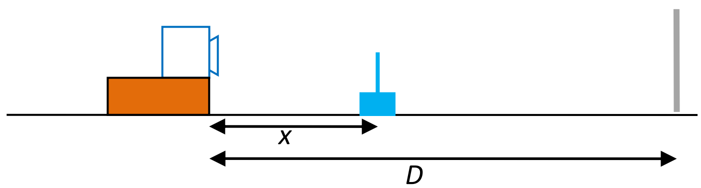
(b) Explain why at the positions of minimum intensity, the intensity is not zero. [2]

(c) The person walks along XY with speed 0.50 m s^{-1} and hears a high intensity of sound every 1.2 s. Estimate the wavelength of the sound. [3]

Question 13		Answers	Marks
a		Sound from one speaker interferes with sound from the other✓ When the path difference is an integral multiple of the wavelength/phase difference zero maximum intensity sounds are heard✓ When the path difference is a half integer multiple of the wavelength/when phase difference is π minimum intensity sounds are heard✓	3
b		The observer receives sound not just from the speakers but also from reflections in the enclosed space✓ The path difference/phase difference will never be such to give complete cancellation✓	2
c		The fringe separation is $s = vt = 0.50\times1.2 = 0.60$ m ✓ $s=\frac{\lambda D}{d} \Rightarrow \lambda = \frac{sd}{D}$ ✓ $\lambda = \frac{0.60\times0.30}{3.2} = 5.6\times10^{-2}$ m ✓	3

14.

A source emits microwaves towards a metal plate from which they are reflected. A microwave detector is placed in between the source and the plate.



(a) Show that the path difference at the detector between the waves reaching it directly and after reflection from the plate is $2(D - x)$. [2]

(b) Using your answer to (a) explain why the detector records maxima and minima of intensity as its distance x from the source is varied. [2]

(c) The wave suffers a phase change of π upon reflection at the plate. The distance D is 81 cm. The wavelength of the microwaves is 12 cm.

(i) Determine the smallest non-zero distance x at which a maximum intensity is recorded. [3]

(ii) State the next distance at which an intensity maximum will be recorded. [1]

Question 14		Answers	Marks
a		The direct path has length x and the indirect path has length $D+(D-x)$ ✓ The path difference is then $D+(D-x)-x=2(D-x)$ ✓	**2**
b		There will be maxima when the phase difference is zero✓ This happens only for specific values of x✓	**2**
c	**i**	Because of the phase change the condition for a maximum in terms of path difference is: path difference $=(n+\frac{1}{2})\lambda$ ✓ $2(D-x)=(n+\frac{1}{2})\lambda \Rightarrow x=81-6(n+\frac{1}{2})=78-6n$ ✓ Minimum x when n = 12, i.e. $x=6.0$ cm ✓	**3**
c	**ii**	The next distance will be half a wavelength away, i.e. at 12 cm ✓ ***OR*** $x=78-6\times 11=12$ cm	**1**

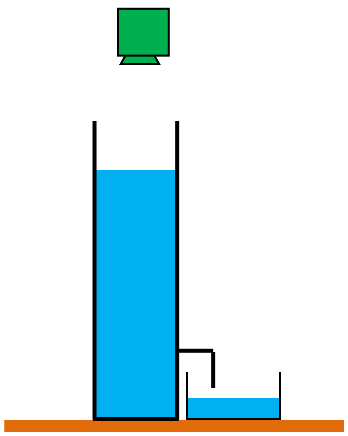
15.

(a)

(i) Outline how a *standing wave* is formed. [2]

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

A source of sound is placed above a tube containing water. A strong sound is heard from the tube when the length of the air column above the water surface is 6.0 cm. Water is slowly taken out of the tube and when the length of the air column becomes 18 cm another strong sound is heard.



(b) (i) Explain the origin of the loud sounds from the tube. [2]

(ii) Suggest why a strong sound is heard only for specific lengths of the air column. [2]

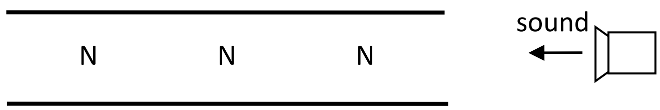
(iii) Predict the next length of the air column for which a loud sound will be heard. [1]

(iv) The frequency of the source is 1400 Hz. Estimate the speed of sound in the tube. [2]

Question 15		Answers	Marks
a	i	A standing wave is formed when two identical travelling waves✓ Moving in opposite directions meet and superpose✓	2
a	ii	A travelling wave transfers energy; a standing wave does not✓ The amplitude in a travelling wave is constant; in a standing wave it is not✓	2
b	i	When the length of the air column above the water is the right length✓ A standing wave will be formed from the superposition of the incoming wave and the reflected wave✓	2
b	ii	The standing wave will have a wavelength equal to $\frac{4L}{n}$ where *L* is the length of the air column and *n* is an odd integer✓ So, for a given wavelength λ this will happen only when $L=\frac{\lambda n}{4}$, i.e. for specific values of the air column length✓	2
b	iii	30 cm✓	1
b	iv	The wavelength of sound is 2×0.12 = 0.24 m✓ $v=1400\times 0.24=336\approx 340\text{ m s}^{-1}$ ✓	2

16.

