X069/701

NATIONAL QUALIFICATIONS 2011

MONDAY, 23 MAY
1.00 PM – 3.30 PM

PHYSICS
ADVANCED HIGHER

Reference may be made to the Physics Data Booklet.

Answer **all** questions.

Any necessary data may be found in the Data Sheet on page two.

Care should be taken to give an appropriate number of significant figures in the final answers to calculations.

Square-ruled paper (if used) should be placed inside the front cover of the answer book for return to the Scottish Qualifications Authority.

DATA SHEET

COMMON PHYSICAL QUANTITIES

Quantity	*Symbol*	*Value*	*Quantity*	*Symbol*	*Value*
Gravitational acceleration on Earth	g	$9{\cdot}8$ m s^{-2}	Mass of electron	m_e	$9{\cdot}11 \times 10^{-31}$ kg
Radius of Earth	R_E	$6{\cdot}4 \times 10^{6}$ m	Charge on electron	e	$-1{\cdot}60 \times 10^{-19}$ C
Mass of Earth	M_E	$6{\cdot}0 \times 10^{24}$ kg	Mass of neutron	m_n	$1{\cdot}675 \times 10^{-27}$ kg
Mass of Moon	M_M	$7{\cdot}3 \times 10^{22}$ kg	Mass of proton	m_p	$1{\cdot}673 \times 10^{-27}$ kg
Radius of Moon	R_M	$1{\cdot}7 \times 10^{6}$ m	Mass of alpha particle	m_α	$6{\cdot}645 \times 10^{-27}$ kg
Mean Radius of Moon Orbit		$3{\cdot}84 \times 10^{8}$ m	Charge on alpha particle		$3{\cdot}20 \times 10^{-19}$ C
Universal constant of gravitation	G	$6{\cdot}67 \times 10^{-11}$ m^3 kg^{-1} s^{-2}	Planck's constant	h	$6{\cdot}63 \times 10^{-34}$ J s
Speed of light in vacuum	c	$3{\cdot}0 \times 10^{8}$ m s^{-1}	Permittivity of free space	ε_0	$8{\cdot}85 \times 10^{-12}$ F m^{-1}
Speed of sound in air	v	$3{\cdot}4 \times 10^{2}$ m s^{-1}	Permeability of free space	μ_0	$4\pi \times 10^{-7}$ H m^{-1}

REFRACTIVE INDICES

The refractive indices refer to sodium light of wavelength 589 nm and to substances at a temperature of 273 K.

Substance	*Refractive index*	*Substance*	*Refractive index*
Diamond	2·42	Glycerol	1·47
Glass	1·51	Water	1·33
Ice	1·31	Air	1·00
Perspex	1·49	Magnesium Fluoride	1·38

SPECTRAL LINES

Element	*Wavelength*/nm	*Colour*
Hydrogen	656	Red
	486	Blue-green
	434	Blue-violet
	410	Violet
	397	Ultraviolet
	389	Ultraviolet
Sodium	589	Yellow

Element	*Wavelength*/nm	*Colour*
Cadmium	644	Red
	509	Green
	480	Blue

Lasers

Element	*Wavelength*/nm	*Colour*
Carbon dioxide	9550, 10590	Infrared
Helium-neon	633	Red

PROPERTIES OF SELECTED MATERIALS

Substance	*Density*/ kg m^{-3}	*Melting Point*/ K	*Boiling Point*/ K	*Specific Heat Capacity*/ J kg^{-1} K^{-1}	*Specific Latent Heat of Fusion*/ J kg^{-1}	*Specific Latent Heat of Vaporisation*/ J kg^{-1}
Aluminium	$2{\cdot}70 \times 10^{3}$	933	2623	$9{\cdot}02 \times 10^{2}$	$3{\cdot}95 \times 10^{5}$	. . . .
Copper	$8{\cdot}96 \times 10^{3}$	1357	2853	$3{\cdot}86 \times 10^{2}$	$2{\cdot}05 \times 10^{5}$	. . . .
Glass	$2{\cdot}60 \times 10^{3}$	1400	. . . .	$6{\cdot}70 \times 10^{2}$	. . . .	. . . .
Ice	$9{\cdot}20 \times 10^{2}$	273	. . . .	$2{\cdot}10 \times 10^{3}$	$3{\cdot}34 \times 10^{5}$	. . . .
Glycerol	$1{\cdot}26 \times 10^{3}$	291	563	$2{\cdot}43 \times 10^{3}$	$1{\cdot}81 \times 10^{5}$	$8{\cdot}30 \times 10^{5}$
Methanol	$7{\cdot}91 \times 10^{2}$	175	338	$2{\cdot}52 \times 10^{3}$	$9{\cdot}9 \times 10^{4}$	$1{\cdot}12 \times 10^{6}$
Sea Water	$1{\cdot}02 \times 10^{3}$	264	377	$3{\cdot}93 \times 10^{3}$	. . . .	. . . .
Water	$1{\cdot}00 \times 10^{3}$	273	373	$4{\cdot}19 \times 10^{3}$	$3{\cdot}34 \times 10^{5}$	$2{\cdot}26 \times 10^{6}$
Air	1·29	. . . .	. . . .	. . . .	. . . .	. . . .
Hydrogen	$9{\cdot}0 \times 10^{-2}$	14	20	$1{\cdot}43 \times 10^{4}$	. . . .	$4{\cdot}50 \times 10^{5}$
Nitrogen	1·25	63	77	$1{\cdot}04 \times 10^{3}$	. . . .	$2{\cdot}00 \times 10^{5}$
Oxygen	1·43	55	90	$9{\cdot}18 \times 10^{2}$	. . . .	$2{\cdot}40 \times 10^{5}$

The gas densities refer to a temperature of 273 K and a pressure of $1{\cdot}01 \times 10^{5}$ Pa.

