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2018

Centre Number

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Candidate Number

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Physics

StemUp Model Solution

Assessment Unit A2 1

assessing

Deformation of Solids, Momentum, Thermal
Physics, Circular Motion, Oscillations
and Atomic and Nuclear Physics



[APH11]

APH11

MONDAY 4 JUNE, AFTERNOON

TIME

2 hours.

INSTRUCTIONS TO CANDIDATES

Write your Centre Number and Candidate Number in the spaces provided at the top of this page.

You must answer the questions in the spaces provided.

Do not write outside the boxed area on each page or on blank pages.

Complete in black ink only. **Do not write with a gel pen.**

Answer **all nine** questions.

INFORMATION FOR CANDIDATES

The total mark for this paper is 100.

Figures in brackets printed down the right-hand side of pages indicate the marks awarded to each question or part-question.

Quality of written communication will be assessed in Question **2(a)**.

Your attention is drawn to the Data and Formulae Sheet which is inside this question paper.

You may use an electronic calculator.

11137.03



- 1 (a) The graph in **Fig. 1.1** shows how the binding energy per nucleon varies with the number of nucleons in the nucleus. Complete **Fig. 1.1** by adding appropriate numerical values to the axes of the graph. [2]

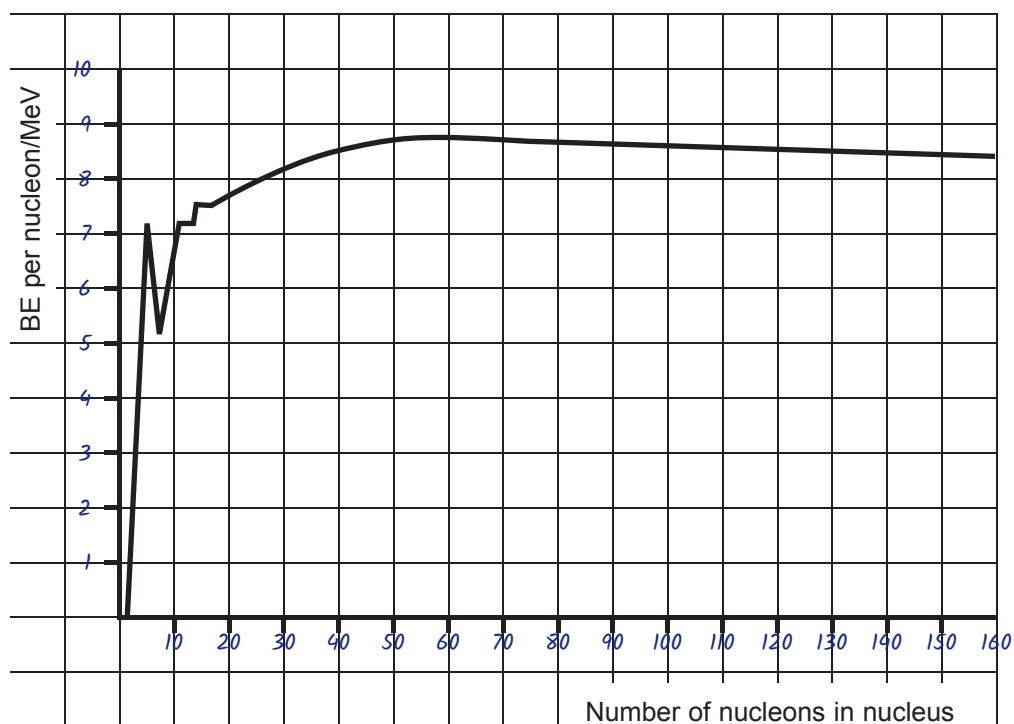


Fig. 1.1



- (b) Describe the principles of fission and fusion. By referring to **Fig. 1.1**, explain how each process can lead to energy being released.

Fission: a large (heavy) nucleus such as U-235 absorbs a slow neutron, becomes unstable and splits into two smaller nuclei of similar mass, releasing two or three neutrons and energy.

Fusion: two light nuclei (e.g. isotopes of hydrogen) join together to form a heavier nucleus. Very high temperatures are needed so the nuclei can overcome their electrostatic repulsion.

Energy is released whenever the binding energy per nucleon of the products is greater than that of the original nuclei: the products are more stable, so mass is lost and released as energy ($E = mc^2$).

Nuclei to the left of the peak (A about 56) are light, so they undergo fusion to move up the curve towards the peak.

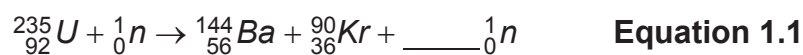
Nuclei to the right of the peak are heavy, so they undergo fission into two smaller nuclei that are higher up the curve, nearer the peak.

