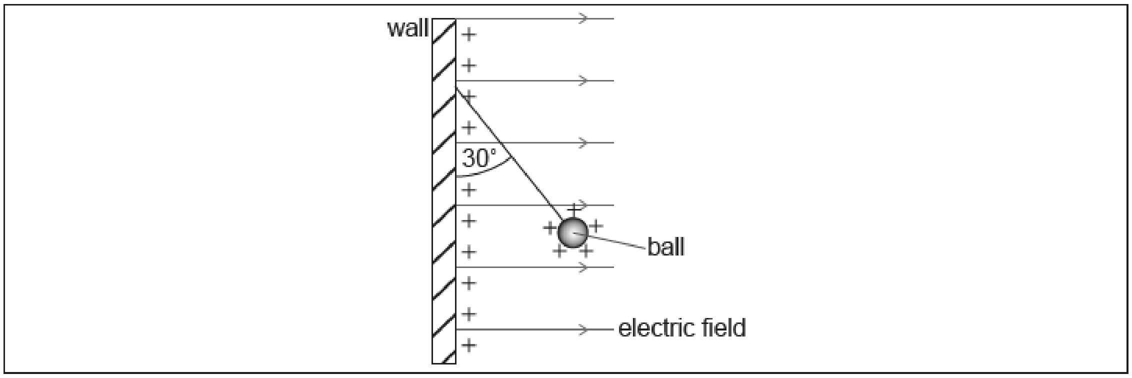
Yellow [very common] *[171 marks]*

A vertical wall carries a uniform positive charge on its surface. This produces a uniform horizontal electric field perpendicular to the wall. A small, positively-charged ball is suspended in equilibrium from the vertical wall by a thread of negligible mass.



1a. The charge per unit area on the surface of the wall is σ. It can be shown that the electric field strength E due to the charge on the wall is given by the equation *[2 marks]*

$E = \frac{\sigma}{2\varepsilon_0}$.

Demonstrate that the units of the quantities in this equation are consistent.

Markscheme

identifies units of σ as $\mathrm{C\,m^{-2}}$ ✓

$\frac{C}{m^2} \times \frac{Nm^2}{C^2}$ seen and reduced to $\mathrm{N\,C^{-1}}$ ✓

Accept any analysis (eg dimensional) that yields answer correctly

1b. The thread makes an angle of 30° with the vertical wall. The ball has a mass of 0.025 kg. *[3 marks]*

Determine the horizontal force that acts on the ball.

Markscheme

horizontal force F on the ball$= T\sin 30$ ✓

$T = \frac{mg}{\cos 30}$ ✓

F«$= mg\tan 30 = 0.025 \times 9.8 \times \tan 30$»$= 0.14$ «N» ✓

Allow g = 10 N kg^{-1}

*Award **[3] marks** for a bald correct answer.*

*Award **[1max]** for an answer of zero, interpreting that the horizontal force refers to the horizontal component of the net force.*

1c. The charge on the ball is 1.2×10^{-6} C. Determine σ. *[2 marks]*

Markscheme

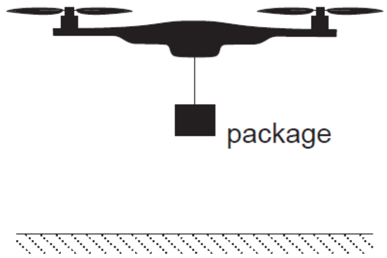
$E = \frac{0.14}{1.2\times10^{-6}}$«$= 1.2 \times 10^{5}$» ✓

$\sigma =$ «$\frac{2\times8.85\times10^{-12}\times0.14}{1.2\times10^{-6}}$»$= 2.1 \times 10^{-6}$ «$\mathrm{C\,m^{-2}}$» ✓

*Allow **ECF** from the calculated F in (b)(i)*

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

A company delivers packages to customers using a small unmanned aircraft. Rotating horizontal blades exert a force on the surrounding air. The air above the aircraft is initially stationary.



The air is propelled vertically downwards with speed v. The aircraft hovers motionless above the ground. A package is suspended from the aircraft on a string. The mass of the aircraft is $0.95\,\text{kg}$ and the combined mass of the package and string is $0.45\ \text{kg}$. The mass of air pushed downwards by the blades in one second is $1.7\ \text{kg}$.

2a. State the value of the resultant force on the aircraft when hovering. *[1 mark]*

Markscheme

zero ✓

2b. Outline, by reference to Newton’s third law, how the upward lift force on the aircraft is achieved. *[2 marks]*

Markscheme

Blades exert a downward force on the air ✓

air exerts an equal and opposite force on the blades «by Newton’s third law»
OR
air exerts a reaction force on the blades «by Newton’s third law» ✓

*Downward direction required for **MP1**.*

2c. Determine v. State your answer to an appropriate number of significant figures. *[3 marks]*

Markscheme

«lift force/change of momentum in one second» $= 1.7v$ ✓

$1.7v = (0.95 + 0.45) \times 9.81$ ✓

$v = 8.1$ «$\mathrm{ms^{-1}}$» ***AND*** answer expressed to 2 sf only ✓

Allow 8.2 from $g = 10\ ms^{-2}$.

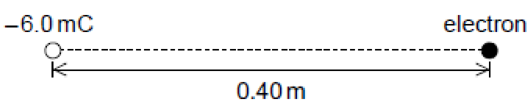
2d. The package and string are now released and fall to the ground. The lift force on the aircraft remains unchanged. Calculate the initial acceleration of the aircraft. *[2 marks]*

Markscheme

vertical force = lift force – weight ***OR*** $= 0.45 \times 9.81$ ***OR*** $= 4.4$ «N» ✓

acceleration$= \frac{0.45 \times 9.81}{0.95} = 4.6$ «$\mathrm{ms^{-2}}$» ✓

An electron is placed at a distance of 0.40 m from a fixed point charge of –6.0 mC.



3a. Show that the electric field strength due to the point charge at the position of the electron is 3.4×10^8 N C^{-1}. *[2 marks]*

Markscheme

$E = \frac{k \times q}{r^2}$ ✔

$E = \frac{8.99 \times 10^9 \times 6.0 \times 10^{-3}}{0.4^2}$ ***OR*** $E = 3.37 \times 10^8$ «$\mathrm{N\ C^{-1}}$» ✔

NOTE: Ignore any negative sign.

3b. Calculate the magnitude of the initial acceleration of the electron. *[2 marks]*

Markscheme

$F = q \times E$ ***OR*** $F = 1.6 \times 10^{-19} \times 3.4 \times 10^{8} = 5.4 \times 10^{-11}$ «N» ✔

$a =$ «$\frac{5.4 \times 10^{-11}}{9.1 \times 10^{-31}} =$» 5.9×10^{19}«$\mathrm{m\ s^{-2}}$»✔

NOTE: Ignore any negative sign.
*Award **[1]** for a calculation leading to $a =$ «$\mathrm{m\ s^{-2}}$»*
*Award **[2]** for bald correct answer*

3c. Describe the subsequent motion of the electron. *[3 marks]*

Markscheme

the electron moves away from the point charge/to the right «along the line joining them» ✔
decreasing acceleration ✔
increasing speed ✔

NOTE: Allow ECF from MP1 if a candidate mistakenly evaluates the force as attractive so concludes that the acceleration will increase

A student strikes a tennis ball that is initially at rest so that it leaves the racquet at a speed of 64 m s^{-1}. The ball has a mass of 0.058 kg and the contact between the ball and the racquet lasts for 25 ms.

