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MINISTRY OF EDUCATION, SINGAPORE
in collaboration with
CAMBRIDGE ASSESSMENT INTERNATIONAL EDUCATION
General Certificate of Education Advanced Level
Higher 2

CANDIDATE NAME

CENTRE NUMBER S

INDEX NUMBER

PHYSICS

9749/02

Paper 2 Structured Questions

October/November 2022

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your Centre number, index number and name 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.
DO **NOT** WRITE ON ANY BARCODES.

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.

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

Singapore Examinations and Assessment Board

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Data

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

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

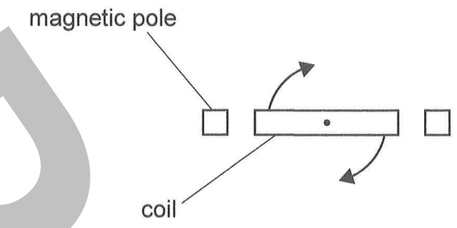


Fig. 7.4

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

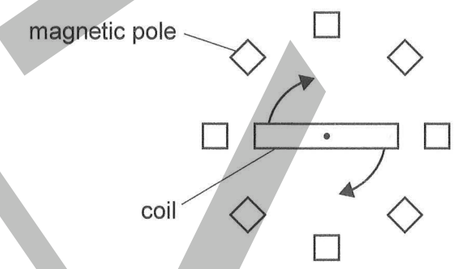


Fig. 7.5

Suggest an advantage of the arrangement shown in Fig. 7.5.

.....

.....

..... [1]

[Total: 21]

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

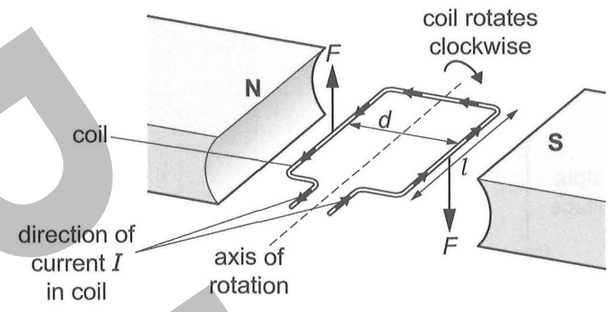


Fig. 7.3

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 Fig. 7.3. This produces a torque that causes the coil to rotate.

(i) The current I in the coil is 96A. 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]

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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	$\phi = -\frac{Gm}{r}$
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	$V = \frac{Q}{4\pi\varepsilon_0 r}$
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	$B = \frac{\mu_0 NI}{2r}$
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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Answer **all** the questions in the spaces provided.

1 **(a)** A mass m is suspended from a vertical spring attached to a fixed support. The mass is pulled down and held at a vertical displacement of 0.16 m from its equilibrium position, as shown in Fig. 1.1.

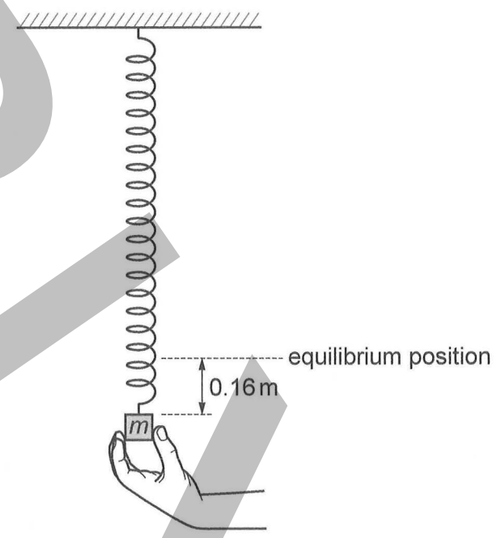


Fig. 1.1

The mass is released.

Ten oscillations are timed using a stop-watch.

The data for the mass and the time, together with their uncertainties, are shown in Table 1.1.

Table 1.1

time for 10 oscillations / s	7.2 ± 0.2
m / g	120 ± 1%

The period T of the oscillations of the mass is given by:

$$T = 2\pi\sqrt{\frac{m}{k}}$$

where T is in s, m is in kg and k is the spring constant in N m^{-1}.

① $T = 0.72 \pm 0.02$ s

② $m = 0.12 \pm 1.2 \times 10^{-3} = (120 \pm 1.2) \times 10^{-3}$ kg

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

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

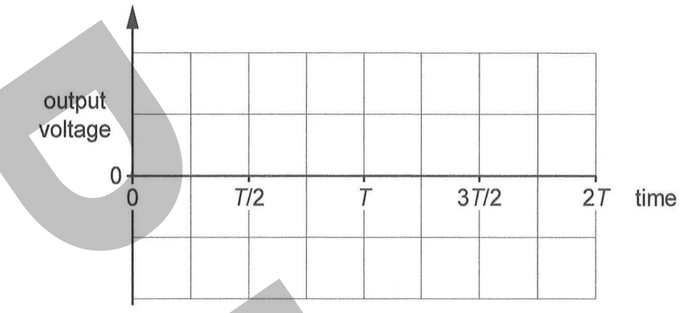


Fig. 7.2

[2]

(d) The typical EV is travelling at a speed of 25 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 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]

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(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 to **(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 Fig. 7.1 using a single component to convert the a.c. input voltage into a d.c. output voltage.



Fig. 7.1

[1]

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Determine the value of k together with its **actual** uncertainty.
Give your answer to an appropriate number of significant figures.

① $T = 2\pi\sqrt{\frac{m}{k}}$ $\therefore$ $k = \frac{4\pi^2 m}{T^2}$

② $k_{true} = \frac{4\pi^2(0.12)}{0.72^2} = 9.1385$

③ $\frac{\Delta k}{k} = \frac{\Delta m}{m} + 2\frac{\Delta T}{T}$

$\therefore \Delta k = 9.1385\left[\frac{1.2\times10^{-3}}{120\times10^{-3}}\right] + 2\left[\frac{0.02}{0.72}\right] = 0.1469$

④ $\therefore k = 9.1385 \pm 0.1469$

$= 9.1 \pm 0.1$

$k =$ 9.1 ± 0.1 N m^{-1} [4]

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(b) The variation with vertical displacement x of the velocity v of the mass on the spring in **(a)** is shown in Fig. 1.2.

