

PHYSICS



EXAM QUESTION PACK

MODULE 5 RISE AND FALL OF THE CLOCKWORK UNIVERSE

SCORE

/518

PERCENTAGE

%

STEMUP

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- 1 Source **A** is a radioisotope with a half-life of 2 hours. Source **B** is a radioisotope with a half-life of 4 hours. The initial activity of source **A** is twice that of source **B**.

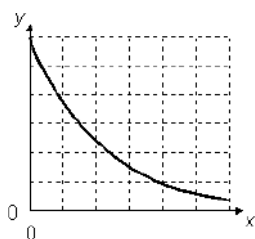
How long will pass before the activity of source **B** is twice that of source **A**?

- A 4 hours
- B 6 hours
- C 8 hours
- D 12 hours

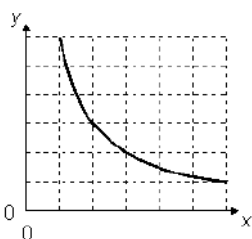
Your answer

[1]

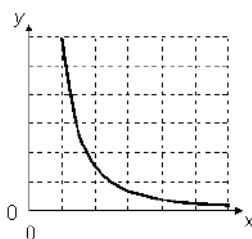
- 2 The graphs **A–D** represent different relationships between variables. The dotted lines mark out equal intervals along the x - and y -axes.



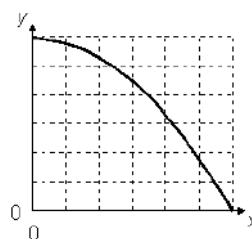
A



B



C



D

Which graph **A**, **B**, **C**, or **D** best represents the relationship between the variables x and y where:

y is the pressure of a fixed mass of gas at room temperature

x is the volume occupied by that gas.

Your answer

[1]

- 3 Four different ions enter a region of uniform magnetic field. Each ion enters with the same velocity. The magnetic field acts at 90° to the path of the ions. Each ion is defined below in terms of its nucleon number and charge.

Which ion will travel in a circular path with the largest radius?

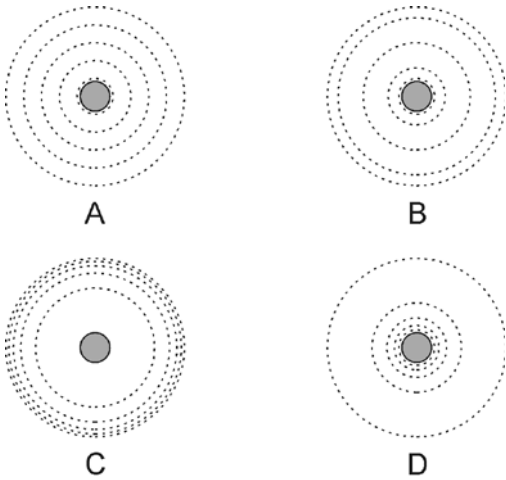
	nucleon number	charge
A	1	1
B	2	1
C	3	1
D	7	2

Your answer

[1]

- 4 Here are four diagrams of possible equipotentials near an isolated star. In each diagram, the difference in gravitational potentials between adjacent equipotentials is the same.

Which diagram is correct?



Your answer

[1]

- 5 A satellite orbits the Earth in a circular orbit of height 2.3×10^6 m above the ground.

What is the angular velocity ω of the satellite?

radius of Earth = 6.4×10^6 m.

mass of Earth = 6.0×10^{24} kg

A $6.1 \times 10^{-7} \text{ rad s}^{-1}$

B $3.3 \times 10^{-5} \text{ rad s}^{-1}$

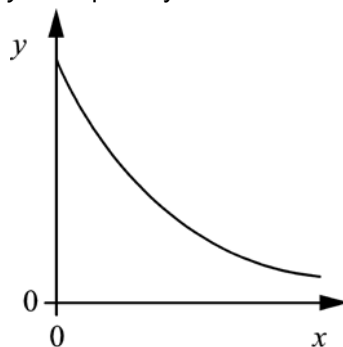
C $7.8 \times 10^{-4} \text{ rad s}^{-1}$

D $5.7 \times 10^{-3} \text{ rad s}^{-1}$

Your answer

[1]

- 6 The graph shows the variation in quantity y with quantity x .



Which pair(s) of quantities produce a similar graph?

- 1 mass remaining of a radioisotope (y) against time (x)
- 2 charge (y) on a capacitor against potential difference (x) across the capacitor
- 3 gravitational field strength from a point mass (y) against distance from mass (x)

- A 1, 2 and 3
- B Only 1 and 2
- C Only 2 and 3
- D Only 1

Your answer

☐

[1]

- 7 A $4700\ \mu\text{F}$ capacitor is discharged through a $2200\ \Omega$ resistor. To the nearest second, how long will it take for the charge on the capacitor to fall to half its original value?

- A 3 s
- B 5 s
- C 7 s
- D 10 s

Your answer

☐

[1]

8 Here are some data about a volume of an ideal gas:

$$\text{volume} = 0.5 \times 10^{-3} \text{ m}^3$$

$$\text{pressure} = 0.25 \text{ MPa}$$

$$\text{temperature} = 30 \text{ }^\circ\text{C}$$

What is the number of particles in the volume of gas?

A 3×10^{20}

B 3×10^{21}

C 3×10^{22}

D 3×10^{23}

Your answer

[1]

- 9 A mass M oscillates in simple harmonic motion between two fixed supports. Frictional effects can be ignored. The time period of the oscillation is T_1 .



The mass is replaced with a mass of $4 M$ and the amplitude of the oscillation is doubled. The new time period is T_2 .

Which is the correct statement?

A $T_2 = 4 T_1$

B $T_2 = 2 T_1$

C $T_2 = T_1$

D $T_2 = \frac{1}{2} T_1$

Your answer

[1]

- 10 The activation energy E_A for the conduction of a semiconductor diode is 0.14 eV. The operating temperature of the diode in a circuit is measured at 85 ± 4 °C. A student is considering the effect this uncertainty causes in the calculation of the Boltzmann factor $e^{-E_A/kT}$.

Which of the following statements is / are true?

- 1 The % uncertainty in the Boltzmann factor will be the same as in the temperature.
- 2 Temperatures should be expressed on the absolute scale in Kelvins for calculations with the Boltzmann factor.
- 3 The % uncertainty in T is 1.5% to two significant figures.

- A 1, 2 and 3 are correct
B Only 1 and 2 are correct
C Only 2 is correct
D Only 1 is correct

Your answer ☐

[1]

11

The ratio of masses $\frac{M_{\text{Earth}}}{M_{\text{Moon}}} \approx 80$ and the ratio of radii $\frac{r_{\text{Earth}}}{r_{\text{Moon}}} \approx 4$.

What is the best estimate of the ratio of gravitational fields at the surface of the two bodies $\frac{g_{\text{Earth}}}{g_{\text{Moon}}}$?

- A 1.6
B 5
C 20
D 320

Your answer ☐

[1]

12

The ratio of masses $\frac{M_{\text{Earth}}}{M_{\text{Moon}}} \approx 80$ and the ratio of radii $\frac{r_{\text{Earth}}}{r_{\text{Moon}}} \approx 4$.

What is the best estimate of the ratio of gravitational potentials at the surface of the two bodies $\frac{V_{\text{Earth}}}{V_{\text{Moon}}}$?

- A 1.6
- B 5
- C 20
- D 320

Your answer

[1]

- 13 The half-life of a muon at rest is $1.52 \mu\text{s}$. Muons in cosmic rays are observed to have half-lives of $10.4 \mu\text{s}$.

Calculate the velocity of the muons in cosmic rays.

velocity = _____ ms^{-1} [3]

14(a) Theory suggests that about 14×10^9 years ago the Universe was much smaller than it is now and that the temperature of the Universe was about 3000 K. Since that time, the Universe has expanded and cooled to a background temperature of about 2.8 K.

State the observation that suggests that the Universe is continuing to expand.

[1]

(b) The energy of photons released in the very early Universe has reduced by a factor of about 1000. Calculate the factor by which the wavelength of the photons has changed during this time.

[2]

16(a) This question is about the decay of protactinium.

Fig. 38.1 shows a graph of the natural log of corrected count rate A against time in seconds.

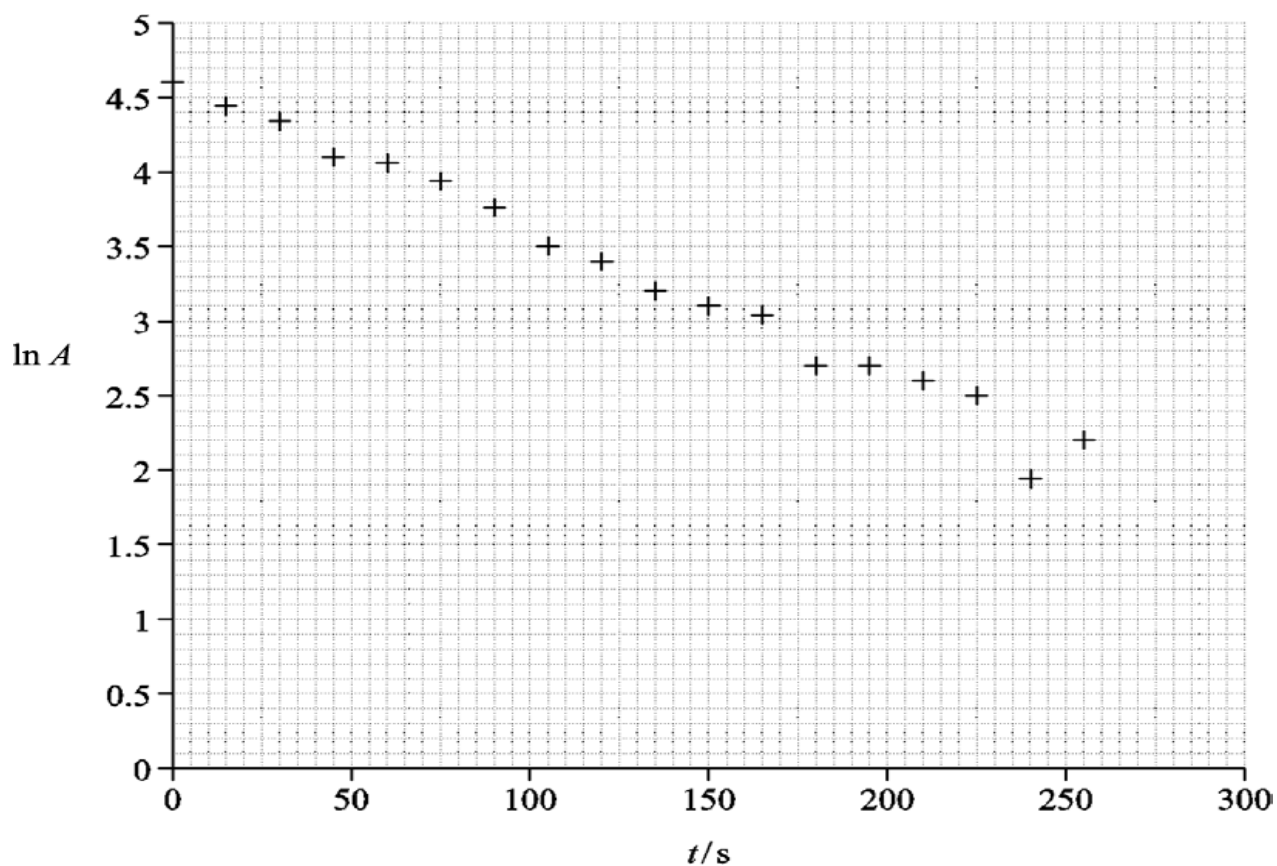


Fig. 38.1

(i) Draw a best fit line on Fig. 38.1.

The equation of the line is $\ln A = \ln A_0 - \lambda t$ where λ is the decay constant and A_0 is the initial activity of the source.

Use this to show that the decay constant of the protactinium is about 0.01 s^{-1} .

[3]

(ii) Use the value from (i) to calculate the half-life of the source.

half-life of source = _____ s [2]

17(a) A student wanted to use a capacitor and a resistor in an electronic timer.
 She used the circuit shown in Fig. 4.1 to test a capacitor C and variable resistor R_2 .

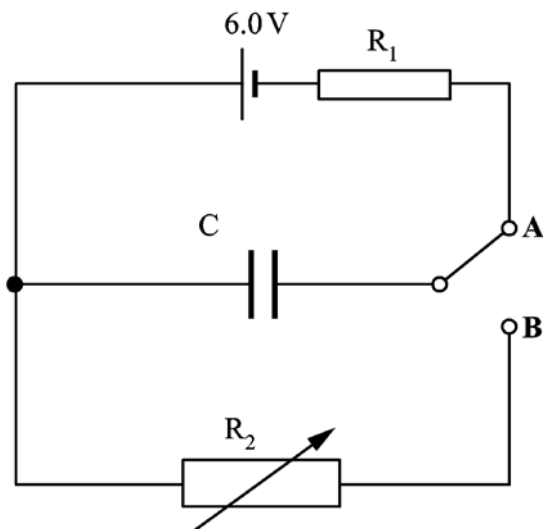


Fig. 4.1

In one test the capacitor was first charged through the fixed resistor R_1 by connecting the switch to A. It was then discharged through the variable resistor R_2 by connecting the switch to B. The student used a data-logger to measure how the voltage across capacitor C varied as it charged and then discharged through the two different resistors. A data table of her results is shown in Fig.4.2.

charging through R_1		discharging through R_2	
t / ms	p.d. ₁ / V	t / s	p.d. ₂ / V
0	0.00	0	6.00
2	0.46	2	5.54
4	0.89	4	5.11
6	1.28	6	4.72
8	1.65	8	4.35
10	1.98	10	4.02
12	2.29	12	3.71
14	2.58	14	3.42
16	2.84	16	3.16
18	3.09	18	2.91
20	3.31	20	2.69
22	3.52	22	2.48
24	3.71	24	2.29
26	3.89	26	2.11

28	4.05	28	1.95
30	4.20	30	1.80

Fig.4.2

Figs. 4.3a and 4.3b show the charge and discharge curves for the data in the table in Fig. 4.2.

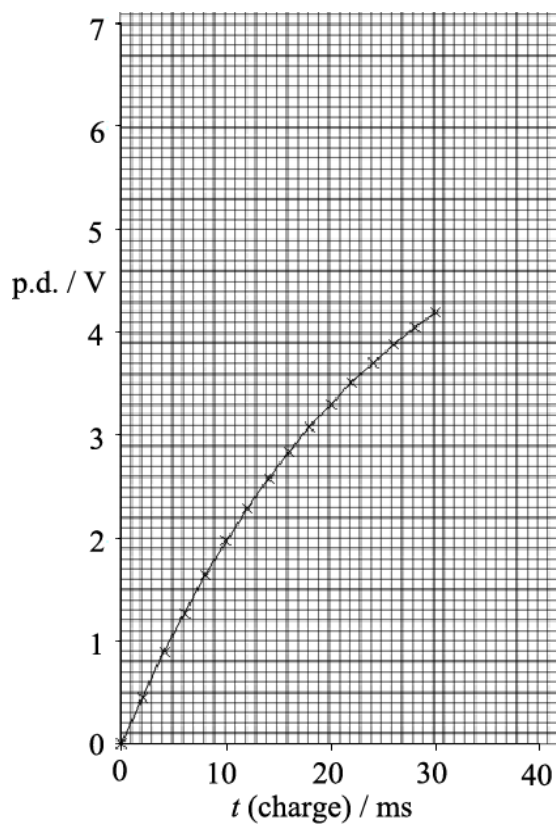


Fig. 4.3a

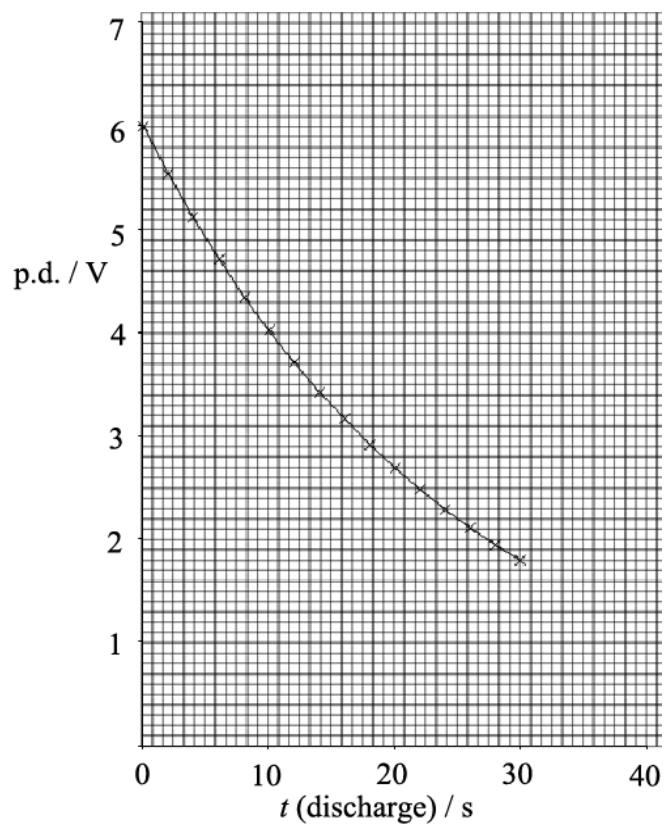


Fig. 4.3b

- (i) Using the graph of Fig. 4.3b, show that the time constant for the discharge is less than 30 seconds.

[3]

- (ii) The capacitor has a value of $4700\ \mu\text{F}$. Show that the initial discharge current would be about $1\ \text{mA}$.

[4]

- (iii) * The student calculated the total amount of charge to flow from the capacitor in the first 30 seconds. She used two methods:

Method 1 – using the relationship $\Delta Q = C \Delta V$

Method 2 – using $I = \frac{V}{R}$ and the area under the $I(t)$ graph where R is $5.0\ \text{k}\Omega$

Show how the total charge flow may be calculated in both cases and comment on how the two methods compare.

[6]

(b) In the student's proposed timer, the p.d. across R_2 must fall to 1.0 V in less than 50 seconds.

Use suitable calculations to demonstrate whether the circuit meets this requirement.

[4]

(c) Calculate the value of the charging resistor R_1 .

resistance = _____ Ω [3]

18(a) A sealed gas jar contains air as shown in Fig.2.1.

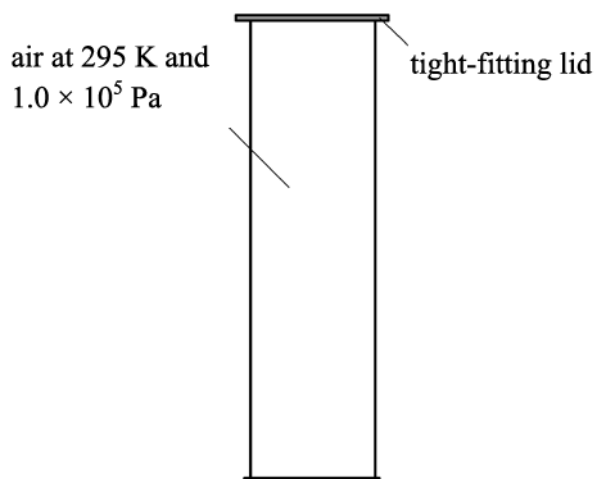


Fig.2.1

The air is at a temperature of 295 K and is at a pressure of $1.0 \times 10^5 \text{ Pa}$. The gas jar has an internal diameter of 50 mm and an internal height of 200 mm.

- (i) Show that the gas jar contains about 10^{22} gas molecules.

$$k = 1.38 \times 10^{23} \text{ J K}^{-1}$$

[3]

- (ii) Assume that each molecule occupies, on average, a cubic space of volume x^3 as shown in Fig. 2.2. The distance x between the centre of adjacent cubes is the mean separation between molecules.

Show that the mean separation x between molecules is about 3 nm.

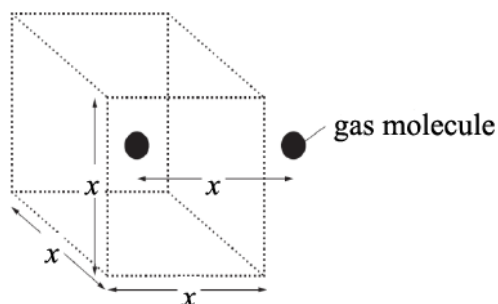


Fig. 2.2

[2]

(b)

- (i) Show that the r.m.s. speed of a molecule of an ideal gas is given by the equation

$$\text{r.m.s. speed} = \sqrt{\frac{3kT}{m}}$$

[2]

- (ii) A crystal of iodine is placed at the bottom of the gas jar. The iodine vapourises. After 5 minutes iodine vapour is detected at a height of 12 cm above the crystal.

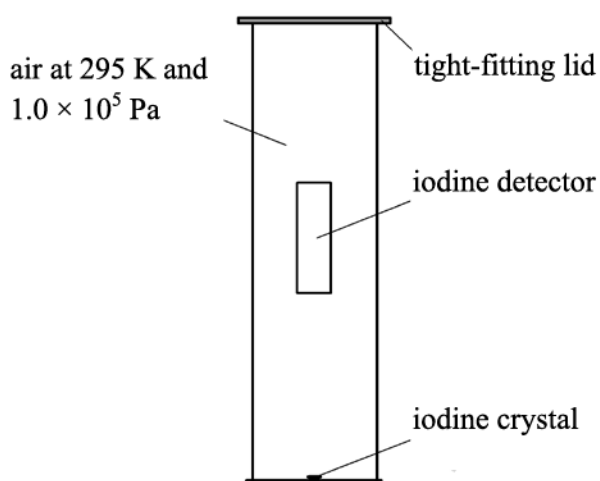


Fig. 2.3

Assuming that iodine vapour behaves as an ideal gas, calculate the mean distance travelled by an iodine molecule in 5 minutes and explain why the iodine vapour travelled only about 12 cm in that time.

$$k = 1.4 \times 10^{-23} \text{ J K}^{-1}$$

$$\text{mass of iodine molecule, } m = 2.1 \times 10^{-25} \text{ kg}$$

[3]

- 19(a) The rod is now pushed vertically down into the water by a distance s , where s is of the order of one or two cm.
Show that the resultant acceleration a is given by

$$a = -\left(\frac{\rho_w g A}{m}\right)s$$

and explain why it would oscillate with simple harmonic motion of period T where

$$T = 2\pi\sqrt{\frac{m}{\rho_w g A}}$$

[5]

- Suggest and explain reasons why the pendulum method is likely to be chosen if a value of g with a small uncertainty is wanted.

In your answer you may wish to consider a pendulum of length 1m and a rod of mass 1 kg and cross sectional area 0.005 m^2 floating in water of density 1000 kg m^{-3} .

[6]

- 20 **Fig. 6.4** shows an annihilation in a cloud chamber. There is a uniform magnetic field acting perpendicularly into the diagram, shown by the shaded area. An antiproton (p^-) enters near the bottom and collides with a stationary proton. The annihilation creates eight hadrons numbered 1 – 8 in **Fig. 6.4**.

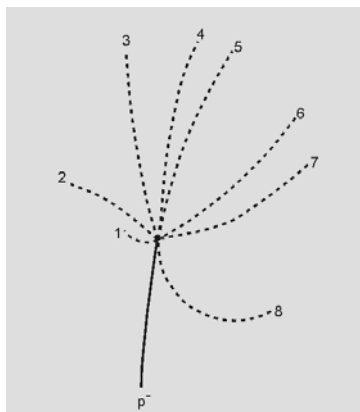


Fig. 6.4

- (i) Explain how the tracks of the particles in **Fig. 6.4** show that charge is conserved in this reaction.

[2]

- (ii) Hadron 8 in **Fig. 6.4** moves on a track with initial radius of 4.6 mm.

Calculate the velocity of this hadron.

hadron charge = 1.6×10^{-19} C

hadron mass = 2.5×10^{-28} kg

magnetic field strength = 2.2 T

velocity = _____ m s⁻¹ [3]

21(a) The article describes the temperature of the solar corona as being far above that of the photosphere (line 13).
The coronal X-rays detected by SOHO are in the wavelength range 0.10 nm to 10 nm.

Use these data to show how the temperature of the solar corona compares with that of the visible surface of the Sun (about 6000 K).

$$k = 1.4 \times 10^{-23} \text{ J K}^{-1}$$

[3]

- (b) Measurements by SOHO's LASCO instrument showed that coronal mass ejections (CMEs) travel at speed between 20 km s^{-1} and 3200 km s^{-1} , with an average of 490 km s^{-1} . Suggest and explain how authorities can use these data, together with continuing observations from SOHO, to reduce the effects that a large CME could have upon the Earth.

[3]

22(a) This question is about the orbit of SOHO.

Show that the centripetal acceleration experienced by SOHO as it orbits the Sun at position L1 (lines 7 to 10 and Fig. 2 in the article) is about $6 \times 10^{-23} \text{ m s}^{-2}$.

$$1 \text{ year} = 3.2 \times 10^7 \text{ s}$$

[4]

- (b) By calculating the gravitational forces exerted on SOHO by the Earth and the Sun, explain how SOHO is kept at point L1.

$$\text{mass of Sun} = 2.0 \times 10^{30} \text{ kg}$$

$$\text{mass of Earth} = 6.0 \times 10^{24} \text{ kg}$$

$$\text{mass of SOHO} = 1900 \text{ kg}$$

[5]

- 23 A comet's distance from the Sun varies considerably as it moves through the Solar System (line 32 of the article). Data for Comet Halley are shown in Fig. 8.1.

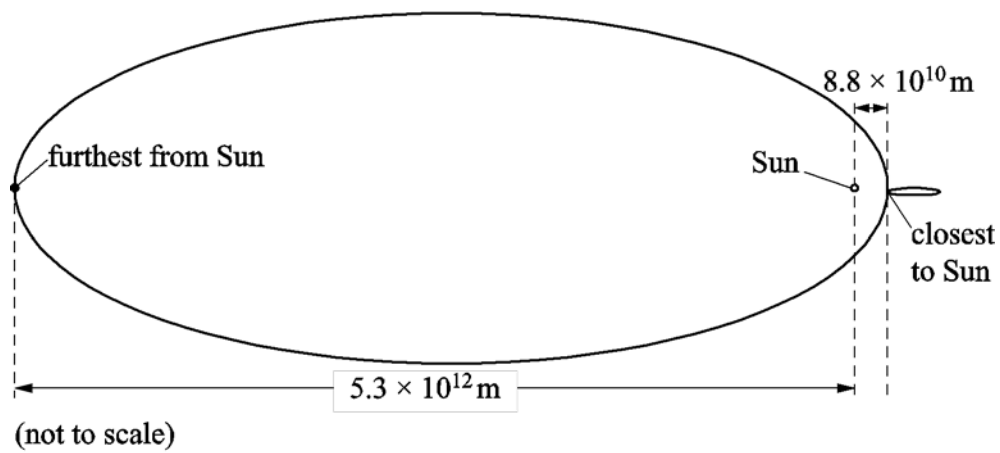


Fig. 8.1

At its furthest distance from the Sun, Comet Halley has a speed of 880 m s^{-1} . Show that it is travelling about 60 times faster than this at its closest approach.

mass of Sun = $2.0 \times 10^{30} \text{ kg}$

mass of Comet Halley = $2.2 \times 10^{14} \text{ kg}$

[4]

24(a) Here is a list of units.

N s N kg^{-1} kg m s^{-1} kg m s^{-2}

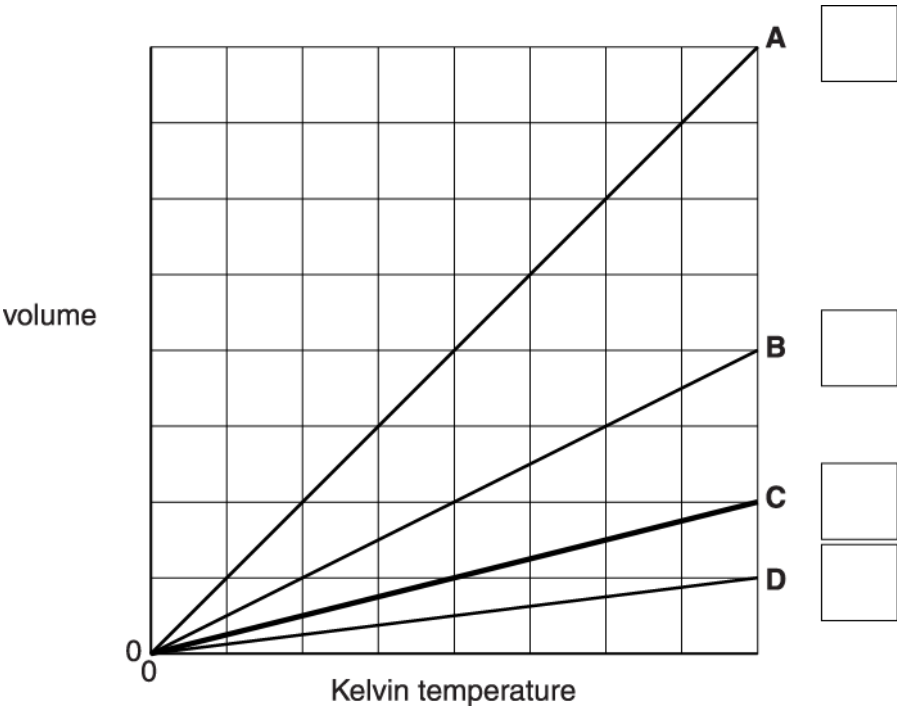
Which is the correct unit for gravitational field strength?

_____ [1]

(b) Which **two** units are the same?

_____ and _____ [1]

25 The line labelled C on the graph shows the expansion of an ideal gas at constant pressure.



Tick the box next to the line that would be produced by **both** doubling the mass of gas **and** halving the pressure at the same time.

[1]

26(a) In a simple model of a solid the energy of its particles is quantised.

The bar chart of Fig. 3.1 shows the number of particles in the energy levels above the lowest one at a particular temperature.

