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PHYSICS
HIGHER LEVEL
PAPER 2

Candidate session number

Wednesday 7 May 2014 (morning)

2 hours 15 minutes

Examination code

2	2	1	4	–	6	5	0	8

INSTRUCTIONS TO CANDIDATES

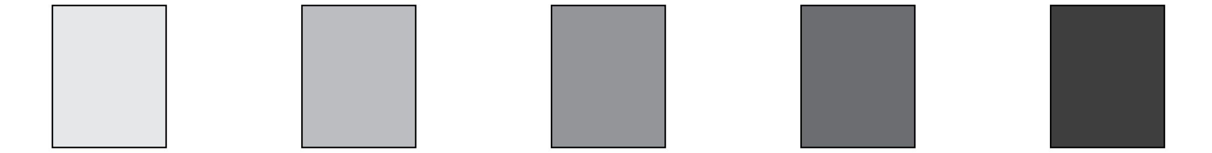
- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all questions.
- Section B: answer two questions.
- Write your answers in the boxes provided.
- A calculator is required for this paper.
- A clean copy of the ***Physics*** *Data Booklet* is required for this paper.
- The maximum mark for this examination paper is *[95 marks]*.

SECTION A

*Answer **all** questions. Write your answers in the boxes provided.*

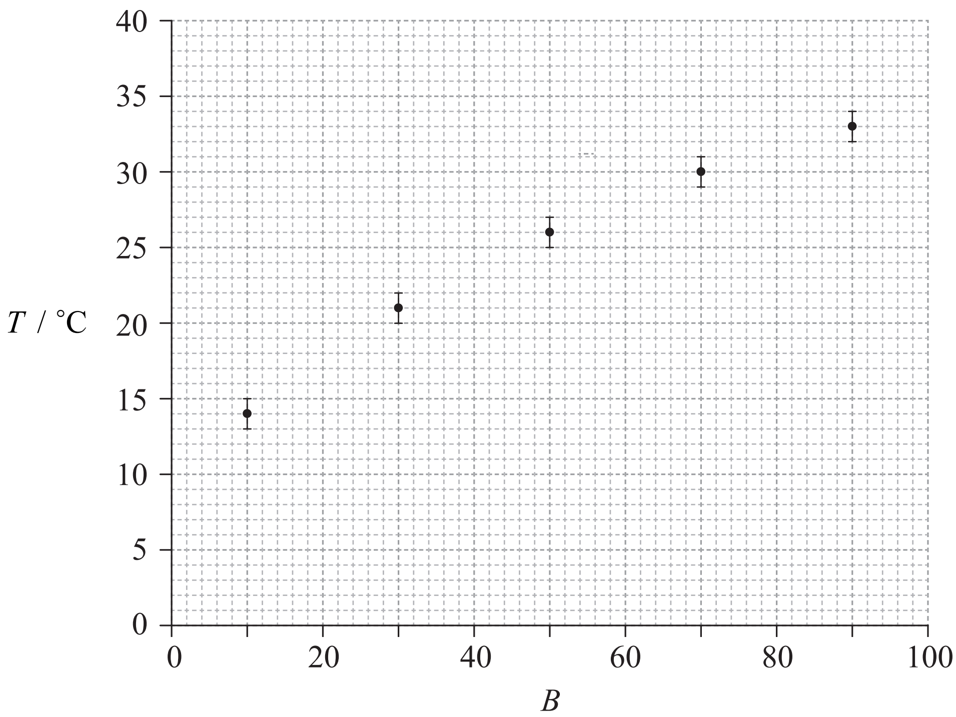
1. Data analysis question.

Connie and Sophie investigate the effect of colour on heat absorption. They make grey paint by mixing black and white paint in different ratios. Five identical tin cans are painted in five different shades of grey.



Connie and Sophie put an equal amount of water at the same initial temperature into each can. They leave the cans under a heat lamp at equal distances from the lamp. They measure the temperature increase of the water, T, in each can after one hour.

(a) Connie suggests that T is proportional to B, where B is the percentage of black in the paint. To test this hypothesis, she plots a graph of T against B, as shown on the axes below. The uncertainty in T is shown and the uncertainty in B is negligible.



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(Question 1 continued)

(i) State the value of the absolute uncertainty in T. *[1]*

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(ii) Comment on the fractional uncertainty for the measurement of T for $B = 10$ and the measurement of T for $B = 90$. *[2]*

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(iii) On the graph opposite, draw a best-fit line for the data. *[1]*

(iv) Outline why the data do not support the hypothesis that T is proportional to B. *[2]*

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(This question continues on the following page)

