H2

MINISTRY OF EDUCATION, SINGAPORE
in collaboration with
CAMBRIDGE INTERNATIONAL EDUCATION
General Certificate of Education Advanced Level

CANDIDATE NAME	

CENTRE NUMBER	S					INDEX NUMBER					

0123456789

PHYSICS **9478/02**

Paper 2 Structured Questions **For examination from 2026**

SPECIMEN PAPER **2 hours**

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and index number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen. Do **not** use correction fluid or tape.
- Do **not** write on any bar codes.
- You may use an approved calculator.

INFORMATION

- The total mark for this paper is 75.
- The number of marks for each question or part question is shown in brackets [ ].

This document has **24** pages. Any blank pages are indicated.

Singapore Examinations and Assessment Board

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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	$\varepsilon_0 = 8.85 \times 10^{-12}\,\mathrm{F\,m^{-1}}$
	$(\frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9}\,\mathrm{m\,F^{-1}})$
elementary charge	$e = 1.60 \times 10^{-19}\,\mathrm{C}$
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	$R = 8.31\,\mathrm{J\,K^{-1}\,mol^{-1}}$
Avogadro constant	$N_A = 6.02 \times 10^{23}\,\mathrm{mol^{-1}}$
Boltzmann constant	$k = 1.38 \times 10^{-23}\,\mathrm{J\,K^{-1}}$
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	$s = ut + \frac{1}{2}at^2$
	$v^2 = u^2 + 2as$
work done on / by a gas	$W = p\Delta V$
pressure	$p = \frac{F}{A}$
gravitational potential	$\phi = -\frac{GM}{r}$
temperature	$T/\mathrm{K} = T/{}^{\circ}\mathrm{C} + 273.15$
pressure of an ideal gas	$p = \frac{1}{3}\frac{Nm}{V}\langle c^2\rangle$
mean translational kinetic energy of an ideal gas particle	$E = \frac{3}{2}kT$

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	$I = nAvq$
resistors in series	$R = R_1 + R_2 + \ldots$
resistors in parallel	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$
capacitors in series	$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$
capacitors in parallel	$C = C_1 + C_2 + \ldots$
energy in a capacitor	$U = \frac{1}{2}QV = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}CV^2$
charging a capacitor	$Q = Q_0\left[1 - e^{-\frac{t}{\tau}}\right]$
discharging a capacitor	$Q = Q_0\, e^{-\frac{t}{\tau}}$
RC time constant	$\tau = RC$
electric potential	$V = \frac{Q}{4\pi\varepsilon_0 r}$
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	$B = \frac{\mu_0 N I}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_0 n I$
energy states for quantum particle in a box	$E_n = \frac{h^2}{8mL^2} n^2$
radioactive decay	$x = x_0 e^{-\lambda t}$
radioactive decay constant	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

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

1 **(a)** A block is held at rest at point A on a frictionless ramp inclined at an angle θ to the horizontal, as shown in Figure 1.1.

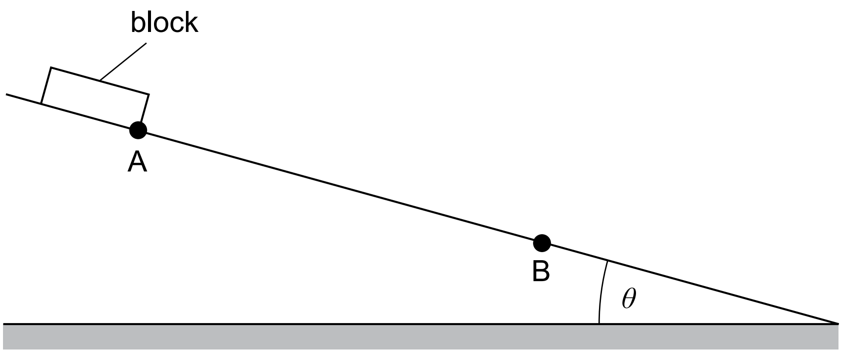

Figure 1.1

The block is released and slides down the slope.

Data for the motion of the block as it moves from point A to point B are shown in Table 1.1.

Table 1.1

distance moved / m	**time taken / s**
0.80 ± 0.01	0.64 ± 0.02

(i) Calculate the acceleration *a* of the block down the slope.

