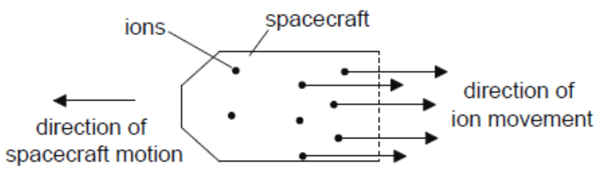
R2019_511P2 *[208 marks]*

Ion-thrust engines can power spacecraft. In this type of engine, ions are created in a chamber and expelled from the spacecraft. The spacecraft is in outer space when the propulsion system is turned on. The spacecraft starts from rest.



The mass of ions ejected each second is 6.6×10^{-6} kg and the speed of each ion is 5.2×10^{4} m s^{-1}. The initial total mass of the spacecraft and its fuel is 740 kg. Assume that the ions travel away from the spacecraft parallel to its direction of motion.

1a. Determine the initial acceleration of the spacecraft. *[2 marks]*

Markscheme

change in momentum each second = $6.6 \times 10^{-6} \times 5.2 \times 10^{4}$ «= 3.4×10^{-1} kg m s^{-1}» ✔

acceleration = «$\frac{3.4\times10^{-1}}{740}$ =» 4.6×10^{-4} «m s^{-2}» ✔

An initial mass of 60 kg of fuel is in the spacecraft for a journey to a planet. Half of the fuel will be required to slow down the spacecraft before arrival at the destination planet.

1b. Estimate the maximum speed of the spacecraft. *[2 marks]*

Markscheme

ALTERNATIVE 1:

(considering the acceleration of the spacecraft)

time for acceleration = $\frac{30}{6.6\times10^{-6}}$ = «4.6×10^{6}» «s» ✔

max speed = «answer to (a) × 4.6×10^{6} =» 2.1×10^{3} «m s^{-1}» ✔

ALTERNATIVE 2:

(considering the conservation of momentum)

(momentum of 30 kg of fuel ions = change of momentum of spacecraft)

$30 \times 5.2 \times 10^{4} = 710 \times$ max speed ✔

max speed = 2.2×10^{3} «m s^{-1}» ✔

1c. Outline why scientists sometimes use estimates in making calculations. *[1 mark]*

Markscheme

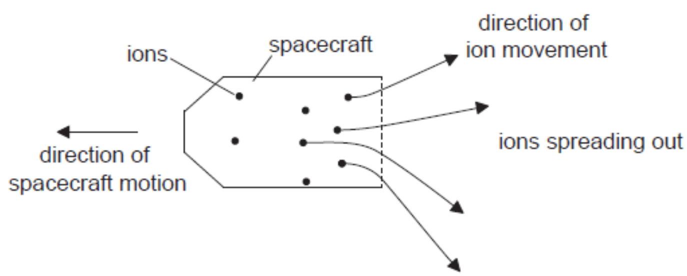
problem may be too complicated for exact treatment ✔

to make equations/calculations simpler ✔

when precision of the calculations is not important ✔

some quantities in the problem may not be known exactly ✔

In practice, the ions leave the spacecraft at a range of angles as shown.



1d. Outline why the ions are likely to spread out. *[2 marks]*

Markscheme

ions have same (sign of) charge ✔

ions repel each other ✔

1e. Explain what effect, if any, this spreading of the ions has on the acceleration of the spacecraft. *[2 marks]*

Markscheme

the forces between the ions do not affect the force on the spacecraft. ✔

there is no effect on the acceleration of the spacecraft. ✔

On arrival at the planet, the spacecraft goes into orbit as it comes into the gravitational field of the planet.

1f. Outline what is meant by the gravitational field strength at a point. *[2 marks]*

Markscheme

force per unit mass ✔

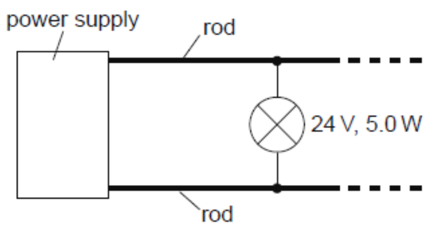
acting on a small/test/point mass «placed at the point in the field» ✔

1g. Newton's law of gravitation applies to point masses. Suggest why the law can be applied to a satellite orbiting a spherical planet of uniform density. *[1 mark]*

Markscheme

satellite has a much smaller mass/diameter/size than the planet «so approximates to a point mass» ✔

A lighting system consists of two long metal rods with a potential difference maintained between them. Identical lamps can be connected between the rods as required.



The following data are available for the lamps when at their working temperature.

Lamp specifications 24 V, 5.0 W

Power supply emf 24 V

Power supply maximum current 8.0 A

Length of each rod 12.5 m

Resistivity of rod metal $7.2 \times 10^{-7}\ \Omega\,m$

2a. Each rod is to have a resistance no greater than 0.10 Ω. Calculate, in m, the minimum radius of each rod. Give your answer to an appropriate number of significant figures. *[3 marks]*

Markscheme

ALTERNATIVE 1:

$r = \sqrt{\frac{\rho l}{\pi \text{R}}}$ ***OR*** $\sqrt{\frac{7.2 \times 10^{-7} \times 12.5}{\pi \times 0.1}}$ ✔

r = 5.352 × 10^{-3} ✔

5.4 × 10^{-3} «m» ✔

ALTERNATIVE 2:

$A = \frac{7.2 \times 10^{-7} \times 12.5}{0.1}$ ✔

r = 5.352 × 10^{-3} ✔

5.4 × 10^{-3} «m» ✔

2b. Calculate the maximum number of lamps that can be connected between the rods. Neglect the resistance of the rods. *[2 marks]*

Markscheme

current in lamp = $\frac{5}{24}$ «= 0.21» «A»

OR

n = 24 × $\frac{8}{5}$ ✔

so «38.4 and therefore» 38 lamps ✔

2c. One advantage of this system is that if one lamp fails then the other lamps in the circuit remain lit. Outline **one** other electrical advantage of this system compared to one in which the lamps are connected in series. *[1 mark]*

Markscheme

when adding more lamps in parallel the brightness stays the same ✔

when adding more lamps in parallel the pd across each remains the same/at the operating value/24 V ✔

when adding more lamps in parallel the current through each remains the same ✔

lamps can be controlled independently ✔

the pd across each bulb is larger in parallel ✔

the current in each bulb is greater in parallel ✔

lamps will be brighter in parallel than in series ✔

In parallel the pd across the lamps will be the operating value/24 V ✔

Accept converse arguments for adding lamps in series:

when adding more lamps in series the brightness decreases

when adding more lamps in series the pd decreases

when adding more lamps in series the current decreases

lamps can't be controlled independently

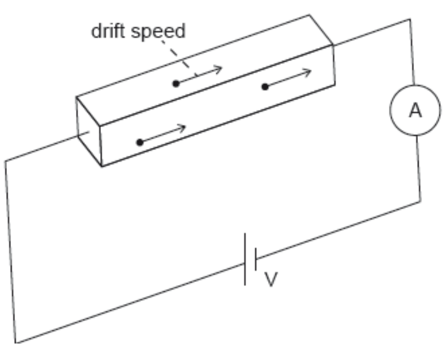
the pd across each bulb is smaller in series

the current in each bulb is smaller in series

in series the pd across the lamps will less than the operating value/24 V

Do not accept statements that only compare the overall resistance of the combination of bulbs.

An ohmic conductor is connected to an ideal ammeter and to a power supply of output voltage V.



The following data are available for the conductor:

density of free electrons = 8.5×10^{22} cm^{-3}

resistivity $\rho = 1.7 \times 10^{-8}$ Ωm

dimensions w × h × l = 0.020 cm × 0.020 cm × 10 cm.

The ammeter reading is 2.0 A.

3a. Calculate the resistance of the conductor. *[2 marks]*

Markscheme

$1.7 \times 10^{-8} \times \frac{0.10}{(0.02\times10^{-2})^2}$

0.043 «Ω»

[2 marks]

3b. Calculate the drift speed *v* of the electrons in the conductor in cm s $^{-1}$. State your answer to an appropriate number of significant figures. *[3 marks]*

Markscheme

v «$= \frac{I}{neA}$» $= \frac{2}{8.5\times10^{22}\times1.60\times10^{-19}\times0.02^2}$

0.368 «cms^{-1}»

0.37 «cms^{-1}»

*Award **[2 max]** if answer is not expressed to 2 sf.*

[3 marks]

A capacitor consists of two parallel square plates separated by a vacuum. The plates are 2.5 cm × 2.5 cm squares. The capacitance of the capacitor is 4.3 pF.

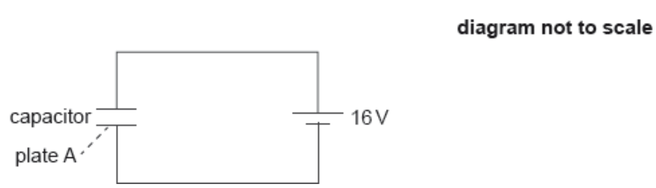
4a. Calculate the distance between the plates. *[1 mark]*

Markscheme

d = «$\frac{8.85\times10^{-12}\times0.025^2}{4.3\times10^{-12}}$ =» 1.3×10^{-3} «m»

[1 mark]

4b. The capacitor is connected to a 16 V cell as shown. *[2 marks]*



Calculate the magnitude and the sign of the charge on plate A when the capacitor is fully charged.

Markscheme

6.9×10^{-11} «C»

negative charge/sign

[2 marks]

4c. The capacitor is fully charged and the space between the plates is then filled with a dielectric of permittivity $\varepsilon = 3.0\varepsilon_0$. *[2 marks]*

Explain whether the magnitude of the charge on plate A increases, decreases or stays constant.

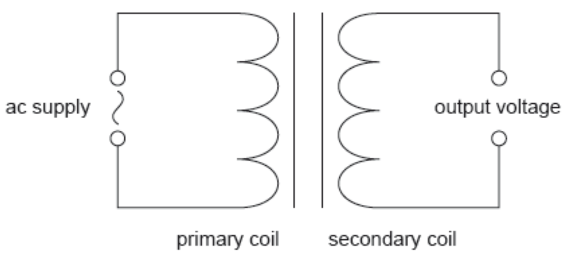
Markscheme

charge increases

because capacitance increases ***AND*** pd remains the same.

[2 marks]

4d. In a different circuit, a transformer is connected to an alternating current (ac) supply. *[3 marks]*



The transformer has 100 turns in the primary coil and 1200 turns in the secondary coil. The peak value of the voltage of the ac supply is 220 V. Determine the root mean square (rms) value of the output voltage.

Markscheme

ALTERNATIVE 1

$\varepsilon_s = \frac{1200}{100} \times 220$

= 2640 «V»

$V_{rms} = \frac{2640}{\sqrt{2}} = 1870$ «V»

ALTERNATIVE 2

(Primary) $V_{rms} = \frac{220}{\sqrt{2}} = 156$ «V»

(Secondary) $V_{rms} = \frac{156 \times 1200}{100}$

$V_{rms} = 1870$ «V»

Allow ECF from MP1 and MP2.