Marks

1. In a process called "spallation", protons are accelerated to relativistic speeds and collide with mercury nuclei. Each collision releases neutrons from a mercury nucleus as shown in Figure 1.

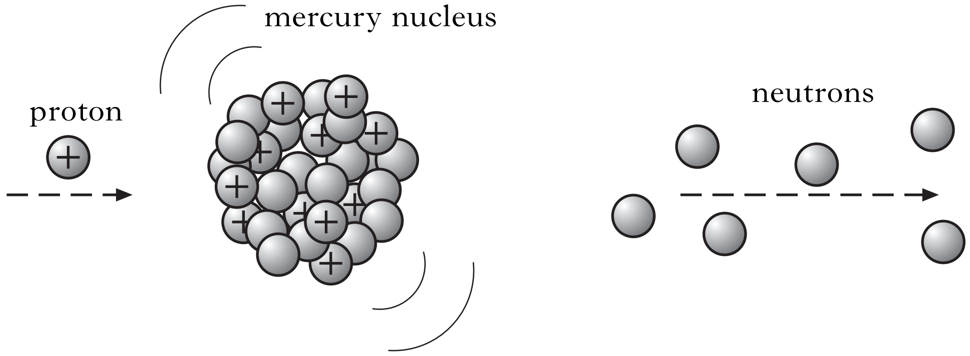

Figure 1

(*a*) (i) The energy of a proton is $2 \cdot 08 \times 10^{-10}$ J. Calculate the relativistic mass of this proton. **2**

(ii) Calculate the speed of this proton. **2**

(*b*) A neutron produced in the spallation process is slowed to a non-relativistic speed, resulting in a kinetic energy of $3 \cdot 15 \times 10^{-21}$ J.

(i) Show that the momentum of the neutron is $3 \cdot 25 \times 10^{-24}\,\mathrm{kg\,m\,s^{-1}}$. **2**

(ii) Calculate the de Broglie wavelength of this neutron. **2**

(*c*) In a mercury nucleus, protons experience electrostatic repulsion, yet the nucleus remains stable.

(i) Name the force responsible for this stability. **1**

(ii) Up to what distance is this force dominant? **1**

(iii) Name the fundamental particles that make up protons and neutrons. **1**

(11)

[Turn over

Marks

2. The front wheel of a racing bike can be considered to consist of 5 spokes and a rim, as shown in Figure 2A.

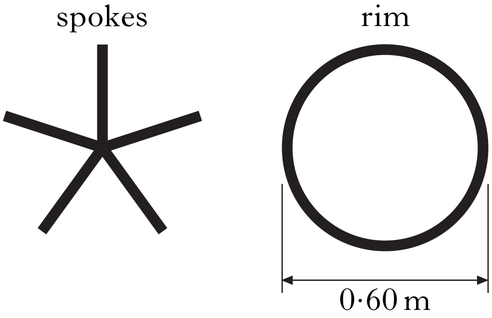

Figure 2A

The mass of each spoke is 0·040 kg and the mass of the rim is 0·24 kg. The wheel has a diameter of 0·60 m.

(*a*) (i) Each spoke can be considered as a uniform rod. Calculate the moment of inertia of a spoke as the wheel rotates. **2**

(ii) Show that the total moment of inertia of the wheel is $2{\cdot}8 \times 10^{-2}\,\text{kg m}^2$. **2**

(*b*) The wheel is placed in a test rig and rotated as shown in Figure 2B.

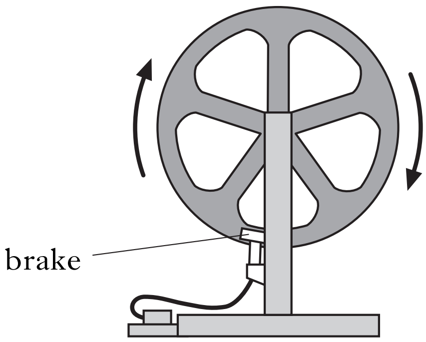

Figure 2B

(i) The tangential velocity of the rim is $19{\cdot}2\,\text{m s}^{-1}$. Calculate the angular velocity of the wheel. **2**

(ii) The brake is now applied to the rim of the wheel, bringing it uniformly to rest in 6·7 s.

(A) Calculate the angular acceleration of the wheel. **2**

(B) Calculate the torque acting on the wheel. **2**

(10)

Marks

3. An X-ray binary system consists of a star in a **circular** orbit around a black hole as shown in Figure 3A.

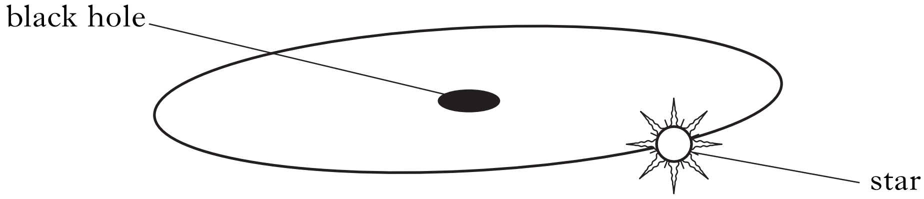

Figure 3A

The star has a mass of $2{\cdot}0 \times 10^{30}$ kg and takes 5·6 days to orbit the black hole. The orbital radius is $3{\cdot}6 \times 10^{10}$ m.