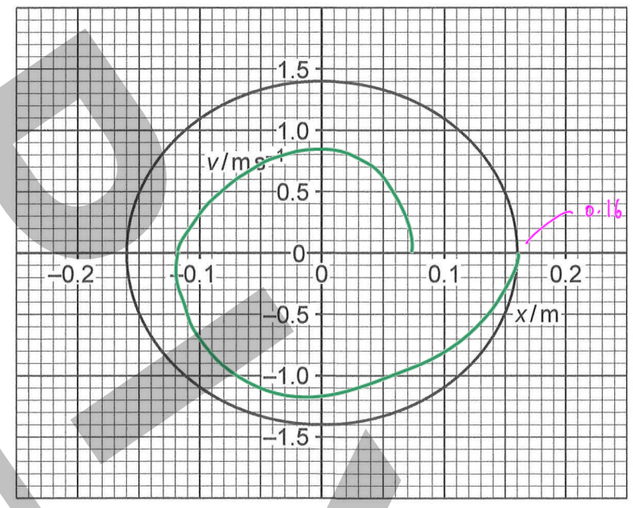


Fig. 1.2

(i) Determine the maximum acceleration a of the mass.

$|a_0| = |-\omega^2 x_0| = \left|-\left(\frac{2\pi}{T}\right)^2 x_0\right| = \left|-\left(\frac{2\pi}{0.72}\right)^2 (0.16)\right| = 12.184 = 12.2\ \text{m s}^{-2}$ (3sf)

a = ... 12.2 ..... m s^{-2} [3]

(ii) A light piece of card is attached to the bottom of the mass so that the oscillations are lightly damped.
The mass is displaced vertically and then released as in **(a)**.

On Fig. 1.2, draw the variation of v with x to show the first complete cycle of these damped oscillations. [2]

[Total: 9]

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(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]

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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.

At present, 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 by 2025 the cost of owning an EV will be the same as that of owning an ICE car. Once there is a market for public charging points, more will be installed. At present, there are about 1600 public charging points in Singapore, and this should increase to 28 000 over the next ten years.

Table 7.1 shows data for a typical EV. This typical EV is similar to 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 32A. 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.

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2 (a) (i) State what is meant by a *vector* quantity.

A physical quantity with both magnitude and direction

..... [1]

(ii) State the name of **one** vector quantity.

Force

..... [1]

(b) An object of weight 16 N travels down a rough slope at constant speed, as shown in Fig. 2.1.

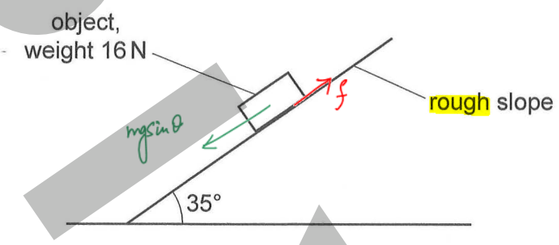


Fig. 2.1

The slope is at an angle of 35° to the horizontal.

(i) Calculate the component *W* of the weight acting down the slope.

$W_{comp} = mg\sin\theta = 16\sin 35 = 9.1772 = 9.18\ N\ (3sf)$ #

W = 9.18 N [1]

(ii) The object is now pulled up the rough slope at constant speed by a force *P*, as shown in Fig. 2.2.

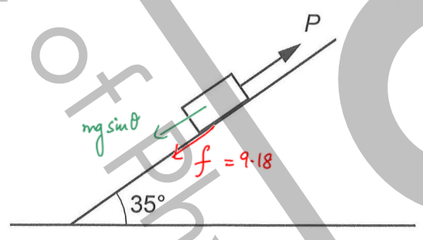


Fig. 2.2

The force *P* is parallel to the slope.

Determine the value of *P*.

By NIL, $F_{net} = 0$

$\therefore P = mg\sin\theta + f$

From (b)(i), $f = mg\sin\theta = 9.18$, from NIL

$\therefore P = 9.1772 + 9.1772$

$= 18.354$

$= 18.4\ N\ (3sf)$ #

P = 18.4 N [2]

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(c) Two isolated objects X and Y travel along the same straight line and then collide. They continue to travel along the same straight line after the collision.

Object X has a mass of 0.22 kg and object Y has a mass of 0.40 kg.

The variation of the velocity of X with time is shown in Fig. 2.3.

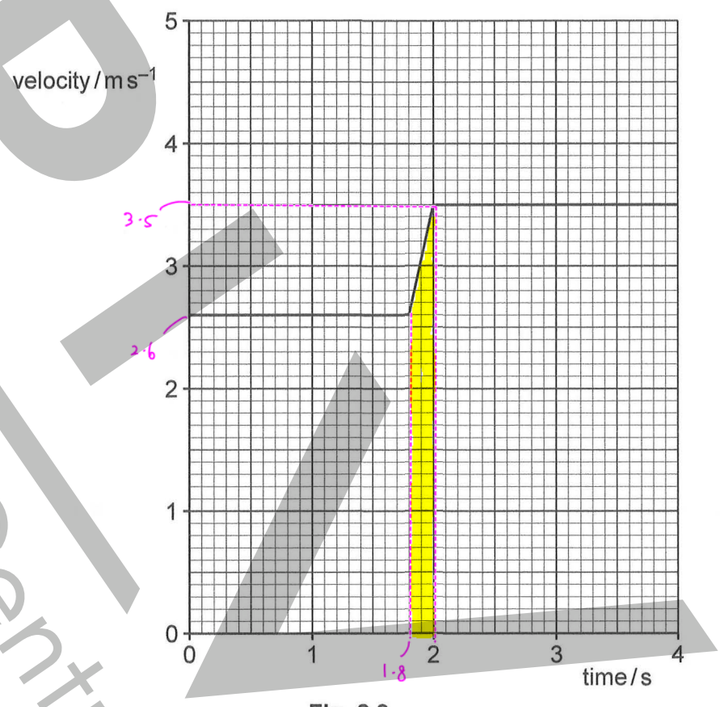


Fig. 2.3

(i) Calculate the impulse exerted on X due to the collision with Y.

$I = \Delta p = m(v_f - v_i) = 0.22(3.5 - 2.6) = 0.198$ Ns (3sf) #

impulse = 0.198 Ns [2]

(ii) Before the collision, Y was travelling at a speed of 3.3 m s^{-1}.

Determine the speed v of Y after the collision.

By com, $I_x = -I_y$

$\therefore 0.198 = -m(v_f - v_i)$

$= -0.4(v_f - 3.3)$

$\therefore v_f = 2.805 = 2.81$ m/s (3sf) #

v = 2.81 m s^{-1} [2]

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(e) An unstable isotope J decays into a stable isotope K.

Determine the ratio:

$$\frac{\text{number of atoms of J}}{\text{number of atoms of K}}$$

for an initially pure sample of isotope J after a time equal to 3.5 half-lives.

ratio = ... [3]

[Total: 12]

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(d) Strontium-90 ($^{90}_{38}$Sr) emits a beta particle to become yttrium (Y).

(i) Complete the nuclear decay equation, including all the decay products.

$^{90}_{38}Sr \rightarrow$ [3]

(ii) The activity A of a sample of unstable strontium-90 varies with the number N of its nuclei, as shown in Fig. 6.2.