*Award **[2]** max for 12.96 V (reversing N_p and N_s).*

[3 marks]

4e. Describe the use of transformers in electrical power distribution. *[3 marks]*

Markscheme

step-up transformers increase voltage/step-down transformers decrease voltage

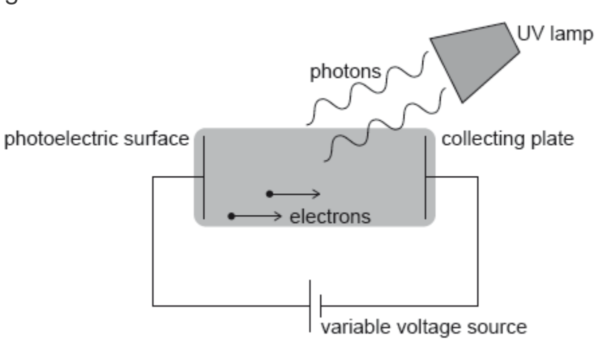
(step-up transformers increase voltage) from plants to transmission lines / (step-down transformers decrease voltage) from transmission lines to final utilizers

this decreases current (in transmission lines)

to minimize energy/power losses in transmission

[3 marks]

Hydrogen atoms in an ultraviolet (UV) lamp make transitions from the first excited state to the ground state. Photons are emitted and are incident on a photoelectric surface as shown.



5a. Show that the energy of photons from the UV lamp is about 10 eV. *[2 marks]*

Markscheme

E_1 = –13.6 «eV» $E_2 = -\frac{13.6}{4}$ = –3.4 «eV»

energy of photon is difference $E_2 - E_1$ = 10.2 «≈ 10 eV»

Must see at least 10.2 eV.

[2 marks]

The photons cause the emission of electrons from the photoelectric surface. The work function of the photoelectric surface is 5.1 eV.

5b. Calculate, in J, the maximum kinetic energy of the emitted electrons. *[2 marks]*

Markscheme

10 – 5.1 = 4.9 «eV»

4.9 × 1.6 × 10^{-19} = 7.8 × 10^{-19} «J»

Allow 5.1 *if* 10.2 *is used to give* 8.2×10^{-19} «J».

5c. Suggest, with reference to conservation of energy, how the variable voltage source can be used to stop all emitted electrons from reaching the collecting plate. *[2 marks]*

Markscheme

EPE produced by battery

exceeds maximum KE of electrons / electrons don't have enough KE

For first mark, accept explanation in terms of electric potential energy difference of electrons between surface and plate.

[2 marks]

5d. The variable voltage can be adjusted so that no electrons reach the collecting plate. Write down the minimum value of the voltage for which no electrons reach the collecting plate. *[1 mark]*

Markscheme

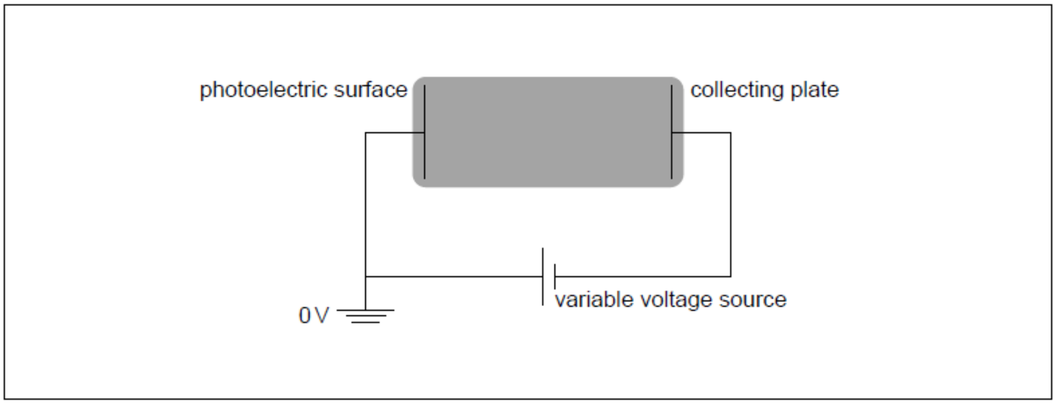
4.9 «V»

Allow 5.1 if 10.2 is used in (b)(i).

Ignore sign on answer.

[1 mark]

The electric potential of the photoelectric surface is 0 V. The variable voltage is adjusted so that the collecting plate is at –1.2 V.

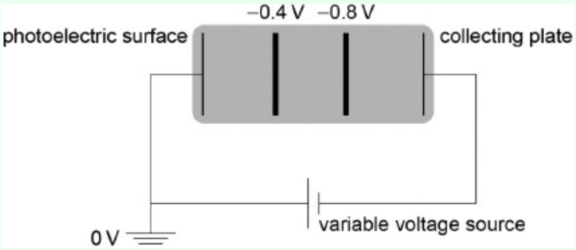


5e. On the diagram, draw and label the equipotential lines at –0.4 V and –0.8 V. *[2 marks]*

Markscheme

two equally spaced vertical lines (judge by eye) at approximately 1/3 and 2/3

labelled correctly



[2 marks]

5f. An electron is emitted from the photoelectric surface with kinetic energy 2.1 eV. Calculate the speed of the electron at the collecting plate. *[2 marks]*

Markscheme

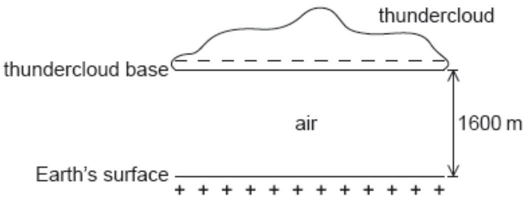
kinetic energy at collecting plate = 0.9 «eV»

speed = «$\sqrt{\frac{2\times0.9\times1.6\times10^{-19}}{9.11\times10^{-31}}}$» = 5.6 × 10^5 «ms^{-1}»

Allow ECF from MP1

[2 marks]

A negatively charged thundercloud above the Earth's surface may be modelled by a parallel plate capacitor.



The lower plate of the capacitor is the Earth's surface and the upper plate is the base of the thundercloud.

The following data are available.

$$\begin{aligned} &\text{Area of thundercloud base} &&= 1.2\times10^{8}\ \text{m}^2\\ &\text{Charge on thundercloud base} &&= -25\ \text{C}\\ &\text{Distance of thundercloud base from Earth's surface} &&= 1600\ \text{m}\\ &\text{Permittivity of air} &&= 8.8\times10^{-12}\ \text{F m}^{-1} \end{aligned}$$

6a. Show that the capacitance of this arrangement is $C = 6.6 \times 10^{-7}$ F. *[1 mark]*

Markscheme

C = «$\varepsilon \frac{A}{d}$ =» $8.8 \times 10^{-12} \times \frac{1.2\times10^{8}}{1600}$

«$C = 6.60 \times 10^{-7}$ F»

[1 mark]

6b. Calculate in V, the potential difference between the thundercloud and the Earth's surface. *[2 marks]*

Markscheme

V = «$\frac{Q}{C}$ =» $\frac{25}{6.6\times10^{-7}}$

$V = 3.8 \times 10^7$ «V»

*Award **[2]** for a bald correct answer*

[2 marks]

6c. Calculate in J, the energy stored in the system. *[2 marks]*

Markscheme

ALTERNATIVE 1

E = «$\frac{1}{2}QV$ =» $\frac{1}{2} \times 25 \times 3.8 \times 10^7$

$E = 4.7 \times 10^8$ «J»

ALTERNATIVE 2

E = «$\frac{1}{2}CV^2$ =» $\frac{1}{2} \times 6.60 \times 10^{-7} \times (3.8 \times 10^7)^2$

$E = 4.7 \times 10^8$ «J» / 4.8×10^8 «J» if rounded value of V used

*Award **[2]** for a bald correct answer*

Allow ECF from (b)(i)

[2 marks]

Lightning takes place when the capacitor discharges through the air between the thundercloud and the Earth's surface. The time constant of the system is 32 ms. A lightning strike lasts for 18 ms.

6d. Show that about –11 C of charge is delivered to the Earth's surface. *[3 marks]*

Markscheme

Q = «$Q_0 e^{-\frac{t}{\tau}}$ =» 25 × $e^{-\frac{18}{32}}$

Q = 14.2 «C»

charge delivered = Q = 25 – 14.2 = 10.8 «C»

«≈ –11 C»

Final answer must be given to at least 3 significant figures

[3 marks]

6e. Calculate, in A, the average current during the discharge. *[1 mark]*

Markscheme

I «= $\frac{\Delta Q}{\Delta t} = \frac{11}{18\times10^{-3}}$» ≈ 610 «A»

Accept an answer in the range 597 – 611 «A»

[1 mark]

6f. State **one** assumption that needs to be made so that the Earth-thundercloud system may be modelled by a parallel plate capacitor. *[1 mark]*

Markscheme

the base of the thundercloud must be parallel to the Earth surface

OR

the base of the thundercloud must be flat

OR

the base of the cloud must be very long «compared with the distance from the surface »

[1 mark]

7a. Bohr modified the Rutherford model by introducing the condition $mvr = n\frac{h}{2\pi}$. Outline the reason for this modification. *[3 marks]*

Markscheme

the electrons accelerate and so radiate energy

they would therefore spiral into the nucleus/atoms would be unstable

electrons have discrete/only certain energy levels

the only orbits where electrons do not radiate are those that satisfy the Bohr condition «$mvr = n\frac{h}{2\pi}$»

[3 marks]

7b. Show that the speed v of an electron in the hydrogen atom is related to the radius r of the orbit by the expression *[1 mark]*

$$v = \sqrt{\frac{ke^2}{m_e r}}$$

where k is the Coulomb constant.

