Centre Number	Index Number	Name	Class
S3016			

RAFFLES INSTITUTION
2023 Preliminary Examination

PHYSICS
Higher 1
Paper 2 Structured Questions

8867/02
September 2023
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 on both sides of the paper.
You may use an HB 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 any **one** question.

The number of marks is given in brackets [ ] at the end of each question or part question.

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

Data

speed of light in free space	c	=	3.00×10^{8} m s^{-1}
elementary charge	e	=	1.60×10^{-19} C
unified atomic mass constant	u	=	1.66×10^{-27} kg
rest mass of electron	m_e	=	9.11×10^{-31} kg
rest mass of proton	m_p	=	1.67×10^{-27} kg
the Avogadro constant	N_A	=	6.02×10^{23} mol^{-1}
gravitational constant	G	=	6.67×10^{-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	=	$u^2 + 2as$
resistors in series	R	=	$R_1 + R_2 + \ldots.$
resistors in parallel	$1/R$	=	$1/R_1 + 1/R_2 + \ldots.$

Section A

Answer ALL questions from this section

1 The acceleration of free fall g can be determined through the period of oscillation T of a simple pendulum of length L. The relationship between these quantities is

$$T = 2\pi\sqrt{\frac{L}{g}}\,.$$

In one particular experiment, the following measurements were made.

$L = (0.850 \pm 0.001)$ m

time for 20 oscillations = (36.9 ± 0.2) s

(a) Use these measurements to determine a value, to three significant figures, of g.

g = ... m s^{-2} [1]

(b) Determine the actual uncertainty in the value of g.

Hence, give a statement of g, with its uncertainty, to an appropriate number of significant figures.

g = ... ± .... m s^{-2} [4]

2 Tarzan wants to get a coconut from a coconut tree by throwing a stone at the coconut to knock it down. The coconut is 18.0 m above the ground as shown in Fig. 2.1.

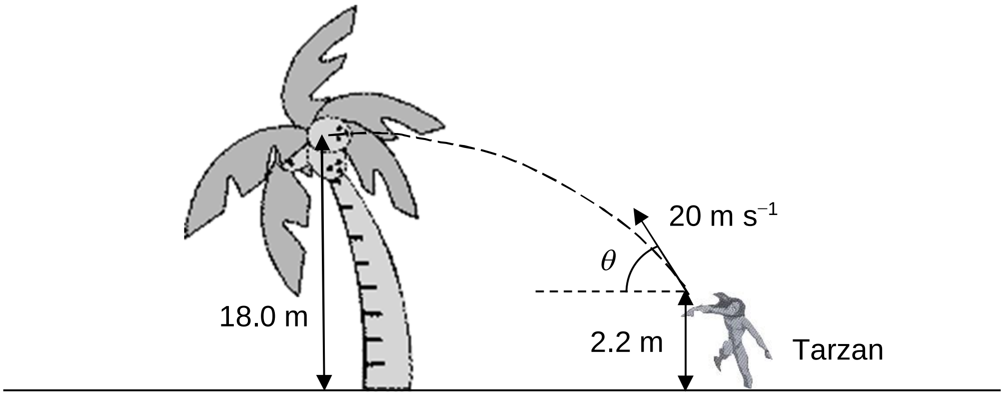

Fig. 2.1

Tarzan throws a stone such that it hits the coconut horizontally. The stone is projected with an initial speed of 20 m s^{-1} at 2.2 m above the ground. Air resistance is negligible.

(a) Determine the angle θ to the horizontal at which the stone has to be projected so that it will hit the coconut horizontally.

θ = ... ° [3]

(b) Determine the time taken for the stone to reach the coconut at this angle of projection.

time taken = ... s [2]

(c) Hence, calculate the horizontal displacement from the coconut at which Tarzan should project the stone so that it hits the coconut horizontally.

horizontal displacement = ... m [2]

(d) If air resistance is not negligible, state and explain how the angle θ calculated in **(a)** and the horizontal displacement calculated in **(c)** should change so that the stone is still able to hit the coconut horizontally when the stone is projected with the same initial speed.

....

....

....

.... [2]

3 **(a)** Define *linear momentum*.

