Unit 4 Topic 1 Further mechanics

1 A radium nucleus mass 226 which can be regarded as stationary emits an alpha particle mass 4.

The ratio: $\dfrac{\text{speed of alpha particle}}{\text{speed of resulting nucleus}}$ is given by

☐ **A** $\frac{4}{222}$

☐ **B** $\frac{226}{4}$

☐ **C** $\frac{222}{4}$

☐ **D** $\frac{222}{226}$

(Total 1 mark)

2 A bullet of mass 5.0 g is fired into a target of mass 100 g, which is initially at rest, and freely suspended. The bullet is fired with a speed of 200 m s^{-1} and does not emerge from the target. The velocity, in m s^{-1}, of the target immediately after being hit by the bullet is

☐ **A** 1.9

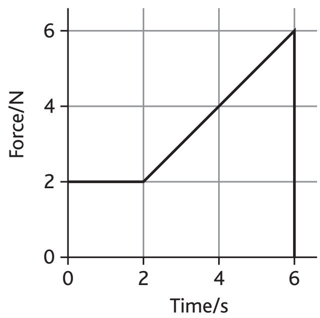
☐ **B** 9.5

☐ **C** 10.0

☐ **D** 20.0

(Total 1 mark)

3 What is the momentum, in kg m s^{-1}, gained by a body acted on by a force which varies as shown in the graph



☐ **A** 6

☐ **B** 20

☐ **C** 24

☐ **D** 36

(Total 1 mark)

Unit 4 Topic 1 Further mechanics (cont.)

4 An object is moving in circular motion with a constant speed. It completes N revolutions of radius r per second. The acceleration is

- [ ] **A** $2\pi rN$
- [ ] **B** $2\pi rN^2$
- [ ] **C** $4\pi^2 rN^2$
- [ ] **D** $4\pi^2 r^2 N^2$

(Total 1 mark)

5 An object of mass m is placed on a rotating turntable at a distance r from the centre. The maximum frictional force between the object and the table is $mg/4$. The angular velocity of the table is steadily increased. The object will begin to slide when the angular velocity of the table is

- [ ] **A** $\sqrt{\frac{g}{4r}}$
- [ ] **B** $\sqrt{\frac{mg}{4r}}$
- [ ] **C** $\frac{gr}{4}$
- [ ] **D** $\sqrt{\frac{mgr}{4}}$

(Total 1 mark)

Unit 4 Topic 2 Electric and magnetic fields

1 The attractive force between two point charges, separated by a distance d, is F. The separation is increased to $4d$. The force between the charges is

☐ **A** $F/4d$

☐ **B** $F/16d$

☐ **C** $F/4d^2$

☐ **D** $F/16$

(Total 1 mark)

2 A 10 μF capacitor is charged to 5 V and then isolated. It is then connected across a second uncharged capacitor of capacitance 15 μF. The potential difference, in V, across both capacitors is

☐ **A** 0.2

☐ **B** 0.5

☐ **C** 2

☐ **D** 3

(Total 1 mark)

3 An electron is situated in an electric field of strength 2000 V m^{-1}. The ratio

$\dfrac{\text{electrical force due to field}}{\text{force due to gravity}}$ is

☐ **A** 2.8×10^{14}

☐ **B** 2.8×10^{6}

☐ **C** 8.8×10^{7}

☐ **D** 3.6×10^{13}

(Total 1 mark)

Unit 4 Topic 2 Electric and magnetic fields (cont.)

4 A 50 μF capacitor is charged to 1.5 V. It is then discharged through a 2.2 kΩ resistor. The initial current, in μA, is

☐ **A** 3

☐ **B** 75

☐ **C** 110

☐ **D** 680

(Total 1 mark)

5 A closed loop of wire 7.2×10^{-3} m^2 is placed so that its plane is at an angle of 60° to a uniform magnetic field. The flux density is changing at 0.1 T s^{-1}. The emf, in V, induced in the loop of wire is

☐ **A** 3.6×10^{-4}

☐ **B** 6.2×10^{-4}

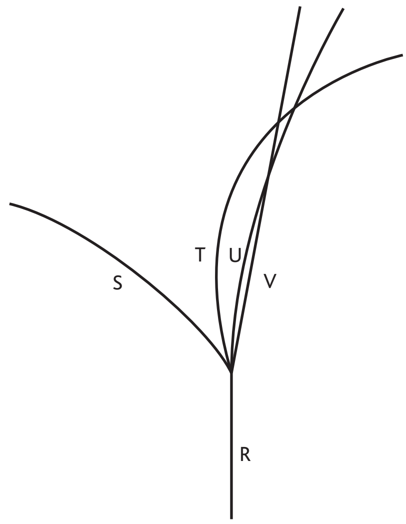
☐ **C** 3.6×10^{-2}

☐ **D** 6.9

(Total 1 mark)

Unit 4 Topic 3 Particle physics

1 The diagram shows the tracks of subatomic particles in a particle detector



Which track shows a particle with the least momentum?

☐ **A** S

☐ **B** T

☐ **C** U

☐ **D** V

(Total 1 mark)

2 A particle has a mass of 1.67×10^{-27} kg and is accelerated through 2.0 MV in a particle accelerator. Its rest mass, in keV/c^2, is

☐ **A** 3.0×10^{-60}

☐ **B** 3.3×10^{-21}

☐ **C** 3.1

☐ **D** 9.4×10^{5}

(Total 1 mark)

Unit 4 Topic 3 Particle physics (cont.)

3 A particle interaction can be described as the annihilation of an antiproton with a proton to produce a negatively charged kaon, a positively charged pion and a neutral kaon.

Which statement describes this using standard particle symbols?

- ☐ **A** $p + p \rightarrow 2\,k + pi$
- ☐ **B** $p + \overline{p} \rightarrow k^- + pi + k$
- ☐ **C** $p + \overline{p} \rightarrow 2k + pi$
- ☐ **D** $p + \overline{p} \rightarrow k^- + k^\circ + \pi^+$

(Total 1 mark)

4 An electron is accelerated until it has a mass of 8000 times its rest mass.

i The potential difference required in the accelerator is

- ☐ **A** 1.3×10^{-15} V
- ☐ **B** 4.1×10^{6} V
- ☐ **C** 4.1×10^{9} V
- ☐ **D** 7.3×10^{15} V

ii The deBroglie wavelength, in m, of this electron is

- ☐ **A** 3.0×10^{-16}
- ☐ **B** 1.3×10^{-15}
- ☐ **C** 9.1×10^{-8}
- ☐ **D** 2.4×10^{-12}

(Total 2 marks)

Unit 5 Topic 4 Thermal energy

1 6400 J of heat energy is used to raise the temperature of 0.40 kg of aluminium from 20 °C to 38 °C. The specific heat capacity, in J kg^{-1} K^{-1}, is

☐ **A** 55

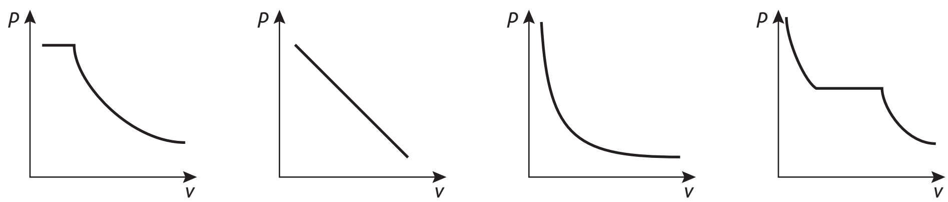
☐ **B** 140

☐ **C** 420

☐ **D** 890

(Total 1 mark)

2 Which one of the following graphs show the relationship between the volume V and pressure p for a fixed mass of an ideal gas at constant temperature?



☐ **A** ☐ **B** ☐ **C** ☐ **D**

(Total 1 mark)

Unit 5 Topic 4 Thermal energy (cont.)

3 The temperature of a mass of gas is 27 °C. The gas is heated so that its temperature increases by 300 °C.

The ratio $\dfrac{\text{initial mean square speed of molecules of gas}}{\text{final mean square speed of molecules of gas}}$ is

- ☐ **A** $\frac{1}{4}$
- ☐ **B** $\frac{1}{2}$
- ☐ **C** 2
- ☐ **D** 4

(Total 1 mark)

4 The pressure of a gas is p and its volume is V. The units of the product pV can be expressed as

- ☐ **A** J
- ☐ **B** N
- ☐ **C** $\mathrm{N\,m^{-2}}$
- ☐ **D** W

(Total 1 mark)

5 The pressure of a fixed mass of ideal gas is decreased without changing its temperature. There is

- ☐ **A** an increase in density
- ☐ **B** no change in internal energy
- ☐ **C** no work done on this gas
- ☐ **D** a change to the product pressure × volume

(Total 1 mark)

Unit 5 Topic 5 Nuclear decay

1 The radioactive nuclide $^{238}_{92}U$ decays by emitting four alpha particles and two beta particles. The resulting nuclide is

☐ **A** $^{222}_{86}Rn$

☐ **B** $^{230}_{92}U$

☐ **C** $^{220}_{82}Pb$

☐ **D** $^{224}_{86}Rn$

(Total 1 mark)

2 A radioactive nuclide Q decays to give a daughter product which is not radioactive. The activity of a quantity of Q is found to decrease from a value 320 to a value of 160 in 7 hours. Which of the following answers most nearly indicates the activity after a further 3.5 hours?

☐ **A** 80

☐ **B** 113

☐ **C** 120

☐ **D** 127

(Total 1 mark)

Unit 5 Topic 5 Nuclear decay (cont.)

3 A source is known to emit two forms of radiation. A Geiger counter is placed 3 cm from the source. When a thin piece of aluminium is placed between the source and counter the reading decreases significantly. When the distance is increased to 5 cm there is little change to the reading. Which of the following correctly identifies the two types of radiation?

☐ **A** alpha beta

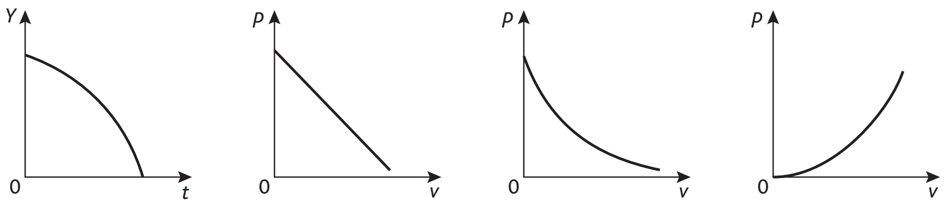
☐ **B** alpha gamma

☐ **C** background beta

☐ **D** beta gamma

(Total 1 mark)

4 A student measures the activity of a radioactive source. She plots a graph of the ln(activity) on the *y*-axis against the time on the *x*-axis. Which of the following would best represent this variation?



☐ **A** ☐ **B** ☐ **C** ☐ **D**

(Total 1 mark)

5 A beta particle is emitted by a source. The change that has taken place to an atom in the source is

☐ **A** that it has lost an electron

☐ **B** a neutron has changed to a proton

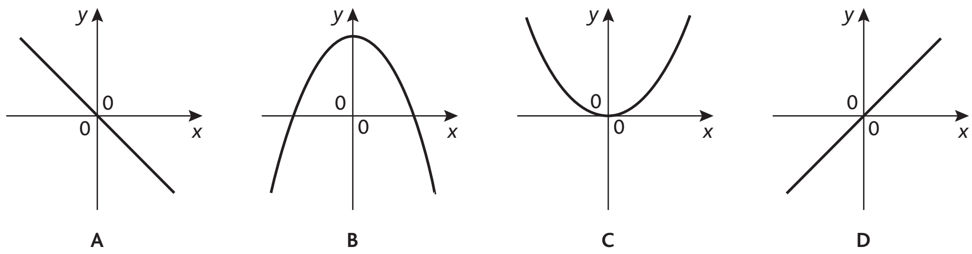
☐ **C** a proton has changed to a neutron

☐ **D** a proton has combined with an electron

(Total 1 mark)

Unit 5 Topic 6 Oscillations

Use the graphs below to answer the next two questions



1 An object is undergoing simple harmonic motion.

Which one of the graphs shows how the acceleration (y-axis) of an object varies with its displacement x?

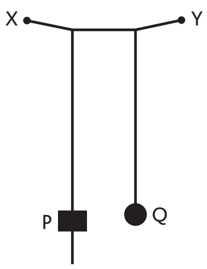
☐ **A** ☐ **B** ☐ **C** ☐ **D**

2 Which one of the graphs show how the kinetic energy (y-axis) of the object varies with displacement x?

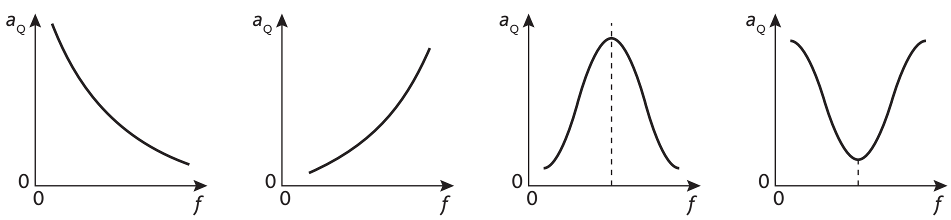
☐ **A** ☐ **B** ☐ **C** ☐ **D**

(Total 2 marks)

3 A heavy pendulum P can be altered so that its frequency of oscillation is f. It is connected to a much lighter pendulum Q by a thread XY.



Which of the following graphs best describes the relationship between the amplitude a_Q of the lighter pendulum as the frequency of the heavy pendulum f is changed?



☐ **A** ☐ **B** ☐ **C** ☐ **D**

(Total 1 mark)

Unit 5 Topic 6 Oscillations (cont.)

4 A tuning fork vibrates with a frequency of 256 Hz. The amplitude of the end of the prong of the tuning fork is 1.0 mm. The maximum acceleration, in $m\,s^{-2}$, of the end of the prong is

☐ **A** 2.6×10^{3}

☐ **B** 2.5×10^{-5}

☐ **C** 2.5×10^{-2}

☐ **D** 4.0×10^{-2}

(Total 1 mark)

5 Which of the following statements is true of the displacement of a particle undergoing simple harmonic motion?

☐ **A** Its magnitude is minimum when the acceleration is maximum.

☐ **B** Its magnitude decreases as the potential energy of the particle increases.

☐ **C** Its magnitude is minimum when the speed of the particle is greatest.

☐ **D** It is always in the opposite direction to the velocity of the particle.

(Total 1 mark)

Unit 5 Topic 7 Astrophysics and cosmology

1 A galaxy has a recessional velocity of $7000\,\text{km}\,\text{s}^{-1}$ and is known to be at a distance of 115 Mpc.

From this information the Hubble constant, in $\text{km}\,\text{s}^{-1}\,\text{MPc}^{-1}$ is about

- [ ] **A** 90
- [ ] **B** 80
- [ ] **C** 70
- [ ] **D** 60

(Total 1 mark)

2 We expect to see more main sequence stars than other stars because

- [ ] **A** stars spend a larger fraction of their life on the main sequence than elsewhere
- [ ] **B** our atmosphere transmits their light
- [ ] **C** the stars in this galaxy contain a higher proportion compared to other galaxies
- [ ] **D** many are very bright

(Total 1 mark)

3 A correct set of units for flux is

- [ ] **A** $\text{W}\,\text{m}^{-1}$
- [ ] **B** $\text{J}\,\text{m}^{-2}$
- [ ] **C** $\text{W}\,\text{m}^{-2}$
- [ ] **D** $\text{J}\,\text{m}$

(Total 1 mark)

Unit 5 Topic 7 Astrophysics and cosmology (cont.)

4 The temperature of the surface of the Sun is 6000 K. The maximum wavelength, in m, of light emitted by the Sun is

☐ **A** 4.6×10^{-7}

☐ **B** 4.8×10^{-7}

☐ **C** 5.1×10^{-7}

☐ **D** 6.1×10^{-7}

(Total 1 mark)

5 If the density of the universe is greater than the critical density the universe will

☐ **A** continue to expand forever at a constant rate

☐ **B** eventually stop expanding

☐ **C** eventually stop expanding and begin contraction

☐ **D** continue to expand at a decreasing rate

(Total 1 mark)

Multiple choice test answers

Topic 1 Further mechanics

1 C   **2** B   **3** B   **4** C   **5** A

Topic 2 Electric and magnetic fields

1 D   **2** C   **3** D   **4** D   **5** A

Topic 3 Particle physics

1 B   **2** D   **3** D   **4** i C   ii A

Topic 4 Thermal energy

1 D   **2** C   **3** B   **4** A   **5** B

Topic 5 Nuclear decay

1 A   **2** B   **3** D   **4** B   **5** B

Topic 6 Oscillations

1 A   **2** B   **3** C   **4** A   **5** C

Topic 7 Astrophysics and cosmology

1 D   **2** A   **3** C   **4** B   **5** C

Unit 4 Topic 1 Further mechanics

58 min **58 marks**

1 A model truck A of mass 1.2 kg is travelling due west with a speed of $0.90\ \mathrm{m\,s^{-1}}$. A second truck B of mass 4.0 kg is travelling due east towards A with a speed of $0.35\ \mathrm{m\,s^{-1}}$.