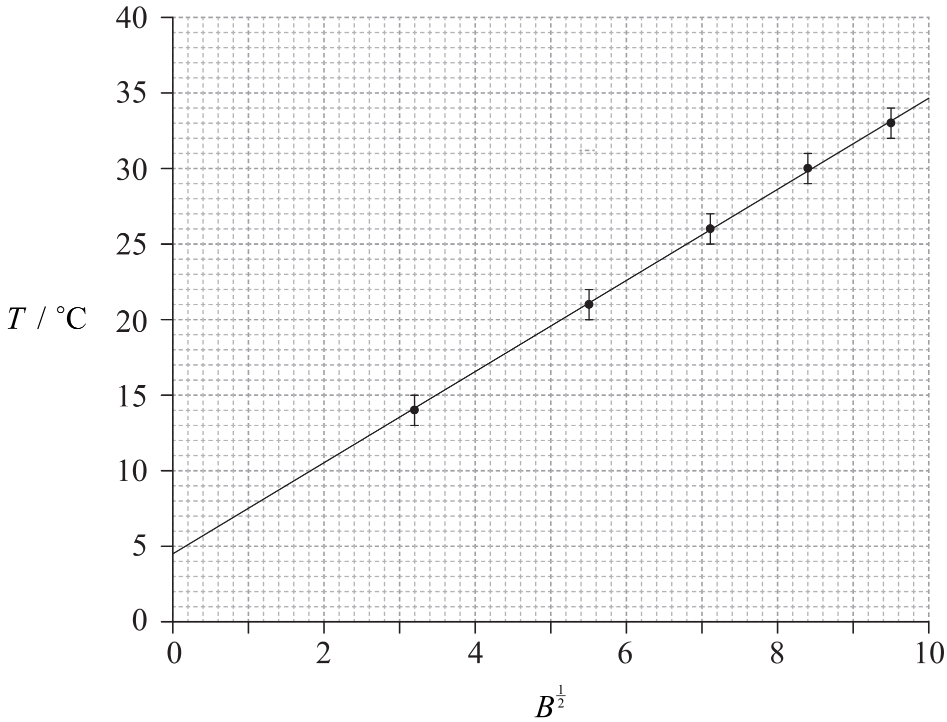
(Question 1 continued)

(b) Sophie suggests that the relationship between T and B is of the form

$$T = kB^{\frac{1}{2}} + c$$

where k and c are constants.

To test whether or not the data support this relationship, a graph of T against $B^{\frac{1}{2}}$ is plotted as shown below. The uncertainty in T is shown and the uncertainty in $B^{\frac{1}{2}}$ is negligible.



(i) Use the graph to determine the value of c with its uncertainty. *[4]*

(This question continues on the following page)

(Question 1 continued)

(ii) State the unit of k. *[1]*

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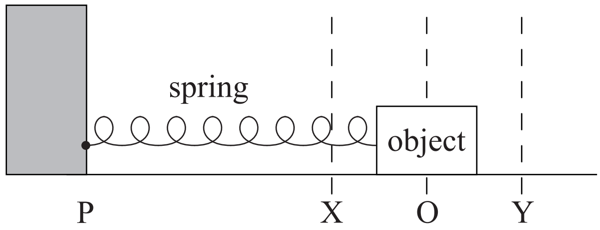
2. This question is about a mass on a spring.

An object is placed on a frictionless surface and attached to a light horizontal spring.



The other end of the spring is attached to a stationary point P. Air resistance is negligible. The equilibrium position is at O. The object is moved to position Y and released.

(a) Outline the conditions necessary for the object to execute simple harmonic motion. *[2]*

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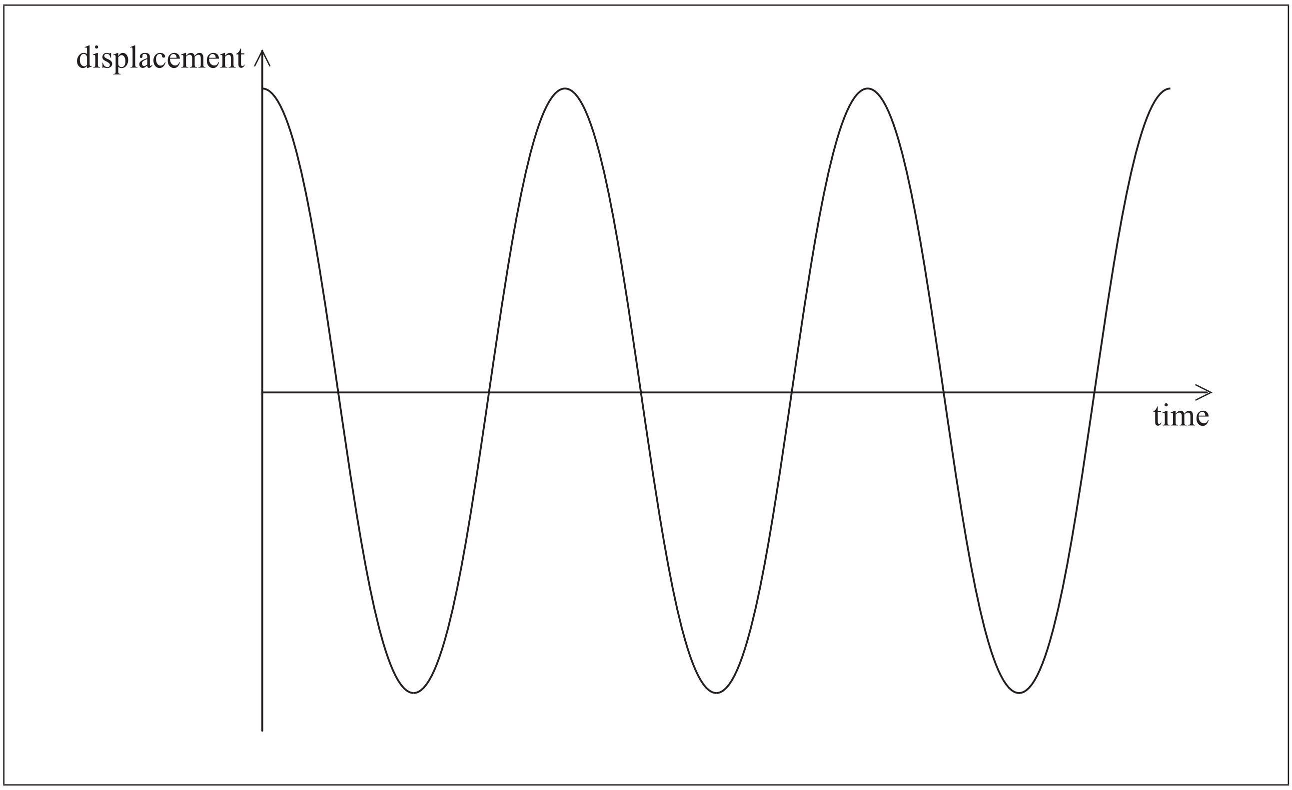
(Question 2 continued)