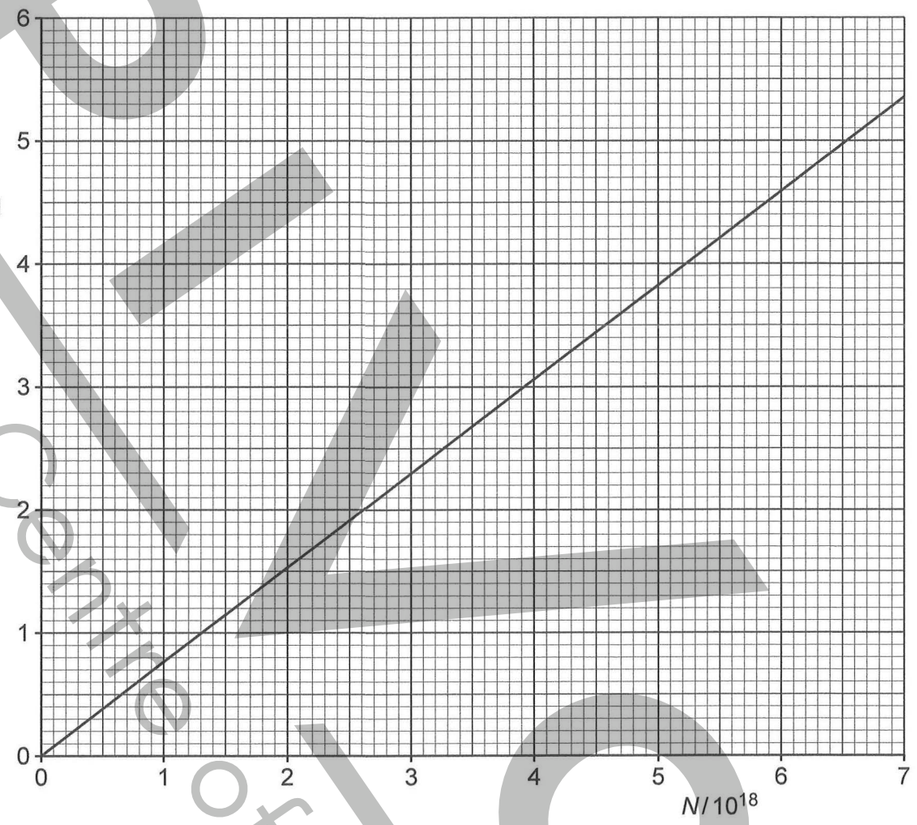


Fig. 6.2

Determine the half-life of strontium-90.

half-life = ... s [2]

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(iii) Determine the distance travelled by X during the time it is in contact with Y.

$D = A_{top} = \frac{1}{2}(a+b)h = \frac{1}{2}(2.6+3.5)(0.2) = 0.610\ m$ (3sf)

distance = 0.610 m [2]

[Total: 11]

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3 **(a)** Fig. 3.1 shows the path of a moving object as it enters and travels through a uniform field of force.

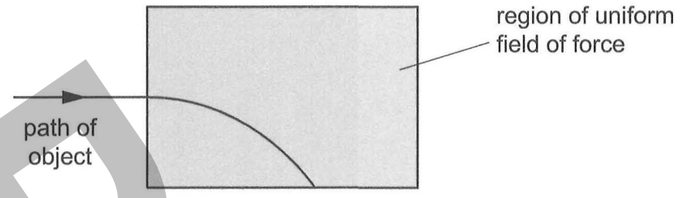


Fig. 3.1

Before the object enters this field, its direction of motion is perpendicular to the direction of the field.

The object could be a mass in a gravitational field or a charged particle in an electric field. In both cases, the shape of the path is the same.

Explain why the shape of the path is the same in both cases.

The shape is parabolic. A constant force is exerted in the vertical direction. In the horizontal direction, there is no force (no acceleration). Vertically, the entity undergoes constant acceleration. Horizontally, it undergoes translational motion with constant velocity. This combination of motion causes the path to be parabolic. [2]

(b) The variations with separation of the gravitational force F_G and of the electric force F_E between two protons are shown in Fig. 3.2.

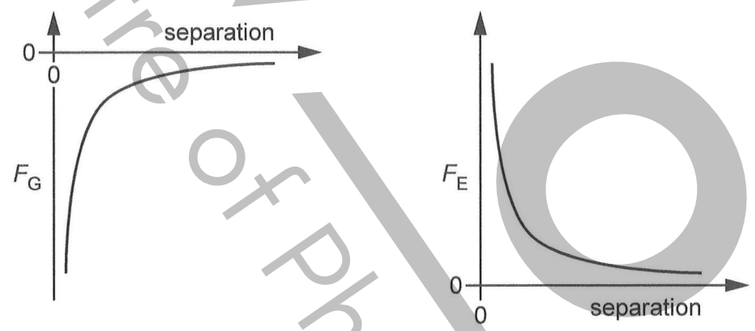


Fig. 3.2

(i) Explain why the gravitational force and the electric force have opposite signs.

Gravitational force between 2 protons is purely attractive, while electric force between 2 protons is purely repulsive. Due to the convention adopted, they have opposite signs. [1]

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6 **(a)** Define the *half-life* of a radioactive isotope.

..... [1]

(b) Explain why, when using an experimental exponential decay curve to determine the half-life of a radioactive isotope, it is better to use the part of the graph where the curve is steep.

..... [1]

(c) A stationary unstable nucleus emits a beta particle.
When the nucleus decays, it recoils. The beta particle is emitted at an angle θ, as shown in Fig. 6.1.

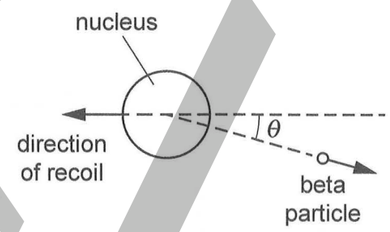


Fig. 6.1

Explain why Fig. 6.1 indicates that another particle is emitted.

..... [2]

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(c) A microwave detector is now positioned between the source and the metal plate in **(b)**. The detector is gradually moved towards the metal plate and away from the source of microwaves.

The variation of the intensity of the signal received at the detector with distance from the source is shown in Fig. 5.2.

