# TEMASEK JUNIOR COLLEGE
## 2023 JC2 Preliminary Examination
## Higher 2

NAME

CG

# PHYSICS 9749/02

Paper 2 Structured Questions

**25 August 2023**

**2 hours**

**READ THESE INSTRUCTIONS FIRST**

Write your name and civics group 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.

Answer **all** questions

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

| For Examiner's Use | |
|---|---|
| **1** | |
| **2** | |
| **3** | |
| **4** | |
| **5** | |
| **6** | |
| **7** | |
| **8** | |
| **s.f** | |
| **Total** | |

## Data

| | | | |
|---|---|---|---|
| speed of light in free space | $c$ | = | $3.00 \times 10^{8}$ m s$^{-1}$ |
| permeability of free space | $\mu_o$ | = | $4\pi \times 10^{-7}$ H m$^{-1}$ |
| permittivity of free space | $\varepsilon_o$ | = | $8.85 \times 10^{-12}$ F m$^{-1}$ or $(1/(36\pi)) \times 10^{-9}$ F m$^{-1}$ |
| elementary charge | $e$ | = | $1.60 \times 10^{-19}$ C |
| the Planck constant | $h$ | = | $6.63 \times 10^{-34}$ Js |
| 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 | $T$/K | = | $T$/°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. | $x$ | = | $x_o \sin\omega t$ |
| velocity of particle in s.h.m. | $v$ | = | $v_o \cos\omega t$ |
| | | = | $\pm\omega\sqrt{(x_o{}^2 - x^2)}$ |
| 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 | $V$ | = | $\frac{Q}{4\pi\varepsilon_o r}$ |
| alternating current/voltage | $x$ | = | $x_o \sin\omega t$ |
| magnetic flux density due to a long straight wire | $B$ | = | $\frac{\mu_o I}{2\pi d}$ |
| magnetic flux density due to a flat circular coil | $B$ | = | $\frac{\mu_o NI}{2r}$ |
| magnetic flux density due to a long solenoid | $B$ | = | $\mu_o nI$ |
| radioactive decay | $x$ | = | $x_0 \exp(-\lambda t)$ |
| decay constant | $\lambda$ | = | $\frac{\ln 2}{t_{1/2}}$ |

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Answer **all** the questions in the spaces provided.

**1** An experimental setup used to measure the acceleration of free fall is shown in Fig. 1.1.

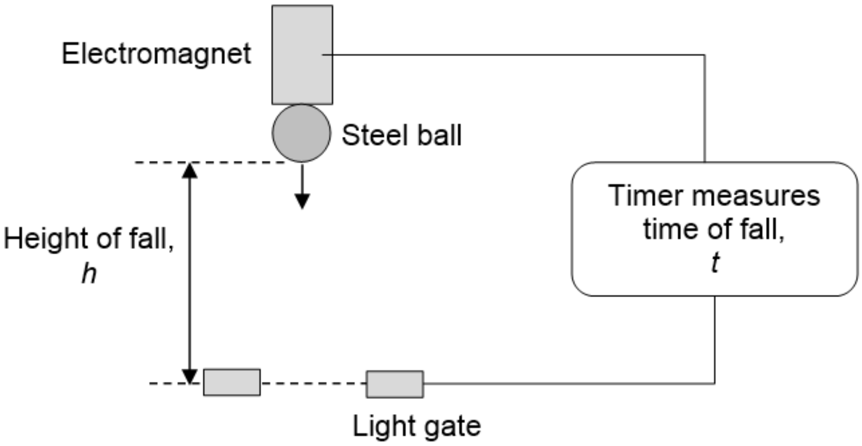


**Fig. 1.1**

The steel ball is suspended at the top by an electromagnet. The electronic timer starts when the electromagnet is turned off. As the steel ball falls by height $h$ and goes through the light gate, the timer stops and displays the time of fall, $t$.

Only one set of data was collected:

$$h = (0.600 \pm 0.001)\ \text{m}$$

$$t = (354 \pm 1)\ \text{ms}$$

**(a)** Determine the acceleration of free fall with its associated uncertainty.

acceleration = .......................... ± ........................ m s$^{-2}$ [3]



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**(b)** It was later found out that when the electromagnet was turned off, there is a constant delay before the steel ball starts falling.