Calculate the magnitude of the total momentum of the trucks.

____

____

Total momentum = ______________________ **(2)**

The trucks collide and stick together. Determine their velocity after the collision.

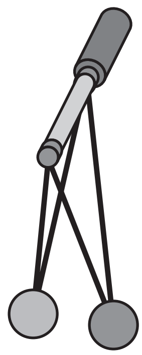
____

____

Velocity = ______________________ **(3)**

(Total 5 marks)

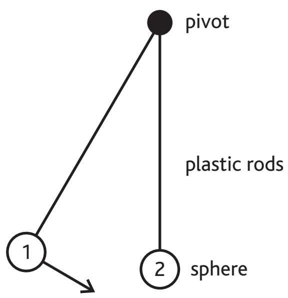
2 The picture shows a toy with two plastic spheres, each suspended by plastic rods. Each sphere is able to swing freely in a vertical circle.



A student decides to carry out an experiment with the toy to investigate momentum. He allows one sphere to strike the other, and measures their speeds just before and just after the collision.

The table shows his data for one collision.

mass of sphere 1	54.0 g
mass of sphere 2	29.0 g
speed of sphere 1 before collision	$2.57\ \mathrm{m\,s^{-1}}$
speed of sphere 2 before collision	0
speed of sphere 2 after collision	$2.12\ \mathrm{m\,s^{-1}}$



Show that the speed of sphere 1 just after the collision is about $1.4\ \mathrm{m\,s^{-1}}$. Assume that the mass of each rod is negligible.

____

____

____

____

____

____ **(3)**

Unit 4 Topic 1 Further mechanics (cont.)

Determine whether this is an elastic collision or an inelastic collision.

(3)

In another experiment the student uses the toy to investigate motion in a vertical circle. He times sphere 2 (mass 29.0 g) as it swings around a complete vertical circle of radius 17 cm. This takes 0.37 s.

Calculate the average speed of the sphere.

Speed = **(2)**

Assuming that the sphere travels at this speed throughout its circular path

(i) calculate the centripetal force acting on it while it is in motion

Centripetal force = **(2)**

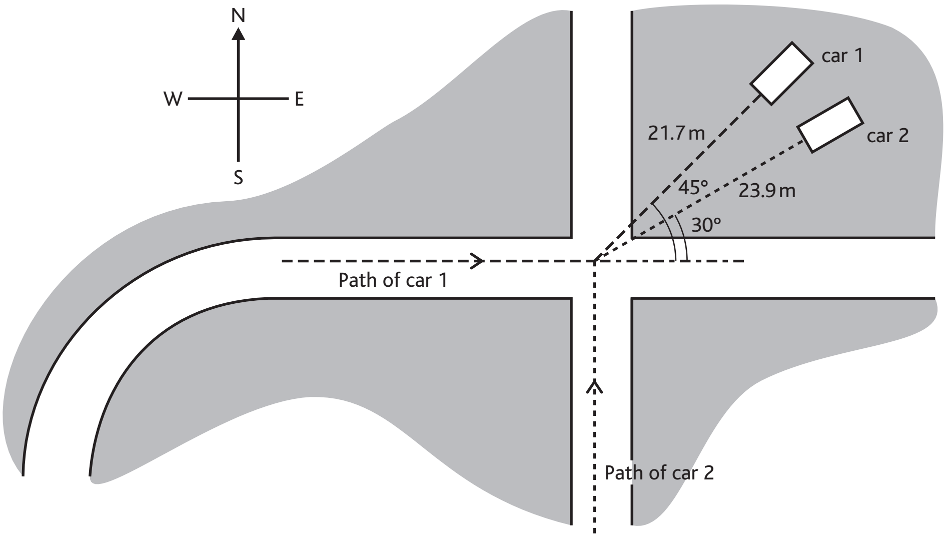
(ii) calculate the net force exerted by the rods on the sphere when it is at the top of the circle.

Tension = **(2)**

(Total 12 marks)

Unit 4 Topic 1 Further mechanics (cont.)

3 The diagram is taken from the notes of an accident investigator after a collision in the countryside.



The driver of car 1 said he was driving within the speed limit and car 2 suddenly drove across the junction in front of him.

The driver of car 2 said that he obeyed the traffic sign and stopped at the junction. He looked carefully before moving slowly straight across the junction. He was suddenly struck by car 1. He thought he hadn't seen it because of the bend in the road 50 m away, and that it must have been speeding.

The investigator found the masses of both cars with their drivers and used a test car to find that the surface produced a deceleration of 3.43 m s^{-2}. The table shows some of the investigator's notes.

	Car 1	Car 2
Mass of car and driver/kg	1950	1430
Distance travelled after collision/m	21.7	23.9
Angle between path followed and main road/degrees	45.0	30.0
Speed immediately after collision/m s^{-1}	12.2	
Magnitude of momentum immediately after collision/kg m s^{-1}	23 800	

Show that the speed of car 2 immediately after the collision was about 13 m s^{-1}.

(2)

Unit 4 Topic 1 Further mechanics (cont.)

Calculate the magnitude of the momentum of car 2 immediately after the collision.

Momentum = ______________________ **(2)**

Next the investigator calculated the component of the momentum to the East immediately after the collision for each car.

Calculate this component of the momentum for each car.

East momentum component for car 1 = ______________________

East momentum component for car 2 = ______________________ **(3)**

Hence determine whether car 1 was speeding before the accident. The speed limit was $17.8\,\mathrm{m\,s^{-1}}$.

(3)

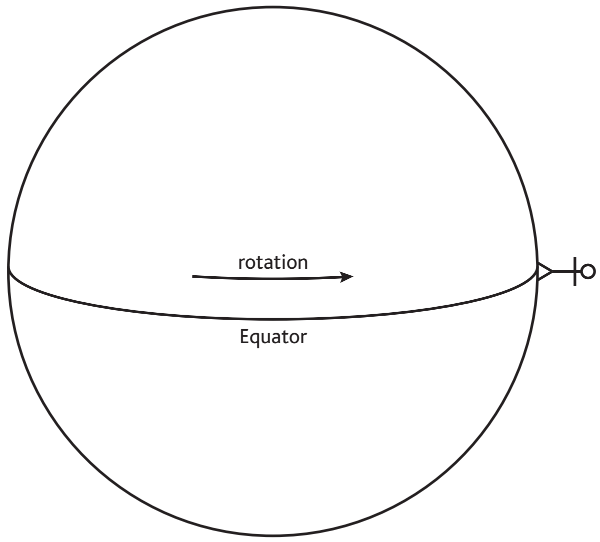
Explain, without calculation, how the investigator could use a conservation law to deduce that car 2 was travelling across the junction at speed.

(2)

(Total 12 marks)

Unit 4 Topic 1 Further mechanics (cont.)

4 A person at the equator of the Earth is moving in a circle and therefore must have a centripetal acceleration.



Explain why a person moving in a circle must have an acceleration.

____

____

____ **(1)**

Show that the centripetal acceleration of a person at the equator is about $0.03\,\mathrm{m\,s^{-2}}$. (Radius of the Earth $= 6.4 \times 10^6\,\mathrm{m}$.)

____

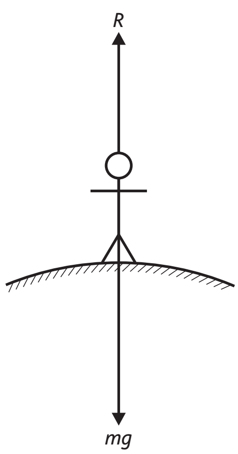
____

____

____

____ **(3)**

For a person standing at the equator, the force R from the ground is slightly different from their weight mg as shown opposite. State and explain which of these forces is the larger.



____

____

____

____

____

____

____ **(2)**

Unit 4 Topic 1 Further mechanics (cont.)

The size of the force R provides a measure of the apparent strength of the gravitational field. Show that the apparent field strength g at the equator differs from that at the poles by about 0.3%.

____

____

____

____ **(1)**

The time of swing T of a simple pendulum depends on the local value of g. Theory shows that a certain percentage variation in g causes half that percentage variation in T. This causes pendulum clocks to run at different rates in different places. Calculate by how many seconds each day a pendulum clock at the equator will differ from one at the pole.

____

____

____

____

Difference = ______________________ s **(2)**

(Total 9 marks)

Unit 4 Topic 1 Further mechanics (cont.)

5 To make an object of mass m move at speed v around a circular path of radius r, a resultant force must act on it. The magnitude of the resultant force is given by mv^2/r.

Explain why a resultant force is required, and state its direction.

____

____

____

____ **(3)**

When vehicles corner on a level road, the resultant force is provided by friction. For a given vehicle and road surface, the friction cannot exceed a certain maximum value. Use these facts, together with the expression for the resultant force, to explain why roads designed for high-speed travel have no sharp bends.

____

____

____

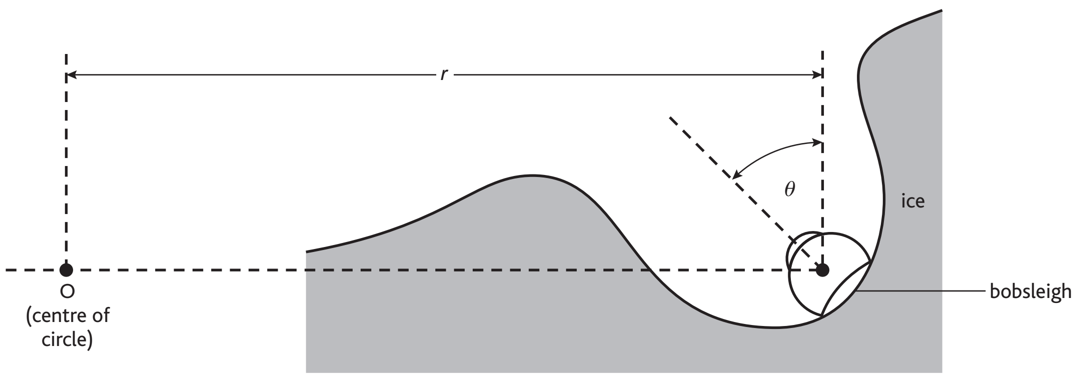
____

____

____ **(2)**

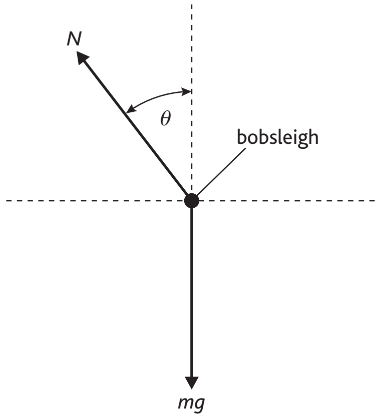
On a bobsleigh run, the bobsleigh travels along an ice channel with little friction. When cornering, it slides up the side of the channel until the required resultant force is provided.

The diagram shows a head-on view of a bobsleigh travelling at speed v round a bend which is part of a horizontal circle centred at the point O. The bobsleigh is tilted through an angle θ.



Unit 4 Topic 1 Further mechanics (cont.)

Below is a free-body force diagram for the bobsleigh. Friction is assumed to be negligible.



The normal contact force exerted by the ice on the bobsleigh is N, and its weight is mg.

Write down an equation expressing the condition for no vertical acceleration.

____

Write down an equation applying Newton's second law horizontally.

____

Hence show that

$$\tan\theta = \frac{v^2}{rg}$$

$(\tan\theta = \sin\theta/\cos\theta)$

____

____

____

____ **(4)**

Calculate the value of angle θ for a bobsleigh travelling at $30.0\,\mathrm{m\,s^{-1}}$ around a bend of radius 20.0 m.

____

____

θ = ______________________ **(1)**

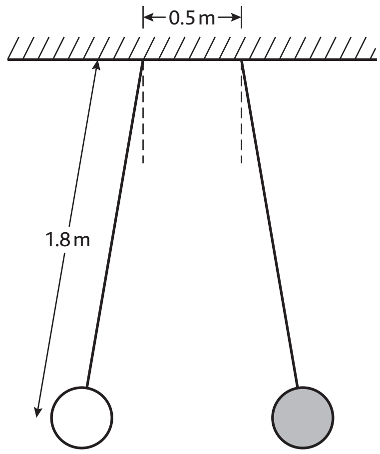
(Total 10 marks)

Unit 4 Topic 2 Electric and magnetic fields

42 min **42 marks**

1 A student wants to test Coulomb's law, which is about the force between two charged objects.

She plans to hang two balloons on insulated threads, charge them both with equal positive charges, and measure the angles at which they hang away from each other. The dimensions she plans to use in her experiment are shown on the diagram.



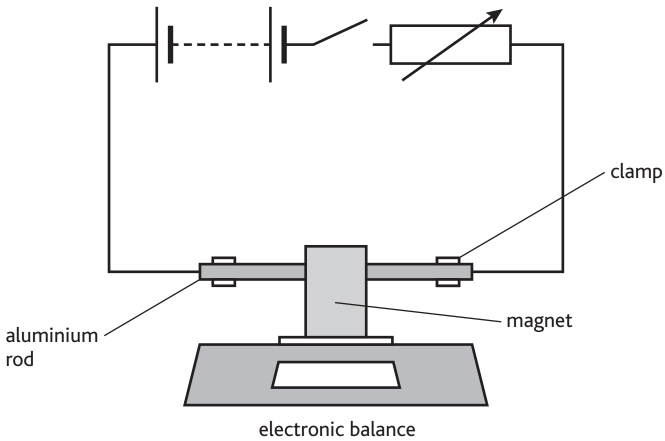
She thinks she can make accurate measurements if the balloons hang at an angle of 1.5° or more from the vertical. **Add to the diagram** to show all the forces acting on one of the balloons. Hence show that the minimum charge Q she needs on each balloon must be about 0.1 μC.
[Assume that each balloon behaves as though the charge were concentrated at its centre.]

The mass of each balloon = 0.0018 kg.

(Total 6 marks)

Unit 4 Topic 2 Electric and magnetic fields (cont.)

2 A U-shaped permanent magnet of mass 85.0 g rests on an electronic balance as shown in the diagram. An aluminium rod connected in a circuit is supported between the opposite poles of the magnet so that it is unable to move.



The switch is closed. The reading on the balance increases to 85.4 g.

(a) **(i)** Calculate the additional force on the magnet when there is current in the circuit.

____

Force = ______________________________ **(1)**

(ii) Explain how this additional force originates. You may be awarded a mark for the clarity of your answer.

____

____

____

____

____

____

____

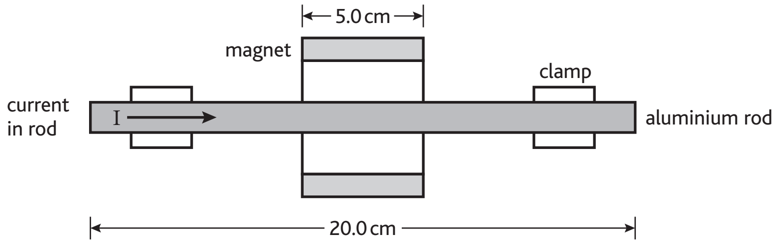
____ **(4)**

Unit 4 Topic 2 Electric and magnetic fields (cont.)

(b) The diagram below shows a plan view of the rod and the poles of the magnet.

(i) On the diagram **label the poles of the magnet** to indicate the direction of field needed to produce a downward force on the magnet.

VIEW AS SEEN FROM ABOVE



(1)

(ii) The rod is 20.0 cm long and the magnet is 5.0 cm wide. The magnetic flux density of the magnet is 30.0 mT. Calculate the current in the rod.

Current = ______ **(3)**

(iii) The direction of the current is reversed. What would be the new reading on the balance?

Balance reading = ______ **(2)**

(Total 11 marks)

Unit 4 Topic 2 Electric and magnetic fields (cont.)