(b) The sketch graph below shows how the displacement of the object from point O varies with time over three time periods.



(i) Label with the letter A a point at which the magnitude of the acceleration of the object is a maximum. *[1]*

(ii) Label with the letter V a point at which the speed of the object is a maximum. *[1]*

(iii) Sketch on the same axes a graph of how the displacement varies with time if a **small** frictional force acts on the object. *[2]*

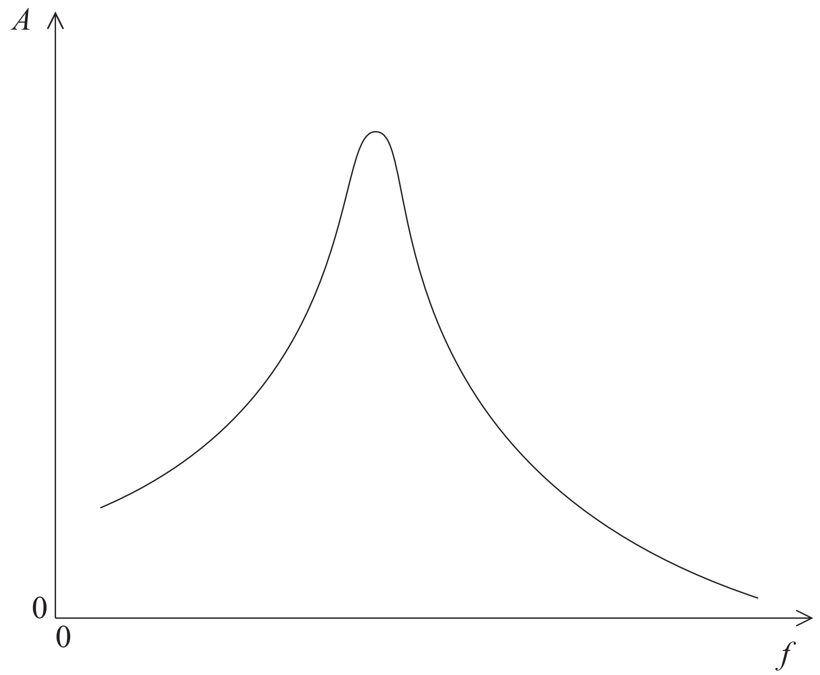
(This question continues on the following page)

(Question 2 continued)

(c) Point P now begins to move from side to side with a small amplitude and at a variable driving frequency *f*. The frictional force is still small.

At each value of *f*, the object eventually reaches a constant amplitude *A*.

The graph shows the variation with *f* of *A*.



(i) With reference to resonance and resonant frequency, comment on the shape of the graph. *[2]*

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(ii) On the same axes, draw a graph to show the variation with *f* of *A* when the frictional force acting on the object is increased. *[2]*

(Section A continues on page 10)

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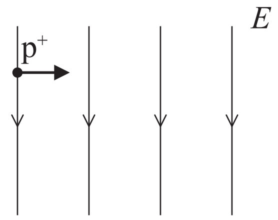
Answers written on this page
will not be marked.

(Section A continued from page 8)

3. This question is about electric and magnetic fields.

A proton travelling to the right with horizontal speed $1.6\times10^{4}\,\text{m}\,\text{s}^{-1}$ enters a uniform electric field of strength E. The electric field has magnitude $2.0\times10^{3}\,\text{N}\,\text{C}^{-1}$ and is directed downwards.