**(i)** Suggest a cause for this delay.

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**(ii)** State and explain whether the type of error caused by this delay is random or systematic.

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**(iii)** Suggest how this delay can be determined.

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[Total: 8]



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**2** In a nuclear reactor, a fast moving neutron with initial speed $u_1$ makes a *head-on elastic* collision with a stationary nucleus of carbon-12. The speed of the neutron and the carbon nucleus after the collision are $v_1$ and $v_2$ respectively as shown in Fig. 2.1.

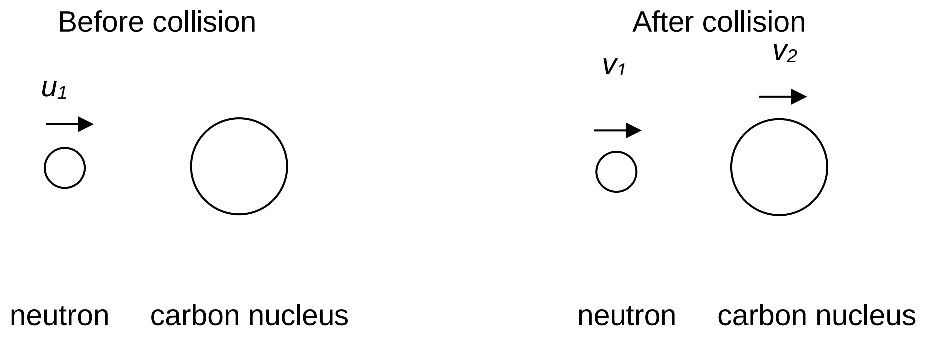


**Fig 2.1**

**(a)** Explain what is meant by *head-on* and *elastic*.

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**(b)** In an elastic collision, the relative speed of separation is equal to the relative speed of approach.

Write an equation in terms of the velocities given to illustrate this fact.

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**(c)** For the collision, determine the ratio of the speeds $\frac{v_1}{u_1}$ of the neutron.

ratio = ................................... [3]



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**(d)** Hence determine the fraction of the kinetic energy of the neutron that is transferred to the carbon nucleus.

fraction = .................................... [2]

**(e)** If the *head-on elastic* collision is with a stationary neutron instead of carbon-12, explain how would the answers in part **(c)** and **(d)** be different. In your explanation, state the new ratio of the speeds and the new fraction of the kinetic energy transferred.

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[Total: 10]

3 **(a)** Define *work done*.

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**(b)** A trolley of mass 400 g is moving at a constant speed of 2.5 m s$^{-1}$ to the right as shown in Fig. 3.1.

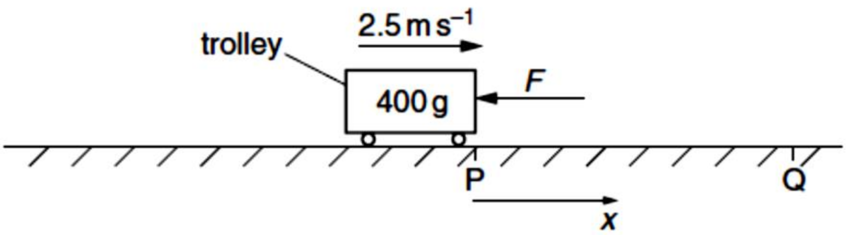


**Fig. 3.1**

A variable force *F* acts to the left on the trolley as it moves between points P and Q. The variation of *F* with displacement *x* from P is shown in Fig. 3.2.

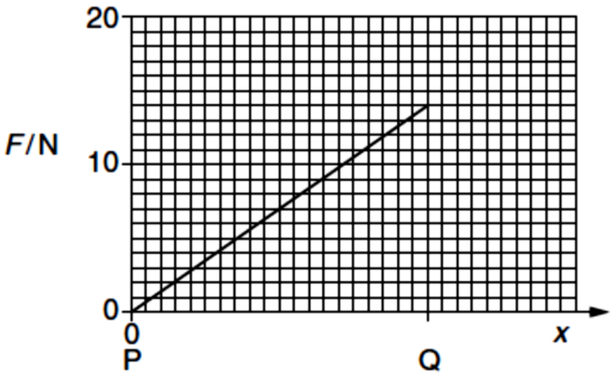


**Fig. 3.2**

The trolley comes to rest at point Q.