Markscheme

$\frac{m_e v^2}{r} = \frac{ke^2}{r^2}$

OR

KE = $\frac{1}{2}$PE hence $\frac{1}{2}m_e v^2 = \frac{1}{2}\frac{ke^2}{r}$

«solving for v to get answer»

Answer given – look for correct working

[1 mark]

7c. Using the answer in (b) and (c)(i), deduce that the radius r of the electron's orbit in the ground state of hydrogen is given by the following expression. *[2 marks]*

$$r = \frac{h^2}{4\pi^2 k m_e e^2}$$

Markscheme

combining $v = \sqrt{\frac{ke^2}{m_e r}}$ with $m_e vr = \frac{h}{2\pi}$ using correct substitution

«*eg*
$m_e{}^2 \frac{ke^2}{m_e r} r^2 = \frac{h^2}{4\pi^2}$»

correct algebraic manipulation to gain the answer

Answer given – look for correct working

Do not allow a bald statement of the answer for MP2. Some further working eg cancellation of m or r must be shown

[2 marks]

7d. Calculate the electron's orbital radius in (c)(ii). *[1 mark]*

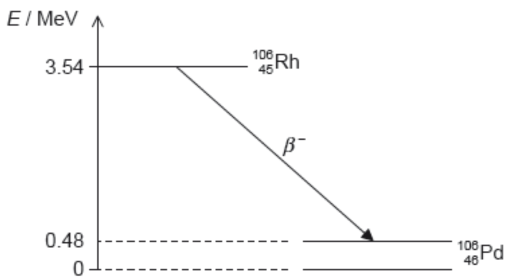
Markscheme

« $r = \frac{(6.63\times10^{-34})^2}{4\pi^2\times8.99\times10^9\times9.11\times10^{-31}\times(1.6\times10^{-19})^2}$»

$r = 5.3 \times 10^{-11}$ «m»

[1 mark]

Rhodium-106 ($^{106}_{45}\mathrm{Rh}$) decays into palladium-106 ($^{106}_{46}\mathrm{Pd}$) by beta minus (β^-) decay. The diagram shows some of the nuclear energy levels of rhodium-106 and palladium-106. The arrow represents the β^- decay.



7e. Explain what may be deduced about the energy of the electron in the β^- decay. *[3 marks]*

Markscheme

the energy released is 3.54 – 0.48 = 3.06 «MeV»

this is shared by the electron and the antineutrino

so the electron's energy varies from 0 to 3.06 «MeV»

[3 marks]

7f. Suggest why the β^- decay is followed by the emission of a gamma ray photon. *[1 mark]*

Markscheme

the palladium nucleus emits the photon when it decays into the ground state «from the excited state»

[1 mark]

7g. Calculate the wavelength of the gamma ray photon in (d)(ii). *[2 marks]*

Markscheme

Photon energy

$E = 0.48 \times 10^6 \times 1.6 \times 10^{-19}$ = «7.68×10^{-14} *J*»

λ = «

$\frac{hc}{E} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{7.68 \times 10^{-14}}$ =» 2.6×10^{-12} «m»

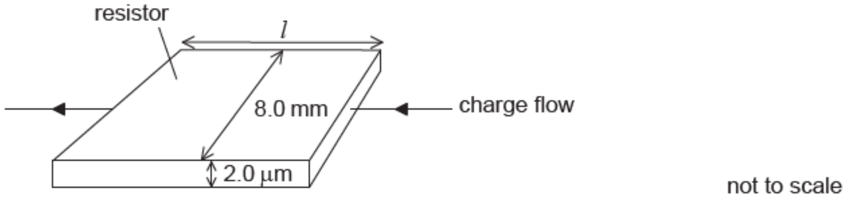
Award ***[2]*** *for a bald correct answer*

Allow ECF from incorrect energy

[2 marks]

Electrical resistors can be made by forming a thin film of carbon on a layer of an insulating material.

A carbon film resistor is made from a film of width 8.0 mm and of thickness 2.0 µm. The diagram shows the direction of charge flow through the resistor.



8a. The resistance of the carbon film is 82 Ω. The resistivity of carbon is 4.1 x 10 $^{-5}$ Ω m. Calculate the length *l* of the film. *[1 mark]*

Markscheme

«$l = \frac{RA}{\rho} = \frac{82 \times 8 \times 10^{-3} \times 2 \times 10^{-6}}{4.1 \times 10^{-5}}$»

0.032 «m»

8b. The film must dissipate a power less than 1500 W from each square metre of its surface to avoid damage. Calculate the maximum allowable current for the resistor. *[2 marks]*

Markscheme

power = 1500 × 8 × 10^{-3} × 0.032 «= 0.384»

«current ≤ $\sqrt{\frac{\text{power}}{\text{resistance}}} = \sqrt{\frac{0.384}{82}}$»

0.068 «A»

Be aware of ECF from (a)(i)

*Award **[1]** for 4.3 «A» where candidate has not calculated area*

8c. State why knowledge of quantities such as resistivity is useful to scientists. *[1 mark]*

Markscheme

quantities such as resistivity depend on the material

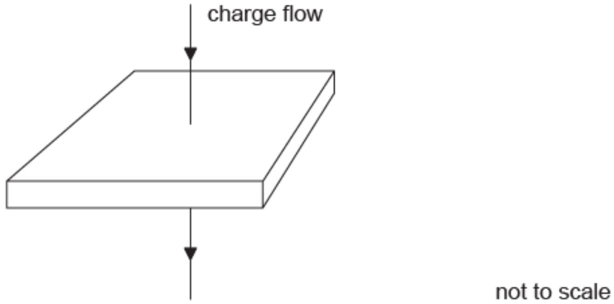
OR

they allow the selection of the correct material

OR

they allow scientists to compare properties of materials

8d. The current direction is now changed so that charge flows vertically through the film. *[2 marks]*



Deduce, without calculation, the change in the resistance.

Markscheme

as area is larger **and** length is smaller

resistance is «very much» smaller

*Award **[1 max]** for answers that involve a calculation*

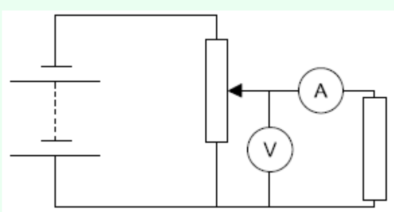
8e. Draw a circuit diagram to show how you could measure the resistance of the carbon-film resistor using a potential divider arrangement to limit the potential difference across the resistor. *[2 marks]*

Markscheme

complete functional circuit with ammeter in series with resistor and voltmeter across it

potential divider arrangement correct

eg:



A heater in an electric shower has a power of 8.5 kW when connected to a 240 V electrical supply. It is connected to the electrical supply by a copper cable.

The following data are available:

Length of cable = 10 m
Cross-sectional area of cable = 6.0 mm^2
Resistivity of copper = $1.7 \times 10^{-8}\ \Omega\ m$

9a. Calculate the current in the copper cable. *[1 mark]*

Markscheme

I «$=\frac{8.5\times10^3}{240}$» $=35$«A»

9b. Calculate the resistance of the cable. *[2 marks]*

Markscheme

$R = \frac{1.7\times10^{-8}\times10}{6.0\times10^{-6}}$

= 0.028 «Ω»

Allow missed powers of 10 for MP1.

9c. Explain, in terms of electrons, what happens to the resistance of the cable as the temperature of the cable increases. *[3 marks]*

Markscheme

«as temperature increases» there is greater vibration of the metal atoms/lattice/lattice ions

OR

increased collisions of electrons

drift velocity decreases «so current decreases»

«as V constant so» R increases

*Award **[0]** for suggestions that the speed of electrons increases so resistance decreases.*

9d. The heater changes the temperature of the water by 35 K. The specific heat capacity of water is 4200 J kg^{-1} K^{-1}. *[4 marks]*

Determine the rate at which water flows through the shower. State an appropriate unit for your answer.

Markscheme

recognition that power = flow rate × cΔT

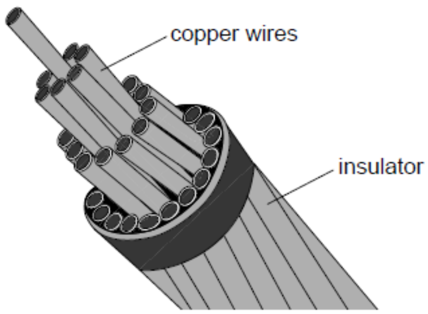
flow rate «$= \frac{\text{power}}{c\Delta T}$» $= \frac{8.5\times10^3}{4200\times35}$

= 0.058 «kg s^{-1}»

kg s^{-1} / g s^{-1} / l s^{-1} / ml s^{-1} / m^3 s^{-1}

Allow MP4 if a bald flow rate unit is stated. Do not allow imperial units.

A cable consisting of many copper wires is used to transfer electrical energy from a generator to an electrical load. The copper wires are protected by an insulator.



10a. The copper wires and insulator are both exposed to an electric field. Discuss, with reference to charge carriers, why there is a significant electric current only in the copper wires. *[3 marks]*

Markscheme

when an electric field is applied to any material «using a cell etc» it acts to accelerate any free electrons

electrons are the charge carriers «in copper»

Accept "free/valence/delocalised electrons".

metals/copper have many free electrons whereas insulators have few/no free electrons/charge carriers

The cable consists of 32 copper wires each of length 35 km. Each wire has a resistance of 64 Ω. The resistivity of copper is 1.7 x 10^{-8} Ω m.

10b. Calculate the radius of each **wire**. *[2 marks]*

Markscheme

area = $\frac{1.7 \times 10^{-3} \times 35 \times 10^{3}}{64}$ «= 9.3 x 10^{-6} m^2»

10c. There is a current of 730 A in the cable. Show that the power loss in 1 m of the cable is about 30 W. *[2 marks]*

Markscheme

«resistance of cable = 2Ω»

power dissipated in cable = 730^2 x 2 «= 1.07 MW»

power loss per meter $= \frac{1.07 \times 10^{-6}}{35 \times 10^{3}}$ ***or*** 30.6 «W m^{-1}»

*Allow **[2]** for a solution where the resistance per unit metre is calculated using resistivity and answer to (b)(i) (resistance per unit length of cable =5.7 x 10^{-5} m)*

10d. When the current is switched on in the cable the initial rate of rise of temperature of the cable is 35 mK s^{-1}. The specific heat capacity of copper is 390 J kg^{-1} K^{-1}. Determine the mass of a length of one metre of the cable. *[2 marks]*

Markscheme

30 = *m* x 390 x 3.5 x 10^{-2}

2.2 k«g»

Correct answer only.

---

11. Calculate the power dissipated in the cable. *[2 marks]*

Markscheme

power = «35^2 × 0.028» = 34 «W»

Allow 35 – 36 W if unrounded figures for R or I are used.
Allow ECF from (a)(i) and (a)(ii).

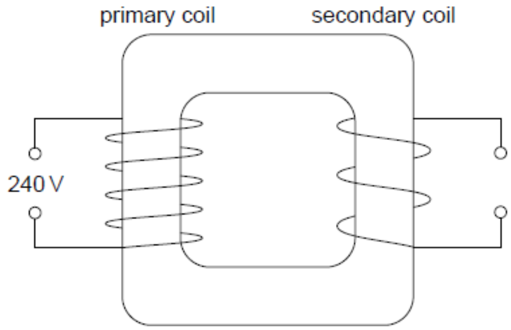
12a. State Faraday's law of induction. *[2 marks]*

Markscheme

the size of the induced emf
is proportional/equal to the rate of change of flux linkage

The word 'induced' is required here.
Allow correctly defined symbols from a correct equation. 'Induced' is required for MP1.

The diagram shows a sketch of an ideal step-down transformer.



The number of turns in the primary coil is 1800 and that in the secondary coil is 90.