[5]

[Turn over]



- (c) (i) **Equation 1.1** shows an incomplete equation to describe a fission reaction. The number of neutrons that are released has been omitted.



How many neutrons are released in the reaction?

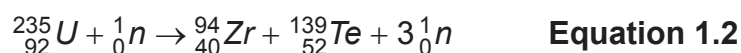
$$235 + 1 = 144 + 90 + n, \text{ so } n = 2$$

Number of neutrons = 2

[1]



(ii) **Equation 1.2** is another example of a fission reaction.



The mass of each nucleus and a neutron are given in **Table 1.1**.

Table 1.1

Nucleus	Mass / u
U-235	235.0439
Zr-94	93.9063
Te-139	138.9347
n	1.0086

Calculate the number of U-235 nuclei that need to undergo fission by the reaction in **Equation 1.2** to produce 1 joule of energy.

$$\text{Mass before} = 235.0439 + 1.0086 = 236.0525 \text{ u}$$

$$\text{Mass after} = 93.9063 + 138.9347 + 3(1.0086) = 235.8668 \text{ u}$$

$$\text{Mass difference } \Delta m = 236.0525 - 235.8668 = 0.1857 \text{ u}$$

$$\Delta m = 0.1857 \times 1.66 \times 10^{-27} = 3.083 \times 10^{-28} \text{ kg}$$

$$E = mc^2 = 3.083 \times 10^{-28} \times (3.00 \times 10^8)^2$$

$$E = 2.774 \times 10^{-11} \text{ J released per fission}$$

$$\text{Number of nuclei} = 1 \text{ J} \div 2.774 \times 10^{-11} \text{ J}$$

$$\text{Number of nuclei} = \underline{3.604 \times 10^{10}}$$

[5]

[Turn over]



2 Quality of written communication will be assessed in part (a) of this question.

- (a)** The control rods and the moderator are two components of a fission reactor. State a material from which each component can be made and describe how they function to produce nuclear power in a safe manner.

The moderator can be made of graphite (or water). Fast neutrons released in fission collide with the nuclei of the moderator and lose kinetic energy, so they are slowed down to thermal speeds.

Slow (thermal) neutrons are much more likely to be absorbed by U-235 nuclei, so they cause further fission reactions and the chain reaction is sustained.

The control rods can be made of boron (or cadmium). They absorb neutrons, removing them from the core so that they cannot cause further fissions.

The rate of the chain reaction is controlled by changing how far the control rods are inserted into the core: lowering them further absorbs more neutrons and slows the reaction, raising them speeds it up.

For safe, steady operation the rods are adjusted so that on average exactly one neutron from each fission causes another fission. In an emergency the rods are fully inserted to absorb enough neutrons to shut the reactor down.

[6]



- (b) The use of fossil fuels in power stations causes considerable environmental pollution due to the gases produced. The government is considering several alternative sources of power.

State one advantage and one disadvantage that nuclear power has over **the other alternatives** to fossil fuel power.

Advantage:

It is reliable: it gives a large, steady output all the time, unlike wind or solar power, which depend on the weather.

Disadvantage:

It produces radioactive waste that must be stored safely for thousands of years, and safety and decommissioning costs are high.

[2]

[Turn over]

11137.03



- 3 (a) Gold foil was used in the historic alpha particle scattering experiment conducted by Geiger and Marsden. Gold has atomic number 79 and mass number 199. Calculate the radius of the nucleus of a gold atom. State your answer in metres. ($r_0 = 1.2 \text{ fm}$)

$$r = r_0 A^{1/3} = 1.2 \times 10^{-15} \times 199^{1/3}$$

$$r = 1.2 \times 10^{-15} \times 5.84$$

Radius of gold atom = 7.0×10^{-15} m [2]

- (b) Fig. 3.1 shows an overhead view of part of the apparatus used in the alpha particle scattering experiment.

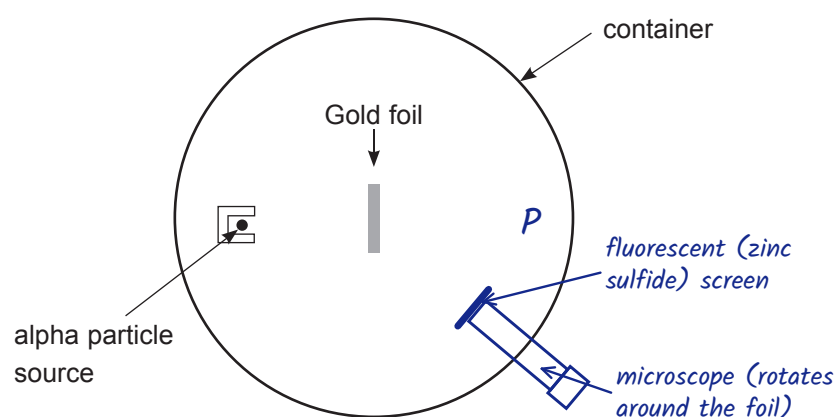


Fig. 3.1

- (i) Complete Fig. 3.1 by drawing and labelling any additional apparatus that was used when Geiger and Marsden carried out the experiment. [2]
- (ii) Indicate, with the letter **P**, the position in which most alpha particles were detected in the experiment. [1]



- (iii) Explain why the diameter of the container can be larger than 5 cm even though the range of alpha particles in air is less than 5 cm.