**(i)** Calculate the distance PQ.

distance = .................................................. m [2]

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**(ii)** On Fig. 3.3, sketch the variation with *x* of the work done on trolley by *F*. Indicate on your sketch the maximum value of the work done by *F*.

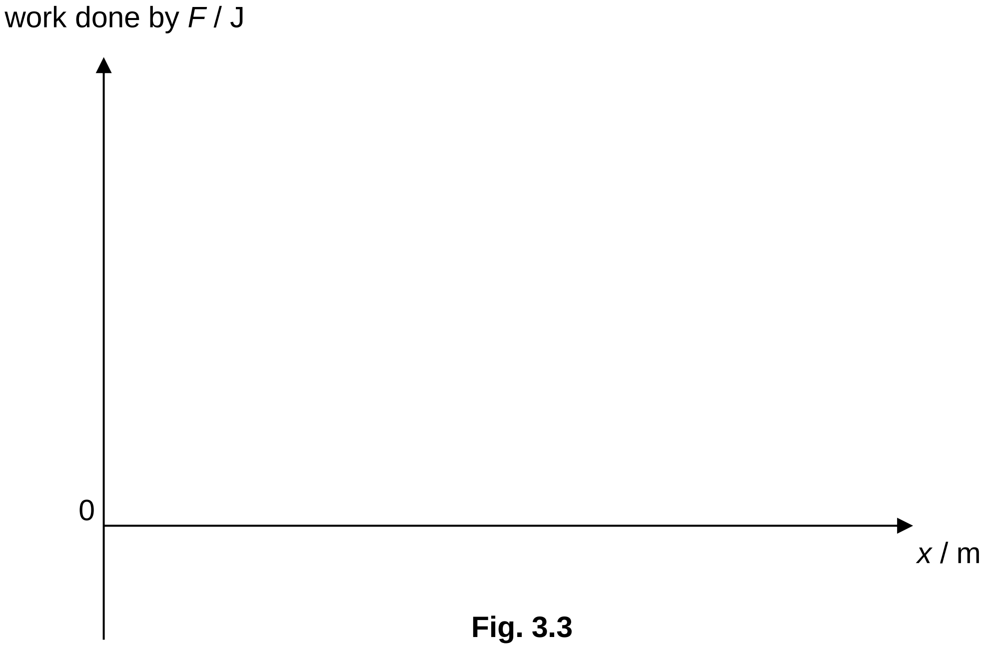


**Fig. 3.3**

[2]

**(iii)** In order to maintain a constant speed of 2.5 m $s^{-1}$, an electric motor attached to the trolley is switched on.

On Fig. 3.4, sketch the variation with *x* of the power supplied by motor while the trolley moves from point P to Q. No numerical value is required.