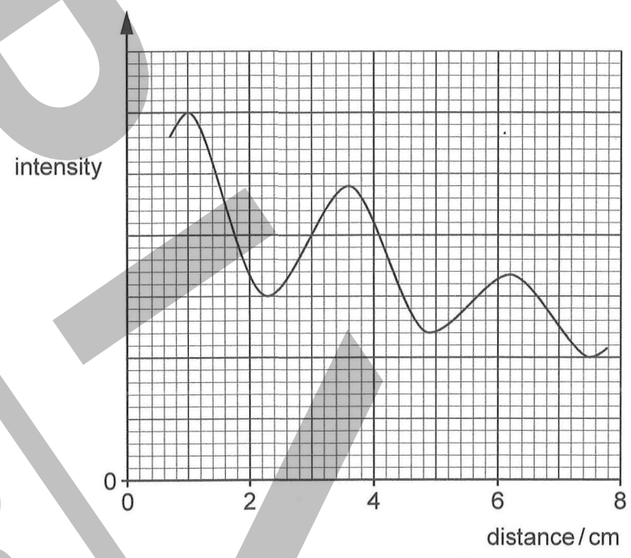


Fig. 5.2

(i) Explain why the intensity of a minimum is never zero.

.....

.....

.....

.....

.....

..... [3]

(ii) Determine the wavelength of the microwaves.

wavelength = ... cm [1]

(iii) Calculate the frequency of the microwaves.

frequency = ... Hz [2]

[Total: 10]

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(ii) State and explain whether the axes on both graphs are drawn to the same scale.

No. Electric forces are about 10^{36} times larger than gravitational forces

..... [2]

(c) Two charged particles, P and R, are isolated in space and separated by a distance of 6.0 cm, as shown in Fig. 3.3.

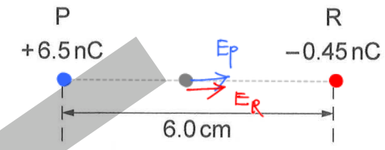


Fig. 3.3

Particle P has a charge of +6.5 nC and particle R has a charge of −0.45 nC.

(i) Explain whether the electric field strength is zero at any point along a straight line between the two charges.

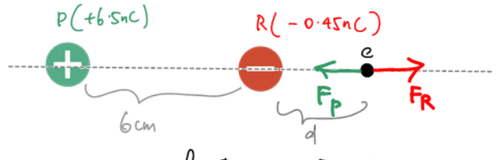
No. The individual electrical fields produced by both P and R points rightwards. Hence, electrical fields do not canel and the net electrical field points rightwards, due to vector addition. [1]

(ii) Explain whether the electric potential is zero at any point along a straight line between the two charges.

Yes. Electrical potential is a scalar and the net potential is the algebraic sum of their individual potentials. Since potential produced by P is positive and that by R, negative, the net potential is 0 at a point closer to R, along straight line between the 2 charges. [1]

(iii) An electron is situated on a straight line that passes through P and R.

Determine the distance in cm from P along the line where there is no resultant force on the electron.



From N2L, for $F_{net} = 0$, $F_R = F_P$

$$\therefore \frac{Q_P e}{4\pi\varepsilon_0 (0.06+d)^2} = \frac{Q_R e}{4\pi\varepsilon_0 d^2}$$

$$\therefore \frac{0.06+d}{d} = \sqrt{\frac{Q_P}{Q_R}} = \sqrt{\frac{6.5}{0.45}} = 3.80058$$

$$\therefore d = 0.02142\ \text{m} = 2.14\ \text{cm}$$

$$\therefore \text{Dist. from P} = 6\text{cm} + d = 8.14\ \text{cm}\ (3\text{sf})$$

distance = 8.14 cm [2]

[Total: 9]

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[Turn over

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4 (a) A sealed vessel contains a fixed amount of gas.

Explain how molecular movement causes the pressure exerted by the gas on the walls of the vessel.

Gas molecules are in constant random motion. When a molecule collides with the walls of a container, it exerts a force which is directly proportional to its mass, speed (or momentum), and frequency of collision. The total force by all molecules acting per unit perpendicular surface area is the pressure exerted by the gas.

[3]

(b) (i) State the assumption of the kinetic theory of gases that relates to the separation of particles in a gas.

There are negligible forces of attraction between the particles, implying that the distance between particles is large.

[1]

(ii) A sealed vessel has a volume of $3.2 \times 10^{-4}\,m^3$ and contains a fixed amount of an ideal gas at a pressure of 180 Pa. The temperature of the gas is 298 K.

Estimate the average distance between the particles of the gas.

$pV = NkT$

$\therefore N = \frac{pV}{kT} = \frac{(180)(3.2\times10^{-4})}{(1.38\times10^{-23})(298)} = 1.400641\times10^{19}$ particles

$\therefore \langle dist \rangle$ bet. particles $= \sqrt[3]{\frac{V}{N}} = \sqrt[3]{\frac{3.2\times10^{-4}}{1.400641\times10^{19}}} = 2.8379\times10^{-8}\,m$

$= 2.84\times10^{-8}\,m$ (3sf)

average distance = 2.84×10^{-8} m [3]

(iii) The approximate diameter of a gas particle is 1×10^{-10} m.

Use your answer in **(b)(ii)** to explain whether the assumption in **(b)(i)** is valid.

Valid. The average distance between particles is about 100 times larger than the diameter of particles, thereby implying that the distance between particles is large.

[1]

[Total: 8]

DO NOT WRITE IN THIS MARGIN

5 (a) State **two** features of a stationary wave that distinguish it from a progressive wave.

1. .....

.....

2. .....

.....

[2]

(b) A point source of microwaves is placed a short distance away from a metal plate, as shown in Fig. 5.1.



Fig. 5.1

A stationary wave is formed between the source and the plate.

Explain how this stationary wave is formed.

.....

.....

..... [2]

PI NOT The Centre of Physics

4 **(a)** A sealed vessel contains a fixed amount of gas.

Explain how molecular movement causes the pressure exerted by the gas on the walls of the vessel.

.....

.....

.....

.....

..... [3]

(b) **(i)** State the assumption of the kinetic theory of gases that relates to the separation of particles in a gas.

.....

..... [1]

(ii) A sealed vessel has a volume of $3.2 \times 10^{-4}\,m^3$ and contains a fixed amount of an ideal gas at a pressure of 180 Pa. The temperature of the gas is 298 K.

Estimate the average distance between the particles of the gas.

average distance = ... m [3]

(iii) The approximate diameter of a gas particle is 1×10^{-10} m.

Use your answer in **(b)(ii)** to explain whether the assumption in **(b)(i)** is valid.

.....

.....

..... [1]

[Total: 8]

DO NOT WRITE IN THIS MARGIN

5 **(a)** State **two** features of a stationary wave that distinguish it from a progressive wave.

1. Wave profile does not advance for stationary waves but energy is transported away from source of disturbance (wave profile advances) in progressive waves

2. In stationary waves, adjacent particles are in phase but out of phase for progressive waves.

..... [2]

(b) A point source of microwaves is placed a short distance away from a metal plate, as shown in Fig. 5.1.