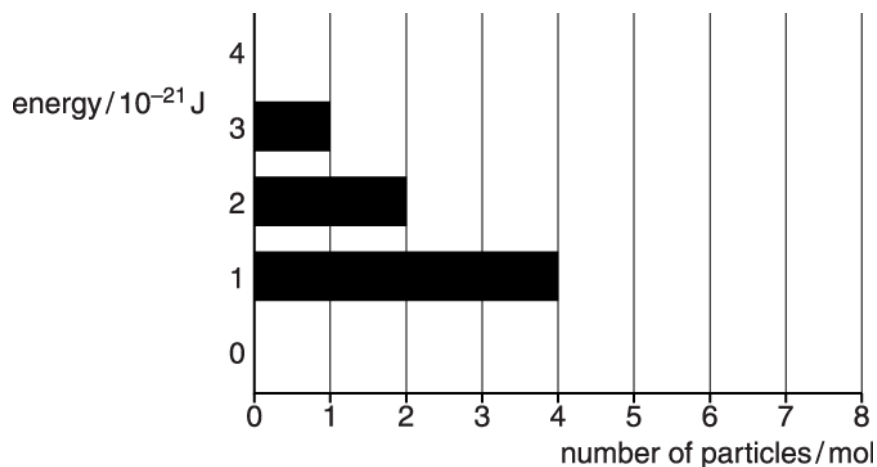


Fig. 3.1

Here is a list of values.

0.5 1 2 4 6 8

The ratio of the number of particles in adjacent energy levels is given by the Boltzmann factor. Which value is the Boltzmann factor for the solid?

Boltzmann factor = _____ [1]

- (b) The bar chart does **not** show the number of particles with zero energy. Which value is the number of particles with no energy?

number of particles = _____ mol [1]

- 27 A student measures the volume V of a fixed mass of air for different values of temperature T and pressure p . The results are shown in the table.

T / K	V / ml	p / kPa	
283	5.5	100	
270	2.2	230	
373	6.0	120	

The student decides that the data are consistent with air obeying the ideal gas equation

$$pV = NkT.$$

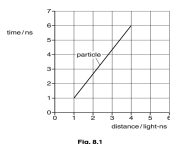
Is this conclusion correct, given the precision of the data in the table?
Justify your answer with calculations.

[3]

- 28 The idea that the Universe started with a big bang almost 14 billion years ago is now a widely accepted theory. Explain how the red shift of distant galaxies provides evidence for this theory.

[2]

29(a) The graph of Fig. 8.1 shows a time-distance graph of an unstable particle as it passes through a laboratory.



The particle is produced at time 1.00 ns, measured by a clock in the laboratory.
The particle decays at time 6.0 ns, giving it a life time of 5.0 ns.

Show that the speed of the particle through the laboratory is about $2 \times 10^8 \text{ m s}^{-1}$.
 $c = 3.0 \times 10^8 \text{ m s}^{-1}$

- [1]
- (b) Calculate the relativistic factor γ , and determine the life time of this particle if it had been at rest in the laboratory.

life time = _____ ns [2]

30 A student sets up the circuit shown in Fig. 9.1 with an old capacitor.

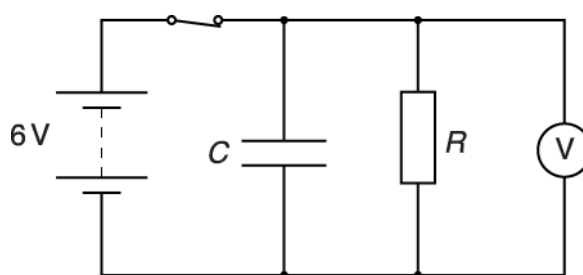


Fig. 9.1

The p.d. across the capacitor in the circuit is measured after the switch has been opened. The results are shown in the graph of Fig. 9.2.

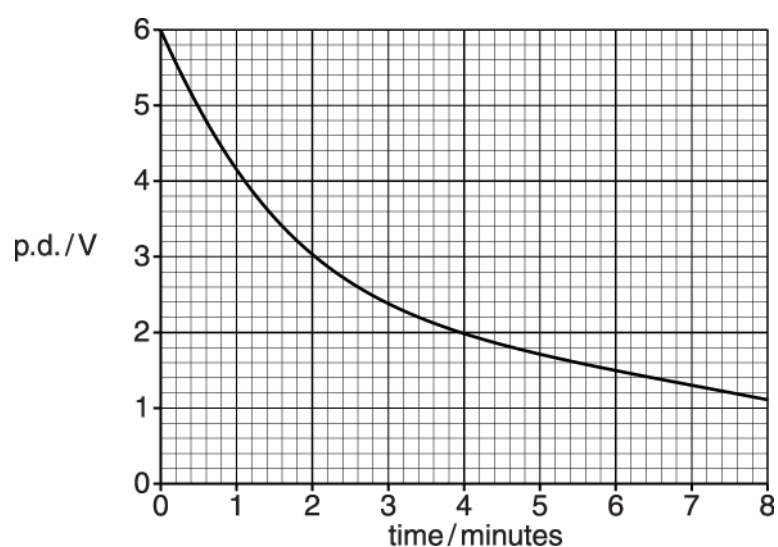


Fig. 9.2

The student expects the graph to show exponential decay, but it does not.

Use data from the graph to show that the graph does not show exponential decay.

[2]

31(a) This question is about the planet Jupiter and its satellite Io.

The mean radius r of the orbit of Io is $4.2 \times 10^8 \text{ m}$ and its orbital period T is 43 hours.

(i) Show that Io's mean orbital speed v is about 20 km s^{-1} .

[2]

(ii) By considering the centripetal force on Io from Jupiter, show that the mass of Jupiter M is given by

$$M = \frac{rv^2}{G}.$$

[2]

(iii) Calculate the mass of Jupiter.

$$G = 6.7 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$$

mass = _____ kg [1]

(b) Io's orbit is actually an ellipse, shown exaggerated in Fig. 10.1.

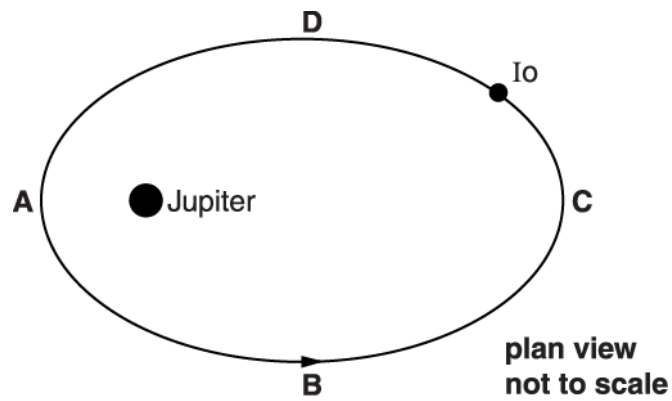


Fig. 10.1

- (i) Draw an arrow on Fig. 10.1 to show the direction of the gravitational force on Io from Jupiter.

[1]

- (ii) On Fig. 10.2, sketch a graph to show how the speed of Io changes in one orbit around Jupiter.

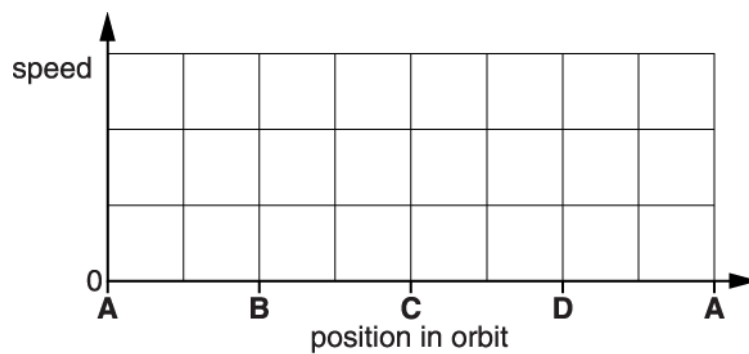


Fig. 10.2

[1]

- (iii) Explain why the speed changes in this way.

[2]

32(a) This question is about the scarcity of helium atoms in the Earth's atmosphere.

Party balloons are often inflated with helium gas. This gas eventually finds its way into the atmosphere. The Earth's gravitational field prevents the atmosphere from escaping into space.

Explain why the kinetic energy E_k of an atom of mass m which is just able to leave a planet's gravitational field is given by the expression

$$E_k = \frac{GMm}{R}$$

where M is the mass of the planet and R is its radius.

[2]

- (b) Show that the minimum energy of a helium atom which **can** escape the Earth's gravitational field is about 4×10^{-19} J.

molar mass of helium = 4.0×10^{-3} kg

Avogadro constant = 6.0×10^{23} mol⁻¹

mass of Earth = 6.0×10^{24} kg

radius of Earth = 6.4×10^6 m

$G = 6.7 \times 10^{-11}$ N m² kg⁻²

[2]

- (c) The average temperature at the surface of the Earth is 15°C.

- (i) Estimate the average energy of a helium atom in the Earth's atmosphere.

$k = 1.4 \times 10^{-23}$ J K⁻¹

average energy = _____ J [2]

- (ii) Explain why energies of helium atoms at a given height and temperature in the Earth's atmosphere have a wide range of values.



Your answer should clearly link the variations in the energy of the helium atoms to the behaviour of

particles in the atmosphere.

[3]

(iii) A student suggests that helium atoms in the atmosphere eventually escape into space.

Use the Boltzmann factor $e^{-\frac{\epsilon}{kT}}$ to discuss this idea.

[3]

33(a) This question is about measuring the air pressure inside a vacuum cleaner hose.

A vacuum cleaner reduces the pressure in its inlet hose to below atmospheric pressure. This reduction in pressure is about 20 kPa.

To test this, a student sets up the experiment shown in Fig. 12.1.

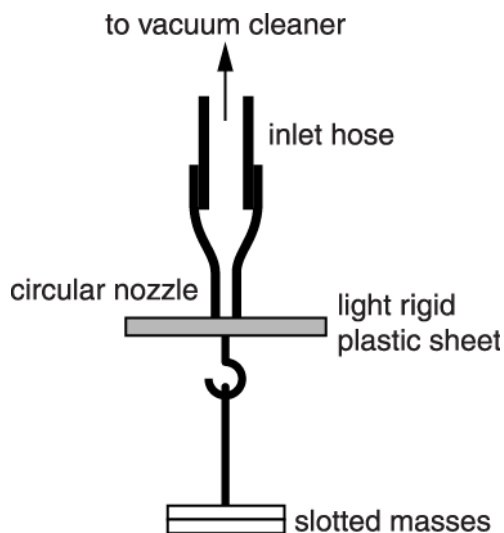


Fig. 12.1

When the vacuum cleaner is turned on, a number of slotted 100 g masses can be hung from the plastic sheet.

- (i) Explain, in terms of the behaviour of the air particles on each side of the sheet, how this difference in pressure holds the sheet in place.



Your answer should clearly link the forces on the sheet to the motion of the air particles on each side of it.

[3]

- (ii) The student finds that only two 100 g masses can be hung from the plastic sheet before it is pulled from the nozzle.

Calculate the pressure of the air in the hose.

nozzle diameter = 12 mm

atmospheric pressure = 100 kPa

$g = 9.8 \text{ N kg}^{-1}$

pressure = _____ Pa [3]

- (b) The student proposes to improve the precision of the measurement by removing the nozzle on the end of the inlet hose, as shown in Fig. 12.2.

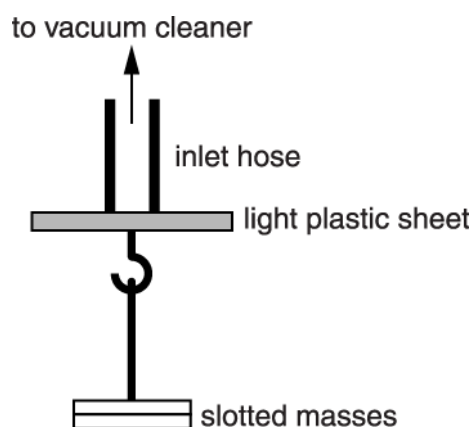


Fig. 12.2

This increases the diameter of the hose touching the sheet to 30 mm. This reduces the uncertainty in the measurement of the maximum mass supported by the light plastic sheet. Calculate what effect this has on the precision of the measurement of the pressure in the vacuum hose.

[3]

34 This question is based on the Advance Notice *Electricity for Spacecraft*.

Long conducting cables ('tethers') hung from some satellites could be used to generate significant voltages (line 42 in the article).

Show that the speed that these satellites orbit the Earth is about $8 \times 10^3 \text{ m s}^{-1}$.

radius of Earth = 6400 km

height of satellite above Earth's surface = 1000 km

orbital period = 100 minutes

[2]

35 Here is a list of oscillators.

1 infrared radiation

2 mains voltage

3 a simple pendulum 1 metre long

Which of the following sequences correctly places them in order of increasing frequency?

A 2 1 3

B 2 3 1

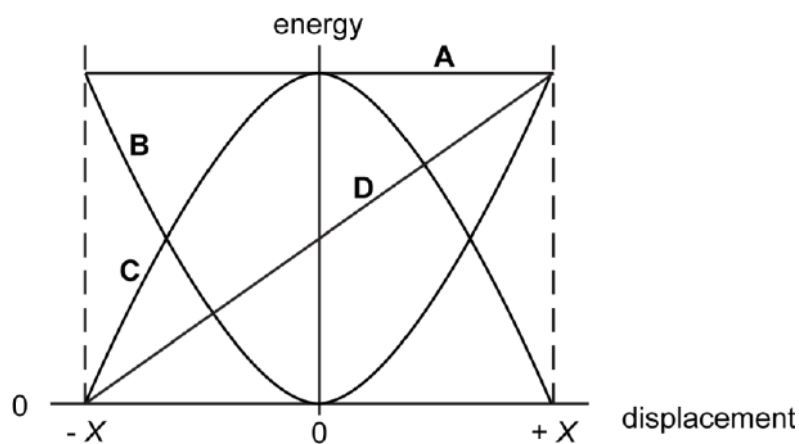
C 3 1 2

D 3 2 1

Your answer

[1]

- 36 The graphs **A** to **D** may plot energy against displacement for a harmonic oscillator.
The oscillator vibrates in a straight line with amplitude X .

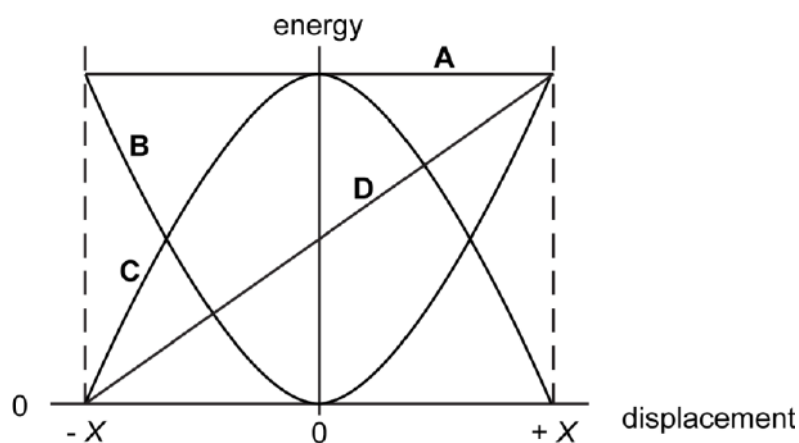


Which graph represents the total energy of the harmonic oscillator?

Your answer

[1]

- 37 The graphs **A** to **D** may plot energy against displacement for a harmonic oscillator.
The oscillator vibrates in a straight line with amplitude X .

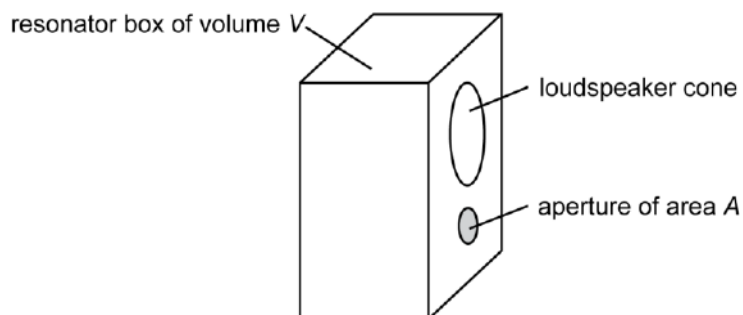


Which graph represents the kinetic energy of the harmonic oscillator?

Your answer

[1]

- 38 Bass speakers can be mounted in a box to act as a resonator at natural frequency f .
The box has a volume V and an aperture of area A cut into its front as shown.



The resonator frequency f is given by $f^2 = \frac{kA}{V}$ where k is a constant.

The designer wants to make the aperture a circle of radius r .

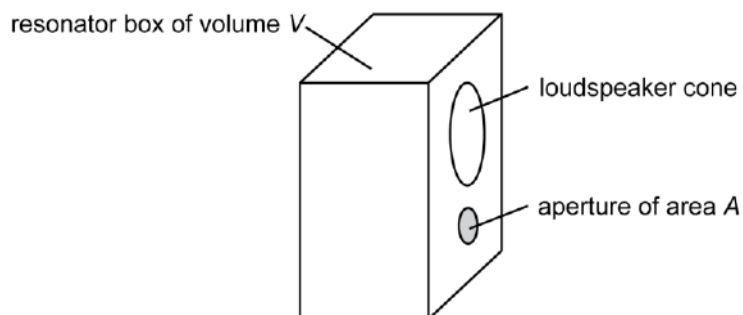
How does the volume V vary with r when the resonant frequency f is kept constant?

- A V is proportional to $\frac{1}{r}$
- B V is proportional to r^2
- C V is proportional to $r^{1/2}$
- D V is proportional to r

Your answer

[1]

- 39 Bass speakers can be mounted in a box to act as a resonator at natural frequency f .
The box has a volume V and an aperture of area A cut into its front as shown.



The resonator frequency f is given by $f^2 = \frac{kA}{V}$ where k is a constant.

The designer wants to make the aperture a circle of radius r .

How does the resonant frequency f vary with r when the volume V is kept constant?

- A f is proportional to $\frac{1}{r}$
- B f is proportional to r^2
- C f is proportional to $r^{1/2}$
- D f is proportional to r

Your answer

[1]

- 40 Two radioactive sources of equal mass are freshly prepared.
One is a β emitter ^{225}Ra with a half-life of 15 days.
The other is an α emitter ^{225}Ac with a half-life of 10 days.

After 30 days, which one of A to D below gives the ratio: $\frac{\text{number of } ^{225}\text{Ra atoms}}{\text{number of } ^{225}\text{Ac atoms}}$?

- A 2.0
- B 1.33
- C 1.0
- D 0.5

Your answer

[1]

- 41 Two radioactive sources of equal mass are freshly prepared.
One is a β emitter ^{225}Ra with a half-life of 15 days.
The other is an α emitter ^{225}Ac with a half-life of 10 days.

After 30 days, which one of A to D below gives the ratio: $\frac{\text{activity of } ^{225}\text{Ra atoms}}{\text{activity of } ^{225}\text{Ac atoms}}$?

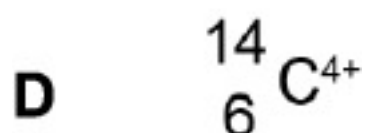
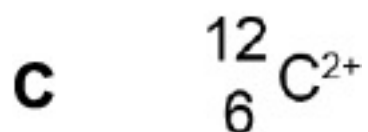
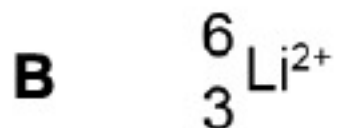
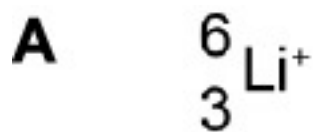
- A 2.0
- B 1.33
- C 1.0
- D 0.5

Your answer

[1]

- 42 The differently charged ions of several isotopes are all fired at the same speed. They pass into a region of uniform magnetic flux density perpendicular to their path.

Which of the ions A to D will travel in the circular path of **smallest** radius?



Your answer

[1]

43 Which of the following three values is / are required to calculate the speed v of a satellite of mass m in a circular orbit of radius r around the Earth?

- 1 the mass m of the satellite
- 2 the radius r of the orbit
- 3 GM (the gravitational constant $G \times M$ the mass of the Earth)

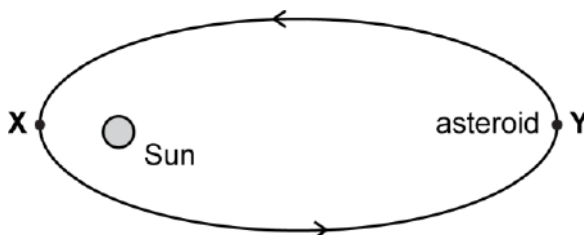
- A 1, 2 and 3 are correct
- B only 1 and 2 are correct
- C only 2 and 3 are correct
- D only 1 is correct

Your answer

☐

[1]

44 An asteroid moves around the Sun in an ellipse, as shown. It is closest to the Sun at X and furthest from the Sun at Y.



Which one of the following quantities is greater at Y than at X?

- A the gravitational force on the asteroid due to the Sun
- B the kinetic energy of the asteroid
- C the speed of the asteroid in its orbit
- D the gravitational potential energy of the Sun-asteroid system

Your answer

☐

[1]

45(a) The equation for the energy stored in a capacitor is $E = \frac{1}{2} Q V$.
 Q is the charge on the capacitor at potential difference V across it.

State the reason for the factor of $\frac{1}{2}$ in the equation.

-----[1]

(b) A 500 μ F capacitor delivers 200J of energy when discharged through a resistor.

Calculate the p.d. across the capacitor before the discharge.

p.d. = ----- V [2]

46(a) Fig. 36.1 and Fig. 36.2 show space-time diagrams for radar ranging of two objects.
 Lines representing the paths of objects through space and time are called worldlines.

The y-axes are in μs and the x-axes in light μs as shown. We are stationary in our frame of reference, travelling only in time and not in space, therefore represented by a vertical worldline from the origin.

Fig. 36.1 shows an object not moving relative to our frame, with another vertical worldline.
 Fig. 36.2 shows an object moving relative to our frame through space and time.
 The objects are at the same distance when radar pulses are reflected.

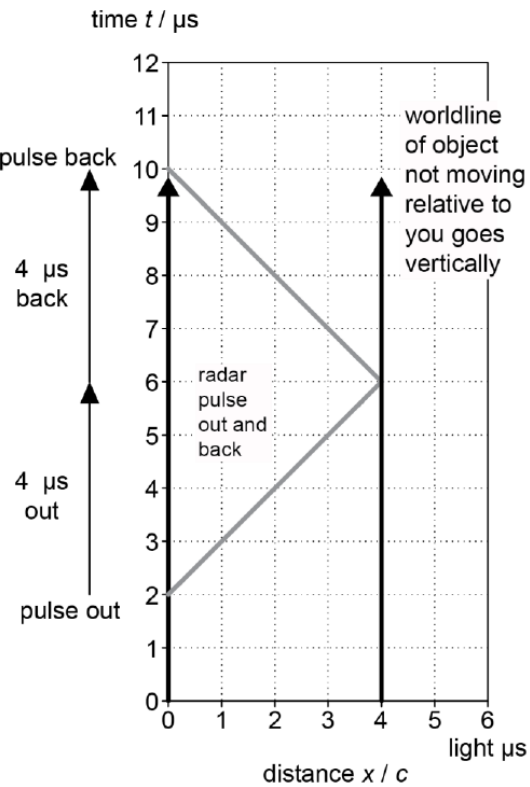


Fig. 36.1

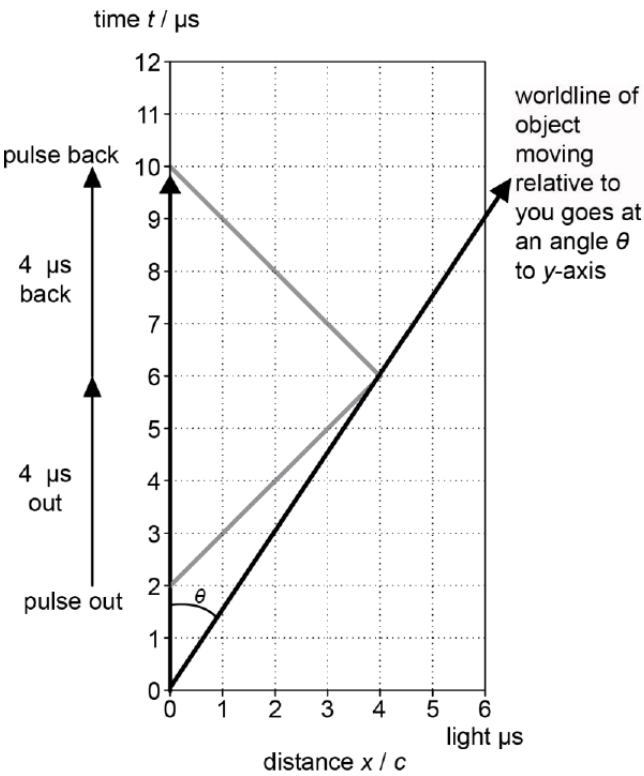


Fig. 36.2

Calculate the range of the objects when the radar pulse is reflected.

range = _____ m [1]

(b)

(i) State why radar pulses on this diagram travel at 45° across the diagram.

-----[1]

(ii) Show that speed of moving object in Fig. 36.2 is given by $\tan \theta$. Calculate this speed.

speed = _____ m s^{-1} [2]

(c) On Fig. 36.1 and Fig. 36.2 draw on the radar pulses emitted at $t = 3.0 \mu\text{s}$ and their reflections.

[2]

47(a) Fig. 40.1 shows the gravitational potential V_g of the Earth from the surface out to 200 Mm. r is the distance measured from the centre of the Earth.

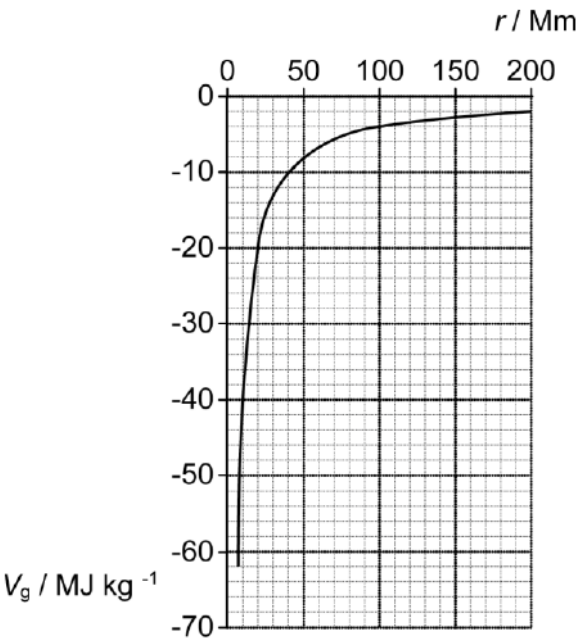


Fig. 40.1

(i) State why the potential is plotted as a negative value.

----- [1]

(ii) Calculate the launch velocity that is needed for a spacecraft to escape Earth's gravity.
Use data from the graph and make your method clear. You can ignore the effects of air drag.

velocity = ----- m s⁻¹ [2]

(b)

(i) Show that the general equation for escape velocity is:

$$V_{\text{escape}} = \sqrt{\frac{2GM}{r}}$$

Make clear what the symbols M , G and r mean.

[3]

(ii) For a spherical body of constant fixed density ρ and radius R show that the escape velocity v_{escape} can be calculated from the equation :

$$V_{\text{escape}} = \sqrt{\frac{8G\pi\rho}{3}} R$$

----- [1]

(iii) A neutron star has a density $\rho \simeq 10^{17} \text{ kg m}^{-3}$. When $v_{\text{escape}} = c$ it will become a black hole.

Estimate the radius of the neutron star when it has an escape velocity of $c = 3 \times 10^8 \text{ m s}^{-1}$.

radius = ----- m [2]

48(a) The decay constant λ of carbon-14 is $3.8 \times 10^{-12} \text{ s}^{-1}$.

Calculate the half-life of carbon-14 in years.

$$1 \text{ year} = 3.2 \times 10^7 \text{ s}$$

half-life = _____ years

[3]

(b) A man of mass 65 kg contains about $1.3 \times 10^{-11} \text{ kg}$ of carbon-14.

Show that the activity of the carbon-14 in a 65 kg man is about 2 kBq.

$$u = 1.7 \times 10^{-27} \text{ kg}$$

[3]

(c) When an organism dies, the carbon-14 stops being replaced and gradually decays away.

- (i) A preserved human body, about 65 kg in mass, was found in a glacier in the Alps. It is thought to be 5000 years old.

State why the activity of the carbon-14 in the body is about 1 kBq.

-----[1]

- (ii) A measurable activity is about 10 Bq (significantly larger than the background count).

Estimate the mass of tissue from the preserved body from the glacier which would have an activity of 10 Bq due to carbon-14, and suggest why museums are reluctant to allow radiocarbon dating of this sort on their specimens.

[2]

49(a) This question is about modelling simple harmonic motion.

Fig.4.1 shows a trolley of mass 1.0 kg tethered between two extended springs. The springs obey Hooke's law.

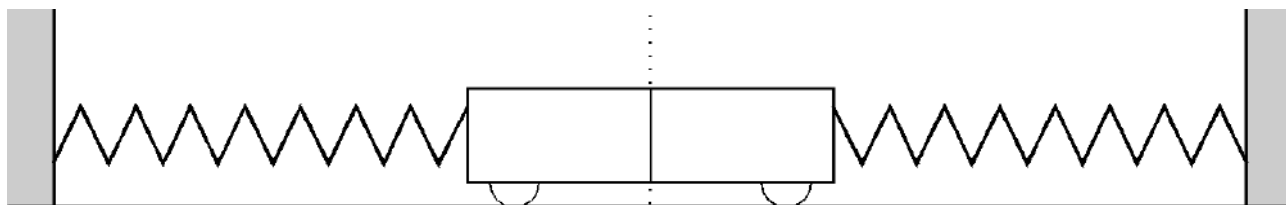


Fig. 4.1

Fig. 4.2 shows the trolley displaced 0.10 m to the right. Both springs are still in tension.

