OCR RECOGNISING ACHIEVEMENT

ADVANCED GCE UNIT **2824**

PHYSICS A

Forces, Fields and Energy

THURSDAY 14 JUNE 2007

Morning

Time: 1 hour 30 minutes

Additional materials:
Electronic calculator

Candidate Name

Centre Number

Candidate Number

INSTRUCTIONS TO CANDIDATES

- Write your name, Centre Number and Candidate number in the boxes above.
- Answer **all** the questions.
- Use blue or black ink. Pencil may be used for graphs and diagrams only.
- Read each question carefully and make sure you know what you have to do before starting your answer.
- Do **not** write in the bar code.
- Do **not** write outside the box bordering each page.
- WRITE YOUR ANSWER TO EACH QUESTION IN THE SPACE PROVIDED. ANSWERS WRITTEN ELSEWHERE WILL NOT BE MARKED.

INFORMATION FOR CANDIDATES

- The number of marks for each question is given in brackets [ ] at the end of each question or part question.
- The total number of marks for this paper is 90.
- You will be awarded marks for the quality of written communication where this is indicated in the question.
- You may use an electronic calculator.
- You are advised to show all the steps in any calculations.

For Examiner's Use		
Qu.	**Max.**	**Mark**
1	**11**	
2	**11**	
3	**15**	
4	**12**	
5	**13**	
6	**12**	
7	**16**	
Total	**90**	

This document consists of **18** printed pages and **2** blank pages.

Data

speed of light in free space,	$c = 3.00 \times 10^{8}\ \mathrm{m\,s^{-1}}$
permeability of free space,	$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{H\,m^{-1}}$
permittivity of free space,	$\epsilon_0 = 8.85 \times 10^{-12}\ \mathrm{F\,m^{-1}}$
elementary charge,	$e = 1.60 \times 10^{-19}\ \mathrm{C}$
the Planck constant,	$h = 6.63 \times 10^{-34}\ \mathrm{J\,s}$
unified atomic mass constant,	$u = 1.66 \times 10^{-27}\ \mathrm{kg}$
rest mass of electron,	$m_e = 9.11 \times 10^{-31}\ \mathrm{kg}$
rest mass of proton,	$m_p = 1.67 \times 10^{-27}\ \mathrm{kg}$
molar gas constant,	$R = 8.31\ \mathrm{J\,K^{-1}\,mol^{-1}}$
the Avogadro constant,	$N_A = 6.02 \times 10^{23}\ \mathrm{mol^{-1}}$
gravitational constant,	$G = 6.67 \times 10^{-11}\ \mathrm{N\,m^{2}\,kg^{-2}}$
acceleration of free fall,	$g = 9.81\ \mathrm{m\,s^{-2}}$

Formulae

uniformly accelerated motion,	$s = ut + \frac{1}{2}at^2$
	$v^2 = u^2 + 2as$
refractive index,	$n = \frac{1}{\sin C}$
capacitors in series,	$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$
capacitors in parallel,	$C = C_1 + C_2 + \ldots$
capacitor discharge,	$x = x_0 e^{-t/CR}$
pressure of an ideal gas,	$p = \frac{1}{3}\frac{Nm}{V}<c^2>$
radioactive decay,	$x = x_0 e^{-\lambda t}$
	$t_{\frac{1}{2}} = \frac{0.693}{\lambda}$
critical density of matter in the Universe,	$\rho_0 = \frac{3H_0^2}{8\pi G}$
relativity factor,	$= \sqrt{(1 - \frac{v^2}{c^2})}$
current,	$I = nAve$
nuclear radius,	$r = r_0 A^{1/3}$
sound intensity level,	$= 10 \lg \left(\frac{I}{I_0}\right)$

Answer **all** the questions.