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

(ii) Determine the percentage uncertainty in the value of *a* calculated in **1(a)(i)**.

percentage uncertainty = ...% [1]

(iii) Use your answers in **1(a)(i)** and **1(a)(ii)** to determine the value of *a*, with its absolute uncertainty, to an appropriate number of significant figures.

a = ... ± .... $m\,s^{-2}$ [2]

(iv) Show that the speed of the block at point B is $2.5\,m\,s^{-1}$.

[1]

(b) A barrier is now fixed at point B, as shown in Figure 1.2.

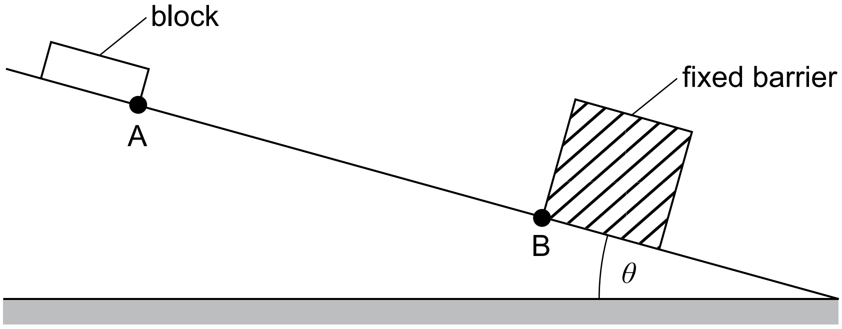

Figure 1.2

The block is released from rest at point A and slides down the ramp.

The block collides with the barrier at point B. The block bounces back off the barrier and moves up the ramp with an initial speed of $1.8\,\mathrm{m\,s^{-1}}$.

The block has a mass of 350 g and is in contact with the barrier for a time of 0.060 s.

(i) Explain whether the collision between the block and the barrier is elastic or inelastic.

....

.... [1]

(ii) Calculate the magnitude of the average force F_{av} between the block and the barrier while they are in contact.

F_{av} = ... N [3]

(iii) Explain whether momentum is conserved in this collision.

....

....

.... [1]

[Total: 10]

Turn over

2 A hot air balloon contains a fixed mass of air that expands on heating, as illustrated in Figure 2.1.

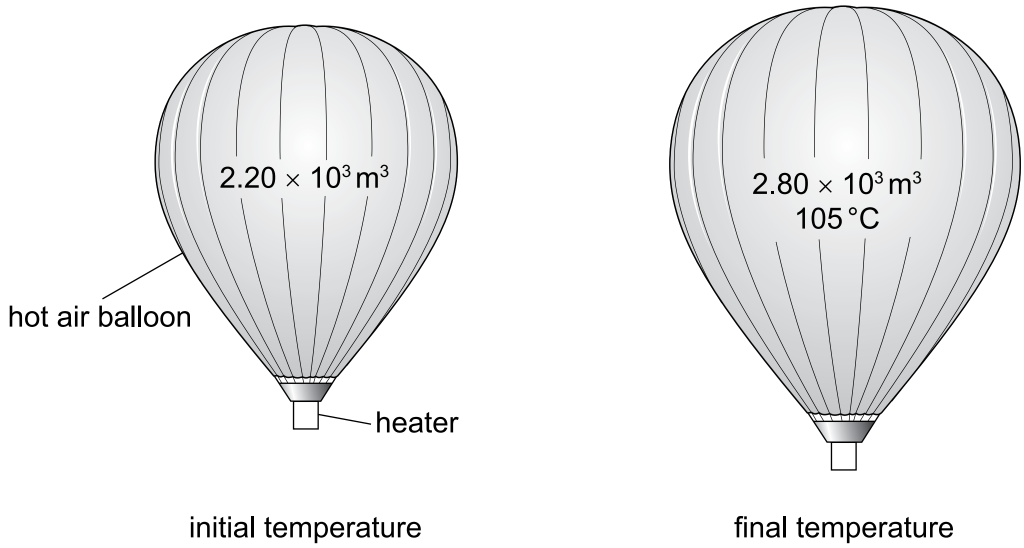

Figure 2.1

The air inside the balloon is heated to a final temperature of 105 °C and the balloon expands in volume at atmospheric pressure from $2.20 \times 10^3\,m^3$ to $2.80 \times 10^3\,m^3$. At this final temperature, the balloon is fully inflated.