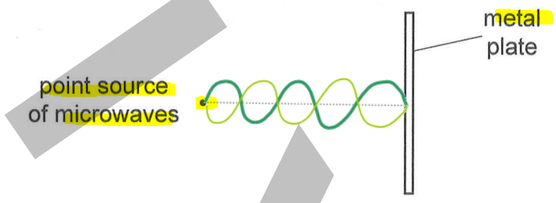


Fig. 5.1

A stationary wave is formed between the source and the plate.

Explain how this stationary wave is formed.

When the coherent microwaves are incident on the metal plate, they will be reflected with a phase difference of π rad and equal amplitude. When the incident and reflected waves superpose (2 equal and opposite waves), the wave trains cancel out (destructive interference) according to the principle of ..... [2]
superposition, producing a stationary wave.

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(c) A microwave detector is now positioned between the source and the metal plate in **(b)**.
The detector is gradually moved towards the metal plate and away from the source of microwaves.

The variation of the intensity of the signal received at the detector with distance from the source is shown in Fig. 5.2.

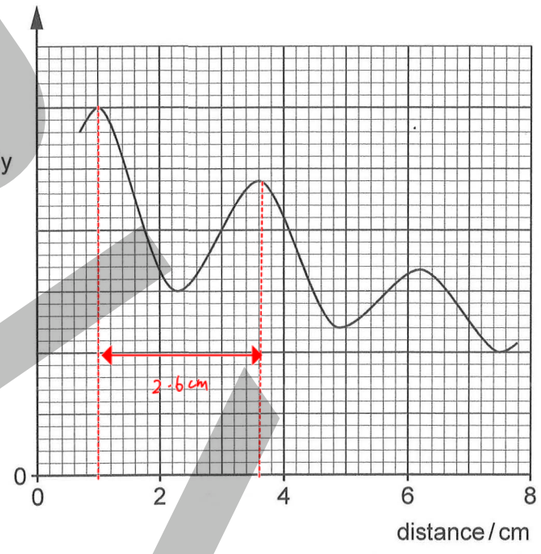


Fig. 5.2

(i) Explain why the intensity of a minimum is never zero.

Intensity is directly proportional to amplitude squared. For amplitude to be minimum, there must be complete cancellation of the incident wave and the reflected (π rad out of phase) wave, from metal plate. But, when microwave is incident on metal plate, it loses energy. Hence, the reflected wave will have smaller amplitudes. So now, when incident and anti-phase reflected wave with smaller amplitude superposes, there is incomplete cancellation. Net amplitude is not zero. So intensity of minimum is not zero. [3]

(ii) Determine the wavelength of the microwaves.

$\lambda = 2 \times 2.6\,\text{cm} = 5.20\,\text{cm}$ (3sf)

wavelength = 5.20 cm [1]

(iii) Calculate the frequency of the microwaves.

From $c = f\lambda$,

$\therefore f = \frac{c}{\lambda} = \frac{3 \times 10^8}{\frac{5.2}{100}} = 5.7692 \times 10^9$ Hz

$= 5.77\,\text{GHz}$ (3sf)

frequency = 5.77×10^9 Hz [2]

[Total: 10]

DO NOT WRITE IN THIS MARGIN

(ii) State and explain whether the axes on both graphs are drawn to the same scale.

.....

.....

..... [2]

(c) Two charged particles, P and R, are isolated in space and separated by a distance of 6.0 cm, as shown in Fig. 3.3.

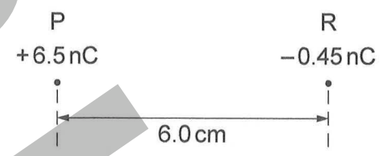


Fig. 3.3

Particle P has a charge of +6.5 nC and particle R has a charge of −0.45 nC.

(i) Explain whether the electric field strength is zero at any point along a straight line between the two charges.

.....

.....

..... [1]

(ii) Explain whether the electric potential is zero at any point along a straight line between the two charges.

.....

.....

..... [1]

(iii) An electron is situated on a straight line that passes through P and R.

Determine the distance in cm from P along the line where there is no resultant force on the electron.

distance = ... cm [2]

[Total: 9]

PI SAMPLE The Centre of Physics

3 **(a)** Fig. 3.1 shows the path of a moving object as it enters and travels through a uniform field of force.

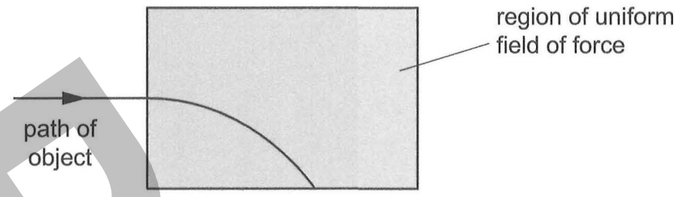


Fig. 3.1

Before the object enters this field, its direction of motion is perpendicular to the direction of the field.

The object could be a mass in a gravitational field or a charged particle in an electric field. In both cases, the shape of the path is the same.

Explain why the shape of the path is the same in both cases.

.....

.....

.....

.....

..... [2]

(b) The variations with separation of the gravitational force F_G and of the electric force F_E between two protons are shown in Fig. 3.2.

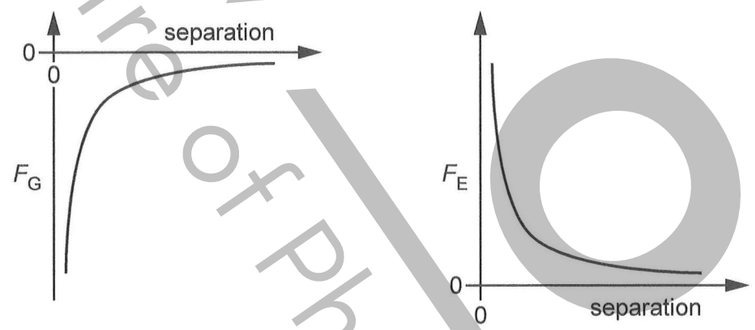


Fig. 3.2

(i) Explain why the gravitational force and the electric force have opposite signs.

.....

.....

..... [1]

DO NOT WRITE IN THIS MARGIN

6 **(a)** Define the *half-life* of a radioactive isotope.

Time taken for half of the original number of radioactive nuclei to decay.

..... [1]

(b) Explain why, when using an experimental exponential decay curve to determine the half-life of a radioactive isotope, it is better to use the part of the graph where the curve is steep.

In the steep part of the curve, for the same duration, the decrease in the number of radioactive nuclei is large and hence the percentage uncertainty in the measurements will be small.

..... [1]

(c) A stationary unstable nucleus emits a beta particle.
When the nucleus decays, it recoils. The beta particle is emitted at an angle θ, as shown in Fig. 6.1.