The container is evacuated (a vacuum), so there are no air molecules for the alpha particles to collide with and lose energy by ionising.

[1]

- (c) Fig. 3.2 shows the path of an alpha particle as it approaches a nucleus.

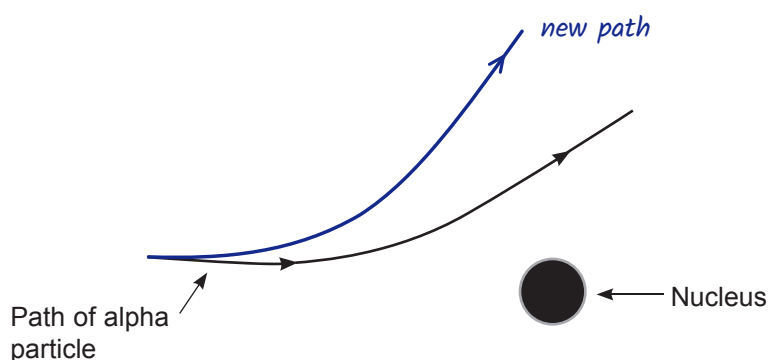


Fig. 3.2

The nucleus is replaced with one with a larger atomic number. On Fig. 3.2, sketch the new path taken by the alpha particle.

[2]

[Turn over]



- 4 (a) Fig. 4.1 shows a fairground carousel where the horses move in a horizontal circle at a constant speed.



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Fig. 4.1

A 136 kg horse on the outside of the carousel travels in a circle of diameter 12.0 m. It takes 42 seconds for the horse to complete one full rotation.

- (i) Use the definition of acceleration to explain why there must be a resultant force on the horse.

Acceleration is the rate of change of velocity. Velocity is a vector:

although the speed is constant, the direction of the horse's motion is

continuously changing, so its velocity changes and it is accelerating

(towards the centre). By Newton's second law, $F = ma$, an

acceleration needs a resultant force.

[3]

- (ii) Calculate the magnitude of the resultant force on the horse.

$$r = 12.0 / 2 = 6.0 \text{ m}, \quad \omega = 2\pi / T = 2\pi / 42 = 0.150 \text{ rad s}^{-1}$$

$$F = mr\omega^2$$

$$F = 136 \times 6.0 \times 0.150^2$$

$$F = 18.3 \text{ N}$$

Force = 18.3 N

[3]



- (b) On another fairground ride, the rollercoaster, a carriage and passengers of combined mass 1200 kg approaches a vertical circular section as shown in Fig. 4.2. The diameter of the circle is 38 m.

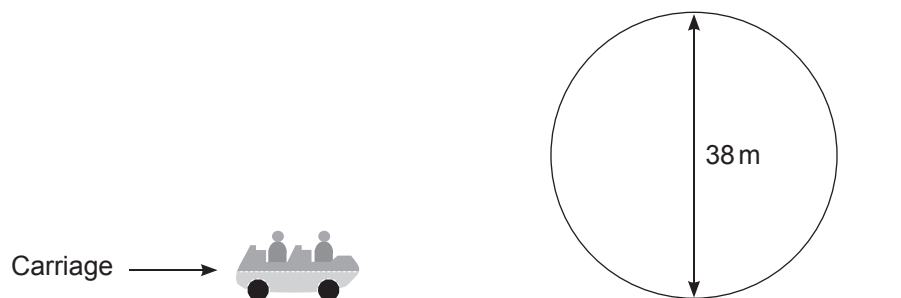


Fig. 4.2

- (i) What is the minimum speed of the rollercoaster carriage for the passengers to feel weightless at the top of the loop?

At the top the weight alone provides the centripetal force:

$$mg = mv^2/r, \text{ so } v = \sqrt{gr}, \text{ with } r = 38 / 2 = 19 \text{ m}$$

$$v = \sqrt{9.81 \times 19}$$

$$v = 13.7 \text{ m s}^{-1}$$

Speed = 13.7 m s⁻¹ [2]

- (ii) Describe what happens to the rollercoaster carriage if the speed is less than that calculated in (i).

The carriage loses contact with the track at the top of the loop: gravity

is greater than the force needed for the circle, so it falls inwards. [1]

- (iii) If the rollercoaster carriage has fewer passengers and therefore less mass than in (i), how will the speed at which weightlessness is experienced be affected?