(a) Calculate the magnitude of the electric force acting on the proton when it is in the electric field. *[2]*

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(b) A uniform magnetic field is applied in the same region as the electric field. A second proton enters the field region with the same velocity as the proton in (a). This second proton continues to move horizontally.

(i) Determine the magnitude and direction of the magnetic field. *[3]*

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(This question continues on the following page)

(Question 3 continued)

(ii) An alpha particle enters the field region at the same point as the second proton, moving with the same velocity. Explain whether or not the alpha particle will move in a straight line. *[2]*

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4. This question is about sound.

A source emits sound of frequency f. The source is moving towards a stationary observer at constant speed. The observer measures the frequency of the sound to be f'.

(a) (i) Explain, using a diagram, why f' is greater than f. *[3]*

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(ii) The frequency f is 275 Hz. The source is moving at speed 20.0 m s^{-1}. The speed of sound in air is 330 m s^{-1}. Calculate the observed frequency f' of the sound. *[2]*

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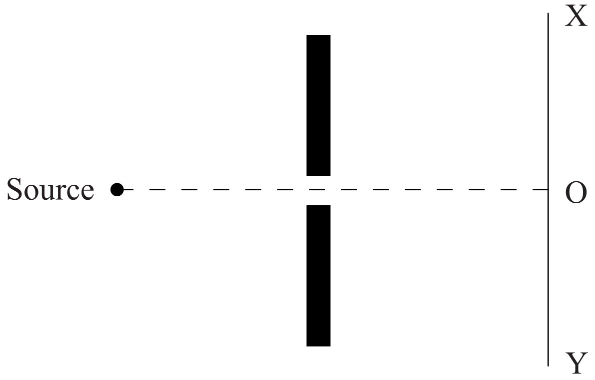
(This question continues on the following page)

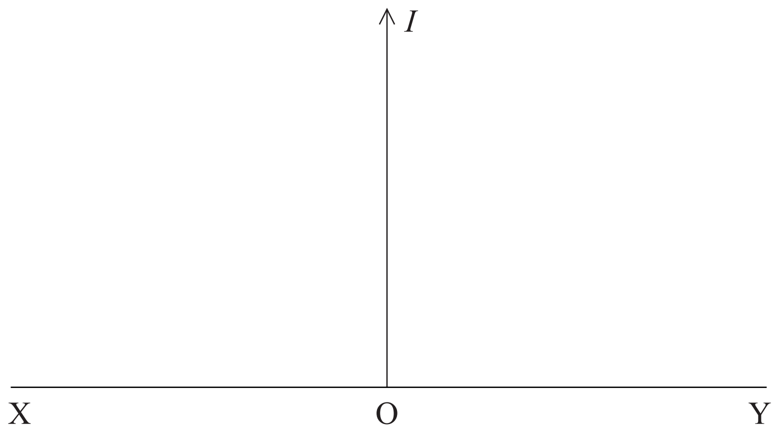
(Question 4 continued)

(b) The source is placed in front of a barrier that has an opening of width comparable to the wavelength of the sound.



A sound detector is moved along the line XY. The centre of XY is marked O.

(i) On the axes below, sketch a graph to show how the intensity I of the sound varies as the detector moves from X to Y. *[3]*



(ii) State the effect on the intensity pattern of increasing the wavelength of the sound. *[1]*

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(This question continues on the following page)

(Question 4 continued)

(c) (i) Outline the difference between a polarized wave and an unpolarized wave. *[2]*

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(ii) State why sound waves cannot be polarized. *[1]*

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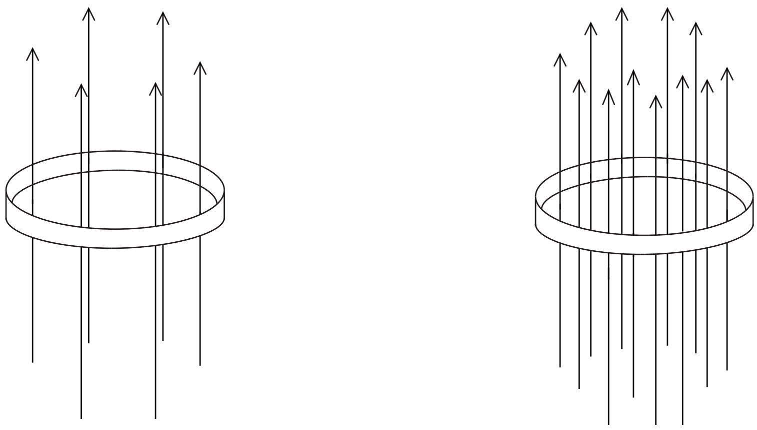
5. This question is about electromagnetic induction.

A metal ring is placed in a magnetic field which is directed upwards. The magnetic flux through the ring increases over a time interval.



(a) State and explain the direction of the current induced in the ring during this change. *[3]*

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(b) The following data are available.