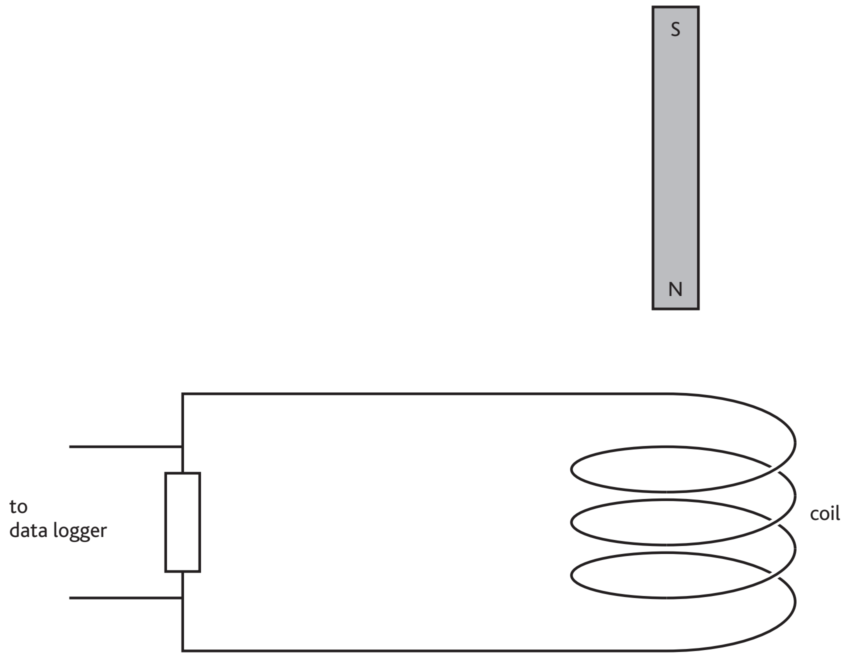
3 State Lenz's law of electromagnetic induction.

____

____

____ **(2)**

A bar magnet is dropped from rest through the centre of a coil of wire which is connected to a resistor and data logger.



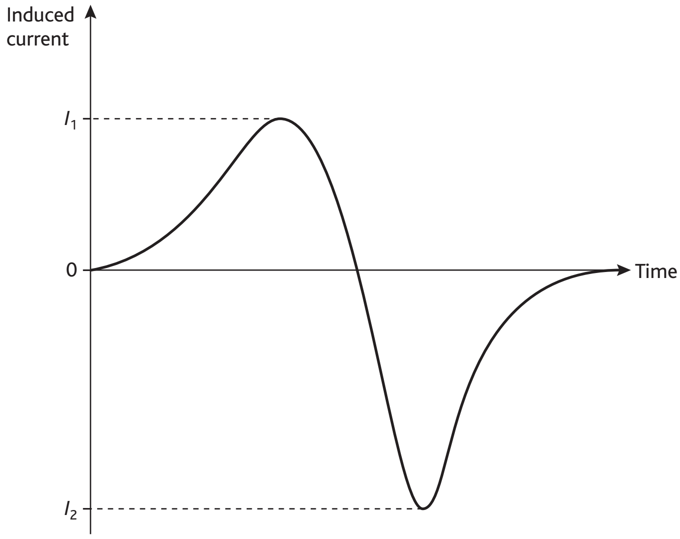
State the induced magnetic polarity on the top side of the coil as the magnet falls towards it.

____

Add an arrow to the wire to show the direction of the induced current as the magnet falls towards the coil. **(2)**

Unit 4 Topic 2 Electric and magnetic fields (cont.)

The graph shows the variation of induced current in the resistor with time as the magnet falls.



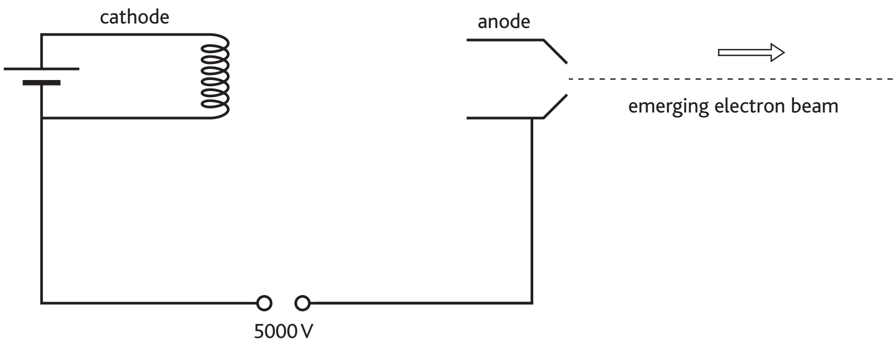
Explain why the magnitude of I_2 is greater than I_1.

(2)

(Total 6 marks)

4 Electrons are accelerated from rest from the cathode to the anode of a vacuum tube through a potential difference of 5000 V.

Figure 1



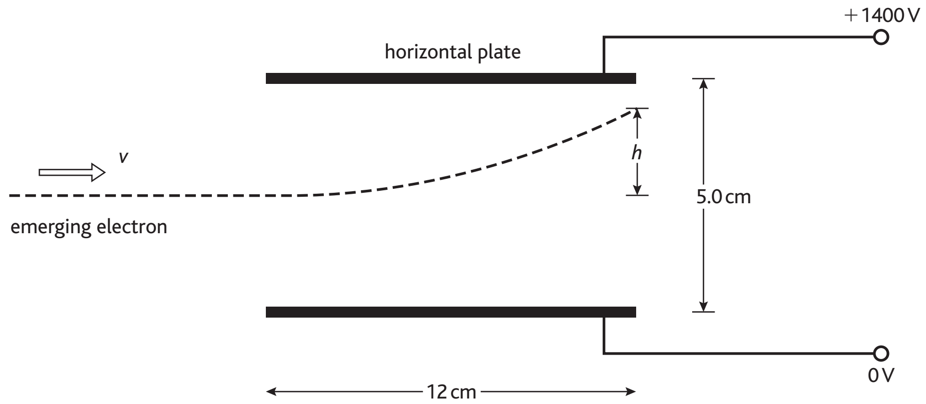
(a) Show that the speed v of an electron as it leaves the anode is approximately $4 \times 10^7\ \mathrm{m\,s^{-1}}$.

(3)

Unit 4 Topic 2 Electric and magnetic fields (cont.)

(b) The emerging beam of electrons follows a parabolic path as it passes between a pair of horizontal parallel plates 5.0 cm apart with a potential difference of 1400 V between them.

Figure 2



(i) Calculate the strength E of the uniform electric field between the horizontal plates.

$E =$ ____________________ **(1)**

(ii) Hence determine the force F exerted by this field on each electron.

$F =$ ____________________ **(1)**

(c) An electron experiences an upward acceleration a as it travels between the plates. Its vertical displacement h after a time t is given by

$$h = \tfrac{1}{2}at^2$$

Calculate the value of h as the electron leaves the plates.

$h =$ ____________________ **(4)**

Unit 4 Topic 2 Electric and magnetic fields (cont.)

(d) (i) Add to Figure 2 the path that the electron beam would follow if the potential difference between the horizontal plates were decreased. Label this path A. **(1)**

(ii) Add to Figure 2 the path that the electron beam would follow if the potential difference between the cathode and the anode were decreased. Label this path B. **(1)**

(Total 11 marks)

5 A defibrillator is a machine that is used to correct irregular heartbeats by passing a large current through the heart for a short time. The machine uses a 6000 V supply to charge a capacitor of capacitance 20 μF. The capacitor is then discharged through the metal electrodes (defibrillator paddles) which have been placed on the chest of the patient.

Calculate the charge on the capacitor plates when charged to 6000 V.

____

Charge = ______________________ **(2)**

Calculate the energy stored in the capacitor.

____

____

Energy = ______________________ **(2)**

When the capacitor is discharged, there is an initial current of 40 A through the patient.

Calculate the electrical resistance of the body tissue between the metal electrodes of the paddles.

____

____

Resistance = ______________________ **(1)**

Assuming a constant discharge rate of 40 A, calculate how long it would take to discharge the capacitor.

____

____

____

____

Time = ______________________ **(2)**

In practice the time for discharge is longer than this calculated time. Suggest a reason for this

____

____

____ **(1)**

(Total 8 marks)

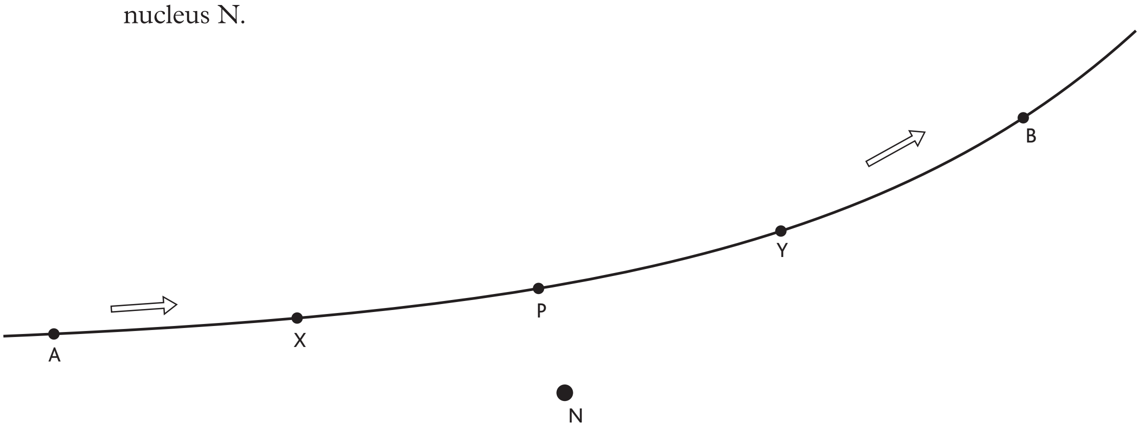
Unit 4 Topic 3 Particle physics

58 min **58 marks**

1 In the Rutherford scattering experiment, fast-moving alpha particles were fired at a thin gold foil. What observations from this experiment suggested that the atom has a small, massive nucleus?

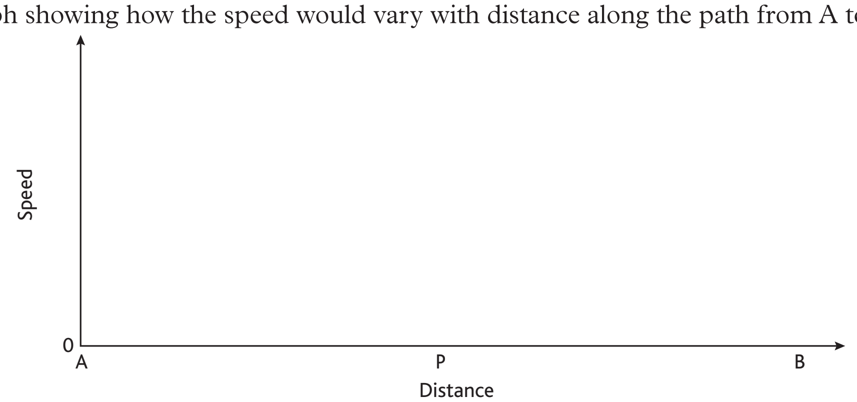
(2)

The diagram shows the path followed by one alpha particle which passes close to a gold nucleus N.



Add arrows to the diagram at points X and Y to show the direction of the force on the alpha particle when it is at each of these points. **(1)**

The speed of the alpha particle was the same at points A and B. On the axes below, sketch a graph showing how the speed would vary with distance along the path from A to B.



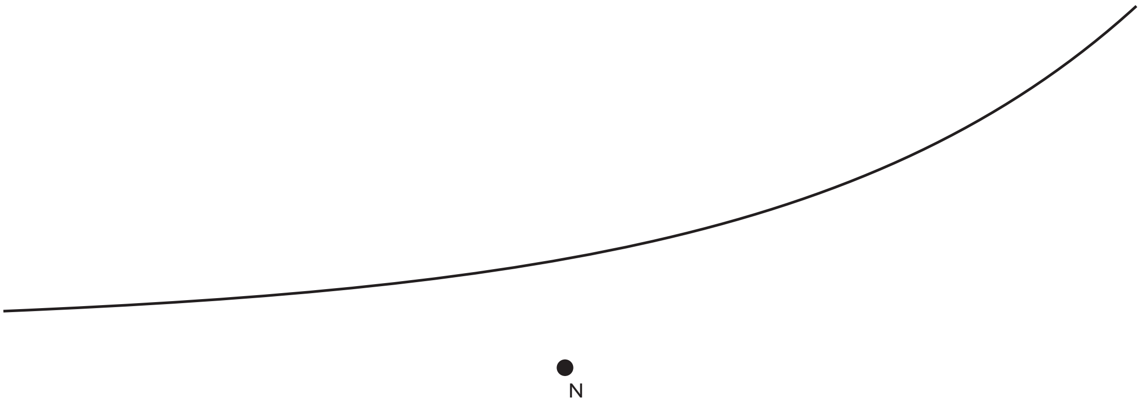
(2)

With reference to the forces you added to the previous diagram, explain the shape of the graph.

(2)

Unit 4 Topic 3 Particle physics (cont.)

The diagram below shows the path of the alpha particle again.



Add a line to this diagram to show the path which would be followed by an alpha particle which was travelling initially along the same line as before, but more slowly. **(1)**

The evidence for a small, massive nucleus from Rutherford scattering might have been less convincing if the alpha particles used had been of lower energy. Suggest how the observations would have changed if lower energy alpha particles had been used.

____

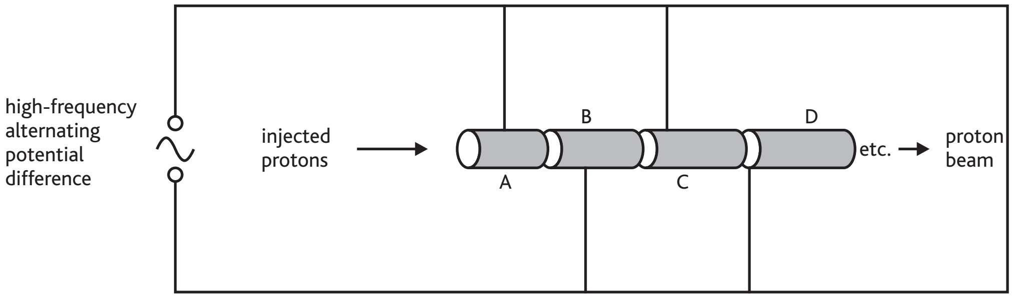
____

____ **(1)**

(Total 9 marks)

Unit 4 Topic 3 Particle physics (cont.)

2 The diagram shows part of a linear accelerator - a linac. Alternate metal tubes are connected together and to opposite terminals of a high-frequency alternating potential difference of fixed frequency.



(a) Describe how the protons are accelerated as they move along the linac and explain why the tubes get longer towards the right. You may be awarded a mark for the clarity of your answer.

(5)

(b) A particular linac has 420 metal tubes and the peak voltage of the alternating supply is 800 kV.

(i) Show that the emerging protons have gained a kinetic energy of about 5×10^{-11} J and express the mass equivalent of this energy as a fraction of the mass of a stationary proton. Take the mass of a proton m_p as 1.01 u.

(6)

Unit 4 Topic 3 Particle physics (cont.)

(ii) The frequency of the alternating supply is 390 MHz. Calculate how long it takes a proton to travel along the linac.

Time = ______ **(2)**

(c) The emerging protons can be made to collide with

(i) a target of fixed protons, e.g. liquid hydrogen, or

(ii) a similar beam of protons travelling in the opposite direction.

State some advantages of either or both experimental arrangement(s).

(2)

(Total 15 marks)

3 In 1989 the Large Electron Positron collider (LEP) at CERN was opened. It was used until 2000, when it was shut down to allow the construction of a new accelerator. At LEP, beams of electrons and positrons were accelerated to energies of 100 GeV in a huge ring with a circumference of 27 km before being made to collide with each other.

Just before LEP closed, scientists using it found some evidence for the proposed Higgs boson at a mass of 115 GeV/c^2.

Explain why 1 eV is equal to 1.6×10^{-19} J.

(2)

Show how GeV/c^2 can be used as a unit of mass.

(2)

Unit 4 Topic 3 Particle physics (cont.)

If the Higgs boson has a mass of 115 GeV/c^2, find its mass in kg.

Mass = ______________________ kg **(2)**

The positron is the antiparticle to the electron. What is an **antiparticle**?