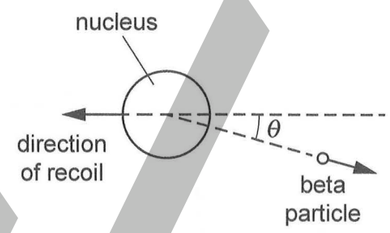


Fig. 6.1

Explain why Fig. 6.1 indicates that another particle is emitted.

No net external force acts on system. From conservation of momentum, total linear momentum horizontally and vertically is conserved. Hence, there must be another particle emitted to produce a vertical momentum component that vectorally cancels with that of the beta particle. [2]

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(d) Strontium-90 ($^{90}_{38}Sr$) emits a beta particle to become yttrium (Y).

(i) Complete the nuclear decay equation, including all the decay products.

$^{90}_{38}Sr \rightarrow {}^{0}_{-1}\beta + {}^{90}_{39}Y + Energy$ [3]

(ii) The activity A of a sample of unstable strontium-90 varies with the number N of its nuclei, as shown in Fig. 6.2.

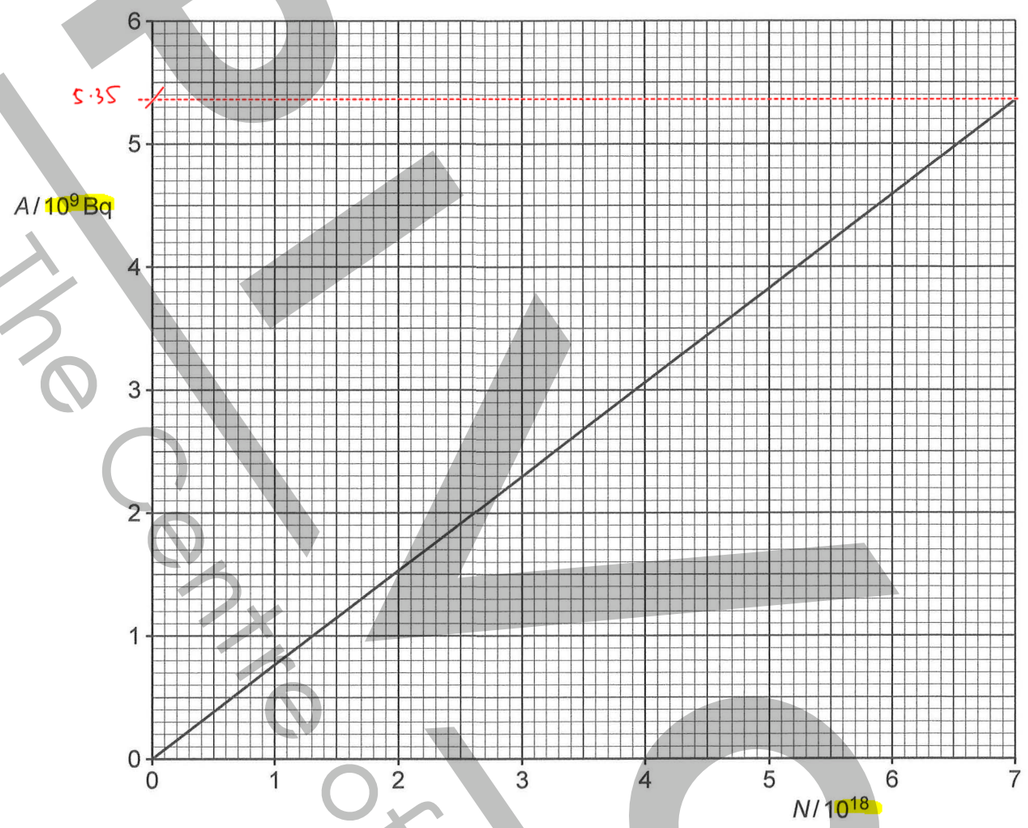


Fig. 6.2

Determine the half-life of strontium-90.

① $A = \lambda N$

② $t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$

$\therefore A = \frac{\ln 2}{t_{\frac{1}{2}}} \cdot N$

Hence, $t_{\frac{1}{2}} = \frac{\ln 2}{A} \cdot N$

$\therefore t_{\frac{1}{2}} = \frac{\ln 2}{5.35 \times 10^9} \times 7 \times 10^{18}$

$= 9.0692 \times 10^8$

$= 9.07 \times 10^8$ s (3sf) *

half-life = 9.07 x10^8 ..... s [2]

DO NOT WRITE IN THIS MARGIN

(iii) Determine the distance travelled by X during the time it is in contact with Y.

distance = ... m [2]

[Total: 11]

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(c) Two isolated objects X and Y travel along the same straight line and then collide. They continue to travel along the same straight line after the collision.

Object X has a mass of 0.22 kg and object Y has a mass of 0.40 kg.

The variation of the velocity of X with time is shown in Fig. 2.3.

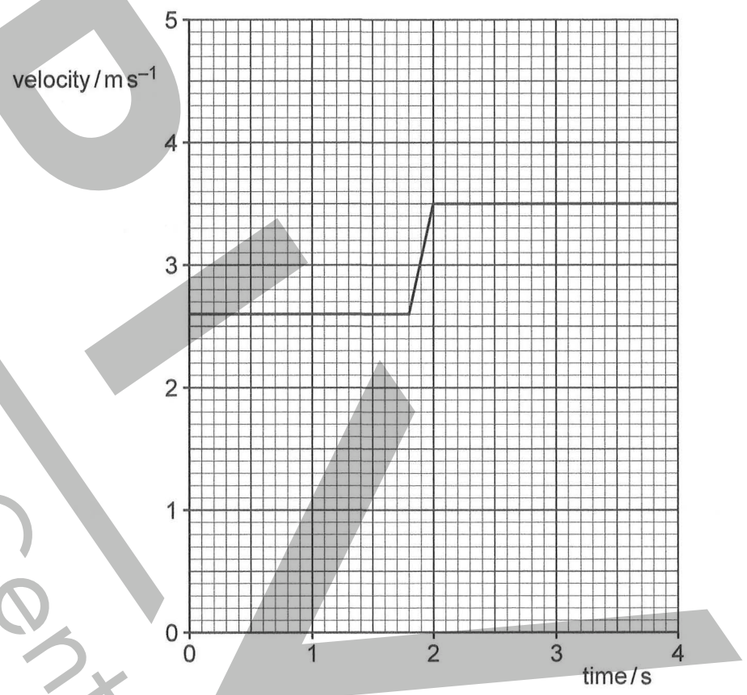


Fig. 2.3

(i) Calculate the impulse exerted on X due to the collision with Y.

impulse = ... Ns [2]

(ii) Before the collision, Y was travelling at a speed of 3.3 m s^{-1}.

Determine the speed v of Y after the collision.

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

DO NOT WRITE IN THIS MARGIN

(e) An unstable isotope J decays into a stable isotope K.