....

.... [1]

(b) Two particles A and B with masses $2m$ and m respectively, move at the same speed u towards each other along a horizontal line and collide elastically. Particle B moves vertically down after the collision and particle A is deflected through an angle θ as illustrated in Fig. 3.1.

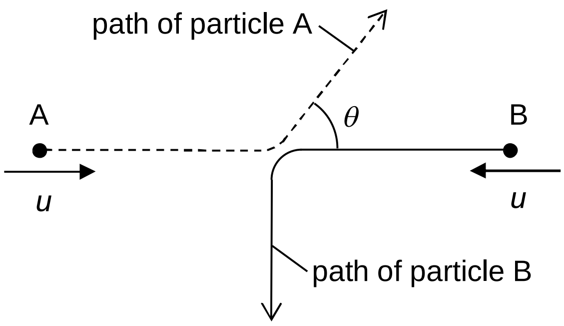

Fig. 3.1

(i) By considering the kinetic energies of both particles, show that:

$$3u^2 = 2{v_A}^2 + {v_B}^2$$

where v_A and v_B are the speeds after collision of particles A and B respectively.

[1]

(ii) The value of m is 1.7×10^{-27} kg and the value of u is 3.5×10^{5} m s^{-1}.

1. By considering the momenta of both particles in the vertical and horizontal directions and using the equation in **(b)(i)**, determine v_B.

v_B = ... m s^{-1} [3]

2. Hence, calculate the change in momentum of particle B due to the collision.

magnitude of change = ... kg m s^{-1}

direction of change = ... [3]

(iii) The two particles are in contact for a time of 1.2 μs during collision.

Determine the average force exerted by particle B on particle A.

magnitude of average force = ... N

direction of average force = ... [2]

4 **(a)** State the conditions for a body to be in equilibrium.

....

....

....

.... [2]

(b) Define moment of a force.

....

.... [1]

(b) A uniform metre rule of mass 0.090 kg is pivoted at its centre as shown in Fig. 4.1.

The left end of the rule is suspended from a fixed point using a spring of force constant 21 N m^{-1}. A mass of 0.25 kg is hung from the same end of the rule using a string.

A block M is hung from the rule using a string at a distance of 30 cm from the pivot.

The rule is horizontal and the extension of the spring is 1.5 cm.

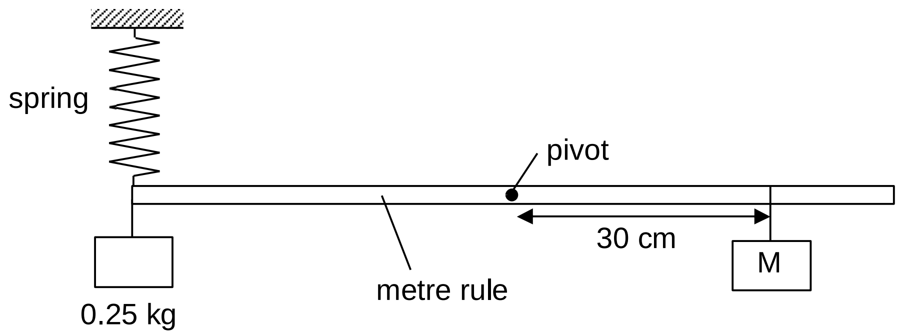

Fig 4.1

(i) Show that the mass of block M is 0.36 kg.

[2]

(ii) Determine the magnitude of the normal contact force acting on the metre rule due to the pivot.

magnitude of the normal contact force = ... N [2]

5 **(a)** State two situations in which a charged particle in a magnetic field does not experience a magnetic force.

1. ....

....

2. ....

.... [2]

(b) Particles of charge $+3.2 \times 10^{-19}$ C travel in a vacuum at 4.7×10^{5} m s^{-1}. The particles enter a region of uniform magnetic field of flux density 0.12 T at right angles to the edge of the region as shown in Fig. 5.1.