(*a*) Show that the angular velocity of the star is $1{\cdot}3 \times 10^{-5}$ rad s^{-1}. **1**

(*b*) Calculate the mass of the black hole. **3**

(*c*) (i) Show that the potential energy of the star in its orbit is $-4{\cdot}4 \times 10^{41}$ J. **1**

(ii) Calculate the kinetic energy of the star. **2**

(iii) Calculate the total energy of the star due to its motion and position. **1**

(*d*) The binary system orbits in the same plane as an earth-based telescope, as shown in Figure 3B.

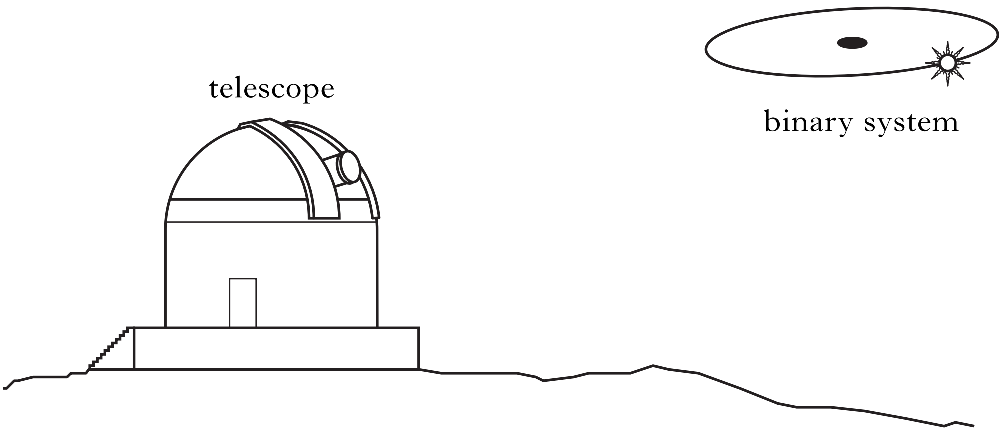

Figure 3B

Light from the star is analysed and found to contain the emission spectrum of hydrogen gas. The frequency of a particular line in the spectrum is monitored and a periodic variation in frequency is recorded.

Explain the periodic variation in the frequency. **2**

(10)

[Turn over

4. A design for electrical power generation consists of a large buoy that drives a water column through a turbine as shown in Figure 4.

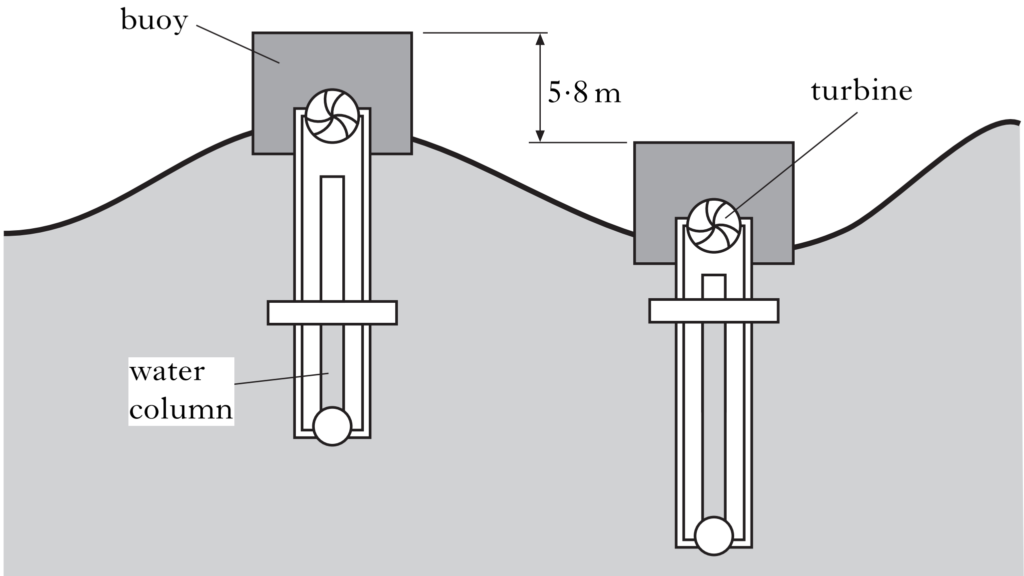

Figure 4

Energy is transferred from the wave motion to the turbines.

The mass of the buoy is $4 \cdot 0 \times 10^4$ kg and its vertical displacement is 5·8 m. The motion of the buoy can be considered to be simple harmonic with a period of oscillation of 5·7 s.