Sound is directed from a loudspeaker into a pipe with both ends open. For a specific frequency of sound, a standing wave is formed in the pipe with three nodes (N) as shown. The length of the pipe is 0.90 m and the speed of sound is 340 m s^{-1}.



(a)

(i) State what is meant by the term *node*. [1]

(ii) A student says an antinode is the point where the displacement is always maximum. Comment on the student's statement. [2]

(iii) State, for this standing wave, the distance between a node and the next antinode. [1]

(b) Determine the frequency of sound. [3]

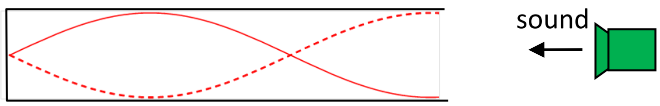
(c) (i) Estimate the lowest frequency of sound that can create a standing wave in this pipe. [2]

(ii) Determine the length of a pipe with one end closed and the other open whose lowest harmonic has the same frequency as the answer to (c) (i). [1]

Question 16		Answers	Marks
a	i	A point where the displacement is always zero✓	1
a	ii	An antinode is a point where the displacement is a maximum for an instant of time✓ So the student is not correct✓	2
a	iii	There are 6 intervals between node and antinode in this standing wave so $\frac{90}{6} = 15\text{ cm}$ ✓	1
b		The distance between consecutive nodes and antinodes is a quarter of a wavelength✓ λ = 4×0.15 = 0.60 m✓ $f = \frac{340}{0.60} = 567 \approx 570\text{ Hz}$ ✓	3
c	i	The lowest frequency corresponds to the first harmonic which has wavelength 2*L* = 2×0.90 = 1.80 m✓ $f = \frac{340}{1.80} = 189 \approx 190\text{ Hz}$ ✓	2
c	ii	$L = \frac{\lambda}{4} = \frac{1.80}{4} = 0.45\text{ m}$ ✓	1

17.

Sound of frequency 168 Hz is directed from a loudspeaker into a pipe with one open and one closed end. The standing wave shown is set up in the pipe. The length of the pipe is 1.50 m.

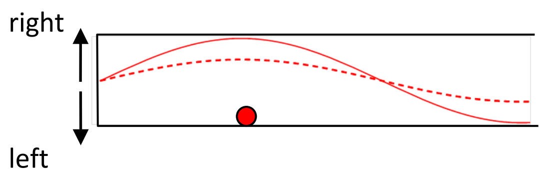


(a) Determine

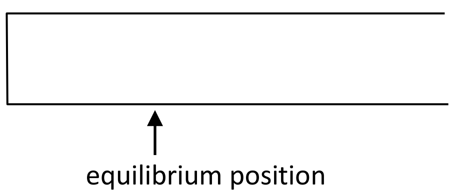
(i) the wavelength of the wave, [1]

(ii) the speed of sound in the pipe. [1]

(b) The solid line shows the standing wave at $t = 0$ and the dotted line an instant of time Δt later. The red dot is the **equilibrium** position of a particle in the pipe.



(i) Show the positions of this particle in the diagram below at $t = 0$ and at $t = \Delta t$. [2]

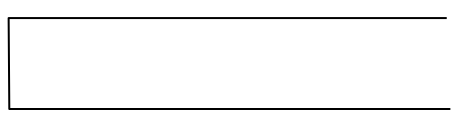


(ii) Draw the wave at $t = T/4$ where T is the period of the wave. [1]

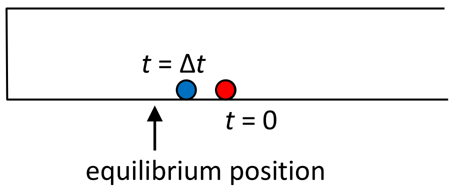
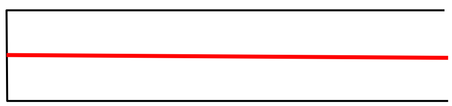
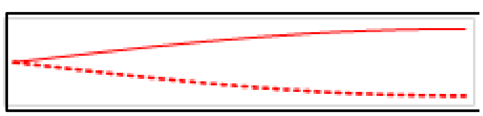
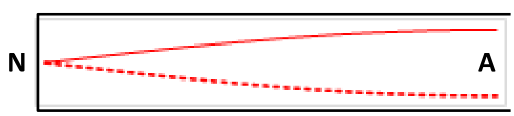
(c) The frequency of the sound from the loudspeaker is changed to 56.0 Hz.