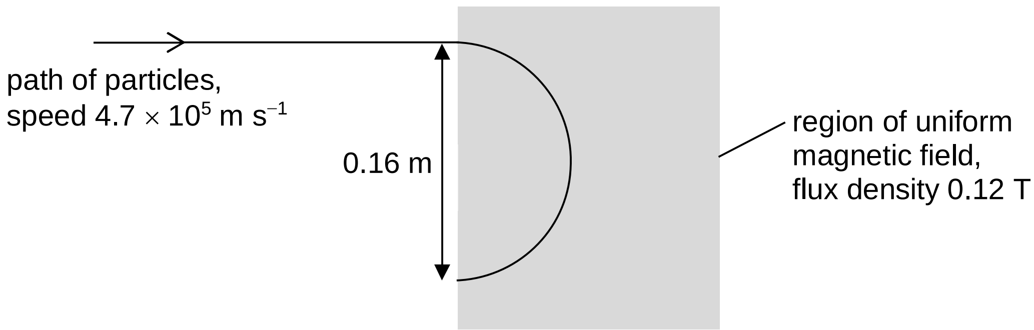

Fig. 5.1

The path of the particles in the magnetic field is a semicircle with diameter 0.16 m.

(i) State the direction of the magnetic field.

.... [1]

(ii) Determine the mass of each particle.

mass = ... kg [3]

(c) A uniform electric field is now produced in the same region so that the particles now pass through the two fields undeflected.

(i) On Fig. 5.1, draw an arrow in the region to show the direction of the electric field. [1]

(ii) Calculate the magnitude of the electric field strength of the uniform electric field.

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

(iii) Other particles that have the same speed and move along the same initial path as the particles in **(b)** now enter the region of the magnetic and electric fields. These other particles have a charge of -1.6×10^{-19} C.

Describe and explain the path of these other particles in the region.

....

.... [1]

6 Read the passage below and answer the questions that follow.

Modern train system

With the advancement in technology, the train system has greatly evolved over the years to meet the need for speed, ride comfort and lower maintenance cost.

One main consideration when designing the train system is for train vehicles to navigate curves at high speeds without derailing or toppling over. To achieve this, the outer side of the track of a railway may be raised. This is similar to the banking of roads for cars to turn around a bend at high speed without skidding.

Fig. 6.1 shows the cross section of a railway track that is tilted by an angle θ. The quantity cant E is used to indicate the amount of banking of the railway track. Cant is the difference in vertical height between the two rails of the track. Another important quantity is the rail gauge w which is the distance between the two rails.

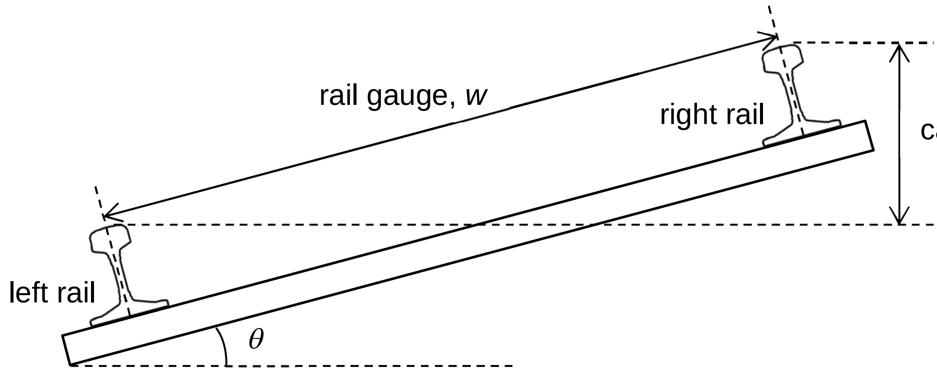

Fig. 6.1

When the train is on the track, the rails exert an effective contact force on the train.

For any banked track with cant E_0, the balance speed v_0 is the speed of the train such that this contact force is perpendicular to the bank.

However, trains do not always travel at the same speed. For example, compared to freight trains, passenger trains move at a higher speed and is usually higher than the balance speed.