4a. Calculate the average force exerted by the racquet on the ball. *[2 marks]*

Markscheme

$F = \frac{\Delta mv}{\Delta t} / m\frac{\Delta v}{\Delta t} / \frac{0.058 \times 64.0}{25 \times 10^{-3}}$ ✔

F = 148«N»≈150«N» ✔

4b. Calculate the average power delivered to the ball during the impact. *[2 marks]*

Markscheme

ALTERNATIVE 1

$P = \frac{\frac{1}{2}mv^2}{t} / \frac{\frac{1}{2}\times 0.058\times 64.0^2}{25\times 10^{-3}}$ ✔

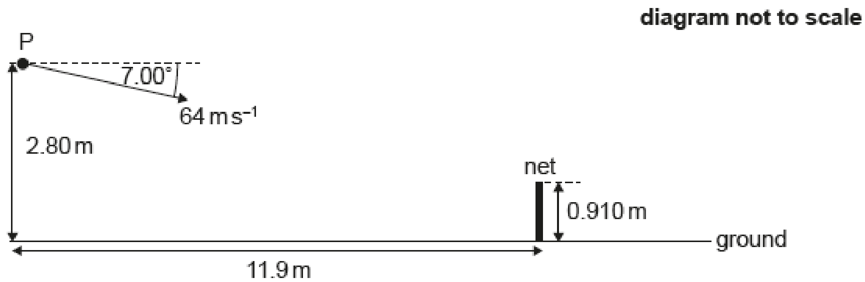
$P = 4700/4800$«W» ✔

ALTERNATIVE 2

$P = \text{average}Fv/148 \times \frac{64.0}{2}$ ✔

$P = 4700/4800$«W» ✔

The student strikes the tennis ball at point P. The tennis ball is initially directed at an angle of 7.00° to the horizontal.



The following data are available.

Height of P = 2.80 m

Distance of student from net = 11.9 m

Height of net = 0.910 m

Initial speed of tennis ball = 64 m s^{-1}

4c. Calculate the time it takes the tennis ball to reach the net. *[2 marks]*

Markscheme

horizontal component of velocity is 64.0 × cos7° = 63.52 «ms^{-1}» ✔

$t =$ «$\frac{11.9}{63.52} =$» $0.187/0.19$«s» ✔

Do not award BCA. Check working.

Do not award ECF from using 64 m s^{-1}.

4d. Show that the tennis ball passes over the net. *[3 marks]*

Markscheme

ALTERNATIVE 1

$u_y = 64 \sin 7 / 7.80$ «ms^{-1}» ✔

decrease in height = 7.80 × 0.187 + $\frac{1}{2}$ × 9.81 × 0.187^2/1.63 «m» ✔

final height = «2.80 − 1.63» = 1.1/1.2 «m» ✔

«higher than net so goes over»

ALTERNATIVE 2

vertical distance to fall to net «= 2.80 − 0.91» = 1.89 «m» ✔

time to fall this distance found using «=1.89 = $7.8t + \frac{1}{2} \times 9.81 \times t^2$»

t = 0.21 «s» ✔

0.21 «s» > 0.187 «s» ✔

«reaches the net before it has fallen far enough so goes over»

Other alternatives are possible

4e. Determine the speed of the tennis ball as it strikes the ground. *[2 marks]*

Markscheme

ALTERNATIVE 1

Initial KE + PE = final KE /

$\frac{1}{2} \times 0.058 \times 64^2 + 0.058 \times 9.81 \times 2.80 = \frac{1}{2} \times 0.058 \times v^2$ ✔

v = 64.4 «ms^{-1}» ✔

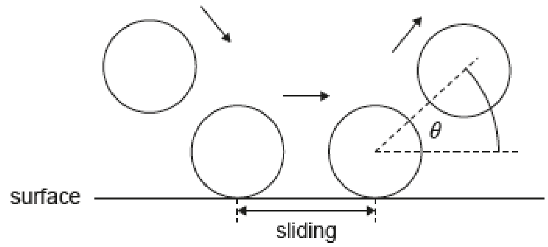
ALTERNATIVE 2

$v_v =$ «$\sqrt{7.8^2 + 2 \times 9.81 \times 2.8}$» $= 10.8$«ms^{-1}» ✔

« $v = \sqrt{63.5^2 + 10.8^2}$ »

$v = 64.4$«ms^{-1}» ✔

4f. The student models the bounce of the tennis ball to predict the angle θ *[3 marks]*
at which the ball leaves a surface of clay and a surface of grass.



The model assumes

- during contact with the surface the ball slides.
- the sliding time is the same for both surfaces.
- the sliding frictional force is greater for clay than grass.
- the normal reaction force is the same for both surfaces.

Predict for the student's model, without calculation, whether θ is greater for a clay surface or for a grass surface.

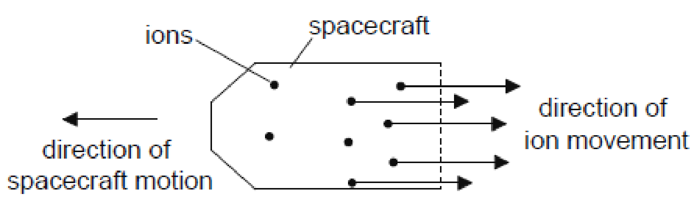
Markscheme

so horizontal velocity component at lift off for clay is smaller ✔

normal force is the same so vertical component of velocity is the same ✔

so bounce angle on clay is greater ✔

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.

5a. 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.

5b. 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}» ✔

5c. Outline why scientists sometimes use estimates in making calculations. *[1 mark]*

Markscheme

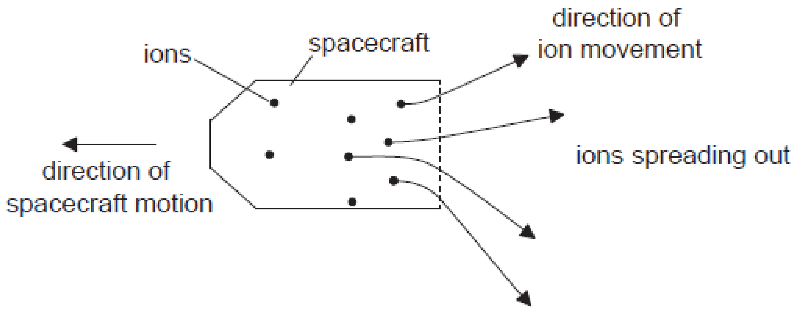
problem may be too complicated for exact treatment ✔

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.



5d. Outline why the ions are likely to spread out. *[2 marks]*

Markscheme

ions have same (sign of) charge ✔

ions repel each other ✔

5e. 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.

5f. Outline what is meant by the gravitational field strength at a point. *[2 marks]*

Markscheme

force per unit mass ✔

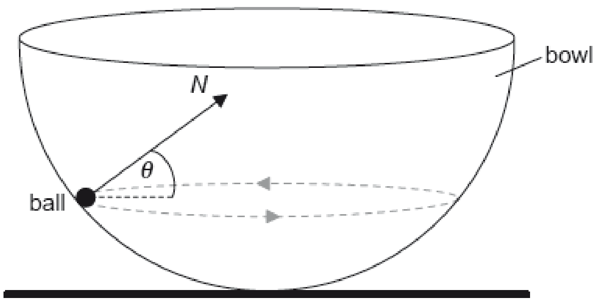
acting on a small/test/point mass «placed at the point in the field» ✔

5g. 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 small ball of mass m is moving in a horizontal circle on the inside surface of a frictionless hemispherical bowl.



The normal reaction force N makes an angle θ to the horizontal.