1 This question is about the energy stored in a capacitor.

(a) (i) One expression for the energy W stored on a capacitor is

$$W = \frac{1}{2} QV$$

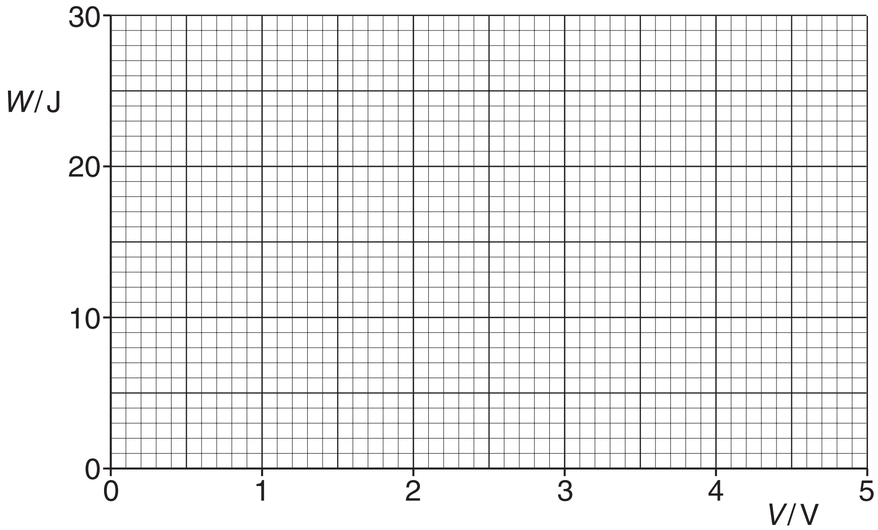
where Q is the charge stored and V is the potential difference across the capacitor. Show that another suitable expression for the energy stored is

$$W = \frac{1}{2} CV^2$$

where C is the capacitance of the capacitor.

[2]

(ii) Draw a graph on the axes of Fig. 1.1 to show how the energy W stored on a 2.2 F capacitor varies with the potential difference V across the capacitor.



[2]

Fig. 1.1

(b) The 2.2 F capacitor is connected in parallel with the power supply to a digital display for a video/DVD recorder. The purpose of the capacitor is to keep the display working during any disruptions to the electrical power supply. Fig. 1.2 shows the 5.0 V power supply, the capacitor and the display. The input to the display behaves as a 6.8 kΩ resistor. The display will light up as long as the voltage across it is at or above 4.0 V.

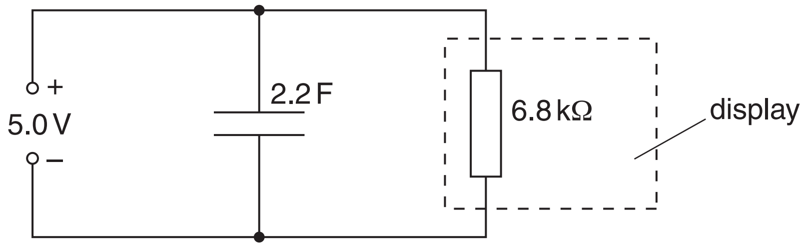


Fig. 1.2

Suppose the power supply is disrupted.

(i) Show that the time constant of the circuit of Fig. 1.2 is more than 4 hours.

[2]

(ii) Find the energy lost by the capacitor as it discharges from 5.0 V to 4.0 V.

energy lost = ... J [2]

(iii) The voltage V across the capacitor varies with time t according to the equation

$$V = V_o e^{-t/RC}.$$

Calculate the time that it takes for the voltage to fall to 4.0 V.

time = ... s [2]

(iv) Calculate the mean power consumption of the display during this time.

mean power = ... W [1]

[Total: 11]

[Turn over

2 This question is about the atmosphere treated as an ideal gas.

(a) The equation of state of an ideal gas is $pV = nRT$. Data about gases are often given in terms of density ρ rather than volume V. Show that the equation of state for a gas can be written as

$$p = \rho RT/M$$

where M is the mass of one mole of gas.