(*a*) Write an equation that describes the vertical displacement y of the buoy. Numerical values are required. **2**

(*b*) Calculate the maximum acceleration of the buoy. **2**

(*c*) Where in the motion is the resultant force on the buoy greatest? **1**

(*d*) Calculate the maximum kinetic energy of the buoy. **2**

(*e*) The water column acts to damp the oscillatory motion of the buoy. How does this affect:

(i) the period; **1**

(ii) the amplitude of the buoy's motion? **1**

(9)

[Turn over for Question 5 on *Page eight*

5. A helium-filled metal foil balloon with a radius of 0·35 m is charged by induction. The charge Q on the surface of the balloon is +120 μC. The balloon is considered to be perfectly spherical.

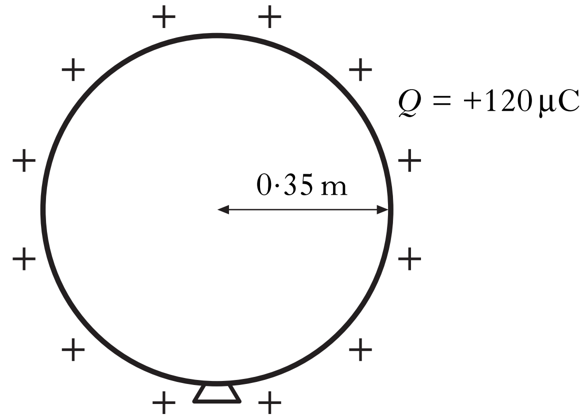

Figure 5A

(*a*) (i) Using diagrams, or otherwise, describe a procedure to charge the balloon by induction so that an evenly distributed positive charge is left on the balloon. **2**

(ii) Calculate the electric field strength at the surface of the balloon. **2**

(iii) Sketch a graph of the electric field strength against distance from the centre of the balloon to a point well beyond the balloon's surface. No numerical values are required. **1**

(*b*) Two parallel charged plates are separated by a distance d. The potential difference between the plates is V.

Lines representing the electric field between the plates are shown in Figure 5B.

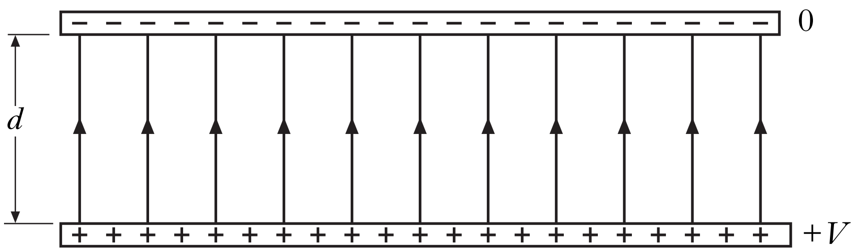

Figure 5B

(i) By considering the work done in moving a point charge q between the plates, derive an expression for the electric field strength E between the plates in terms of V and d. **2**

Marks

5. (*b*) (continued)

(ii) The base of a thundercloud is 489 m above an area of open flat ground as shown in Figure 5C.

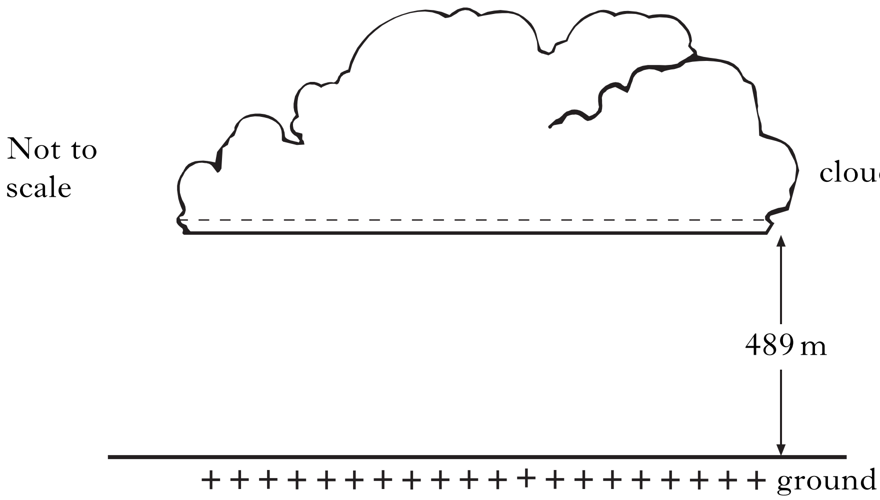

Figure 5C

The uniform electric field strength between the cloud and the ground is $7{\cdot}23 \times 10^4$ N C^{-1}.

Calculate the potential difference between the cloud and the ground. **1**

(iii) During a lightning strike a charge of 5·0 C passes between the cloud and the ground in a time of 348 μs. The strike has negligible effect on the potential of the cloud. Calculate the average power of the lightning strike. **2**

(*c*) An uncharged metal foil balloon is released and floats between the thundercloud and ground, as shown in Figure 5D.