6a. State the direction of the resultant force on the ball. *[1 mark]*

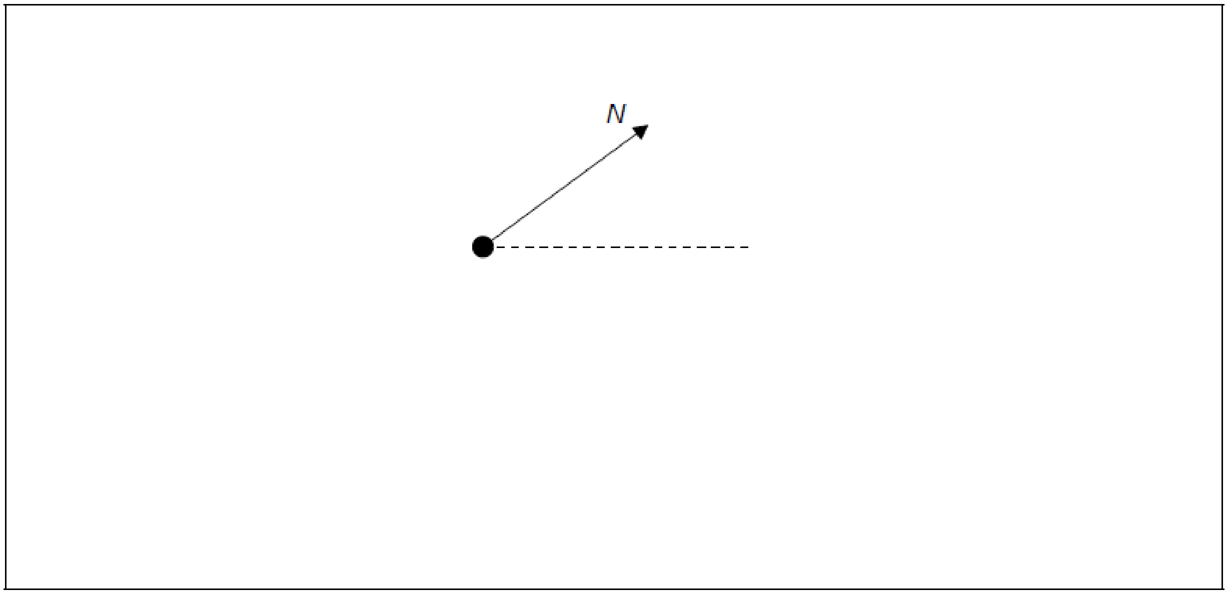
Markscheme

towards the centre «of the circle» / horizontally to the right

Do not accept towards the centre of the bowl

[1 mark]

6b. On the diagram, construct an arrow of the correct length to represent the weight of the ball. *[2 marks]*



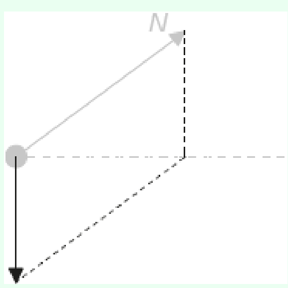
Markscheme

downward vertical arrow of any length

arrow of correct length

Judge the length of the vertical arrow by eye. The construction lines are not required. A label is not required

eg:



[2 marks]

6c. Show that the magnitude of the net force *F* on the ball is given by the following equation. *[3 marks]*

$$F = \frac{mg}{\tan\theta}$$

Markscheme

ALTERNATIVE 1

$F = N\cos\theta$

$mg = N\sin\theta$

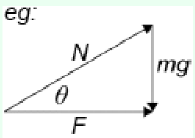
dividing/substituting to get result

ALTERNATIVE 2

right angle triangle drawn with *F*, *N* and *W/mg* labelled

angle correctly labelled and arrows on forces in correct directions

correct use of trigonometry leading to the required relationship



$\tan\theta = \frac{O}{A} = \frac{mg}{F}$

[3 marks]

6d. The radius of the bowl is 8.0 m and θ = 22°. Determine the speed of the ball. *[4 marks]*

Markscheme

$\frac{mg}{\tan\theta} = m\frac{v^2}{r}$

$r = R\cos\theta$

$v = \sqrt{\frac{gR\cos^2\theta}{\sin\theta}} / \sqrt{\frac{gR\cos\theta}{\tan\theta}} / \sqrt{\frac{9.81\times 8.0\cos 22}{\tan 22}}$

v = 13.4/13 «ms^{-1}»

*Award **[4]** for a bald correct answer*

*Award **[3]** for an answer of 13.9/14 «ms^{-1}». MP2 omitted*

[4 marks]

6e. Outline whether this ball can move on a horizontal circular path of radius equal to the radius of the bowl. *[2 marks]*

Markscheme

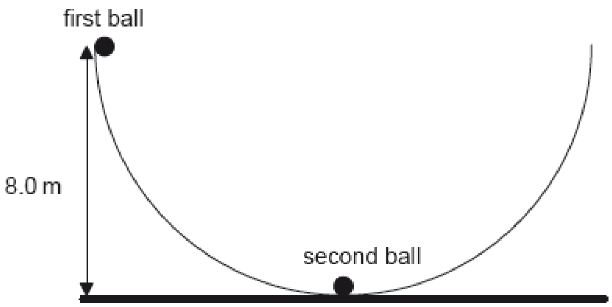
there is no force to balance the weight/N is horizontal

so no / it is not possible

Must see correct justification to award MP2

[2 marks]

6f. A second identical ball is placed at the bottom of the bowl and the first ball is displaced so that its height from the horizontal is equal to 8.0 m. *[3 marks]*



The first ball is released and eventually strikes the second ball. The two balls remain in contact. Determine, in m, the maximum height reached by the two balls.

Markscheme

speed before collision v = «$\sqrt{2gR}$ =» 12.5 «ms^{-1}»

«from conservation of momentum» common speed after collision is $\frac{1}{2}$ initial speed «$v_c = \frac{12.5}{2}$ = 6.25 ms^{-1}»

h = «$\frac{{v_c}^2}{2g} = \frac{6.25^2}{2\times 9.81}$» 2.0 «m»

Allow 12.5 from incorrect use of kinematics equations

*Award **[3]** for a bald correct answer*

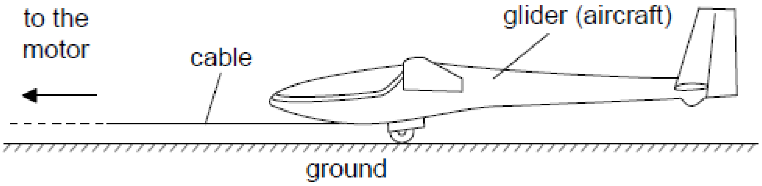
*Award **[0]** for mg(8) = 2mgh leading to h = 4 m if done in one step.*

Allow ECF from MP1

Allow ECF from MP2

[3 marks]

A glider is an aircraft with no engine. To be launched, a glider is uniformly accelerated from rest by a cable pulled by a motor that exerts a horizontal force on the glider throughout the launch.



7a. The glider reaches its launch speed of 27.0 m s^{-1} after accelerating for 11.0 s. Assume that the glider moves horizontally until it leaves the ground. Calculate the total distance travelled by the glider before it leaves the ground. *[2 marks]*

Markscheme

correct use of kinematic equation/equations

148.5 ***or*** 149 ***or*** 150 «m»

Substitution(s) must be correct.