No change. The mass cancels in $mg = mv^2/r$, so $v = \sqrt{gr}$ does not

depend on mass. [1]

[Turn over]



- 5 **Equation 5.1** shows the relationship between the number of radioactive nuclei N left after time t . λ is the decay constant and N_0 is the initial number of radioactive nuclei.

$$N = N_0 e^{-\lambda t} \quad \text{Equation 5.1}$$

One isotope of copper, Cu-62, can be used for medical imaging. The isotope is injected into the bloodstream and then a scan is carried out to detect the gamma rays emitted.

- (a) **Fig. 5.1** shows a graph of the natural logarithm, $\ln$, of the percentage of radioactive Cu-62 nuclei remaining with time.

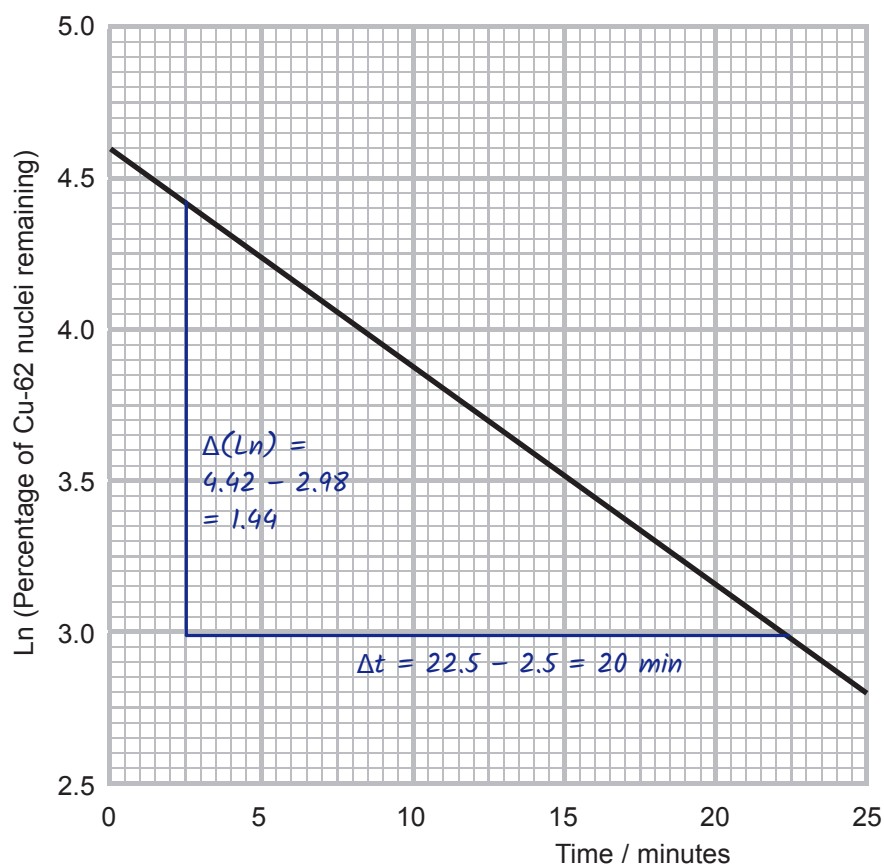


Fig. 5.1



- (i) What is meant by the half-life of a radioactive source and why is it important to consider the half-life when a source is used for medical imaging?

The half-life is the average time taken for the activity (or the number of undecayed nuclei) of a radioactive source to fall to half of its initial value.

It must be long enough for the isotope to be carried round the body in the bloodstream and still be active enough to be detected in the scan, but short enough that the patient's radiation exposure is minimal.

[3]

- (ii) Use Fig. 5.1 to calculate the half-life of Cu-62.

Using the large triangle drawn on Fig. 5.1:

$$\text{gradient} = -1.44 / 20 = -0.072 \text{ min}^{-1}, \text{ so } \lambda = 0.072 \text{ min}^{-1}$$

$$t_{1/2} = 0.693 / \lambda = 0.693 / 0.072$$

$$t_{1/2} = 9.6 \text{ minutes}$$

$$\text{Half-life} = \underline{9.6} \text{ minutes}$$

[3]

- (b) After two hours the activity of the source has dropped to 0.46 Bq. Calculate the initial activity of the source.

$$A = A_0 e^{-\lambda t}, \quad t = 2 \text{ hours} = 120 \text{ min}$$

$$0.46 = A_0 e^{-0.072 \times 120}$$

$$A_0 = 0.46 \times e^{8.64} = 0.46 \times 5650 = 2600 \text{ Bq}$$

$$\text{Initial Activity} = \underline{2600} \text{ Bq}$$

[2]

[Turn over]



- 6 The Young modulus is an important property of the material from which contact lenses are made. Comfortable wearing of a lens is achieved using a more flexible contact lens that drapes easily over the cornea, but a high degree of flexibility can be a disadvantage when trying to achieve optimum vision. The Young modulus of two types of contact lens is shown in **Table 6.1**.