[3]

(b) One simple model of the atmosphere assumes that air behaves as an ideal gas at a constant temperature. Using this model the pressure p of the atmosphere at a temperature of 20 °C varies with height h above the Earth's surface as shown in Fig. 2.1.

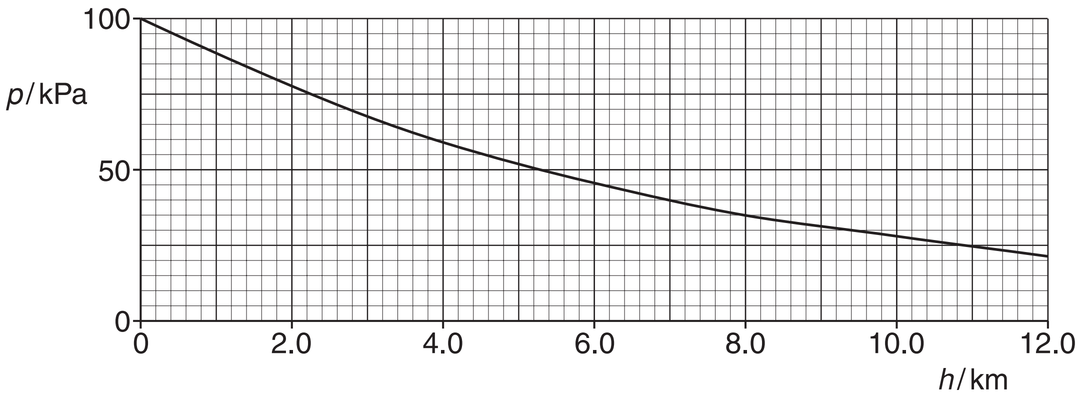


Fig. 2.1

Use data from the graph to show that the variation of pressure with height follows an exponential relationship.

[2]

(c) The ideal gas equation in **(a)** shows that, at constant temperature, pressure *p* is proportional to density ρ. Use data from Fig. 2.1 to find the density of the atmosphere at a height of 8.0 km.

density ρ of air at $h = 0$ is 1.3 kg m^{-3}

ρ = ... kg m^{-3} [3]

(d) In the real atmosphere the density, pressure and temperature all decrease with height. At the summit of Mt. Everest, 8.0 km above sea level, the pressure is only 0.30 of that at sea level. Take the temperature at the summit to be –23 °C and at sea level to be 20 °C.

Calculate, using the ideal gas equation, the density of the air at the summit.

density ρ of air at sea level = 1.3 kg m^{-3}

ρ = ... kg m^{-3} [3]

[Total: 11]

3 This question is about a simple model of a hydrogen iodide molecule.
Fig. 3.1 shows a simple representation of the hydrogen iodide molecule. It consists of two ions, $^{1}_{1}H^{+}$ and $^{127}_{53}I^{-}$, held together by electric forces.

Fig. 3.1

(a) **(i)** Draw on Fig. 3.1 lines to represent the resultant electric field between the two ions. [2]

(ii) Calculate the electrical force *F* of attraction between the ions.
Treat the ions as point charges a distance 5.0×10^{-10} m apart. Each ion has a charge of magnitude 1.6×10^{-19} C.

F = ... N [4]

(b) The electrical attraction is balanced by a repulsive force so that the two ions are in equilibrium. When disturbed the ions oscillate in simple harmonic motion. Fig. 3.2 shows a simple mechanical model of the molecule consisting of two unequal masses connected by a spring of negligible mass.

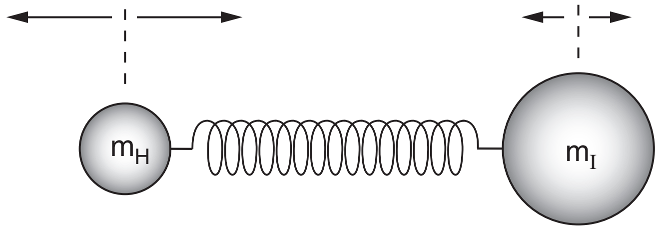


Fig. 3.2

Use Newton's laws of motion and the definition of simple harmonic motion to explain why the amplitude of oscillation of the hydrogen ion is 127 times the amplitude of oscillation of the iodine ion.