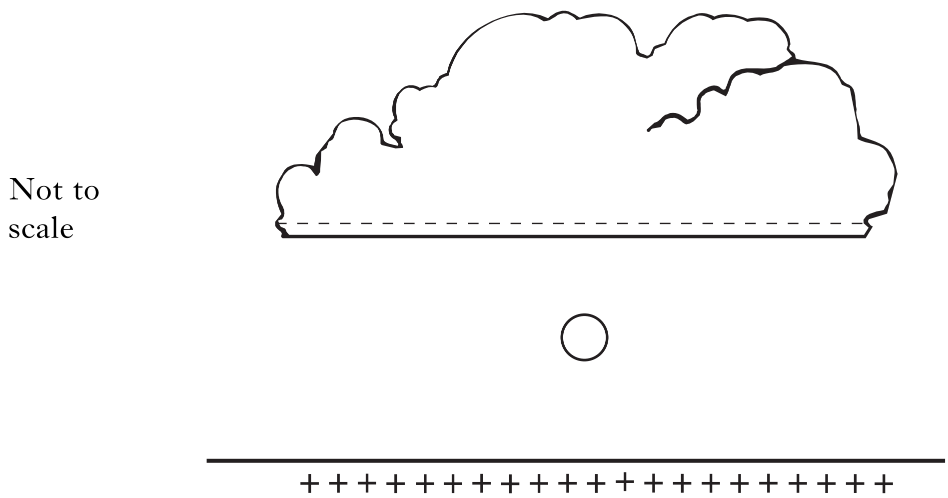

Figure 5D

Draw a diagram showing the charge distribution on the balloon and the resulting electric field around the balloon. **2**

(12)

6. Modern trains have safety systems to ensure that they stop before the end of the line. One system being tested uses a relay operated by a reed switch. The reed switch closes momentarily as it passes over a permanent magnet laid on the track. An inductor in the relay activates the safety system as shown in Figure 6A.

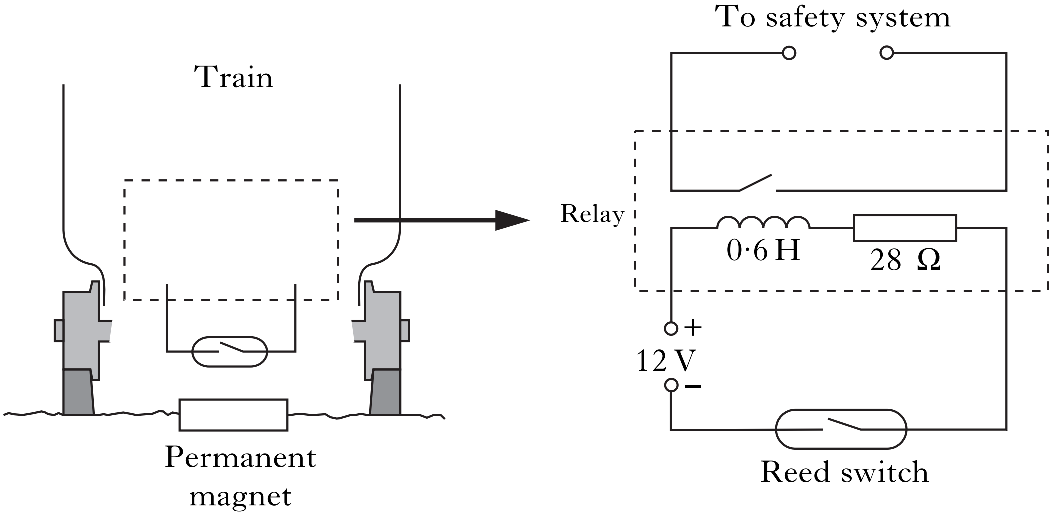

Figure 6A

(*a*) (i) Explain why there is a short time delay between the reed switch closing and the relay activating. **2**

(ii) The inductor is connected to a 12·0 V d.c. supply. The inductor has an inductance of 0·6 H and the total resistance of the circuit is 28 Ω. Calculate the initial rate of change of current as the reed switch is closed. **2**

(iii) The inductance of the inductor on the train is 0·6 H. Define one henry. **1**

(iv) The reed switch opens as it moves away from the permanent magnet. Explain why a spark occurs across the contacts of the reed switch. **2**

(v) A diode is placed across the inductor to prevent sparks across the reed switch as it opens as shown in Figure 6B. The diode must be chosen to carry the same current as the maximum current which occurs in the circuit when the reed switch closes. Calculate this current. **1**

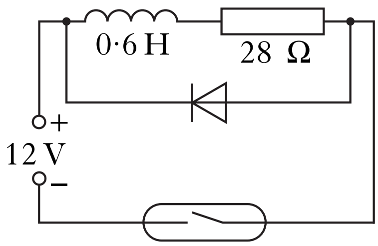

Figure 6B

6. (continued)

(*b*) Another safety system prevents trains approaching a stop signal at excessive speed. When a train is travelling too fast the brakes are applied automatically and the train is brought uniformly to rest. An inductor at the front of the train is used to determine the average speed as it travels between the electromagnets 1 and 2 as shown in Figure 6C.