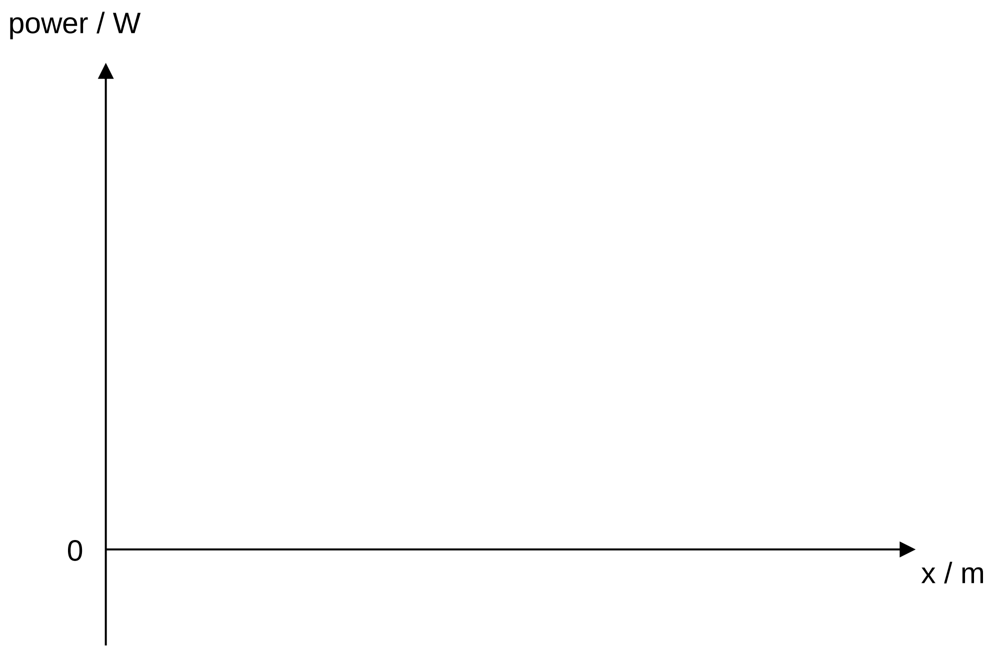


**Fig. 3.4**

[1]

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4 **(a)** Use Newton's laws of motion to explain why a body moving with uniform speed in a circle must experience a force towards the centre of the circle.

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**(b)** A massless spring of force constant $k$ = 78.4 N m$^{-1}$ is fixed on the left side of a level track. A block of mass $m$ = 0.50 kg is pressed against the spring and compresses it by a distance $d$ as shown in Fig. 4.1. The block is then released from rest and travels toward a circular loop-the-loop of radius $R$ = 1.5 m.

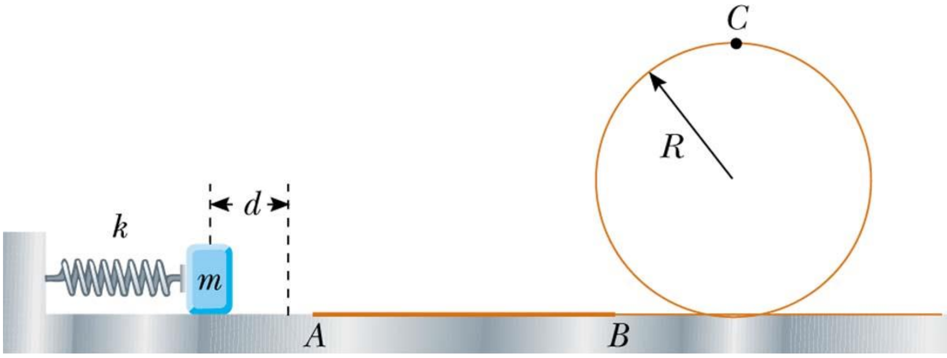


**Fig. 4.1**

The entire track and the loop-the-loop are frictionless except for the section of track between points **A** and **B**.

The friction between the block and the track along **AB** is 1.47 N and the length of **AB** is 2.5 m.

**(i)** Calculate the minimum speed $v_{min}$ at C such that the mass remains in contact at point C.

$v_{min}$ = .................................................. m s$^{-1}$ [2]

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**(ii)** Determine the minimum compression $d$ of the spring that enables the block to just complete the vertical circle without falling off the track at **C**.

compression = .................................................... m [2]

**(c)** The block is moving with minimum speed $v_{min}$ at point **C**. State and explain how $v_{min}$ changes when the block is replaced with one with a lower mass.

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[Total: 8]



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**5** To simulate the motion of a boat in rough seas, a block of mass 10 kg is forced to oscillate by means of water waves created by a vibrating wooden plank as shown in Fig. 5.1.