....

....

....

....

....

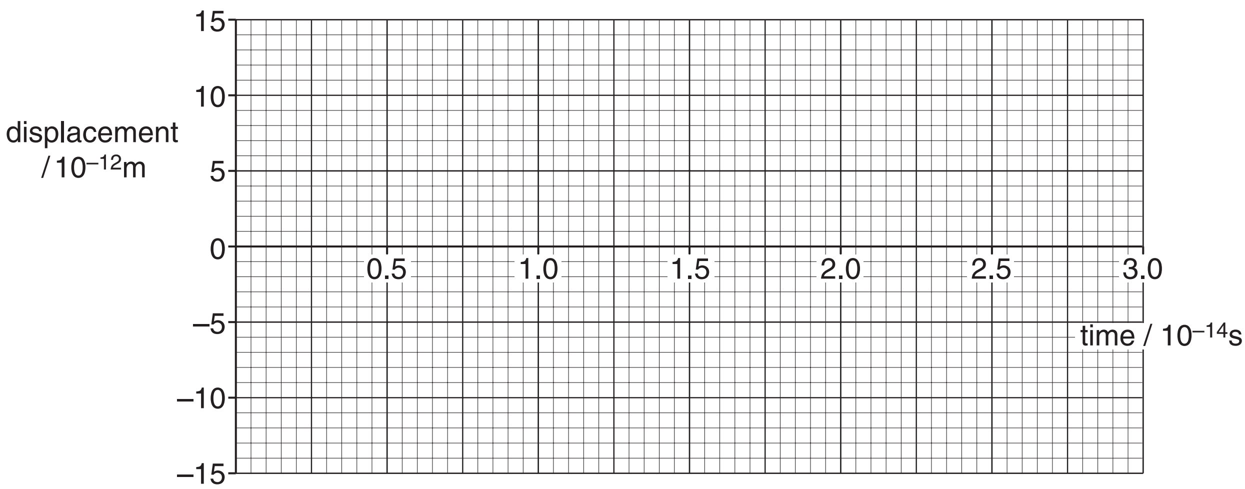
....

....

....[4]

(c) The natural frequency of oscillation of the hydrogen ion is 6.7×10^{13} Hz. Take the amplitude of oscillation to be 8.0×10^{-12} m.

(i) Sketch on Fig. 3.3 a displacement against time graph for the hydrogen ion.



[3]

Fig. 3.3

(ii) It is found that infra-red radiation of frequency close to 6.7×10^{13} Hz, incident on the molecules, can cause this oscillation, but other frequencies of infra-red do not. Suggest how this result can be explained.

....

....

....

....[2]

[Total: 15]

4 In a distant galaxy, the planet Odyssey is orbited by two small moons Scylla and Charybdis, labelled **O**, **S**, **C** respectively in Fig. 4.1. The distances of the moons from the centre of the planet are $5R$ and $4R$, where R is the radius of the planet.