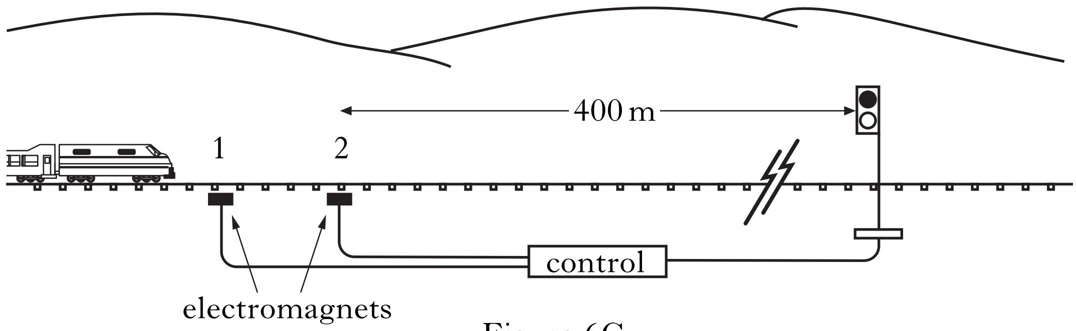

Figure 6C

The train travels between the electromagnets at a constant speed of $99\,\mathrm{km\,h^{-1}}$. The brakes are applied automatically as the train passes the second electromagnet. The train is accelerated at $-1{\cdot}0\,\mathrm{m\,s^{-2}}$. Show by calculation whether the train stops before the signal. **2**

(*c*) The train is stopped and a passenger hears a siren on another train approaching along a parallel track. The approaching train is travelling at a constant speed of $28{\cdot}0\,\mathrm{m\,s^{-1}}$ and the siren produces a sound of frequency 294 Hz.

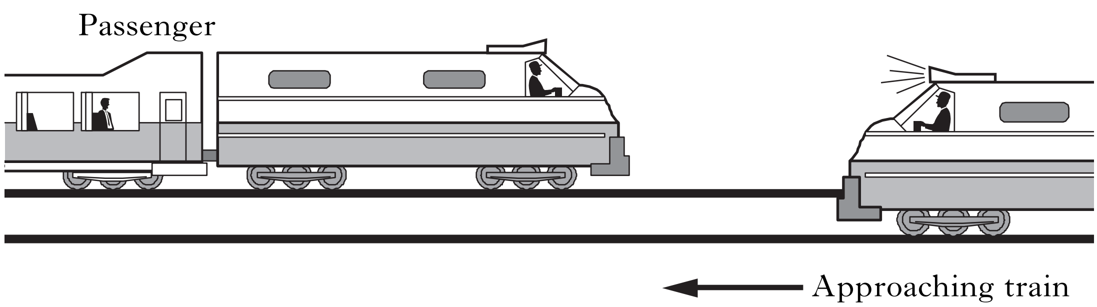

Figure 6D

(i) Show that the frequency *f* of the sound heard by the passenger is given by

$$f = f_s\left(\frac{v}{v - v_s}\right)$$

where symbols have their usual meaning. **2**

(ii) Calculate the frequency of the sound heard by the passenger:

(A) as the train approaches; **1**

(B) once the train has passed the passenger. **2**

(15)

Marks

7. (*a*) Two very long straight wires X and Y are suspended parallel to each other at a distance r apart. The current in X is I_1 and the current in Y is I_2 as shown in Figure 7A.

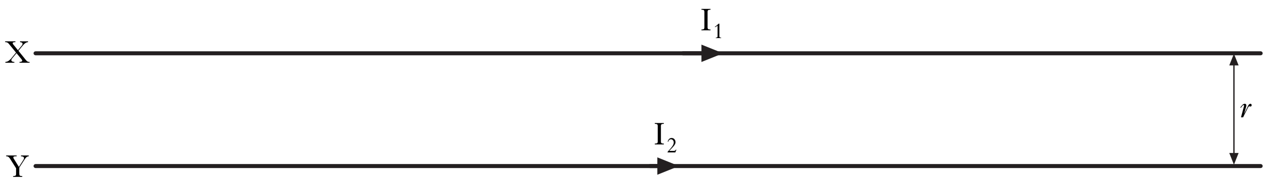

Figure 7A

(i) State the direction of the magnetic force acting on wire X. **Justify your answer**. **2**

(ii) The wires are separated by a distance of 360 mm and each wire carries a current of 4·7A. Calculate the force per unit length which acts on each wire. **2**

(*b*) A student investigating the force on a current carrying wire placed perpendicular to a uniform magnetic field obtains the following measurements and uncertainties.

Force (N)	0·0058 0·0061 0·0063 0·0057 0·0058 0·0062 Scale reading uncertainty ± 1 digit Calibration uncertainty ± 0·00005 N
Current (A)	Reading 1·98 A Absolute uncertainty ± 0·02 A
Length (m)	Reading 0·054 m Absolute uncertainty ± 0·0005 m

(i) From this data, calculate the magnetic induction, B. **3**

(ii) Calculate the absolute uncertainty in the value of the force. **3**

(iii) Calculate the overall absolute uncertainty in the value of the magnetic induction. **3**

(13)

Marks

8. (*a*) Figure 8A shows a current carrying wire of length l, perpendicular to a magnetic field B. A single charge $-q$ moves with constant velocity v in the wire. Using the relationship for the force on a current carrying conductor placed in a magnetic field, derive the relationship $F = qvB$ for the magnitude of the force acting on charge q. **2**

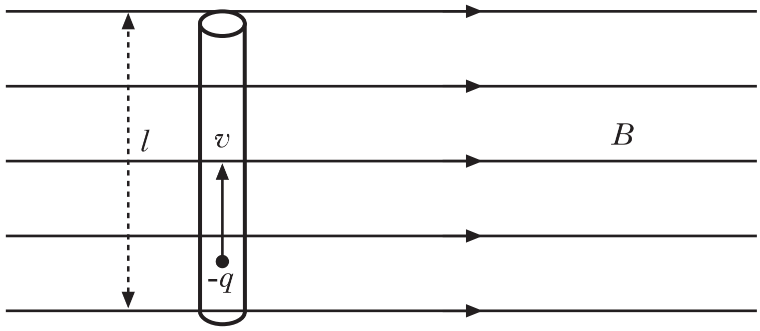

Figure 8A

(*b*) An electron with a speed of $2{\cdot}0 \times 10^6\,\mathrm{m\,s^{-1}}$ enters a uniform magnetic field at an angle θ. The electron follows a helical path as shown in Figure 8B.