12b. Explain, using Faraday's law of induction, how the transformer steps down the voltage. *[4 marks]*

Markscheme

varying voltage/current in primary coil produces a varying magnetic field

this produces a change in flux linkage / change in magnetic field in the secondary coil

a «varying» emf is induced/produced/generated in the secondary coil

voltage is stepped down as there are more turns on the primary than the secondary

Comparison of number of turns is required for MP4.

12c. The input voltage is 240 V. Calculate the output voltage. *[2 marks]*

Markscheme

output voltage $= \frac{90 \times 240}{1800}$

= 12 «V»

12d. Outline how energy losses are reduced in the core of a practical transformer. *[2 marks]*

Markscheme

laminated core reduces eddy currents

less thermal energy is transferred to the surroundings

12e. Step-up transformers are used in power stations to increase the voltage at which the electricity is transmitted. Explain why this is done. *[2 marks]*

Markscheme

for a certain power to be transmitted, large V means low I

less thermal energy loss as $P = I^2R$ / joule heating

The following data are available for a natural gas power station that has a high efficiency.

Rate of consumption of natural gas	$= 14.6\ \text{kg s}^{-1}$
Specific energy of natural gas	$= 55.5\ \text{MJ kg}^{-1}$
Efficiency of electrical power generation	= 59.0 %
Mass of CO_2 generated per kg of natural gas	= 2.75 kg
One year	$= 3.16 \times 10^7$ s

13a. Electrical power output is produced by several alternating current (ac) generators which use transformers to deliver energy to the national electricity grid. *[4 marks]*

The following data are available. Root mean square (rms) values are given.

ac generator output voltage to a transformer = 25 kV ac generator output current to a transformer = 3.9 kA Transformer output voltage to the grid = 330 kV Transformer efficiency = 96%

(i) Calculate the current output by the transformer to the grid. Give your answer to an appropriate number of significant figures.

(ii) Electrical energy is often delivered across large distances at 330 kV. Identify the main advantage of using this very high potential difference.

Markscheme

i

$I = 0.96 \times \left(\frac{25\times10^3\times3.9\times10^3}{330\times10^3}\right)$

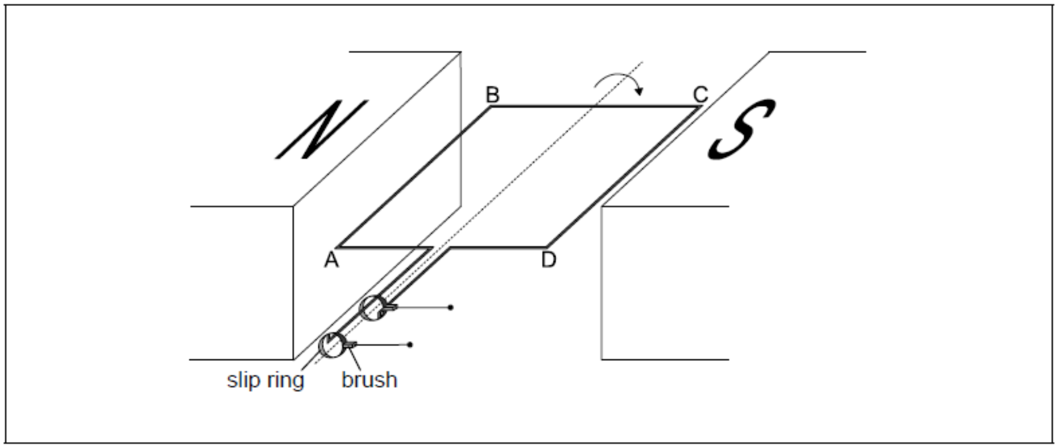
*Award **[2]** for a bald correct answer to 2 sf.*
*Award **[1 max]** for correct sf if efficiency used in denominator leading to 310 A or if efficiency ignored (e=1) leading to 300 A (from 295 A but 295 would lose both marks).*

=280 «A»
Must show two significant figures to gain MP2.

ii
higher V means lower *I* «for same power»

thermal energy loss depends on *I* ***or*** is $\propto I^2$ ***or*** is I^2R so thermal energy loss will be less
Accept "heat" or "heat energy" or "Joule heating" for "thermal energy".
Reference to energy/power dissipation is not enough.

13b. In an alternating current (ac) generator, a square coil ABCD rotates in a magnetic field. *[5 marks]*



The ends of the coil are connected to slip rings and brushes. The plane of the coil is shown at the instant when it is parallel to the magnetic field. Only one coil is shown for clarity.

The following data are available.

Dimensions of the coil = 8.5 cm×8.5 cm Number of turns on the coil = 80 Speed of edge AB = 2.0 ms^{-1} Uniform magnetic field strength = 0.34 T

(i) Explain, with reference to the diagram, how the rotation of the generator produces an electromotive force (emf) between the brushes.

(ii) Calculate, for the position in the diagram, the magnitude of the instantaneous emf generated by a **single** wire between A and B of the coil.

(iii) Hence, calculate the total instantaneous peak emf between the brushes.

Markscheme

i

«long» sides of coil AB/CD cut lines of flux
OR
flux «linkage» in coil is changed

«Faradays law:» induced emf depends on rate of change of flux linked
OR
rate at which lines are cut

"Induced" is required
Allow OWTTE or defined symbols if "induced emf" is given.
Accept "induced" if mentioned at any stage in the context of emf or accept the term "motional emf".
*Award **[2 max]** if there is no mention of "induced emf".*

emfs acting in sides AB/CD add / act in same direction around coil

process produces an alternating/sinusoidal emf

ii

$Blv = 0.34 \times 8.5 \times 10^{-2} \times 2 = 0.058$ «V»

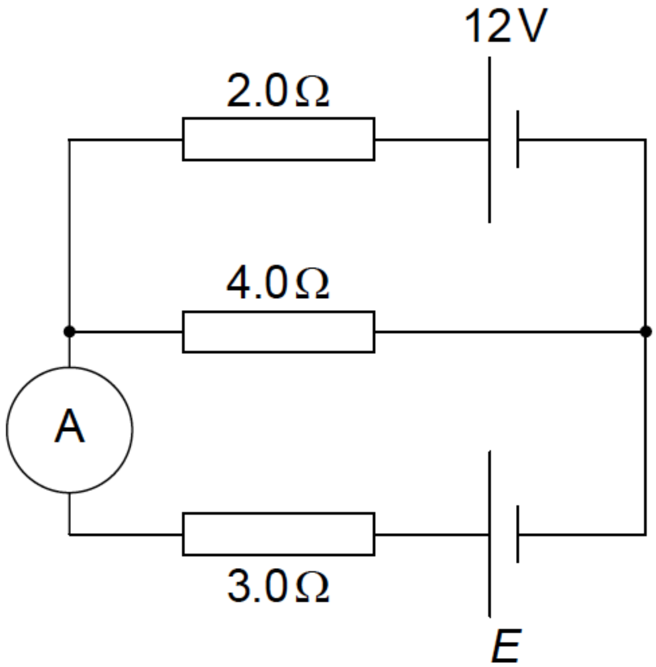
Accept 0.06V.

iii

160×(c)(ii) = 9.2 ***or*** 9.3 ***or*** 9.6 «V»

Allow ECF from (c)(ii)
If 80 turns used in cii, give full credit for cii x 2 here.

14a. Two cells of negligible internal resistance are connected in a circuit. *[2 marks]*



The top cell has electromotive force (emf) 12V. The emf of the lower cell is unknown. The ideal ammeter reads zero current.

Calculate the emf *E* of the lower cell.

Markscheme

ALTERNATIVE 1
correct application of Kirchhoff to at least one loop
E=«4.0×2.0=»8.0V

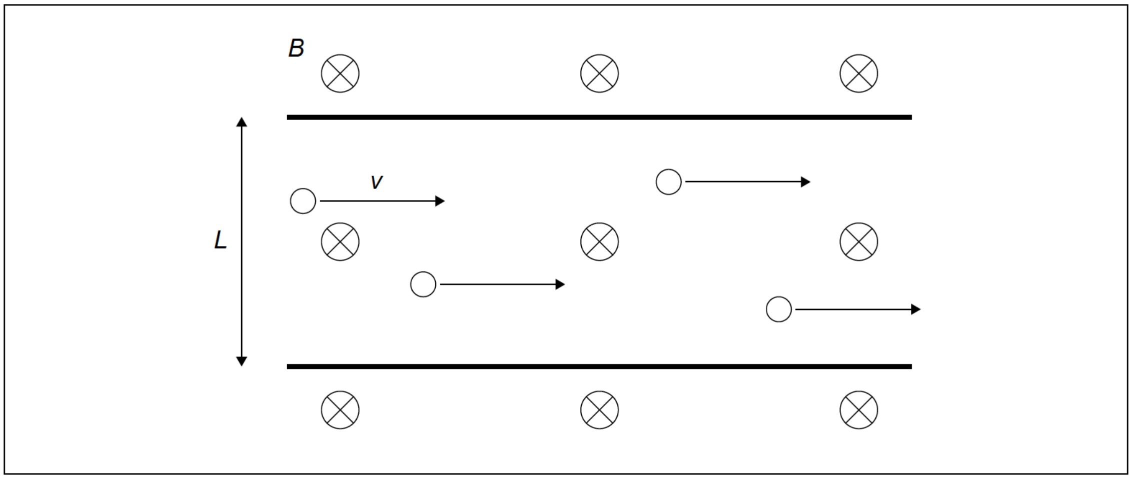
FOR EXAMPLE
12 = 2.0 I_1 + 4.0 I_2 for top loop with loop anticlockwise
«but I_2 = I_1 as I_3 = 0»
«*E* =» 8.0 V

ALTERNATIVE 2
«recognition that situation is simple potential divider arrangement»
pd across 4Ω resistor = $\frac{12\times4}{(2+4)}$

=8V

*Award **[0]** for any answer that begins with the treatment as parallel resistors.*

14b. The diagram shows charge carriers moving with speed *v* in a metallic conductor of width *L*. The conductor is exposed to a uniform magnetic field *B* that is directed into the page. *[3 marks]*



(i) Show that the potential difference *V* that is established across the conductor is given by *V*=*vBL*.

(ii) On the diagram, label the part of the conductor where negative charge accumulates.