(1)

A description of LEP refers to '....the relatively small magnetic field required for LEP's gentle curvature....'.

Explain the need for a magnetic field and why it can be 'relatively small' in this case.

(4)

(Total 11 marks)

Unit 4 Topic 3 Particle physics (cont.)

4 In July 2003 scientists at the SPring-8 synchrotron in Japan announced the discovery of a pentaquark – a particle made up of 5 quarks.

Previously, quarks had been known to occur in two types of combinations called hadrons. Name these and describe the quark composition of each.

Name ____________________

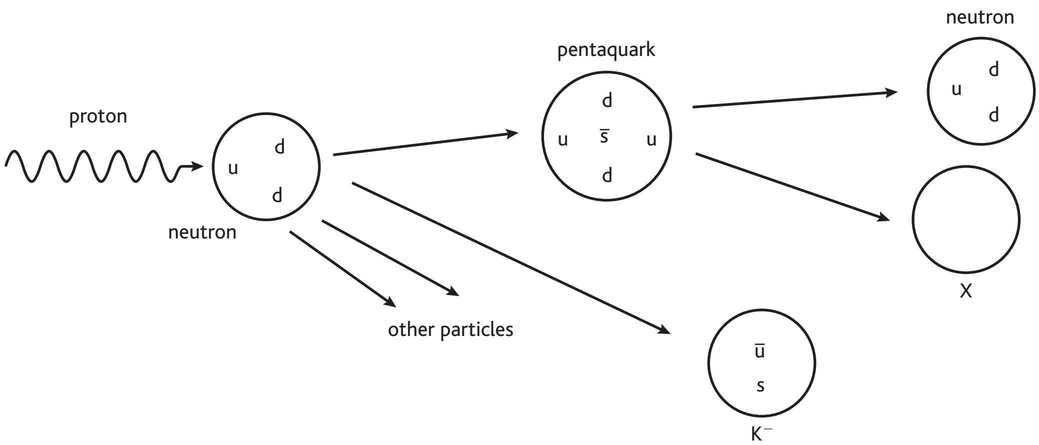
Quark composition ____________________

Name ____________________

Quark composition ____________________ **(4)**

The pentaquark was produced by firing gamma photons at a target. It decayed very rapidly into other products.

The diagram shows some of the particles involved in the production and decay of the pentaquark, including the quark composition for several of them.



Name three quantities conserved during the decay of the pentaquark.

____

____________________ **(2)**

The table shows the charges of the six types of quarks as a fraction of the charge on a proton.

Quark type			Charge
up	charm	top	2/3 e
down	strange	bottom	−1/3 e

Find the charge of the pentaquark. Express your answer as a fraction of the charge on a proton.

____

____

Charge = ____________________ **(1)**

Unit 4 Topic 3 Particle physics (cont.)

Explain whether particle X must be positive, negative or neutral.

___

___

___ **(1)**

Suggest a possible quark composition for particle X. Explain your choice of quarks.

___

___

___ **(2)**

The pentaquark had a mass of 1.54 GeV/c^2. Find its mass in kg.

___

___

___

___

Mass = ___ kg **(2)**

(Total 12 marks)

Unit 4 Topic 3 Particle physics (cont.)

5 Bubble chambers can be used to observe the tracks of charged particles through magnetic fields. As charged particles pass through the liquid they cause ionisation which triggers the formation of bubbles, recording the tracks of the particles. The picture below shows the spiral track of an electron in a bubble chamber.

State whether the electron is travelling clockwise or anticlockwise.

____ **(1)**

Explain why the track is curved, and why it has a spiral shape.

____

____

____

____

____ **(3)**

Take measurements from the image to estimate the maximum momentum of the electron in $kg\,m\,s^{-1}$. (Magnetic flux density = 4.0 T)

____

____

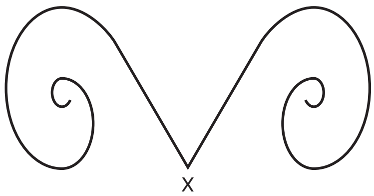
____

____

Momentum = ______________________ $kg\,m\,s^{-1}$ **(3)**

Unit 4 Topic 3 Particle physics (cont.)

The diagram below shows a second set of tracks, produced by an event which occurs at point **X.**



It is thought that the event which occurs at **X** is:

photon → electron + positron

Give two ways in which the tracks are consistent with this interpretation.

____

____

____

____ **(2)**

Explain how this event obeys two conservation laws.

____

____

____

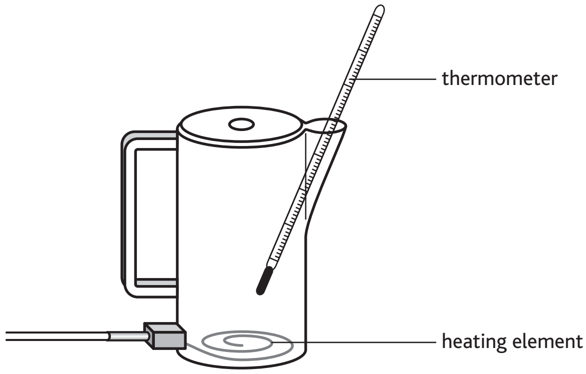
____ **(2)**

(Total 11 marks)

Unit 5 Topic 4 Thermal energy

43 min **43 marks**

1 Water in a plastic kettle is heated by an electric element near the bottom of the kettle. The temperature of the water near its surface can be recorded on a thermometer.



A kettle contains 0.70 kg of water at an initial temperature of 20 °C. It is calculated that about 250 kJ of thermal energy is needed to heat the water from 20 °C to 100 °C. Show how this value is calculated.

(The specific heat capacity of water is 4200 J kg^{-1} K^{-1}.)

____

____

____ **(2)**

Calculate the time it should take for an element rated at 2.2 kW to supply this energy.

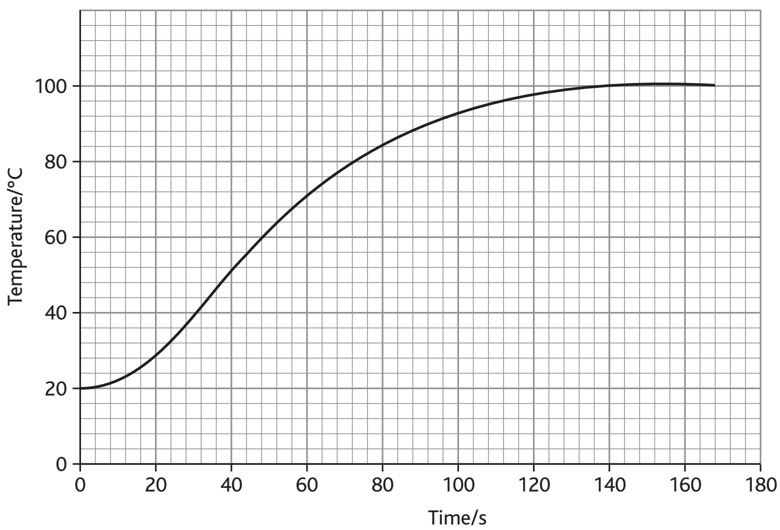
____

____

____

Time = ______________________ **(3)**

To check this calculation, the kettle is switched on at t = 0 s and temperature readings are taken as the water is heated. The graph shows how the temperature varies with time.



Unit 5 Topic 4 Thermal energy (cont.)

Use the graph to fully describe qualitatively how the temperature of the water changes during the first 160 s.

____

____

____

____ **(3)**

Estimate the efficiency of the electric heating element in bringing the water to the boil.

____

____

____

Efficiency = ______________________ **(2)**

(Total 10 marks)

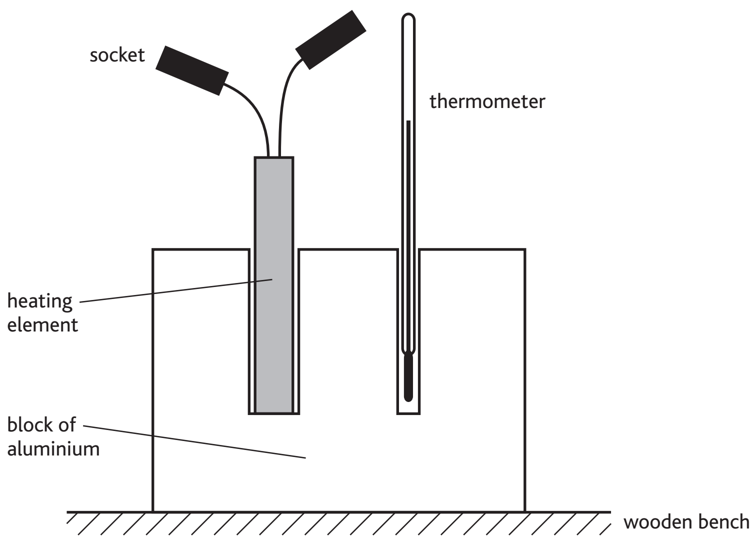
2 Define the term **specific heat capacity**.

____

____

____ **(2)**

A student decides to measure the specific heat capacity of aluminium by an electrical method. He selects his apparatus and then assembles the aluminium block, the thermometer and the heating element as shown.



The student intends to substitute his results into the relationship

$$mc\Delta T = VIt$$

Unit 5 Topic 4 Thermal energy (cont.)

Draw a diagram of the electrical circuit he would need to set up in order to be able to carry out the experiment.

(3)

What other pieces of apparatus would he need?

____

____ **(2)**

He carries out the experiment and then calculates his value for the specific heat capacity of aluminium. He discovers that his value is higher than the accepted value of 900 J kg^{-1} K^{-1}.

Suggest why his result is higher than 900 J kg^{-1} K^{-1}.

____

____ **(1)**

With reference to the apparatus shown in the diagram, state two modifications that he should make in order to minimise the discrepancy.

1. ____

____

2. ____

____ **(2)**

(Total 10 marks)

Unit 5 Topic 4 Thermal energy (cont.)

3 The kinetic model gives the following formula for the pressure exerted by a gas

$$p = \tfrac{1}{3}\rho\langle c^2\rangle$$

where the symbols have their usual meanings.

Five gas molecules have speeds of 340 m s^{-1}, 420 m s^{-1}, 670 m s^{-1}, 550 m s^{-1} and 590 m s^{-1}. Calculate the value of $\langle c^2\rangle$ for these molecules.

$\langle c^2\rangle =$ ______ **(3)**

Write an expression for the density of a gas in terms of the number of molecules N, the mass of each molecule m and the volume of the gas V.

______ **(1)**

For ideal gases $pV = NkT$.

Show that for a given mass of an ideal gas the mean kinetic energy of a molecule is proportional to the kelvin temperature of the gas.

______ **(3)**

(Total 7 marks)

Unit 5 Topic 4 Thermal energy (cont.)

4 The equation of state for an ideal gas is

$$pV = NkT$$

(a) For each of these symbols, state the physical quantity and its SI unit. One has been done as an example for you.

Symbol	Physical quantity	SI unit
p		
V		
N		
k	Boltzmann constant	$\mathrm{J\,K^{-1}}$
T		

(4)

(b) An ideal gas of volume $1.0 \times 10^{-4}\,\mathrm{m^3}$ is trapped by a movable piston in a cylinder. The initial temperature of the gas is 20 °C.

The gas is heated and its volume increases by $5.0 \times 10^{-5}\,\mathrm{m^3}$ at a constant pressure. Calculate the new temperature of the gas in °C.

Temperature of gas = ______ °C **(4)**

(Total 8 marks)

5 **(a)** **(i)** An ideal gas sample of volume V contains N molecules, each of mass m. Write down an expression for the density ρ of the gas.

(1)

(ii) The mean square speed of the molecules is $\langle c^2 \rangle$. Write an expression for the average kinetic energy E of a molecule.

(1)

Unit 5 Topic 4 Thermal energy (cont.)

(b) The average kinetic energy of a molecule is directly proportional to the kelvin temperature T, i.e. E = constant × T. The pressure p of an ideal gas is given by the equation

$$p = \frac{1}{3}\rho\langle c^2\rangle$$

Use this information to show that p is directly proportional to T for a fixed mass of gas at constant volume.

(3)

(c) An aerosol can contains a propellant gas at a pressure of three times atmospheric pressure at a temperature of 20 °C. The aerosol can is able to withstand a maximum pressure of seven times atmospheric pressure. Calculate the temperature at which the can will explode.

Temperature = ____________ **(3)**

(Total 8 marks)

Unit 5 Topic 5 Nuclear decay

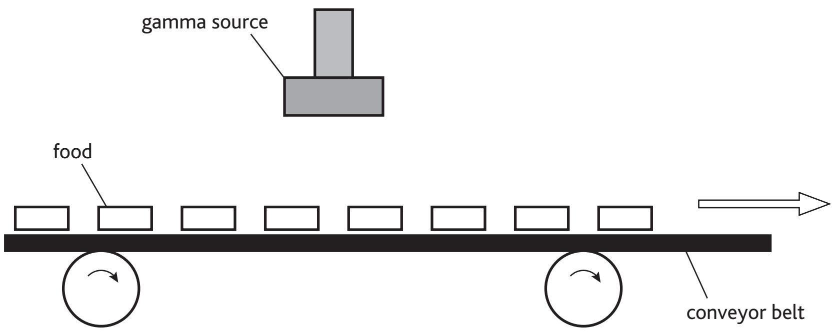
38 min **38 marks**

1 Radioactive isotopes emitting gamma radiation can be used to preserve food. The food is exposed to the radiation which kills most of the bacteria that occur naturally.

Why is gamma radiation used in this process rather than alpha or beta?

____ **(1)**

The food is passed on a conveyor belt under a radiation source.



State **two** factors which control the amount of radiation reaching each item of food.

____

____ **(2)**

A thick wall surrounds the irradiation room to prevent the radiation escaping. Suggest a suitable material and thickness for this wall.

____

____ **(2)**

Many consumers are worried about irradiated food, as they wrongly believe that this makes it become radioactive. Food does, however, contain a small level of naturally occurring radiation. Name something other than food that is also a source of natural radiation.

____ **(1)**

(Total 6 marks)

2 An airport decides to use γ-radiation to examine luggage.

How are γ-rays dangerous to people?

____

____

____ **(2)**

Unit 5 Topic 5 Nuclear decay (cont.)

Suggest a material which could be used for the shielding of airport staff, and the minimum thickness required.

(2)

Why is α radiation not used to examine luggage?

(1)

Explain why air travellers are exposed to increased doses of background radiation.

(2)

(Total 7 marks)

3 **(a)** Name two sources of background radiation.

1

2 **(2)**

(b) **(i)** A student is doing an experiment using radioactive material. She uses a counter to record the total count. Her teacher points out that she has forgotten to measure the background count rate. Describe the procedure the student should follow. You must mention any additional equipment she might need to use.

(4)

Unit 5 Topic 5 Nuclear decay (cont.)

(ii) Why might it have been unnecessary to measure the background count rate?

____

____ **(1)**

(Total 7 marks)

4 A smoke detector contains a small radioactive source. A typical source contains 1.2×10^{-8} g of americium-241, which has a half-life of 432 years. Show that the decay constant of americium-241 is approximately $5 \times 10^{-11}\ s^{-1}$.

____

____

____ **(2)**

Calculate the number of nuclei in 1.2×10^{-8} g of americium-241, given that 241 g contains 6.0×10^{23} nuclei.

____

____

Number of nuclei = ______________________ **(1)**

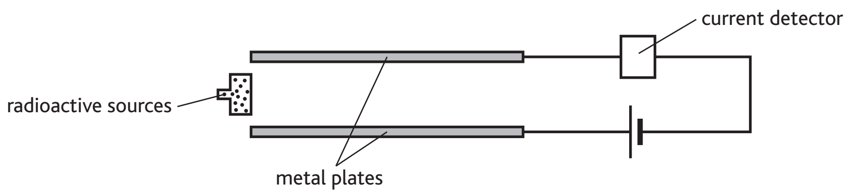
Hence calculate the activity of 1.2×10^{-8} g of americium-241.

____

____

Activity = ______________________ **(2)**

The diagram below shows the principle of the smoke detector.



Radiation from the source ionises the air between the plates, and a small current is detected. If smoke enters the detector, the ions 'stick' to the smoke particles, reducing the current and triggering an alarm.

Americium-241 is an alpha emitter. Explain why an alpha emitter is a suitable source for this apparatus.

____

____

____

____ **(2)**

Unit 5 Topic 5 Nuclear decay (cont.)