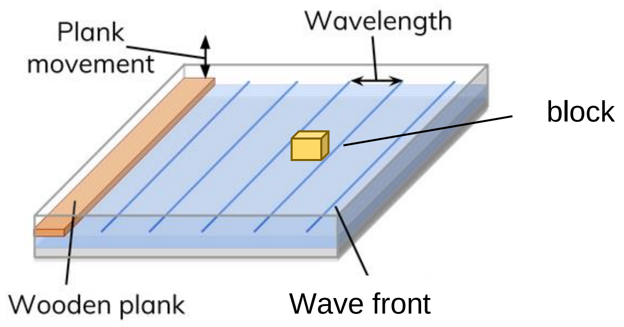


**Fig. 5.1**

At one particular wavelength setting, the depth $h$ of the block as measured from *below* the water surface to the base of the block shown in Fig. 5.2, is plotted against time $t$ in Fig. 5.3.


**Fig. 5.2**

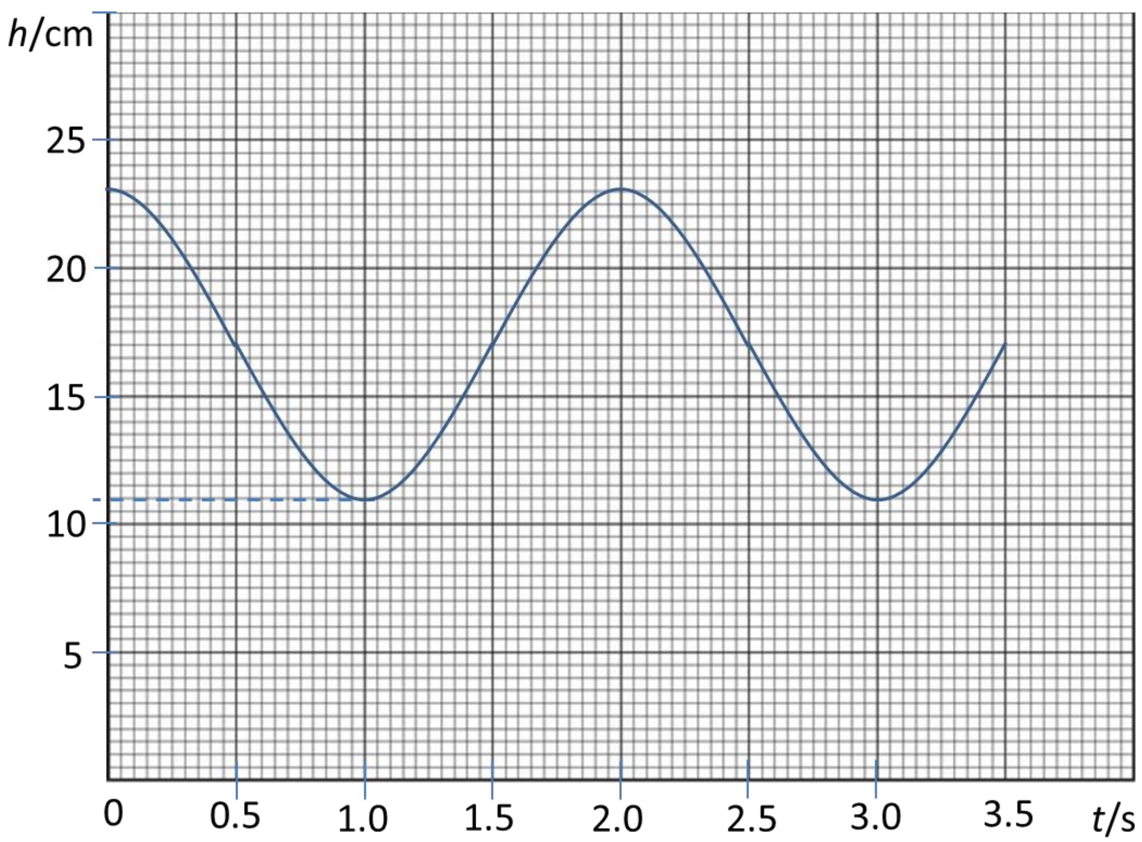


**Fig. 5.3**

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**(a)** Distinguish between *free* and *forced oscillations.*

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(b) Determine the amplitude of the oscillation of the block.

amplitude = ................................................ m [1]

**(c)** Determine the angular frequency of the oscillation.

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

**(d)** Hence or otherwise, calculate the total energy of the oscillation.

total energy = ................................................ J [2]

**(e)** A small quantity of sand is placed onto the top of the plank. Initially the sand remains in contact with the plank as it oscillates. The amplitude of vibration of the plank is gradually increased.