Assume that the air inside the balloon is an ideal gas.

(a) Initially, before being heated, the air inside the balloon is in thermal equilibrium with the material from which the balloon is made. This material is in thermal equilibrium with the atmosphere.

(i) Calculate the initial temperature, in °C, of the air inside the balloon.

initial temperature = ... °C [2]

(ii) Explain what can be deduced about the initial temperature of the atmosphere from the zeroth law of thermodynamics.

....

....

.... [2]

(b) During the expansion, the internal energy of air inside the balloon increases by 116 MJ.

Atmospheric pressure is 1.01×10^5 Pa.

(i) Calculate the work done on the atmosphere by the expanding balloon.

work done = ... J [1]

(ii) Use the first law of thermodynamics to determine the thermal energy supplied to the air inside the balloon during the expansion. Explain your reasoning.

thermal energy = ... J [2]

(c) **(i)** State what is meant by the internal energy of a system.

....

....

.... [2]

(ii) Explain, with reference to the energy of particles, why the internal energy of the air inside the balloon increases during the expansion.

....

....

.... [2]

[Total: 11]

3 **(a)** Two waves travelling in opposite directions in the same medium meet and superpose.

State **two** conditions that must be met for an observable stationary wave to be formed.

1 ....

....

2 ....

....
[2]

(b) Figure 3.1 shows apparatus used to demonstrate a stationary sound wave.

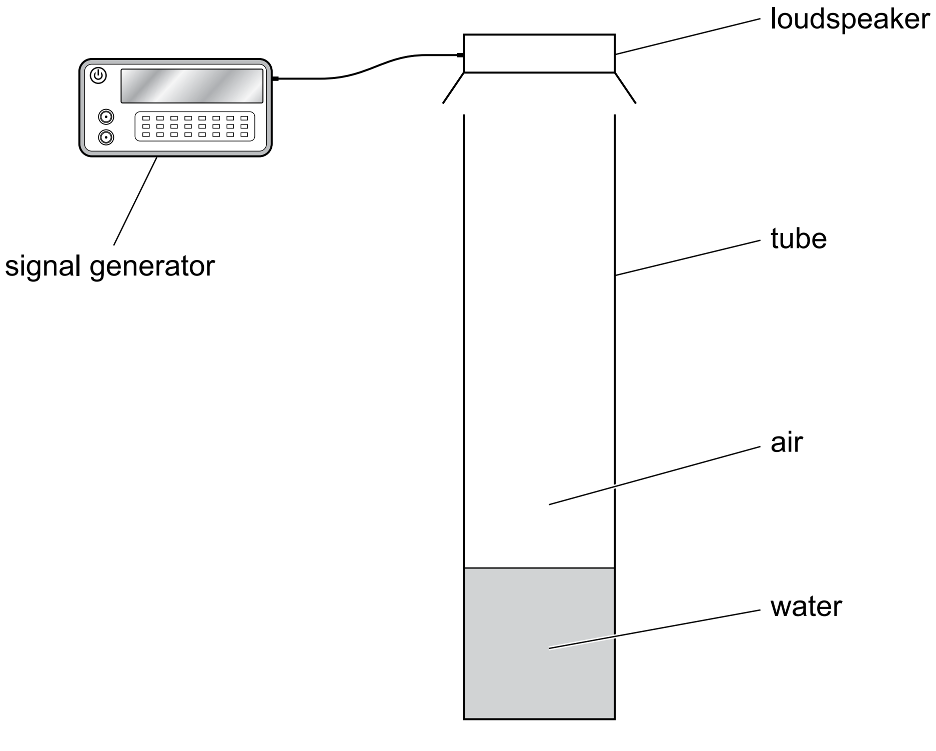

Figure 3.1

The frequency of the sound produced by the loudspeaker is set so that a stationary wave with the longest possible wavelength is formed in the air column in the tube.

(i) Describe the movement of the air particles at the top of the air column.

....

....

.... [2]

(ii) On Figure 3.2, label the position of a displacement node **DN** and the position of a pressure node **PN**.

