Centre Number	Index Number	Name	Class
3016			

RAFFLES INSTITUTION
2017 Preliminary Examination

PHYSICS **9749/03**
Higher 2

19 September 2017
Paper 3 Longer Structured Questions **2 hours**

Candidates answer on the Question Paper.
No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your index number, name and class in the spaces at the top of this page.
Write in dark blue or black pen in the spaces provided in this booklet.
You may use pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.
The use of an approved scientific calculator is expected, where appropriate.

Section A
Answer **all** questions.

Section B
Answer **one** question only and **circle the question number** on the cover page.

You are advised to spend one and half hours on Section A and half an hour on Section B.
The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use		
Section A	**1**	/ 10
	2	/ 10
	3	/ 11
	4	/ 10
	5	/ 9
	6	/ 10
Section B (circle 1 question)	**7**	/ 20
	8	/ 20
Deduction		
Total		/ 80

This document consists of **23** printed pages and **1** blank page.

DATA AND FORMULAE

Data

speed of light in free space	$c = 3.00 \times 10^{8}$ m s^{-1}
permeability of free space	$\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}
	$= (1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge	$e = 1.60 \times 10^{-19}$ C
the Planck constant	$h = 6.63 \times 10^{-34}$ J s
unified atomic mass constant	$u = 1.66 \times 10^{-27}$ kg
rest mass of electron	$m_e = 9.11 \times 10^{-31}$ kg
rest mass of proton	$m_p = 1.67 \times 10^{-27}$ kg
molar gas constant	$R = 8.31$ J K^{-1} mol^{-1}
the Avogadro constant	$N_A = 6.02 \times 10^{23}$ mol^{-1}
the Boltzmann constant	$k = 1.38 \times 10^{-23}$ J K^{-1}
gravitational constant	$G = 6.67 \times 10^{-11}$ N m^{2} kg^{-2}
acceleration of free fall	$g = 9.81$ m s^{-2}

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$
	$v^2 = u^2 + 2as$
work done on/by a gas	$W = p\Delta V$
hydrostatic pressure	$p = \rho gh$
gravitational potential	$\phi = -Gm/r$
temperature	$T/\text{K} = T/^{\circ}\text{C} + 273.15$
pressure of an ideal gas	$p = \frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$
mean translational kinetic energy of an ideal gas molecule	$E = \frac{3}{2}kT$
displacement of particle in s.h.m.	$x = x_0 \sin \omega t$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t = \pm\omega\sqrt{x_0^2 - x^2}$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \ldots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \ldots$
electric potential	$V = Q/(4\pi\varepsilon_0 r)$
alternating current/voltage	$x = x_0 \sin \omega t$
magnetic flux density due to a long straight wire	$B = \frac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	$B = \frac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_0 nI$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

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Section A

Answer **all** the questions from this section in the spaces provided.

1 A buoy floats in the sea next to a seawall. A lamp at the top of the buoy oscillates through a vertical distance of 0.22 m, as shown in Fig. 1.1. The oscillations are simple harmonic with a frequency of 0.40 Hz.

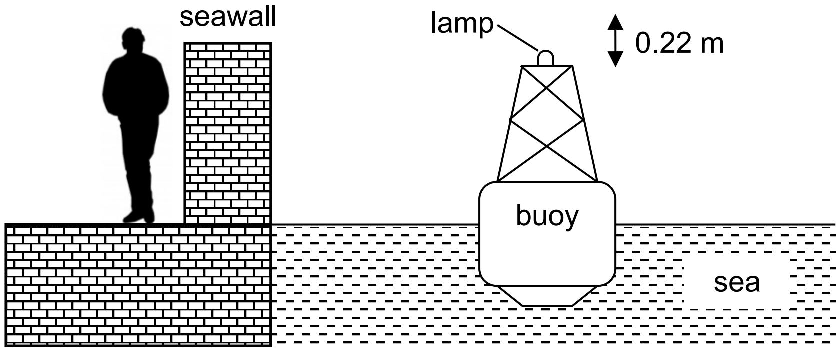

Fig. 1.1

(a) Define *simple harmonic motion*.