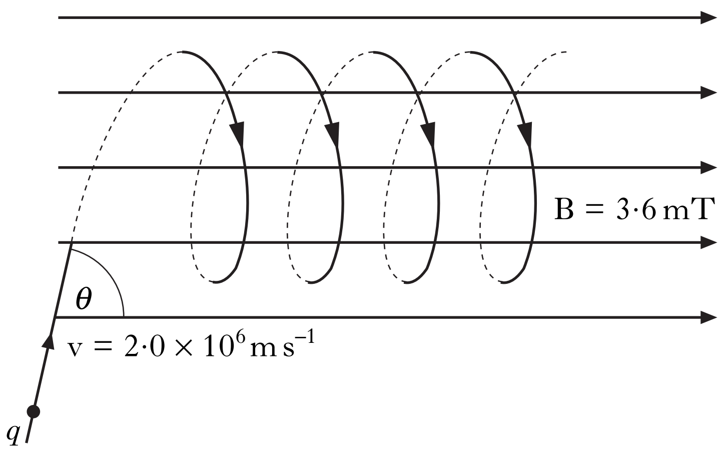

Figure 8B

The uniform magnetic induction is $3{\cdot}6\,\mathrm{mT}$ and the radius of the helical path is $2{\cdot}8\,\mathrm{mm}$. Calculate the value of angle θ. **3**

(*c*) A second electron travelling at the same speed enters the field at a smaller angle θ.

Describe how the path of the second electron differs from the first. **2**

(7)

[Turn over

9. A laser-based quality control system to measure thread spacing in fabric samples is being evaluated. The 2-dimensional interference pattern is displayed on a screen shown in Figure 9A.

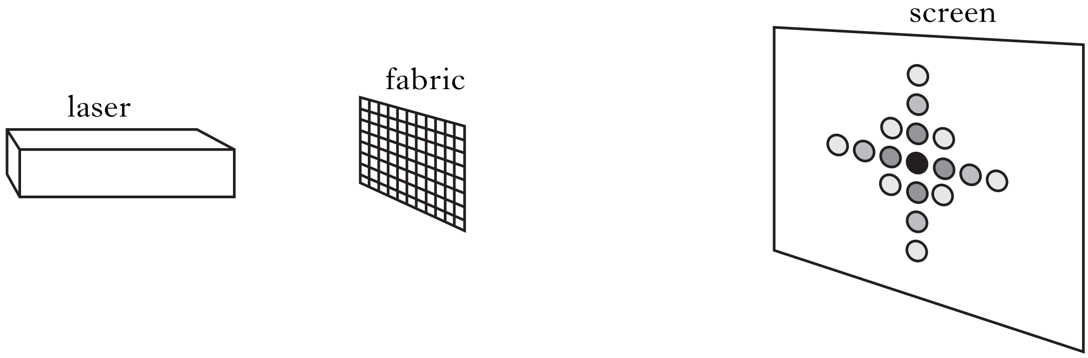

Figure 9A

(*a*) Explain how this 2-D interference pattern is produced. **2**

(*b*) When a fine beam of laser light of wavelength 488 nm is used, the separation of the maxima in the horizontal direction is 8·00 mm. The distance from the fabric sample to the screen is 3·60 m.

Assume the spaces between the threads act like Young's slits.

Calculate the spacing between the threads in the sample. **2**

9. (continued)

(*c*) The interference pattern from a standard fabric sample using a 488 nm laser is shown in Figure 9B.

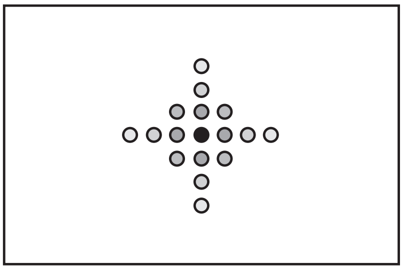

Figure 9B

(i) The 488 nm laser is replaced with a 667 nm laser. Which interference pattern from Figure 9C best represents the new interference pattern? Justify your answer. **2**