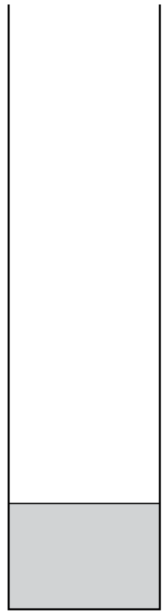

Figure 3.2

[2]

(iii) The length of the air column is 18 cm.

The frequency of the sound emitted by the loudspeaker is 490 Hz.

Calculate the speed of sound in the air column.

speed = ... $m\,s^{-1}$ [2]

[Total: 8]

4 **(a)** Define electric field strength.

....

.... [1]

(b) A charged metal sphere of mass 2.50×10^{-5} kg is suspended from a light, insulating thread so that it hangs midway between two vertical metal plates, as shown in Figure 4.1.

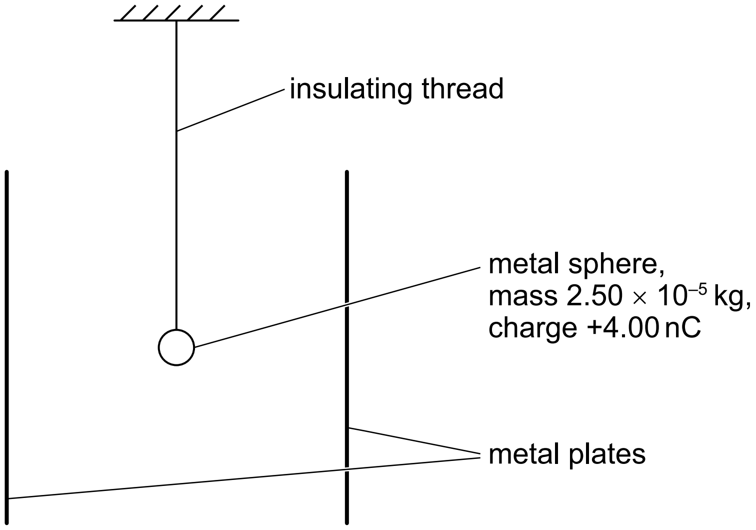

Figure 4.1

The charge on the sphere is +4.00 nC.

A potential difference (p.d.) of 5.70 kV is now applied across the plates such that the right-hand plate is at a higher potential than the left-hand plate. The left-hand plate is earthed.

(i) On Figure 4.2, draw a line representing the +3.80 kV equipotential due to the charged plates only (ignoring the charged sphere). Label your line **V**.

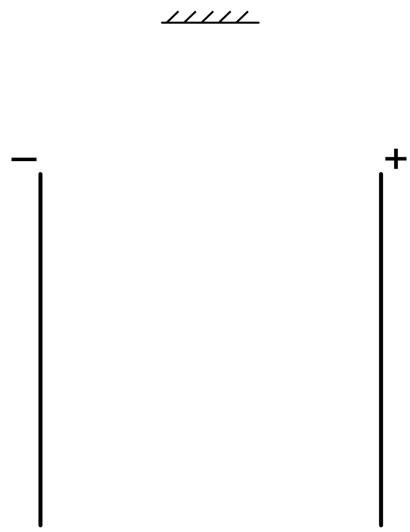

Figure 4.2

[2]

(ii) The applied p.d. causes the sphere to move to a new position. The sphere does not touch either plate.

On Figure 4.2, draw the new position of the charged sphere. [1]

(iii) The perpendicular distance between the plates is 2.00×10^{-1} m.

Calculate the electric field strength due to the applied p.d. in the region between the plates. Include the unit with your answer.

electric field strength = ... unit .... [3]

(iv) Determine the magnitude of the force exerted on the sphere by the electric field.

force = ... N [2]

(v) Use your answer in **4(b)(iv)** to determine the angle to the vertical of the thread.

angle = ... ° [2]

(c) It is found that, in practice, the actual angle of deflection of the thread in **4(b)** is different from the answer in **4(b)(v)**.

Suggest, with a reason, how the actual angle compares with the answer in **4(b)(v)**.

....

....