Determine the ratio:

$$\frac{\text{number of atoms of J}}{\text{number of atoms of K}}$$

for an initially pure sample of isotope J after a time equal to 3.5 half-lives.

① $N = N_0 \left(\frac{1}{2}\right)^n$ (present value, initial value)

② $J_p = J_0 \left(\frac{1}{2}\right)^{3.5}$

③ $K = J_0 - J_p$

$\therefore$ Ratio $= \frac{J_p}{K} = \frac{J_0 \left(\frac{1}{2}\right)^{3.5}}{J_0 \left(1 - \frac{J_p}{J_0}\right)} = \frac{\left(\frac{1}{2}\right)^{3.5}}{1 - \left(\frac{1}{2}\right)^{3.5}} = 0.09695$

$= 0.0970$ (3 sf) #

ratio = 0.0970 [3]

[Total: 12]

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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.

At present, 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 by 2025 the cost of owning an EV will be the same as that of owning an ICE car. Once there is a market for public charging points, more will be installed. At present, there are about 1600 public charging points in Singapore, and this should increase to 28 000 over the next ten years.

Table 7.1 shows data for a typical EV. This typical EV is similar to 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.

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2 (a) (i) State what is meant by a *vector* quantity.

.....

..... [1]

(ii) State the name of **one** vector quantity.

..... [1]

(b) An object of weight 16 N travels down a rough slope at constant speed, as shown in Fig. 2.1.

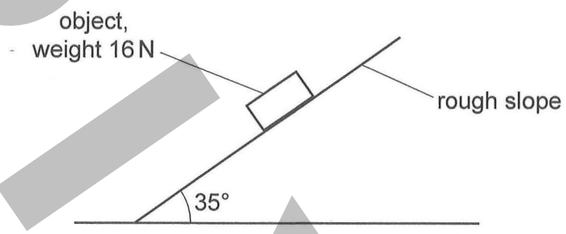


Fig. 2.1

The slope is at an angle of 35° to the horizontal.

(i) Calculate the component *W* of the weight acting down the slope.

W = ... N [1]

(ii) The object is now pulled up the rough slope at constant speed by a force *P*, as shown in Fig. 2.2.

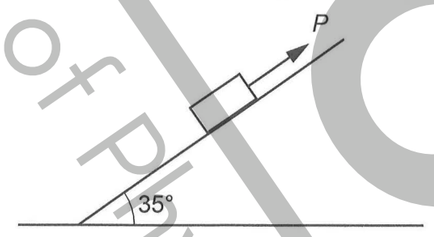


Fig. 2.2

The force *P* is parallel to the slope.

Determine the value of *P*.

P = ... N [2]

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(b) The variation with vertical displacement x of the velocity v of the mass on the spring in **(a)** is shown in Fig. 1.2.

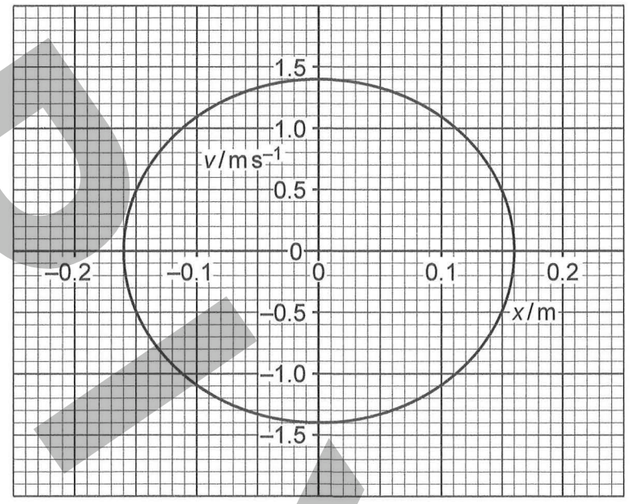


Fig. 1.2

(i) Determine the maximum acceleration a of the mass.

a = ... m s^{-2} [3]

(ii) A light piece of card is attached to the bottom of the mass so that the oscillations are lightly damped.
The mass is displaced vertically and then released as in **(a)**.

On Fig. 1.2, draw the variation of v with x to show the first complete cycle of these damped oscillations. [2]

[Total: 9]

DO NOT WRITE IN THIS MARGIN

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

Calculate the ratio:

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

$$\text{Ratio} = \frac{\frac{(72\,\text{kWh})(\$0.23)}{400}}{\frac{\$80}{800\,\text{km}}} = 0.414 \text{ (3sf)}$$

ratio = ... 0.414 ..... [1]

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

The weekly average distance travelled by a car (290km) is less than the maximum distance (range) travel-able on full charge (400km) ..... [1]

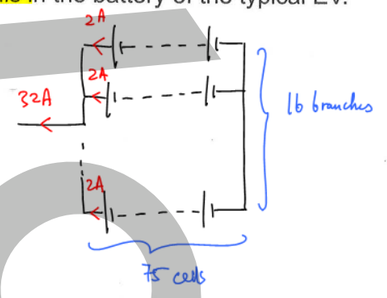
(b) **(i)** Each individual cell in the battery of the typical EV has a maximum allowable charging current of 2.0A. Each cell has a maximum terminal voltage of 3.0V when being charged.

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.

① $P = VI$, So $V = \frac{P}{I} = \frac{7.2 \times 10^3}{32} = 225\,V$

② $\frac{225V}{3V} = 75$ series cells.

③ Total cells = $75 \times 16 = 1200$ *



..... [3]

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

For every hour of charge, the distance the EV can travel is 40km. ..... [1]

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

Energy per unit mass stored by the battery is 141 Wh (141 W x 3600 s = 507600 J) per kg.

.....

..... [1]

(iv) Determine the mass of the battery.

① $E_{battery} = 72 kWh = 72000 Wh$

② Sp. energy, SE = 141 Wh kg^{-1}

$SE = \frac{E}{m}$, $\therefore m = \frac{E}{SE} = \frac{72000}{141} = 510.63 = 54 kg$ (2sf)

mass = 54 kg [1]

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

Given the battery's large mass, it is placed at the bottom of the car to lower the cars' centre of gravity (c.o.g.) and increase its stability.

..... [1]

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

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

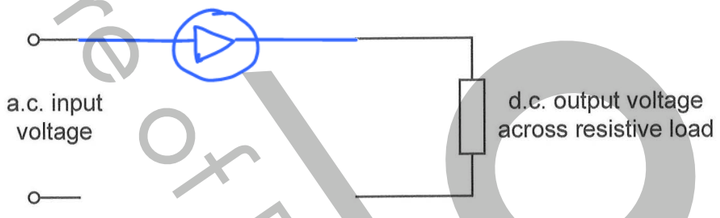


Fig. 7.1

[1]

DO NOT WRITE IN THIS MARGIN

Determine the value of k together with its **actual** uncertainty.
Give your answer to an appropriate number of significant figures.

k = ... ± ..... N m^{-1} [4]

DO NOT WRITE IN THIS MARGIN

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

1 **(a)** A mass *m* is suspended from a vertical spring attached to a fixed support. The mass is pulled down and held at a vertical displacement of 0.16 m from its equilibrium position, as shown in Fig. 1.1.