Discuss other features of this americium sample which make it a suitable source for the smoke detector.

____

____

____

____ **(3)**

(Total 10 marks)

5 **(a) (i)** Carbon has two important isotopes, ${}^{12}_{6}C$ and ${}^{14}_{6}C$. Carbon-14 is unstable but carbon-12 is stable.

What is meant by saying that carbon-12 is stable?

____

____ **(1)**

(ii) Carbon-14 is formed in the atmosphere when a particle ${}^{1}_{0}X$ collides with an atom of nitrogen.

Complete the equation to show the missing nucleon and proton numbers:

$${}^{14}_{7}N + {}^{1}_{0}X \rightarrow {}^{14}_{6}C + {}^{---}_{---}Y$$ **(1)**

(iii) Identify the particles X and Y.

X = ____________ Y = ____________ **(2)**

(b) (i) The half-life of carbon-14 is 5568 years. Show that the decay constant of carbon-14 is about $4 \times 10^{-12}\,s^{-1}$. (You may assume 1 year = 3.2 × 107 s.)

____

____

____

____ **(2)**

(ii) A sample of carbon-14 has an activity of 16 counts min^{-1}. Calculate the number of nuclei of carbon-14 in this sample.

____

____

____

____

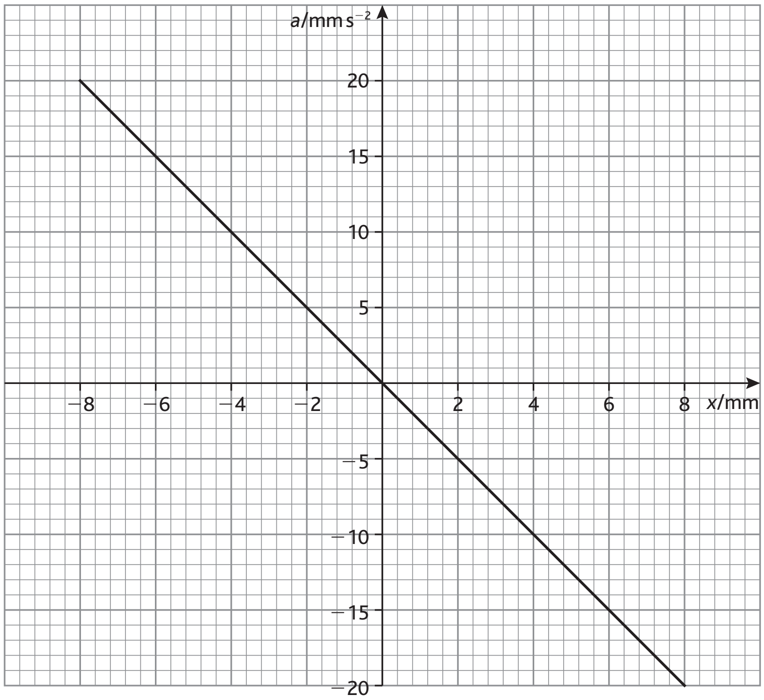
Number of nuclei = ____________ **(2)**

(Total 8 marks)

Unit 5 Topic 6 Oscillations

36 min **36 marks**

1 The graph shows how the acceleration a varies with displacement x for a particle undergoing simple harmonic motion.



Calculate the gradient of this graph.

Gradient = ______________________ **(2)**

Use your value to deduce the frequency for this motion.

Frequency = ______________________ **(2)**

Hence, write down the period of the motion.

______________________ **(1)**

Unit 5 Topic 6 Oscillations (cont.)

On the grid below sketch a graph of acceleration against time for this motion. Assume that the displacement is zero and the velocity is positive at $t = 0$.

Add suitable scales to the axes. Draw at least two complete cycles.

(3)

(Total 8 marks)

2 Define simple harmonic motion (SHM).

____

____

____ **(2)**

A mass on a spring is displaced 0.036 m vertically downwards from its equilibrium position. It is then released. As it passes upwards through its equilibrium position a clock is started. The mass takes 7.60 s to perform 20 cycles of its oscillation.

Assuming that the motion is SHM it can be described by the equation

$$x = A \sin 2\pi f t$$

where x is the displacement in the upward direction and t the time since the clock was started. What are the values of A and f in this case?

A = ______________________________

____

____

f = ______________________________ **(3)**

Unit 5 Topic 6 Oscillations (cont.)

Use the equation to calculate the displacement when $t = 1.00$ s.

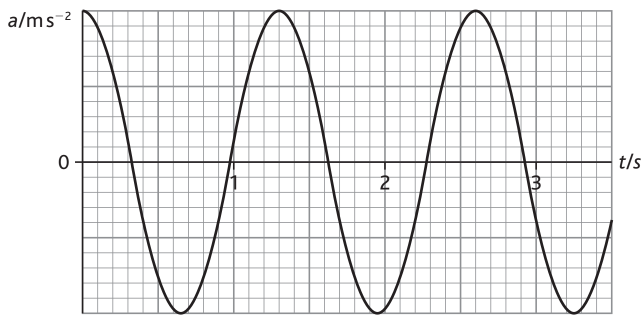
$x =$ ______________________ **(1)**

In practice, simple harmonic motion is not a perfect model of the motion of the mass, and so the equation above does not predict the displacement correctly. Explain how and why the motion differs from that predicted by the equation.

(2)

(Total 8 marks)

3 A body performs simple harmonic oscillations. The graph shows how the acceleration a of the body varies with time t.

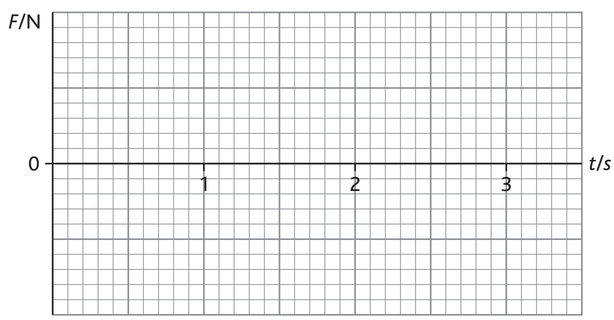


State the frequency of the oscillations.

(1)

Add to the graph above a curve showing how the *velocity* of the same body varies with time over the same period. **(2)**

On the grid below, sketch a graph to show how the *force F* acting on the same body varies with time over the same period.



(2)

(Total 5 marks)

Unit 5 Topic 6 Oscillations (cont.)

4 After the first bounce of a bungee jump, a jumper oscillates on the end of the rope. These oscillations have an initial amplitude of 4.0 m and a period of 5.0 s.

The velocity of the jumper is given by $v = -\omega A \sin \omega t$. Show that the maximum velocity of the jumper is about $5\,\mathrm{m\,s^{-1}}$.

(2)

Explain why the tension in the rope and the jumper's weight must be balanced when the velocity of the jumper is maximum.

(2)

The time period T of the oscillations is given by $T = 2\pi\sqrt{\frac{m}{k}}$.

Calculate the stiffness k for the rope. The jumper has a mass m of 70 kg.

$k =$ ______ **(2)**

Verify, with a suitable calculation, that the rope is never slack during these oscillations.

(3)

Briefly describe the oscillations experienced by the jumper during the minute after the first bounce.

(1)

(Total 10 marks)

Unit 5 Topic 6 Oscillations (cont.)

5 The following invention will allow you to play your music at top volume without annoying the neighbours:

> A layer of small lead spheres is embedded into rubber. If you line your room with this material then the transmitted sound will be significantly reduced. This coating is particularly effective with low frequency sounds, the ones which most annoy the neighbours, as these cause the spheres to resonate.
>
> Adapted from *New Scientist*, Vol.167, Issue 2256

Explain the phenomenon of resonance in the context outlined above and describe how the intensity of the transmitted sound is reduced.

(Total 5 marks)

Unit 5 Topic 7 Astrophysics and cosmology

57 min **57 marks**

1 **(a)** State Newton's law for the gravitational force between two point masses.

____

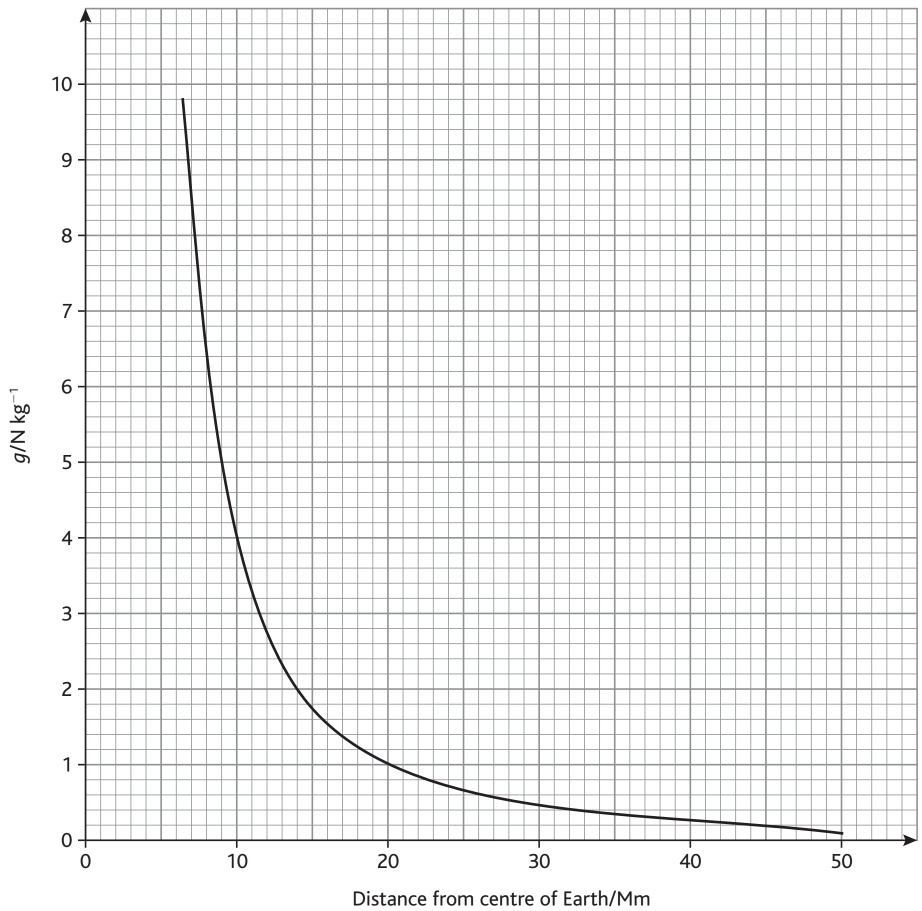
____

____

____

____ **(2)**

(b) The graph shows how the gravitational field strength g above the Earth's varies with the distance from its centre.



Unit 5 Topic 7 Astrophysics and cosmology (cont.)

(i) Use the graph to demonstrate that the relationship between g and distance from the centre of the Earth obeys an inverse square law.

(3)

(ii) The average distance between the centre of the Moon and the centre of the Earth is 380 Mm. Use information from the graph to determine the Earth's gravitational field strength at this distance.

Gravitational field strength = **(2)**

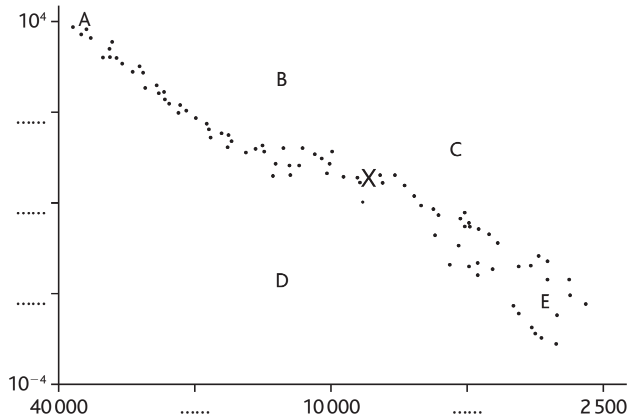
(c) What effect, if any, does the Earth's gravitational field have on the Moon?

(1)

(Total 8 marks)

Unit 5 Topic 7 Astrophysics and cosmology (cont.)

2 On the Hertzsprung–Russell diagram shown below X indicates the position of the Sun.



(i) Add labels and units to each axis. **(2)**

(ii) Complete the scale on the *y*-axis by adding three further values where indicated. **(2)**

(iii) Complete the scale on the *x*-axis by adding two further values where indicated. **(1)**

(iv) Letters A, B, C, D and E represent different stars. Identify all stars which could be:

a red giant	
a low mass star on the main sequence	

(2)

(v) Use the data below to show that the luminosity of the star ζ Tau (Zeta Tauri) is approximately 4×10^{30} W.

Intensity $= 1.9 \times 10^{-8}\,\mathrm{W\,m^{-2}}$

Distance from Earth $= 4.0 \times 10^{18}\,\mathrm{m}$

____

____

____

______________________________ **(3)**

(vi) One of the labelled stars on the Hertzsprung–Russell diagram is ζ Tau. Calculate the luminosity of ζ Tau in terms of solar luminosities and thus deduce which letter must represent this star. Luminosity of the Sun $L_{\odot} = 3.9 \times 10^{26}$ W.

____

____

____

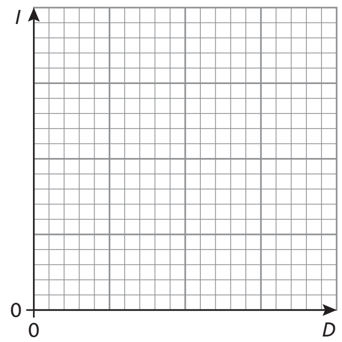
Luminosity = ______________________________

Star = ______________________________ **(3)**

(Total 13 marks)

Unit 5 Topic 7 Astrophysics and cosmology (cont.)

3 **(a)** On the axes below sketch a graph showing how the intensity I of a star varies with distance D from the star.



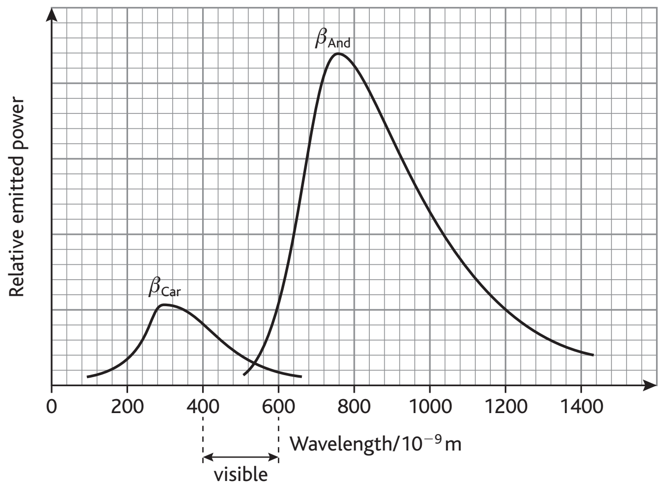
(2)

Give two reasons why measurements of a star's intensity are often made from above the Earth's atmosphere.

1. ______________________

2. ______________________ **(2)**

(b) The graph shows the energy distribution in the spectra of two stars β_{Car} and β_{And}.



What can be deduced about the colours of the two stars from the graph?

____

______________________ **(1)**

Estimate the surface temperature of β_{And}.

____

____

____

______________________ **(3)**

Unit 5 Topic 7 Astrophysics and cosmology (cont.)

The luminosity of β_{Car} is 2.0×10^{28} W and it has a surface temperature of 9300 K. Calculate the surface area of β_{Car}.

(3)

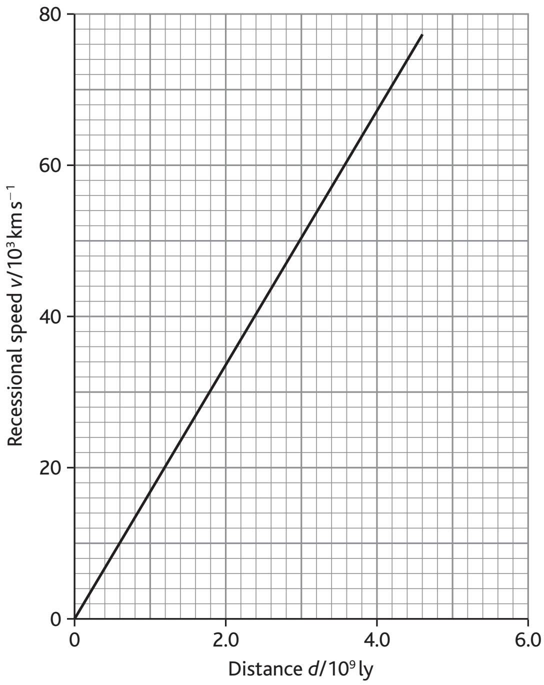
By comparing the areas under the two graphs, estimate the luminosity of β_{And}.