.... [2]

[Total: 13]

5 Two parallel wires X and Y have a separation of 0.12 m, as shown in Figure 5.1.

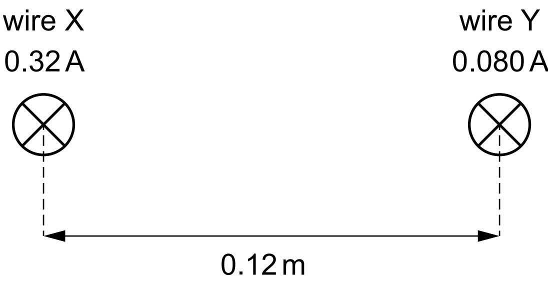

Figure 5.1

The current in wire X is 0.32 A and the current in wire Y is 0.080 A.

In both wires, the direction of the current is into the page.

(a) Determine the magnitude and direction of the resultant magnetic flux density at the midpoint between the two wires.

Explain your reasoning.

magnitude = ... T

direction = ...
[4]

(b) Explain the direction of the magnetic force exerted on wire X by wire Y.

....

....

.... [2]

[Total: 6]

6 The orbital electron in a hydrogen atom may be thought of as being trapped in an infinite square potential well such that the electron is confined to a region of width L, as shown in Figure 6.1.

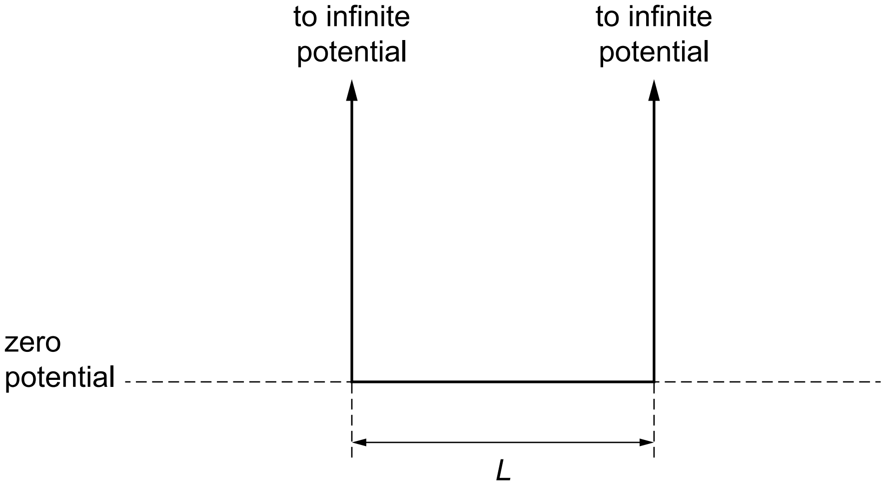

Figure 6.1

The electron is represented by a standing wave that has wavefunction ψ given by:

$$\psi = A \sin nkx$$

where x is the distance of the electron from the left-hand edge of the potential well, n is a non-zero integer and A and k are constants that depend on L.

(a) When n = 1, the electron is in its ground state.

(i) On Figure 6.1, draw the standing wave that represents the electron in its ground state. [1]

(ii) Use your answer in **6(a)(i)** to determine an expression for k in terms of L.

[2]

(b) **(i)** State what is represented by $|\psi|^2$.

....

.... [1]

(ii) Determine an expression for A. Show your working.

[2]

[Total: 6]

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

It has been announced that, by 2040, cars using an internal combustion engine (ICE) will be phased out in Singapore. All new cars after 2040 will be electric vehicles (EVs). In Singapore, a car typically travels 290 km a week. The average range of a car using an ICE is 800 km. The average cost to refuel an ICE car is S$80.

Some drivers in Singapore have concerns about this phasing out of ICE cars. EVs are more expensive to buy, the number of public charging points is at present very limited, the time to charge is substantial, and there are also environmental issues such as the recycling of old batteries. In addition, the range of an EV from one charge is not as great as the range of an ICE car using one tank of fuel.

Many of these concerns may be resolved by supply and demand. The price of EVs will decrease as the technology becomes more mainstream. It is predicted that, long before 2040, the cost of owning an EV will become the same as that of owning an ICE car. Once there is a market for public charging points, more will be installed. The number of public charging points in Singapore should increase from about 1600 to 28 000 over the next ten years.