Markscheme

(i)
ALTERNATIVE 1
equating electric to magnetic force *qE*=*qvB*

substituting $E = \frac{V}{L}$

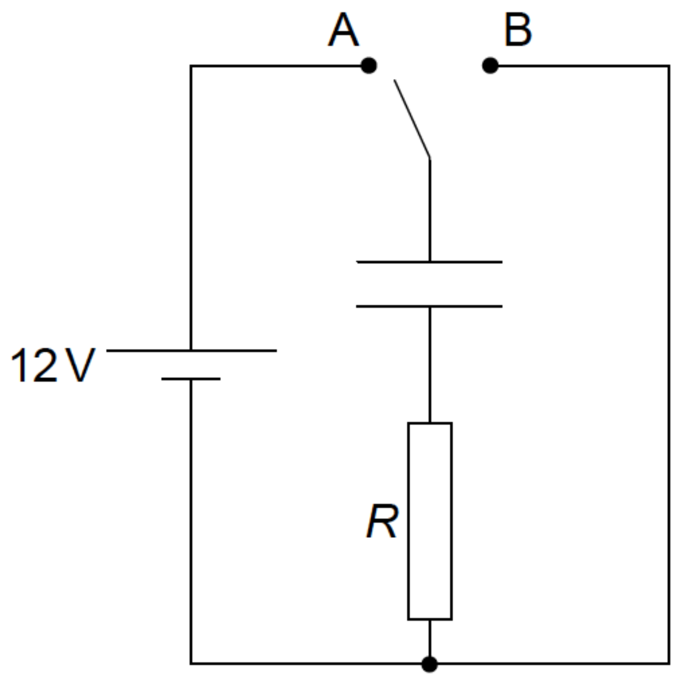
«to get given result»

ALTERNATIVE 2
$V = \frac{\text{workdone}}{Q}$ ***AND*** work done = force × distance
work done = *qv*=*Bqv*×*L*
«to get given result»

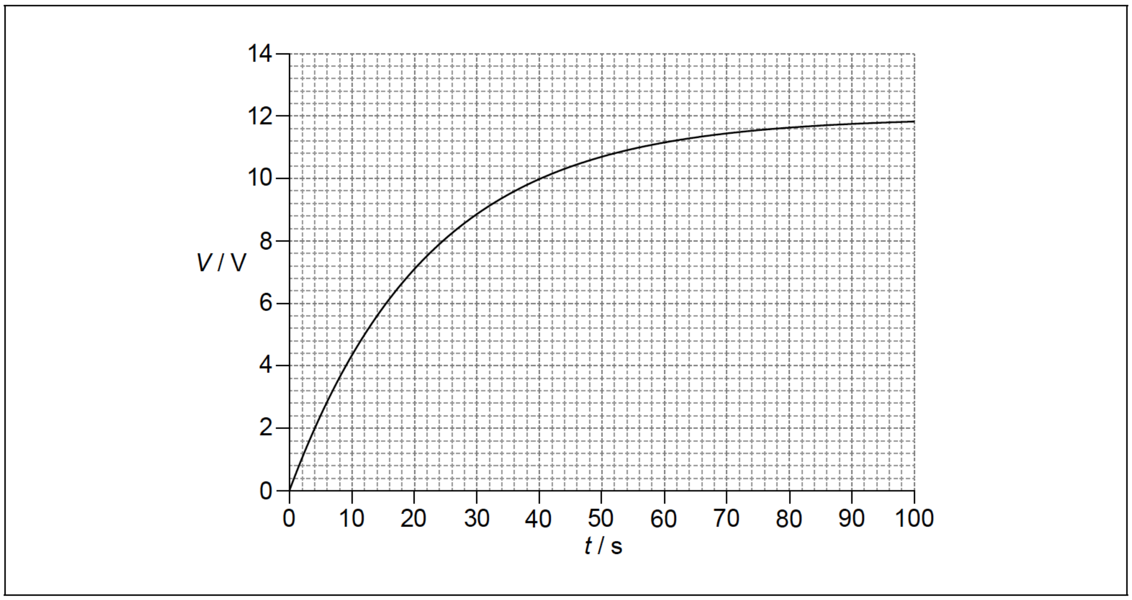
(ii)
some mark indicating lower surface of conductor
OR
indication that **positive** charge accumulates at top of conductor

Do not allow negative or positive at top ***and*** *bottom.*

An uncharged capacitor in a vacuum is connected to a cell of emf 12V and negligible internal resistance. A resistor of resistance *R* is also connected.

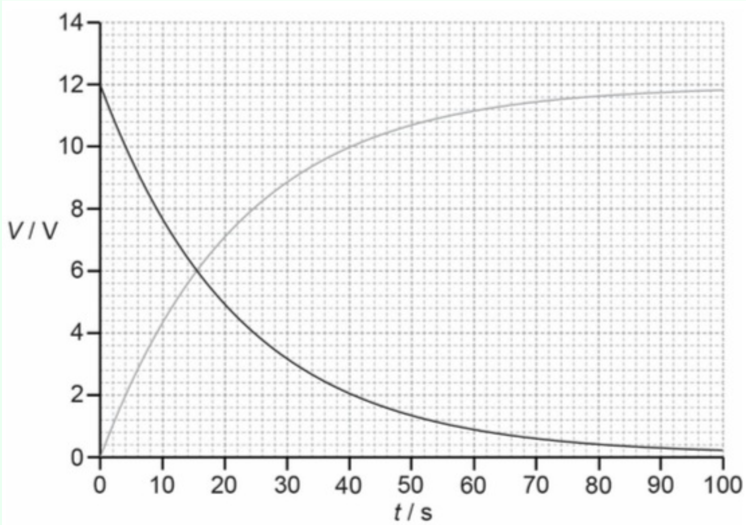


At t=0 the switch is placed at position A. The graph shows the variation with time t of the voltage V across the capacitor. The capacitor has capacitance 4.5μF in a vacuum.



15a. On the axes, draw a graph to show the variation with time of the voltage across the resistor. *[2 marks]*

Markscheme



general shape starting at 12 V
crosses at 6 V

Line must not touch time axis for MP2.

Allow tolerance of one square in 12 V (start) and 6 V (crossing).

15b. (i) The time constant of this circuit is 22s. State what is meant by the time constant. *[2 marks]*

(ii) Calculate the resistance *R*.

Markscheme

(i)
the time for the voltage/charge/current «in circuit» to drop to $\frac{1}{e}$ ***or*** 37% of its initial value

«as the capacitor discharges»

OR

time for voltage/charge/current «in circuit» to increase to $\left(1-\frac{1}{e}\right)$ ***or*** 63% of its final value

«as the capacitor charges»

(ii)
$R = \ll \frac{22}{4.5\times10^{-6}} = \gg 4.9\times10^{6}\Omega$

15c. A dielectric material is now inserted between the plates of the fully charged capacitor. State the effect, if any, on *[2 marks]*

(i) the potential difference across the capacitor.

(ii) the charge on one of the capacitor plates.

Markscheme

(i)
no change
OR
«remains at» 12 V

(ii)
increases
OR
doubles

Allow “doubles” in the light of (d).

15d. (i) The permittivity of the dielectric material in (c) is twice that of a vacuum. Calculate the energy stored in the capacitor when it is fully charged. *[3 marks]*

(ii) The switch in the circuit is now moved to position B and the fully charged capacitor discharges. Describe what happens to the energy in (d)(i).

Markscheme

(i)
recognises that new capacitance is 9.0 μF
$E = \ll \frac{1}{2}CV^2 = \frac{1}{2} \times 9.0 \times 10^{-6} \times 12^2 \gg = 0.65\text{mJ}$ or 6.5×10^{-4}J

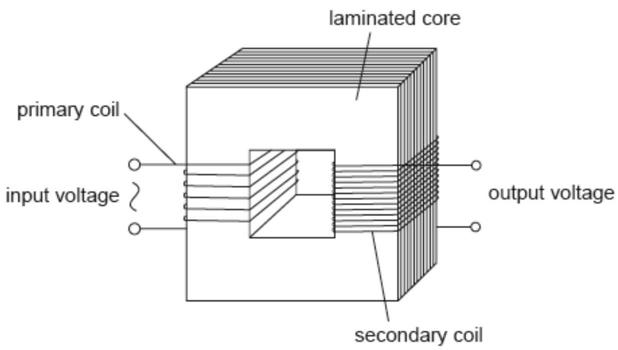
Allow 11.8 V (value on graph at t=100s).

(ii)
energy goes into the resistor/surroundings
OR
«energy transferred» into thermal/internal energy form

Do not accept “dissipated” without location or form.
Do not allow “heat”.

Part 2 Power transmissions

The diagram shows the main features of an ideal transformer whose primary coil is connected to a source of alternating current (ac) voltage.



16a. Outline, with reference to electromagnetic induction, how a voltage is induced across the secondary coil. *[3 marks]*

Markscheme

(alternating) pd/voltage across primary coil leads to (alternating) current (in primary coil);

hence there is a changing/alternating magnetic field in primary;

leading to a changing magnetic flux linked to/appearing in secondary;

according to Faraday's law, an alternating emf is induced in the secondary coil;

16b. The primary coil has 25 turns and is connected to an alternating supply with an input voltage of root mean squared (rms) value 12 V. The secondary coil has 80 turns and is not connected to an external circuit. Determine the peak voltage induced across the secondary coil. *[2 marks]*

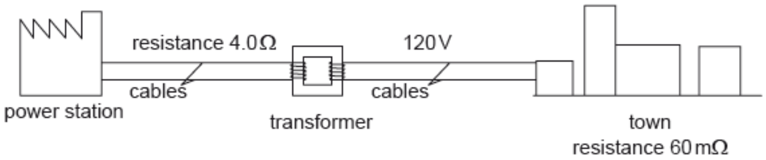
Markscheme

rms secondary voltage $= 38.4\ \mathrm{(V)}$;

peak voltage $= \left(38\sqrt{2} =\right)\ 54\ \mathrm{(V)}$; *(allow ECF from MP1)*

*Award **[2]** for a bald correct answer.*

A different transformer is used to transmit power to a small town.



The transmission cables from the power station to the transformer have a total resistance of 4.0 Ω. The transformer is 90% efficient and steps down the voltage to 120 V. At the time of maximum power demand the effective resistance of the town and of the cables from the transformer to the town is 60 mΩ.

16c. Calculate the current in the cables connected to the town *[1 mark]*

Markscheme

$\left(I_s = \frac{120}{60\times10^{-3}}\right) = 2.0\text{ k(A)}$; *(30 A is a common and incorrect answer)*

16d. Calculate the power supplied to the transformer. *[2 marks]*

Markscheme

power (supplied to town) $= 2.0 \times 10^3 \times 120$ ***or*** 2.4×10^5; *(allow ECF from (f)(i))*

power (supplied to transformer) $= \left(\frac{2.4\times10^5}{0.9} =\right) 2.67 \times 10^5\text{ (W)};\}$ *(30 A in (f)(i) leads to 4 kW)*

*Award **[2]** for a bald correct answer.*

16e. Determine the input voltage to the transformer if the power loss in the cables from the power station is 2.0 kW. *[2 marks]*

Markscheme

$I_p = \sqrt{\frac{2\times10^3}{4.0}} = 22.4\text{ (A)};$

$V = \frac{P}{I} = \frac{2.67\times10^5}{22.4} = 12\text{ k(V)};$

Allow ECF from (f)(i) and (f)(ii).