7b. The glider and pilot have a total mass of 492 kg. During the acceleration the glider is subject to an average resistive force of 160 N. Determine the average tension in the cable as the glider accelerates. *[3 marks]*

Markscheme

$a = \frac{27}{11}$ ***or*** 2.45 «m s^{-2}»

F – 160 = 492 × 2.45

1370 «N»

Could be seen in part (a).
*Award **[0]** for solution that uses a = 9.81 m s^{-2}*

7c. The cable is pulled by an electric motor. The motor has an overall efficiency of 23 %. Determine the average power input to the motor. *[3 marks]*

Markscheme

ALTERNATIVE 1

«work done to launch glider» = 1370 x 149 «= 204 kJ»

«work done by motor» $= \frac{204 \times 100}{23}$

«power input to motor» $= \frac{204 \times 100}{23} \times \frac{1}{11} = 80$ ***or*** 80.4 ***or*** 81 k«W»

ALTERNATIVE 2

use of average speed 13.5 m s^{-1}

«useful power output» = force x average speed «= 1370 x 13.5»

power input = «$1370 \times 13.5 \times \frac{100}{23} =$» 80 ***or*** 80.4 ***or*** 81 k«W»

ALTERNATIVE 3

work required from motor = KE + work done against friction «
$= 0.5 \times 492 \times 27^2 + (160 \times 148.5)$» = 204 «kJ»

«energy input» $= \frac{\text{work required from motor} \times 100}{23}$

power input $= \frac{883000}{11} = 80.3$ k«W»

*Award **[2 max]** for an answer of 160 k«W».*

7d. The cable is wound onto a cylinder of diameter 1.2 m. Calculate the angular velocity of the cylinder at the instant when the glider has a speed of 27 m s^{-1}. Include an appropriate unit for your answer. *[2 marks]*

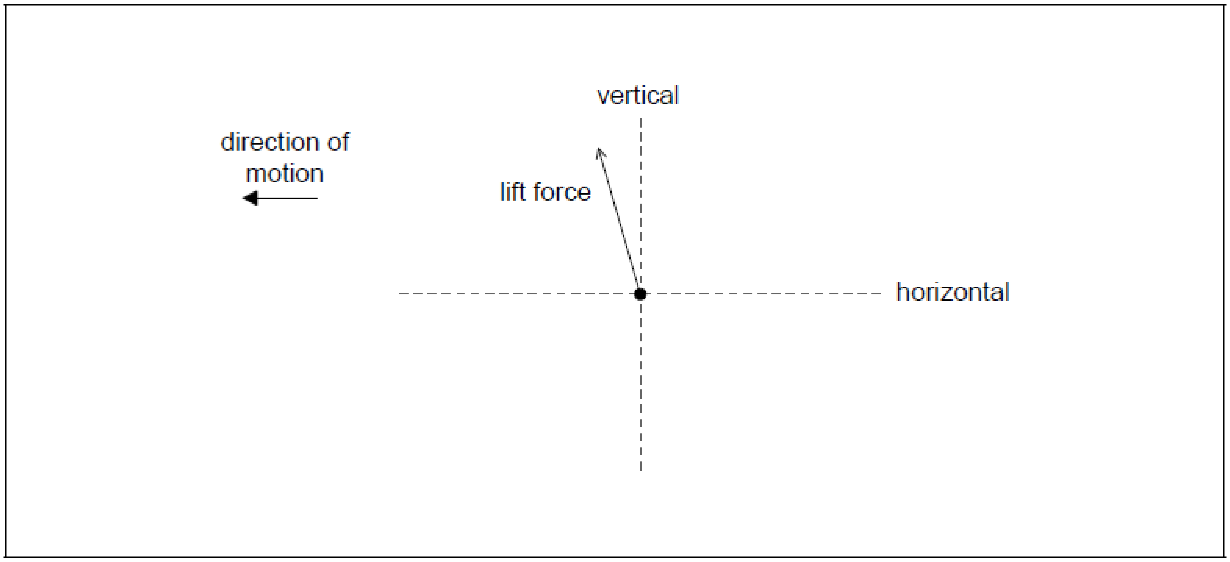
Markscheme

$\omega =$ «$\frac{v}{r} =$» $\frac{27}{0.6} = 45$

rad s^{-1}

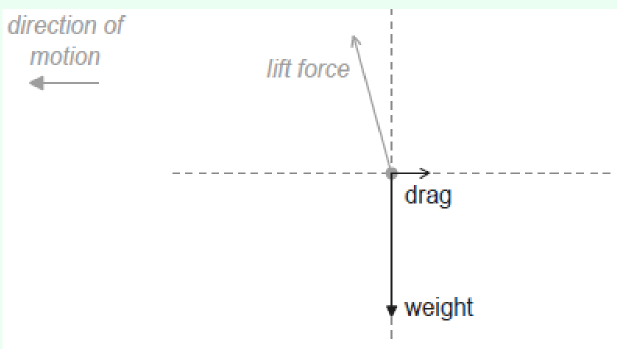
Do not accept Hz.
*Award **[1 max]** if unit is missing.*

7e. After takeoff the cable is released and the unpowered glider moves horizontally at constant speed. The wings of the glider provide a lift force. The diagram shows the lift force acting on the glider and the direction of motion of the glider. *[2 marks]*



Draw the forces acting on the glider to complete the free-body diagram. The dotted lines show the horizontal and vertical directions.

Markscheme



drag correctly labelled and in correct direction

weight correctly labelled and in correct direction ***AND*** no other incorrect force shown

*Award **[1 max]** if forces do not touch the dot, but are otherwise OK.*

7f. Explain, using appropriate laws of motion, how the forces acting on the glider maintain it in level flight. *[2 marks]*

Markscheme

name Newton's first law

vertical/all forces are in equilibrium/balanced/add to zero
OR
vertical component of lift mentioned

as equal to weight

7g. At a particular instant in the flight the glider is losing 1.00 m of vertical height for every 6.00 m that it goes forward horizontally. At this instant, the horizontal speed of the glider is 12.5 m s^{-1}. Calculate the **velocity** of the glider. Give your answer to an appropriate number of significant figures. *[3 marks]*

Markscheme

any speed and any direction quoted together as the answer

quotes their answer(s) to 3 significant figures

speed = 12.7 m s^{-1} ***or*** direction = 9.46º ***or*** 0.165 rad «below the horizontal» ***or*** gradient of $-\frac{1}{6}$

A mass of 1.0 kg of water is brought to its boiling point of 100 °C using an electric heater of power 1.6 kW.

8a. The molar mass of water is 18 g mol^{-1}. Estimate the average speed of the water molecules in the vapor produced. Assume the vapor behaves as an ideal gas. *[2 marks]*

Markscheme

E_k = « $\frac{3}{2}\left(1.38 \times 10^{-23}\right)\left(373\right)$» = 7.7×10^{-21} «J» ✓

v = «$\sqrt{\frac{3 \times 1.38 \times 10^{-23} \times 6.02 \times 10^{23} \times 373}{0.018}}$» = 720 «m s^{-1}» ✓

8b. State **one** assumption of the kinetic model of an ideal gas. *[1 mark]*

Markscheme

particles can be considered points «without dimensions» ✓

no intermolecular forces/no forces between particles «except during collisions»✓

the volume of a particle is negligible compared to volume of gas ✓

collisions between particles are elastic ✓

time between particle collisions are greater than time of collision ✓

no intermolecular PE/no PE between particles ✓

Accept reference to atoms/molecules for "particle"

A mass of 0.86 kg of water remains after it has boiled for 200 s.