(2)

(Total 13 marks)

Unit 5 Topic 7 Astrophysics and cosmology (cont.)

4 **(a)** Edwin Hubble examined the relationship between the recessional speed of galaxies, v, and their distance, d, from Earth. The graph shows the best-fit line for his results.



(i) Use the graph to determine a value for the Hubble constant, H, in s^{-1}. Show your working.

____

____

____

____

____

____

Hubble constant = ________________________ s^{-1} **(4)**

(ii) What is the main source of uncertainty in the value of H?

____ **(1)**

(b) Explain how the Hubble constant provides us with an estimate for the age of the Universe, t.

____

____

____

____

____

____ **(2)**

Unit 5 Topic 7 Astrophysics and cosmology (cont.)

(c) Ionised calcium has a line spectrum which includes a spectral line of wavelength 393 nm. The observed wavelength of this calcium line in the radiation from a distant galaxy is 469 nm. Calculate the galaxy's recessional speed.

Recessional speed = ______________________ **(3)**

(d) Briefly explain how the value of the average mass-energy density of the Universe will determine whether the Universe is open or closed.

(2)

(Total 12 marks)

Unit 5 Topic 7 Astrophysics and cosmology (cont.)

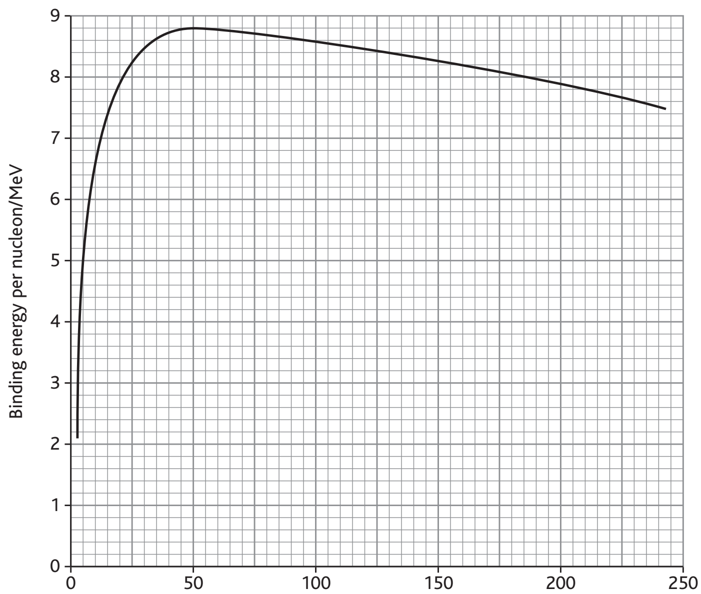
5 (a) In a fast breeder reactor a nucleus of uranium $^{238}_{92}U$ absorbs a neutron to produce uranium, $^{238}_{92}U$. Write a balanced nuclear equation for this reaction.

____ **(1)**

The $^{238}_{92}U$ subsequently undergoes a beta-minus decay to form neptunium Np. Write a balanced nuclear equation for this reaction.

____ **(3)**

(b) The graph shows how the binding energy per nucleon varies with another quantity.



(i) Add an appropriate label to the *x*-axis. **(1)**

(ii) Mark clearly on the graph the approximate position of

- deuterium $^{2}_{1}H$, labelling this point H,
- iron $^{56}_{26}Fe$, labelling this point Fe,
- uranium $^{235}_{92}U$, labelling this point U. **(2)**

(iii) Circle the most stable nucleus on the graph. **(1)**

(iv) Use the graph to calculate the binding energy of a uranium-235 nucleus. Give your answer in GeV.

____

____

____

____

Binding energy = ______________________________ GeV **(3)**

(Total 11 marks)

Unit 4 Topic 1 Further mechanics

1 **Momentum:**

Use of $p = mv$ **(1)**

total momentum = 0.32 kg m s^{-1} or N s **(1)**

Velocity:

Use of conservation of momentum **(1)**

0.062 m s^{-1} [Allow e.c.f. from wrong first answer] **(1)**

East/in same direction as B moved originally **(1)**

[Only award last mark if momenta subtracted in first part] **(Total 5 marks)**

2 **Speed of sphere 1:**

Momentum conserved [stated or implied] **(1)**

Correct substitution in LHS or RHS of conservation of momentum equation **(1)**

Correct answer [$v = 1.43$ (m s^{-1})] **(1)**

Example of calculation:

$54 \times 2.57\ (+0) = 54 \times v + 29 \times 2.12$ (g m s^{-1})

$\Rightarrow 138.78 = 54 \times v + 61.48$

$\Rightarrow v = 1.43$(m s^{-1})

Elastic or inelastic collision:

Recall KE: $\frac{1}{2} mv^2$ **(1)**

Correct values for both KEs [178(mJ), 120(mJ), no u.e.] **(1)**

Conclusion consistent with their results for KE **(1)**

[Max **1** if only words used and inelastic ≡ energy lost implied]

Example of calculation:

$= \frac{1}{2} \times 54 \times 2.57^2 = 178$ mJ

Final total KE: $\frac{1}{2} \times 29 \times 2.12^2 + \frac{1}{2} \times 54 \times 1.43^2$ mJ

$= 65$ mJ $+ 55$ mJ

$= 120$ mJ

$\Rightarrow$ Inelastic

Average speed of the sphere 2:

Recall $v = 2\pi r/t$ **(1)**

Correct answer [2.9 m s^{-1}] **(1)**

Example of calculation:

$v = 2\pi r/t = 2 \times \pi \times 0.17$ m / 0.37 s

$= 2.9$ m s^{-1} or 290 cm s^{-1}

(i) Calculation of centripetal force:

Recall $F = mv^2/r$ OR $mr\omega^2$ OR $mv\omega$ **(1)**

Correct answer [1.43 N, e.c.f. for their v] **(1)**

Example of calculation:

$F = mv^2/r$

$= 0.029 \times 2.9^2 / 0.17$ N [watch out for 29 twice]

$= 1.43$ N [e.c.f.]

(ii) Tension:

Weight of sphere ($= mg = 0.029 \times 9.81$ N $=$) 0.28 N **(1)**

$T = F - W$ **OR** $F = T + W$ [using their values for F and T] **(1)**

Example of calculation:

$T = 1.43 - 0.28$ (N)

$\Rightarrow T = 1.15$ N **(Total 12 marks)**

Unit 4 Topic 1 Further mechanics (cont.)

3 **Speed of car 2:**

$v^2 - u^2 = 2as$

$\Rightarrow (-)u^2 = (-)2 \times 3.43 \times 23.9$ [substitution or rearrangement] (m s^{-1}) **(1)**

$\Rightarrow u = 12.8$ (m s^{-1}) [value] **(1)**

Magnitude of the momentum of car 2:

$p = mv$ **(1)**

$= 1430 \times 12.8$ (13) (kg m s^{-1})

$= 18\,300$ (18 600) N s or kg m s^{-1} **(1)**

Calculation of easterly components of momentum:

Component = momentum $\times \cos\theta$ **(1)**

Car 1: 23 800 N s $\times$ cos 45° = 16 800 N s **(1)**

Car 2: 18 300 (18 600) N s $\times$ cos 30° = 15 800 (16 100) N s **(1)**

Whether car 1 was speeding before accident:

(Sum of two easterly components) ~ 33 000 N s [e.c.f.] **(1)**

($\div$ mass of car 1) $\Rightarrow$ ~ 16.8 m s^{-1} [e.c.f.] **(1)**

Conclusion related to speed limit (17.8 m s^{-1}) **(1)**

Explanation of how investigator could use conservation law:

Any two from:

- Momentum conservation
- After collision there is significant northerly momentum
- Before collision car 1 had no northerly momentum/only car 2 had northerly momentum **(2)**

(Total 12 marks)

4 **Why person moving in a circle must have an acceleration:**

Acceleration due to changing direction

OR

If not the person would continue in a straight line **(1)**

Centripetal acceleration:

$a = \frac{v^2}{r}$ OR $r\omega^2$ **(1)**

$v = \frac{2\pi r}{T} = \frac{2\pi \times 6.4 \times 10^6}{24 \times 60 \times 60} = 465$ (m s^{-1})

OR

$\omega = 7.3 \times 10^{-5}$ (rad s^{-1}) **(1)**

$\Rightarrow a = 0.034$ (m s^{-2}) [no u.e.] **(1)**

Which force is the larger?

mg is larger than R / R is smaller than mg **(1)**

$mg - R$ is the centripetal/accelerating/resultant force that acts towards centre **(1)**

Differing apparent field strength:

(0.034 $\div$ 9.81) $\times$ 100% = 0.35%

OR

(0.03 $\div$ 9.81) $\times$ 100% = 0.31 % [NOT 0.3%] **(1)**

Pendulum clock:

Variation in T = 0.35% $\div$ 2 = 0.175% [0.15% from 0.3% in question] **(1)**

One day:

24 $\times$ 60 $\times$ 60 $\times$ 0.175/100 = 151 s (130 s from 0.3%) [e.c.f.] **(1)**

(Total 9 marks)

Unit 4 Topic 1 Further mechanics (cont.)

5 **Resultant force:**

Direction of travel changing **(1)**
Velocity changing/accelerating **(1)**
Force is towards centre of circle **(1)**

Why no sharp bends:

Relate sharpness of bend to r **(1)**
Relate values of v, r and F **(1)**
[e.g. if r large, v can be large without force being too large/if r small, v must be small to prevent force being too large]

Bobsleigh:

$N \cos \theta = mg$ **(1)**
$N \sin \theta$ **(1)**
$= mv^2/r$ OR ma **(1)**
Proof successfully completed [consequent on using correct formula] **(1)**

Calculation of angle:

77–78° **(1)**

(Total 10 marks)

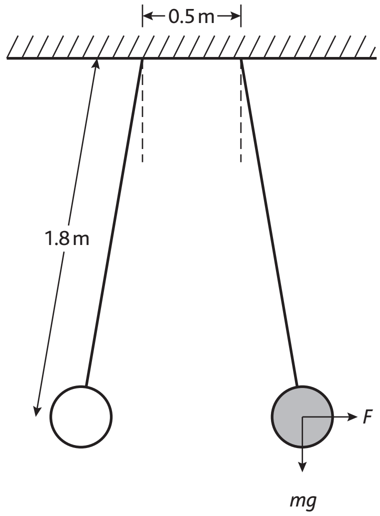
Unit 4 Topic 2 Electric and magnetic fields

1 **Minimum charge on balloon:**

Diagram marks (max **2** marks):

Any 2 forces correct **(1)**

Further mark for all 3 forces correct **(1)**



Intermediate steps (max **3** marks):

$F = kq_1q_2/r^2$; $F = kq^2/r^2$ **(1)**

$mg = T\cos\theta$; $T = 1.8 \times 10^{-2}$ N **(1)**

$F = T\sin\theta$; $F = mg\tan\theta$; $F = 4.6 \times 10^{-4}$ N **(1)**

$r = 0.5 + 2 \times 1.8\sin 1.5°$ (= 0.594 m) **(1)**

$\Rightarrow q^2 = Fr^2/k = Fr^2 \times 4\pi\varepsilon_0$ **(1)**

$= 0.0018 \times 9.81 \times \tan 1.5° \times 0.594^2 \times 4\pi\varepsilon_0$

Answer:

$q = 1.35 \times 10^{-7}$ C **(1)**

[NB **2** for diagram, maximum **3** for intermediate parts, and final **1** for the answer]

(Total 6 marks)

2 (a) (i) **Additional force:**

Correct answer [3.9×10^{-3} N] **(1)**

Example of answer:

$0.4 \times 10^{-3}\,\text{kg} \times 9.81\,\text{N kg}^{-1} = 3.9 \times 10^{-3}\,\text{N}$

(ii) **Explanation** (max **4** marks):

Quality of written communication **(1)**

(Current produces) a magnetic field around the **rod** **(1)**

[Do not accept 'in the rod']

There is an interaction between the two magnetic fields / fields combine to give catapult field **(1)**

Fleming's left hand rule / Fleming's motor rule **(1)**

The rod experiences an upward force **(1)**

Using Newton's third law of motion → downward force on magnet

(b) (i) **Diagram:**

Lower pole labelled North/N and upper pole labelled South/S **(1)**

(ii) **Calculation of current in rod:**

Use of $F = BIl$ (Ignore 10^x. F is the force already calculated and l is 5 cm) **(1)**

See conversions; mT to T and cm to m **(1)**

Correct answer [2.6/2.7 A] **(1)**

Example of calculation:

$I = 3.9 \times 10^{-3}\,\text{N} / (30 \times 10^{-3}\,\text{T} \times 5 \times 10^{-2}\,\text{m}) = 2.6\,\text{A}$

(iii) **New reading on the balance**:

Value < 85 g [not a negative value] **(1)**

84.6 g **(1)**

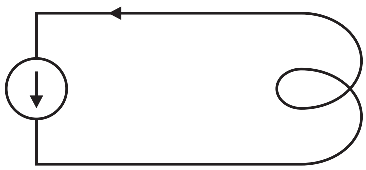
(Total 11 marks)

Unit 4 Topic 2 Electric and magnetic fields (cont.)

3 **Lenz's law:**
The direction of an induced current/emf/voltage is such as **(1)**
to oppose the change (in flux) that produces it. **(1)**

Polarity at top of coil:
North **(1)**

Direction of current :



Only ONE arrow required **(1)**
Graph (Max **2** marks):
Magnet is moving faster / accelerating (under gravity) **(1)**
(Rate of) change/ cutting of flux is greater **(1)**
Induced emf is greater **(1)**

(Total 6 marks)

4 (a) **Electron speed:**
Substitution of electronic charge and 5000 V in eV **(1)**
Substitution of electron mass in $\frac{1}{2}mv^2$ **(1)**
Correct answer [4.2 (4.19) $\times 10^7$ (m s^{-1}), no u.e.] to at least 2 sf **(1)**
[Bald answer scores zero, reverse working can score 2/3 only]
Example of calculation:

$$v^2 = (2 \times 1.6 \times 10^{-19}\,\text{C} \times 5000\,\text{V})/(9.11 \times 10^{-31}\,\text{kg}) = 1.76 \times 10^{15}$$
$$v = 4.19 \times 10^7\,\text{m s}^{-1}$$

(b) (i) **Value of *E*:**
Correct answer [$2.80 \times 10^4\,\text{V m}^{-1}$/N C^{-1} or $2.80 \times 10^2\,\text{V cm}^{-1}$] **(1)**
Example of calculation:

$$E = V/d = 1400\,\text{V} / 5.0 \times 10^{-2}\,\text{m}$$
$$= 28\,000\,\text{V m}^{-1}$$

(ii) **Value of force *F*:**
Correct answer [4.5×10^{-15} N, e.c.f. for their E] **(1)**
Example of calculation:

$$F = Ee = 2.80 \times 10^4\,\text{V m}^{-1} \times 1.6 \times 10^{-19}\,\text{C}$$
$$= 4.48 \times 10^{-15}\,\text{N}$$

Unit 4 Topic 2 Electric and magnetic fields (cont.)