Table 6.1

Contact Lens	Young modulus / MPa
Type 1	1.1
Type 2	0.49

- (a) Which contact lens would be most comfortable for the user?
Explain your answer.

Type 2, because it has the lower Young modulus, so it is more flexible and drapes easily over the cornea.

[1]

- (b) To find a value for the Young modulus of a lens material, lenses made from the same material with powers ranging from -8.0 D to $+4.0\text{ D}$ were tested.

- (i) What was the range of focal lengths of the lenses tested in centimetres?

$$f = 1/P$$

$$f = 1 / (-8.0) = -0.125\text{ m} = -12.5\text{ cm}$$

$$f = 1 / (+4.0) = 0.25\text{ m} = 25\text{ cm}$$

Focal lengths range from -12.5 to 25 cm [3]



(ii) Complete **Table 6.2** for lenses with positive and negative power.

Table 6.2

Power	Type of lens	Defect in vision that the lens is used to correct
negative	<i>concave (diverging)</i>	<i>short sight (myopia)</i>
positive	<i>convex (converging)</i>	<i>long sight (hypermetropia)</i>

[4]

(iii) In the test, a sample of the lens material that had a width of 2.5 mm and length of 12.0 mm, as shown in **Fig. 6.1**, was used. The Young modulus of one of the lenses tested was found to be 1.5 MPa. A force F of 4.2 mN in the direction shown produced a strain of 0.04.

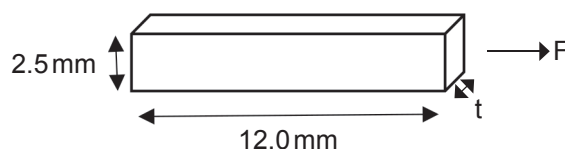


Fig. 6.1

Calculate the thickness t of the sample.

$$E = \text{stress} / \text{strain}, \text{ so stress} = E \times \text{strain}$$

$$\text{stress} = 1.5 \times 10^6 \times 0.04 = 6.0 \times 10^4 \text{ Pa}$$

$$\text{stress} = F / A, \text{ so } A = F / \text{stress} = 4.2 \times 10^{-3} / 6.0 \times 10^4$$

$$A = 7.0 \times 10^{-8} \text{ m}^2$$

$$A = \text{width} \times t, \text{ so } t = 7.0 \times 10^{-8} / 2.5 \times 10^{-3}$$

$$t = 2.8 \times 10^{-5} \text{ m}$$

Thickness = 2.8×10^{-5} m

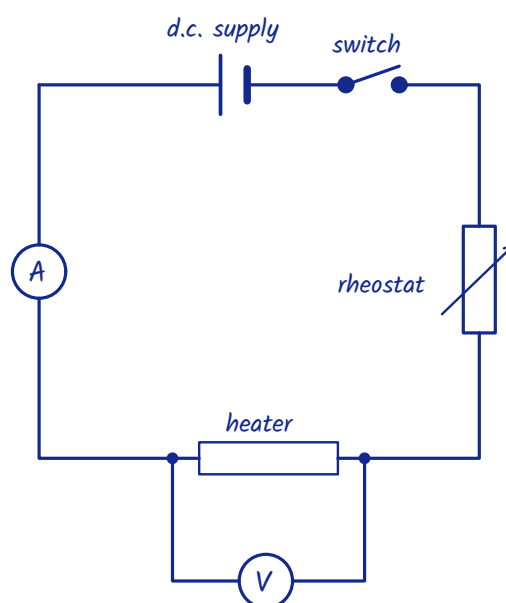
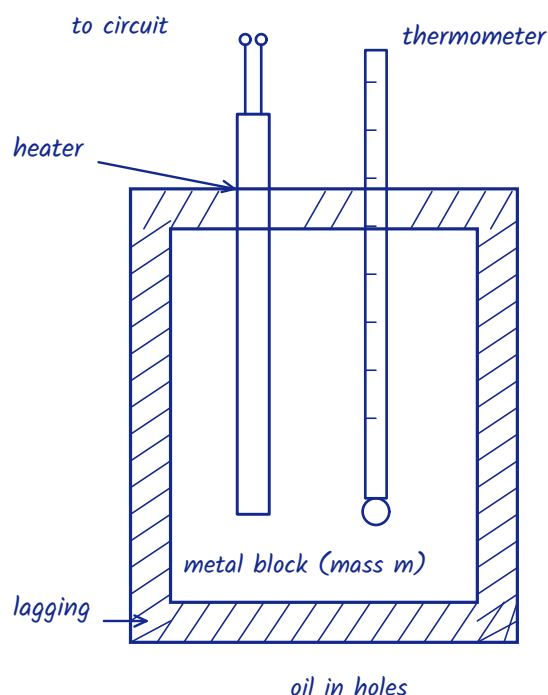
[5]

[Turn over]



7 (a) Describe an experiment to determine the specific heat capacity of a metal block. Include in your answer:

- a diagram of the apparatus used that will ensure an accurate result,
- the electrical circuit,
- the measurements taken,
- how the specific heat capacity is determined from the measurements.