At speeds above v_0, a larger cant E_v would be required to ensure that the contact force is perpendicular to the bank. The difference between the required cant E_v and actual cant E_0 is known as the cant deficiency, CD, where

$$CD = E_v - E_0$$

For example, a train moving on a track of cant E_0 = 120 mm has v_0 = 125 km h^{-1}.
When it moves at v = 140 km h^{-1} on the same track, the cant E_v required = 150 mm.
Hence,

$$CD = 150\text{ mm} - 120\text{ mm} = 30\text{ mm}$$

In every railway design, there is a maximum allowable cant deficiency CD_{max} to ensure that trains do not derail and skid outwards.

The CD_{max} for common railway systems in the world are shown in Fig. 6.2.

type of railway	**rail gauge, w / mm**	**maximum allowable cant deficiency, CD_{max} / mm**
A	1435	110
B	1524	125
C	1668	135

Fig. 6.2

(a) A train is turning on a banked track at balance speed v_o.

(i) Explain why the train has an acceleration despite moving at a constant speed.

....

.... [1]

(ii) With reference to Fig. 6.1, show that the angle θ is related to the cant E and rail gauge w by the expression

$$\tan\theta = \frac{E}{\sqrt{\left(w^2 - E^2\right)}}$$

[1]

(iii) Show that the balance speed v_0 for the train is

$$v_0 = \left(\frac{Erg}{\sqrt{w^2 - E^2}}\right)^{\frac{1}{2}}$$

where r is the radius of curvature of the track and g is the acceleration due to gravity.

[2]

(b) A passenger train that runs on a type A railway system travels around a bend with a cant of 95 mm and a radius of curvature of 1500 m.

(i) Suggest why passenger trains travel at a higher speed compared to freight trains.

....

.... [1]

(ii) Using Fig. 6.2 and the equation in **(a)(iii)**, determine the maximum speed that the passenger train can travel.

maximum speed = ... $m\ s^{-1}$ [3]

(iii) A luggage bag of mass 19.6 kg sits on the train carriage when it is turning at 150 $km\ h^{-1}$. Fig. 6.3 shows the frictional force between the luggage bag and the carriage floor.

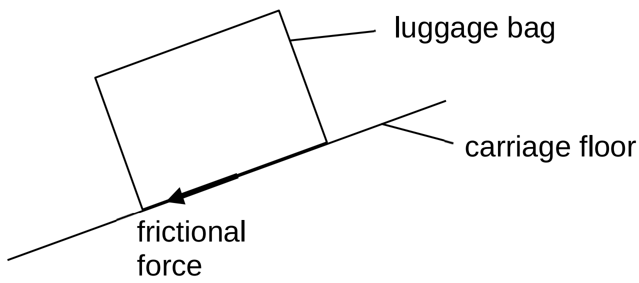

Fig. 6.3

1. On Fig. 6.3, draw and label arrows to show the other forces acting on the luggage bag.

[1]

2. Show that the centripetal force acting on the luggage bag is 23 N.

[1]

3. Show that the carriage floor is tilted at an angle of 3.8° with the horizontal.

[1]

4. The maximum friction between the bag and the carriage floor is 20 N.

Determine whether the luggage will slide when the train is turning.

[4]

(c) Another safety consideration for a train going around a bend is to ensure that both train wheels are constantly in contact with the rails. Otherwise, the train might derail.

As the wheels on each side of the train are connected by an axle, they always rotate at the same angular speed when the train is moving. When the train goes around a bend, the outer rail traces a slightly longer arc length than the inner rail, as shown in Fig. 6.4.

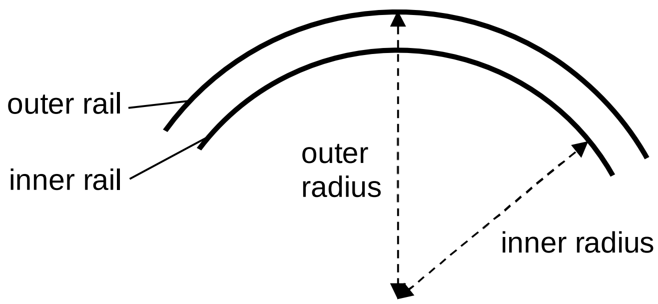

Fig. 6.4

This creates a problem as the outer wheel needs to cover more distance than the inner wheel. To overcome this problem, train wheels are designed to be slightly conical. When the train turns, it will move outward such that the effective diameter of the outer wheel becomes D_o and the effective diameter of the inner wheel becomes D_i where $D_o > D_i$ as shown in Fig. 8.5.