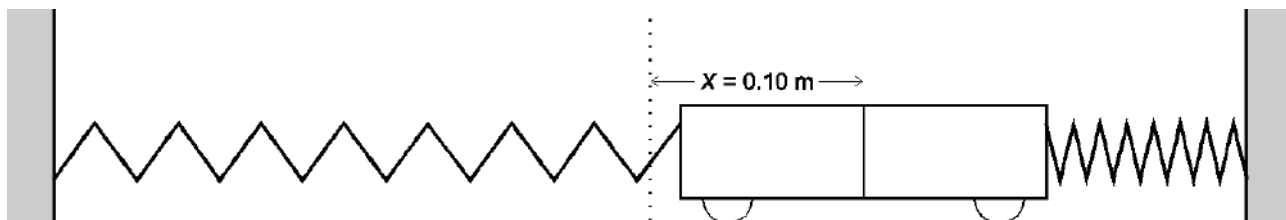


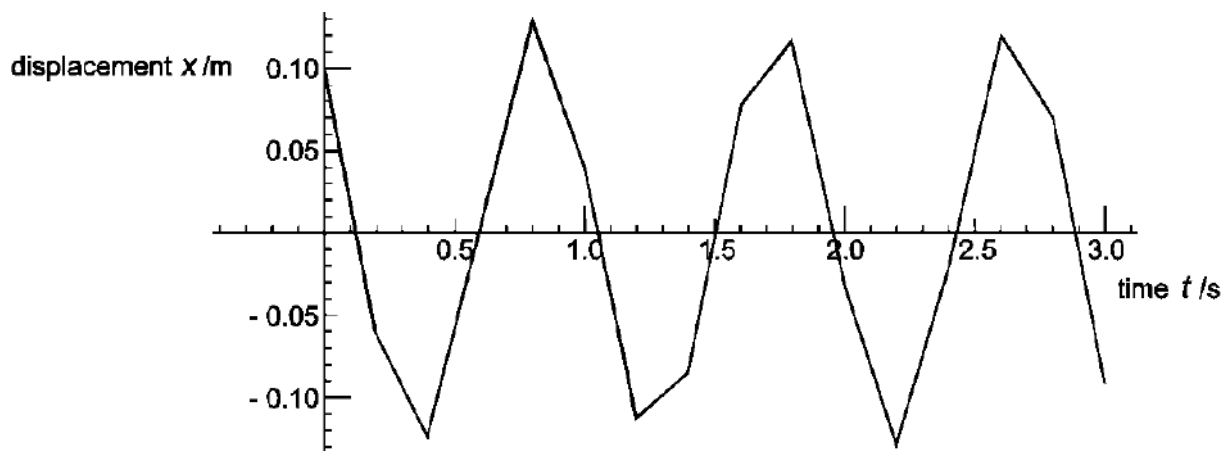
Fig. 4.2

The trolley will move with simple harmonic motion if the equation $a \propto -x$ is true, where a is the acceleration and x the displacement from the centre.

Explain why acceleration is proportional to the negative of the displacement for this spring / trolley system.

[3]

- (b) A modelling program produced the graph of Fig. 4.3. The program calculated the acceleration at time intervals of 0.2 s, and used these values to estimate the changes in velocity and displacement for the next time interval.



- (i) Use the graph of Fig. 4.3 to estimate the period of the oscillation predicted by the model.

period = _____ s

[1]

- (ii) Compare your answer in part (i) to the period of a spring / trolley system of mass m and spring constant k calculated using the equation

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Suggest a reason for any differences between the two values of the time period.

----- [3]

- (iii) Suggest **one** method for improving the model in part (i) and explain why the improvement would give a result closer to the value of the period T calculated from the equation.

----- [3]

(c) A student suggests that the model does not represent the real situation because the amplitude of a real oscillator decreases exponentially with time.

Explain what this statement means and suggest how the student could demonstrate that the amplitude of a spring / trolley system decreases exponentially.

[4]

50(a) This question is about the gravitational fields of asteroids and moons in the Solar System.

- (i) A roughly-spherical asteroid has a radius of about $5 \times 10^2 \text{ m}$ and a mass of $3.0 \times 10^{12} \text{ kg}$. Show that an 1100 kg spacecraft would have a weight of about 0.9 N on the surface of the asteroid.

[2]

- (ii) By equating the gravitational force on the spacecraft with the centripetal force required to keep the spacecraft on the surface of the asteroid, explain why the spacecraft cannot remain on the equator of the asteroid if the asteroid makes one revolution every 80 minutes.

[5]

- (iii) The gravitational potential energy of the spacecraft on the asteroid is about -450 J .

Explain why this quantity is negative.

[2]

- (iv) Explain why the spacecraft will escape the asteroid if it is projected vertically upwards from the surface with a velocity greater than about 0.9 m s^{-1} .

----- [2]

- (b) Titan, one of Saturn's moons, is very much larger than this asteroid. It has an atmosphere of nitrogen, while the atmosphere of the planet Saturn is mostly hydrogen.

The table shows the gravitational potential energy that one molecule of each gas would have on the surface of Titan.

molecule	$E_{\text{grav}} / 10^{-19} \text{ J}$
nitrogen	-1.7
hydrogen	-0.12

- (i) State why these two values are different.

[1]

- (ii) The temperature T of the surface of Titan is 93 K. Calculate a value for the typical kinetic energies of particles at this temperature. Use this value with the values of the gravitational potential energy E_{grav} in the table to explain why Titan has an atmosphere of nitrogen but no hydrogen.

[4]

51(a) This question is about a portable, flexible electrical extension cable. The cross-section of the cable is shown in Fig. 6.1

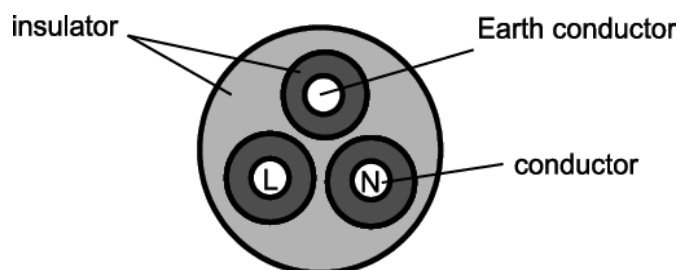
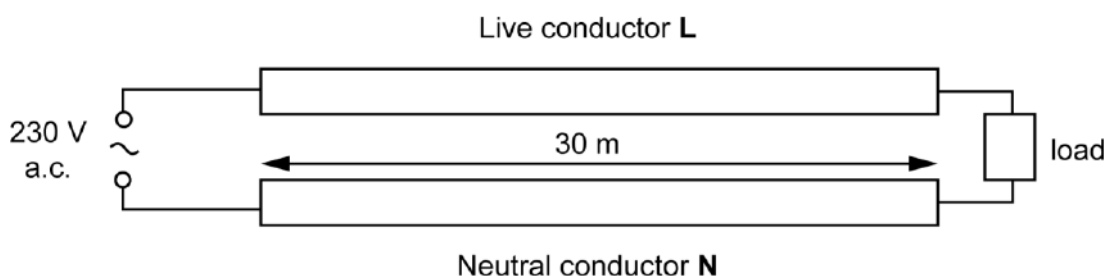


Fig. 6.1

The live **L** and neutral **N** conductors are connected in series with the load and the supply as shown below.



- (i) The cable is 30 m long, so that the total length of conductor is 60 m. The conductor has a diameter of 1.5 mm.

Copper has a conductivity of $5.9 \times 10^7 \text{ S m}^{-1}$.

Calculate the conductance of the cable.

conductance = _____ S [3]

- (ii) Calculate the voltage dropped across the 60 m of cable when it carries a current of 13 A.

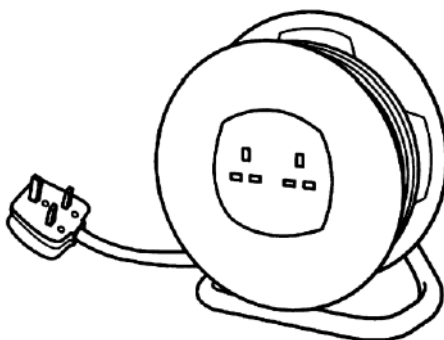
voltage dropped = _____ V [2]

- (iii) Explain why a 2.8 kW 230 V kettle would take slightly longer to boil when connected to the mains supply with

this extension lead, but the performance of a 500 W electric drill would not be significantly affected by using this extension cable.

[3]

- (b) * The cable is stored tightly wound on a reel as shown. The manufacturer recommends that if the cable is used coiled on its reel, the current must be significantly less than 13 A to prevent overheating.



Use your answers to part (a) to calculate the power dissipated by the cable. Make further estimates and calculations to show why the current should be kept significantly less than 13 A when the cable is wound on a reel.

specific thermal capacity of copper = $390 \text{ J kg}^{-1} \text{ K}^{-1}$

density of copper = 9000 kg m^{-3}

[6]

52(a) This question is about the effect of temperature on the rate of chemical reactions. It is based on the Advance Notice article.

Show that 70 kJ mol^{-1} is about $1.2 \times 10^{-19} \text{ J}$ per molecule. (line 33 in the article)

[1]

(b) The table below shows how the Boltzmann factor for a typical Maillard reaction varies with temperature.

	freezer	refrigerator	cool oven	boiling water	warm oven	hot oven
temperature T/K	255	275	360	373	410	
Boltzmann factor	1.55×10^{-15}	1.85×10^{-14}	3.23×10^{-11}	7.51×10^{-11}	6.15×10^{-10}	2.80×10^{-8}

(i) Use the value of the Boltzmann factor to calculate the temperature of the hot oven.

activation energy for a typical Maillard reaction $E = 1.2 \times 10^{-19} \text{ J}$

temperature = _____ °C

[3]

(ii) A useful approximate rule for many reactions in the temperature range shown in the table is that the rate of reaction approximately doubles for every 10 K rise in temperature.

Explain why the rate of reaction is affected by the Boltzmann factor.

- (iii) Test the rule that the rate of reaction doubles for every 10 K rise in temperature (lines 38 – 40 in the article) for the temperature range between a cool oven and a warm oven (a temperature difference of 50 K). Comment on your answer.

53(a) This question is about an experiment investigating the relationship between volume of a gas, V , and temperature, T , at constant pressure. Fig 4.1 shows measurements taken by a student.

$T / ^\circ\text{C}$ $\pm 1 ^\circ\text{C}$	V / mm^3 $\pm 5 \text{ mm}^3$
1	115
6	117
10	119
15	122
20	124
25	127
30	130

Fig. 4.1

Fig. 4.2 shows the graph for five of the data points.

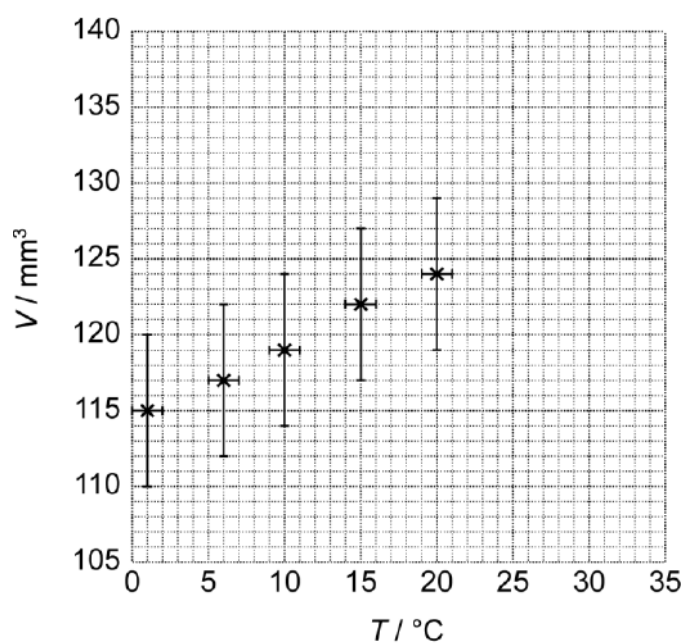


Fig. 4.2

- (i) Add the **two** remaining data points to the graph. Include uncertainty bars for the points and an appropriate

line of best fit.

[4]

(ii) Calculate the percentage uncertainty for the values of V and T at point (30, 130).

Percentage uncertainty in V = _____ %

Percentage uncertainty in T = _____ %

[2]

(iii) The sample contains $4.5 \mu\text{mol}$ of particles. Use data from the graph to calculate the pressure of the gas, P .

P = _____ Pa

[4]

- (b) Fig. 4.3 shows the same data set plotted on different axes. The uncertainties in T and V are too small to be shown on this graph.

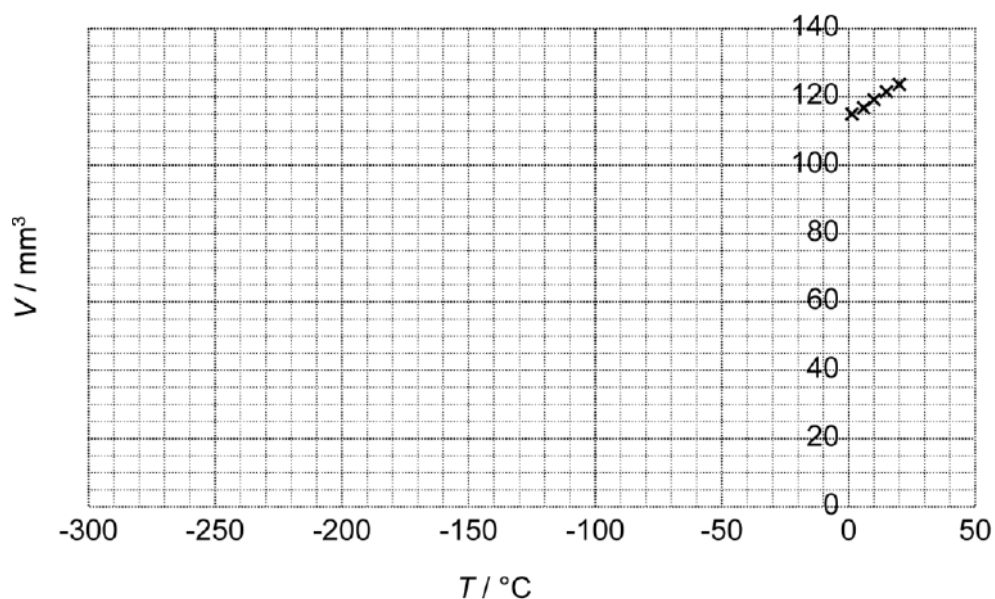


Fig. 4.3

- (i) Add a line of best fit to the data points and extrapolate the line so that it intercepts the x-axis.

State the value of the x-intercept from the graph.

x-intercept = _____ [1]

- (ii) Describe and explain how the motion of the particles in an ideal gas changes as the gas approaches and reaches the temperature given in b(i). Compare and explain any differences in the behaviour of a real gas such as nitrogen as it reaches the temperature given b(i).

----- [4]

- (iii) The accepted value of the x-intercept is $-273\text{ }^{\circ}\text{C}$. Use your answer from **b(i)** to determine the percentage difference between the experimental and accepted value.

----- % [1]

- (iv) The uncertainty in the x-intercept is found to be 7%. Use this and your answer to **b(iii)** to discuss the accuracy of the investigation.

----- [2]

- (v) State and explain whether the gas in the investigation can be treated as an ideal gas in the temperature range used.

----- [1]

- (vi) The molar mass of N_2 is 28 g mol^{-1} .

Treating nitrogen as an ideal gas, calculate the ratio of the r.m.s speed of the gas molecules between $T = 20\text{ }^{\circ}\text{C}$ and $T = -196\text{ }^{\circ}\text{C}$.

Number of particles in one mole = $6.0 \times 10^{23}\text{ mol}^{-1}$

[4]

54(a) Here is a list of units.

$$\text{N m kg}^{-1}$$

$$\text{N kg}^{-1}$$

$$\text{J m}^{-1}$$

$$\text{kg m s}^{-1}$$

$$\text{m s}^{-1}$$

Which one is a correct unit for gravitational field strength?

----- [1]

(b) Which one is a correct unit for gravitational potential?

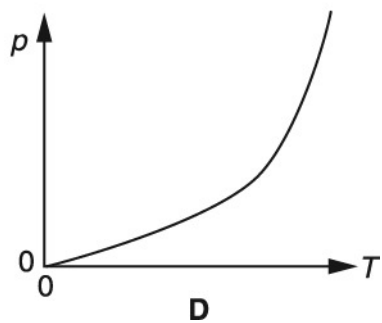
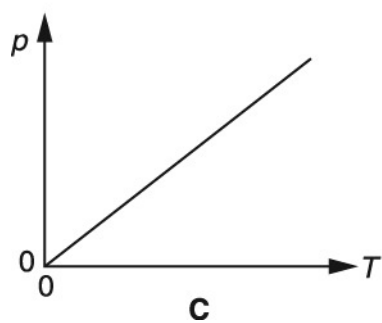
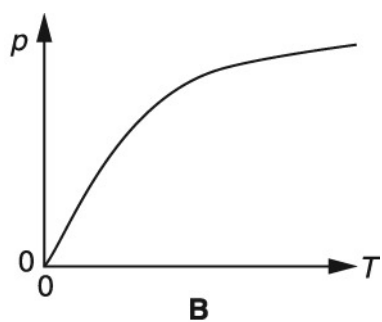
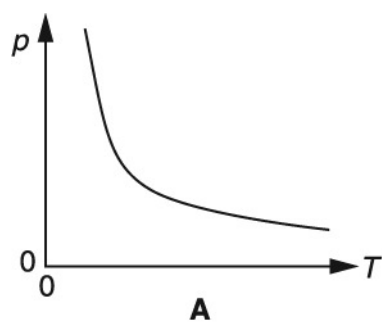
----- [1]

55 The Big Bang theory states that the Universe has been expanding ever since it first appeared.

State and explain **one** piece of evidence for this theory.

[2]

- 56 Which one of these four graphs A, B, C or D shows how the pressure p of a fixed mass of gas at a constant volume V changes with kelvin temperature T ?



answer [1]

57 The table shows some measurements of air density at different temperatures at constant pressure.

Temperature / K	Density / kg m ⁻³
273	1.29
283	1.25
293	1.20
303	1.16

Kinetic theory suggests that the density ρ of an ideal gas with particles of mass m and pressure p is related to its kelvin temperature T by the equation

$$\rho = \frac{pm}{kT}$$

where k is the Boltzmann constant.

Do the measurements support this equation? Justify your answer with calculations.

[2]

58 The equation $\frac{dN}{dt} = -\lambda N$ can be used to model the decay of a radioisotope.

Suggest how a value for the term λ can be determined experimentally for the radioisotope.

[1]

59 Fig. 9.1 shows a binary star system. Both stars have the same mass and radius.

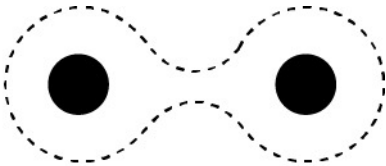


Fig. 9.1

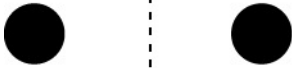
Fig. 9.2 shows four different attempts to sketch a gravitational equipotential curve in the binary star system. Which attempt A, B, C or D is correct?



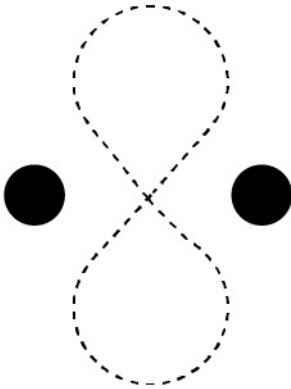
A



B



C



D

Fig. 9.2

answer _____ [1]

60(a) This question is about possible flaws in an attempt to estimate a value for the gravitational constant G using Earth-based observations.

The table contains the results of data required.

radius of Earth at equator	$6.4 \times 10^6 \text{ m}$
mean density of surface rocks on Earth	$2.7 \times 10^3 \text{ kg m}^{-3}$
period of Moon's orbit around the Earth	$2.4 \times 10^6 \text{ s}$
time for a laser pulse fired at the Moon to return	2.5 s

The Moon of mass m orbits the Earth of mass M in a circular path of radius r with a period T . By setting the centripetal force on the Moon equal to its gravitational attraction to the Earth, show that

$$G = \left(\frac{4\pi^2}{M} \right) \frac{r^3}{T^2}$$

[3]

(b) The mass M of the Earth can be estimated from its radius R and its density ρ .

Use the data for radius and density in the table to show that they give a value of M which is about $3 \times 10^{24} \text{ kg}$.

[2]

- (c) The distance r from the centre of the Earth to the centre of the Moon can be estimated by timing the return of laser pulses reflected from the Moon's surface.

The relationship $r = \frac{c\Delta t}{2}$ can be used to estimate a value for r from the time interval Δt between the emission and return of a laser pulse.

- (i) State **two** assumptions required for the relationship to be valid.

[2]

- (ii) Use the data from the table to calculate a value for r and hence show that the value of G obtained from (a) and (b) is very different from the accepted value of $6.7 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$.

$$c = 3.0 \times 10^8 \text{ m s}^{-1}$$

$$G = \text{-----} \text{ N m}^2 \text{ kg}^{-2} \text{ [2]}$$

- (iii) Suggest a reason why your calculated value of G is very different from the accepted value. Justify your answer.

[2]

61(a) This question is about the pressure of the atmosphere.

Use the behaviour of air molecules to explain how the Earth's atmosphere exerts a pressure on the ground.



Your answer should clearly link the behaviour of the molecules to gas pressure.

[3]

- (b) The equation $pV = \frac{1}{3} N m \overline{c^2}$ relates the mean square speed $\overline{c^2}$ of N gas molecules of mass m to the pressure p and volume V of an ideal gas.

- (i) By assuming that air at 20 °C is an ideal gas, show that the root mean square speed of its molecules is about 500 m s⁻¹.

$$m = 4.7 \times 10^{-26} \text{ kg}$$

$$k = 1.4 \times 10^{-23} \text{ J K}^{-1}$$

[3]

(ii) Atmospheric pressure at 20 °C is typically 1.0×10^5 Pa.

Estimate the rate at which air molecules collide with an object of surface area 0.56 m^2 to provide this pressure.

State **one** assumption you have to make.

collision rate = _____ s^{-1} [4]

62(a) The circuit shown in Fig. 12.1 is used to determine the capacitance of a capacitor.

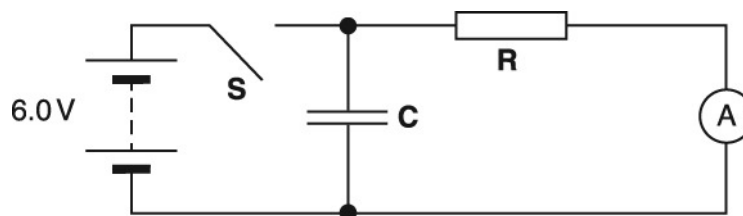


Fig. 12.1

The switch **S** is closed at time $t = 0$ s. This allows the 6.0 V battery to charge the capacitor **C**.

The switch is then opened at time $t = 20$ s, allowing the capacitor to discharge through resistor **R**. The graph of Fig. 12.2 shows how the current I in the ammeter varies with time.

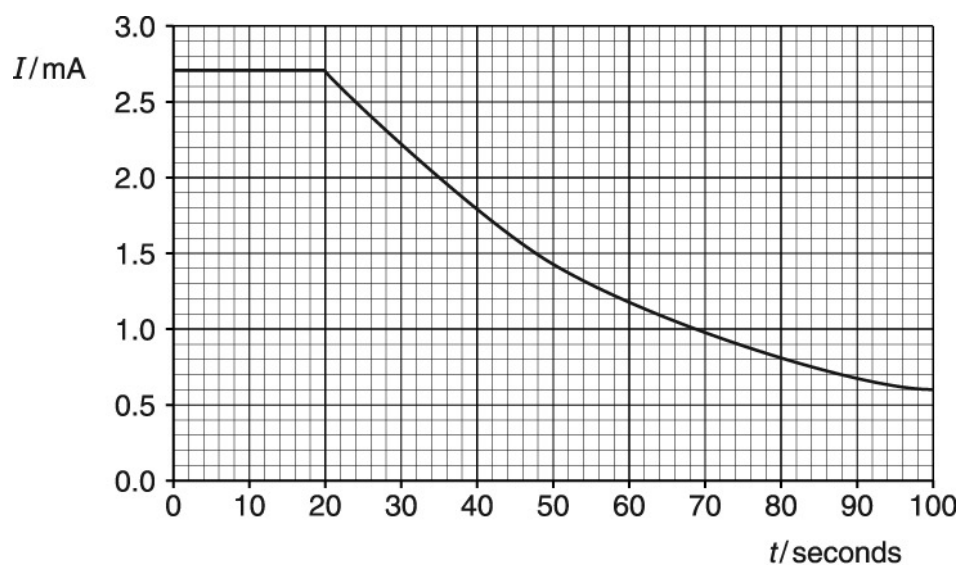


Fig. 12.2

Use the data to

(i) show that **R** has a value of about 2 k Ω

(ii) calculate a value **C** for the capacitance of **C**.

[1]

$C = \text{----- F}$ [2]

- (b) A $470 \mu\text{F}$ capacitor is placed in the circuit of Fig. 12.3.



Fig. 12.3

When the switch **S** is opened, the reading on the voltmeter decreases by 0.12 V in 60 s . This is because the insulator which separates the capacitor plates does not have infinite resistance. Charge is able to flow directly from one plate to another through the insulator, making a *leakage current*.

- (i) Calculate the leakage current in the insulator.

leakage current = $\text{----- } \mu\text{A}$ [2]

- (ii) Leakage current increases with temperature. The Boltzmann factor can be used to predict that the leakage current I is related to the temperature T by the equation $I = Ae^{-\epsilon/kT}$, where A is a constant.

Suggest the meaning of the quantity ϵ in this equation.

[2]

- (iii) The leakage current rises from $1.0\ \mu\text{A}$ to $10\ \mu\text{A}$ as the temperature of the capacitor increases from $300\ \text{K}$ to $400\ \text{K}$. Calculate the value of ϵ .

$$k = 1.4 \times 10^{-23}\ \text{J K}^{-1}$$

$$\epsilon = \text{----- J [2]}$$

63(a) This question is about avoiding resonant oscillations in an earthquake.

The lift in a skyscraper can be modelled as a mass suspended by a spring from the top of the building. The lift will therefore have a natural frequency of vertical oscillations f_0 . If the value of f_0 lies within the range 2 Hz–0.2 Hz, there is a risk that surface waves from an earthquake will set the lift into resonance.

Explain why it is important to design the lift so that it cannot be easily set into resonance.

[2]

- (b) Fig. 13.1 shows a lift cage suspended by steel cables from the top of a tall building.
Here are some data for a typical lift.

mass of empty cage	1500 kg
maximum load of 8 people	640 kg
maximum length of cable	300 m
overall cross-sectional area of cables	$2.5 \times 10^{-4} \text{ m}^2$
Young modulus of steel	$2.0 \times 10^{11} \text{ Pa}$
yield stress of steel	$2.5 \times 10^8 \text{ Pa}$

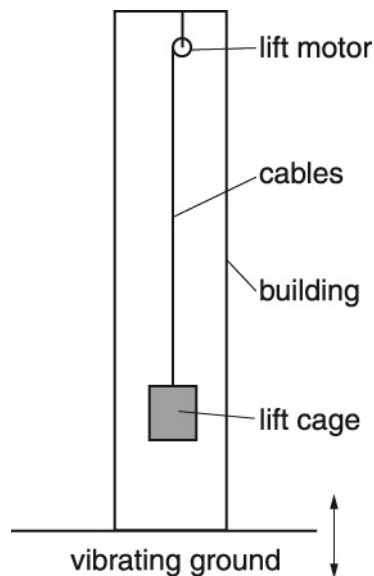


Fig. 13.1

- (i) Show that the force constant k of a cable of length L , cross-sectional area A and Young modulus E is given by

$$k = \frac{EA}{L}$$

[2]

- (ii) Use calculations to show that the lift is in danger of resonance from earthquake waves when it contains a maximum load and the cables are at their maximum length.

[3]

(c)

- (i) Suggest why it is impractical to make the lift safe from resonance by adding some damping.

[1]

- (ii) Suggest and explain **one** other practical modification to the lift which would reduce the risk of resonance in an earthquake.



Your answer should clearly explain how your suggestion reduces the risk.

[2]

64(a) This question is based on the insert.

This question is about the use of lithium fluoride (LiF) crystals in measuring radiation dose.

Show that the number of magnesium defect sites in a single chip is about 5×10^{17} . Assume a doping level of one magnesium ion per thousand pairs of LiF ions.

dimensions of a chip: $3.0 \text{ mm} \times 2.0 \text{ mm} \times 1.5 \text{ mm}$

density of LiF = 2600 kg m^{-3}

molar mass of LiF ion pairs = $26 \times 10^{-3} \text{ kg mol}^{-1}$

Avogadro constant = $6.0 \times 10^{23} \text{ mol}^{-1}$

[4]

- (b) The energy received by a single chip from a dose of 2 Gy is about $6 \times 10^{-5} \text{ J}$. 0.5% of this is used to promote electrons within the crystal (line 20). For this dose, 1 in 10^6 defect sites gain a promoted electron. Show that the energy provided for each electron transition is about 4 eV.

electronic charge = $1.6 \times 10^{-19} \text{ C}$

energy provided by radiation for each electron transition = _____ eV [4]

- (c) Calculate the wavelength of the light emitted when an electron returns to the ground level after heating (line 30). Assume that all this energy is given to the emitted photon.

$$h = 6.6 \times 10^{-34} \text{ J s}$$

$$c = 3.0 \times 10^8 \text{ m s}^{-1}$$

wavelength = _____ m [2]

65 This question is based on the insert.

Electrons promoted to the higher energy level by incident radiation will naturally fall back to their ground state in time. This is called *fading* (line 25) and can amount to 5% over a three month period. Assuming the decay is exponential, the half life can be calculated as follows:

$$N = N_0 e^{-\lambda t}$$
$$\frac{N}{N_0} = 0.95 = e^{-\lambda t} \quad (1)$$

$$\ln 0.95 = -\lambda t \quad (2)$$

$$\lambda = -\ln 0.95 / 3 \text{ month} = 0.017 \text{ month}^{-1} \quad (3)$$

$$t_{1/2} = 0.69 / 0.017 \text{ month}^{-1} = 41 \text{ months} \quad (4)$$

Explain each of the steps (1) to (4) in this correct calculation:

(1)

(2)

(3)

(4)

[4]

66(a) Here is a list of units.

$$\text{kg m}^{-1} \text{s}^{-2}$$

$$\text{kg m s}^{-1}$$

$$\text{kg m}^2 \text{s}^{-1}$$

$$\text{kg m}^2 \text{s}^{-2}$$

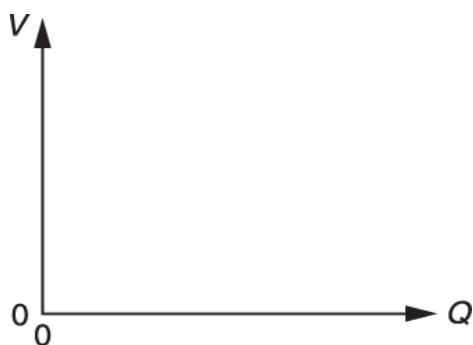
Which **one** is a correct unit for momentum?

----- [1]

(b) Which **one** is a correct unit for pressure?