Resistance of ring	$= 3.0\times10^{-3}\,\Omega$
Initial magnetic flux	$= 1.2\times10^{-5}\,\text{Wb}$
Final magnetic flux	$= 2.4\times10^{-5}\,\text{Wb}$
Time interval	$= 2.0\times10^{-3}\,\text{s}$

Calculate the average current induced in the ring. *[2]*

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SECTION B

*This section consists of four questions: 6, 7, 8 and 9. Answer **two** questions. Write your answers in the boxes provided.*

6. This question is in **two** parts. **Part 1** is about solar radiation and the greenhouse effect. **Part 2** is about orbital motion.

Part 1 Solar radiation and the greenhouse effect

The following data are available.

Quantity	**Symbol**	**Value**
Radius of Sun	R	$7.0 \times 10^{8}\,\text{m}$
Surface temperature of Sun	T	$5.8 \times 10^{3}\,\text{K}$
Distance from Sun to Earth	d	$1.5 \times 10^{11}\,\text{m}$
Stefan-Boltzmann constant	σ	$5.7 \times 10^{-8}\,\text{W}\,\text{m}^{-2}\,\text{K}^{-4}$

(a) State the Stefan-Boltzmann law for a black body. *[2]*

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(b) Deduce that the solar power incident per unit area at distance d from the Sun is given by

$$\frac{\sigma R^2 T^4}{d^2}.$$ *[2]*

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(Question 6, part 1 continued)

(c) Calculate, using the data given, the solar power incident per unit area at distance *d* from the Sun. *[2]*

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(d) State **two** reasons why the solar power incident per unit area at a point on the surface of the Earth is likely to be different from your answer in (c). *[2]*

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2: . . . .

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(e) The average power absorbed per unit area at the Earth's surface is $240\,W\,m^{-2}$. By treating the Earth's surface as a black body, show that the average surface temperature of the Earth is approximately 250 K. *[2]*

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(This question continues on the following page)

(Question 6, part 1 continued)

(f) Explain why the actual surface temperature of the Earth is greater than the value in (e). *[3]*

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(g) Outline why the burning of fossil fuels may lead to an increase in the average surface temperature of the Earth. *[2]*

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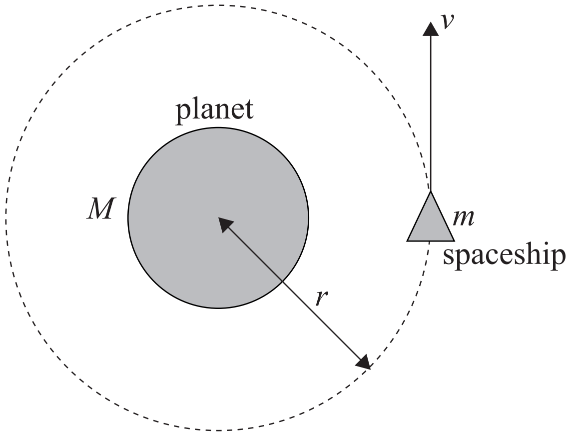
(Question 6 continued)

Part 2 Orbital motion

A spaceship of mass m is moving at speed v in a circular orbit of radius r around a planet of mass M.



(not to scale)

(h) (i) Identify the force that causes the centripetal acceleration of the spaceship. *[1]*

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(ii) Explain why astronauts inside the spaceship would feel "weightless", even though there is a force acting on them. *[3]*

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(Question 6, part 2 continued)

(i) Deduce that the speed of the spaceship is $v = \sqrt{\frac{GM}{r}}$. *[2]*

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(This question continues on the following page)

(Question 6, part 2 continued)

(j) The table gives equations for the forms of energy of the orbiting spaceship.

Form of Energy	Equation
Kinetic	$E_K = \frac{GMm}{2r}$
Gravitational potential	$E_P = -\frac{GMm}{r}$
Total (kinetic + potential)	$E = -\frac{GMm}{2r}$

The spaceship passes through a cloud of gas, so that a small frictional force acts on the spaceship.

(i) State and explain the effect that this force has on the total energy of the spaceship. *[2]*

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(ii) Outline the effect that this force has on the speed of the spaceship. *[2]*

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7. This question is in **two** parts. **Part 1** is about nuclear reactions. **Part 2** is about a heat engine.

Part 1 Nuclear reactions

(a) (i) Define the term *unified atomic mass unit*. *[1]*

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(ii) The mass of a nucleus of einsteinium-255 is 255.09 u. Calculate the mass in $MeV\,c^{-2}$. *[1]*

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(b) Describe the phenomenon of artificial (induced) transmutation. *[2]*

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(c) When particle X collides with a stationary nucleus of calcium-40 (Ca-40), a nucleus of potassium (K-40) and a proton are produced.

$$^{40}_{20}\mathrm{Ca} + \mathrm{X} \rightarrow {}^{40}_{19}\mathrm{K} + {}^{1}_{1}\mathrm{p}$$

(This question continues on the following page)

(Question 7, part 1 continued)

The following data are available for the reaction.