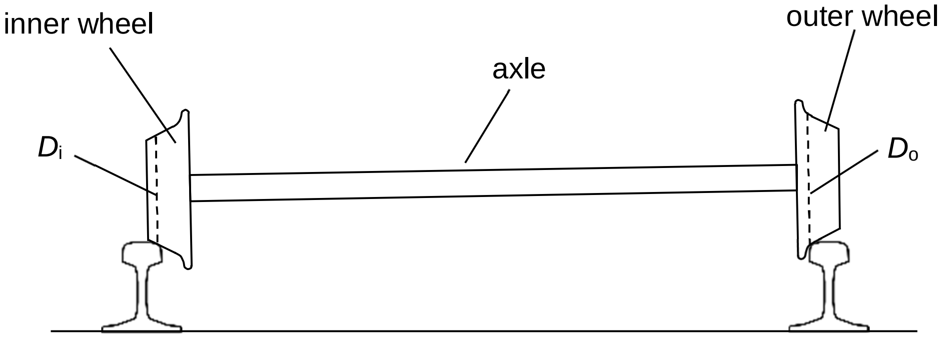

Fig. 6.5

(i) Explain how the conical shape of the wheels allows trains to stay in contact with the rails when going around a bend.

....

.... [1]

(ii) On a particular bend along a type B railway on level ground, the inner rail has a radius of 200 m and D_i is 1150 mm.

Determine D_o for the train to stay on track while turning.

D_o = ... m [2]

(d) Generally, train systems can run on ground level, elevated or underground.

Suggest one advantage of a train system that runs

(i) on ground level

....

.... [1]

(ii) underground.

....

.... [1]

Section B

Answer ONE question from this section

7 **(a)** A cell of e.m.f. 6.0 V and internal resistance *r* is connected in series with a fixed resistor S and a variable resistor as shown in Fig. 7.1. Voltmeter X is connected across the cell while voltmeter Y is connected across the variable resistor.

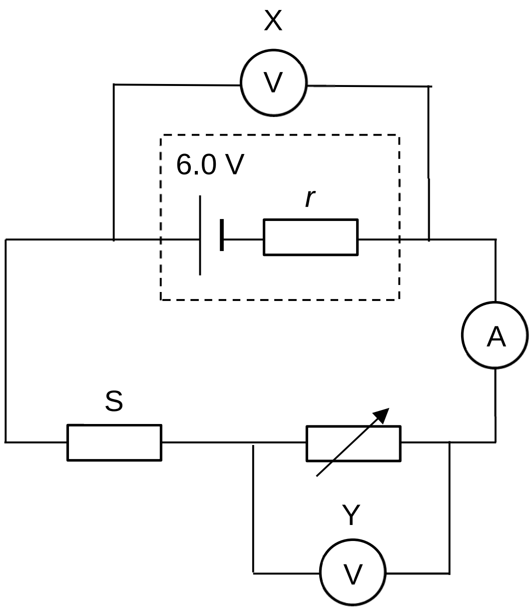

Fig. 7.1

(i) State what is meant by *resistance* of a resistor.

....

.... [1]

(ii) The resistance of the variable resistor is varied and the variations of the readings *V* on voltmeters X and Y with the reading *I* on the ammeter are shown in Fig. 7.2.