....

....

.... [2]

(b) State the amplitude of the oscillation.

amplitude = ... m [1]

(c) Calculate the angular frequency of the oscillation.

angular frequency = ... rad s^{-1} [2]

(d) On Fig. 1.2, sketch the variation of the velocity of the lamp with its displacement from the equilibrium position as it moves downwards from its equilibrium position to its lowest position. Label the axes with appropriate values. Take upward displacement to be positive.

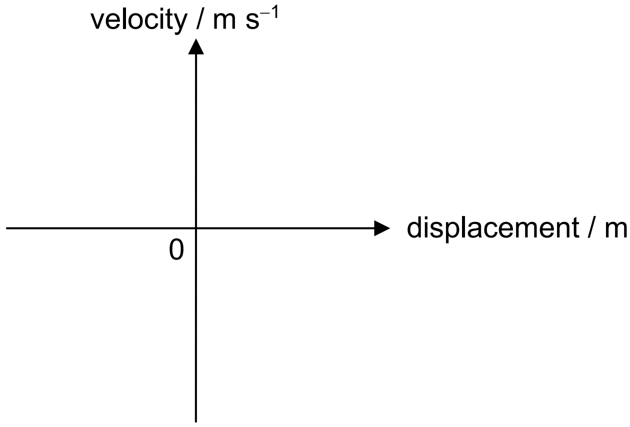

Fig. 1.2

[2]

(e) The lamp is above the top of the seawall for 1.8 s for each cycle of oscillation.

Determine the distance of the equilibrium position of the lamp from the top of the seawall.

distance = ... m [3]

2 Fig. 2.1 shows a dipper vibrating at a constant frequency on the surface of a pond. Ripples spread out as progressive transverse waves with circular wavefronts. Assume that the energy of the wave is spread over the entire circumference of the ripple and that no energy is lost in the propagation of the ripple.

Two identical plastic balls placed on the water surface at points P and Q are observed to move up and down. The distance between points P and Q is shorter than one wavelength.

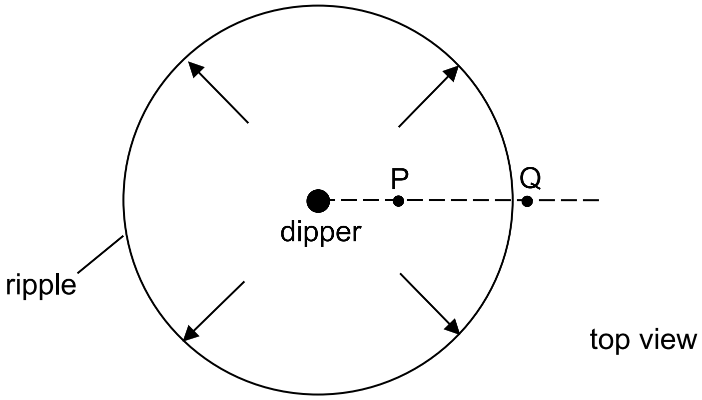

Fig. 2.1

The variation of the displacements of points P and Q with time is shown in Fig. 2.2. The solid line represents point P and the dotted line point Q.