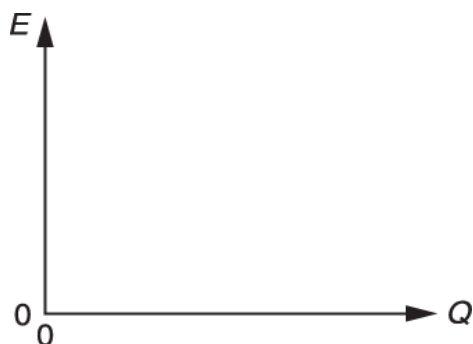
----- [1]

67(a) Sketch a graph on the axes below to show how the potential difference V across a capacitor varies with the charge Q on its plates.



[1]

(b) Sketch a graph on the axes below to show how the energy E stored in the capacitor varies with the charge Q on its plates.



[1]

68(a) This question is about the behaviour of a mass suspended by a spring from a vibrating support.

Describe the condition required for the mass-spring system to go into **resonance**.

[1]

(b) Damping is applied to the mass-spring system.

Describe and explain one effect of damping when the system goes into resonance.

[2]

69 The atmosphere of Mars is mostly carbon dioxide at a mean temperature of $-63\text{ }^{\circ}\text{C}$.

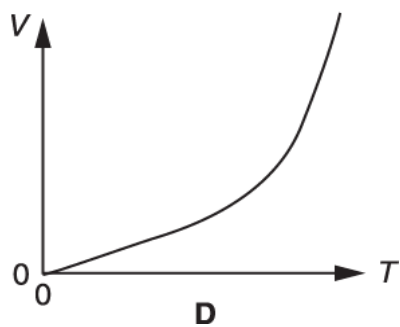
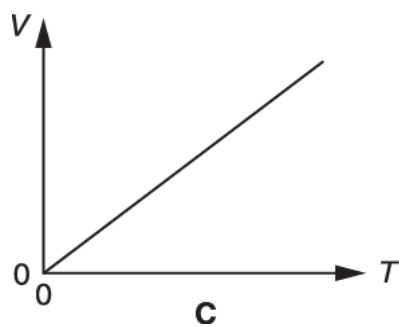
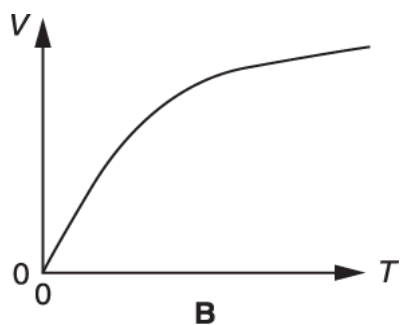
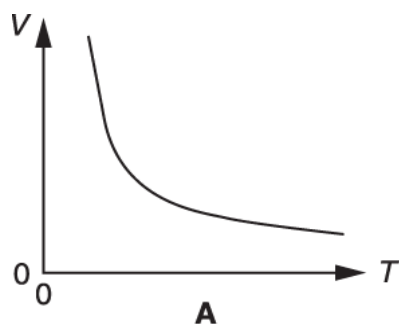
Estimate the speed v of carbon dioxide molecules at this temperature.

mass of a carbon dioxide molecule = $7.3 \times 10^{-26}\text{ kg}$

$k = 1.4 \times 10^{-23}\text{ J K}^{-1}$

$V = \text{----- ms}^{-1}$ [3]

70 Which one of these four graphs (A, B, C or D) shows how the volume V of a fixed mass of gas at a constant pressure changes with kelvin temperature T ?



answer [1]

71(a) This question is about the random walk of a molecule through air.

Explain why the molecule does a random walk.

[2]

(b) A typical molecule in still air is displaced by a distance of 5 mm in a time of 1 s.

Explain why it will take 100 s for the molecule to be displaced by a distance of 50 mm.

[2]

72 The recessional velocity of a distant galaxy is measured to be $3.5 \times 10^3 \text{ km s}^{-1}$.

Use the age of the Universe (14×10^9 years) to estimate the distance from Earth to this galaxy. State the assumption you have to make.

$$1 \text{ year} = 3.2 \times 10^7 \text{ s}$$

distance = _____ m [3]

73(a) The asteroid belt between Mars and Jupiter contains a large number of rocks in circular orbit around the Sun.

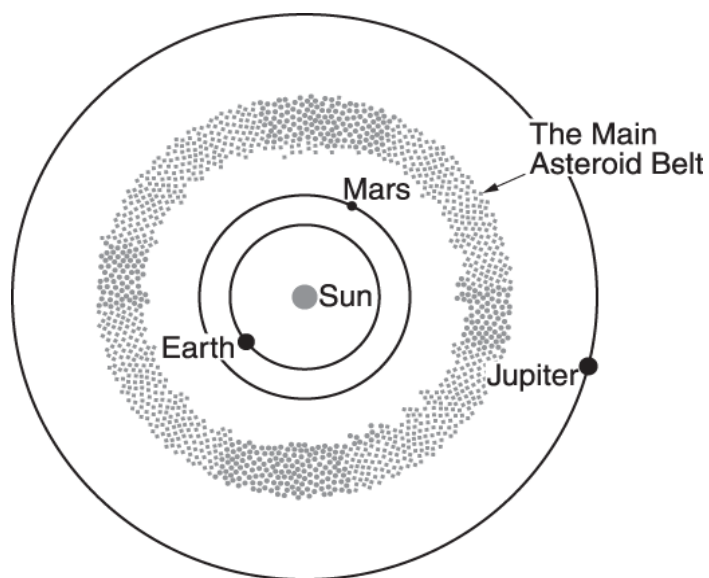


Fig. 9.1

Show that the speed v of an asteroid of mass m in a circular orbit of radius r around the Sun of mass M is given by

$$v = \sqrt{\frac{GM}{r}}.$$

[2]

(b) One particular asteroid in the asteroid belt is in a circular orbit of radius 3.6×10^{11} m.

(i) Show that it has a kinetic energy of about 10^{11} J.

mass of asteroid = 500 kg

mass of Sun = 2.0×10^{30} kg

$G = 6.7 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$

[2]

(ii) It is believed that collisions between asteroids can put them into elliptical orbits which cross the Earth's orbit. These asteroids may then collide with the Earth, causing widespread damage.

If a collision changes the direction of motion of the asteroid in (i) **without** changing its kinetic energy, calculate its speed v when it crosses the Earth's orbit.

radius of the Earth's orbit = 1.5×10^{11} m

$v = \text{-----} \text{ m s}^{-1}$ [4]

(c) Astronomers study many asteroids whose orbits approach the Earth's orbit.

Explain how the distance from Earth to a nearby asteroid can be measured using radar.



Your answer should state clearly the assumptions behind the method you describe.

[3]

74(a) A heater raises the temperature of the water in the pool from 10 °C to 30 °C.

Calculate the energy supplied to the heater.

State an assumption you have to make.

specific thermal capacity of water = $4.2 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$

energy = _____ J [2]

(b) Evaporation is one way in which water in a swimming pool cools down.

The Boltzmann factor can be used to model how the rate of evaporation varies with temperature.

(i) The energy required to evaporate 1.0 kg of water is $2.3 \times 10^6 \text{ J}$.

Show that the energy required to remove **one molecule** of water from the pool into the air above it is about $7 \times 10^{-20} \text{ J}$.

molar mass of water = $1.8 \times 10^{-2} \text{ kg mol}^{-1}$

Avogadro constant = $6.0 \times 10^{23} \text{ mol}^{-1}$

[2]

(ii) The rate of evaporation from the pool R is estimated by

$$R = Ce^{-\frac{\epsilon}{kT}}.$$

Explain how the Boltzmann factor $f = e^{-\frac{\epsilon}{kT}}$ can be used to justify this equation.



Your answer should clearly link the Boltzmann factor to the behaviour of the water molecules.

[3]

- (iii) The rate of evaporation from the pool is $7.2 \times 10^{-3} \text{ kg s}^{-1}$ when the temperature is $+30^\circ\text{C}$.
Estimate the rate of evaporation at a temperature of $+10^\circ\text{C}$.

Show your working.

$$k = 1.4 \times 10^{-23} \text{ J K}^{-1}$$

rate of evaporation = _____ kg s^{-1} [2]

75(a) This question is about a measurement of the half-life of protactinium.

A fresh sample of protactinium was placed in a detector of radiation.

The count rate of the sample was measured at intervals of one minute for six minutes.

The activity A , the count rate corrected for background radiation, is given in the table.

time / minutes	0	1	2	3	4	5	6
activity A / Bq	943	523	287	161	79	61	20

Describe how the correction for background radiation is made.

[2]

- (b) Use the relationships $N = N_0 e^{-\lambda t}$ and $\frac{\Delta N}{\Delta t} = -\lambda N$ to show that the results of the experiment should obey the relationship $\ln A = C - \lambda t$, where C is a constant.

[3]

- (c) The graph of Fig. 11.1 shows the variation of $\ln A$ with time.

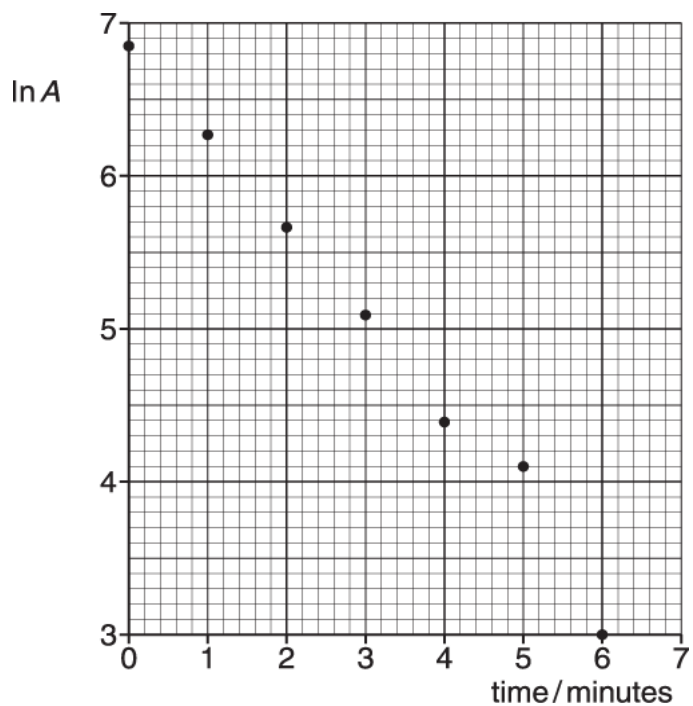


Fig. 11.1

- (i) Use the graph to determine a value for the half-life of protactinium.

half-life = _____ s [3]

- (ii) Give a reason why some of the points on the graph of Fig. 11.1 are not expected to lie close to a straight line.

[1]

76(a) This question is about a derivation of the relationship $PV = NkT$ for a gas from a simple model.

Fig. 12.1 shows one particle of mass m moving with speed v directly towards the left-hand face of a cubical box of side d . There are no other particles in the box.

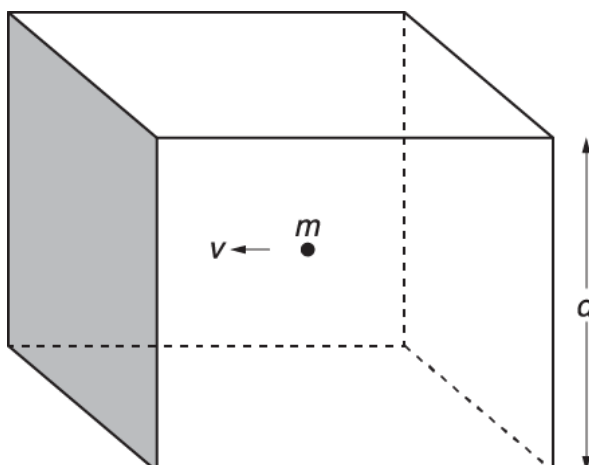


Fig. 12.1

The rate at which the left-hand face gains momentum p from the particle in the box is given by

$$\frac{\Delta p}{\Delta t} = \frac{2mv}{\frac{2d}{v}}.$$

- (i) State what assumption has to be made about the motion of the particle for $\Delta p = 2mv$.

[1]

- (ii) Explain why $\Delta t = \frac{2d}{v}$.

[1]

(b) The box now contains N particles of the gas, all with the same speed and mass, so that it models a gas.

(i) Explain why the total force F on the left-hand face of the box is given by

$$F = \frac{N}{3} \times \frac{mv^2}{d}.$$

[3]

(ii) State another assumption made about the N particles in the box.

[1]

(c) The pressure P on the left-hand face of the box is then given by

$$P = \frac{F}{A} = \frac{Nmv^2}{3V}.$$

By making appropriate assumptions about the particles of a gas, this can be used to show that $P = \frac{NkT}{V}$.

State the assumptions required and explain how they lead to the final equation.

[3]

77(a) This question is based on the insert.

While in operation, an electron microscope produces a continuous beam of electrons travelling along an evacuated tube (line 50).

The pressure in the tube is 1.0×10^{-5} Pa.

The device is operating at 300 K (room temperature).

Calculate the number of gas particles per cubic centimetre in the chamber.

Boltzmann constant $k = 1.4 \times 10^{-23}$ J K⁻¹

number of gas particles per cubic centimetre = _____

[3]

- (b) The source of the electrons is a small coil of tungsten wire (the filament). A current is passed through the coil and electrons boil off the hot surface of the wire. The electrons receive the energy to do this from the thermal vibrations of the metal lattice. The energy, E , required to remove an electron in this way is about 7×10^{-19} J (just over 4 eV, line 42).

- (i) The beam current I_B will depend upon the Boltzmann factor:

$$I_B \propto e^{-E/kT}$$

Explain why it is reasonable to expect the beam current to be proportional to the Boltzmann factor.

[3]

(ii) When the filament is at a temperature of 2200 K, N electrons are emitted per second.

Use the Boltzmann factor to calculate an estimate of the temperature the wire must reach to emit $3N$ electrons per second.

$$k = 1.4 \times 10^{-23} \text{ J K}^{-1}$$

temperature _____ K

[3]

78 This question is based on the insert.

In a typical scanning electron microscope, the electrons are accelerated from rest through a potential difference of 40 kV.

When the electrons strike a sample most of their energy is converted to thermal energy (line 56). Excessive heating could damage the sample.

Calculate the minimum number of electrons required to strike a small sample in order to raise its temperature by 1 K.

electron energy $E = 6.0 \times 10^{-15} \text{ J}$

mass of sample $m = 0.25 \times 10^{-6} \text{ kg}$

specific thermal capacity of sample $c = 3000 \text{ J kg}^{-1} \text{ K}^{-1}$

number of electrons = _____

[2]

79 The mass attached to a spring undergoes simple harmonic motion.

The spring has a spring constant of 25 N m^{-1} .

What is the best estimate for the time period T of the simple harmonic oscillations?

A 0.14 s

B 0.90 s

C 1.1 s

D 7.1 s

Your answer

[1]

After 64 days the activity of a radioactive nuclide has fallen to one sixteenth $\left(\frac{1}{16}\right)$ of its original value.

What is the half-life of the radioactive nuclide?

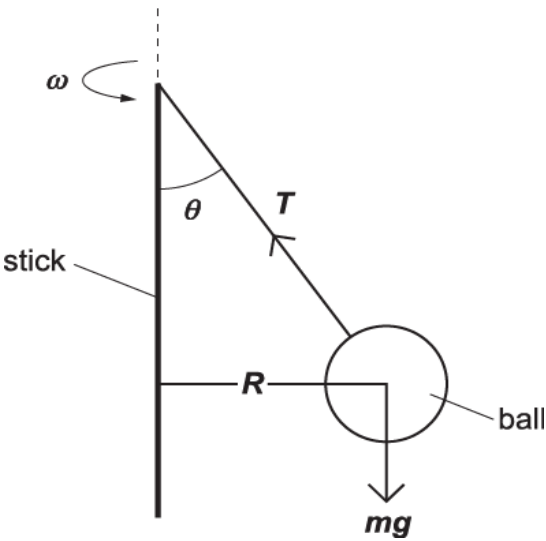
- A 2 days
- B 4 days
- C 8 days
- D 16 days

Your answer

[1]

81 A ball of mass m is suspended on a string from a stick which is rotated at angular speed ω as illustrated below.

The ball moves in a horizontal circle of radius R . The tension in the string is T and the angle of the string to the vertical is θ .



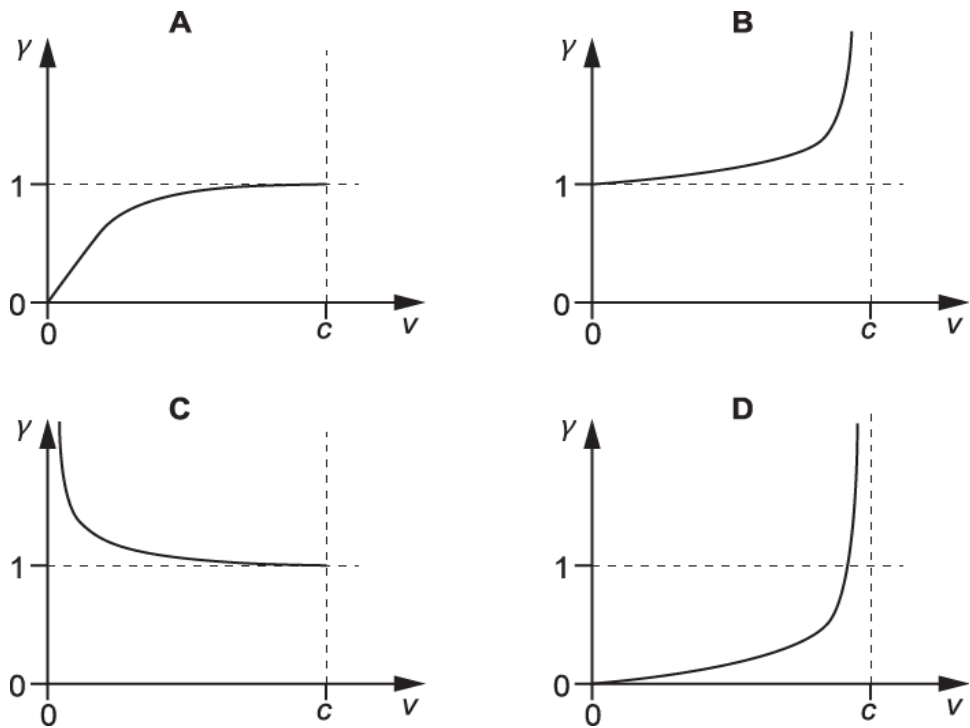
What are the equations for the vertical and horizontal force components of the motion?

	Vertical resolution	Horizontal resolution
A	$mg = T \sin \theta$	$T \cos \theta = m R^2 \omega$
B	$mg = T \sin \theta$	$T \cos \theta = m R \omega^2$
C	$mg = T \cos \theta$	$T \sin \theta = m R^2 \omega$
D	$mg = T \cos \theta$	$T \sin \theta = m R \omega^2$

Your answer ☐

[1]

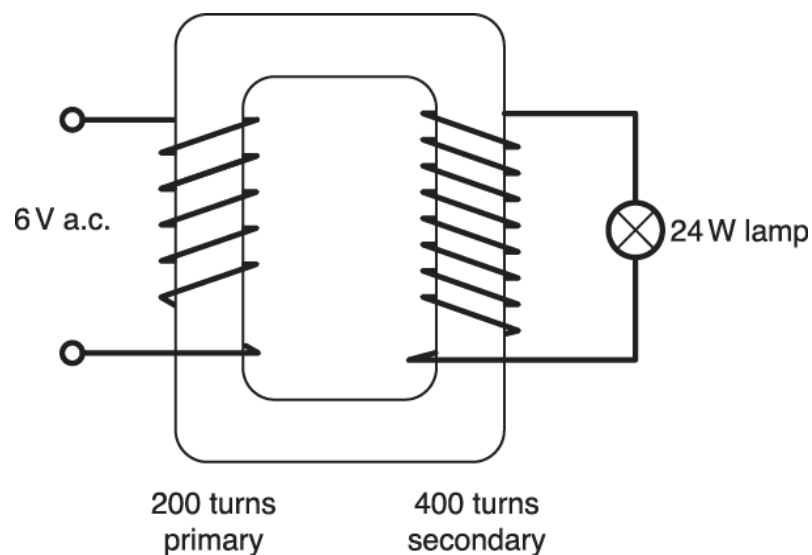
82 Which graph shows the correct relationship between the relativistic γ factor and the speed v of a moving particle?



Your answer

[1]

83 This diagram shows an ideal transformer.



Here are four values of currents:

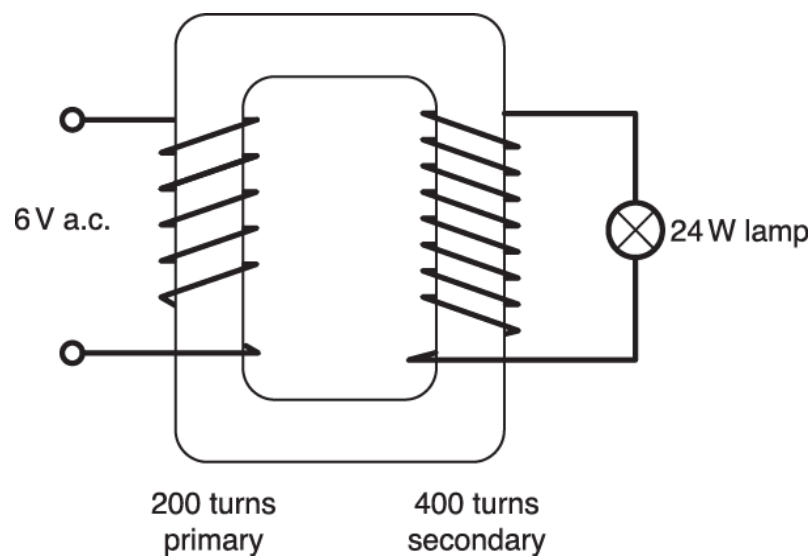
- A $\frac{1}{4}$ A
- B $\frac{1}{2}$ A
- C 2 A
- D 4 A

Which is the best estimate of the current in the secondary circuit?

Your answer

[1]

84 This diagram shows an ideal transformer.



Here are four values of currents:

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

Which is the best estimate of the current in the primary circuit?

Your answer

[1]

- 85 A satellite with orbital speed v takes 24 hours to make one orbit of the Earth, remaining stationary above a fixed point on the Earth's surface.

Which of the following statements is/are correct?

- 1 Any radius R of orbit is possible, provided that $\frac{2\pi R}{v} = 24$ hours.
- 2 It must be in an orbit above the equator.
- 3 Any mass of satellite can be chosen.

- A 1, 2 and 3 are correct
B only 1 and 2 are correct
C only 2 and 3 are correct
D only 1 is correct

Your answer

☐

[1]

- 86 10 kg of water at 90 °C is mixed with 30 kg of water at 30 °C in a warm bath.

Assume there is no energy transferred by heating to the surroundings.

Which of the following statements is/are correct?

- 1 Energy transferred by heating from the hotter water = energy transferred by heating to the cooler water.
- 2 The temperature drop of hotter water = 3 × temperature rise of cooler water.
- 3 The final temperature of the mixture will be 45 °C.

- A 1, 2 and 3 are correct
B only 1 and 2 are correct
C only 2 and 3 are correct
D only 1 is correct

Your answer

☐

[1]

87(a) Show that the gravitational potential at the surface of the Earth is about -63 MJ kg^{-1} .

mass of Earth = $6.0 \times 10^{24} \text{ kg}$

radius of Earth = $6.4 \times 10^6 \text{ m}$

[2]

(b) Fig. 31.1 shows the gravitational equipotential at the surface of the Earth.

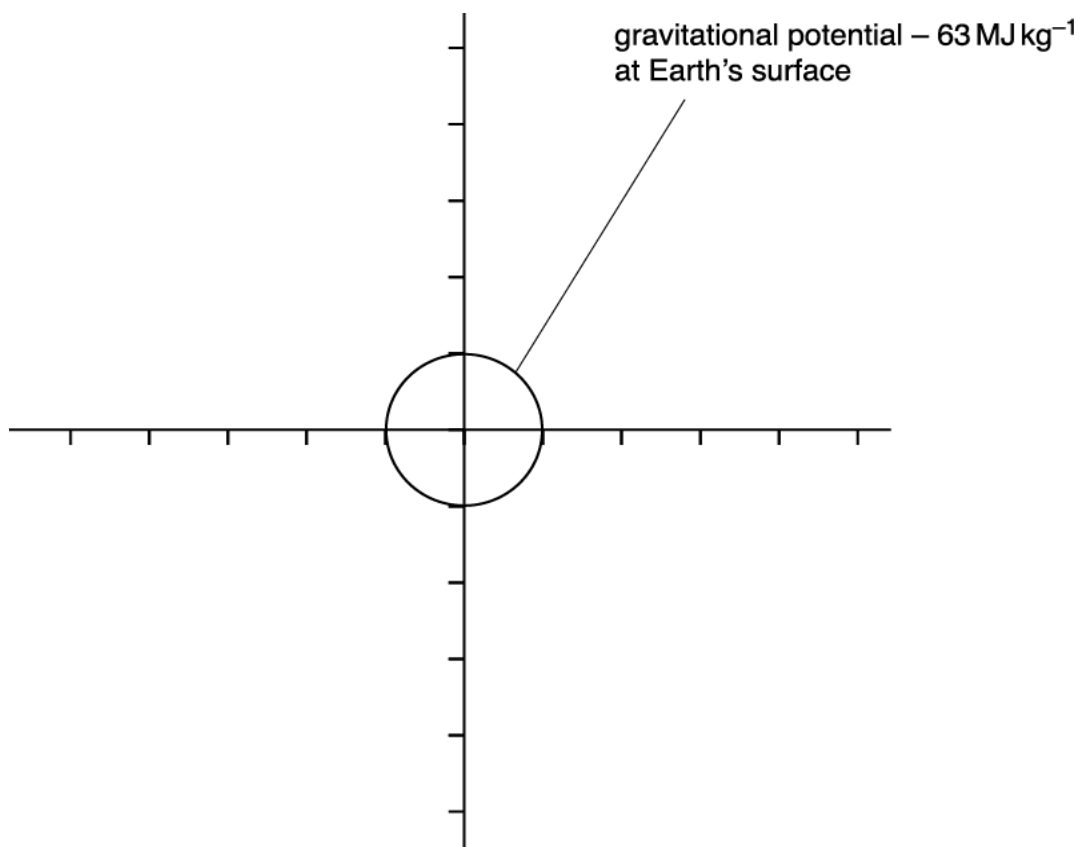


Fig. 31.1

On Fig. 31.1 draw the equipotential line for the Earth at -15.5 MJ kg^{-1} .

[2]

(c) The magnitude of the Earth's gravitational field strength at the surface is 9.8 N kg^{-1} .

Estimate the magnitude of the radial gravitational field on the -15.5 MJ kg^{-1} equipotential.

gravitational field strength = _____ N kg^{-1} [2]

88(a) This question is about modelling the decay of charge from a capacitor using iteration in discrete time intervals Δt .

The iterations are calculated using this model:

$$\Delta Q = -I \Delta t = -\frac{V}{R} \Delta t = -\frac{Q}{RC} \Delta t$$

State the assumption that is made.

_____ [1]

(b) In the model $\Delta t = 10 \text{ s}$ and the time constant for the circuit $RC = 25 \text{ s}$.

State and explain how the model could be made to be a more accurate representation of the decay.

_____ [2]

(c) In the table below, the first row sets up the initial conditions. Values in following rows are calculated by iteration using the model rules.

t elapsed / s	Charge Q on capacitor / mC	Charge lost during $\Delta t = \frac{Q}{RC} \Delta t$ / mC
0	50	20
10	30	
20		

Complete the empty boxes in the table.

[2]

89(a) Fig. 35.1 shows two hydrogen spectra, on the same wavelength scale. One is from a laboratory reference frame and the other from a distant, receding cloud of hydrogen gas.



Fig. 35.1

Compare features of the spectra and explain how they support the idea of Doppler red-shift.

[2]

- (b) Use the non-relativistic Doppler shift equation $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$

to show that the recession velocity v of the distant hydrogen gas cloud is about $0.1 c$.

[3]

90 *A student missed the lesson when the topic of **resonance of simple harmonic oscillators** was introduced. You are asked to make notes and labeled diagrams to help explain these ideas and enable the student to catch up.

In your answer include a description of an experiment that illustrates and explains the resonance of a simple harmonic oscillator, including the effect of damping.

[illegible]

[6]

91(a) This question is about a circular particle accelerator called a cyclotron.

The cyclotron consists of two hollow semicircular metal “dees”, dee 1 and dee 2, in a vacuum. The dees are in a uniform magnetic field B of 0.80 T and are separated by a narrow gap as shown in Fig. 40.1.

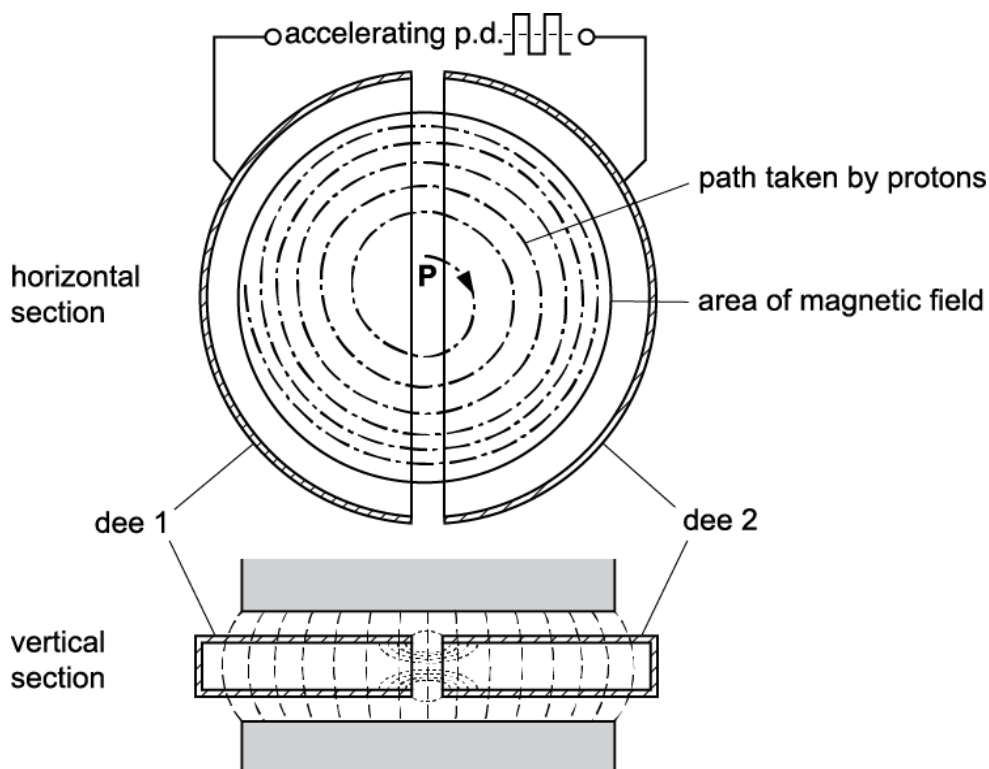


Fig. 40.1

Protons are injected into the gap between the dees at P and are accelerated by the electric field between the dees. The dees are horizontal and the magnetic field is in the vertical direction. The protons move in horizontal semi-circular paths within the dees, the path diameter increases after each crossing of the gap.