(c) Calculation of *h* (Max **4** marks):

See a = their F / 9.11 × 10^{-31} kg **(1)**

[→ $a = 4.9 \times 10^{15}\,\mathrm{m\,s^{-2}}$]

See t = 12 (× 10^{-2}) m / 4 × $10^{7}\,\mathrm{m\,s^{-1}}$ (or use 4.2 × $10^{7}\,\mathrm{m\,s^{-1}}$) **(1)**

[$t = d/v$, with d = plate length; 12 cm]

[→ $t = 3.0 \times 10^{-9}$ s, or 2.86 × 10^{-9} s]

See substitution of a and t values [*arrived at by above methods*] into $\frac{1}{2}at^2$ **(1)**

Correct answer [h = 0.020−0.022 m] **(1)**

[Full e.c.f. for their value of F **if** methods for a and t correct **and** their $h \leqslant 5.0$ cm]

Example of calculation:

$$h = \tfrac{1}{2}at^2$$
$$= \tfrac{1}{2} \times 4.9 \times 10^{15}\,\mathrm{m\,s^{-2}} \times (2.86 \times 10^{-9}\,\mathrm{s})^2$$
$$= 2.0 \times 10^{-2}\,\mathrm{m}$$

(d) (i) Path A of electron beam:

Less curved than original **(1)**

(ii) Path B of electron beam:

More curved than original, curve starting as beam enters field [started by 'h' of the horizontal plate label] **(1)**

[For **both** curves:
- ignore any curvature beyond plates after exit
- new path must be same as original up to plates]

[No marks if lines not identified, OK if either one is labelled]

(Total 11 marks)

5 **Calculation of charge:**

6000 V × 20 × 10^{-6} F **(1)**

= 0.12 C **(1)**

Energy stored in capacitor:

$$\left(\frac{CV^2}{2}\right) \frac{20 \times 10^{-6}\,\mathrm{C} \times (6000\,\mathrm{V})^2}{2} \textbf{ (1)}$$

= 360 J **(1)**

Resistance:

$$\frac{6000\,\mathrm{V}}{40\,\mathrm{A}} = 150\,\Omega \quad \textbf{(1)}$$

Time to discharge capacitor:

$$\text{Time} = \frac{0.12\,\mathrm{C/their}\ Q}{40\,\mathrm{A}} \quad \textbf{(1)}$$

= 0.0030 s / 3.0 × 10^{-3} s [e.c.f.] **(1)**

Reason:

Time is longer because the rate of discharge decreases/current decreases with time **(1)**

(Total 8 marks)

Unit 4 Topic 3 Particle physics

1 **Rutherford scattering experiment:**
Most went (nearly) straight through **(1)**
A small proportion deflected through large angles **(1)**

Arrows to diagram:
Two arrows directed away from N **(1)**

Sketch graph:
Speeds equal at A and B **(1)**
A non-zero minimum at P **(1)**

Explaining shape of graph:
A to P: force (component) against velocity so decelerates **(1)**
P to B: force (component) in direction of velocity so accelerates **(1)**

Add to diagram:
Same initial path but deflected through larger angle **(1)**

Observations:
More alpha particles deflected/alphas deflected through large angles/fewer pass straight through **(1)**

(Total 9 marks)

2 (a) **Description of protons movement along linac** (Max **5** marks):
Quality of written communication **(1)**
Protons drift/move uniformly inside tubes **(1)**
Accelerate between the tubes/in the gaps **(1)**
Alternating pd reverses while proton is in tube **(1)**
The tubes must get longer as proton speeds up **(1)**
For time inside tube to be constant or to synchronise movement with the pd **(1)**

(b) (i) **Kinetic energy gained:**
Multiply by 419 or 420 **(1)**
Multiply by 1.6×10^{-19} **(1)**
Correct answer to at least 2 **sf** **(1)**
[$5.36/5.38/5.4 \times 10^{-11}$ (J)] [no u.e.]
Δm = energy ÷ ($9.0 \times 10^{16}\ \text{m}^2\,\text{s}^{-2}$) **(1)**
[e.c.f. their energy or 5×10^{-11}] **(1)**
$\Delta m \div 1.01 \times 1.66 \times 10^{-27}$ kg [e.c.f. their Δm] **(1)**
Correct answer **(1)**
[0.36 or 36%] [Use of 5×10^{-11} gives 33%] **(1)**
[Accept routes via Δm in u and m_p in J]

(ii) **Travel time of proton:**
Use of $1/f$ **(1)**
∴ time down linac = $420 \div 3.9 \times 10^8\ \text{s}^{-1}$
or $210 \div 3.9 \times 10^8\ \text{s}^{-1}$ **(1)**
[$t = 1.07/1.08/1.1 \times 10^{-6}$ (s) or 0.54×10^{-6} (s)]

Unit 4 Topic 3 Particle physics (cont.)

(c) Advantages and disadvantages of experimental arrangement (Max 2 marks):

(i) Fixed target:
Large(r) number of /more collisions or more likely to get collisions
[not easier to get collisions] **(1)**
Other particle beams produced **(1)**

(ii) Colliding beams:
More energy available for new particles **(1)**
$p = 0$ so all energy available **(1)**

(Total 15 marks)

3 **Explanation:**
Energy gained by electron accelerated through 1 V/$W = QV$ **(1)**
$W = 1.6 \times 10^{-19}$ C $\times$ 1 V $= 1.6 \times 10^{-19}$ J **(1)**

Unit of mass:
$\Delta E = c^2 \Delta m$ so $\Delta m = \Delta E/c^2$ **(1)**
GeV is energy $\Rightarrow$ GeV/c^2 is mass **(1)**

Mass of Higgs boson:
$m = 115 \times [10^9] \times 1.6 \times 10^{-19}/(3 \times 10^8)^2$ **(1)**
$= 2.04 \times 10^{-25}$ kg **(1)**

Antiparticle:
Same mass and opposite charge **(1)**
[Accept particle and its antiparticle annihilate ($\rightarrow$ photons)] **(1)**

Explanation of need for a magnetic field and why it can be small:
Force deflects particles/force produces circular motion **(1)**
Force is perpendicular to motion/force provides centripetal force **(1)**
r is large or curvature is small/gentle **(1)**
reference to $B = p/rQ$ to show why small B is needed **(1)**

(Total 11 marks)

4 **Quark compositions**
baryon **and** 3 quarks **(1) (1)**
[If only one correct then 1 mark]
meson **and** quark + antiquark **(1) (1)**
[If only one correct then 1 mark]
[May use symbols for quarks]

Conserved quantities:
Momentum, charge, (mass-)energy, lepton number **(1) (1)**
[2 right gets **1** mark; all 3 right get **2** marks]
[Do not credit kinetic energy]

Charge of the pentaquark:
$$2 \times \frac{+2}{3} + 2 \times \frac{-1}{3} + \frac{1}{3}$$
$= (+)1(\text{e})$ **(1)**

Unit 4 Topic 3 Particle physics (cont.)

Charge on X:
Positive since pentaquark was positive, neutron neutral [e.c.f.] **(1)**
[Reasoning needed]

Possible quark composition for X **with explanation:**
u $\bar{s}$ **(1)**
Left behind (after removing neutron/udd) **(1)**

Mass of pentaquark:
Conversion from GeV to J or substitution of c^2 **(1)**
Correct answer [no u.e.] **(1)**
$1.54 \times 10^9 \times 1.6 \times 10^{-19}/(3 \times 10^8)^2 = 2.7 \times 10^{-27}$ kg

(Total 12 marks)

5 **Direction of travel of electron:**
Anticlockwise **(1)**

Why track is curved and spiral:
Force perpendicular to v **(1)**
Force perpendicular to B **(1)**
Electron loses energy *or* v decreases **(1)**

Measurements from image:
r_{max} = 108 (100−120) mm **(1)**

$$\left.\begin{array}{l}\Rightarrow p = BQr \\ = 4 \times 1.6 \times 10^{-19} \times 0.108\ (108)\end{array}\right\}\text{equation OR substitution } \mathbf{(1)}$$

$= 6.9\ (6.4-7.7) \times 10^{-20}$ (kg m s^{-1}) [no u.e.] **(1)**

Consistency of tracks:
Any two from:
- photon leaves no track
- opposite/different directions of curvatures/spiral [NOT opposite directions without reference to curve/spiral]
- similar/same curvatures/radii/shape
- no evidence of any other particles/two tracks only **(2)**

[Symmetrical scores once under bullet point 2 or 3]

How event obeys two conservation laws (Max **2** marks)**:**
Naming two laws, e.g. charge and momentum **(1)**
Any one from:
- Charge $0 \rightarrow +1 + -1$
- Momentum (↕) γ initial → electron + positron
- Momentum ↔ electron = positron
- Energy of photon = mass + energy of electron and positron **(1)**

(Total 11 marks)

Unit 5 Topic 4 Thermal energy

1 **Energy calculation:**

$\Delta Q = mc\Delta T$

$\Delta Q = 0.7\,\text{kg} \times 4200\,\text{J}\,\text{kg}^{-1}\,\text{K}^{-1} \times 80\,\text{K}$ **(1)**

$\Delta Q = 235\,200$ (J) [or 235 (kJ)] [no u.e.] **(1)**

Time taken:

$\text{Time} = \dfrac{\text{energy}}{\text{power}}$

$\dfrac{235\,200\,\text{J}}{2200\,\text{W}}$

Formula **(1)**

Substitution [Allow e.c.f.] **(1)**

Time = 106.9 s [or 110 s] **(1)**

[Allow use of 250 kJ to give 114 s]

Graph:

Temperature becomes constant at the end **(1)**

Uniform rate of temperature rise/straight line in central region **(1)**

Initially rate slow, then rate increases, then rate decreases **(1)**

Efficiency:

Efficiency = ratio of two times or two energies **(1)**

in range 0.67–0.78 **(1)**

[Allow their calculated time value and time from graph in range 145–160 s]

(Total 10 marks)

2 **Definition of specific heat capacity**

Energy (needed) **(1)**

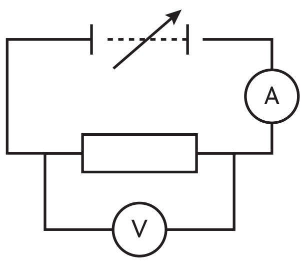
(per) unit mass/ kg) (per) unit temperature change/°C / K) **(1)**

OR

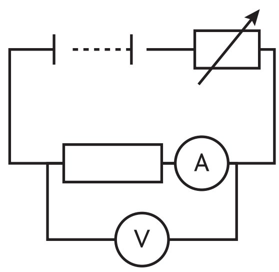
Correct formula [does not need to be rearranged] **(1)**

with correctly defined symbols **(1)**

Circuit diagrams:



OR



[Accept voltmeter across heater and ammeter as well as voltmeter across heater only.]

Means of varying pd/current **(1)**

Voltmeter in parallel with a resistor *symbol* **(1)**

Ammeter in series with any representation of heater **(1)**

Other apparatus:

- (Top pan) balance / scales **(1)**
- Stopwatch / timer / clock **(1)**

Unit 5 Topic 4 Thermal energy (cont.)

Explanation (Max **1** mark):
Energy/heat loss to surroundings/air/bench **(1)**
OR
$mc\Delta\theta + \Delta Q = VIt$ or equivalent in words (e.g. student ignores energy loss in calculations) **(1)**
OR
$mc\Delta T + \Delta Q = VIt$ or equivalent words **(1)**

Modifications:
Any two from:
- Use of insulation around block
- Ensure all of heater is within block
- Grease heater/thermometer **(2)**

(Total 10 marks)

3 **Mean square speed:**
Attempt to find either squares or any mean **(1)**
See 2.8×10^5 (278 300) **(1)**
Units: $m^2\,s^{-2}$ or $(m\,s^{-1})^2$ **(1)**
Expression:
$(\rho =)\ \frac{Nm}{V}$ **(1)**
Mean kinetic energy (Max **3** marks):
Substitution of $\frac{Nm}{V}$ for ρ **(1)** State kinetic energy $= \frac{1}{2}m\langle c^2\rangle$ **(1)**
Equate $NkT = \frac{1}{3}Nm\langle c^2\rangle$ [i.e. makes a correct substitution for pV] **(1)**
States m, N and k constant (so KE $\propto T$) **(1)**

(Total 7 marks)

4 **(a) Completing table:**
p: pressure; $N\,m^{-2}$/Pa **(1)**
V: volume; m^3 **(1)**
N: number of molecules; no unit **(1)**
T: temperature; K **(1)**
[Accept words for the units]

(b) Temperature of gas:
Use of $V_1/T_1 = V_2/T_2$ **(1)**
Conversion of °C to K **(1)**
Final volume $= 1.5 \times 10^{-4}\,m^3$ **(1)**
Correct answer 167 (°C) **(1)**
Example of calculation:

$$\frac{1.0 \times 10^{-4}\ m^3}{293\ K} = \frac{1.5 \times 10^{-4}\ m^3}{T_2}$$

$$T_2 = 439.5\ K$$

(Total 8 marks)

Unit 5 Topic 4 Thermal energy (cont.)

5 (a) (i) **Density of gas and KE of molecules:** $\rho = Nm/V$ **(1)**

(ii) **Expression for average KE:** $KE = \frac{1}{2}m\langle c^2\rangle$ **(1)**

(b) **Pressure proportional to temperature**

Substitute for density in the pressure equation **(1)**

$\frac{1}{2}m\langle c^2\rangle = 3pV/2N$ **(1)**

Equate this expression to constant $\times$ T **(1)**

(c) **Temperature calculation:**

Use of $p_1/T_1 = p_2/T_2$ **(1)**

$T_1 = 293\,\mathrm{K}$ **(1)**

Temperature 684 K/411°C **(1)**

(Total 8 marks)

Unit 5 Topic 5 Nuclear decay

1 **Why gamma radiation used**
γ is the *most*/*more* penetrating **(1)**
(OR α/β *less* penetrating)

Factors controlling amount of radiation:
Any 2 from:
- strength/type of radiation source/half-life/age of source
- speed of conveyor belt/exposure time
- shape/size of food packages/surface area
- distance from radiation source **(2)**

Suitable material for wall:
Concrete/lead **(1)**

Suitable thickness:
Concrete: 30 cm − 1 m; lead: 1 − 10 cm **(1)**
[Thickness mark dependent on named material]

Source of natural radiation:
Rocks, soil, cosmic rays, named radioactive element, Sun, space, air **(1)**

(Total 6 marks)

2 **Why γ-rays are dangerous**
Penetrates (skin) **(1)**
Can cause ionisation/cell damage/mutation **(1)**
[not kill cells]

Material for shielding
Lead **(1)**
Several centimetres (0.5–5 cm) **(1)**

Why α radiation not used
Not (sufficiently) penetrating (not absorbed by luggage) **(1)**

Exposure of air travellers to increased background radiation:
Exposed to more cosmic radiation **(1)**
Less atmosphere above them for shielding **(1)**

(Total 7 marks)

3 (a) **Sources of background radiation**
Any 2 from:
cosmic rays, rocks, soil, food, nuclear power/industry [buried waste as alternative], atmosphere, building material, medical uses, nuclear weapons testing (in the 1960s), Sun, radon gas **(2)**
[Do not credit more than one example in each category, e.g. coffee and Brazil nuts is 1 mark not 2]

Unit 5 Topic 5 Nuclear decay (cont.)

(b) (i) Measurement of background count rate (Max **4** marks):
- Use GM tube or stop watch/ratemeter/data logger **(1)**
- All sources must be in their (lead) containers / placed away from the experiment / place thick lead around tube **(1)**
- Measure count over measured period of time (and divide count by time) **(1)**
- Repeat and average / measure the count for at least 5 minutes **(1)**
- Subtract background (count rate) from readings **(1)**

(ii) Why it might be unnecessary to measure background count rate:
Count rate for the radioactive material is much greater than the background count rate. **(1)**
[Comparison required with count rate of radioactive material]

(Total 7 marks)

4 **Decay constant of americium-241:**
$\lambda = 0.69/432$ (yr^{-1}) **(1)**
$\lambda = 5.1 \times 10^{-11}$ (s^{-1}) [At least 2 sf] **(1)**

Number of nuclei:
3.0×10^{13} **(1)**

Activity calculation:
Use of $A = \lambda N$ **(1)**
$A = 1.5 \times 10^{3}$ Bq / s^{-1} [e.c.f.] **(1)**

Explanation:
Range few cm in air/short range **(1)**
Alpha would produce enough ions (to cross gap)
OR ionises densely/strongly/highly **(1)**

Features of americium sample:
Half-life long enough to emit over a few years **(1)**
Count well above background **(1)**
Suitable as safe as range very low/shielded **(1)**

(Total 10 marks)

5 (a) (i) **Meaning of stable:**
Will not: decay / disintegrate / be radioactive / emit radiation / emit particles / break down **(1)**
[Do not accept ‘will not emit energy’]

(ii) Complete equation:
${}^{1}_{1}Y$ **(1)**

(iii) Identify particles:
X = neutron **(1)**
Y = proton **(1)**

Unit 5 Topic 5 Nuclear decay (cont.)