Particle	Rest mass / $MeV\,c^{-2}$
calcium-40	37214.694
X	939.565
potassium-40	37216.560
proton	938.272

(i) Identify particle X. *[1]*

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(ii) Suggest why this reaction can only occur if the initial kinetic energy of particle X is greater than a minimum value. *[2]*

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(iii) Before the reaction occurs, particle X has kinetic energy 8.326 MeV. Determine the total combined kinetic energy of the potassium nucleus and the proton. *[3]*

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(This question continues on the following page)

(Question 7, part 1 continued)

(d) Another isotope of potassium is potassium-38, which decays with a half-life of eight minutes.

(i) Define the term *radioactive half-life*. *[1]*

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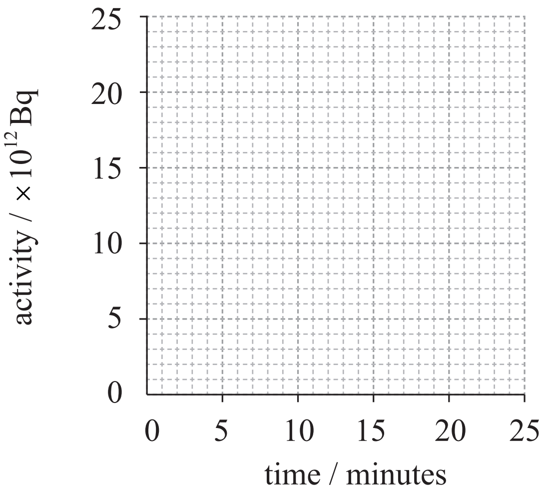
(ii) A sample of potassium-38 has an initial activity of 24×10^{12} Bq. On the axes below, draw a graph to show the variation with time of the activity of the sample. *[2]*



(iii) Determine the activity of the sample after 2 hours. *[2]*

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(This question continues on page 26)

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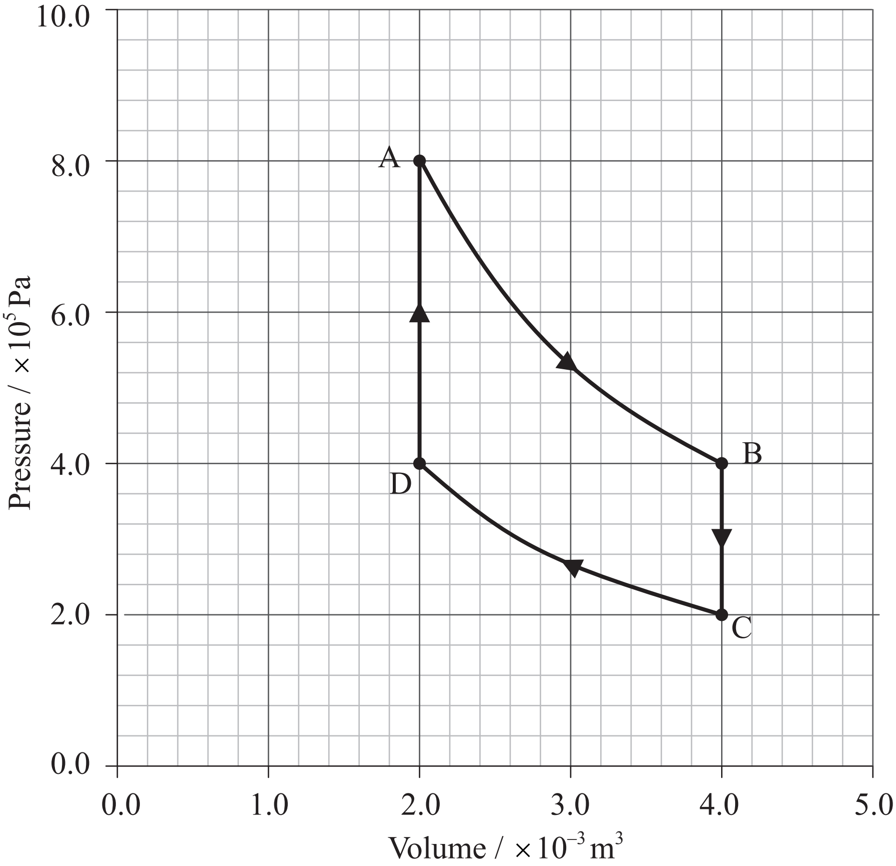
will not be marked.

(Question 7 continued)

Part 2 A heat engine

The piston of an engine contains a fixed mass of an ideal gas. During one cycle of the engine, the gas undergoes the thermodynamic processes shown below.