30 A and 4 kW earlier leads to 179 V.

*Award **[2]** for a bald correct answer.*

16f. Outline why laminating the core improves the efficiency of a transformer. *[2 marks]*

Markscheme

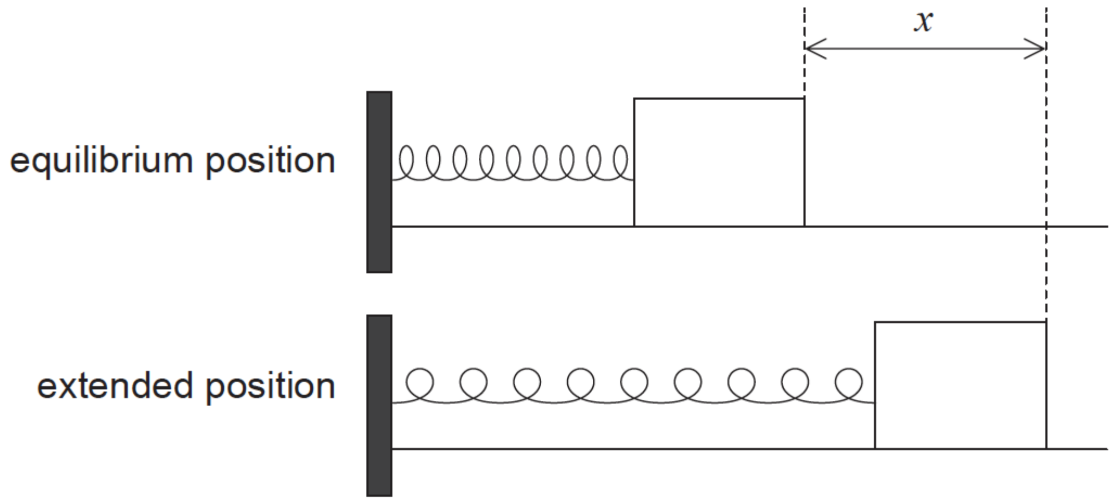
laminations increase resistance / reduce current in core material/metal / reduce eddy currents;

thus reducing I^2R/power/(thermal) energy/heat losses in the core;

This question is in two parts. **Part 1** is about simple harmonic motion (SHM). **Part 2** is about current electricity.

Part 1 Simple harmonic motion (SHM)

An object is placed on a frictionless surface. The object is attached by a spring fixed at one end and oscillates at the end of the spring with simple harmonic motion (SHM).



The tension *F* in the spring is given by *F* = *k x* where *x* is the extension of the spring and *k* is a constant.

17a. Show that $\omega^2 = \frac{k}{m}$. *[2 marks]*

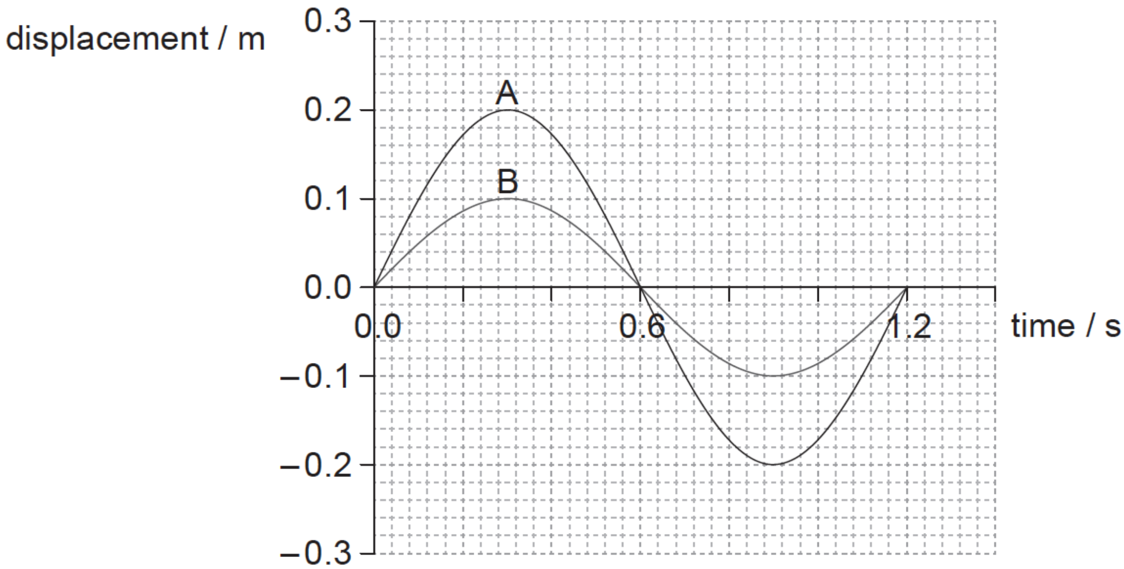
Markscheme

ma
$= -kx$;
$a = -\frac{k}{m}x$; (*condone lack of negative sign*)
$\left(\omega^2 = \frac{k}{m}\right)$

or

implied use of defining equation for simple harmonic motion $a = -\omega^2 x$;
$\left(\text{so}\omega^2 = \frac{k}{m}\right)$
$ma = -kx$ so $a = -\left(\frac{k}{m}\right)x$;

17b. One cycle of the variation of displacement with time is shown for two separate mass–spring systems, A and B. *[3 marks]*



(i) Calculate the frequency of the oscillation of A.

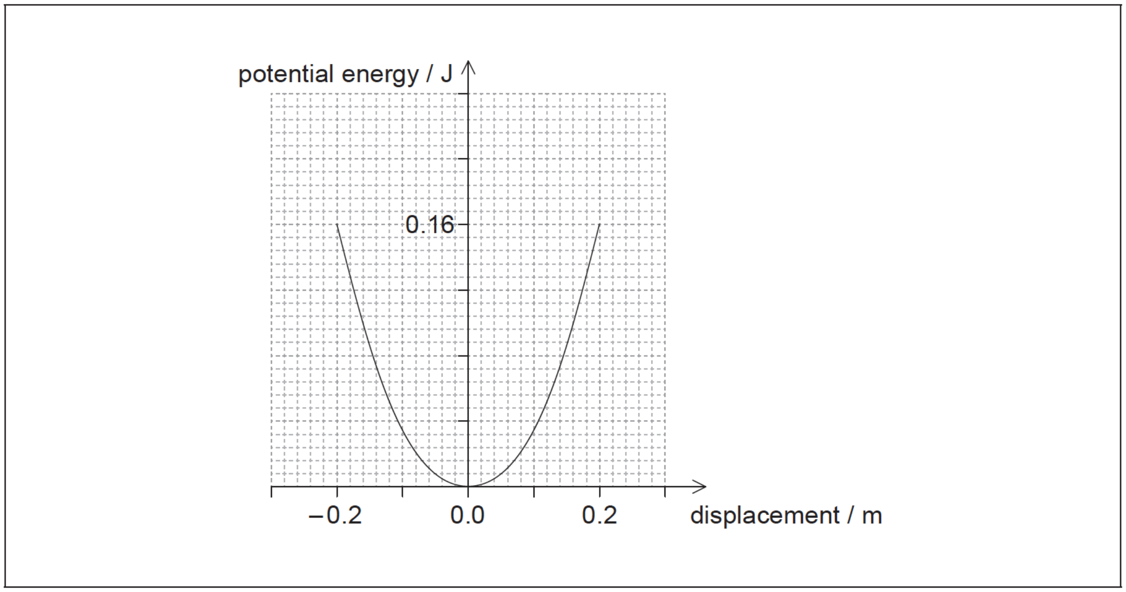
(ii) The springs used in A and B are identical. Show that the mass in A is equal to the mass in B.

Markscheme

(i) 0.833 (Hz);

(ii) frequency/period is the same so ω is the same;
k is the same (as springs are identical);
(so *m* is the same)

17c. The graph shows the variation of the potential energy of A with displacement. *[5 marks]*



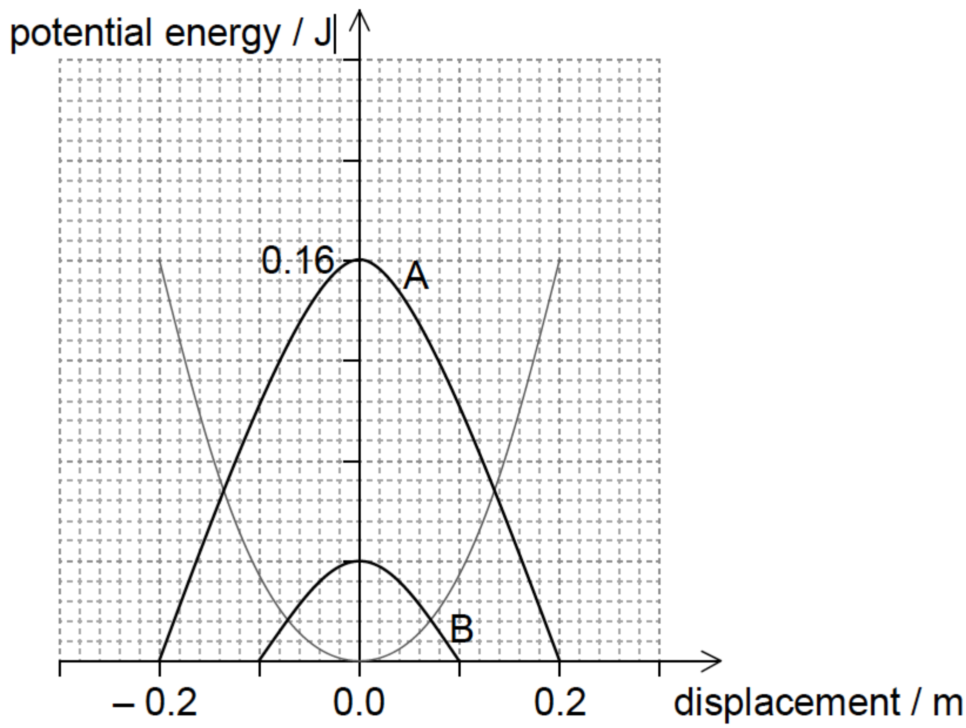
On the axes,

(i) draw a graph to show the variation of kinetic energy with displacement for the mass in A. Label this A.

(ii) sketch a graph to show the variation of kinetic energy with displacement for the mass in B. Label this B.