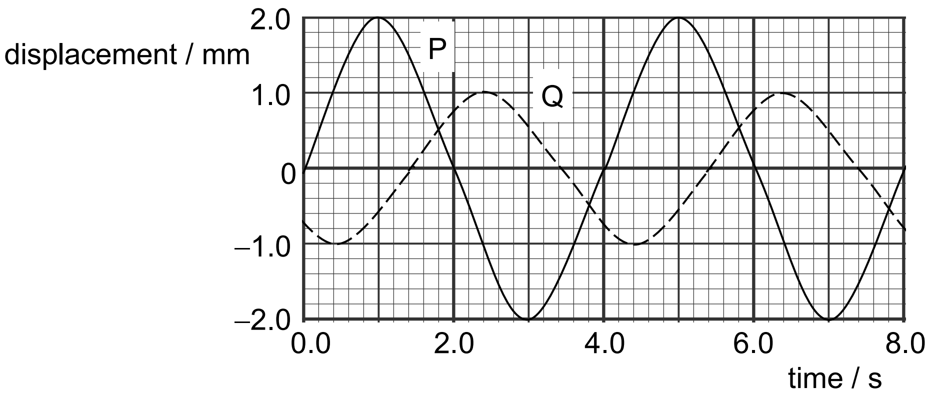

Fig. 2.2

(a) Explain what is meant by a *progressive transverse* wave.

progressive : ....

....

transverse: ....

.... [2]

(b) State the period of the wave.

period = ... s [1]

(c) Determine the phase difference between the waves reaching points P and Q.

phase difference = ... rad [2]

(d) The distance of point P from the dipper is 150 mm. Use Fig. 2.2 to show that the distance of point Q from the dipper is 600 mm.

[2]

(e) Using answers in **(c)** and **(d)**, determine the wavelength of the ripples.

wavelength = ... mm [2]

(f) On Fig. 2.3, sketch a possible variation of the displacement of a wave with distance from the dipper for two wavelengths. Numerical values are not expected.

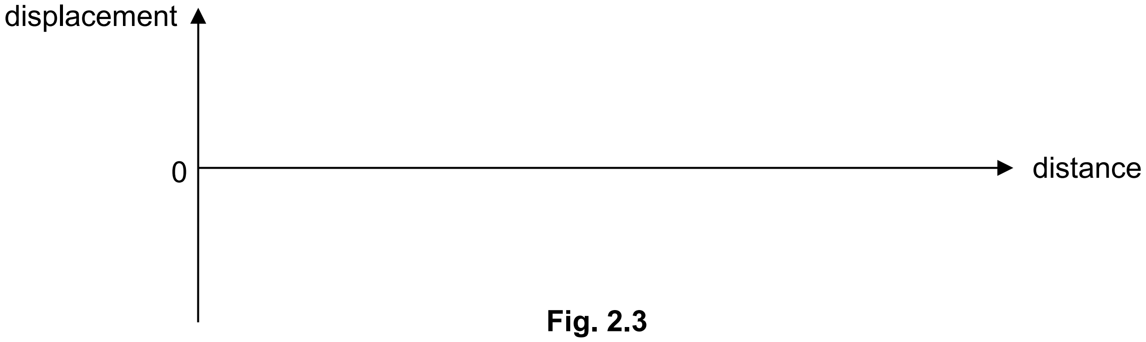

Fig. 2.3

[1]

3 **(a)** A satellite orbits the Earth at a constant speed and height. Two radio waves transmitters on the surface of the Earth emit coherent waves of equal amplitudes, as shown in Fig. 3.1.

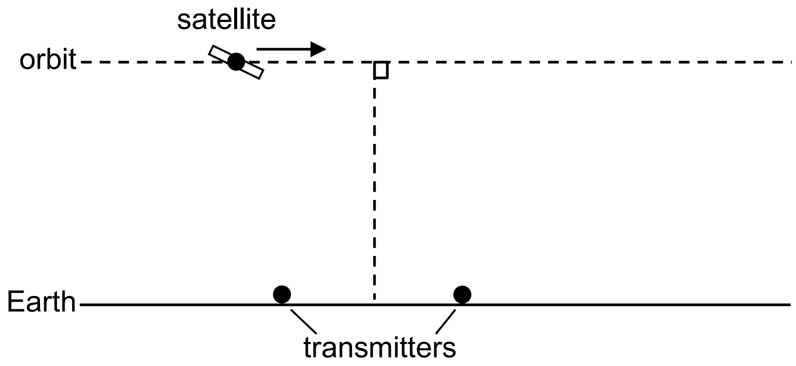

Fig. 3.1

The intensity of the signal that the satellite receives varies periodically.

(i) State what is meant by *coherent* waves.

....