8c. Estimate the specific latent heat of vaporization of water. State an appropriate unit for your answer. *[2 marks]*

Markscheme

«$mL = Pt$» so «$L = \frac{1600 \times 200}{0.14}$» = 2.3 x 10^6 «J kg^{-1}» ✓

J kg^{-1} ✓

8d. Explain why the temperature of water remains at 100 °C during this time. *[1 mark]*

Markscheme

«all» of the energy added is used to increase the «intermolecular» potential energy of the particles/break «intermolecular» bonds/**OWTTE** ✓

Accept reference to atoms/molecules for "particle"

8e. The heater is removed and a mass of 0.30 kg of pasta at −10 °C is added to the boiling water. *[3 marks]*

Determine the equilibrium temperature of the pasta and water after the pasta is added. Other heat transfers are negligible.

Specific heat capacity of pasta = 1.8 kJ kg^{-1} K^{-1}
Specific heat capacity of water = 4.2 kJ kg^{-1} K^{-1}

Markscheme

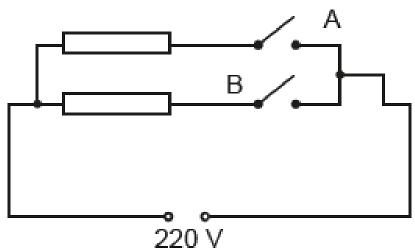
use of mcΔT ✓

0.86 × 4200 × (100 – *T*) = 0.3 × 1800 × (*T* +10) ✓

T_{eq} = 85.69«°C» ≅ 86«°C» ✓

Accept T_{eq} in Kelvin (359 K).

The electric heater has two identical resistors connected in parallel.



The circuit transfers 1.6 kW when switch A only is closed. The external voltage is 220 V.

8f. Show that each resistor has a resistance of about 30 Ω. *[1 mark]*

Markscheme

$P=\frac{v^2}{R}$ so $\frac{220^2}{1600}$ so $R=30.25$ «Ω» ✓

Must see either the substituted values ***OR*** *a value for R to at least three s.f.*

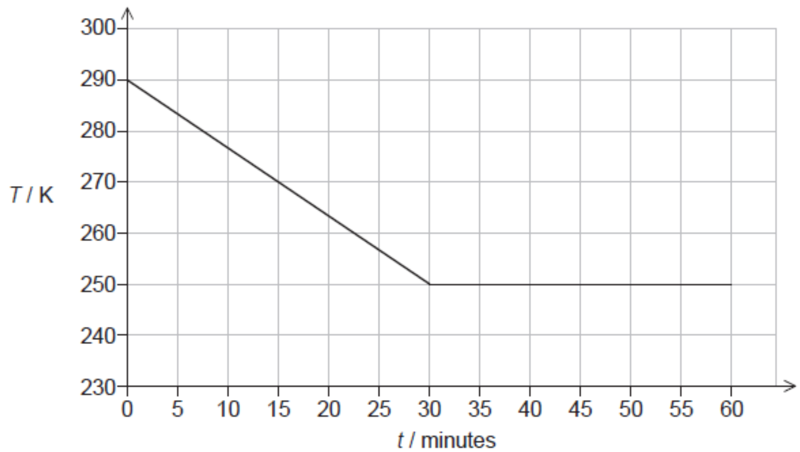
8g. Calculate the power transferred by the heater when both switches are closed. *[2 marks]*

Markscheme

use of parallel resistors addition so R_{eq} = 15 «Ω» ✓

P = 3200 «W» ✓

A sample of vegetable oil, initially in the liquid state, is placed in a freezer that transfers thermal energy from the sample at a constant rate. The graph shows how temperature T of the sample varies with time t.



The following data are available.

Mass of the sample $= 0.32 \text{ kg}$

Specific latent heat of fusion of the oil $= 130 \text{ kJ kg}^{-1}$

Rate of thermal energy transfer $= 15 \text{ W}$

9a. Calculate the thermal energy transferred from the sample during the first 30 minutes. *[1 mark]*

Markscheme

$«15 \times 30 \times 60» = 27000$ «J» ✓

9b. Estimate the specific heat capacity of the oil in its liquid phase. State an appropriate unit for your answer. *[2 marks]*

Markscheme

$27 \times 10^3 = 0.32 \times c \times (290 - 250)$ ***OR*** 2100 ✓

$\mathrm{J\,kg^{-1}\,K^{-1}}$ ***OR*** $\mathrm{J\,kg^{-1}\,{}^0C^{-1}}$ ✓

Allow any appropriate unit that is $\frac{energy}{mass \times termperature}$

9c. The sample begins to freeze during the thermal energy transfer. Explain, in terms of the molecular model of matter, why the temperature of the sample remains constant during freezing. *[3 marks]*

Markscheme

«intermolecular» bonds are formed during freezing ✓

bond-forming process releases energy
OR
«intermolecular» PE decreases «and the difference is transferred as heat» ✓

«average random» KE of the molecules does not decrease/change ✓

temperature is related to «average» KE of the molecules «hence unchanged» ✓

To award MP3 or MP4 molecules/particles/atoms must be mentioned.

9d. Calculate the mass of the oil that remains unfrozen after 60 minutes. *[2 marks]*

Markscheme

mass of frozen oil « $= \frac{27 \times 10^3}{130 \times 10^3}$ » $= 0.21$ « kg » ✓

unfrozen mass « $= 0.32 - 0.21$ » $= 0.11$ « kg » ✓

Liquid oxygen at its boiling point is stored in an insulated tank. Gaseous oxygen is produced from the tank when required using an electrical heater placed in the liquid.

The following data are available.

Mass of 1.0 mol of oxygen = 32 g

Specific latent heat of vaporization of oxygen = 2.1×10^5 J kg^{-1}

10a. Distinguish between the internal energy of the oxygen at the boiling point when it is in its liquid phase and when it is in its gas phase. *[2 marks]*

Markscheme

Internal energy is the sum of all the PEs and KEs of the molecules (of the oxygen) ✔

PE of molecules in gaseous state is zero ✔

(At boiling point) average KE of molecules in gas and liquid is the same ✔

gases have a higher internal energy ✔

Molecules/particles/atoms must be included once, if not, award ***[1 max]***

An oxygen flow rate of 0.25 mol s^{-1} is needed.

10b. Calculate, in kW, the heater power required. *[2 marks]*

Markscheme

ALTERNATIVE 1:

flow rate of oxygen = 8 «g s^{-1}» ✔

«$2.1 \times 10^5 \times 8 \times 10^{-3}$» = 1.7 «kW» ✔

ALTERNATIVE 2:

Q = «$0.25 \times 32 \times 10^{-3} \times 2.1 \times 10^5$ =» 1680 «J» ✔

power = «1680 W =» 1.7 «kW» ✔

10c. Calculate the volume of the oxygen produced in one second when it is allowed to expand to a pressure of 0.11 MPa and to reach a temperature of 260 K. *[1 mark]*

Markscheme

V = «$\frac{nRT}{p}$ =» 4.9 × 10^{-3} «m^3»

10d. State **one** assumption of the kinetic model of an ideal gas that does not apply to oxygen. *[1 mark]*

Markscheme

ideal gas has point objects ✔

no intermolecular forces ✔

non liquefaction ✔

ideal gas assumes monatomic particles ✔

the collisions between particles are elastic ✔

Allow the opposite statements if they are clearly made about oxygen eg oxygen/this can be liquified

In an experiment to determine the specific latent heat of fusion of ice, an ice cube is dropped into water that is contained in a well-insulated calorimeter of negligible specific heat capacity. The following data are available.