Determine the minimum amplitude of an oscillation with the same angular frequency as **(c)** that would cause the sand to lose contact with the plank.

amplitude = .......................................... m [2]

[Total: 8]

**6** **(a)** A circuit is set up as shown in Fig. 6.1.

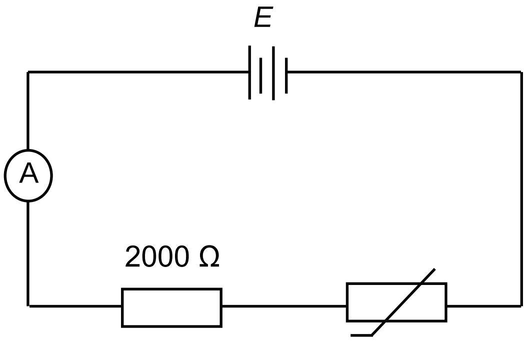


**Fig. 6.1**

The battery source of emf $E$ is found to provide 2.4 x $10^5$ J of electrical energy to the 2000 Ω resistor and thermistor when a charge of 2.2 x $10^4$ C passes through the ammeter. At room temperature, the thermistor has a resistance of 1800 Ω.

**(i)** For the thermistor at room temperature,

**1.** show that $E$ is 11 V.

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[1]

**2.** determine the time taken for a charge of 2.2 x $10^4$ C to pass through the ammeter.

time = .............................................s [2]

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3. determine the fraction of power dissipated in the thermistor.

fraction = ............................................ [2]

**(b)** The circuit shown in Fig. 6.3 is used to compare potential differences.

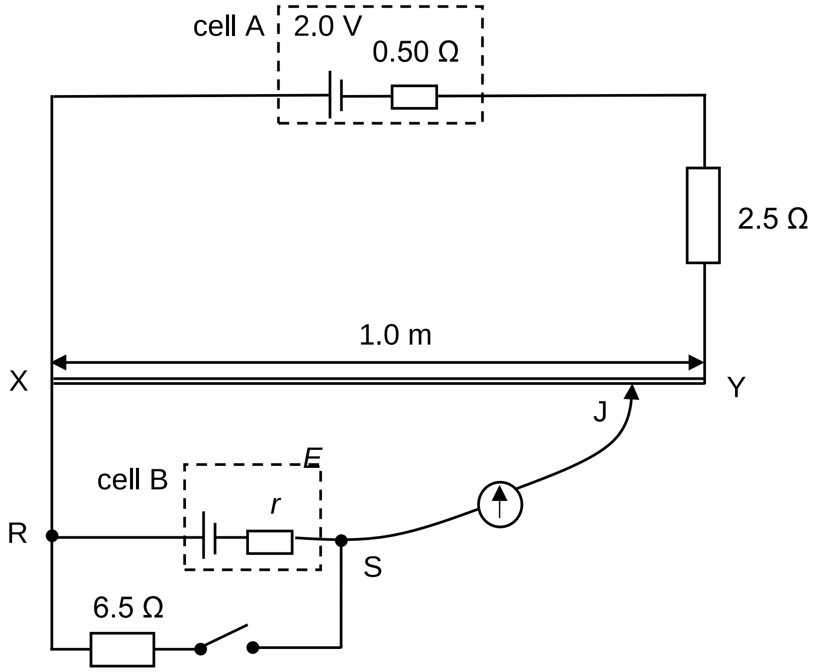


**Fig. 6.3**

The uniform resistance wire XY has length 1.0 m and resistance 8.0 Ω. Cell A has e.m.f. 2.0 V and internal resistance 0.50 Ω. Cell B has e.m.f. *E* and internal resistance *r*.

**(i)** The switch is opened. The galvanometer shows no deflection when the moveable contact J is adjusted so that the length XJ is 0.90 m.

Show that the e.m.f. *E* of cell B is 1.3 V.