.... [1]

(ii) Explain why the intensity of the signal varies periodically.

....

....

....

....

.... [3]

(iii) The transmitters are 150 m apart and the radio waves emitted have a wavelength of 1.2 m. The speed of the satellite is 8.0×10^3 m s^{-1} and the signal it receives varies in intensity with a frequency of 4.0 Hz.

Calculate the height of the satellite above the surface of the Earth.

height = ... m [3]

(b) The Arecibo telescope is one of the largest telescopes on Earth which scans the sky for sources that emit electromagnetic waves. The dish of the telescope has a diameter of 300 m.

Two distant sources are emitting radio waves of wavelength 1.2 m. They are separated by a distance of 2.0×10^{12} m from each other and 3.0×10^{16} m from the telescope.

(i) Determine whether the telescope can resolve these two sources.

[3]

(ii) Fig. 3.2 shows the intensity distribution of the diffraction pattern formed by one of the sources.

Sketch the intensity distribution of the other source if the diffraction patterns formed by the two sources are just resolved according to the Rayleigh criterion.

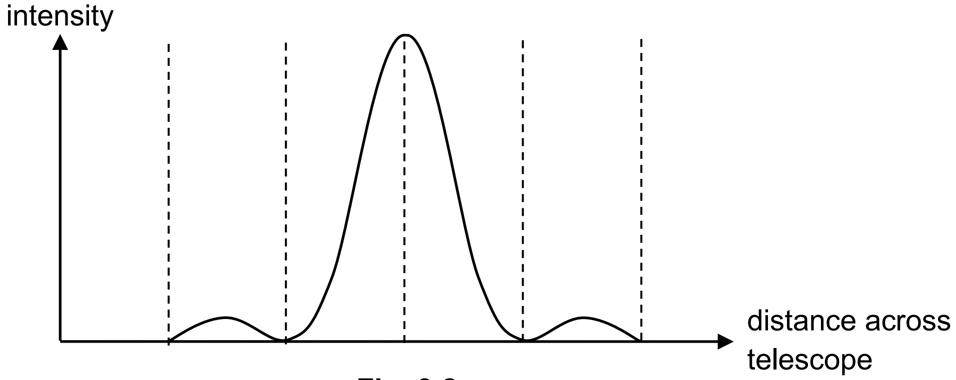

Fig. 3.2

[1]

4 A metal sphere of radius 20 mm and charge –12 nC is placed in a vacuum.

(a) **(i)** Define *electric field strength* at a point.

....

.... [1]

(ii) Calculate the magnitude of the electric field strength at the surface of the sphere.

electric field strength = ... N C^{-1} [2]

(iii) On Fig 4.1, sketch the variation of the electric field strength E with distance d from the centre of the sphere. Numerical values are not expected.

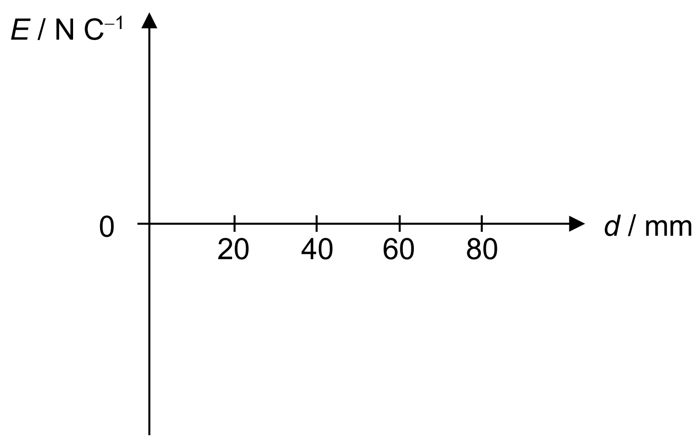

Fig. 4.1

[2]

(iv) A positive point charge of mass 0.030 g and charge 6.0 nC is released from rest at a distance of 60 mm from the centre of the sphere.