Show that the protons of mass m and charge q move in a circular path of radius $r = \frac{mv}{Bq}$ with constant speed v inside each dee. Assume non-relativistic conditions.

----- [2]

(b)

- (i) Show that the time T to travel around a semi-circle within a dee is independent of v .

[1]

- (ii) State the implication this has on the frequency of the alternating accelerating p.d. across the dees.

----- [1]

- (iii) The frequency f of the accelerating p.d. is given by $f \approx \frac{1}{2T} = \frac{Bq}{2\pi m}$.

Calculate this frequency for protons in a uniform magnetic field of 0.80 T.

frequency = ----- Hz [1]

- (iv) Each time the protons cross the gap between the dees they are accelerated through a p.d. of 5.0 kV.

Calculate the number of loops in their spiral path that is needed to accelerate them to an energy of 1.2 MeV.

number = ----- [2]

- (v) Use the relativistic factor γ to show that a non-relativistic approach for this cyclotron is a reasonable approximation.

rest energy of proton = 940 MeV

[2]

92(a) This question is about the first three minutes of the big bang, the formation of protons and neutrons and their fusion to produce the first nuclei of hydrogen and helium.

The table shows a time line at some interesting moments.

Time from big bang / s	0.02	1.1	180
Temperature / K	10^{11}	10^{10}	10^9
Energy kT / MeV	8.8	0.88	0.088
Density / kg m^{-3}	3.8×10^{12}	3.8×10^8	3.8×10^4

The big bang represents an incredibly hot and dense state of matter that was rapidly expanding and cooling.

(i) Show that at a temperature of 10^{11} K the thermal energy of particles and photons is around 9 MeV per particle.

[1]

(ii) Show that electron and positron pairs can easily be created from photon collisions at 10^{11} K

[2]

(iii) Explain why the creation of proton – antiproton pairs requires an earlier, hotter period of time during the big bang.

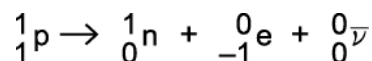
[1]

- (b) Free neutrons decay into protons with the emission of an electron and antineutrino. Free neutrons have a half-life of about 10 minutes. Once bound in a nucleus they become stable. Neutrons are more massive than protons.

$$m_{\text{PROTON}} = 1.007276 \text{ u} \quad m_{\text{NEUTRON}} = 1.008665 \text{ u} \quad m_{\text{ELECTRON}} = 0.000549 \text{ u}$$

$$1 \text{ u} = 1.661 \times 10^{-27} \text{ kg} = 931.3 \text{ MeV}$$

A proton can convert to a neutron by the process:



- (i) Show that the minimum energy for this process is about 1.8 MeV.

[2]

- (ii) 1.8 MeV is the activation energy for the conversion of a proton into a neutron. Use the Boltzmann factor to suggest why the ratio of numbers of protons : neutrons rises as the early universe cools, and at a temperature of 10^{11} K it is 1 : 0.812.

[3]

(c) As the universe cools to 10^{10} K, the proton : neutron ratio continues to rise. Neutrons can be fused to protons forming the simplest compound nucleus of deuterium ${}^2_1\text{H}$.

(a) Show that the binding energy for ${}^2_1\text{H}$ is about 2 MeV.

$$m_{\text{DEUTERON}} = 2.013553 \text{ u}$$

[2]

(b) Explain why some of the deuterons formed will also break apart at this temperature

----- [1]

93(a) Fig. 1 shows a simple charging circuit. The capacitor is initially uncharged. When the switch is closed, the capacitor begins to charge.

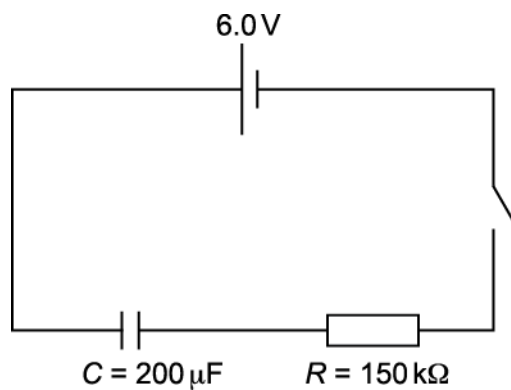


Fig. 1

(i) Show that the p.d. across the capacitor after the switch has been closed for one minute is about 5.2 V.

[2]

(ii) Calculate the p.d. across the resistor after the switch has been closed for one minute.

p.d. across resistor = _____ V [2]

(iii) Calculate the energy stored on the capacitor after the switch has been closed for one minute.

energy stored = _____ J [2]

- (b) People suffering heart problems can be fitted with **implantable defibrillators** which can deliver an electric shock to 'kick start' the heart. Fig. 1.2 shows a defibrillator in position.

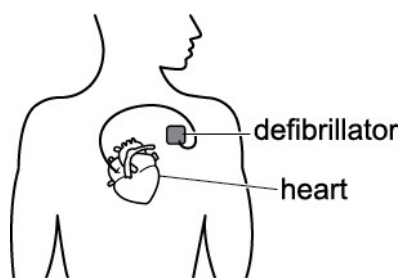


Fig. 1.2

- (i) Explain why a capacitor can be considered to be fully charged after charging for $5RC$ s. You may use calculations in your explanation.

[3]

- (ii) The $200\mu\text{F}$ capacitor in the defibrillator discharges into the heart in 40 ms. Calculate an estimate for the resistance in the circuit, making your method clear.

resistance = ----- Ω [2]

94(a) This question is about the kinetic model of gas behaviour.

Consider a single particle of mass m moving directly towards the shaded face of the cube as shown in Fig. 4.1. The particle makes elastic collisions with the walls of the cube.

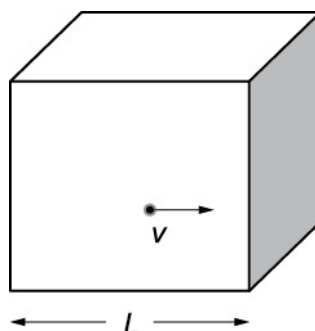


Fig. 4.1

Use the relationship $F = \frac{\Delta mv}{\Delta t}$ to show that the mean force F from repeated collisions of the particle with the shaded face is given by $F = \frac{mv^2}{L}$.

- (b) Explain why, if the cube contains N particles each of mass m moving in random directions, the pressure on any face is given by $p = \frac{1}{3} \frac{Nm \overline{c^2}}{V}$ where V is the volume of the cube and $\overline{c^2}$ is the mean square speed of the particles. [3]

[3]

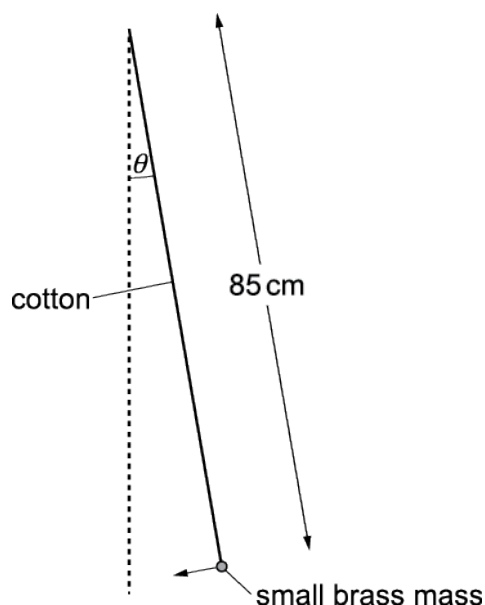
(e) The root mean square speed of a gas molecule can be found using the equation

$$\text{root mean square speed} = 1.2 \times \text{most probable speed}$$

The most probable speed in Fig. 4.1 is 400 m s^{-1} .

The mass of a molecule of the gas is $4.7 \times 10^{-26} \text{ kg}$. Calculate the temperature of the gas.

temperature = _____ K [4]



When the pendulum is displaced through a small angle θ and released, it performs simple harmonic motion about its rest position.

- (i) A student uses this 85 cm pendulum to determine a value for g . He times three complete oscillations, and obtains a time of 5.61 s.

Calculate the value of g given by this data. Express your answer to an appropriate number of significant figures.

[2]

- (ii) Suggest and explain one way in which this student could refine the experiment to get a more precise value for g .

[2]

96(a) This question is about centripetal acceleration and gravity.

The Earth orbits the Sun at a radius r of 1.5×10^{11} m. The time for one orbit (the orbital period T) is 3.2×10^7 s (one year). Calculate the centripetal acceleration of the Earth in its orbit.

$$\text{circumference of orbit} = 2\pi r$$

$$\text{centripetal acceleration} = \text{-----} \text{ m s}^{-2} \text{ [2]}$$

(b)

- (i) By equating the centripetal force on a planet with the gravitational force on the planet, show that $\frac{r^3}{T^2}$ is a constant for planets orbiting the Sun, where r is the radius of the planet's orbit and T is the orbital period.

[4]

- (ii) Mars orbits the Sun at an average radius of 2.28×10^{11} m.

Use the relationship in (i) and data from previous question to find the orbital period of Mars in years.

$$\text{orbital period} = \text{-----} \text{ years [2]}$$

(c) The orbit of Mars is not circular. Its distance from the Sun varies between 2.1×10^{11} m at its closest and 2.5×10^{11} m at its most distant.

(i) Show that the gravitational potential energy of the planet changes by about 7×10^{31} J between its furthest distance from the Sun and its nearest.

mass of Mars = 6.4×10^{23} kg

mass of Sun = 2.0×10^{30} kg

[3]

(ii) At its furthest point from the Sun, Mars travels at a speed of 2.7×10^4 m s⁻¹.

Use your answer to (i) to calculate its speed at its closest approach to the Sun. Make your method clear.

speed at closest approach = _____ m s⁻¹ [3]

97(a) This question is about cobalt-60 used in radiotherapy (lines 11–14).

Show that 1 g of cobalt-60 will produce an activity of roughly 4×10^{13} Bq.

Molar mass of cobalt-60 = 60 g mol^{-1}

1 year = $3.2 \times 10^7 \text{ s}$

[3]

(b) Use calculations to estimate the power output of 1.0 g of cobalt-60. State any assumptions you make.

power output = _____ W [2]

98 *This question is about positron emitters and PET scans (lines 41–61).

Fluorine-18 has a half-life of 110 minutes.

Describe and explain why PET scanning facilities need easy access to particle accelerators and why patients who have been given fluorine-18 must remain in the radiography room for a few hours after the procedure. Include an explanation of any precautions the medical personnel should take.

You may include calculations in your answer. You may find it helpful to assume that the activity of the fluorine-18 at the beginning of the procedure is 3000 Bq.

[6]

This image shows a full page of primary-ruled paper. It features multiple sets of horizontal dashed lines, each set consisting of three lines (two outer solid lines and one middle dashed line). These sets are repeated down the entire page, providing a guide for handwriting practice. The background is white, and the lines are black. There is no text or other content on the page.

99(a) This question is about the determination of the specific thermal capacity of aluminium.

An electrical heater is used to raise the temperature of a 1.0 kg aluminium block in the circuit shown in Fig. 1.1.

The switch is closed, switching the heater on for ten minutes before the switch is opened, which turns the heater off.

The temperature of the block is recorded at one minute intervals for fifteen minutes.

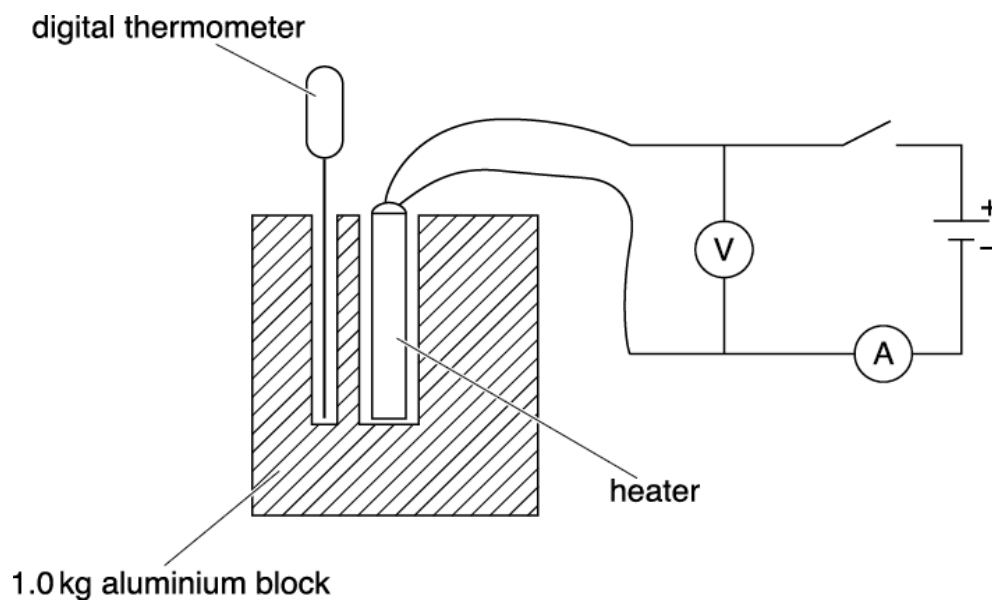


Fig. 1.1

Readings are taken of potential difference across the heater and current through the heater every two minutes. The results are shown in the table.

Time t / minutes	Potential difference V / V	Current I / A	Power P / W
0		2.30	19.8
2	8.67	2.35	20.4
4	8.74		20.3
6	8.75	2.42	21.0
8	8.69	2.39	20.8
10	8.70	2.41	

(i) Complete the missing values in the table.

(ii) Calculate the mean power. Include the uncertainty in the value.

mean power = _____ $\pm$ _____ W [2]

Fig. 1.2 shows a graph of temperature against time.

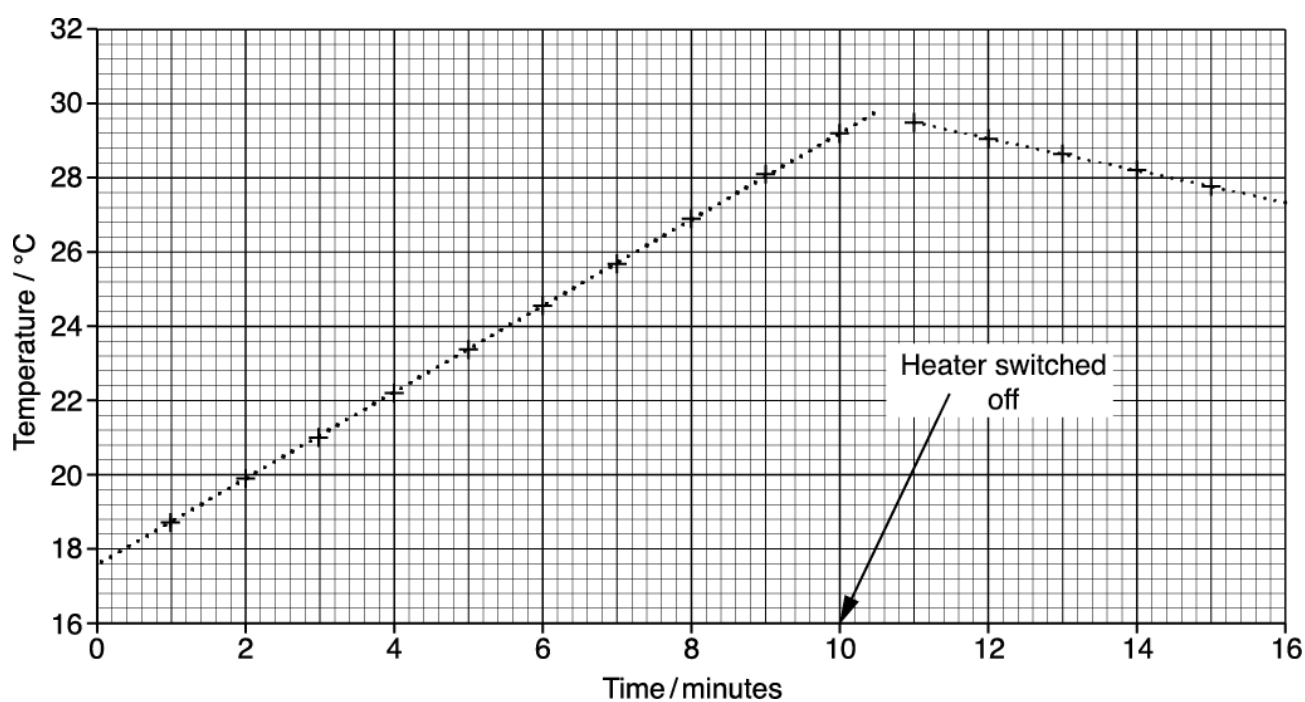


Fig. 1.2

(b)

- (i) Use data from the first ten minutes of the graph and your answer to (a)(ii) to show that the specific thermal capacity of aluminium is about $1000 \text{ J kg}^{-1} \text{ K}^{-1}$.

[3]

- (ii) Use Fig. 1.2 to estimate the maximum rate of cooling when the switch is opened.

maximum rate of cooling = _____ K min^{-1} [2]

- (c) The total percentage uncertainty in the investigation is found to be 5 %. The accepted value of the specific thermal capacity of aluminium is $897 \text{ J kg}^{-1} \text{ K}^{-1}$.

Calculate the percentage difference between your calculated value from (b)(i) and the accepted value and use this to comment on the accuracy of the investigation. Suggest reasons for the difference between the investigation value and the accepted value.

[4]

100(This question is about charging a capacitor in a circuit with two resistors in series.

a)

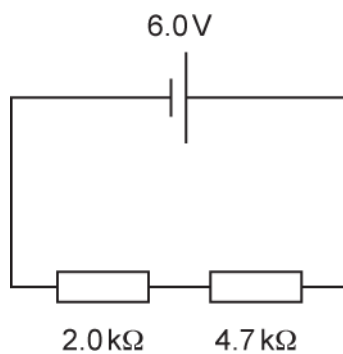


Fig. 2.1

A student constructs the circuit as shown in Fig. 2.2

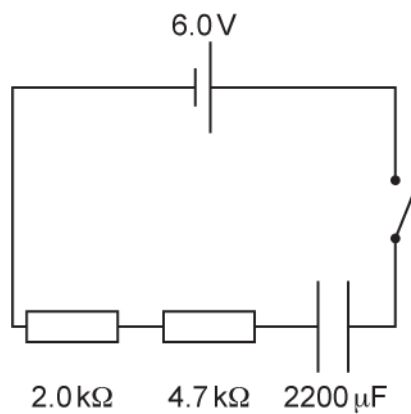


Fig. 2.2

Show that the time constant of the circuit is about 15 s.

[2]

- (b) The graph in Fig. 2.3 shows how the p.d. across the capacitor varies with time up to $5RC$. Add a line to the graph that shows how the p.d. across the $4.7\text{ k}\Omega$ resistor varies with time.

Add another line to show how the p.d. across the $2.0\text{ k}\Omega$ resistor varies with time. Label the lines.

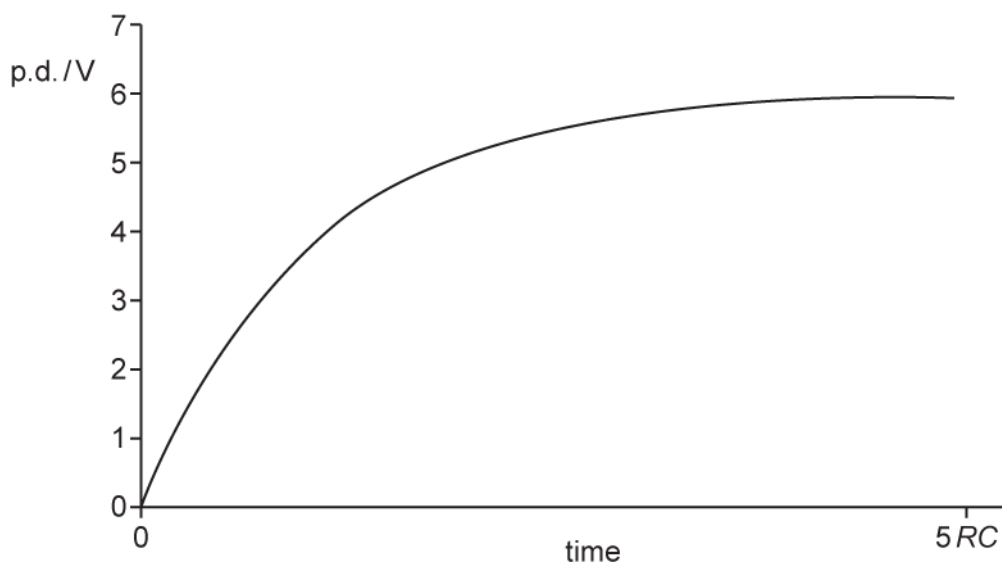


Fig. 2.3

[2]

- (c) Calculate the time it takes from the start of the charging for the p.d. across the capacitor to reach 5.0 V.

time = ... s [4]

END OF QUESTION PAPER

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
1			C	1	
			Total	1	
2			B	1	
			Total	1	
3			D	1	
			Total	1	
4			D	1	
			Total	1	
5			C	1	
			Total	1	
6			D	1	
			Total	1	
7			C	1	
			Total	1	
8			C	1	
			Total	1	
9			B	1	
			Total	1	
10			C	1	
			Total	1	
11			B	1	
			Total	1	
12			C	1	
			Total	1	
13			$\gamma = 6.84$ (1) $= 1/\sqrt{1 - v^2/c^2}$ Working through to $v^2/c^2 = 0.979$ (1) Working through to $v = 2.97 \times 10^8$ (m s ⁻¹) (1)	3	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			Total	3	
14	a		Red shift of (distant) galaxies	1	Accept Hubble's law
	b		$\lambda = hc/E$ rearrangement (1) By calculation or simple ratio, increase in λ = 1000 times (1)	2	
			Total	3	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
15			Level 3 (5–6 marks) Marshals argument in a clear manner linking the idea of particle collisions and gaining energy with the model with the definition / explanation of the mathematical formalism of the BF Shows clear working of BF ratio leading to answer in range <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Covers at least two aspects of the argument. Physics correct but perhaps not sufficiently detailed / doesn't cover enough indicative points. Mathematical aspect poorly worked or inaccurate. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Makes two expected points but the answer is superficial and incomplete. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	6	Indicative scientific points may include: Particle collisions: • Particles exchange energy on collisions • Some particles will gain energy in a number of consecutive collisions • This can lead to particles with sufficient energy to evaporate Boltzmann factor • Gives the ratios of particles in energy states differing by ϵ • Linking this ratio to the probability of a particle moving from one energy state to the next(classical) particles cannot superpose Comparison of rates: • Rate of evaporation proportional to BF • Explanation of the above point (greater probability mean that more will leave the liquid per second) • Clear mathematical working – either direct or via natural logs. For example: $\ln(f_{303}/f_{293}) = 293/303$ • Answer in range 1.5–2.7 (variation large because BF so sensitive to intermediate roundings if candidate calculate individual E / kT values)
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
16	a	i	Good best fit line, with ruler (1) Two pairs of points taken from line, $\times$ values separated by at least 150 s. (1) Calculation of gradient e.g. $1/100 = 0.01 \text{ s}^{-1}$	3	A candidate could calculate the half life by subtracting 0.693 from a y value and finding the difference in x, or by converting ln values to count rate. This is acceptable. Read offs correct to half a small square.
		ii	Half-life = $0.693/0.01$ (1) = 69 (s) (1)	2	Range of values from candidates decay constant

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b		Level 3 (5–6 marks) Marshals argument in a clear manner and includes clear explanation of three strands: • randomness • the exponential curve as a model • the effect of the number of nuclei present <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Shows clear understanding of at least two of the three strands above to the argument or covers all three at a superficial manner and does not include enough indicative points for Level 3. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Makes at least two independent points that are relevant to the argument but does not link them together and shows only superficial engagement with the argument. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	6	Indicative scientific points may include: Randomness • cannot know when an individual nucleus will decay • explanation of the meaning of the decay constant (e.g. probability of decay of individual nucleus in unit time) • λ as the probability related to dN/dt • discussion of an analogue (e.g. coins or dice) The exponential curve as a model • reference in correct context to $N = N_0 e^{-\lambda t}$ or • linking to $dN/dt = -\lambda t$ The effect of the number of nuclei present • for fixed λ the number of nuclei decaying in a given time can be predicted given sufficiently large sample • as count rate falls, the number of nuclei that may decay also falls • as the number of nuclei falls the variation from the predicted outcome will increase • with increase variation comes increasing scatter
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
17	a	i	Time constant is the time taken for the voltage to fall to 1/e of original value or $0.37 \times 6 \checkmark$ $= 2.2 \text{ V} \checkmark$ Shown on graph to be about 25 seconds $\checkmark$	3	ORA accept answers using initial tangent at $t = 0$ accept answers in range 24.5 to 25.5 s
		ii	$R = \tau / C \checkmark$ $R = 25 / 4700 \times 10^{-6} = 53(2)0 \Omega \checkmark$ Then $I = V/R = 6 / 5320 \checkmark$ $= 1.1 \times 10^{-3} \text{ A} \checkmark$	4	Credit correct answers based on own value of time constant from part (a) OR $I = \Delta Q / \Delta t = C \Delta V / \Delta t$ with $\Delta V = 0.50 \text{ V}$ gives 1.2 mA for full marks

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	* Level 3 (5–6 marks) Performs both calculations correctly and appreciates the strengths and limitations of both. Principally: for Method 1 relies on $Q \propto V$ which is valid; for Method 2 the y-axis needs to be re-interpreted and the area being measured (integration by counting squares) gives an approximate estimated answer. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Performs both calculations successfully but method may not be completely clear or does not compare them sufficiently well. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Attempts one or both calculations but does not successfully compare the two methods. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	6	expected comparison of two methods - method 1 does not depend on the time variation of $V(t)$, only on the accuracy of start and end p.d.s. and the R and C values. It is a calculation based on theory. - method 2 depends on counting squares and fractions of squares under the exponential decay curve which is an approximation to the area under the graph leading to an estimate of the charge flow. points worthy of credit: - method 1 calculation: $\Delta Q = C\Delta V$ with $\Delta V = (6 - 1.8) \text{ V}$ - gives 19.7 mC - method 2 estimation: re-scaling of y-axis to represent current - area under $I(t)$ represents $\Delta Q = I \Delta t = V\Delta t/R$ - each 1 cm square $1 \times 10/5000 = 2 \text{ mC}$ - between 0 and 30 s there are about 10 squares - so total charge flow = $10 \times 2.0 \times 10^{-3} = 20 \text{ mC}$ accept answers in range 18 to 22 mC
	b		$V_t = V_0 \exp(-t/\tau)$ ✓ in which $V_0 = 6 \text{ V}$, $V_t = 1 \text{ V}$ ✓ so $t = 25 \times \ln 6 = 45 \text{ s}$ ✓ (ecf on RC value) 45 < 50 so YES it does meet requirement ✓	4	accept alternative method: after another τ p.d. will drop to $2.2/e = 0.81 \text{ V}$ so YES

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		charge & discharge graphs match time constant except for factor 1000 on time scale OR charge $V = 6(1 - e^{-t/R_1C})$ t in s & discharge $V = 6 e^{-t/R_2C}$ t in ms ✓ so $R_2C = 1000 R_1C$ $R_1 = 5320 / 1000 = 5.3 (\Omega)$ ✓	3	accept other correct methods e.g. both graphs take same time value to reach $\frac{1}{2}$ V max except for time scale in s and ms OR full calculation of time constant during charging Accept 5000/1000 = 5.0 (Φ)
			Total	20	
18	a	i	$V = 0.20 \times \pi \times 0.025^2 = 3.9 \times 10^{-4} (\text{m}^3)$ ✓ $N = pV/kT$ or $N = (1.0 \times 10^5 \times 3.9 \times 10^{-4}) / (295 \times 1.38 \times 10^{-23})$ ✓ $= 9.7 \times 10^{21} (\approx 10^{22})$ ✓	3	1st mark for getting the volume of the jar; marks 2 and 3 are method and evaluation marks for calculation of the number of molecules. Correct answer gains 3 marks
		ii	V per molecule $= 3.9 \times 10^{-4} / 9.5 \times 10^{21} = 4.1 \times 10^{-26} (\text{m}^3)$ ✓ $x = \sqrt[3]{(4.1 \times 10^{-26})} = 3.4 \times 10^{-9} (\text{m}) (\approx 3 \text{ nm})$ ✓	2	Can use 10^{22} to get $3.9 \times 10^{-26} \text{ m}^3$ (gives the same x) Correct answer gains 2 marks
	b	i	$pV = \frac{1}{3} N m \overline{c^2} = N k T$ ✓ $\overline{c^2} = 3 k T / m \Rightarrow \text{r.m.s. speed} = \sqrt{\overline{c^2}}$ ✓	2	
		ii	r.m.s. speed $= \sqrt{\frac{3 \times 1.38 \times 10^{-23} \times 295}{2.1 \times 10^{-25}}} = 240 (\text{m s}^{-1})$ ✓ distance travelled in the 5 minutes $= 240 \times 300 = 72\,000 \text{ m}$ ✓ random walk due to multiple collisions (with air molecules) ✓	3	
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
19	a		upwards force = $\rho_w(d + s)Ag$ and downwards force is still $mg = \rho_w Adg$ ✓ so resultant force $F = \rho_w Asg$ and acceleration = $F/m = \rho_w Asg/m$ ✓ $a \propto -s$ so this is simple harmonic motion ✓ $a = -\omega^2 s$ so $\omega^2 = \rho_w Ag/m$ ✓ $T = 2\pi/\omega$ ✓ ($= 2\pi\sqrt{(m/\rho_w Ag)}$)	5	allow reference to additional weight of water displaced when moved from equilibrium. accept in the opposite direction for (–) sign Full credit for corresponding alternative with $2\pi f$ for ω