(i) In the space below draw the standing wave that would be formed in the pipe. [2]

(ii) Label any nodes (N) or antinodes (A). [1]

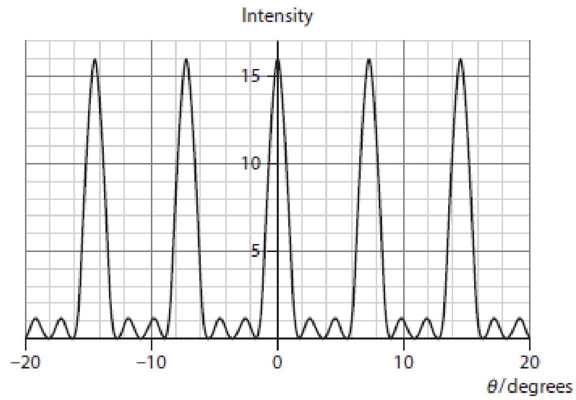


(d) Predict whether a standing wave will be formed in the pipe if the frequency is changed to 112 Hz. [1]

Question 17		**Answers**	**Marks**
a	**i**	$\lambda=\frac{4L}{3}=\frac{4\times 1.50}{3}=2.00\text{ m}$ ✓	**1**
a	**ii**	$v=\lambda f=2.00\times 168=336\text{ m s}^{-1}$ ✓	**1**
b	**i**	 Position at 0✓ Position at Δt✓	**2**
b	**ii**	 Shape shown✓	**1**
c	**i**	$56=\frac{168}{3}$ so we need the first harmonic✓  ✓	**2**
c	**ii**	 ✓	**1**
d		No, because 112 Hz is not an odd multiple of 56 Hz✓	**1**

18.

The graph shows the interference pattern for a number of very thin parallel slits. One unit of intensity corresponds to the intensity from one slit alone.



(a) The intensity of light is proportional to the square of the amplitude. Explain why the number of slits is 4. [2]

(b) The number of slits becomes very large, but the slit separation stays the same. State what happens to

(i) the number of secondary maxima in between two consecutive primary maxima, [1]

(ii) the intensity of the secondary maxima, [1]

(iii) the angular position of the primary maxima. [1]

Question 18		Answers	Marks
a		With one slit $I = kA^2$ where A is the amplitude f the wave from one slit✓ $16I = kA'^2$ so $A' = 4A$, hence 4 slits✓	2
b	i	Increases✓	1
b	ii	Decreases✓	1
b	iii	Stays the same✓	1

19.

A diffraction grating produces two consecutive maxima at angles 31.33° and 51.26° when light of wavelength 521 nm is incident on the grating.

(a)

(i) Show that the spacing of the slits of the grating is 2.00×10^{-6} m. [3]

(ii) Calculate the number of orders that are visible. [3]

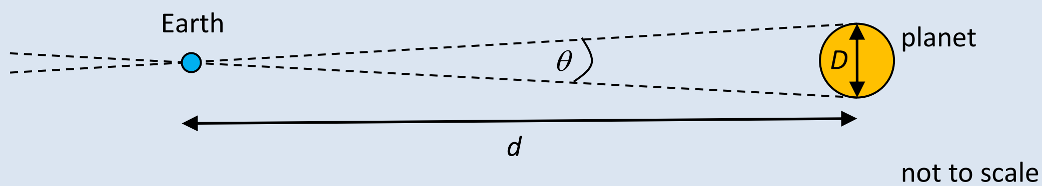
(b) Light containing two wavelengths of 452 nm and 678 nm is incident on the grating. Determine the angle at which a maximum of one wavelength coincides with a maximum of the other. [3]