Mass of ice cube = 25g
Mass of water = 350g
Initial temperature of ice cube = 0˚C
Initial temperature of water = 18˚C
Final temperature of water = 12˚C
Specific heat capacity of water = 4200$Jkg^{-1}K^{-1}$

11a. Using the data, estimate the specific latent heat of fusion of ice. *[4 marks]*

Markscheme

use of $m \times c \times \theta$ with correct substitution for either original water or water from melted ice

energy available to melt ice = «8820 – 1260 =» 7560 J

equates 7560 to mL

3.02×10^5 J kg^{-1}

FOR EXAMPLE
0.35 × 4200 × (18 – 12) ***OR*** 0.025 × 4200 × 12
7560 J
$L = \frac{7560}{0.025}$
3.02×10^5 J kg^{-1}

*Award **[3 max]** if energy to warm melted ice as water is ignored (350 kJ kg^{-1}).*

Allow ECF in MP3.

11b. The experiment is repeated using the same mass of crushed ice. *[2 marks]*

Suggest the effect, if any, of crushing the ice on

(i) the final temperature of the water.

(ii) the time it takes the water to reach its final temperature.

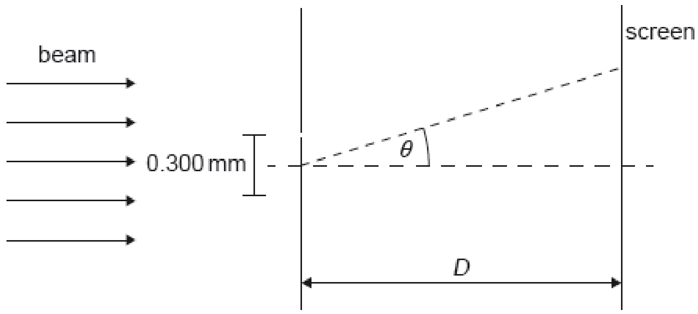
Markscheme

(i)
no change in temperature/no effect, the energies exchanged are the same

(ii)
the time will be less/ice melts faster, because surface area is greater ***or*** crushed ice has more contact with water

A beam of coherent monochromatic light from a distant galaxy is used in an optics experiment on Earth.

The beam is incident normally on a double slit. The distance between the slits is 0.300 mm. A screen is at a distance *D* from the slits. The diffraction angle θ is labelled.



12a. A series of dark and bright fringes appears on the screen. Explain how a dark fringe is formed. *[3 marks]*

Markscheme

superposition of light from each slit / interference of light from both slits

with path/phase difference of any half-odd multiple of wavelength/any odd multiple of π (in words or symbols)

producing destructive interference

Ignore any reference to crests and troughs.

[3 marks]

12b. The wavelength of the beam as observed on Earth is 633.0 nm. The separation between a dark and a bright fringe on the screen is 4.50 mm. Calculate *D*. *[2 marks]*

Markscheme

evidence of solving for *D* «$D = \frac{sd}{\lambda}$»

«$\frac{4.50\times10^{-3}\times0.300\times10^{-3}}{633.0\times10^{-9}}$ × 2» = 4.27 «m»

*Award **[1]** max for 2.13 m.*

[2 marks]

The air between the slits and the screen is replaced with water. The refractive index of water is 1.33.

12c. Calculate the wavelength of the light in water. *[1 mark]*

Markscheme

$\frac{633.0}{1.33}$ = 476 «nm»

[1 mark]

12d. State **two** ways in which the intensity pattern on the screen changes. *[2 marks]*

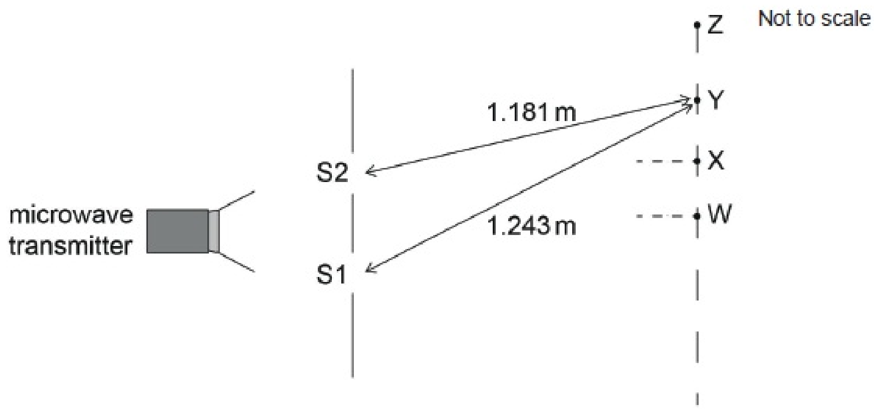
Markscheme

distance between peaks decreases

intensity decreases

[2 marks]

A beam of microwaves is incident normally on a pair of identical narrow slits S1 and S2.



When a microwave receiver is initially placed at W which is equidistant from the slits, a maximum in intensity is observed. The receiver is then moved towards Z along a line parallel to the slits. Intensity maxima are observed at X and Y with one minimum between them. W, X and Y are consecutive maxima.

13a. Explain why intensity maxima are observed at X and Y. *[2 marks]*

Markscheme

two waves superpose/mention of superposition/mention of «constructive» interference ✔

they arrive in phase/there is a path length difference of an integer number of wavelengths ✔

Ignore references to nodes/antinodes.

13b. The distance from S1 to Y is 1.243 m and the distance from S2 to Y is 1.181 m. *[3 marks]*

Determine the frequency of the microwaves.

Markscheme

path difference = 0.062 «m» ✔

so wavelength = 0.031 «m» ✔

frequency = 9.7×10^9 «Hz» ✔

If no unit is given, assume the answer is in Hz. Accept other prefixes (eg 9.7 GHz)

*Award **[2 max]** for 4.8×10^9 Hz.*

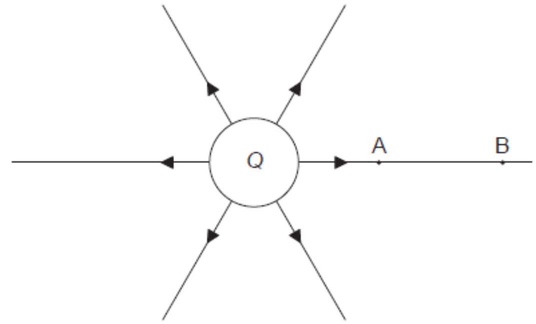
13c. Outline **one** reason why the maxima observed at W, X and Y will have different intensities from each other. *[1 mark]*

Markscheme

intensity varies with distance ***OR*** points are different distances from the slits ✔

Accept "Intensity is modulated by a single slit diffraction envelope".

The diagram shows the electric field lines of a positively charged conducting sphere of radius R and charge Q.



Points A and B are located on the same field line.