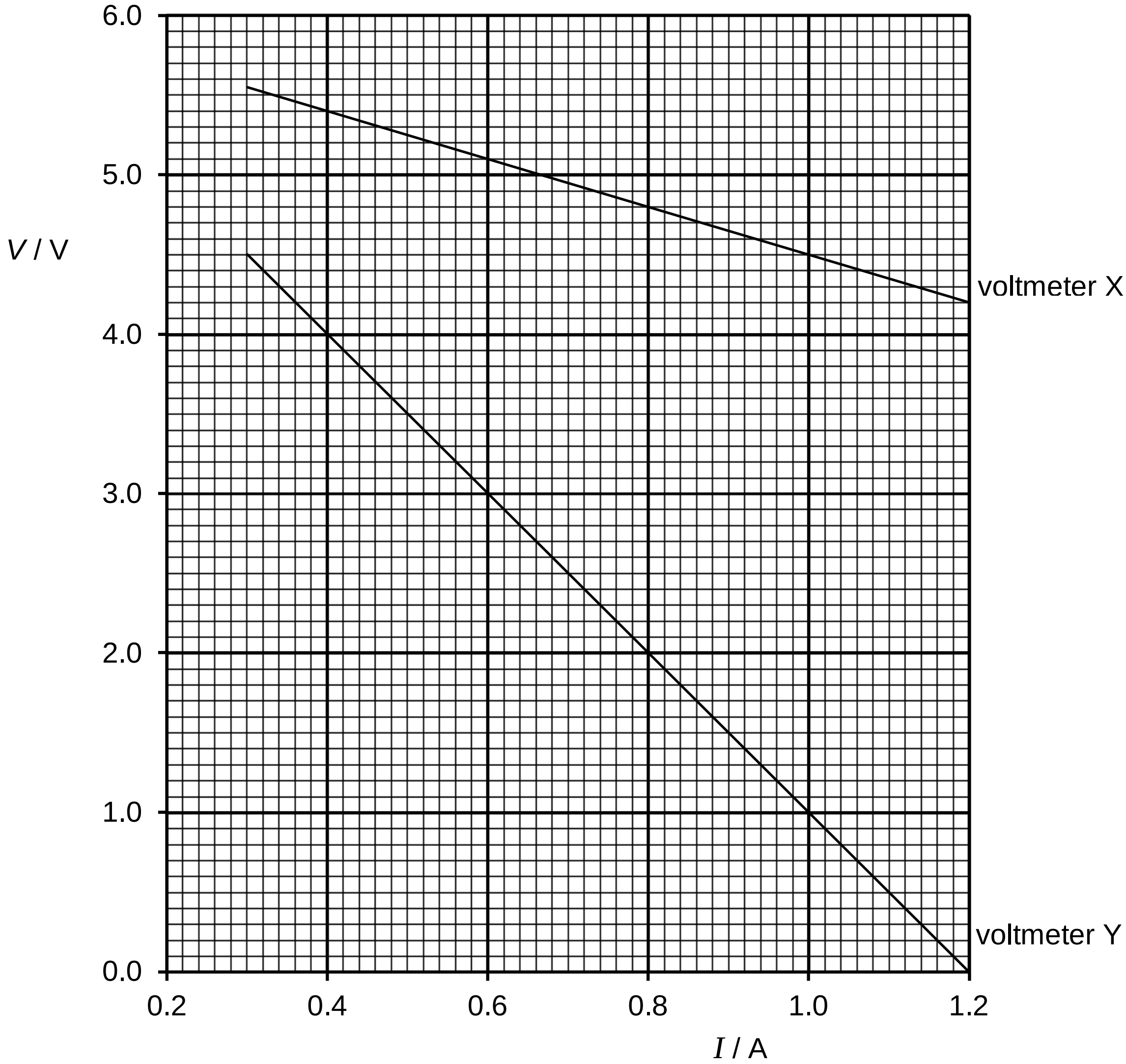

Fig. 7.2

1. Determine the internal resistance *r* of the cell.

r = ... Ω [2]

2. Show that the resistance of resistor S is 3.5 Ω.

[2]

(iii) Explain why the current in the circult cannot fall below 0.30 A.

....

.... [1]

(iv) The variable resistor is adjusted such that the reading on voltmeter X is 5.25 V.

Calculate the power dissipated in the variable resistor.

power = ... W [2]

(v) **1.** On Fig. 7.2, draw a graph of the variation of the potential difference across resistor S with I.

Label this graph Z.

[1]

2. Hence or otherwise, state the value of I when the potential difference across resistor S and the potential difference across the variable resistor are equal.

I = ... A [1]

(b) The circuit in Fig. 7.3 shows a thermistor connected in series to a 200 Ω resistor and a 12 V battery of negligible internal resistance. Fig. 7.4 shows how the resistance R_{th} of the thermistor varies with temperature.