Markscheme

(i)



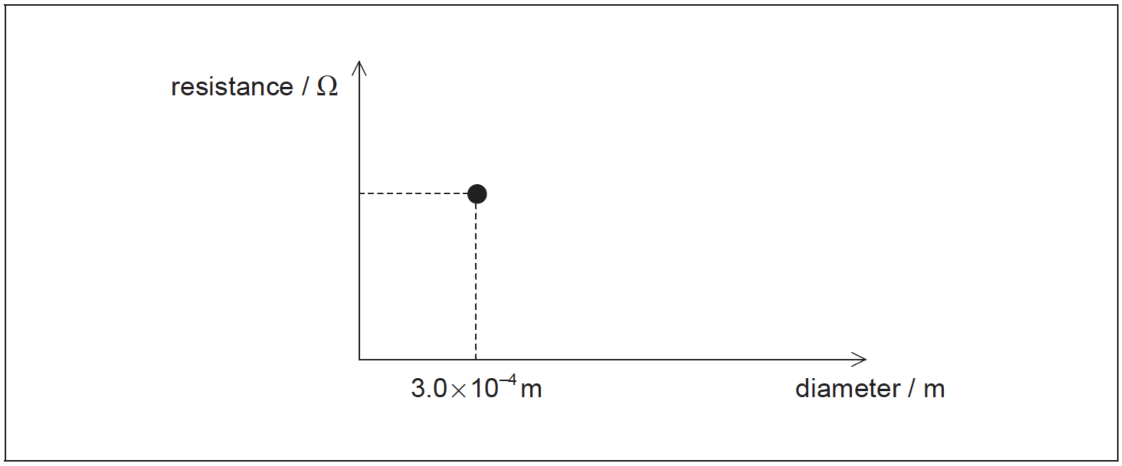
correct shape;
maximum at 0.16 J;

(ii) end displacements correct $\pm$ 0.01m;
maximum lower than 0.16J;
maximum equal to 0.04J $\pm$ half square;

17d. A 24 Ω resistor is made from a conducting wire. *[4 marks]*

(i) The diameter of the wire is 0.30 mm and the wire has a resistivity of 1.7 $\times 10^{-8}$Ωm. Calculate the length of the wire.

(ii) On the axes, draw a graph to show how the resistance of the wire in (d)(i) varies with the diameter of the wire when the length is constant. The data point for the diameter of 0.30 mm has already been plotted for you.



Markscheme

(i) $l = \frac{\pi d^2 R}{4\rho}$ seen / correct substitution

into equation: $24 = \frac{l \times 1.7 \times 10^{-8}}{\pi \times (0.15 \times 10^{-3})^2}$; } (*condone use of r for* $\frac{d}{2}$ *in first alternative)*

99.7 (m);
*Award **[2]** for bald correct answer.*
*Award **[1 max]** if area is incorrectly calculated, answer is 399 m if conversion to radius ignored, ie: allow ECF for second marking point if area is incorrect provided working clear.*

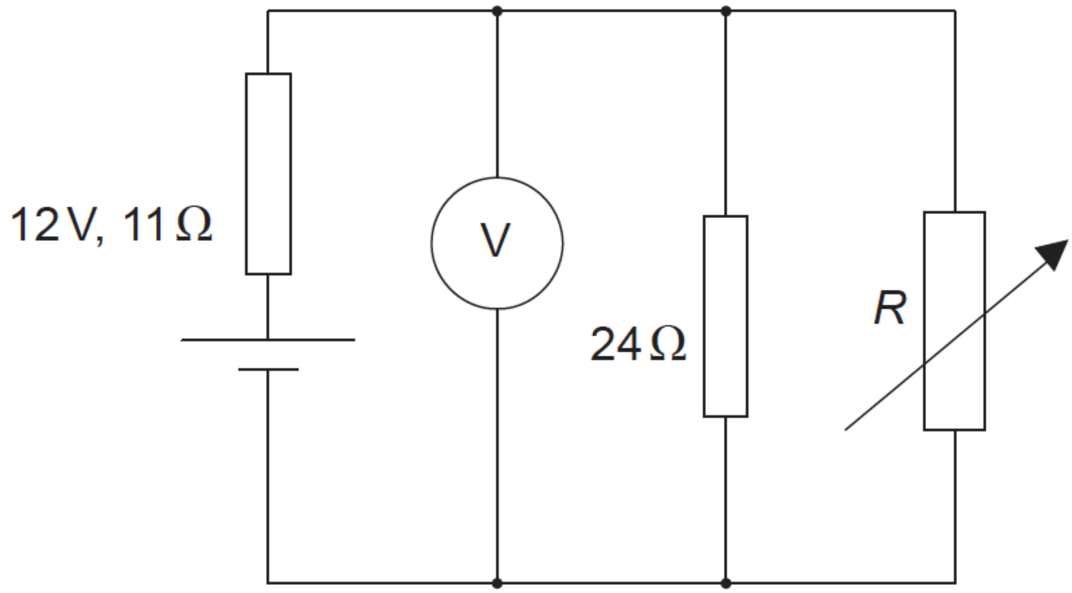
(ii) any line showing resistance decreasing with increasing diameter **and** touching point;
correct curved shape showing asymptotic behavior on at least one axis;

17e. The 24 Ω resistor is covered in an insulating material. Explain the reasons for the differences between the electrical properties of the insulating material and the electrical properties of the wire. *[3 marks]*

Markscheme

current/conduction is (related to) flow of charge;
conductors have many electrons free/unbound / electrons are the charge carriers / insulators have few free electrons;
pd/electric field accelerates/exerts force on electrons;
smaller current in insulators as fewer electrons available / larger current in conductors as more electrons available;

17f. An electric circuit consists of a supply connected to a 24Ω resistor in parallel with a variable resistor of resistance *R*. The supply has an emf of 12V and an internal resistance of 11Ω. *[8 marks]*



Power supplies deliver maximum power to an external circuit when the resistance of the external circuit equals the internal resistance of the power supply.

(i) Determine the value of *R* for this circuit at which maximum power is delivered to the external circuit.

(ii) Calculate the reading on the voltmeter for the value of *R* you determined in (f)(i).

(iii) Calculate the total power dissipated in the circuit when the maximum power is being delivered to the external circuit.

Markscheme

(i) use of total resistance = 11Ω; *(can be seen in second marking point)*
$\frac{1}{11} = \frac{1}{R} + \frac{1}{24}$;
20.3(Ω) ;

(ii) as current is same in resistor network and cell and resistance is same, half of emf must appear across resistor network;
6.0 (V);

or

$I = \frac{12}{(11+11)} = 0.545\,(\mathrm{A})$;
V=(0.545×11=) 6.0 (V);

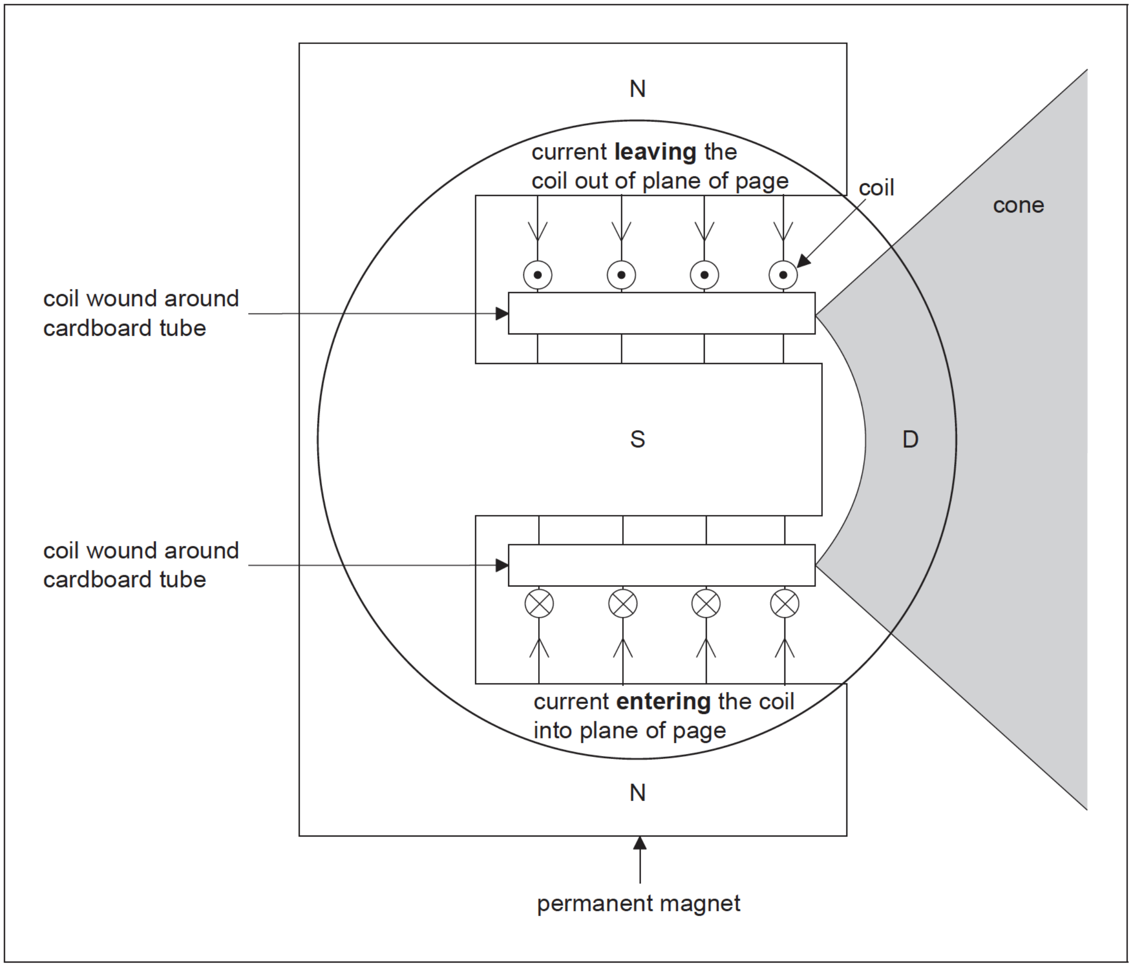
Other calculations are acceptable.
*Award **[2]** for a bald correct answer.*

(iii) use of 22 (ohm) ***or*** 11+11 (ohm) seen;
use of $\frac{V^2}{R}$ or equivalent;
6.54 (W);
*Award **[3]** for bald correct answer.*
*Award **[2 max]** if cell internal resistance ignored, yields 3.27 V.*

This question is in two parts. **Part 1** is about the electrical and magnetic characteristics of a loudspeaker. **Part 2** is about vibrations and waves.

Part 1 Electrical and magnetic characteristics of a loudspeaker

The diagram shows the main features of a loudspeaker L. A current-carrying coil is positioned within the magnetic field provided by a permanent magnet. The diagram also shows the directions of the magnetic field and of the current in the coil at a particular instant. The dust cap D prevents dust from blocking the gap between the cardboard tube and the south pole of the magnet.



The coil consists of 150 turns, each of average diameter 2.5 cm. The magnetic field of the permanent magnet has strength 0.40 mT. The peak current in the coil is 0.45 mA.

18a. Identify, **on the diagram**, the direction of the force on the coil with the current directions shown. *[2 marks]*

Markscheme

force in correct location on diagram, ie arrow on coil;
force direction to the right;
Award [1 max] if any other forces drawn.