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
	b	*Level 3 (5–6 marks) Both methods compared and advantages of SP and disadvantages of FR identified. Qualitative comparison of uncertainties of the different methods made, even if not completely successful, linking to value for g. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Compares both methods and identifies some advantages of SP method. Partial attempt to quantify differences. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Makes direct comparison between at least one shortcoming of FR method and an advantage of SP method. No attempt to quantify uncertainty. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	6	Indicative scientific points may include: floating rod method • Method is indirect • Rod may oscillate in different directions • Damping will stop oscillations • Difficult to time a large number of oscillations to reduce ΔT • Water surface will move making it hard to judge position of rod • Use of the formula in the form $g = \frac{4\pi^2 m}{T^2 \rho_w A}$ • Percentage uncertainty in m and A are small compared with T • T will be of the order of 1 s • $\Delta T/T$ significantly larger than for pendulum • logical argument linking uncertainties in measurement through to value of g simple pendulum method • Method is indirect • Can time a large number of oscillations to reduce ΔT • May be systematic error in measuring L • Use of dense bob and light, flexible thread minimises frictional losses • Easy to judge position of bob e.g. passing through centre • Use of the formula in the form $g = \frac{4\pi^2 l}{T^2}$ • T will be of the order of 2s • $\Delta T/T$ significantly smaller than for floating rod • logical argument linking uncertainties in measurement through to value of g
		Total	11	

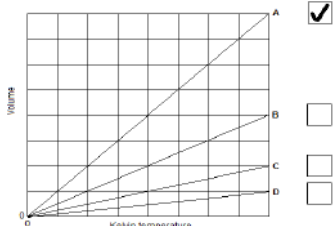
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
20		i	total charge before = 0 (p^+ and p^-) ✓ 4 hadron tracks curve clockwise and 4 anticlockwise, so for every + charge there is a – charge ✓	2	
		ii	$mv^2/R = Bqv$ ✓ so $v = BqR/m$ ✓ $= (2.2 \times 1.6 \times 10^{-19} \times 4.6 \times 10^{-3}) / 2.5 \times 10^{-28}$ $= 6.5 \times 10^6 \text{ (m s}^{-1}\text{)}$ ✓	3	
			Total	5	
21	a		$hc / \lambda = kT \Rightarrow T = hc / k\lambda$ ✓ $T = 6.6 \times 10^{-34} \times 3 \times 10^8 / (\lambda \times 1.4 \times 10^{-23})$ Gives range of $1.4 \times 10^6 \text{ K}$ to $1.4 \times 10^8 \text{ K}$ ✓ Compares with T of photosphere, e.g. at least $200 \times$ higher temperature ✓	3	Accept other sensible Boltzmann approximations e.g. $3/2 kT$ Accept Boltzmann factor considerations leading to lower temperatures
	b		Must consider 'worst case scenario', i.e. 3200 km s^{-1} speed ✓ time to reach Earth = $150 \times 10^9 \text{ m} / 3200 \times 10^3 \text{ m s}^{-1} = 46875 \text{ s} = 13 \text{ hours}$ ✓ Action taken: any one from shut down satellites facing Sun / prepare for power cuts / shield sensitive circuits / disconnect grid circuit breakers ✓	3	ecf wrong choice of speed must convert to hours or days (to have realistic view of time left) allow other reasonable suggestion
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
22	a		SOHO orbital radius = $(1.50 \times 10^{11} - 1.5 \times 10^9) = 1.485 \times 10^{11} \text{ (m)}$ ✓ $\omega = 2\pi/T$ ✓ $= 2\pi/(3.2 \times 10^7 \text{ s}) = 1.96 \times 10^{-9} \text{ rad s}^{-1}$ ✓ $a = (-)r\omega^2 = (1.485 \times 10^{11} \text{ m}) \times (1.96 \times 10^{-9} \text{ rad s}^{-1})^2 = (-)5.7 \times 10^{-3} \text{ m s}^{-2}$ ✓	4	<i>Alternative</i> SOHO orbital radius = $(1.50 \times 10^{11} - 1.5 \times 10^9)$ $= 1.485 \times 10^{11} \text{ (m)}$ ✓ Speed of SOHO = orbital circumference / time $= 2\pi \times (1.485 \times 10^{11} \text{ m}) / 3.2 \times 10^7 \text{ s}$ ✓ $= 29000 \text{ m s}^{-1}$ ✓ $a = v^2 / r = (29000 \text{ m s}^{-1})^2 / (1.485 \times 10^{11} \text{ m}) = 5.7 \times 10^{-3} \text{ m s}^{-2}$ ✓
	b		Net F_{grav} on SOHO = $(-)Gm(M_{\text{S}}/r_{\text{S}}^2 - M_{\text{E}}/r_{\text{E}}^2)$ ✓ $= (-)11 \text{ N}$ ✓ From (c) centripetal force = mass SOHO × centripetal acceleration $= 1900 \text{ kg} \times (-)5.7 \times 10^{-3}$ ✓ $= (-)11 \text{ N}$ ✓ net gravitational force provides the centripetal force required to enable SOHO to orbit in 1 Earth year ✓	5	ecf from (c) as necessary. ORA
			Total	9	
23			Conservation of energy i.e. $\Delta\text{GPE} = \Delta\text{KE}$ ✓ $GMm(1/r_{\text{closest}} - 1/r_{\text{furthest}}) = \frac{1}{2}m(v_{\text{closest}}^2 - v_{\text{furthest}}^2)$ $3.29 \times 10^{23} \text{ J} = (1.1 \times 10^{14})(V_{\text{closest}}^2 - 880^2)$ ✓ $V_{\text{closest}} = 54\,000 \text{ m s}^{-1}$ ✓ which is 62 times greater than 880 m s^{-1} ✓	4	
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
24	a		N kg^{-1}	1	Accept ' $/$ ' for ' $^{-1}$ ' e.g., N/kg instead of N kg^{-1} Examiner's Comments This was generally well done.
	b		Ns and kg ms^{-1}	1	Reject: n for N . Examiner's Comments This was generally well done. Most candidates correctly identified the units. It was noted that a small number of candidates used lowercase ' N ' while others might use ' $/$ ' instead of the negative power – both should be avoided – the ' n ' is of course symbolic of a prefix and the ' $/$ ' could indicate that the candidate knows the units but is unaware of the mathematical formalism using the negative sign, so is simply stating the units they recall, not selecting from the list.
			Total	2	
25				1	Examiner's Comments This question seemed to discriminate well. Weaker candidates often did not get the mark and if the answer was wrong, ' C ' seemed to be the common mistake.
			Total	1	
26	a		0.5	1	Accept $\frac{1}{2}$ instead of 0.5 Examiner's Comments This was generally well done.
	b		8	1	Examiner's Comments This was generally well done. It was surprising to see how many felt that the Boltzmann factor would be greater than 1.
			Total	2	

Mark Scheme

Question			Answer/Indicative content				Marks	Guidance													
27			<table><tr><td>T / K</td><td>V / ml</td><td>p / kPa</td><td>pV/T</td></tr><tr><td>283</td><td>5.5</td><td>100</td><td>1.94</td></tr><tr><td>270</td><td>2.2</td><td>230</td><td>1.87</td></tr><tr><td>373</td><td>6.0</td><td>120</td><td>1.93</td></tr></table>	T / K	V / ml	p / kPa	pV/T	283	5.5	100	1.94	270	2.2	230	1.87	373	6.0	120	1.93	3	evidence of calculating pV/T or an appropriate equivalent ... e.g., pV/kT, T/pV, kT/pV for [1] correct evaluation to at least 2 s.f. for all three rows [1] correct conclusion with reason: yes, because all same value to 2 s.f. set by V for [1] Note: If the student uses pV/kT with $k = 1.4 \times 10^{-23}$, the values are not the same to 2SF (1.4, 1.3, 1.4) but accept a sensible conclusion based on the SF set by V. The focus here, is on SF so IGNORE any reference to decimal places. Examiner's Comments Many candidates did well on this question, achieving 2 of the 3 available marks. The range of different values calculated was quite large with PV/T, PV/NT (with an incorrect value for N) and the inverse of these two options. The cohort also used 1.38 or 1.4 for k. A minority of candidates achieved all 3 marks – most failed to obtain the final mark because, although answers were often expressed to 2 SF, there was no justification given, even though the question referenced the precision of the data. Very few commented on the 2 SF for V.
T / K	V / ml	p / kPa	pV/T																		
283	5.5	100	1.94																		
270	2.2	230	1.87																		
373	6.0	120	1.93																		
			Total	3																	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
28			There are two ways to get the first marking point: red shift suggests that all (distant) galaxies are moving away (from us / each other). Recessional velocity of (distant) galaxies increases (linearly) with increasing distance;	1	The reference to galaxies needs to be plural so ... <i>a galaxy is moving away from us</i> , would not trigger the mark. IGNORE all references to an explanation of what redshift is.
			so at some time in the past all galaxies / matter / everything would have been at one point / singularity;	1	Reject: Close together / at the same place / position. Reject: The universe started at a single point. The emphasis here, is on the matter / galaxies, not the whole universe. Examiner's Comments This question was generally not done well. Candidates often seemed to ignore the question and simply explain what is meant by redshift. It was also disappointing to see the large number of candidates that refer to stars or planets rather than 'distant' galaxies, as discussed in the question. This was a very good example of a question where candidates needed to read the question carefully and answer what is requested, rather than answer the question they want it to be. For the second marking point, many failed to include the 'at some time in the past' element, so that their descriptions could fit the steady state theory as well as the big bang theory. Again, many failed to tie this to galaxies.
			Total	2	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
29	a		$v = \frac{3 \times 10^{-9} \times 3 \times 10^8}{5 \times 10^{-9}} = \underline{1.8} \times 10^8 \text{ m s}^{-1};$	1	At least 2SF required in the final answer. Note: $2.4 \times 10^8 \text{ m s}^{-1} = [0]$ Examiner's Comments (a) was generally done well and the slightly unusual axis did not cause many problems.
	b		$\gamma = \sqrt{\frac{1}{1 - 0.6^2}} = 1.25 \quad / \quad \frac{5}{4};$ life time = $5.0 / 1.25 = 4 \text{ ns}$;	1 1	$v = 2 \times 10^8$ gives $\gamma = 1.34$, lifetime = 3.7 ns for [2] Accetable values are between 3.7ns and 4.0ns. Allow ECF ONLY for a value calculated in (a) that rounds to $2 \times 10^8 \text{ ms}^{-1}$ e.g., $v = 2.4 \times 10^8$ gives $\gamma = \frac{5}{3}$ and lifetime of 3ns. Allow ECF on any value for γ greater than 1. Watch out for mistakes in the calc of γ, and the subsequent calc for lifetime, that give 4ns e.g., $\gamma = \sqrt{1 - \frac{v^2}{c^2}} = 0.8$ followed by ... $0.8 \times 5 = 4$ Examiner's Comments (b) was tougher, than (a), with many candidates calculating gamma but then almost randomly either multiplying or dividing it with t. A minority of candidates lost the second mark for giving the answer with '$\times 10^{-9}$' without crossing out the 'ns' on the answer line. This is a typical error and candidates must watch out for the format of the answer line.
			Total	3	

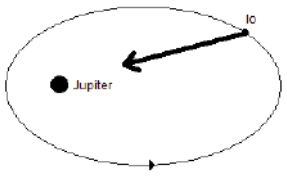
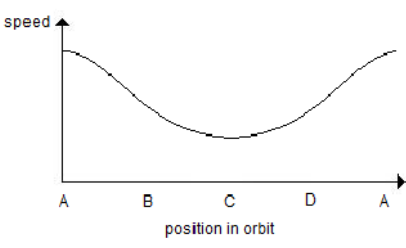
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
30			A correct test clearly stated for [1]; Note: This could be implied in the comments made e.g., calculations for two gradients at two stated <u>gradient</u> voltages, is followed by ... <i>the voltage is NOT a constant value.</i>	1	e.g., ... • an exponential then should have a constant half-life (of $0.7RC$); • The ratio of voltages in equal time intervals should be the same. $\frac{\Delta \ln(V)}{\Delta t} = \text{const}$ • A plot of $\ln(V)$ vs t would be a straight line. • $\frac{\text{gradient of curve}}{\text{voltage}} = \text{const}$ • Correct use of $V = V_0 e^{-t/RC}$
			Evidence from graph that it isn't [1] e.g. 6 V to 3 V in 2 minutes, but 3 V to 1.5 V in 4 minutes;	1	There should be a minimum of two data points from the graph. An incorrect test would not allow this second mark to be obtained. Candidate must not simply state two pieces of data. Examiner's Comments Candidates generally fell into one of two camps with this question. They either focused on the half-life, showing that the two obvious half-lives (6 V to 3 V & 3 V to 1.5 V) are not the same, or they tried using some other, more complex method. Most candidates using the 'half-life' route scored both marks while more complicated methods were often flawed.
			Total	2	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
31	a	i	$v = \frac{2\pi \times r}{T} / v = \frac{2\pi \times 4.2 \times 10^8}{43 \times 3600};$	1	EOR
		i	$= 1.7 \times 10^4 \text{ m s}^{-1}$	1	Accept $1.8 \times 10^4 \text{ m s}^{-1}$ produced by $T = 1.5 \times 10^5 \text{ s}$ i.e., 2SF.
		i			Examiner's Comments This was generally done well but far too many candidates did not seem aware of the correct formula for the circumference of a circle.
		ii	$\frac{GMm}{r^2} = \frac{mv^2}{r};$	1	$\frac{GMm}{r^2}$ If a '-' sign is used for $\frac{GMm}{r^2}$, this must also be used with $\frac{mv^2}{r}$. If not, zero marks.
		ii	clear rearrangement to $M = \frac{rv^2}{G};$	1	If the student begins with the equations for a and not F (i.e., $\frac{GM}{r^2} = \frac{v^2}{r}$), they score zero. There should be at least 1 line of correct working. Watch out for correct and clear cancelling. M and m should be clearly distinguished in the working.
		ii			Examiner's Comments Well done. The major problem was when candidates started with a negative in Newton's law of gravitation and did not set this equal to a negative centripetal equation. Having the negative sign simply vanish along the way, would not be creditworthy. It is important for candidates to be careful with their symbols for M and m – they should look different if subscripts are not used.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	$M = \frac{4.2 \times 10^8 \times (1.7 \times 10^4)^2}{6.7 \times 10^{-11}} = 1.8 \times 10^{27} \text{ kg}$	1	20 kms⁻¹ gives 2.5×10^{27} kg for [1] 18 kms⁻¹ gives $2.0(3) \times 10^{27}$ kg for [1] Allow an ECF from (i) ONLY if the value rounds to 2×10^4 Examiner's Comments Candidates should take care when using km to remember to $\times 1000$ and typically, many forgot the square in the formula that they had just derived.
	b	i		1	Arrow of any length from Io to Jupiter. NOT by eye. An acceptable extended straight line would pass through Io and Jupiter. Possibly use a transparent ruler to check. Examiner's Comments Jupiter was quite a wide target but regardless, many candidates were careless with their arrow and it was very disappointing to see the number of answers which clearly did not use a ruler. Common mistakes were directing the arrow to the centre of the orbit or directing it tangential to the orbit.
		ii		1	look for minimum at C, maximum at A The points for A must be the same speed within $\frac{1}{4}$ of a square. The minima must be within $\frac{1}{4}$ of a square of C AND must NOT touch the x-axis. Reject a U shaped curve (there should be inflection points). Examiner's Comments This question seemed to discriminate well. Many answers had roughly the right shape with points of inflection but with the line a long way from being horizontal at A.
		iii	EITHER less GPE at A/ as moon approaches planet;	1	Accept: The GPE becomes more negative as Io approaches the planet.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	so more KE as energy conserved; OR There is a component / part of the force along orbit path / (gravitational) force is not perpendicular to the velocity; accelerates moon as it approaches planet / decelerates moon as it goes away from planet;	1	Do not accept <i>speed</i>, since this has no direction. Examiner's Comments Very few candidates answered this question well. The most worrying feature was in the discussion of the forces and/or energy changes in an elliptical orbit, which was poorly done. It was disappointing to see so many candidates thinking that Io has more GPE when it is close to Jupiter. Many invoked Kepler's law about areas swept out not understanding that this was not an explanation but an empirical law and not amounting to the explanation that was required. They also demonstrated their poor understanding when they stated that Io does not accelerate at A. A small number of answers seem to have confused velocity (v) with gravitational potential (V_g).
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
32	a		$GPE = -\frac{GMm}{R}$ at surface of planet;	1	Without a statement about the surface of the planet, accept R to indicate the surface of the planets, not r . The GPE MUST have the '-' sign.
			$KE + GPE > 0$ for atom to escape gravitational field;	1	We are looking for a statement about the total energy OR the decrease in KE = gain in GPE OR $KE > \Delta GPE$ so the removal of the negative sign can be explained. Accept $KE + GPE = 0$ Examiner's Comments This was not well done. There were some excellent answers but most candidates did not start with the correct equation for GPE and had to contrive to get the right answer. Further, many kept their equations general with the use of ' r ', when ' R ' was required.
	b		$m = 4.0 \times 10^{-3} / 6.0 \times 10^{23} = 6.67 \times 10^{-27}$ kg;	1	no ECF for incorrect calculation of m There must be evidence that E_k has been calculated Examiner's Comments This was generally well answered. A small number of candidates tried to use $P = h\rho g$ to calculate the reduction in atmospheric density but this did not lead to correct answers.
			$E_k = \frac{6.7 \times 10^{-11} \times 6.0 \times 10^{24} \times 6.67 \times 10^{-27}}{6.4 \times 10^6} = 4.2 \times 10^{-19} \text{ J}$	1	
	c	i	$T = 273 + 15 = 288 \text{ K};$	1	Only accept ECF for incorrect $T = 15 \text{ K}$ gives $2.1 \times 10^{-22} \text{ J}$
		i	$kT = 1.4 \times 10^{-23} \times (288) = 4.0 \times 10^{-21} \text{ J}$	1	Accept $1.5 kT = 6.0 \times 10^{-21} \text{ J}$ for [2] Accept 1 SF for the final answer.
		i			Examiner's Comments Many good answers and it was pleasing to see that very few candidates seemed confused with °C and K.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	Particles / helium atoms / molecules collide with other particles;	1	It needs to be clear that the particles are colliding with other articles, not inferred from the argument. ignore changes of GPE
		ii	(in the collisions) there is an exchange of energy;	1	ignore changes of temperature Reject: in collisions there is a <i>change</i> of energy
		ii	the exchange of energy in a collision is random;	1	Examiner's Comments There were many good answers to this question. However, too many poor answers were linked to the candidates ignoring the question when it asked that ... <i>...answers should clearly link the variations in the energy of the helium atoms to the behaviour of particles...</i> Several answers were in terms of the energy changing with distance from the centre of the Earth, and ignored the request to discuss the <i>range</i> of energies. It was not good to see so many answers which show that candidates had little real understanding of the concept of temperature and felt that they could discuss the temperature of an individual particle rather than the system.
		iii	BF for helium is $e^{-4.2 \times 10^{-19} / 4.0 \times 10^{-21}} = 5 \times 10^{-46}$;	1	calculation [1] Accept any BF that looks reasonable and produces an answer around 10^{-46} to 10^{-44} .
		iii	BF is the proportion / fraction / probability of atoms which have enough energy to escape (after a collision);	1	what BF represents [1] Accept BF is <i>related</i> to / determines / defines / gives / the probability

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	chances of escape small unless enough collisions are considered / lots of collisions needed owtte;	1	conclusion [1] Examiner's Comments It was good to see that many candidates defined the Boltzmann factor, but did not do so within the context of this question, leaving it as a general statement about effectively, a 2-state system. Very few considered the huge number of collisions made by atoms and many complicated their argument by adding 'per second' to their definition of the Boltzmann factor.
			Total	12	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
33	a	i	Particles collide (with the surface) and exert a force;	1	Accept there is a force generated by the colliding particles
		i	More particles collide with the bottom surface (per second) than the top surface;	1	not particles move slower on top Reject no collisions on the top surface or no downward force. Reject The outside force > inside force (direction needed).
		i	There is a net upwards force / $F_{up} > F_{down}$;	1	QWC: award third mark only if reason for net upwards force clearly linked to particles. Examiner's Comments There were some good answers to this question but not as many as would have been indicated by the answers to Qu11(c)(iii) – the earlier good descriptions of kinetic theory did not seem to translate to this question. It was disappointing to see the number of candidates that referred to the inside of the tube as being a vacuum, particularly when the questions stated that the pressure is simply reduced. Also, many arguments were based on outside molecules "... trying to move to the area of lower pressure" or "... being sucked towards the vacuum cleaner", suggesting a poor grasp of the underlying mechanisms. Descriptions of how pressure arises due to the collision of particles was quite poor.
		ii	$F = mg = 0.2 \times 9.8 = 1.96\text{N}$;	1	accept any mass from 0.20 kg to 0.29 kg e.g. 0.25 kg for 2.45 N and 21 kPa for [1]
		ii	pressure (difference) = $F/A = 1.96/\pi \times (6 \times 10^{-3})^2 = 1.7 \times 10^4 \text{ Pa}$;	1	Rounding the area to $1.1 \times 10^{-4} \text{ m}^2$ gives 18kPa leading to 82kPa[3]

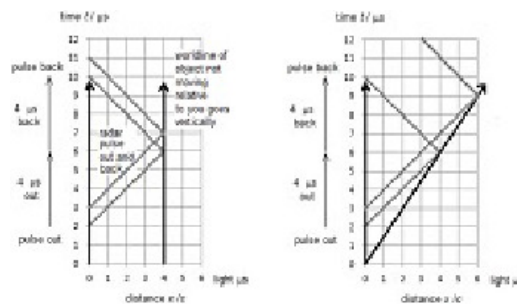
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	net pressure = $100 - 17 = 83 \text{ kPa}$; ----- Alternative answer: based on forces: $F = mg = 0.2 \times 9.8 = 1.96\text{N}$; $(F_{\text{up}} = 100 \times 10^3 \pi (6 \times 10^{-3})^2 = 11.3\text{N})$ $\Delta F = 11.3 - 1.96 = 9.35\text{N}$; net pressure = $\frac{9.35}{\pi(6 \times 10^{-3})^2} = 83 \text{ kPa}$;	1	Note: If diameter is used as the radius, the net pressure = 96kPa [2] max Accept $100 - 20 = 80\text{kPa}$ for [1]max No ECF on incorrect F. Examiner's Comments Generally well answered although it was very disappointing to see a large number of candidates were unable to calculate the area of a circle given its diameter – this was another example of many candidates not having a grasp of basic geometry.
	b		The ratio of the areas = $\frac{30^2}{12^2} = 6(.25)$ OR the ratio of the masses is $\frac{1.2}{0.2} = 6(.25)$; With the same absolute uncertainty in mass (e.g., 0.1), the precision in the pressure measurement improves by 6(.25);	1 1 1	new mass is $1.7 \times 10^4 \times \pi \times (15 \times 10^{-3})^2 / 9.8 = 1.2.\text{kg}$ Full ECF on pressure calculated in (a)(ii) [1]max available for a qualitative argument along the lines: • Larger area leads to ... • Larger load ... • And a greater precision on the measurement of P Allow ECF from the area / mass calculation. Examiner's Comments This was very poorly answered. It was interesting to note that many answers to this question were descriptive when the question clearly instructed that a calculation of some sort was needed. The candidates did not understand this question although some tried to translate 'precision' as 'uncertainty' and gave some sensible attempts. Remarks about the pressure in the hose being more uniform once the nozzle had been removed revealed some of their misconceptions about pressure and kinetic theory.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
34			$r = (6400 + 1000) \text{ km}$ (1) So $v = 2 \pi \times 7400 \times 10^3 / (100 \times 60)$ $= 7750 \text{ m s}^{-1}$ (1)	2	Ignore rounding errors Accept $7.7 \times 10^3 \text{ m s}^{-1}$ and $7.8 \times 10^3 \text{ m s}^{-1}$ Need clear working and own value Examiner's Comments These were standard calculations.
			Total	2	
35			D	1	
			Total	1	
36			A	1	
			Total	1	
37			C	1	
			Total	1	
38			D	1	
			Total	1	
39			C	1	
			Total	1	
40			A	1	
			Total	1	
41			B	1	
			Total	1	
42			B	1	
			Total	1	
43			C	1	
			Total	1	
44			D	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
45	a		energy = area under $Q \propto V$ graph is Δ area $\frac{1}{2} Q V$ ✓ or $\Delta E = Q \Delta V$ and $E = \Sigma Q \Delta V = \frac{1}{2} Q V$	1	accept not all Q can be taken at the max p.d. as V falls as ΔQ is removed $\frac{1}{2} V$ s average p.d. or $E = Q \times V_{\text{mean}} = \frac{1}{2} Q V$
	b		$V = \sqrt{\{(2 \times E) / C\}}$ or $\sqrt{\{(2 \times 200) / 500 \times 10^{-6}\}}$ ✓ $= 890 \text{ (V)}$ ✓	1 1	method in rearranged algebra or numbers evaluation accept 894 (V)
			Total	3	
46	a		$4 \text{ light-}\mu\text{s} = 4 \times 10^{-6} \times 3 \times 10^8 = 1200 \text{ (m)}$ ✓	1	
	b	i	e-m radiation pulses travel $1 \text{ light-}\mu\text{s}$ in $1 \mu\text{s}$ (so $45^\circ \Delta$) ✓	1	
		ii	e.g. $\tan \theta = 4 \text{ light-}\mu\text{s} / 6 \mu\text{s}$ ✓	1	
		ii	$= 4 c / 6 = 2/3 c = 2.0 \times 10^8 \text{ (ms}^{-1}\text{)}$ ✓	1	accept $2/3 c$ for the mark
	c		all pulses out and return at 45° angles on each figure ✓✓	2	accept judged by eye 
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
47	a	i	gravitational force is always attractive so potential energy per kg increases as body is lifted above the Earth's surface, towards zero at ∞ by convention ✓	1	accept arbitrary zero of potential is at ∞ separation, so as bodies approach, potential energy decreases below zero hence negative
		ii	to launch $\frac{1}{2} v^2 = 62 \times 10^6 \text{ J kg}^{-1}$ or $v = \sqrt{(124 \times 10^6)}$ ✓	1	method accept energy per kg or for mass m which cancels in words / algebra / numbers
		ii	$v = 1.1(1) \times 10^4 \text{ (ms}^{-1}\text{)}$ ✓	1	evaluation
	b	i	(k.e. lost = p.e. gained) $\Rightarrow$ ✓	1	
		i	$\frac{1}{2} m v^2 = GMm / r \Rightarrow v = \sqrt{(2GM / r)}$ ✓	1	
		i	where M is mass of spherical body of radius r that you are trying to escape and G is the gravitational constant ✓	1	
		ii	$v = \sqrt{(2G \{ \frac{4}{3} \pi R^3 \rho \} / R)} \Rightarrow v = \sqrt{(\frac{8}{3} G \pi \rho R)}$ ✓	1	algebraic reasoning accept $M = \frac{4}{3} \pi R^3 \rho$
		iii	$R = \sqrt{(3 / 8 G \pi \rho)} c$ or $= \sqrt{(3 / (8 \times 6.7 \times 10^{-11} \times \pi \times 10^{17}))} \times 3 \times 10^8$ ✓	1	method change subject of equation and sub for c in algebra / numbers
		iii	$= 4.0 \times 10^4 \text{ (m)}$	1	evaluation
			Total	9	
48	a		$T_{1/2} = \ln(2)/\lambda = \ln(2)/3.8 \times 10^{-12} \text{ s}^{-1} = 1.8 \times 10^{11} \text{ s}$ ✓ $= (1.8 \times 10^{11} / 3.2 \times 10^7) \text{ years}$ ✓ = 5700 years ✓	3	
	b		Number of atoms = $1.3 \times 10^{-11} \text{ kg} / (14 \times 1.7 \times 10^{-27} \text{ kg})$ ✓ $= 5.46 \times 10^{14} \text{ atoms}$ ✓ Activity = $(-)\lambda N = 3.8 \times 10^{-12} \text{ s}^{-1} \times 5.5 \times 10^{14} = 2100 \text{ Bq}$ ✓	3	
	c	i	Age $\sim T_{1/2}$ so activity $\sim \frac{1}{2} \times 2 \text{ kBq} = 1 \text{ kBq}$ ✓	1	Ref. to time (about) 1 half-life gets ✓
		ii	Mass $\sim$ hundredth of 65 kg $\sim 0.6 \text{ kg}$ ✓ (substantial) damage to ancient relic ✓	2	
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
49	a		$F \propto x$ as above ✓; $a \propto F$ by Newton II ✓ a in opposite direction to x ✓ /reference to vector nature	3	
	b	i	$0.7 \text{ s} \leq T \leq 1.0 \text{ s}$ ✓	1	Graph gives 0.92 s
		ii	$T = 2\pi\sqrt{1.0 \text{ kg}/40 \text{ N m}^{-1}} = 2\pi \times 0.158 \text{ s}$ ✓ $= 0.99 \text{ s}$ ✓ s/e Rapid changes in $x/v/a$ not modelled ✓	3	
		iii	Model with shorter time intervals ✓ Give example of shorter time interval ✓ Reasoning: velocity held constant for shorter time so shorter time scale changes can be modelled / error will be smaller as the model will recalculate after shorter time ✓	3	
	c		Description of exponential decay: equal ratio (or fractional AW) changes (drops AW) ✓ in equal times AW ✓ Experimental test: measure amplitude over time ✓ Check for constant ratio property/ plot $\ln A$ vs time graph ✓	4	
			Total	14	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
50	a	i	$F = -6.7 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 3 \times 10^{12} \text{ kg} \times 1100 \text{ kg} / (5 \times 10^2 \text{ m})^2 \checkmark$ $= 0.88 \text{ N} \sim 0.9 \text{ N} \checkmark$	2	Must have own answer and show working
		ii	$\frac{mv^2}{r} = \frac{GMm}{r^2} \checkmark$ Maximum velocity $= \sqrt{\frac{GM}{r}} \checkmark$ $= 0.63 \text{ m s}^{-1} \checkmark$ $\frac{2\pi}{80 \times 60} = 0.65 \text{ m s}^{-1} \checkmark$ Comparison of speeds and clear conclusion $\checkmark$	5	Alternative approaches possible, e.g. $\frac{mv^2}{r} = \frac{GMm}{r^2} \checkmark$ $T^2 = \frac{4\pi^2 r^3}{GM} \checkmark$ $T = \sqrt{\frac{4\pi^2 r^3}{GM}} (= 2\pi \sqrt{\frac{r^3}{GM}})$ $T = 4955 \text{ s} \checkmark$ $= 83 \text{ min} \checkmark$ Comparison of times and clear conclusion $\checkmark$
		iii	Zero of potential energy defined at infinity $\checkmark$ Need to supply energy to remove L.P from surface/ reference to gravitational potential well AW $\checkmark$	2	
		iv	Calculation of k.e. at about 450 J $\checkmark$ This is sufficient to escape potential well AW $\checkmark$	2	Need clear link with energy required to leave potential well.
	b	i	Hydrogen and nitrogen molecules differ in mass $\checkmark$	1	
		ii	$kT = 1.38 \times 10^{-23} \text{ J K}^{-1} \times 93 \text{ K} \checkmark$ $= 1.3 \times 10^{-21} \text{ J} \checkmark$ For H_2 , $kT \sim 9 E_{\text{grav}}$, so molecule can escape $\checkmark$ For N_2 , $kT \sim 150 E_{\text{grav}}$, so molecule cannot escape $\checkmark$	4	Needs explicit comparison between E & kT
			Total	16	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
51	a	i	$A = \pi r^2 = \pi \times (0.75 \times 10^{-3} \text{ m})^2 = 1.77 \times 10^{-6} \text{ m}^2 \checkmark$ $G = (5.9 \times 10^7 \text{ S m}^{-1} \times 1.77 \times 10^{-6} \text{ m}^2) / (60 \text{ m}) \checkmark$ $= 1.7 \text{ S} \checkmark$	3	Stages can be implicit
		ii	$V = I/G = 13 \text{ A} / 1.7 \text{ S} \checkmark$ $= 7.8 \text{ V} \checkmark$	2	ecf from a i
		iii	any three points from: • 2.8 kW means $I \approx 13 \text{ A}$ as in (a)(ii) • p.d. across kettle reduced from 'normal' 230 V (to 223 V) reducing the current (to $\approx 223/230$ of 'normal') so power is reduced (to $\approx (223/230)^2$ of 'normal') • 500 W drill draws smaller current ($\approx 2 \text{ A}$), so fewer 'lost volts' ($\approx 1.3 \text{ V}$) than for kettle • p.d. across / current in drill not significantly different when using extension cable	3	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b		* Level 3 (5 – 6 marks) Marshals argument in a clear manner linking calculated power to temperature rise with little thermal transfer to surroundings. Makes sensible estimates throughout. Correctly calculates the thermal capacity of the cable <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3 – 4 marks) Makes a clear argument explaining the manufacturers' recommendation but does not use all available data to support the argument. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1 – 2 marks) Makes some correct calculations but these are not linked to the central argument and the incomplete nature of the argument significantly weakens it. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit	6	Indicative scientific points may include: • Correct calculation of power dissipated (100 W to 1 s.f.) • Correct calculation of mass of cable (1 kg to 1 s.f.) • Sensible choice of time of current flowing in a wound state • Correct calculation of temperature rise • Statement about thermal loss in wound cable • Statement about thermal loss in unwound cable • Statement about consequences of high temperature in wound cable • Statement about effect of reducing current
			Total	14	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
52	a		$70 \text{ kJ mol}^{-1} = 70 \times 10^3 \text{ J} / 6.0 \times 10^{23} \text{ molecules}$ $= 1.17 \times 10^{-19} \text{ J molecule}^{-1} \checkmark$	1	
	b	i	$\ln 2.8 \times 10^{-8} = -1.2 \times 10^{-19} / (1.4 \times 10^{-23} \times T) \checkmark$ $T = -1.2 \times 10^{-19} / (1.4 \times 10^{-23} \times \ln 2.8 \times 10^{-8}) \checkmark$ $= 490 \text{ K (2 sf)} \checkmark$	3	Accept 493 K. NOT 292 K (rounding error) bald correct answer scores 3 use of 1.17×10^{-28} gives 480 or 481 K
		ii	reaction rate depends on number of molecules having enough energy to react $\checkmark$; Boltzmann factor gives fraction of molecules with enough energy $\checkmark$	2	
		iii	ratio of Boltzmann factors at 410 K and 360 K $= 6.15 \times 10^{-10} / 3.23 \times 10^{-11} = 20 \checkmark$ (rule suggests that) rate of reaction should increase by $2^5 = 32 \checkmark$ Sensible comment e.g. correct order of magnitude/ assuming that BF is proportional to reaction rate / not a good rule over this range as increase is only 2/3 of that predicted.	3	Candidates can gain 1 mark by correctly calculating a BF for 370 K ($= 6.2 \times 10^{-11}$) and comparing the BF ratio for the two temperatures ($= 1.92$) The third mark is still available. Third marking point needs more than an opinion.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
53	a	i	Points plotted correctly ✓ uncertainty bars for temperature plotted correctly ✓ uncertainty bars for volume plotted correctly ✓ Straight line of best fit plotted going through all of the error bars ✓	4	± ½ square ± ½ square ± ½ square
		ii	1/30 = 0.033 or 3.3% ✓ 5/130 = 0.038 or 3.8% ✓	2	Accept as a decimal Accept as a decimal. Accept to 1 sf.
		iii	Calculation of the gradient = 4.29×10^{-10} ✓ Gradient shown to be equivalent to $\frac{Nk}{P}$ or $\frac{nR}{P}$ ✓ Correct values substituted in; $\frac{4.5 \times 10^{-6} \times 6.022 \times 10^{23} \times 1.38 \times 10^{-23}}{P} = 4.29 \times 10^{-10}$ Or $\frac{4.5 \times 10^{-6} \times 8.31}{P} = 4.29 \times 10^{-10}$ ✓ Evaluation, P = 87.2 kPa ✓	4	Must be clearly shown that graph was used rather than the data. Gradient within the range $4.0 \times 10^{-10} - 5.1 \times 10^{-10}$ Penalise small triangles Gives answer within range 73.3 – 93.5 kPa
	b	i	Suitable line of best fit drawn with x-intercept in the range –260 to –280. ✓	1	Only straight LOBF given credit.
		ii	Particles slow down to zero speed ✓ as the average energy of particles reduces of particles reduces ✓ Gas will liquefy / solidify ✓ As inter-molecular bonds will form ✓	4	OWTTE Zero velocity will not be achieved/particles will continue to vibrate Absolute zero cannot be reached
		iii	$\frac{b(i) - -273}{-273} (x 100\%)$ ✓	1	Must be the candidate's value from b(i) Accept a decimal accepted value must be the denominator
		iv	Meaningful comparison of percentage uncertainty and percentage difference. ✓ Correct conclusion. ✓	2	Expect % uncert > % diff accurate
		v	If accurate from b(iv) yes (no mark) As T is directly proportional to V ✓	1	If inaccurate from b(iv) no (no mark) As T is not directly proportional to V