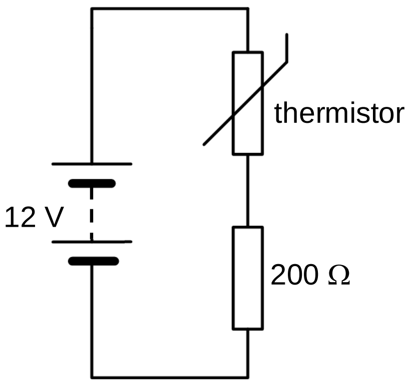

Fig. 7.3

Fig. 7.4

(i) Calculate the current in the circuit when the temperature is 25 ºC

current = ... A [2]

(ii) Calculate the potential difference across the thermistor at 25 ºC

potential difference = ... V [2]

(iii) Without further calculation, explain how the potential difference across the thermistor changes as the temperature increases from 25 ºC.

....

.... [1]

(iv) The circuit in Fig. 7.3 is modified by removing the 200 Ω resistor to give the circuit shown in Fig. 7.5. The temperature of the thermistor is increased at a steady rate from 25 ºC to 45 ºC in 10 minutes.

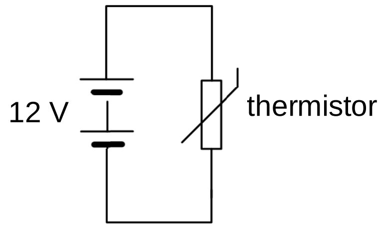

Fig. 7.5

1. Calculate the power dissipated in the thermistor at 25 ºC and at 45 ºC

power dissipated at 25 ºC = ... W

power dissipated at 45 ºC = ... W [2]

2. By taking the average of your answers in **(b)(iv)1.**, calculate an approximate value of the energy supplied by the battery during the period in which the temperature of the thermistor increases.

energy = ... J [2]

(v) Explain why the energy determined in **(b)(iv)2.** is only an estimate.

....

.... [1]

[Total: 20]

8 **(a)** **(i)** The nuclear binding energy **per nucleon** varies with nucleon number.

On Fig. 8.1, sketch a graph showing this variation for nucleon number from 1 to 250. Label the nucleon number axis with appropriate values.