[2]

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**(ii)** The switch is now closed.

**1.** For the galvanometer to show no deflection, contact J has to be adjusted so that length XJ is 0.75 m.

Determine the internal resistance *r* of cell B

r = .............................................Ω [3]

**2.** A resistor is connected in parallel with the 6.5 Ω resistor.

Deduce how the balanced length XJ would be affected.

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**7** **(a)** A particle has mass *m*, charge +*q* and speed *v*.

State the magnitude and direction of the force, if any, on the particle when the particle is travelling along the direction of

**(i)** a uniform electric field of field strength *E*,

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**(ii)** a uniform magnetic field of flux density *B*.

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**(b)** Two charged horizontal metal plates, situated in a vacuum, produce a uniform electric field of field strength *E* between the plates. The field strength outside the region between the plates is zero.

The particle in **(a)** enters the region of the electric field at right-angles to the direction of the field, as illustrated in Fig. 7.1.

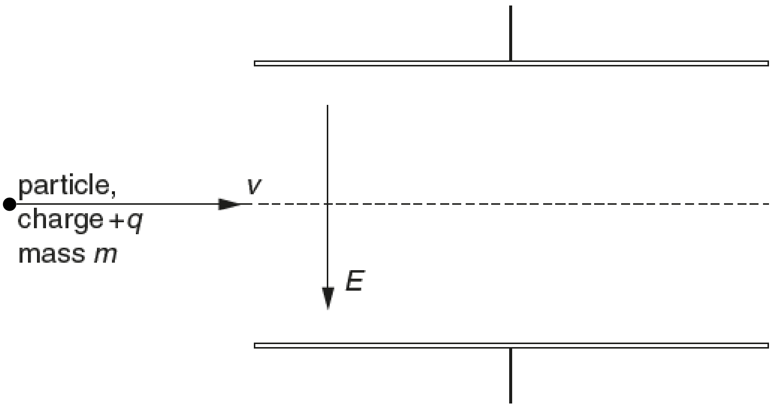


**Fig. 7.1**

A uniform magnetic field is applied in the same region as the electric field so that the particle passes undeviated through the region between the plates.

**(i)** State the direction of the magnetic field.

.................................................................................................................................... [1]

**(ii)** Derive, with clear explanation, an expression for the speed $v$ in terms of the magnitudes of the electric field strength $E$ and the magnetic flux density $B$.

[2]

**(c)** The same particle in (a) now enters a non-uniform magnetic field $B$ at an angle $\theta$ with the horizontal as shown in Fig. 7.2.