14a. Explain why the electric potential decreases from A to B. *[2 marks]*

Markscheme

ALTERNATIVE 1

work done on moving a positive test charge in any outward direction is negative ✓

potential difference is proportional to this work «so V decreases from A to B» ✓

ALTERNATIVE 2

potential gradient is directed opposite to the field so inwards ✓

the gradient indicates the direction of increase of V «hence V increases towards the centre/decreases from A to B» ✓

ALTERNATIVE 3

$V = \frac{kQ}{R}$ so as r increases V decreases ✓

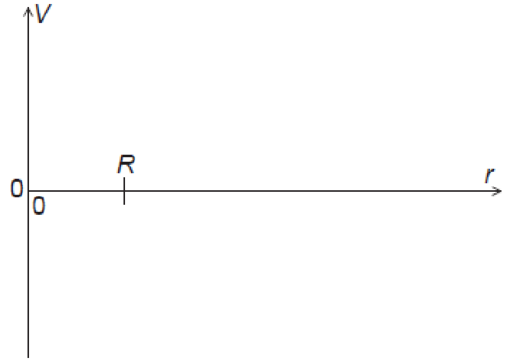
V is positive as Q is positive ✓

ALTERNATIVE 4

the work done per unit charge in bringing a positive charge from infinity ✓

to point B is less than point A ✓

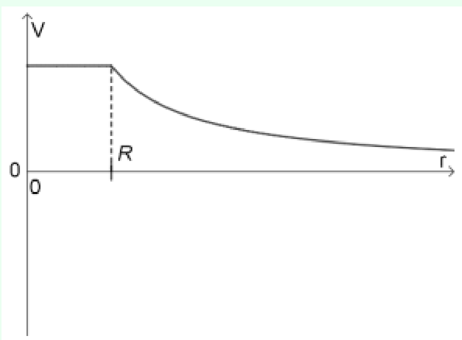
14b. Draw, on the axes, the variation of electric potential V with distance r from the centre of the sphere. *[2 marks]*



Markscheme

curve decreasing asymptotically for $r > R$ ✓

non $-$ zero constant between 0 and R ✓



A proton is placed at A and released from rest. The magnitude of the work done by the electric field in moving the proton from A to B is 1.7×10^{-16} J. Point A is at a distance of 5.0×10^{-2} m from the centre of the sphere. Point B is at a distance of 1.0×10^{-1} m from the centre of the sphere.

14c. Calculate the electric potential difference between points A and B. *[1 mark]*

Markscheme

«$\frac{W}{q} = \frac{1.7\times10^{-16}}{1.60\times10^{-19}} =$ »1.1×10^{3} «V» ✓

14d. Determine the charge Q of the sphere. *[2 marks]*

Markscheme

$8.99 \times 10^9 \times Q \times \left(\frac{1}{5.0 \times 10^{-2}} - \frac{1}{1.0 \times 10^{-1}}\right) = 1.1 \times 10^3$ ✓

$Q = 1.2 \times 10^{-8}$ «C» ✓

14e. The concept of potential is also used in the context of gravitational fields. Suggest why scientists developed a common terminology to describe different types of fields. *[1 mark]*

Markscheme

to highlight similarities between «different» fields ✓

A photovoltaic cell is supplying energy to an external circuit. The photovoltaic cell can be modelled as a practical electrical cell with internal resistance.

The intensity of solar radiation incident on the photovoltaic cell at a particular time is at a maximum for the place where the cell is positioned.

The following data are available for this particular time:

Operating current = 0.90 A
Output potential difference to external circuit = 14.5 V
Output emf of photovoltaic cell = 21.0 V
Area of panel = 350 mm × 450 mm

15a. Explain why the output potential difference to the external circuit and the output emf of the photovoltaic cell are different. *[2 marks]*

Markscheme

there is a potential difference across the internal resistance
OR
there is energy/power dissipated in the internal resistance ✓

when there is current «in the cell»/as charge flows «through the cell» ✓

Allow full credit for answer based on $V = \varepsilon - Ir$

15b. Calculate the internal resistance of the photovoltaic cell for the maximum intensity condition using the model for the cell. *[3 marks]*

Markscheme

ALTERNATIVE 1

pd dropped across cell $= 6.5$ «V» ✓

internal resistance $= \frac{6.5}{0.9}$ ✓

7.2«Ω» ✓

ALTERNATIVE 2

$\varepsilon = I(R + r)$ *so* $\varepsilon = V + Ir$ ✓

$21.0 = 14.5 + 0.9 \times r$ ✓

7.2«Ω» ✓

Alternative solutions are possible

*Award **[3]** marks for a bald correct answer*

15c. The maximum intensity of sunlight incident on the photovoltaic cell at the place on the Earth's surface is 680 W m^{-2}. *[3 marks]*

A measure of the efficiency of a photovoltaic cell is the ratio

$$\frac{\text{energy available every second to the external circuit}}{\text{energy arriving every second at the photovoltaic cell surface}}.$$

Determine the efficiency of this photovoltaic cell when the intensity incident upon it is at a maximum.

Markscheme

power arriving at cell = 680 x 0.35 x 0.45 = «107 W» ✓

power in external circuit = 14.5 x 0.9 = «13.1 W» ✓

efficiency = 0.12 ***OR*** 12 % ✓

*Award **[3] marks** for a bald correct answer*

*Allow **ECF** for **MP3***

15d. State **two** reasons why future energy demands will be increasingly reliant on sources such as photovoltaic cells. *[2 marks]*

Reason 1: . . . .

. . . .

Reason 2: . . . .

. . . .

Markscheme

«energy from Sun/photovoltaic cells» is renewable
OR
non-renewable are running out ✓

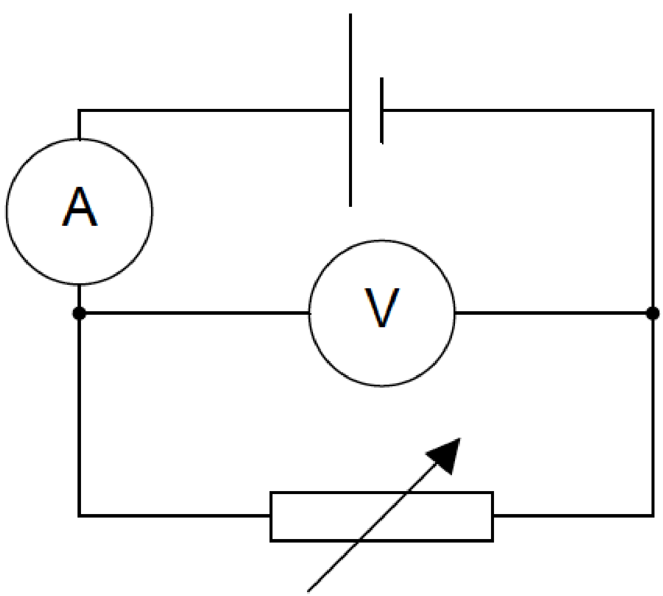
non-polluting/clean ✓

no greenhouse gases
OR
does not contribute to global warming/climate change ✓

OWTTE

Do not allow economic aspects (e.g. free energy)

In an experiment a student constructs the circuit shown in the diagram. The ammeter and the voltmeter are assumed to be ideal.