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		vi	Calculation of molecular mass = $\frac{28}{6.0 \times 10^{23}} = 4.7 \times 10^{-23} \text{ g} \checkmark$ Equation of $pV = nRT$ and $pV = \frac{1}{2} N m \overline{c^2}$ re-arranged to $\sqrt{\overline{c^2}} = \frac{3kT}{m}$ Calculation of $\sqrt{\overline{c^2}}$ for both temperatures: For T = 293 K, $\sqrt{\overline{c^2}} = 508 \text{ ms}^{-1}$ A For T = 77 K, $\sqrt{\overline{c^2}} = 260 \text{ ms}^{-1} \checkmark$ Ratio 1.95 : 1 $\checkmark$	4	Accept use of $KE = \frac{1}{2} m \overline{c^2}$ and $KE = \frac{3}{2} kT$ Accept 1.95
			Total	23	
54	a		N kg ⁻¹	1	
	b		N m kg ⁻¹	1	Examiner's Comments The vast majority of candidates correctly identified the unit for gravitational field strength, but weaker ones had some difficulty identifying a possible unit for gravitational potential.
			Total	2	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
55			EITHER red shift of light/radiation from (distant) <u>galaxies</u>; because galaxies are moving away from each other / have recessional velocity <u>owtte</u>; OR (uniform) microwave background; which is red-shifted light from early universe;	1 1	ignore references to expansion of the universe accept increase/stretching of wavelength as red shift accept galaxies moving away from Earth accept cosmological microwaves accept radiation for light Examiner's Comments Although most candidates scored at least one mark for this question about evidence for the Big Bang, many failed to earn the second mark. Those who opted for background microwave radiation often didn't explain that this was red-shifted radiation from an earlier time in the universe. Others forgot to mention that the recessional velocity of galaxies was deduced from the red-shift of the light from them.
			Total	2	
56			C	1	Examiner's Comments The vast majority of candidates were able to identify the correct p-T graph for an ideal gas.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
57			evidence of suitable test e.g. is pT constant;	1	accept calculations to more than 3 s.f with a conclusion which mentions that numbers are either not the same to 3 s.f. or the same to 2 s.f. ignore any conclusion about the truth of the relationship Examiner's Comments Many weak candidates ignored the data and tried to justify the formula. Those who used the data often failed to use all of it to test the relationship. Only a minority of strong candidates used an appropriate number of s. f. in their calculations.
			test applied to all data to 2 s.f. or 3 s.f.; $273 \times 1.29 = 352$ (350) $283 \times 1.25 = 354$ (350) $293 \times 1.20 = 352$ (350) $303 \times 1.16 = 351$ (350)	1	
			Total	2	
58			EITHER	1	accept measure half-life from activity-time graph Examiner's Comments Just under half of the candidates were able to describe a practical method for determining the decay constant. Too many assumed that N was the activity of the sample, and those that glibly said "measure the half-life" without explaining how to do it lost the mark.
			measure time for half the sample to decay $(t_{1/2})$, use $\lambda = \frac{\ln 2}{t_{1/2}}$ OR take a known number of atoms, measure activity and use equation given; OR measure gradient $(-\lambda)$ of a $\ln(\text{activity})$ -time graph;		
			Total	1	
59			B	1	Examiner's Comments This question didn't discriminate at all, although most candidate were able to identify the correct equipotential curve around the binary star.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
60	a		$\frac{mv^2}{r} = \frac{GMm}{r^2}$	1	accept $m\omega^2$ as $\frac{mv^2}{r}$ not $\frac{mv^2}{r} = -\frac{GMm}{r^2}$
			evidence of $v = \frac{2\pi r}{T}$	1	accept $\omega = \frac{2\pi}{T}$, $v = r\omega$, $\omega = 2\pi f$
			algebraic manipulation to final formula;	1	look for clear steps ignore loss of minus sign in final manipulation
	b		$V = \frac{4}{3}\pi r^3 = 1.098 \times 10^{21} \text{ m}^3$	1	look for correct formula or evaluation
			$M = \rho V = 2.7 \times 10^3 \times 1.098 \times 10^{21} = 2.96 \times 10^{24} \text{ kg}$	1	accept 3.0×10^{24} with full working for [2] accept $V = 1.1 \times 10^{21} \text{ m}^3$ gives $2.97 \times 10^{24} \text{ kg}$ for [2]
	c	i	any two points from: - time for pulse to reach moon = time for pulse to return; - radius of Moon / Earth is comparably negligible; - speed of pulse is constant (throughout the journey) or Earth's atmosphere does not affect speed of pulse or pulse travels at speed of light in a vacuum ($3 \times 10^8 \text{ m s}^{-1}$) or speed of light is constant;	2	not distance for time, accept (laser) light for pulse not just travels at the speed of light
		ii	$r = \frac{3.0 \times 10^8 \times 2.5}{2} = 3.75 \times 10^8 \text{ m}$	1	no ecf for incorrect value of r $r = 3.8 \times 10^8 \text{ m}$ gives $G = 1.25 \times 10^{-10}$ or 1.3×10^{-10}
		ii	$G = \left(\frac{4\pi^2}{3.0 \times 10^{24}} \right) \frac{(3.75 \times 10^8)^3}{(2.4 \times 10^6)^2} = 1.2 \times 10^{-10} \text{ Nm}^2 \text{ kg}^{-2};$	1	
		iii	density / mass of Earth incorrect;	1	accept mass / density is too great

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	need to use density of whole Earth / core and mantle are made of different material / density increases with increasing depth;	1	accept orbit may not be circular for [1] ignore references to radius of Earth and Moon Examiner's Comments This question about estimating a value for G proved to be very straightforward for most candidates. However, in part (a), a large proportion of weak candidates could not do the algebraic manipulation; those who started off with the correct relationships often erroneously included a minus sign which had to be quietly forgotten at a late stage. The two-part calculation of part (b), although involving complicated formulae, proved to be quite straightforward for the most candidates. Similarly, few candidates were unable to state one assumption behind the Earth-Moon distance calculation for part (c)(i), but only about half were able to give two. A common error was the assumption that the Moon had to be stationary for the method to work. Part (c)(ii) was another two-part calculation which was well answered by the majority of candidates. However, only a minority of strong candidates were able to identify the mass of the Earth as the source of the error for part (c)(iii).
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
61	a		molecules bounce off the ground; any two of the following 1. each bounce transfers momentum to ground 2. force on ground is rate of transfer of momentum 3. pressure is force per unit area	3	accept collide with the ground accept impulse as momentum transfer / change ignore algebraic formulae e.g. $F = \frac{\Delta p}{\Delta t}$ $P = \frac{F}{A}$ $\Delta p = mv - mu$ QWC: first marking point Examiner's Comments This required candidates to explain how air molecules can provide a pressure on the Earth's surface. It was poorly answered. Although nearly all candidates mentioned that the molecules hit the surface, only some of them stated that this transferred momentum to the ground, and even fewer that the force on the ground was the rate at which momentum was being transferred to it. Very many candidates lost marks by quoting general rules about force and momentum transfer without mentioning the objects (molecule or surface) involved.
	b	i	$NkT = \frac{1}{3} Nmc^2$	1	not $kT = \frac{1}{2} mc^2$
		i	$T = 293 \text{ K};$	1	
		i	$\sqrt{c^2} = \sqrt{\frac{3kT}{m}} = 512 \text{ ms}^{-1} \approx 510 \text{ m s}^{-1}$	1	ecf $T = 20 \text{ K}$ gives 134 ms^{-1} for [2] allow $c^2 = 2.62 \times 10^5$ for [2]
		ii	any one of the following assumptions 1. elastic collisions 2. molecules impact surface at right angles to it 3. all molecules moving at rms speed	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	evidence of use of $F = PA$ (= $1.0 \times 10^5 \times 0.56 = 5.6 \times 10^4$ N); EITHER	1	
		ii	$F = \frac{\Delta p}{\Delta t} = \frac{2nm\sqrt{c^2}}{1}$ and $n = 1.2 \times 10^{27} \text{ s}^{-1}$; (2) $F = \frac{\Delta p}{\Delta t} = \frac{2nm\sqrt{c^2}}{1}$ and $n = 2.3 \times 10^{27} \text{ s}^{-1}$; (1)	2	$\sqrt{c^2} 500 \text{ m s}^{-1}$ gives $2.4 \times 10^{27} \text{ s}^{-1}$ Examiner's Comments The calculation of part (i) proved to be very straightforward, with only a small minority of candidates being unable to convert degrees centigrade into kelvins. Part (ii) was a stretch-and-challenge question which discriminated well. Although most candidates calculated the force correctly, many lost a mark by forgetting that the molecules bounce off the surface when they hit it, and omitting to state a relevant assumption.
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
62	a	i	$(R = \frac{V}{I} =) \frac{6.0}{2.7 \times 10^{-3}} = 2.2(2) \times 10^3 \Omega$	1	
		ii	EITHER use of half-life = $0.69RC = 33 \pm 1 \text{ s} / 53 \pm 1 \text{ s}$; OR use of $RC = 1/e$ drop time = $49 \pm 1 \text{ s} / 69 \pm 1 \text{ s}$; OR data from graph, use of $I = I_0 e^{-t/RC}$;	1	evidence of method [1]
		ii	$C = 2.2 \pm 0.3 \times 10^{-2} \text{ F}$	1	correct answer [1] Examiner's Comments This question was about discharging a capacitor. Part (i) proved to be straightforward for the vast majority of candidates, but part (ii) caused them difficulty, usually because many of the candidates ignored the fact that discharge did not start when the time was zero. Although questions like this have been set many times before, most weaker candidates wanted to use $Q = CV$ to find the value of the capacitor instead of reading the half-life off the graph.
	b	i	$\Delta Q = C\Delta V = 470 \times 10^{-6} \times 0.12 = 5.64 \times 10^{-5} \text{ C}$;	1	
		i	$I = \frac{\Delta Q}{\Delta t} = \frac{5.64 \times 10^{-5}}{60} = 9.4 \times 10^{-7} \text{ A} = 0.94 \mu\text{A}$;	1	no ecf on incorrect ΔQ
		ii	energy required;	1	
		ii	for an electron to break free (from an atom) / enter the conduction band / become a free electron / move freely within the insulator;	1	not just to get from one plate to the other
		iii			look for method which will eliminate A [1]

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	use of $\ln/ = \ln A - \frac{\epsilon}{kT}$ to eliminate A ; $\epsilon = 3.9 \times 10^{-20} \text{ J}$;	1	correct answer for [2] Examiner's Comments Less than half of the candidates could calculate the leakage current for part (i), mostly because they failed to distinguish between Q and ΔQ . Many candidates correctly identified ϵ as energy for an electron, most wrongly assumed that it was to force the electron across the capacitor rather than allow it to move freely through the dielectric. The calculation of part (iii) was another stretch-and-challenge question, with only stronger candidates able to successfully solve the simultaneous equations with the help of logs.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
63	a		large amplitude (vertical) oscillations;	1	ignore references to sideways oscillations / swinging
			make it dangerous/unpleasant for occupants of lift;	1	accept break cables Examiner's Comments This question concerned forced vibrations of a lift. Although many candidates could satisfactorily explain the safety aspects of resonance in the system.
	b	i	use of $k = \frac{F}{x}$ or $F = kx$;	1	accept $k = \frac{F}{\Delta L}$
		i	use of $\frac{F}{A} = E \frac{x}{L}$ to obtain required expression	1	
		ii	$k = \frac{2.0 \times 10^{11} \times 2.5 \times 10^{-4}}{300} = 1.67 \times 10^5 \text{ Nm}^{-1}$	1	no ecf on incorrect k allow ecf if mass is just 1500 kg (1.7 Hz) or 640 kg (2.6 Hz) for [2] Examiner's Comments Many had difficulty with the synoptic element from G491 in part (i). Many candidates were unable to do this, often confusing the length of the cable with its extension in their attempts to derive the required rule. The calculation of part (ii) discriminated very well, with weaker candidates often selecting the wrong mass for the lift cage and confusing the period of the oscillation with its frequency.
		ii	$T = (2\pi \sqrt{\frac{m}{k}} = 2\pi \sqrt{\frac{1500 + 640}{1.67 \times 10^5}}) = 0.711 \text{ s}$	1	
		ii	$f = \frac{1}{T} = \frac{1}{0.711} = 1.4 \text{ Hz}$	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c	i	idea that damping requires friction / energy transfer from lift AND slowing down the lift / reducing efficiency of lift	1	
		ii	EITHER reducing L (to increase k);	1	any realistic modification [1] which is explained [1] not increasing L
		ii	raising f_0 (above 2 Hz); OR increasing mass of load / cage; lowering f_0 (below 0.2 Hz); OR decreasing mass of load / cage raising f_0 (above 2 Hz) OR increasing csa of cables (to increase k) raising f_0 (above 2 Hz); OR use a cable material which is stiffer / increased E ; raising f_0 (above 2 Hz)	1	not reducing csa of cables not more elastic material QWC against second marking point (organise information clearly) Examiner's Comments Part (i) was very poorly answered, with most candidates unable to explain why damping was impractical for a lift, usually because they failed to mention a damping mechanism, such as friction. However, many were able to suggest and explain a practical modification which would improve the safety of the lift.
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
64	a		Mass of chip = density $\times$ volume (1) No. of moles= mass of chip / relative atomic mass (1) No. of particles= no. of moles $\times$ Avogadro (1) No. of defect centres = $10^{-3} \times 5.4 \times 10^{20}$ $= 5.4 \times 10^{17}$(1)	4	Only credit rearranged equation - not quoting directly from data sheet Reward mass = 2.34×10^{-5} kg Reward number of moles = 9×10^{-4} Reward number of particles = 5.4×10^{20} Must give own value Examiner's Comments This question consisted of three calculations. Nearly half the candidates gained all ten marks here and showed confidence and clarity in their working. Nearly all candidates gained four marks for this part.(final answer = 5.4×10^{17}).

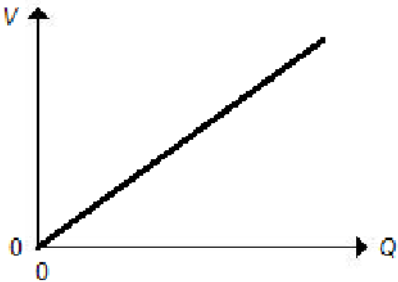
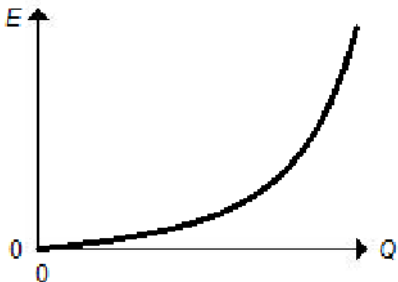
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b		No. promoted = $5 \times 10^{17} / 10^6 = 5 \times 10^{11}$ (1) Energy used = $0.5\% \times 6 \times 10^{-5} = 3 \times 10^{-7}$ J (1) Energy per transition = $3 \times 10^{-7} / 5 \times 10^{11} = 6 \times 10^{-19}$ J (1) = $6 \times 10^{-19} / 1.6 \times 10^{-19} = 3.75$ eV (1)	4	If 5.4×10^{17} used from (a) number promoted = 5.4×10^{11} If 5.4×10^{17} used from (a) Energy per transition = 5.56×10^{-19} J = 3.5 eV (2sf) Need own answer. If candidate misses out 10^6 factor, 2 marks maximum. If candidate miss out 0.5%, 2 marks maximum. Examiner's Comments This part, requiring candidates to show the energy of a transition to be about 4 eV, was more challenging with the lower fifth of the candidates gaining no marks. The working of the weaker candidates showed rather random calculations which sometimes reached a reasonable-looking value but gained no credit. The better answers showed that the candidate had considered the question before putting pen to paper. There is a lot of information in the stem of the question which needs a little thought to marshal into a data set that can be worked with.
	c		$\lambda = 6.6 \times 10^{-34} \times 3.0 \times 10^8 / 6 \times 10^{-19}$ (1) = 3.3×10^{-7} m (1)	2	Credit using 4 eV (6.4×10^{-19}), 3.5 eV (5.6×10^{-19}) leading to 3.1×10^{-7}, 3.5 or 3.6×10^{-7} m. Calculating frequency as 9.7×10^{14}, 9.1×10^{14}, 8.5×10^{14} Hz gains one mark. Accept correct bald answers Examiner's Comments This was a straightforward question and the majority reached the correct value of 3.3×10^{-7} m.
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
65			15% decayed leaving 95% i.e. 0.95 (1) 2 Take (natural) logs of both sides (1) 3 (Re-arrange and) substitute $t = 3$ months (1) 4 Use half-life = $\ln 2 / \lambda$ (1)	4	Correct justification for use of 0.95 e.g $1 - 0.05 = 0.95$ Allow "ln both sides" Need to see $\ln 2$ rather than 0.69(3) Examiner's Comments This rather novel question was answered well by many, but showed good discrimination with candidates scoring across the range of marks. About one-third of the answers gained full marks. The poorest answers did not address the question, putting the symbols into words rather than explaining the steps that lead from one line to the next. Medium-ranked candidates lost marks for imprecise statements such as 'take the (natural) log of 0.95' rather than 'take natural logs of both sides'.
			Total	4	
66	a		kg m s^{-1}	1	
	b		$\text{kg m}^{-1} \text{s}^{-2}$	1	Examiner's Comments This was the usual units question to start off the paper. Very few candidates were unable to identify the correct SI unit for momentum. The equivalent unit for pressure proved to be more difficult, with many weak candidates clearly guessing instead of trying to work it out.
			Total	2	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
67	a			1	any straight line through the origin Examiner's Comments The majority of candidates were able to correctly sketch the V-Q graph for a capacitor.
	b			1	any curve with increasing gradient through the origin Examiner's Comments Only a minority of even the most able candidates were able to sketch the correct E-Q graph; many candidates wrote down the formula $E = QV/2$ and decided that E had to be proportional to Q.
			Total	2	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
68	a		frequency of support equals/matches natural frequency of mass-spring system	1	accept driving frequency/vibration frequency as frequency of support accept resonant frequency as natural frequency Examiner's Comments This question was about resonance in mass-spring systems. Many candidates lost the mark for by not being precise enough about what it was that was oscillating - the mass or the support.
	b		reduces amplitude of oscillations; by transferring energy from it / applying friction;	1 1	accept reduces resonant frequency accept broadens the peak of the amplitude-frequency (accept graph with labelled axes) accept lose energy Examiner's Comments This question was about resonance in mass-spring systems. Most candidates were able to explain the effect of damping.
			Total	3	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
69			$T = 273 + \{-63\} = (210 \text{ K});$ EITHER	1	correct conversion to kelvin [1]
			$(pV) = NkT = \frac{Nmc^2}{3}$	1	use of correct relationships [1]
			$\sqrt{c^2} = 348 \text{ m s}^{-1}$ OR $\frac{1}{2}mv^2 = kT$ $v = 284 \text{ m s}^{-1}$	1	evaluation [1] allow ecf from incorrect conversion to kelvin for [2] $\frac{1}{2}mv^2 = \frac{3}{2}kT$ gives 348 m s^{-1} for [3] Examiner's Comments The vast majority of candidates earned full marks for their calculation of the speed of a molecule. This is impressive since they have to combine two separate formulae from the data sheet to obtain the answer.
			Total	3	
70			C	1	Examiner's Comments The vast majority of candidates were able to correctly identify the V-T graph for an ideal gas.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
71	a		collides with other molecules; then any one of:	1	accept particles / atoms accept interacts as collides ignore collisions with walls
			results in a random/unpredictable change of • velocity • momentum • direction • path length;	1	look for randomness clearly associated with change of direction not the timing of collisions ignore description of a random walk Examiner's Comments Although most candidates knew that random walks were the result of collisions between molecules, only a minority made it clear that it was the results of those collisions that was random. Most candidates tried to fit the data provided to a square root rule without justification; only the strongest candidates started from the root-N rule for particle displacement.
	b		distance $\propto \sqrt{N}$ so distance ² $\propto N$;	1	accept just mention of distance $\propto \sqrt{N}$ rule for first mark [1]
			$N \propto t$ so distance $\propto \sqrt{t}$ so $\frac{\text{distance}}{\sqrt{\text{time}}} = \text{constant}$ so $\frac{5}{\sqrt{1}} = \frac{50}{\sqrt{100}}$	1	accept argument without algebra e.g 50 mm is 10×5 mm, so it needs $10^2 = 100$ times as many steps so takes 100 times as long; Examiner's Comments Although most candidates knew that random walks were the result of collisions between molecules, only a minority made it clear that it was the results of those collisions that was random. Most candidates tried to fit the data provided to a square root rule without justification; only the strongest candidates started from the root-N rule for particle displacement.
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
72			age of universe = $14 \times 10^9 \times 3.2 \times 10^7 = 4.48 \times 10^{17}$ s;	1	
			distance = $3.5 \times 10^6 \times 4.48 \times 10^{17} = 1.6 \times 10^{24}$ m; assumption:	1	ecf: award [1] for 1.6×10^{21} m
			• steady expansion of universe • constant (recessional) velocity of galaxy • constant value for H_0;	1	Examiner's Comments Most candidates were able to use the Hubble law for this calculation as well as state the assumption behind it.
			Total	3	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
73	a		$\frac{mv^2}{r} = \frac{GMm}{r^2}$	1	look for $v^2 = \frac{GM}{r}$ as the smallest intermediate step in rearrangement and cancellation Examiner's Comments This question was about the motion of an asteroid in the Sun's gravitational field. It was good to find that the vast majority of candidates were able to select and correctly combine two formulae from the data sheet to prove the required expression for the speed of the asteroid in a circular orbit.
			then rearrangement and cancellation to $v = \sqrt{\frac{GM}{r}}$	1	
	b	i	$v = 1.93 \times 10^4 \text{ m s}^{-1} / v^2 = 3.72 \times 10^8 \text{ m}^2 \text{ s}^{-2};$	1	look for correct use of $v = \sqrt{\frac{GM}{r}}$ for first mark allow ecf on incorrect value of v for second mark accept $9 \times 10^{10} \text{ J}$
		i	$\frac{1}{2}mv^2 = 9.31 \times 10^{10} \text{ J};$	1	
		ii	EITHER $\Delta E_{\text{GPE}} = 6.7 \times 10^{-11} \times 2.0 \times 10^{30} \times 5.0 \times 10^2 \left(\frac{1}{1.5 \times 10^{11}} - \frac{1}{3.6 \times 10^{11}} \right)$	1	use of $V_g = -\frac{GM}{r}$ or $E_{\text{GPE}} = -\frac{GMm}{r}$ for [1] calculation of GPE drop for [1] calculation of KE at Earth orbit for [1]
		ii	$\Delta E_{\text{GPE}} = -2.61 \times 10^{11} \text{ J};$	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	$E_{KE} = 9.31 \times 10^{10} + 2.61 \times 10^{11} \text{ J} = 3.54 \times 10^{11} \text{ J};$ OR total E in original orbit $= -9.31 \times 10^{10} \text{ J};$ E_{GPE} in Earth orbit $= -4.47 \times 10^{11} \text{ J};$ E_{KE} in Earth orbit $= -9.31 \times 10^{10} + 4.47 \times 10^{11} = 3.54 \times 10^{11} \text{ J};$ THEN	1	calculation of speed at Earth orbit for [1] no ecf from one stage to the next allow ecf from incorrect E_{KE} in (b)(i) Examiner's Comments Most candidates were able to use the expression to calculate its kinetic energy; weak candidates often tried to start from scratch and calculate the gravitational energy as a first step. The next part of the question was stretch-and-challenge, designed to be inaccessible to weak candidates, and so it proved. Only the strongest candidates understood what to do. The commonest error was for candidates to use the circular-orbit formula to calculate the kinetic energy, not realising that it couldn't apply to an elliptical orbit.
		ii	$v = \sqrt{\frac{2E_{KE}}{m}} = 3.76 \times 10^4 \text{ m s}^{-1}$	1	
	c		send a pulse of EM waves (radio, microwaves, light) towards the asteroid (and detect its reflection); $\text{distance} = \frac{(\text{pulse time} - \text{echo time})}{2} \times \text{speed of light}$ EITHER speed of EM waves constant (throughout journey) OR time out same as time back;	1 1 1	ignore radar accept equivalent in algebra e.g. $d = \frac{\Delta t}{2} c$ with defined Δt QWC for correct assumption accept travels at the speed of light throughout the journey ignore references to motion of asteroid not distance out same as distance back Examiner's Comments This required candidates to explain how remote distance measurements are made; many lost marks by not being precise about the nature of the radiation being used (radar on its own earned no credit) or the definition of t in their formula $d = ct/2$.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
74	a		$4.2 \times 10^3 \times 1.48 \times 10^5 \times (30 - 10) = 1.2(4) \times 10^{10} \text{ J};$ any one from - no energy transfers from the water - no energy transfers into the heater - no evaporation of water owtte - specific thermal heat capacity independent of temperature	1	$1.5 \times 10^5 \text{ m}^3$ gives $1.26 \times 10^{10} \text{ J}$ for [1] accept ecf from incorrect mass for [1]
				1	accept heater is 100% efficient not uniform temperature, or constant mass accept heat as energy accept no energy loss Examiner's Comments This question was about using the Boltzmann factor to model the evaporation of water. Calculation of the energy required to raise the temperature of the water caused most candidates little difficulty, although too many neglected to state the assumption or provided incorrect ones (such as heating the water evenly). Similarly, the vast majority of candidates correctly calculated the evaporation energy per molecule from the data provided. It was good to find that the majority of candidates were able to explain the meaning of the Boltzmann factor correctly, although few candidates related it to the continual exchange of energy between molecules through collisions
	b	i	EITHER molecules per kg = $6.0 \times 10^{23} / 1.8 \times 10^{-2} = 3.33 \times 10^{25};$	1	
		i	energy per molecule = $2.3 \times 10^6 / 3.33 \times 10^{25} = 6.9 \times 10^{-20} \text{ J}$ OR mass of one molecule $1.8 \times 10^{-2} / 6.0 \times 10^{23} = 3.00 \times 10^{-26} \text{ kg};$ energy per molecule = $2.3 \times 10^6 \times 3.00 \times 10^{-26} = 6.9 \times 10^{-20} \text{ J};$	1	
		ii	BF is probability that a molecule / fraction of molecules;	1	accept proportion / ratio / percentage not number
		ii	can gain enough energy to leave pool / evaporate;	1	
		ii	through (random) collisions (with other molecules);	1	QWC for describing molecule collisions