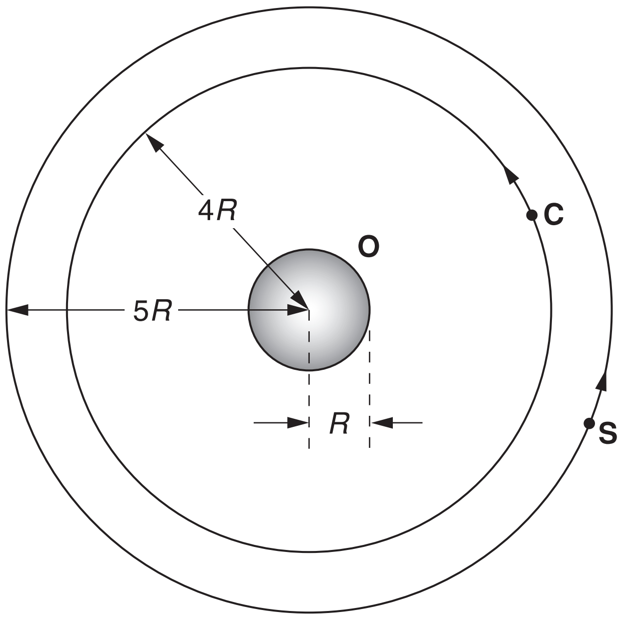


Fig. 4.1

(a) Draw a gravitational field line of the planet passing through moon **S**. [1]

(b) The radius R of the planet is 2.0×10^7 m. The gravitational field strength g at its surface is $40\,\text{N kg}^{-1}$.

(i) Write down a formula for the gravitational field strength g at the surface of the planet of mass M.

....[1]

(ii) Use the data above to show that the gravitational field strength at **S** is $1.6\,\text{N kg}^{-1}$.

[2]

(iii) Show that the gravitational field strength at **C** is $2.5\,\text{N kg}^{-1}$.

[1]

(iv) Using an average value of *g*, estimate the increase ΔE in gravitational potential energy of a small space vehicle of mass 3.0×10^3 kg when it moves from the orbit of **C** to the orbit of **S**.

ΔE = ... J [3]

(c) Calculate the orbital period of **S**. Assume that the gravitational effects of the two moons on each other are negligible in comparison to the gravitational force of **O**.

gravitational field strength at **S** = $1.6\,\mathrm{N\,kg^{-1}}$
radius of orbit = 1.0×10^8 m

period = ... s [4]

[Total: 12]

5 (a) (i) Define the *momentum* of a body.

....[1]

(ii) A body, initially at rest, explodes into two unequal fragments of mass m_A and m_B. Mass m_A has a velocity v_A and mass m_B has a velocity v_B. Using the principle of conservation of momentum, derive an expression for v_A/v_B.

[2]

(b)

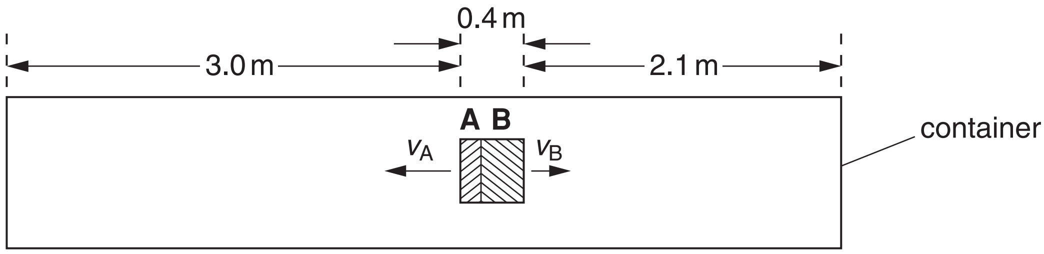


Fig. 5.1

Fig. 5.1 shows a large container of mass 45 kg and length 5.5 m in deep space. An astronaut looking into the container observes an object of mass 15 kg, stationary relative to the container. The object explodes into two pieces at time $t=0$. Piece **A** has mass 5 kg and piece **B** has mass 10 kg. The fragments move apart as shown in Fig. 5.1 until they impact and stick to the end walls of the container.

(i) The explosion gives piece **A** a momentum of 10 kg m s^{-1}. Calculate the speeds of the two fragments.

v_A = ... m s^{-1}

v_B = ... m s^{-1} [1]

(ii) Piece **A** strikes the container first. Calculate the time t_1 at which the container starts to move.

t_1 = ... s [1]

(iii) Calculate the distance x between **B** and the right hand end of the container at time t_1.

x = ... m [1]

(iv) Show that the speed of approach between **B** and the container immediately after time t_1 is $1.2\,\mathrm{m\,s^{-1}}$.