(e) (i) State what is meant by an isothermal process. *[1]*

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(This question continues on the following page)

(Question 7, part 2 continued)

(ii) Show that process AB is isothermal. *[3]*

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(f) State the nature of process BC. *[1]*

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(g) During the cycle ABCD, the net work done by the gas is 550 J. Calculate the net thermal energy absorbed by the gas. *[2]*

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(Question 7, part 2 continued)

(h) Explain why it is not possible for this engine, operating in this cycle, to be 100 % efficient. *[3]*

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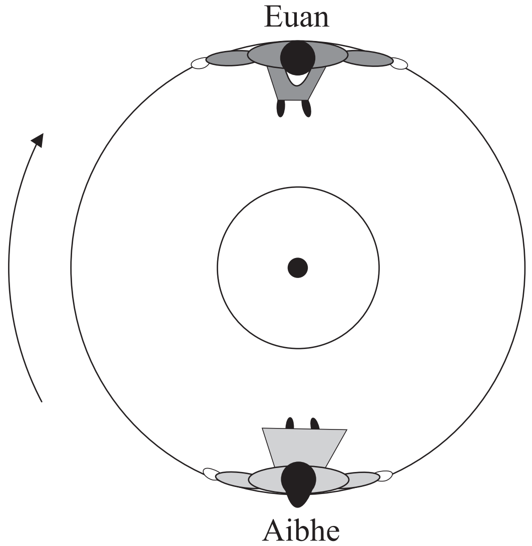
8. This question is in **two** parts. **Part 1** is about two children on a merry-go-round. **Part 2** is about charge-coupled devices (CCDs).

Part 1 Two children on a merry-go-round

Aibhe and Euan are sitting on opposite sides of a merry-go-round, which is rotating at constant speed around a fixed centre. The diagram below shows the view from above.



Aibhe is moving at speed $1.0\,m\,s^{-1}$ relative to the ground.

(a) Determine the magnitude of the velocity of Aibhe relative to

(i) Euan. *[1]*

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(ii) the centre of the merry-go-round. *[1]*

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(This question continues on the following page)

(Question 8, part 1 continued)

(b) (i) Outline why Aibhe is accelerating even though she is moving at constant speed. *[2]*

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(ii) Draw an arrow on the diagram on page 29 to show the direction in which Aibhe is accelerating. *[1]*

(iii) Identify the force that is causing Aibhe to move in a circle. *[1]*

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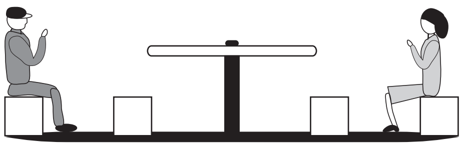
(iv) The diagram below shows a side view of Aibhe and Euan on the merry-go-round.



Explain why Aibhe feels as if her upper body is being "thrown outwards", away from the centre of the merry-go-round. *[2]*

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(Question 8, part 1 continued)

(c) Euan drags his foot along the ground to act as a brake. The merry-go-round comes to a stop after 4.0 rotations. The radius of the merry-go-round is 1.5 m. The average frictional force between his foot and the ground is 45 N. Calculate the work done. *[2]*

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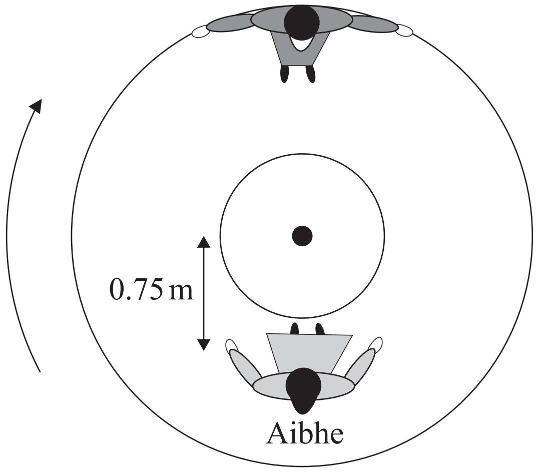
(Question 8, part 1 continued)

(d) Aibhe moves so that she is sitting at a distance of 0.75 m from the centre of the merry-go-round, as shown below.



Euan pushes the merry-go-round so that he is again moving at 1.0 m s^{-1} relative to the ground.

(i) Determine Aibhe's speed relative to the ground. *[3]*

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(ii) Calculate the magnitude of Aibhe's acceleration. *[2]*

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(This question continues on the following page)

(Question 8 continued)

Part 2 Charge-coupled devices (CCDs)

(e) Outline how light incident on a pixel of a CCD causes a potential difference to be developed across the pixel. *[3]*

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(f) Light of frequency 4.4×10^{14} Hz and intensity $1.4\,\text{mW m}^{-2}$ is incident on a pixel for a time of 42 ms. The area of the pixel is $4.0\times10^{-10}\,\text{m}^2$ and its capacitance is 16 pF. The quantum efficiency of the pixel is 60 %.

(i) Show that the number of photons incident on the pixel is about 8.1×10^4. *[2]*

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(This question continues on the following page)

(Question 8, part 2 continued)

(ii) Determine the potential difference developed across the pixel. *[3]*

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(g) A digital camera containing a CCD is used to take a photograph of an object. With reference to the intensity of light falling on each pixel of the CCD, outline how the image is retrieved and displayed on a screen. *[2]*

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9. This question is in **three** parts. **Part 1** is about thermal energy transfer. **Part 2** is about electric circuits. **Part 3** is about the photoelectric effect and the Heisenberg uncertainty principle.

Part 1 Thermal energy transfer

(a) Define the *specific latent heat* of fusion of a substance. *[2]*

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(b) A piece of ice is placed into a beaker of water and melts completely.

The following data are available.