Table 7.1 shows data for an EV that is typical of those that are currently available on the market.

Table 7.1

battery capacity	72 kW h
range	400 km
time to accelerate 0–100 km h^{-1}	7.6 s
total mass of EV	1685 kg
maximum output torque	395 N m

The typical EV uses a rechargeable battery that is located under the floor of the EV. The battery is made up of an arrangement of many individual cells, and it uses a technology that is very similar to that of batteries in laptop computers. The battery can be charged approximately 4000 times before requiring replacement. The home battery charger for the typical EV uses an a.c. supply to provide power of 7.2 kW with an equivalent direct current of 32 A. The battery takes 10 hours to fully charge – the manufacturer describes this as a ‘charging speed’ of 40 km h^{-1}. When fully charged, the battery has a specific energy of 141 W h kg^{-1}.

EVs can use regenerative braking systems to extend driving range. This is where the kinetic energy of the EV is used to charge the battery, rather than being converted into thermal energy by the brakes. This system is activated by the driver, so it does not automatically happen every time the EV brakes.

One recent advance in battery technology is the use of wireless charging. A simple wireless charger uses a 1.0 m^2 pad on the ground containing a coil of wire. This is attached directly to the a.c. electricity grid. A second coil is contained in a pad inside the EV, with the pad positioned as close to the ground as possible. The arrangement operates in a very similar way to the way in which a transformer works. In the future, it may be possible to have charging coils of wire built into the road network that continuously top up the batteries in EVs.

(a) **(i)** The cost of electrical energy is S\$0.23 per kW h.

Calculate the ratio:

$$\frac{\text{cost to travel 1.0 km in the typical EV}}{\text{cost to travel 1.0 km in an ICE car}}.$$

ratio = ... [1]

(ii) State why EVs for use in Singapore typically need to be charged less than once per week.

....

.... [1]

(b) **(i)** Each individual cell in the battery of the typical EV has a maximum allowable charging current of 2.0 A. Each cell has a maximum terminal voltage of 3.0 V when being charged.

By considering the arrangement of cells in the battery, use the information and data from the passage to determine the minimum number of cells in the battery of the typical EV.

....

....

....

.... [3]

(ii) Suggest what the manufacturer means by a ‘charging speed’ of 40 km h^{-1}.

....

.... [1]

(iii) Suggest what is meant by a specific energy of 141 W h kg^{-1}.

....

....

.... [1]

(iv) Determine the mass of the battery.

mass = ... kg [1]

(v) Use your answer in **7(b)(iv)** to suggest a physics-based reason for the location of the battery.

....

....

.... [1]

(c) Battery chargers sometimes need to convert a.c. into d.c.

(i) Complete Figure 7.1 using a single component to convert the a.c. input voltage into a d.c. output voltage.

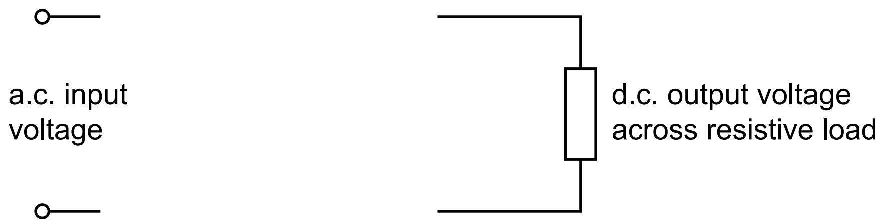

Figure 7.1

[1]

(ii) The a.c. input voltage varies sinusoidally with time and has period T.

On Figure 7.2, sketch the variation with time of the d.c. output voltage in **7(c)(i)** for **two** cycles of the a.c. input.