Determine the kinetic energy of the point charge when it reaches a distance of 40 mm from the centre of the sphere.

kinetic energy = ... J [2]

(v) With reference to Fig. 4.1, suggest how the change in potential between d = 40 mm and d = 60 mm can be obtained.

....

.... [1]

(b) The negatively charged sphere is now brought close to an earthed metal plate.

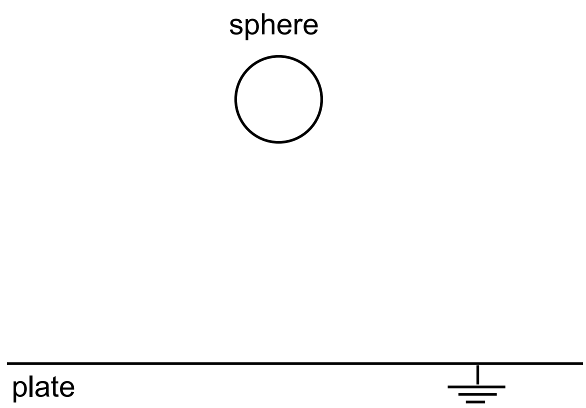

Fig. 4.2

Draw electric field lines to represent the electric field in the region between the sphere and the plate. [2]

5 A long straight wire carrying a current of 2.0 A is placed on the same plane as a square coil of wire of 50 turns. The coil is moved perpendicularly away from the straight wire at a constant speed, as shown in Fig. 5.1. The length of each side of the coil is 1.0 cm.

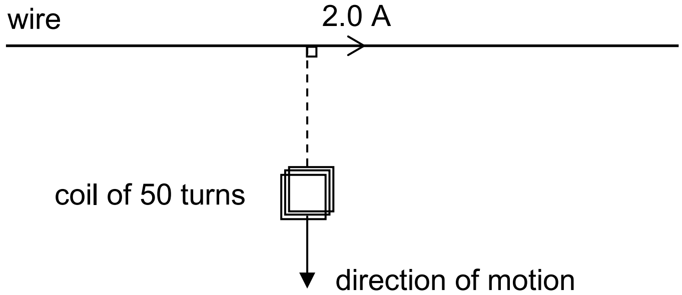

Fig. 5.1

(a) Show that the magnetic flux density at a distance of 10 cm from the wire is 4.0×10^{-6} T.

[1]

(b) The coil is moved such that the distance between the wire and the centre of the coil changes from 10.0 cm to 20.0 cm in a duration of 0.40 s.

(i) State Faraday's law of electromagnetic induction.

....

....

.... [1]

(ii) Calculate the average e.m.f. induced in the coil.

Assume that the magnetic flux density through the coil is the same as the value at the centre of the coil.

average e.m.f. = ... V [3]

(c) **(i)** With reference to Lenz's law, state and explain the direction of the induced current in the coil.

....

....

....

.... [2]

(ii) Hence, explain why work has to be done to move the coil away from the straight wire at a constant velocity.

....

....

....

.... [2]

6 **(a)** A beam of white light, consisting of wavelengths between 400 nm and 700 nm, is incident on a cool sodium gas at low pressure. Fig. 6.1 shows the four lowest energy levels of the sodium atom.

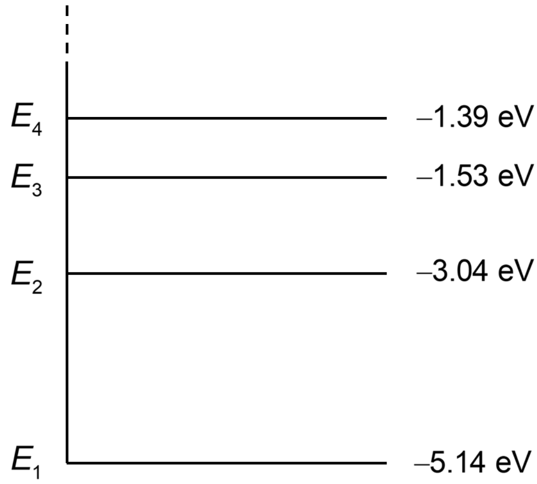

Fig. 6.1

(i) Explain the formation of an absorption line spectrum.