Initial mass of ice	$= 0.020\,\text{kg}$
Initial mass of water	$= 0.25\,\text{kg}$
Initial temperature of ice	$= 0\,^\circ\text{C}$
Initial temperature of water	$= 80\,^\circ\text{C}$
Specific latent heat of fusion of ice	$= 3.3 \times 10^{5}\,\text{J}\,\text{kg}^{-1}$
Specific heat capacity of water	$= 4200\,\text{J}\,\text{kg}^{-1}\,\text{K}^{-1}$

(i) Determine the final temperature of the water. *[3]*

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(This question continues on the following page)

(Question 9, part 1 continued)

(ii) State **two** assumptions that you made in your answer to part (b)(i). *[2]*

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(This question continues on the following page)

(Question 9 continued)

Part 2 Electric circuits

(c) Define the *electric resistance* of a wire. *[1]*

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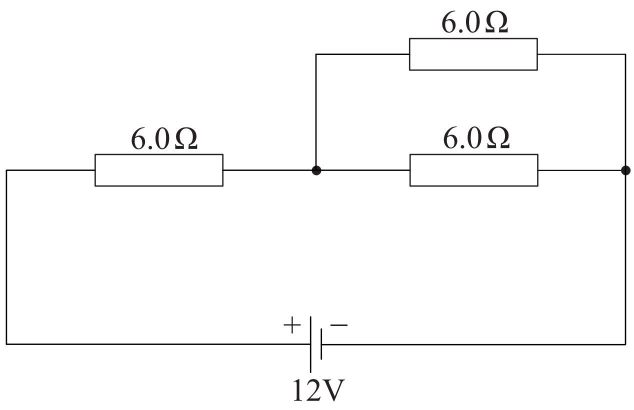
(d) Three resistors, each of resistance 6.0 Ω, are arranged in the circuit shown below. The cell has an emf of 12 V and negligible internal resistance.



Determine the total power supplied by the cell. *[3]*

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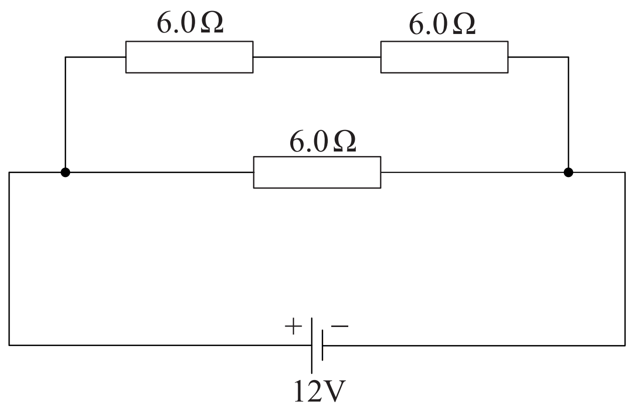
(Question 9, part 2 continued)

(e) The same resistors and cell are now re-arranged into a different circuit, as shown below.



Explain why the total power supplied by the cell is greater than for the circuit in (d). *[3]*

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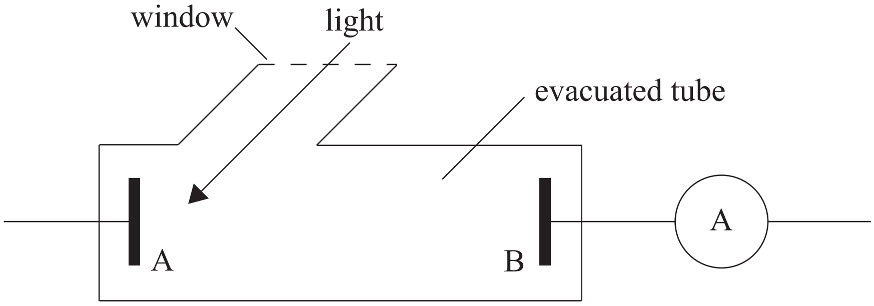
(This question continues on the following page)

(Question 9 continued)

Part 3 The photoelectric effect and the Heisenberg uncertainty principle

(f) Light is incident on a metal surface A. A potential difference is applied between A and an electrode B. Photoelectrons arrive at B and the resulting current is measured by a sensitive ammeter. (Note: the complete electrical circuit is not shown.)



(i) The frequency of the light is reduced until the current measured by the ammeter falls to zero. Explain how Einstein's photoelectric theory accounts for this observation. *[4]*

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(This question continues on the following page)

(Question 9, part 3 continued)

(ii) A different metal surface is used so that a current is again measured. Outline the effect on the photoelectric current when the intensity of the light is doubled and the frequency remains constant. *[2]*

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(g) A photon of energy 6.6×10^{-19} J is incident upon a clean sodium surface. The work function of sodium is 3.7×10^{-19} J. The photon causes an electron to be emitted from the surface with the maximum possible kinetic energy. The position of this electron is measured with an uncertainty of 5.0×10^{-9} m.

Calculate the

(i) momentum of the electron. *[3]*

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(ii) uncertainty in the momentum of the electron. *[2]*

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