(b) (i) Decay constant of carbon-14

Use of $\lambda = \frac{0.69}{t_{1/2}}$, i.e. $= \frac{0.69}{5568 \times 3.2 \times 10^7\text{ s}}$ **(1)**

[Do not penalise incorrect time conversion]

Correct answer [3.87×10^{-12} (s^{-1})] to at least 2 sf [no u.e.] **(1)**

[Bald answer scores 0]

(ii) Number of nuclei of carbon-14

Use of $A = \lambda N$ e.g. $\frac{16}{60} = (-)\ 4 \times 10^{-12} N$ **(1)**

[e.c.f. their value of λ] [Do not penalise incorrect time conversion]

Answer in range 6.6×10^{10} to 7.0×10^{10} **(1)**

(Total 8 marks)

Unit 5 Topic 6 Oscillations

1 **Gradient of graph:**
Gradient (numerical value) = 2.5 **(1)**
Unit s^{-2} or negative sign **(1)**

Frequency:
$(2\pi f)^2 = 2.5$ [or above value] **(1)**
$f = 0.25$ Hz [e.c.f. ONLY for gradient error] **(1)**

Period:
$T = 4$ s e.c.f. their f **(1)**

Acceleration against time graph:
Any sinusoidal curve over at least two cycles **(1)**
Negative sine curve **(1)**
y-axis scale showing $a = 20$ (mm s^{-2}) OR x-axis scale showing $T = 4$ (s) / their T **(1)**

(Total 8 marks)

2 **Simple harmonic motion:**
Acceleration proportional to displacement (from equilibrium position/point) **(1)**
and in opposite direction/directed towards equilibrium position/point) **(1)**
OR
accept fully defined equation **(2)**

Oscillations:
$A = 0.036$ m **(1)**
Period = 7.60 s/20 = 0.380 s **(1)**
$f = 2.63$ Hz **(1)**

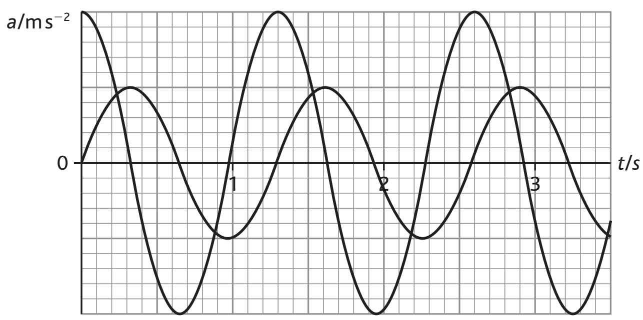
Displacement when t = 1.00 s:
$x = (-)0.026$ m **(1)**

How and why motion differs from prediction:
Motion is damped/amplitude decreases with time **(1)**
(Because of) air resistance **(1)**

(Total 8 marks)

3 **Frequency:**
0.7 Hz → 0.8 Hz **(1)**

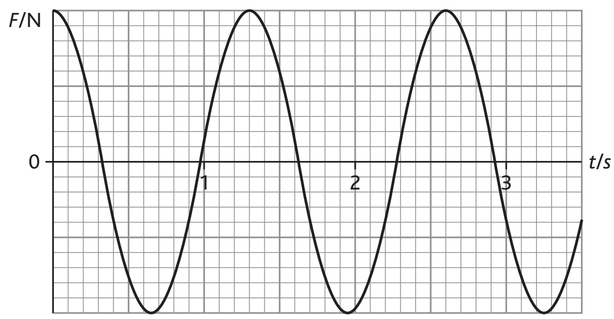
Addition to graph:



(2) [If inverted, **(1)**, **(0)**]

Unit 5 Topic 6 Oscillations (cont.)

Graph showing how force varies with time:



(2) [If inverted, **(1)**, **(0)**]

(Total 5 marks)

4 **Velocity of jumper:**

$\omega = 2\pi/T = 2\pi/5.0\text{ s}$ ($= 1.26\text{ s}^{-1}$) **(1)**

$v_{max} = A\omega = 4.0\text{ m} \times 2\pi/5.0\text{ s} = 5.0(3)$ (m s^{-1}) **(1)**

Why tension in rope and jumper's weight must be balanced:

When v is maximum, acceleration $= 0$ **(1)**

so net force $= 0$ **(1)**

[OR: If forces not in equilibrium, he would accelerate/decelerate. **(1)**

So velocity cannot be maximum **(1)**]

Calculation of stiffness *k* for rope:

Use of $T = 2\pi\sqrt{m/k}$ **(1)**

Hence $k = 4\pi^2 m/T^2 = 4\pi^2 \times 70\text{ kg}/(5.0\text{ s})^2$

$= 109\text{–}111\text{ N m}^{-1}$ [kg s^{-2}] **(1)**

Verification that rope is never slack during oscillations:

$F = mg = 70\text{ kg} \times 9.81\text{ N kg}^{-1} = 687\text{ N}$ **(1)**

At centre of oscillation, when forces in equilibrium:

$x = F/k = 687\text{ N}/110\text{ N m}^{-1}$ (allow e.c.f. from previous part) **(1)**

$= 6.2\text{ m}$ which is larger than amplitude **(1)**

OR

Calculation of a_{max} ($= -\omega^2 A$) [6.32 m s^{-2}] **(1)**

Comparison with g of 9.81 m s^{-1} **(1)**

Deduction **(1)**

Likewise for forces approach.

Motion of jumper: Any 1 from:

- motion is damped SHM
- so amplitude decreases
- but period stays (approximately) the same. **(1)**

(Total 10 marks)

Unit 5 Topic 6 Oscillations (cont.)

5 **Phenomenon of resonance in the context outlined, etc.**

Any five from:

- spheres can oscillate
- resonance when forcing frequency = natural frequency
- sound provides forcing frequency
- low frequency due to mass/density of lead spheres

At resonance, there is:

- large amplitude of oscillation (of spheres)
- maximum energy transfer to spheres
- energy transfer to thermal in the rubber
- minimum energy transfer to neighbours. **(5)**

(Total 5 marks)

Unit 5 Topic 7 Astrophysics and cosmology

1 (a) **Newton's law**

Equation route:

$F = \dfrac{Gm_1m_2}{r^2}$ **(1)**

m_1, m_2, r defined correctly, G defined correctly or not defined **(1)**

[Both marks can be awarded for word equation]

OR

Proportion route:

(force is directly) proportional to the **product** of the masses [plural] **(1)**

and inversely proportional to the square of their separation [not just 'radius', unless related to orbital motion] **(1)**

(b) (i) **Graph** (Max **3** marks):

Take two pairs of values off graph **(1)**

(A) Find gr^2 for one pair [≈ 400 ($\times 10^{12}$)]

Attempt to show $gr^2 \approx$ same for second pair **(1)**

(within uncertainty limits of data read from graph) **(1)**

OR

(B) Compare pairs of values to show that as r changes by a factor n, g changes by a factor $1/n^2$. **(1)** **(1)**

OR

(C) Substitute into formula with one pair to give a value of m or some other constant. **(1)**

Repeat with second pair to give same value OR substitute back to confirm agreement of second pair of values. **(1)**

(ii) **Gravitational field strength:**

Valid approach via routes A, B or C above. **(1)**

$g = 0.0027 - 0.0031\ \mathrm{N\,kg^{-1}}$ **(1)**

Example of calculation:

$g \times 380^2 = 400 \rightarrow g = 400/380^2 = 0.002\,77\ \mathrm{N\,kg^{-1}}$

(c) **Effect** (Max **1** mark):

Any one from: maintains the Moon in orbit around the Earth / keeps Moon **(1)** rotating around the Earth / provides (**all** the) centripetal **(1)** force/acceleration for its circular motion / pulls Moon towards Earth. [**not** just exerts force on the Moon]

(Total 8 marks)

Unit 5 Topic 7 Astrophysics and cosmology (cont.)

2 (a) H–R diagram:

(i) Axis labels:
L and T **(1)**
$L_\odot$ and K **(1)**
or L and $L_\odot$ **(1)**, T and K **(1)**, not W]

(ii) Scale on y-axis:
Any 2 correct [of 10^2, 1 or 10^0, 10^{-2}] **(1)**
All 3 correct **(1)**

(iii) Scale on x-axis:
20 000 and 5000 **(1)**

(iv) Identify stars:
Red giant = (B and) C **(1)**
Low mass main sequence star = E [ignore X] **(1)**

(v) Zeta Tauri luminosity:
Use of $L = 4\pi D^2 I$ **(1)**
Correct substitution **(1)**
$3.8(2) \times 10^{30}$ (W) **(1)**

(vi) Zeta Tauri identification (e.c.f.):
$3.8(2) \times 10^{30}$ W ÷ 3.9×10^{26} W [or 4×10^{30} W used] **(1)**
Correct ratio [e.g. 9700, 9800, 10 300 or 10^4, etc.] **(1)**
Hence A [from answer in range 9700 to 10 300] **(1)**

(Total 13 marks)

3 (a) Graph:
Falling concave curve **(1)**
Not intercepting x-axis or y-axis **(1)**

Two reasons:

- light is **scattered** by dust (or air molecules)/refraction **(1)** [allow twinkling]
- some wavelengths are absorbed by the atmosphere **(1)**

(b) Two spectra:
β_{Car} is bluish; β_{And} is reddish [not just different colours] **(1)**

Temperature estimate:
Read off $\lambda_{max} \approx$ (760–770) nm [beware 680 nm] **(1)**
Use of Wien's law **(1)**
Answer T = 3800 K [allow 3600 K to 4000 K] **(1)**

Calculation of surface area:
Use $L = \sigma A T^4$ **(1)**
$A = 2.0 \times 10^{28}\,\text{W} \div (9300\,\text{K}^4 \times 5.67 \times 10^{-8}\,\text{W m}^{-2}\,\text{K}^{-4})$ **(1)**
$= 4.7 \times 10^{19}\,\text{m}^2$ **(1)**

Estimate of luminosity:
Attempt at areas giving ~ 7 × [(× 5 – × 8) allowed] **(1)**
$= 1.4 \times 10^{29}$ W [$(1.0 - 1.6) \times 10^{29}$ W allowed] **(1)**

(Total 13 marks)

Unit 5 Topic 7 Astrophysics and cosmology (cont.)

4 (a) (i) **Hubble constant:**

Use of $v = Hd$ or gradient $= H$ **(1)**

Converts yr to s, i.e. $\times$ ($365 \times 24 \times 60 \times 60$) **(1)**

Correct $\times$ by 'c' **(1)**

[Seeing 9.46×10^{15} gets previous two marks]

1.7 to 1.8×10^{-18} (s^{-1}) **(1)**

[No marks for a bald answer]

Example calculation:

$$H = 60 \times 10^6 \, m\,s^{-1} / (3.6 \times 10^9 \, 1y \times 365 \times 24 \times 3600 \times 3 \times 10^8 \, m \, 1y^{-1})$$
$$= 1.8 \times 10^{-18} \, s^{-1}$$

(ii) **Uncertainty in *H*:**

Distance / d **(1)**

(b) **Age of Universe:**

States that $d = vt$ (any arrangement) **(1)**

Combines this with restated Hubble law (any arrangement) to give:

$t = \frac{1}{H}$ **(1)**

(c) **Recessional speed:**

Red shift = 76 nm / 469–393 nm **(1)**

Use of $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ **(1)**

$5.8 \times 10^7 \, m\,s^{-1}$ **(1)**

Example calculation:

$$v = 76 \times 10^{-9} \, m \times 3 \times 10^8 \, m\,s^{-1} / 393 \times 10^{-9} \, m$$
$$= 5.8 \times 10^7 \, m\,s^{-1}$$

(d) **Average mass–energy density:**

Closed: high density/above critical density **(1)**

Then gravitational pull (or force or attraction) sufficient to cause Big Crunch/pull everything back/stop expansion **(1)**

[NOT to hold the galaxies together]

OR equivalent argument for Open. [Don't accept mass for density in mark 1 or just 'gravity' in mark 2]

(Total 12 marks)

Unit 5 Topic 7 Astrophysics and cosmology (cont.)

5 (a) **Neutron capture equation:**

$^{238}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{239}_{92}\text{U}$ **(1)**

Beta minus decay:

$^{239}_{92}\text{U} \rightarrow ^{239}_{93}\text{Np} + ^{0}_{-1}\beta + \overline{v}$

$\text{U} \rightarrow \text{Np} + \beta^-$ **(1)**

Hence all six numbers correct **(1)**

Antineutrino shown **(1)**

(b) (i) **Label for *x*-axis of binding energy per nucleon graph:**

Nucleon number / mass number **(1)**

(ii) **Position of nuclei on graph** (Max **2** marks):

H at start of curve ($<$ 3 MeV); Fe at peak of curve (at 56); U at end of curve (at 235) [to $\pm$ 1 mm]

Any two **(1);** additional mark for all three **(1)**

(iii) **Identifying most stable nucleus:**

Fe (e.c.f.) **(1)**

(iv) **Binding energy of U**

7.5/7.6 (e.c.f.) **(1)**

$\times$ 235 **(1)**

1.8 (GeV) [allow 1.76–1.80, no e.c.f.] **(1)**

(Total 11 marks)

Data

The value of the following constants will be provided in each examination paper.

Acceleration of free fall	$g = 9.81\ \mathrm{m\,s^{-2}}$ (close to Earth's surface)
Boltzmann constant	$k = 1.38 \times 10^{-23}\ \mathrm{J\,K^{-1}}$
Coulomb's law constant	$k = \dfrac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9}\ \mathrm{N\,m^2\,C^{-2}}$
Electron charge	$e = -1.60 \times 10^{-19}\ \mathrm{C}$
Electron mass	$\mathrm{m}_e = 9.11 \times 10^{-31}\ \mathrm{kg}$
Electronvolt	$1\ \mathrm{eV} = 1.60 \times 10^{-19}\ \mathrm{J}$
Gravitational constant	$G = 6.67 \times 10^{-11}\ \mathrm{N\,m^{-2}\,kg^{-2}}$
Gravitational field strength	$g = 9.81\ \mathrm{N\,kg^{-1}}$ (close to Earth's surface)
Permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{F\,m^{-1}}$
Planck constant	$h = 6.63 \times 10^{-34}\ \mathrm{J\,s}$
Proton mass	$m_\mathrm{p} = 1.67 \times 10^{-27}\ \mathrm{kg}$
Speed of light in a vacuum	$c = 3.00 \times 108\ \mathrm{m\,s}{-1}$
Stefan–Boltzmann constant	$\sigma = 5.67 \text{ x } 10^{-8}\ \mathrm{W\,m^{-2}\,K^{-4}}$
Unified atomic mass unit	$u = 1.66 \text{ x } 10^{-27}\ \mathrm{kg}$

Formulae

Unit 4

Mechanics	
Momentum	$p = mv$
Kinetic energy of a nonrelativistic particle	$E_k = p^2/2m$
Motion in a circle	$v = \omega r$ $T = 2\pi/\omega$ $F = ma = mv^2/r$ $a = v^2/r$ $a = r\omega^2$
Fields	
Coulomb's law	$F = kQ_1Q_2/r^2$ where $k = 1/4\pi\epsilon_0$
Electric field	$E = F/Q$ $E = kQ/r^2$ $E = V/d$
Capacitance	$C = Q/V$
Energy stored in capacitor	$W = \frac{1}{2}QV$
Capacitor discharge	$Q = Q_0\, e^{-t/RC}$
In a magnetic field	$F = BIl \sin\theta$ $F = Bqv \sin\theta$ $r = p/BQ$
Faraday's and Lenz's laws	$\varepsilon = -d(N\Phi)/dt$
Particle physics	
Mass–energy	$\Delta E = c^2\Delta m$
de Broglie wavelength	$\lambda = h/p$

Formulae

Unit 5

Energy and matter	
Heating	$\Delta E = mc\Delta\theta$
Molecular kinetic theory	$\frac{1}{2}m < c^2 > = \frac{3}{2}kT$
Ideal gas equation	$pV = NkT$
Nuclear physics	
Radioactive decay	$\mathrm{d}N/\mathrm{d}t = -\lambda N$ $\lambda = \ln 2/t_{\frac{1}{2}}$ $N = N_0\,\mathrm{e}^{-\lambda t}$
Mechanics	
Simple harmonic motion	$a = -\omega^2 x$ $a = -A\omega^2 \cos \omega t$ $v = A\omega \sin \omega t$ $x = A \cos \omega t$ $T = 1/f = 2\pi/\omega$
Gravitational force	$F = Gm_1m_2/r^2$
Observing the universe	
Radiant energy flux	$F = L/4\pi d^2$
Stefan–Boltzmann law	$L = \sigma T^4 A$ $L = 4\pi r^2 \sigma T^4$
Wien's law	$\lambda_{max} T = 2.898 \times 10^{-3}\,\mathrm{m\,K}$
Redshift of electromagnetic radiation	$z = \Delta\lambda/\lambda \approx \Delta f/f \approx v/c$
Cosmological expansion	$v = H_0 d$