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	$7.2 \times 10^{-3} = Ce^{-6.9 \times 10^{-20}/1.4 \times 10^{-23} \times (273+30)}$; $C = 8.34 \times 10^4$;	1	award [1] for method which would eliminate C or give it a value
		iii	$8.34 \times 10^4 e^{-6.9 \times 10^{-20}/1.4 \times 10^{-23} \times (273+10)} = 2.28 \times 10^{-3} \text{ kg s}^{-1}$	1	$\epsilon = 7 \times 10^{-20} \text{ J}$ gives $C = 1.06 \times 10^5$ and $2.24 \times 10^{-3} \text{ kg s}^{-1}$ for [2] Examiner's Comments The last part of the question was another stretch-and-challenge calculation, this time involving an exponential. As expected, weak candidates got nowhere with it and most strong candidates got it out correctly.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
75	a		repeat the procedure without the protoactinium;	1	accept count rate as activity but not background radiation Examiner's Comments Many candidates understood how to apply the correction for background radiation.
			subtract result from recorded value with protoactinium;	1	
	b		$A = -\frac{\Delta N}{\Delta t} (= \lambda N);$ $A = \lambda N_0 e^{-\lambda t};$ $\ln A = \ln(\lambda N_0) - \lambda t;$	1 1 1	look for correct use of minus sign in first step ignore $A = A_0 e^{-\lambda t}$ correct algebra which ignores the minus sign can earn [2] Examiner's Comments Many candidates were not very clear about how background radiation could be measured in the first place. Most were unable to convincingly combine the two given formulae to generate the required expression for $\ln A$; only a minority appreciated that the activity had to be $-DN/Dt$, so most candidates ended up trying to take the logarithm of a negative quantity.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c	i		3	best straight line through points [1] accept any line through majority of points to meet time axis between 6.0 and 7.0 minutes gradient = $-3.85 / (6.30 \times 60) = -1.02 \times 10^{-2} \text{ s}^{-1}$ [1] accept from $-0.90 \times 10^{-2} \text{ s}^{-1}$ to $-1.1 \times 10^{-2} \text{ s}^{-1}$ half-life = $0.693 / 1.0 \times 10^{-2} = 69 \text{ s}$ [1] accept from 77 s to 63 s allow ecf on calculation of half-life from incorrect λ for [1] accept pair of data points from graph and use of $A = Ce^{-\lambda t}$ to obtain correct value for [2]
		ii	radioactive decay is a random process;	1	Examiner's Comments The calculation of half -life from the data in the graph proved to be much more difficult than expected. Many candidates ignored the expression that they had just proved and tried other methods, usually to no avail. A majority of strong candidates realised that they needed to use the graph to obtain a value for the decay constant which could then be used to calculate a half-life; too many failed to notice that the horizontal axis was in minutes, not seconds. About half of the candidates realised that the random nature of radioactive decay meant that real data didn't have to exactly match values calculated from the model.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
76	a	i	any one from - collides with walls with no loss of energy - momentum after collision is equal and opposite to momentum before collision - velocity after collision is equal and opposite to velocity before collision;	1	accept collisions are elastic / no change of speed / no change in magnitude of momentum not moving at right angles to wall
		ii	time between collisions = $\frac{\text{distance to other face and back}}{\text{speed}}$	1	accept travels to right-hand face and back before hitting the left- hand face again owtte not just distance = $2d$
	b	i	$F = \left(\frac{\Delta p}{\Delta t}\right) = \frac{mv^2}{d}$ (for one particle);	1	
		i	three pairs of faces / three dimensions of box;	1	accept three directions in box
		i	so $N/3$ particles hit left-hand face;	1	look for explicit statement, not just algebra
		ii	particles do not collide with each other / have no interaction / have no size / N is a very big number;	1	not same temperature / energy / speed / mass / hit faces at right angles / elastic collisions
	c		temperature T is proportional to (average) energy of particles;	1	accept energy of a particle is kT not just $\frac{1}{2}mv^2 = \frac{3}{2}kT$ or $\frac{mv^2}{3} = kT$
			kinetic energy = $\frac{1}{2}mv^2$	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			then correct manipulation of $\frac{1}{2}mv^2 \propto T$ to achieve $p = \frac{NkT}{V}$;	1	Examiner's Comments This question was about the assumptions behind the derivation of the ideal gas law $PV = NkT$. About half of the candidates failed to explain that the model assumed elastic collisions between the particles and the container walls, and only a small minority convincingly explained why each particle travelled twice the length of the box between collisions. Although most strong candidates were able to correctly justify the factor of N/3 when considering all of the particles in the box, too many candidates invoked the six faces of the box or the formula $p = \frac{1}{3} \rho c^2$ rather than the three different dimensions in our universe. For the final part of the question, candidates had to explain how one equation could be made to look like the ideal gas law; the majority simply used algebra, with no words of explanation, earning little credit. Only the strongest of candidates mentioned the assumptions about relating average kinetic energy to temperature and show how they led to the final expression.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
77	a		$1 \text{ cm}^3 = 10^{-6} \text{ m}^3$ (1) $pV = NkT$ So, $10^{-5} \times 10^{-6} = N \times 1.4 \times 10^{-23} \times 300$ (1) $N = 2.4 \times 10^9$ (1)	3	POT error (–1) for incorrect conversion of cm^3 to m^3 Accept correct bald answer Allow use of $pV = nRT$ (reaching 4×10^{-15} mol gains two marks) Examiner's Comments This was a rather greater challenge. The better candidates correctly converted 1 cm^3 into m^3 and reached the correct value. Candidates scoring two out of three marks realised that a conversion was required but showed a power of ten error. Weaker candidates only gained one mark as they simply ignored the volume factor.
	b	i	Beam current linked to number of electrons emitted per second (1) Electrons escape (boil off) when they have sufficient energy / get lucky in random collisions (1) BF gives the probability of an electron escaping / fraction of electrons that can escape (at any given instant) (1)	3	Penalise confusion with filament current e.g. 'the greater the current the more electrons boil off.' Allow 'rate of ...' for 'per second' 'BF gives probability of an electron having enough energy to escape' is worth two marks (energy mark and probability mark) Examiner's Comments This was generally well-answered with many candidates producing very clear arguments. Weaker responses described the Boltzmann factor in general terms rather than applying it to the specific situation.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	$BF_{2200} = e^{-(7 \times 10^{-19}/K.2200)} (1) = 1.35 \times 10^{-10}$ $BF_T = 4.04 \times 10^{-10} = e^{-(7 \times 10^{-19}/kT)} (1)$ Evaluation to T= 2310 (K) (1)	3	Alternative methods possible. For example: $I_2/I_1 = 3 (1)$ $= \exp (E/k (1/T_1 - 1/T_2)) (1)$ to give $T_2 = 2310 (1)$ Correct bald answer gains all marks Examiner's Comments This challenging calculation was performed correctly by more than half the candidates, even though their working was sometimes labyrinthine and difficult to follow. Weaker candidates simply multiplied 2200 by 3 to gain 6600.
			Total	9	
78			Energy required = $mc\Delta\theta$ $= 0.25 \times 10^{-6} \times 3000 \times 1 (1) = 7.5 \times 10^{-4} \text{ J}$ No. of electrons required = $7.5 \times 10^{-4} / 6 \times 10^{-15}$ $= 1.25 \times 10^{11} (1)$	2	Correct bald answer worth two No ecf from energy to number of electrons Examiner's Comments As with the other parts to this question, most candidates reached the correct answer.
			Total	2	
79			B	1	
			Total	1	
80			D	1	
			Total	1	
81			D	1	
			Total	1	
82			B	1	
			Total	1	
83			C	1	
			Total	1	
84			D	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
85			C	1	
			Total	1	
86			A	1	
			Total	1	
87	a		$(-6.67 \times 10^{-11} \times 6.0 \times 10^{24} / 6.4 \times 10^6) \checkmark$ $= -62.5(3) \text{ (MJ kg}^{-1}\text{)} \checkmark$	L L	evaluation accept 62.5 (MJ kg ⁻¹) RE show that must have at least 3 SF
	b		circular shape $\checkmark$ at 4 Earth radii from centre of Earth $\checkmark$	L M	judged by eye but must have all four axis intercepts equal not at 4 Earth radii from surface
	c		$g = 9.81 / 4^2 \checkmark$ $= 0.6(13) \text{ N kg}^{-1} \checkmark$	M M	method : use of inverse squared law OR $g \propto 1 / R^2$ accept full calculation at $R = 4 \times 6.4 \times 10^6 \text{ m}$ evaluation
			Total	6	
88	a		the charge remains constant during the interval $\Delta t \checkmark$	M	accept the current remains constant
	b		using smaller Δt means $\checkmark$ better approximation to constant current during interval so overestimate of charge leaving during Δt is smaller error $\checkmark$	L H	state explain
	c		$\Delta Q_{\text{LOST}} = 30 \times 10/25 = 12 \text{ (mC)} \checkmark$ $Q_{\text{REMAINING}} = 30 - 12 = 18 \text{ (mC)} \checkmark$	L M	 no ecf
			Total	5	

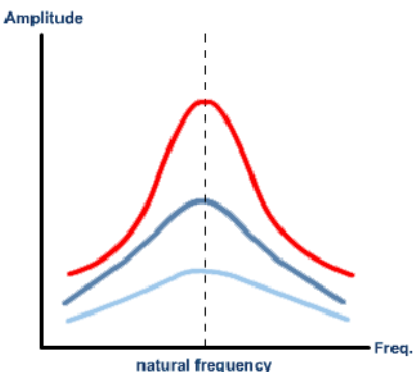
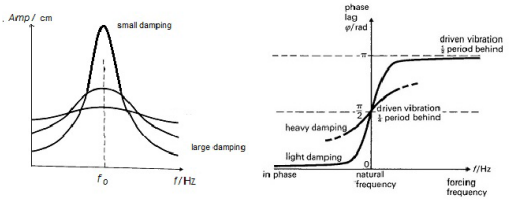
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
89	a		recognisable “fingerprint” lines are shifted towards red end of spectrum / longer wavelengths OR the emission / absorption lines are shifted towards red end of spectrum / longer wavelengths ✓ the increase $\Delta\lambda \propto \lambda$ OR as source recedes emitted waves are stretched out in space and so observed wavelength at Earth increases ✓	M H	credit any two separate points
	b		Use of measurement and scaling to get a value for λ ✓ {720-656} $c / 656$ ✓ = 0.098c ✓	L H H	Teachers should check measurements from their printed papers. This solution is based on scale of 36 mm $\equiv$ 222 nm applied to any spectral line { red is best: shifted to $\approx$ 720 nm } accept their value of λ evaluation accept v in range 0.090 c to 0.110 c
			Total	5	

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
90		* Level 3 (5–6 marks) Marshals argument in a clear manner and includes clear explanation of three strands: - describing a resonance experiment - simple harmonic oscillator and meaning of resonance - typical results including the effect of damping <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i>	HH	Indicative scientific points may include: resonance experiment mechanical or electrical oscillator - labelled diagram of hacksaw oscillator driven by massive pendulum or electromagnet coil OR - mass on vertical spring driven by signal generator OR - resonant bottle driven by small speaker OR - LCR circuit driven by sig. gen. OR - Barton's pendulums - coupling by spring / magnetic force - varying driving frequency through natural frequency - measuring the amplitude or phase response - how to vary damping by air resistive force on card mechanically OR accept by resistance R in LCR circuit
		Level 2 (3–4 marks) Shows clear understanding of at least two of the three strands above to the argument or covers all three at a superficial manner and does not include enough indicative points for level 3. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i>	MM	resonance - the large increase in A as $f_{\text{DRIVER}} \approx f_{\text{NATURAL}}$ - maximum energy transfer - analogy of child on swing driven by regular pushes - the phase relationship between driver and driven changing through resonance

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
	Level 1 (1–2 marks) Makes at least two independent points that are relevant to the argument but does not link them together and shows only superficial engagement with the argument. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit 	LL	typical results including the effect of damping - graphs or description of response curve - typical resonance peak curves - broadening and lowering of peak due to damping $\pi/2$ phase shift at resonance driver leading driven - in phase at lower f or out of phase at higher f - effect of damping on steepness of phase transition 
	Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
91	a		Lorentz force / Bqv supplies centripetal force ✓	L	accept Bqv force remains perpendicular to v and pulls path into a circle keeping speed constant, acceleration causing only a change in direction
			$Bqv = mv^2 / r \rightarrow Bq = mv / r \rightarrow r = mv / Bq$ ✓	M	
	b	i	$T = \pi r / v = \pi mv / Bqv = \pi m / Bq$ (independent of v) ✓	M	
		ii	(faster protons go further but time to traverse dee remains constant so) accelerating frequency can remain constant ✓	H	
		iii	$f = 0.8 \times 1.6 \times 10^{-19} / \{2 \pi \times 1.673 \times 10^{-27}\}$ $= 12 \text{ M(Hz)}$ ✓	L	accept 12.17 MHz OR $1.217 \times 10^7 \text{ Hz}$
		iv	2 crossings per spiral loop OR 10 k eV per loop	H	evaluation Award 1 mark for correct method and evaluation using 5 keV
		iv	number of loops = $1.2 \text{ MeV} / 10 \text{ keV} = 120$ ✓	H	
		v	$\gamma = E_{\text{TOTAL}} / E_{\text{REST}} = \{940 + 1.2\} \text{ MeV} / 940 \text{ MeV}$ ✓	M	method
		v	$= 1.001(3) \approx 1$ so non-relativistic approach reasonable ✓	M	evaluation and conclusion accept is a small deviation from 1
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
92	a	i	$kT = 1.4 \times 10^{-23} \times 10^{11} / \{1.6 \times 10^{-19}\} \text{ (eV)}$ $= 8.75 \times 10^6 \text{ eV } (\approx 9 \text{ MeV}) \checkmark$	L	method and show that evaluation to 8.75 or 8.8 MeV accept 8.63 MeV using $k = 1.38 \times 10^{-23}$
		ii	rest energy of electron or positron $\approx 9.11 \times 10^{-31} \times (3 \times 10^8)^2 / (1.6 \times 10^{-13}) = 0.512 \text{ MeV}$ OR pair = 1.02 MeV $\checkmark$	H	
		ii	$\ll 9 \text{ MeV}$	H	
		iii	but for proton or antiproton is $\approx 1000 \text{ MeV} \gg 9 \text{ MeV}$ for a substantial proportion of photons to have sufficient energy the temperature needs to be higher / about x10 to x100 higher $\checkmark$	H	
	b	i	mass created = $m_{\text{NEUTRON}} - m_{\text{PROTON}} + m_{\text{ELECTRON}}$ OR $= \{1.008665 - 1.007276 + 0.000549\} \text{ u } \checkmark$	M	accept mass / energy of neutrino may be zero / negligible as standalone alternative for first mark
		i	$= 0.001938 \text{ u} = 1.810 \text{ MeV } \checkmark$	M	
		ii	As T falls $e^{-\frac{E}{kT}}$ gets smaller, the number of p with enough energy to become n reduces. so ratio of p to n increases. $\checkmark$	H	method
		ii	fraction of particles with activation energy to create	S & C	evaluation
		ii	neutrons = Boltzmann factor = $e^{-\frac{E}{kT}} = e^{-\frac{1.8}{8.8}} \checkmark$ $e^{-0.209} = 0.812 \text{ (p : n = 1 / 0.812)} \checkmark$	S & C	
	c	i	mass released as binding energy = $m_{\text{DEUTERON}} - m_{\text{PROTON}} + m_{\text{NEUTRON}} = 0.002388 \text{ u } \checkmark$	M	Evaluation accept calculation of mass and use of $E = mc^2$
		i	$= 0.002388 \times 931.1 \text{ MeV / u} = 2.2(2) \text{ MeV } \checkmark$	M	and conversion to MeV gives 2.23 MeV

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	thermal energy of particles / photons will be ≈ 0.9 MeV but in the Boltzmann / Planck distribution tail there will be particles with 2.2 MeV energy to break deuterons apart ✓	S&C	accept alternative words or estimated calculations e.g. fraction with activation energy $\approx$ $e^{-\frac{2.2}{0.88}} = 0.082$
			Total	12	
93	a	i	$V = 6.0 \text{ V}(1 - e^{-60 \text{ s}/(150 \times 10^3 \Omega \times 200 \times 10^{-6} \text{ F})})$ ✓ $= 6.0 \text{ V} - (1 - 0.135) = 5.19 \text{ V}$ ✓	2	No s.f. penalty. Must show clear working and own answer
		ii	p.d. across resistor = $6.0 - 5.19$ ✓ $= 0.8 \text{ V}$ ✓	2	e.c.f
		iii	$E = \frac{1}{2} \times 200 \times 10^{-6} \text{ F} \times (5.2 \text{ V})^2$ ✓ $= 0.0027 \text{ J}$ ✓	2	
	b	i	p.d. across capacitor after $5 RC$ $V = 6.0(1 - e^{-5})$ ✓ $= 5.96 \text{ V}$ ✓ This is more than 99% of the supply voltage so the p.d. across capacitor is roughly at maximum. As charge is proportional to voltage, the capacitor is nearly fully charged at this point. ✓	3	Can argue from $Q = Q_0(1 - e^{-t/RC})$: First mark for calculating maximum charge ($= 0.0012 \text{ C}$) ✓ After $5RC$, $Q = 0.0012(1 - e^{-5})$ ✓ $= 0.00119$, more than 99% of maximum charge ✓
		ii	Discharge = $5 RC$ $= R = 40 \times 10^{-3} / (5 \times 2 \times 10^{-4})$ ✓ $= 40 \Omega$ ✓	2	Allow use of $6RC$
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
94	a		$\Delta mv = 2 mv \checkmark$ $\Delta t = \frac{2L}{v} \checkmark$ $F = \frac{\Delta mv}{\Delta t} = \frac{2mv}{(2L/v)} = \frac{mv^2}{L} \checkmark$	3	
	b		Statement showing that 1/3 of the velocity components of the N molecules will be perpendicular to a given face. $\checkmark$ Force on face $F = \frac{1}{3} \frac{Nmc^2}{L} \checkmark$ $P = F/A = \frac{1}{3} \frac{Nmc^2}{L \times L^2} = \frac{1}{3} \frac{Nmc^2}{V} \checkmark$	3	
	c		One from: • Particles have range of energies because of the range of speeds • Particles collide with one another • Energy exchanged in collisions To gain energy much greater than 'average' requires many consecutive collisions in which the molecule gains energy AW $\checkmark$ This is unlikely hence few molecules will gain sufficient energy to have much greater velocities $\checkmark$	3	
	d		$\frac{1}{3} Nm \overline{c^2} = NkT \Rightarrow m \overline{c^2} = 3kT \checkmark$ kinetic energy $= \frac{1}{2} m \overline{c^2} = \frac{3}{2} kT \checkmark$	2	
	e		r.m.s speed $= 1.2 \times 400 \text{ m s}^{-1} = 480 \text{ m s}^{-1} \checkmark$ $E_k = \frac{1}{2} \times 4.7 \times 10^{-26} \text{ kg} \times (480 \text{ m s}^{-1})^2 = 5.4 \times 10^{-21} \text{ J} \checkmark$ $T = 2 \times 5.4 \times 10^{-21} \text{ J} / (3 \times 1.38 \times 10^{-23} \text{ J K}^{-1}) \checkmark = 260 \text{ K} \checkmark$	4	Allow alternative correct methods
			Total	15	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
95		i	$T = 5.61 \text{ s}/3 = 1.87 \text{ s}$ & $L = 0.85 \text{ m}$ $T = 2\pi\sqrt{L/g} \Rightarrow g = 4\pi^2 L/T^2 \checkmark$ $= 9.596 \text{ m s}^{-2} = 9.6 \text{ m s}^{-2} \checkmark$	2	First mark is for correct T and L and rearrangement of equation Second mark is for evaluation and rounding to 2 s.f.
		ii	suggestion $\checkmark$ explanation $\checkmark$	2	e.g. time more oscillations $\checkmark$ because %age error in timing is reduced by division $\checkmark$ e.g. repeat measurement (for $L = 85 \text{ cm}$) several times and average $\checkmark$ because it reduces random error $\checkmark$ e.g. repeat for different values of L and plot graph of T^2 against L to find gradient (and hence g) $\checkmark$ because graphing counteracts random error $\checkmark$
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
96	a		$\frac{(2\pi r/T)^2}{r}$ ✓ acceleration = = $5.8 \times 10^{-3} \text{ m s}^{-2}$ ✓	2	Correct bald answer gains both marks
	b	i	$\frac{v^2}{r} = \frac{GM}{r^2}$ $V^2 r = GM \checkmark$ $\frac{4\pi^2 r^3}{T^2} = GM \checkmark$ $\frac{r^3}{T^2} = \frac{GM}{4\pi^2} \checkmark$ statement that G, M, π^2 are all constants so $\frac{r^3}{T^2}$ is a constant ✓	4	Any clear, complete, derivation gains first three marks
		ii	$\frac{(1.5 \times 10^{11})^3}{1^2} = \frac{(2.28 \times 10^{11})^3}{T^2}$ Calculated result: orbital period of Mars = 1.87 years ✓	2	Correct bald answer gains both marks
	c	i	$\Delta V_g = -GMm \left(\frac{1}{r_1} - \frac{1}{r_2} \right) \checkmark$ $= -6.7 \times 10^{-11} \times 6.4 \times 10^{23} \times 2 \times 10^{30}$ $\left(\frac{1}{2.5 \times 10^{11}} - \frac{1}{2.1 \times 10^{11}} \right) \checkmark$ $= 6.5(3) \times 10^{31} \text{ J} \checkmark$	3	Correct bald answer gains three marks Other methods acceptable. One mark for calculating p.e. at greatest distance (aphelion) = $-2.3 \times 10^{32} \text{ J}$ One mark for calculating p.e. at smallest distance (perihelion) = $-2.98 \times 10^{32} \text{ J}$
		ii	k.e. of Mars at aphelion = $2.3 \times 10^{32} \text{ J} \checkmark$ k.e. at perihelion = $2.3 \times 10^{32} + 6.5 \times 10^{31}$ = $2.95 \times 10^{32} \text{ J} \checkmark$ velocity at perihelion = $3.1 \times 10^4 \text{ m s}^{-1} \checkmark$	3	Ecf from c (i) if answer to c(i) rounds to 7×10^{31} If 7×10^{31} used, $v = 3.1 \times 10^4 \text{ m s}^{-1}$ ($3.06 \times 10^4 \text{ m s}^{-1}$)
			Total	14	
97	a		Decay constant = $4.1 \times 10^{-9} \text{ s}^{-1} \checkmark$ Number of nuclei present = $1 \times 10^{22} \checkmark$ Activity $1 \times 10^{22} \times 4.1 \times 10^{-9} = 4.1 \times 10^{13}$ (Bq) ✓	3	Alternative methods possible, must show working and own answer.
	b		Total energy of gamma rays = $1.17 + 1.33 \text{ MeV} \checkmark$ power = $2.50 \times 10^6 \times 1.6 \times 10^{-19} \times 4.1 \times 10^{13} = 16 \text{ (W)} \checkmark$	2	
			Total	5	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance								
98			Level 3 (5–6 marks) Marshals argument in a clear manner. All technical vocabulary is used with accuracy and clarity. The candidate's response shows an understanding of the properties of gamma radiation and the answer is informed by quantitative reasoning based on the data given. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) The response may cover the three aspects listed in the guidance but may lack clarity or depth. A calculation, if present, may not be clearly linked to the main argument. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) The calculation may be incorrect or missing, the answer is based on assumptions rather than analysis of the article or question. The specific properties of gamma radiation may not be considered (i.e. why the patient can irradiate others) <i>The information is basic and communicated in an unstructured way.</i> 0 marks No response or no response worthy of credit No response or no response worthy of credit.	6	Indicative scientific points may include: Safety: Minimise time of exposure from patient, minimise close contact. Access to accelerator: short half-lives mean that the useful time of the radiochemical is limited. proximity to accelerator (which produces the radioisotope) reduces transit time, giving more time to prepare chemical. Patient remaining in location: Radiochemical will still be emitting gamma rays at a rate above background Gamma rays can pass through patient and irradiate other people. Candidate includes a calculation of activity of fluorine-18 in patient. Values from possible calculations: <table><tr><th>time elapsed/hr</th><th>Activity of fluorine-18</th></tr><tr><td>1</td><td>2060</td></tr><tr><td>2</td><td>1400</td></tr><tr><td>3</td><td>950</td></tr></table>	time elapsed/hr	Activity of fluorine-18	1	2060	2	1400	3	950
time elapsed/hr	Activity of fluorine-18												
1	2060												
2	1400												
3	950												
			Total	6									

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
99	a	i	top row: 8.61 (V) ✓	1	Accept 20.97 to 4 sf
		i	Third row: 2.32 (A) ✓	1	
		i	Bottom row: 21.0 (W) ✓	1	
		ii	Mean Power = 20.6 W ✓	1	
		ii	Uncertainty (half range), (21.0 – 19.8)/2 = ± 0.60 W ✓	1	
	b	i	Use of $E = m c \Delta\theta$ and $P = E/t$ to give $c = P t / m \Delta\theta$ ✓	1	Allow ECF from (a)(ii) $t / \Delta\theta = \text{gradient} = \text{cm} / P$
i		Use two readings off the graph and substitute. ✓ e.g. $c = 20.6 \times (10 - 2) \times 60/ 1 \times (29.1 - 19.9)$ $= 1070 \text{ J Kg}^{-1} \text{ K}^{-1}$ ✓	1		
i			1	Ignore sign	
		ii	Find gradient of cooling line of best fit from graph $= -0.45 \text{ K min}^{-1}$ ✓	1	Acceptable range = -0.43 to -0.47 K min^{-1}
		ii	Two plots read off correctly, at least half the length of the line apart. ✓	1	
	c		Percentage difference = $(1070 - 897) \times 100/897 = 19 \%$ ✓	1	Allow ecf from (b)(i)
			Percentage difference is larger than the percentage uncertainty so experiment is not very accurate ✓	1	
			Any two from: ✓ ✓ The block is cooling at rate calculated in b(ii), which means that it should have had a larger temp difference; Heater not 100 % efficient; Energy has gone into heating heater/wires/digital thermometer; Temperature of the block may not have been uniform; Etc.	2	
			Total	14	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
100	a		$RC = 2200 \times 10^{-6} \text{ F} \times 6.7 \times 10^3 \Omega \checkmark$ $= 14.7 \text{ s} \checkmark$	2	Need own value and working shown Calculator value = 14.74 s Examiner's Comments This question was about discharging and charging capacitors. This part of the question was answered correctly by the majority of the candidates.
	b		4.7 k Ω at 4.0 or 4.2 V at $t = 0$, exponentially (by eye) decreasing to 0.0 V at $t = 5 RC$. $\checkmark$ 2.0 k Ω at 2.0 or 1.8 V at $t = 0$, exponentially (by eye) decreasing to 0.0 V at $t = 5 RC$. $\checkmark$	2	Lines must be labelled. Credit one mark if both lines labelled and start from correct p.d. at $t = 0 \text{ s}$ and show decrease of p.d. over time. Examiner's Comments This part asked candidates to draw two lines showing the p.d. across each of the two series resistors during the charging of the capacitor. A sizeable minority showed the p.d. across the resistors increasing over time, showing a lack of understanding of the situation. Others drew curves of negative gradient beginning at the correct p.d.s but failed to gain full marks either through lack of labelling or inaccurate drawing. Candidates losing marks through insufficient care with diagrams is not a new problem.
	c		$e^{-t/RC} = 1 - 5/6 \checkmark$ $-t/RC = \ln(1/6) \checkmark$ $-t/(15 \text{ s}) = -1.79 \checkmark$ $t = 27 \text{ s} \checkmark (26.9)$ Alternative method: Horizontal line drawn on graph from p.d. = 5.0 V $\checkmark$ Vertical line to RC in range 1.7 – 1.9 RC (expected 1.8 RC) $\checkmark$ $t = RC \text{ value} \times 1.8 \checkmark$ t in range 25 s to 28 s $\checkmark$	4	26 s if 14.7 s used for time constant 26.3 s if 14.7 s used for time constant Correct bald answer gains four marks ECF from 2 (b) Examiner's Comments This part was one of the most challenging questions on the paper. Many candidates used the discharge equation to reach an incorrect answer whilst some who used the correct equation inserted the incorrect values. There was an unsurprising but still noteworthy correlation between poor answers to parts (c) and (d).
			Total	8	