....

....

....

....

....

....

....

.... [3]

(ii) Show that the wavelength of the photon that causes the transition from E_1 to E_2 is 592 nm.

[1]

(iii) Determine the number of absorption spectral lines that are observed. Show your working.

number of observable lines = ... [2]

(b) An electron microscope uses an array of electromagnetic lenses to accelerate and focus a beam of electrons to create an enlarged image of a specimen.

(i) Determine the kinetic energy, in eV, of an electron which has a de Broglie wavelength that is the same as the wavelength of the photon in **(a)(ii)**.

kinetic energy = ... eV [2]

(ii) Suggest one advantage and one disadvantage of an electron microscope over an optical microscope.

Advantage: ....

....

Disadvantage: ....

.... [2]

Section B

Answer **one** question from this section in the spaces provided.

7 A binary star system consists of two stars of masses 5.00×10^{31} kg and 3.00×10^{31} kg, as shown in Fig. 7.1. The line XY passes perpendicularly to the line AB, joining the centres of the two stars, at point D. A point C on the line XY is 1.86×10^{12} m from point A and 1.31×10^{12} m from point B.

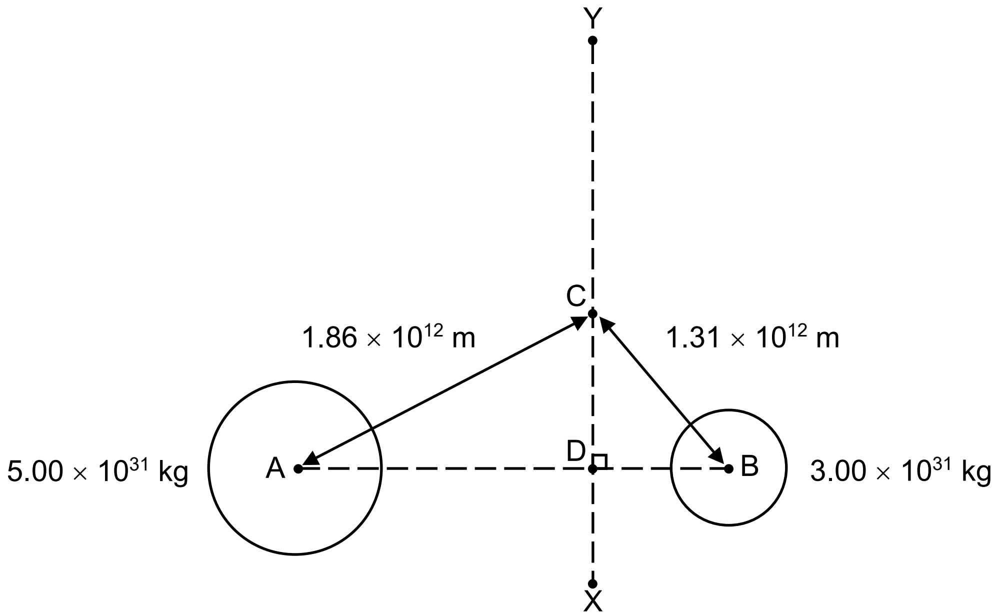

Fig. 7.1

(a) **(i)** Define *gravitational potential* at a point.

....

....

.... [1]

(ii) Explain why gravitational potential is negative.

....

....

....

....

....

.... [3]

(iii) Show that the gravitational potential at point C is -3.32×10^9 J kg^{-1}.

[1]

(b) An asteroid passes through point C with speed u.

Determine the minimum value of u such that the asteroid is just able to escape from the gravitational attraction of the binary star system.

minimum value of u = ... m s^{-1} [2]

(c) Fig. 7.2 shows the variation of gravitational potential ϕ with distance from point X to point Y.