Question 19		Answers	Marks
a	i	$d\sin(31.33^\circ)=n\times 521\times 10^{-9}$ and $d\sin(51.26^\circ)=(n+1)\times 521\times 10^{-9}$ ✓ $\frac{\sin(31.33^\circ)}{\sin(51.26^\circ)}=\frac{n}{(n+1)}\Rightarrow n=2$ ✓ $d=\frac{2\times 521\times 10^{-9}}{\sin(31.33^\circ)}=2.00397\times 10^{-6}\approx 2.00\times 10^{-6}$ m ✓	3
a	ii	$d\sin(90^\circ)=n\times 521\times 10^{-9}$ ✓ $n=\frac{2.00\times 10^{-6}\times\sin(90^\circ)}{521\times 10^{-9}}=3.84$ so n = 3✓ Hence 3 + 3 + 1 = 7✓	3
b		$d\sin\theta=(n+1)\times 452\times 10^{-9}$ and $d\sin\theta=n\times 678\times 10^{-9}$ ✓ $(n+1)\times 452\times 10^{-9}=n\times 678\times 10^{-9}\Rightarrow n=2$ ✓ $2.00\times 10^{-6}\times\sin\theta=3\times 452\times 10^{-9}\Rightarrow\theta=42.7^\circ$ ✓	3

20.

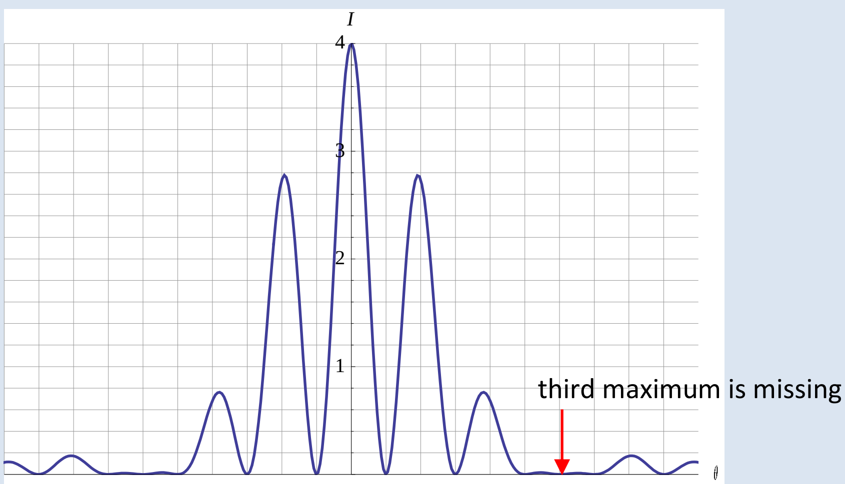
(a) State what is meant by *diffraction*. [2]

(b) The diameter *D* of a planet can be determined if we know the distance *d* to the planet and the angular width θ of the planet.



Suggest why diffraction introduces an uncertainty in the measurement of θ. [2]

(c) The graph shows the variation of the intensity of light with diffraction angle θ in a two slit interference experiment.



The two slits are separated by 3.6×10^{-5} m. The wavelength of light is 6.8×10^{-7} m. The third order maximum is missing.

(i) Explain why this maximum is missing. [2]

(ii) Calculate the angle θ, in radians, of the position of the missing maximum. [2]

(iii) Estimate the width of each of the slits. [2]

(d) The light is replaced by light of wavelength 4.5×10^{-7} m. Suggest whether the third maximum would still be missing or not. [2]

Question 20		Answers	Marks
a		The spreading of a wave✓ As it goes through an aperture or past an obstacle✓	**2**
b		The image will be blurred due to diffraction✓ Making it difficult to determine the boundaries of the image✓	**2**
c	**i**	The interference pattern for 2 slits is modulated by the single slit diffraction pattern✓ The third order maximum coincides with the first minimum of the diffraction pattern of a single slit✓	**2**
c	**ii**	$d\sin\theta = 3\lambda$ so $\sin\theta = \frac{3\times 6.8\times 10^{-7}}{3.6\times 10^{-5}} = 5.667\times 10^{-2}$ ✓ $\theta = 5.667\times 10^{-2} \approx 5.7\times 10^{-2}$ rad ***OR*** $\theta = 3.2^{\circ}$ ✓	**2**
c	**iii**	$\theta = \frac{\lambda}{b} \Rightarrow b = \frac{\lambda}{\theta}$ ✓ $b = \frac{6.8\times 10^{-7}}{5.667\times 10^{-2}} = 1.2\times 10^{-5}$ m ✓	**2**
d		The third order maximum is expected at the angle $\theta = \sin^{-1}\frac{3\times 4.5\times 10^{-7}}{3.6\times 10^{-5}} = 3.75\times 10^{-2}$ rad and the first minimum of the single slit pattern at $\theta = \frac{4.5\times 10^{-7}}{1.2\times 10^{-5}} = 3.75\times 10^{-2}$ rad ✓ So order is still missing✓ ***OR*** $d\sin\theta = 3\lambda \Rightarrow d\theta = 3\lambda$ since is small and also $\theta = \frac{\lambda}{b}$ ✓ Hence $d\frac{\lambda}{b} = 3\lambda \Rightarrow d = 3b$ so the condition of the missing order is independent of the wavelength✓	**2**

21. A binary star consists of two stars orbiting the same centre. The orbit radius of X is double that of Y. The stars have the same period of revolution T. Star X emits light of wavelength 471 nm and star Y light of wavelength 668 nm.