Apparatus: a metal block of known mass with two holes drilled in it, an electric heater in one hole and a thermometer in the other (a little oil in each hole improves thermal contact). The block is wrapped in lagging (insulation) to reduce heat losses to the surroundings.

Circuit: the heater is connected to a low voltage d.c. supply with an ammeter in series and a voltmeter in parallel across the heater, with a switch and a rheostat to keep the current steady.

Measurements: measure the mass m of the block on a balance and record the initial temperature θ_1 . Switch on and start the stopclock; record the



current I and voltage V . After a time t (about 10 minutes) switch off and stop the clock, then record the highest final temperature θ_2 reached, as it keeps rising briefly after switching off.

Calculation: energy supplied $Q = VIt$ and temperature rise $\Delta\theta = \theta_2 - \theta_1$.

Since $Q = mc\Delta\theta$, the specific heat capacity is $c = Q / (m\Delta\theta) = VIt / (m\Delta\theta)$.

[8]

- (b) A kettle with a 2700W heating element is used to boil 750 cm³ of water. The water is initially at a temperature of 18 °C. Calculate the time taken for the water to boil if the heating element has an efficiency of 75%.

The specific heat capacity of water is 4.187 J g⁻¹ °C⁻¹ and its density is 1 g cm⁻³.

$$m = 750 \text{ cm}^3 \times 1 \text{ g cm}^{-3} = 750 \text{ g}, \quad \Delta\theta = 100 - 18 = 82 \text{ }^\circ\text{C}$$

$$Q = mc\Delta\theta = 750 \times 4.187 \times 82 = 2.575 \times 10^5 \text{ J}$$

$$\text{Energy supplied} = 2.575 \times 10^5 / 0.75 = 3.433 \times 10^5 \text{ J}$$

$$t = E / P = 3.433 \times 10^5 / 2700$$

$$t = 127 \text{ s}$$

Time = 127 s

[6]

[Turn over]



- 8 A 0.25 kg mass on the end of a spring is pulled down a distance of 3 cm **below** equilibrium position and released so that it oscillates with simple harmonic motion. A graph of how the displacement of the mass varies with time is shown in Fig. 8.1.

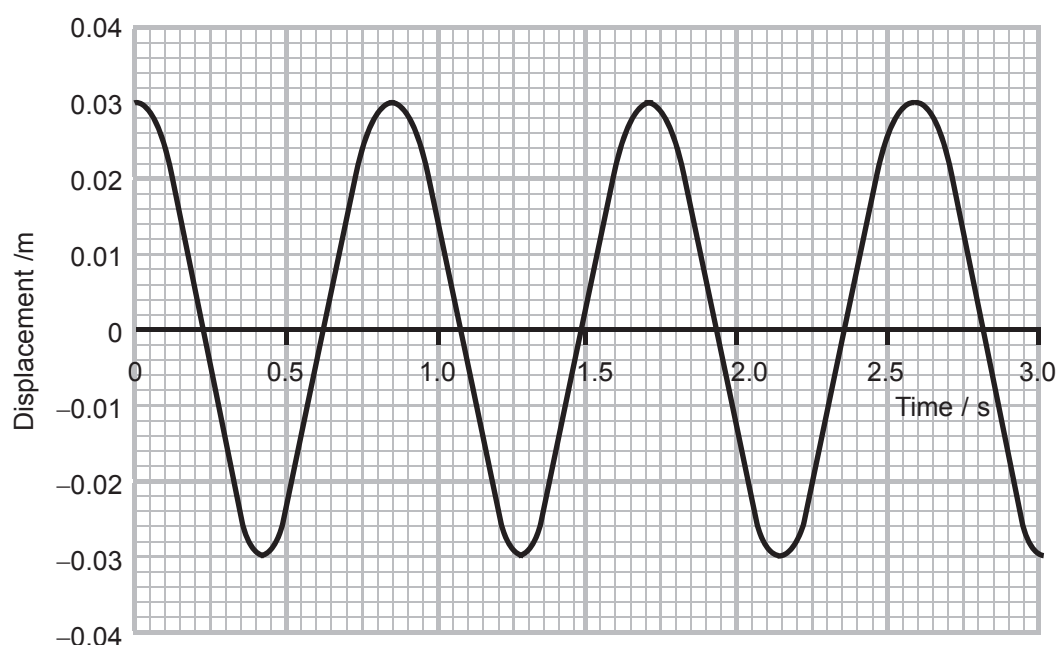


Fig. 8.1

- (a) (i) Explain what is meant by simple harmonic motion.