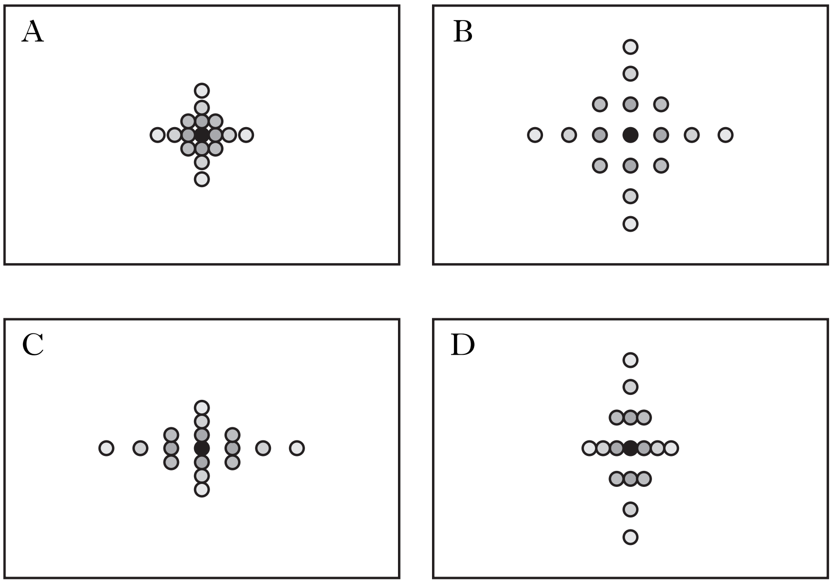

Figure 9C

(ii) The **original** 488 nm laser is restored and the fabric sample is stretched as shown in Figure 9D.

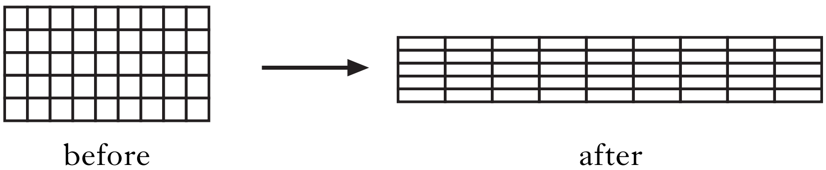

Figure 9D

Which pattern from Figure 9C best represents the new pattern? Justify your answer. **2**

(8)

10. A stretched wire, supported near its ends, is made to vibrate by touching a tuning fork of unknown frequency to the supporting surface. One of the supports is moved until a stationary wave pattern appears as shown in Figure 10A.

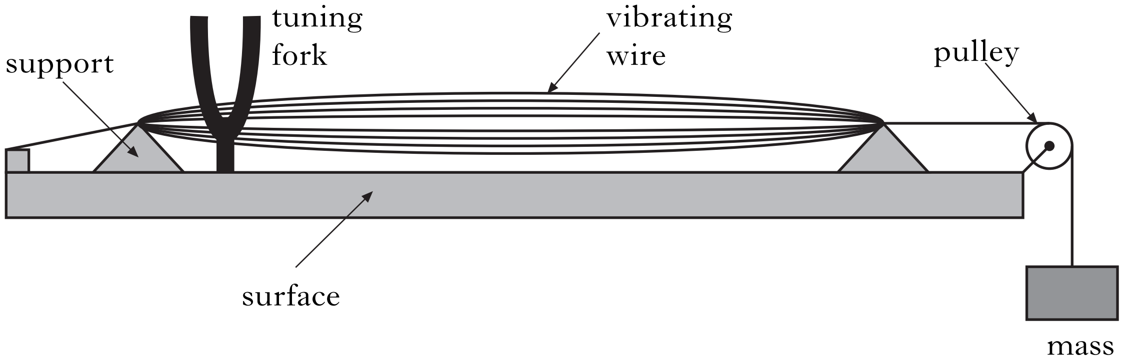

Figure 10A

(*a*) Explain how waves on this wire produce a stationary wave pattern. **2**

(*b*) The formula for the frequency of the note from a stretched wire is given by:

$$f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$$

where l is the distance between the supports,
T is the stretching force,
μ is the mass per unit length of the wire.

The results of the experiment are given below:

mass per unit length of wire $= 1{\cdot}92 \times 10^{-4}\,\text{kg m}^{-1}$
distance between the supports $= 0{\cdot}780\,\text{m}$
mass of load on wire $= 4{\cdot}02\,\text{kg}$

(i) The table below gives information about the note produced by tuning forks of different frequency. Identify the note most likely to correspond to the tuning fork used in the experiment. **2**

Note	A	B	C	D	E	F	G
Frequency (Hz)	220	245	262	294	330	349	392

Marks

10. (*b*) (continued)

(ii) A second tuning fork produces the pattern shown in Figure 10B. Suggest a frequency for this tuning fork. **1**

(5)

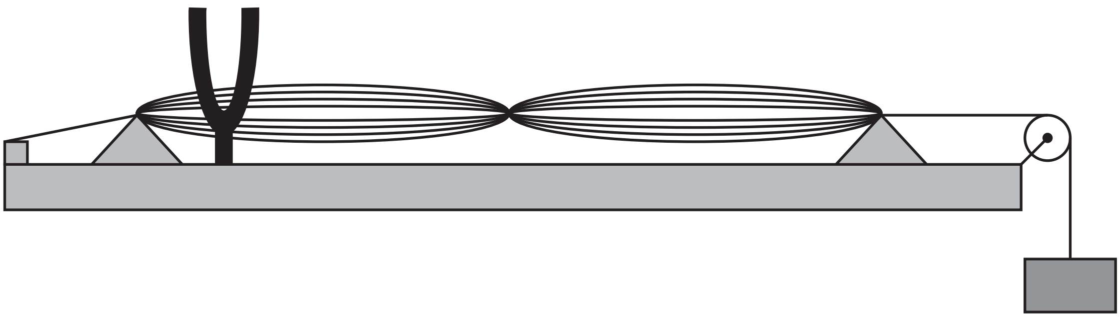

Figure 10B

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