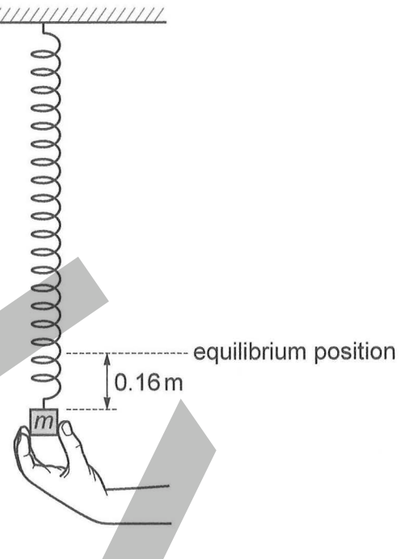


Fig. 1.1

The mass is released.

Ten oscillations are timed using a stop-watch.

The data for the mass and the time, together with their uncertainties, are shown in Table 1.1.

Table 1.1

time for 10 oscillations / s	7.2 ± 0.2
m / g	120 ± 1%

The period *T* of the oscillations of the mass is given by:

$$T = 2\pi\sqrt{\frac{m}{k}}$$

where *T* is in s, *m* is in kg and *k* is the spring constant in N m^{-1}.

DO NOT WRITE IN THIS MARGIN

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

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

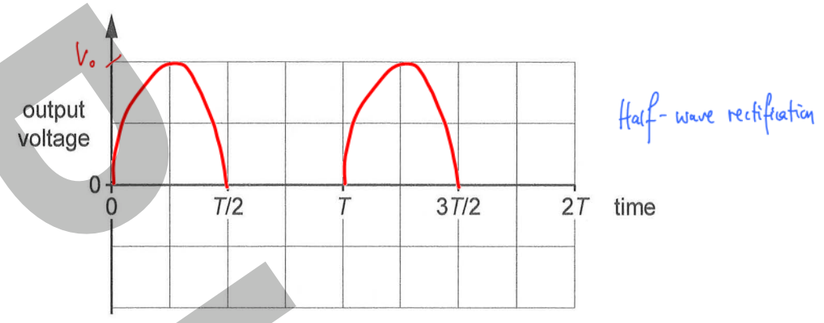


Fig. 7.2

[2]

(d) The typical EV is travelling at a speed of 25 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 the EV can travel on this regenerated energy.

① $KE = \frac{1}{2}mv^2 = \frac{1}{2}(1685)(25)^2 = 5.26562 \times 10^5$ J

② $72\,\text{kWh} = (72000\,\text{W})(3600\,\text{s}) = 2.592 \times 10^8$ J → 400 km

$\therefore 5.26562 \times 10^5\,\text{J} \rightarrow \frac{400(5.26562 \times 10^5)}{2.592 \times 10^8} = 0.8125 = 0.813\,\text{km}$ (3 s.f.)

distance = 0.813 km [3]

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

With ac voltage, there will be varying magnetic flux linkage in the coil with respect to time. By Faraday's law of electromagnetic induction, there will be induced emf in the EV's coil. [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.

To allow maximum flux linking between the 2 coils for larger induced emf in EV's coil

[1]

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

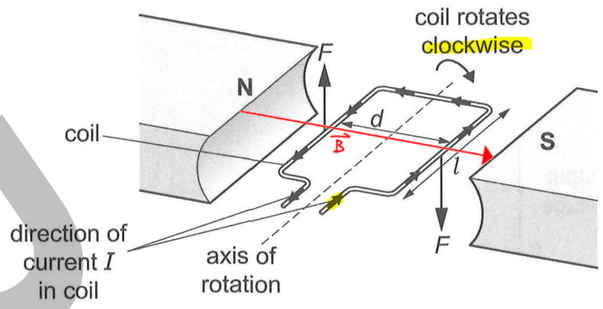


Fig. 7.3

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 Fig. 7.3. This produces a torque that causes the coil to rotate.

(i) The current I in the coil is 96A. The area of the rectangular coil in the magnetic field of the magnet is 6.1×10^{-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.

$C = F \cdot d = BIL \cdot N \cdot d$

$\therefore B = \dfrac{C}{I_L d N} = \dfrac{C}{I \cdot A \cdot N} = \dfrac{395}{(96)(6.1\times10^{-3})(1200)} = 0.56210 = 0.562\,T\ (3sf)$

$B =$ 0.562 T [3]

DO NOT WRITE IN THIS MARGIN

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	$\phi = -\dfrac{Gm}{r}$
temperature	$T/\text{K} = T/^\circ\text{C} + 273.15$
pressure of an ideal gas	$p = \dfrac{1}{3}\dfrac{Nm}{V}\langle c^2 \rangle$
mean translational kinetic energy of an ideal gas molecule	$E = \dfrac{3}{2}kT$
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	$V = \dfrac{Q}{4\pi\varepsilon_0 r}$
alternating current / voltage	$x = x_0 \sin\omega t$
magnetic flux density due to a long straight wire	$B = \dfrac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	$B = \dfrac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_0 nI$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \dfrac{\ln 2}{t_{\frac{1}{2}}}$

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Data

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

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

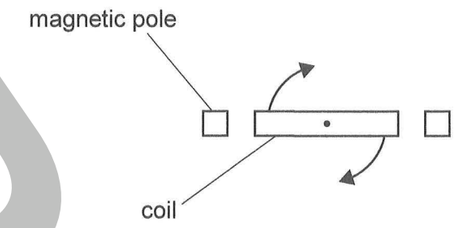


Fig. 7.4

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

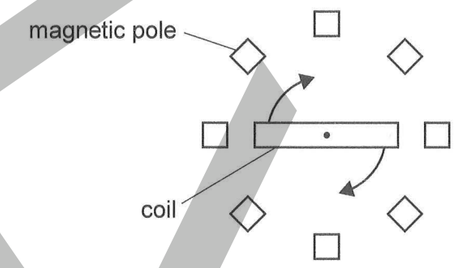


Fig. 7.5

Suggest an advantage of the arrangement shown in Fig. 7.5.

A 4-pair magnetic pole system ensures that the maximum magnetic flux density acting perpendicular to the coil occurs 4 times more. Hence, maximum torque is achieved consistently.

..... [1]

[Total: 21]

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2 hours

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Write your Centre number, index number and name in the spaces at the top of this page.
Write in dark blue or black pen on both sides of the paper.
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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.

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