18b. Calculate the maximum magnetic force acting on the coil. *[3 marks]*

Markscheme

$L = (2\pi rN) = 2 \times \pi \times 1.25 \times 10^{-2} \times 150 = (11.8)\,\mathrm{m}$;

$F = (\mathrm{BIL}) = 0.40 \times 10^{-3} \times 0.45 \times 10^{-3} \times 11.8$;

$= 2.1 \times 10^{-6}\mathrm{N}/2.1\mu\mathrm{N}$

18c. Explain, with reference to electromagnetic induction, the effect of the motion of the coil on the current. *[3 marks]*

Markscheme

(as the coil moves the) conductor cuts the magnetic field / there is a change in flux linkage;
induces an emf across the coil / a current through the coil;
opposes the driving potential difference;
reduces the (net) current;

This question is in **two** parts. **Part 1** is about the motion of a car. **Part 2** is about electricity.

Part 1 Motion of a car

19a. A car accelerates uniformly along a straight horizontal road from an initial speed of $12\,\mathrm{m\,s^{-1}}$ to a final speed of $28\,\mathrm{m\,s^{-1}}$ in a distance of 250 m. The mass of the car is 1200 kg. Determine the rate at which the engine is supplying kinetic energy to the car as it accelerates. *[4 marks]*

Markscheme

use of a kinematic equation to determine motion time $(= 12.5\ \mathrm{s})$;

change in kinetic energy $= \frac{1}{2} \times 1200 \times \left[28^2 - 12^2\right]\ (= 384\ \mathrm{kJ})$;

rate of change in kinetic energy $= \frac{384000}{12.5};\}$ *(allow ECF of 162 from (28 – 12)^2 for this mark)*

31 (kW);

or

use of a kinematic equation to determine motion time $(= 12.5\ \mathrm{s})$;

use of a kinematic equation to determine acceleration $(= 1.28\,\mathrm{m\,s^{-2}})$;

work done $= \frac{F \times s}{\mathrm{time}} = \frac{1536 \times 250}{12.5}$;

31 (kW);

A car is travelling along the straight horizontal road at its maximum speed of 56 m s^{-1}. The power output required at the wheels is 0.13 MW.

19b. A car is travelling along a straight horizontal road at its maximum speed of 56 m s^{-1}. *[5 marks]*
The power output required at the wheels is 0.13 MW.

(i) Calculate the total resistive force acting on the car when it is travelling at a constant speed of 56 m s^{-1}.

(ii) The mass of the car is 1200 kg. The resistive force F is related to the speed v by $F \propto v^2$. Using your answer to (b)(i), determine the maximum theoretical acceleration of the car at a speed of 28 m s^{-1}.

Markscheme

(i) $\text{force} = \frac{\text{power}}{\text{speed}}$;

2300 ***or*** 2.3k (N);

*Award **[2]** for a bald correct answer.*

(ii) resistive force $= \frac{2300}{4}$ ***or*** $\frac{2321}{4}$ $(= 575)$; *(allow ECF)*

so accelerating force = $(2300 - 580 =)\ 1725\ (\text{N})$ ***or*** 1741 (N);

$a = \frac{1725}{1200} = 1.44\ (\text{ms}^{-2})$ ***or*** $a = \frac{1741}{1200} = 1.45\ (\text{m s}^{-2})$;

*Award **[2 max]** for an answer of 0.49 (m s^{-2}) (omits 2300 N).*

A driver moves the car in a horizontal circular path of radius 200 m. Each of the four tyres will not grip the road if the frictional force between a tyre and the road becomes less than 1500 N.

19c. (i) Calculate the maximum speed of the car at which it can continue to move in the circular path. Assume that the radius of the path is the same for each tyre. *[6 marks]*

(ii) While the car is travelling around the circle, the people in the car have the sensation that they are being thrown outwards. Outline how Newton's first law of motion accounts for this sensation.

Markscheme

(i) centripetal force must be $< 6000\ (\text{N})$; *(allow force = 6000 N)*

$v^2 = F \times \frac{r}{m}$;

$31.6\ (\text{m s}^{-1})$;

*Allow **[3]** for a bald correct answer.*

*Allow **[2 max]** if 4$\times$ is omitted, giving 15.8 (m s^{-1}).*

(ii) statement of Newton's first law;

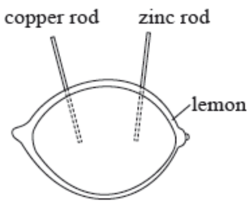
(hence) without car wall/restraint/friction at seat, the people in the car would move in a straight line/at a tangent to circle;

(hence) seat/seat belt/door exerts centripetal force;

(in frame of reference of the people) straight ahead movement is interpreted as "outwards";

Part 2 Electricity

A lemon can be used to make an electric cell by pushing a copper rod and a zinc rod into the lemon.



A student constructs a lemon cell and connects it in an electrical circuit with a variable resistor. The student measures the potential difference *V* across the lemon and the current *I* in the lemon.

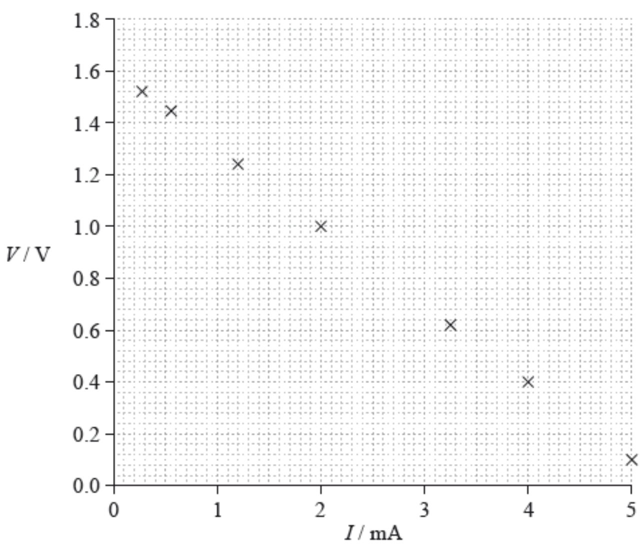
19d. (i) Draw a circuit diagram of the experimental arrangement that will enable the student to collect the data for the graph. *[10 marks]*

(ii) Show that the potential difference V across the lemon is given by

$$V = E - Ir$$

where E is the emf of the lemon cell and r is the internal resistance of the lemon cell.

(iii) The graph shows how V varies with I.



Using the graph, estimate the emf of the lemon cell.

(iv) Determine the internal resistance of the lemon cell.

(v) The lemon cell is used to supply energy to a digital clock that requires a current of $6.0\ \mu\text{A}$. The clock runs for 16 hours. Calculate the charge that flows through the clock in this time.

Markscheme

(i) voltmeter in parallel with cell; *(allow ammeter within voltmeter leads)*

ammeter in series with variable resistor; } *(must draw as variable arrangement or as potential divider)*

Allow cell symbol for lemon/cell/box labelled "lemon cell".

*Award **[1 max]** if additional cell appears in the circuit.*

(ii) $E = I(R + r)$ and $V = IR$ used; *(must state both explicitly)*

re-arrangement correct *ie* $E = V + Ir$; } *(accept any other correct re-arrangement eg. involving energy conversion)*

(iii) line correctly extrapolated to *y*-axis; *(judge by eye)*

1.6 ***or*** 1.60 (V); *(allow ECF from incorrect extrapolation)*

(iv) correct read-offs from large triangle greater than half line length;

gradient determined;

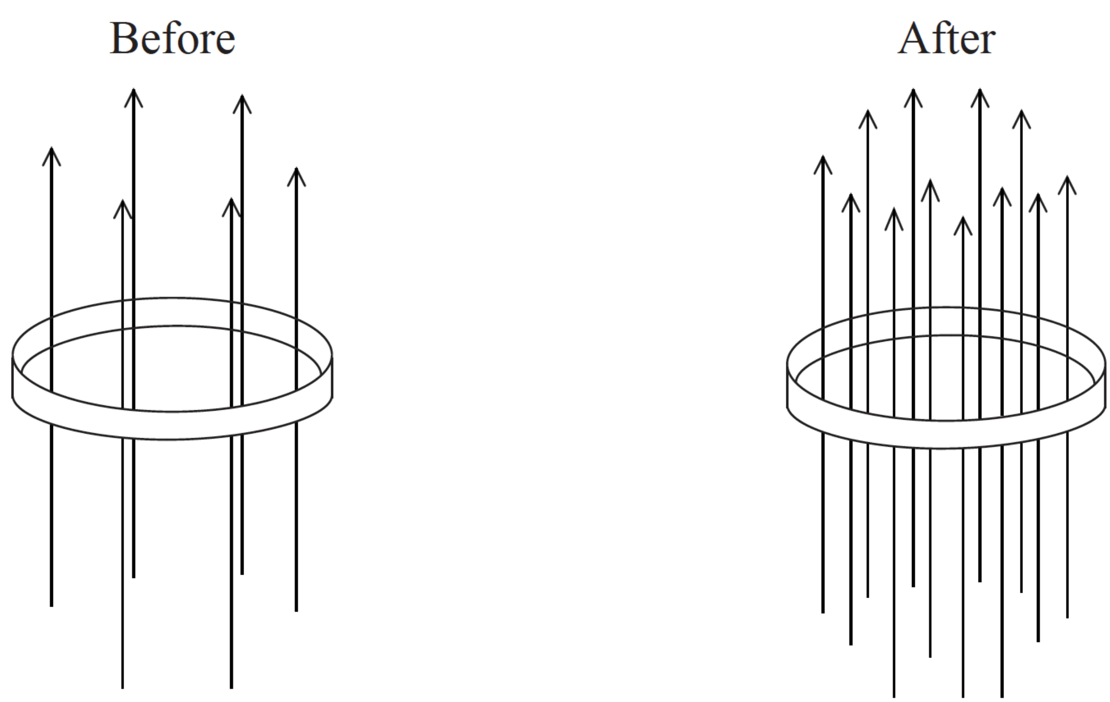
290 to 310 (Ω);

*Award **[2 max]** for the use of one point on line and equation.*

(v) 0.35 (C);

This question is about electromagnetic induction.

A metal ring is placed in a magnetic field which is directed upwards. The magnetic flux through the ring increases over a time interval.



20a. State and explain the direction of the current induced in the ring during this change. *[3 marks]*

Markscheme

field caused by (induced) current must be downwards;
to oppose the change that produced it;
hence the current must be clockwise;

20b. The following data are available. *[3 marks]*

Resistance of ring = $3.0\times10^{-3}\Omega$
Initial magnetic flux = 1.2×10^{-5}Wb
Final magnetic flux = 2.4×10^{-5}Wb
Time interval = 2.0×10^{-3}s

Calculate the average current induced in the ring.

Markscheme

$\varepsilon = \left(\frac{\Delta\Phi}{\Delta t} =\right) \frac{2.4\times10^{-5}-1.2\times10^{-5}}{2.0\times10^{-3}}$ or 6.0×10^{-3}(v);

$I = \left(\frac{\varepsilon}{R} = \frac{6.0\times10^{-3}}{3.0\times10^{-3}} =\right) 2.0\,(\mathrm{A})$;
*Award **[2]** for a bald correct answer.*