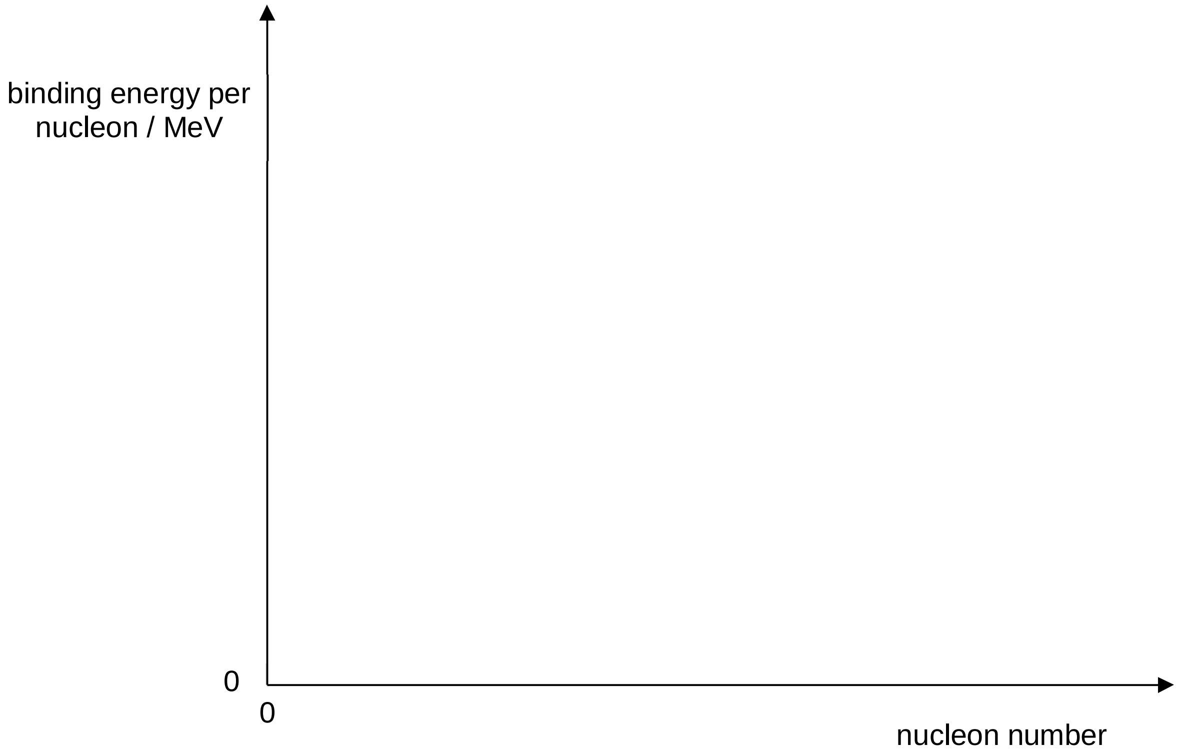

Fig. 8.1

[2]

(ii) Explain the significance of the nuclear binding energy per nucleon for nuclear fusion.

....

....

....

.... [2]

(b) With current technology, the most feasible fusion reaction as a large-scale and carbon-free source of energy is to fuse two isotopes of hydrogen, deuterium ${}^{2}_{1}\mathrm{H}$ and tritium ${}^{3}_{1}\mathrm{H}$. This fusion reaction may be represented by the equation

$${}^{3}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n}$$

In one particular reaction, the deuterium nuclide and the tritium nuclide have momentum of the same magnitude and collide head-on. The deuterium nuclide and tritium nuclide have kinetic energies of 24 keV and 16 keV respectively.

Data for the reaction are:

binding energy per nucleon of ${}^{2}_{1}\mathrm{H}$ = 1.1123 MeV
binding energy per nucleon of ${}^{3}_{1}\mathrm{H}$ = 2.8273 MeV
binding energy per nucleon of ${}^{4}_{2}\mathrm{He}$ = 7.0739 MeV
mass of ${}^{4}_{2}\mathrm{He}$ = 4.0026 u
mass of ${}^{1}_{0}\mathrm{n}$ = 1.0087 u.

(i) State three quantities that are conserved in nuclear reactions.

1. ....

2. ....

3. .... [3]

(ii) Calculate the kinetic energy of the neutron.

kinetic energy = ... MeV [5]

(c) Radioactive decay is a random and spontaneous process.

Explain what is meant by:

(i) random decay: ....

.... [1]

(ii) spontaneous decay: ....

.... [1]

(d) Fig. 8.2 shows apparatus used to determine the half-life of a radioactive source. The source emits both alpha particles and gamma rays and is placed 20 cm from a detector that can detect all types of radiation. The detector is connected to a counter.

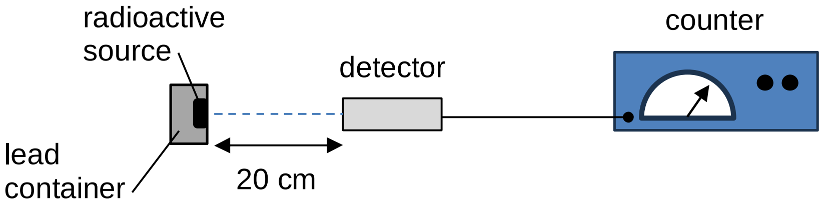

Fig. 8.2

(i) Explain why alpha particles emitted from the source are not able to arrive at the detector.

....

.... [1]

(ii) Without the source, the counter gives a count-rate of 18 min^{-1}.

When the source is placed 20 cm from the detector, the count rates at two different times *t* are shown in Table 8.1.

Table 8.1

t / h	count-rate / min^{-1}
0	6659
6.0	1051

Determine the half-life of the radioactive source.

half-life = ... h [3]

(iii) Explain how the half-life of the radioactive source for alpha decay may be determined.

....

....

....

.... [2]

[Total: 20]