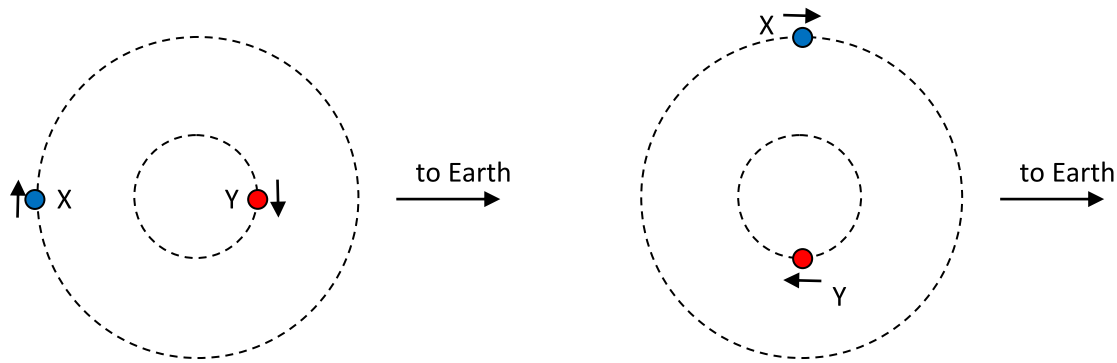


Diagram 1: $t = 0$ Diagram 2: $t = T/4$

(a) Explain why X has double the speed of Y. [1]

Light from the stars is received on Earth.

(b) (i) State and explain the wavelengths of light received on Earth when the light is emitted when the stars are in the positions of diagram 1. [2]

(ii) When the light is emitted when the stars are in the positions of diagram 2, the light from X measured on Earth is 461 nm.
Determine the wavelength on Earth of the light from Y. [4]

(c) Determine the wavelengths measured on Earth at $t = 3T/4$. [2]

Question 21		Answers	Marks
a		X covers double the distance in the same time✓	1
b	i	471 nm and 668 nm✓ In this position the stars are neither approaching nor receding earth and so no Doppler effect✓	2
b	ii	For X: $\frac{\Delta\lambda}{\lambda}=\frac{v_X}{c}=\frac{10}{471}$ ✓ For Y: $\frac{\Delta\lambda}{\lambda}=\frac{v_Y}{c}=\frac{1}{2}\frac{v_X}{c}=\frac{5}{471}$ ✓ $\Delta\lambda_Y=\frac{5}{471}\times 668\times 10^{-9}=7.091$ ✓ So received wavelength is 675 nm✓	4
c		X: 471 + 10 = 481 nm✓ Y: 668 – 7 = 661 nm✓	2

22.

(a) State what is meant by the *Doppler effect*. [1]

(b) Illustrate the Doppler effect for the case of a moving source using wavefront diagrams. [2]

(c) Outline one medical application of the Doppler effect. [2]

(d) Light from a galaxy has a wavelength 656 nm when it is emitted. The light has wavelength 641 nm when received on Earth. Determine the speed and direction of the galaxy. [2]

(e) Sound of frequency 16.2 kHz is directed at a moving car. The sound is reflected by the car and arrives back at its source where the frequency is measured to be 12.8 kHz. The speed of sound is 336 m s^{-1}. Determine the velocity of the car. [4]

Question 22		Answers	Marks
a		The change in the observed frequency when there is relative motion between source and receiver✓	**1**
b		See textbook	**2**
c		See textbook	**2**
d		$\frac{\Delta\lambda}{\lambda}=\frac{v}{c}\Rightarrow v=\frac{15}{656}\times 3\times 10^{8}=6.9\times 10^{6}\text{ m s}^{-1}$ ✓ We have a blueshift so galaxy is moving towards the observer✓	**2**
e		Frequency is reduced so car is moving away✓ Frequency received by car $f'=f\times\frac{c-v}{c}=16.2\times\frac{336-v}{336}$ (moving observer)✓ Frequency received at source $f''=f'\times\frac{c}{c+v}=\left(16.2\times\frac{336-v}{336}\right)\times\frac{336}{336+v}=16.2\times\frac{336-v}{336+v}$ (moving source)✓ $12.8=16.2\times\frac{336-v}{336+v}$, solving $v=39\text{ m s}^{-1}$ ✓	**4**