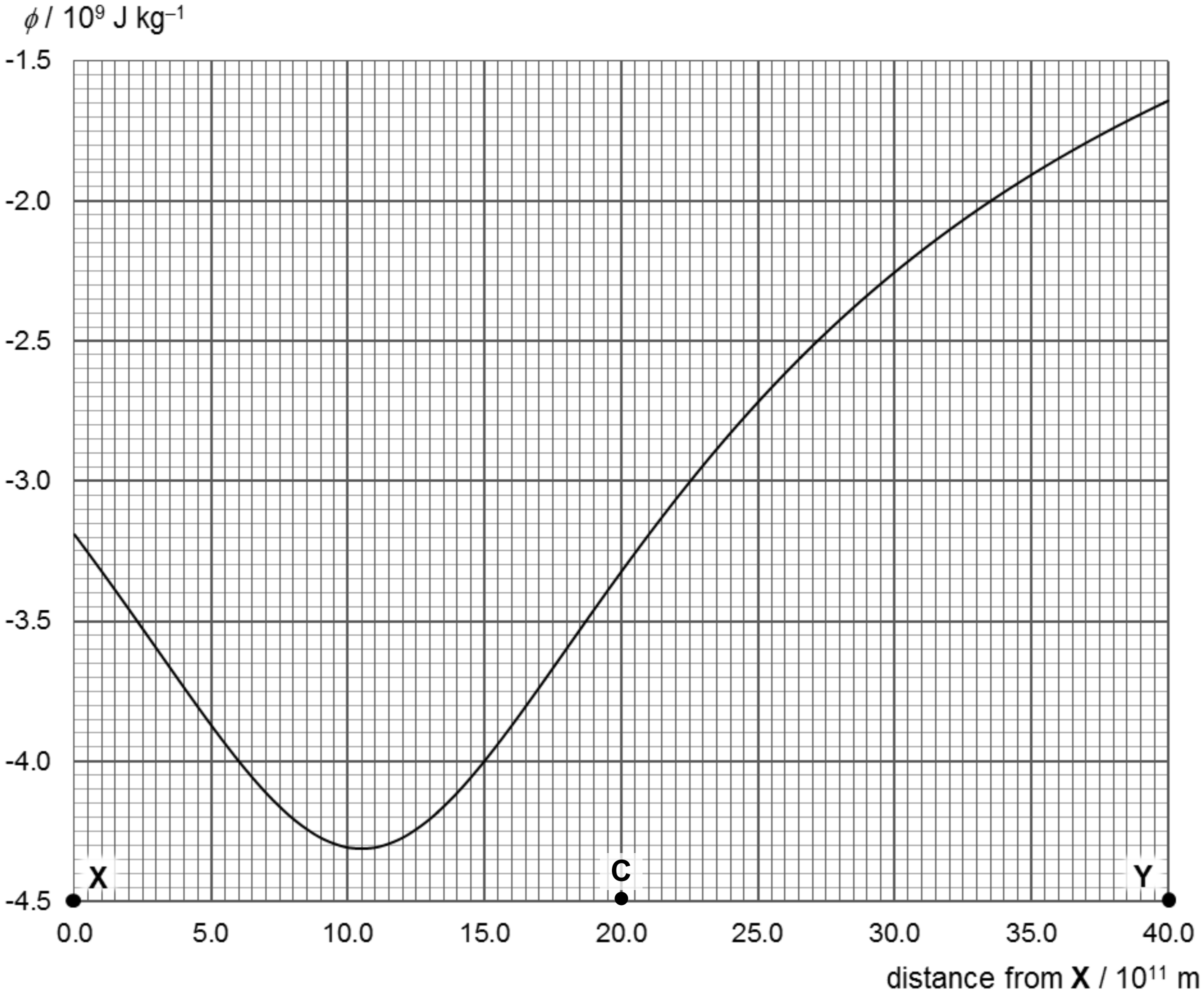

Fig. 7.2

Using Fig. 7.2,

(i) determine the magnitude of the component of gravitational field strength along the line XY at point C. Show your working.

gravitational field strength = ... N kg^{-1} [3]

(ii) label the position of point D on the curve. Explain how it is determined.