The acceleration of the object is directly proportional to its displacement from a fixed (equilibrium) point and is always directed in the opposite direction to the displacement, i.e. towards that fixed point.

[2]



- (ii) Calculate the displacement of the mass at a time of 12.5 seconds and state whether the mass is above or below the equilibrium position at this time.

From Fig. 8.1, 3 complete oscillations take 2.6 s, so $T = 0.87$ s

$$f = 1/T = 1/0.87 = 1.15 \text{ Hz}$$

$$\omega = 2\pi f = 2\pi \times 1.15 = 7.23 \text{ rad s}^{-1}$$

$$x = A \cos \omega t \quad (x = +0.03 \text{ m at } t = 0)$$

$$x = 0.03 \cos(7.23 \times 12.5) \quad (\text{calculator in radians})$$

$$x = 0.03 \times \cos(90.4) = -0.022 \text{ m}$$

Positive displacement is below equilibrium (the mass was pulled down 3 cm and $x = +0.03$ m at $t = 0$), so negative x means above.

$$\text{Displacement} = \underline{-0.022} \text{ m}$$

$$\text{Position relative to equilibrium position} = \underline{\text{above equilibrium}} \quad [6]$$

- (iii) Calculate the maximum strain energy stored in the spring.

$$T = 2\pi\sqrt{m/k}, \text{ so } k = 4\pi^2 m / T^2 = 4\pi^2 \times 0.25 / 0.87^2$$

$$k = 13 \text{ N m}^{-1}$$

$$\text{Extension at equilibrium: } mg/k = 0.25 \times 9.81 / 13 = 0.19 \text{ m}$$

$$\text{Maximum extension} = 0.19 + 0.03 = 0.22 \text{ m (lowest point)}$$

$$E = \frac{1}{2}kx^2 = \frac{1}{2} \times 13 \times 0.22^2 = 0.31 \text{ J}$$

$$\text{Energy} = \underline{0.31} \text{ J} \quad [4]$$

[Turn over]



- (b) Describe how the maximum velocity of the mass could be determined from Fig. 8.1.

Draw a tangent to the curve at a point where the displacement is zero

(where the graph crosses the time axis, the steepest part). The gradient of this tangent is the maximum velocity.

[3]

- (c) (i) Describe how the mass on the spring could be forced to resonate.

Attach the top of the spring to a vibration generator driven by a signal generator and vary the driving frequency until it equals the natural frequency of the mass-spring system (about 1.15 Hz).

[1]

- (ii) How can you tell that the mass on the spring is resonating?

The amplitude of the oscillations of the mass is a maximum.

[1]





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11137.03

[Turn over



- 9 (a) (i) What is the difference between the internal energy of a real gas and the internal energy of an ideal gas?

In an ideal gas there are no intermolecular forces, so its internal energy is only the random kinetic energy of the molecules. In a real gas the internal energy is the sum of the kinetic energy and the potential energy of the molecules.

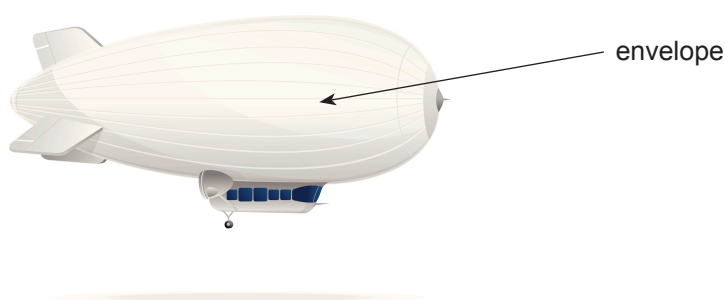
[2]

- (ii) For a real gas to behave more like an ideal gas how should the pressure of the gas be adjusted?

The pressure should be decreased.

[1]

- (b) Fig. 9.1 shows an airship with an envelope containing helium gas at a pressure of 1.03×10^5 Pa.



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Fig. 9.1



- (i) The envelope of the airship has a volume of 8230 m^3 . If the temperature of the gas is 14°C , calculate the mass of helium in the envelope of the airship.