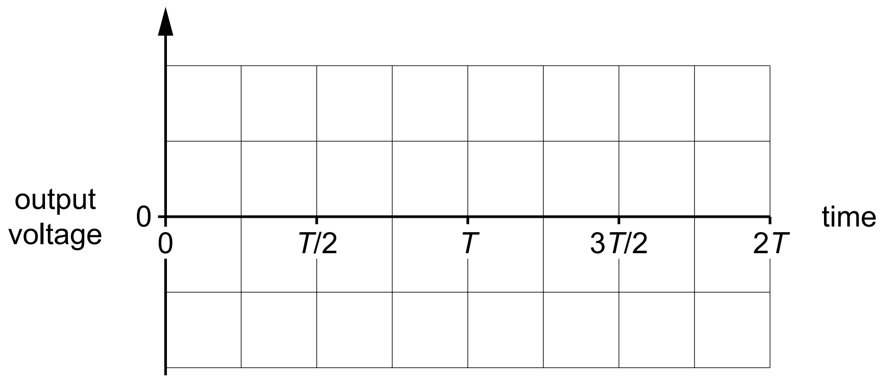

Figure 7.2

[2]

(d) The typical EV is travelling at a speed of $25\,\mathrm{m\,s^{-1}}$ when the driver activates the regenerative braking system. The EV decelerates to rest and all its kinetic energy is used to charge the battery.

Determine the distance, in km, that the EV can travel on this regenerated energy.

distance = ... km [3]

(e) **(i)** Explain why a wireless charger needs to use an a.c. voltage rather than a d.c. voltage.

....

.... [1]

(ii) Explain why the coil in the ground pad of a wireless charger and the coil in an EV need to be as close together as possible.

....

.... [1]

(f) Figure 7.3 shows the coil of a simple electric motor between the poles of a magnet.

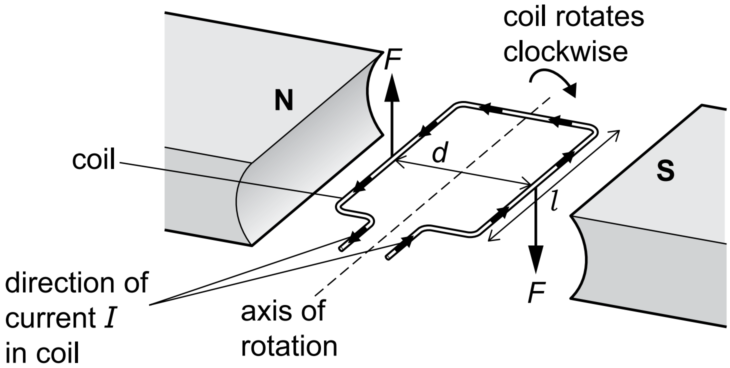

Figure 7.3

The coil has length l and width d. The entire coil lies within the magnetic field. The magnetic flux density between the poles of the magnet is B. There is a current I in the coil.

Two forces, each of magnitude F, act in opposite directions on the two sides of the coil, as shown in Figure 7.3. This produces a torque that causes the coil to rotate.

(i) The current I in the coil is 96 A. The area of the rectangular coil in the magnetic field of the magnet is $6.1 \times 10^{-3}\,m^2$ and the coil contains 1200 turns.

Calculate the magnetic flux density B needed to produce the maximum output torque of the typical EV.

B = ... T [3]

(ii) A simple motor uses one pair of magnetic poles, as shown in Figure 7.4.

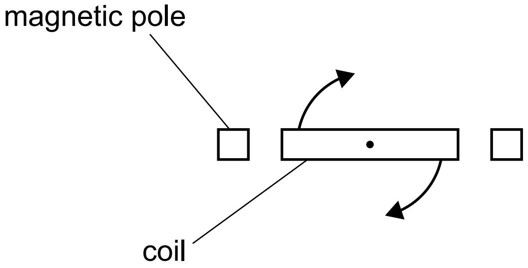

Figure 7.4

A more practical motor uses four pairs of magnetic poles arranged around the coil, as shown in Figure 7.5.

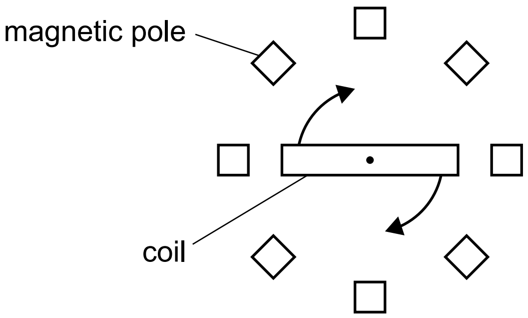

Figure 7.5

Suggest an advantage of the arrangement shown in Figure 7.5.

....

....

.... [1]

[Total: 21]

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