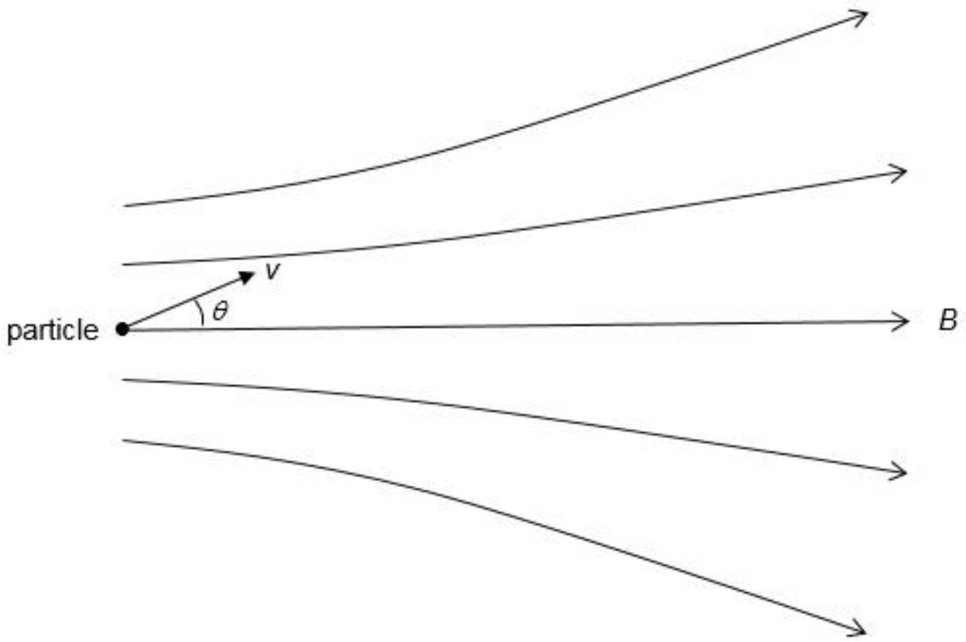


**Fig. 7.2**

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**(i)** By considering the components of the velocity parallel to and at right angles to the magnetic field, explain the subsequent motion of the charged particle in the field.

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**(ii)** Draw a sketch, in Fig. 7.2, to illustrate the path. [1]

[Total: 10]

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**8** Artificial pacemakers can be used to stimulate the heart when the patient's own pacemaker is faulty. These artificial pacemakers need to contain an electrical power source and timing circuits to control the beat. Since these pacemakers need to be implanted within the patient's body, the batteries that power them must be both long-lasting and safe.

Atomic powered batteries contain a radioisotope and can provide appropriate power sources for these devices. The casing of the unit needs to prevent irradiation of the surrounding area. In one design a thermal converter uses the energy of radioactive decay to heat thermocouples which produce electricity.

The selection of a suitable radioisotope for the battery in a pacemaker is crucial. Critical issues are the avoidance of isotopes that include gamma emitters in their decay chains and the choice of an isotope with a long half-life. Beta emitters are used more often than alpha emitters because an alpha particle can sometimes lead to neutron production when it is absorbed. Low energy beta emissions are preferred because high energy particles can produce gamma radiation that would necessitate shielding. Fig. 8.1 gives data for some of the useable isotopes.

| Isotope | Mode of decay | Energy released per decay/ keV | Half life/year | Activity of 1 g of isotope/$10^{12}$ Bq |
|---|---|---|---|---|
| Nickel-63 | $\beta^-$ | 70 | 100 | 2.1 |
| Hydrogen-3 | $\beta^-$ | 19 | 12 | 3600 |
| Strontium-90 | $\beta^-$ | 550 | 29 | 5.2 |
| Polonium-210 | $\alpha$ | 5400 | 0.38 | 1700 |
| Plutonium-238 | $\alpha$ | 5600 | 88 | 0.63 |
| Curium-244 | $\alpha$ | 5900 | 18 | 3.0 |

**Fig. 8.1**

The early atomic batteries for pacemakers each contained 0.16 g of Plutonium-238. This battery produced an average electrical power output of 0.75 mW when new. Use of this type of battery was discontinued and replaced by a more suitable alternative source.

**(a)** **(i)** Define *activity* of an radioisotope.

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**(ii)** Calculate the decay constant of Plutonium-238.

decay constant = ...................................................... $s^{-1}$ [2]

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**(iii)** Show that the initial number of atoms in 0.16 g of plutonium source in the early atomic battery is approximately $4 \times 10^{20}$.

[2]

**(b)** **(i)** Calculate the energy released per second by the radioactive decay of the plutonium when the battery is new.

energy per second = .................................................... J [3]

**(ii)** Calculate the efficiency of the battery.

efficiency = .................................................... % [2]

**(c)** Calculate the maximum life-span, in s, of the battery if the power output should not be allowed to fall below 0.60 mW.

maximum life-span = .................................................... s [2]

**(d)** If a pacemaker delivers 0.68 mW of energy to a 6.7 g of tissue which has a specific heat capacity of 410 J $kg^{-1}$ $K^{-1}$, calculate the temperature rise in the first 12 hours after insertion of the pacemaker, assuming that there are no other energy losses.

rise in temperature = ........................................................ °C [2]

**(e)** According to the passage, alpha particle can sometimes lead to neutron production. Explain the risk posed by neutron production and hence suggest why it would be useful to investigate the decay chain from an isotope before making a selection.

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**(f)** Inspect the data in Fig. 8.1 and select an alternative choice for an isotope for use in an atomic battery designed for pacemakers. Explain your choice.

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