....

.... [2]

(iii) show that the separation between the centres A and B of the two stars is 2.50×10^{12} m.

[2]

(d) The separation of the centres of the two stars remains constant at 2.50×10^{12} m as they rotate about a common centre.

Determine the distance of the centre of rotation of the binary star system from point A. Explain your working.

distance = ... m [3]

(e) The star of mass 5.00×10^{31} kg has a radius of 1.00×10^{9} m.

(i) Calculate the mean density of this star.

mean density = ... kg m^{-3} [1]

(ii) Suggest, with a reason, whether the density is likely to vary with distance from the centre of the star.

....

....

.... [2]

8 Uranium-235 is an isotope of uranium and makes up about 0.70% of natural uranium. It is a common isotope used in nuclear power plant. The half-life of uranium-235 is 7.0×10^8 years.

(a) Explain what is meant by

(i) *isotopes*,

....

....

.... [1]

(ii) *fission*,

....

....

.... [2]

(iii) *half-life*.

....

....

.... [1]

(b) In a particular nuclear fission of uranium-235 (U), caesium-137 (Cs) and rubidium-95 (Rb) isotopes are produced, as represented by the following equation:

$$^{235}_{92}\mathrm{U} + {}^{p}_{q}\mathrm{n} \rightarrow {}^{137}_{55}\mathrm{Cs} + {}^{95}_{r}\mathrm{Rb} + x\,{}^{p}_{q}\mathrm{n}$$

(i) Determine the values of p, q, r and x.

p = ...

q = ...

r = ...

x = ... [2]

(ii) Fig. 8.1 shows the variation of binding energy per nucleon with nucleon number.

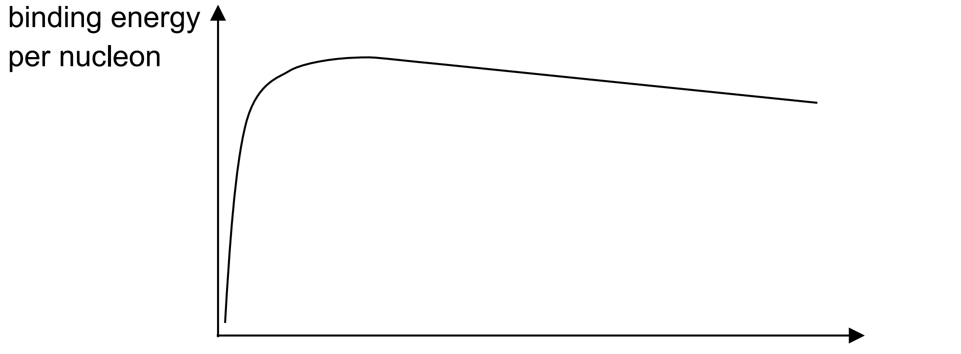

Fig. 8.1

Using Fig. 8.1,

1. mark the approximate positions of U, Cs and Rb on the curve, [1]

2. explain why the fission of uranium-235 releases energy.

....

....

.... [2]

(iii) The energy released in this nuclear fission is 289 MeV. The rest masses of the nuclei are

caesium-137,	*m*
uranium-235,	235.1727 u
rubidium-95,	94.92964 u
neutron,	1.008665 u

Determine the value of *m*.

m = ... kg [3]

(c) Caesium-137 is a radioactive isotope that has a half-life of 30.2 years and it is highly soluble in water.

During the Fukushima nuclear accident in Japan in 2011, 27.0 kg of caesium-137 was released into the environment.

(i) Suggest one method of removing caesium-137 from contaminated water.

....

.... [1]

(ii) Calculate the decay constant of caesium-137. Include the unit in your answer.

decay constant = ... [3]

(iii) Determine the activity of caesium-137 when it was released during the accident.

activity = ... Bq [2]

(iv) Caesium-137 decays by beta emission to form barium-137.

Explain why the kinetic energy of the beta particle is lower than the total energy released in the beta decay.

....

....

.... [2]

End of Paper 3