[1]

(v) Calculate the time t_2 between the explosion and the impact of **B** with the container.

t_2 = ... s [1]

(vi) Describe what happens to the container at time t_2 and explain why.

....

....

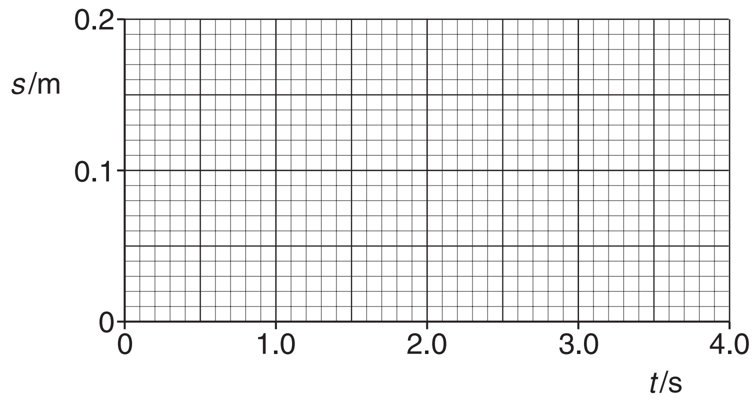
....

....

....

....[2]

(vii) On Fig. 5.2 plot a graph of the **displacement** *s* of the container for the time *t* shown.



[3]

Fig. 5.2

[Total: 13]

6 **(a)** The activity *A* of a sample of a radioactive nuclide is given by the equation

$$A = \lambda N$$

Define each of the terms in the equation.

A ....

....

λ ....

....

N ....

....[3]

(b) A 1000 MW coal-fired power station burns 7.0×10^6 kg of coal in one day. Two parts per million of the mass of the coal is $^{238}_{92}U$. The uranium remains in the residue left after the coal is burnt. The uranium nuclide $^{238}_{92}U$ decays by α-particle emission with a half-life of 4.5×10^9 years to an isotope of thorium.

(i) Write down

1 the proton number *Z* of thorium ....

2 the nucleon number *A* for this isotope of thorium ....[1]

(ii) Calculate the mass of uranium produced in the residue in one day.

mass = ... kg [1]

(iii) Hence show that the number of uranium atoms in this mass of uranium is 3.5×10^{25}.

[1]

(iv) Calculate the activity of this mass of uranium. Give a suitable unit with your answer.

1 year $= 3.2 \times 10^7$ s

activity = ... unit .... [3]

(c) To drive the turbines in the power station superheated steam at 450 K is required. Cold water enters the boilers at 290 K. Suggest and explain **two** reasons why it is **not** possible to use the formula

$$\Delta Q = mc\Delta\theta$$

to calculate the total energy used to transform the cold water into superheated steam. In the formula ΔQ is the energy absorbed by a mass m of water, c is the specific heat capacity of water and $\Delta\theta$ is its change in temperature.

....

....

....

....

....

....[3]

[Total: 12]

7 In this question, four marks are available for the quality of written communication.

(a) Faraday invented the concept of a field of force. Starting from the definitions of electric, gravitational and magnetic field strengths, discuss the similarities and differences between the three force fields.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....[7]

(b) To explain the laws of electromagnetic induction (Faraday's law and Lenz's law) Faraday introduced the concept of magnetic flux. Describe how the flux model is used in these laws. Start by defining *magnetic flux* and *magnetic flux linkage*.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....[5]

Quality of Written Communication [4]

[Total: 16]

END OF QUESTION PAPER

BLANK PAGE

PLEASE DO NOT WRITE ON THIS PAGE

BLANK PAGE

PLEASE DO NOT WRITE ON THIS PAGE

PLEASE DO NOT WRITE ON THIS PAGE