The molar mass of helium = $4.003 \times 10^{-3} \text{ kg mol}^{-1}$.

$$T = 14 + 273 = 287 \text{ K}$$

$$pV = nRT, \text{ so } n = pV / RT$$

$$n = (1.03 \times 10^5 \times 8230) / (8.31 \times 287)$$

$$n = 3.554 \times 10^5 \text{ mol}$$

$$\text{mass} = n \times M = 3.554 \times 10^5 \times 4.003 \times 10^{-3}$$

$$\text{mass} = 1423 \text{ kg}$$

Mass of helium = 1423 kg

[3]

- (ii) Calculate the root mean square speed of the helium gas atoms in the envelope of the airship.

$$\text{mass of one atom } m = M / N_A = 4.003 \times 10^{-3} / 6.02 \times 10^{23}$$

$$m = 6.65 \times 10^{-27} \text{ kg}$$

$$\frac{1}{2}m\langle c^2 \rangle = \frac{3}{2}kT, \text{ so } \langle c^2 \rangle = 3kT / m$$

$$\langle c^2 \rangle = 3 \times 1.38 \times 10^{-23} \times 287 / 6.65 \times 10^{-27} = 1.787 \times 10^6$$

$$c_{\text{rms}} = \sqrt{1.787 \times 10^6} = 1337 \text{ m s}^{-1}$$

Root mean square speed = 1337 m s^{-1}

[3]

THIS IS THE END OF THE QUESTION PAPER



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Question Number	Marks
1	
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Total Marks	
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Examiner Number

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Rewarding Learning

ADVANCED
General Certificate of Education

Physics

Assessment Units A2 1 and A2 2

[APH11/APH21]

DATA AND FORMULAE SHEET

FOR USE FROM 2018 ONWARDS

Data and Formulae Sheet for A2 1 and A2 2

Values of constants

speed of light in a vacuum	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
permittivity of a vacuum	$\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$ $\left(\frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ F}^{-1} \text{ m} \right)$
elementary charge	$e = 1.60 \times 10^{-19} \text{ C}$
the Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$
(unified) atomic mass unit	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$
mass of electron	$m_e = 9.11 \times 10^{-31} \text{ kg}$
mass of proton	$m_p = 1.67 \times 10^{-27} \text{ kg}$
molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
the Avogadro constant	$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$
the Boltzmann constant	$k = 1.38 \times 10^{-23} \text{ J K}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
acceleration of free fall on the Earth's surface	$g = 9.81 \text{ m s}^{-2}$
electron volt	$1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$
the Hubble constant	$H_0 \approx 2.4 \times 10^{-18} \text{ s}^{-1}$

Useful formulae

The following equations may be useful in answering some of the questions in the examination:

Mechanics

conservation of energy $\frac{1}{2}mv^2 - \frac{1}{2}mu^2 = Fs$
for a constant force

Hooke's Law $F = kx$ (spring constant k)
strain energy $E = \frac{1}{2}Fx = \frac{1}{2}kx^2$

Uniform circular motion

centripetal Force $F = \frac{mv^2}{r}$

Simple harmonic motion

displacement $x = A \cos \omega t$
simple pendulum $T = 2\pi \sqrt{\frac{l}{g}}$
loaded spiral spring $T = 2\pi \sqrt{\frac{m}{k}}$

Waves

two-source interference $\lambda = \frac{ay}{d}$
diffraction grating $d \sin \theta = n \lambda$

Thermal physics

average kinetic energy of
a molecule

$$\frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} kT$$

kinetic theory

$$pV = \frac{1}{3} Nm \langle c^2 \rangle$$

thermal energy

$$Q = mc\Delta\theta$$

Capacitors

capacitors in series

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

capacitors in parallel

$$C = C_1 + C_2 + C_3$$

time constant

$$\tau = RC$$

capacitor discharge

$$Q = Q_0 e^{\frac{-t}{CR}}$$

$$\text{or } V = V_0 e^{\frac{-t}{CR}}$$

$$\text{or } I = I_0 e^{\frac{-t}{CR}}$$

Light

lens formula

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

Electricity

terminal potential difference

$$V = E - Ir$$

(e.m.f., E ; Internal Resistance, r)

potential divider

$$V_{\text{out}} = \frac{R_1 V_{\text{in}}}{R_1 + R_2}$$

a.c. generator

$$E = BAN\omega \sin\omega t$$

Nuclear Physics

nuclear radius

$$r = r_0 A^{\frac{1}{3}}$$

radioactive decay

$$A = -\lambda N, \quad A = A_0 e^{-\lambda t}$$

half-life

$$t_{\frac{1}{2}} = \frac{0.693}{\lambda}$$

Particles and photons

Einstein's equation

$$\frac{1}{2} m v_{\max}^2 = hf - hf_0$$

de Broglie equation

$$\lambda = \frac{h}{p}$$

Astronomy

red shift

$$z = \frac{\Delta \lambda}{\lambda}$$

recession speed

$$z = \frac{v}{c}$$

Hubble's law

$$v = H_0 d$$