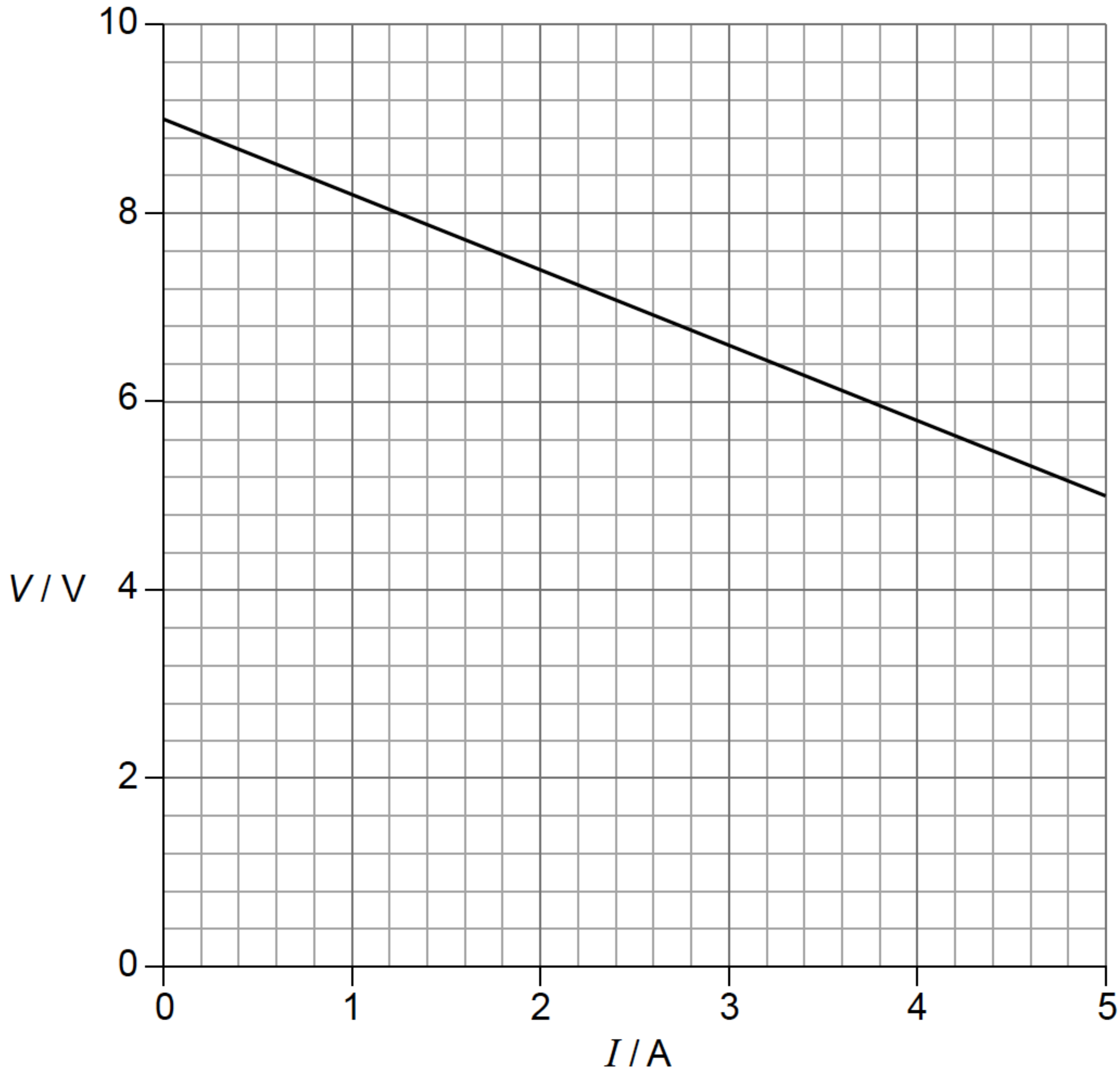
16a. State what is meant by an ideal voltmeter. *[1 mark]*

Markscheme

infinite resistance ***OR*** draws no current from circuit/component ***OR*** has no effect on the circuit

Do not allow “very high resistance”.

16b. The student adjusts the variable resistor and takes readings from the ammeter and voltmeter. The graph shows the variation of the voltmeter reading *V* with the ammeter reading *I*. *[3 marks]*



Use the graph to determine

(i) the electromotive force (emf) of the cell.

(ii) the internal resistance of the cell.

Markscheme

(i)
«vertical intercept = emf» = 8.8 − 9.2 V

(ii)
attempt to evaluate gradient of graph
=0.80Ω

Accept other methods leading to correct answer, eg using individual data points from graph.

Allow a range of 0.78 – 0.82 Ω.

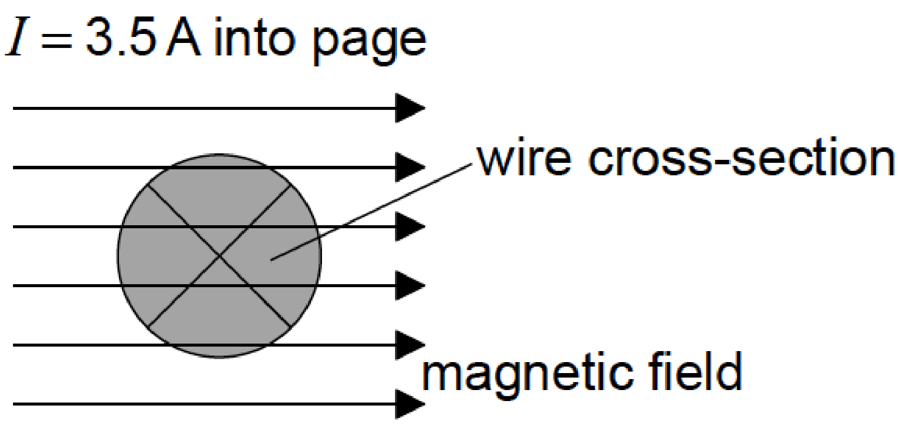
If ε = I(R + r) is used then the origin of the value for R must be clear.

16c. A connecting wire in the circuit has a radius of 1.2mm and the current in it is 3.5A. The number of electrons per unit volume of the wire is $2.4\times10^{28}m^{-3}$. Show that the drift speed of the electrons in the wire is $2.0\times10^{-4}ms^{-1}$. *[1 mark]*

Markscheme

$3.5=2.4\times10^{28}\times\pi(1.2\times10^{-3})^2\times1.6\times10^{-19}\times v$«$\Rightarrow v=2.0\times10^{-4}ms^{-1}$»

16d. The diagram shows a cross-sectional view of the connecting wire in (c). *[2 marks]*



The wire which carries a current of 3.5A into the page, is placed in a region of uniform magnetic field of flux density 0.25T. The field is directed at right angles to the wire.

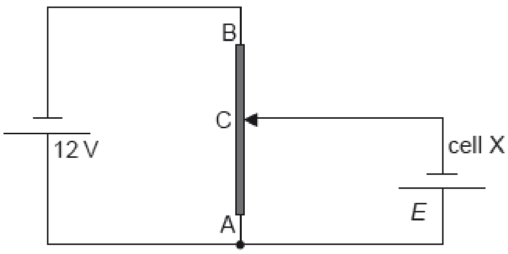
Determine the magnitude **and** direction of the magnetic force on one of the charge carriers in the wire.

Markscheme

F = «qvB =1.6×10$^{–19}$ ×2.0×10^{-4} ×0.25 =»8.1×10^{-24} N

directed down ***OR*** south

The diagram shows a potential divider circuit used to measure the emf *E* of a cell X. Both cells have negligible internal resistance.



17a. State what is meant by the emf of a cell. *[2 marks]*

Markscheme

the work done per unit charge

in moving charge from one terminal of a cell to the other / all the way round the circuit

*Award **[1]** for "energy per unit charge provided by the cell"/"power per unit current"*

*Award **[1]** for "potential difference across the terminals of the cell when no current is flowing"*

Do not accept "potential difference across terminals of cell"

[2 marks]

AB is a wire of uniform cross-section and length 1.0 m. The resistance of wire AB is 80 Ω. When the length of AC is 0.35 m the current in cell X is zero.

17b. Show that the resistance of the wire AC is 28 Ω. *[2 marks]*

Markscheme

the resistance is proportional to length / see 0.35 ***AND*** 1«.00»

so it equals 0.35 × 80

«= 28 Ω»

[2 marks]

17c. Determine *E*. *[2 marks]*

Markscheme

current leaving 12 V cell is $\frac{12}{80}$ = 0.15 «A»

OR

$E = \frac{12}{80} \times 28$

E = «0.15 × 28 =» 4.2 «V»

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

Allow a 1sf answer of 4 if it comes from a calculation.

Do not allow a bald answer of 4 «V»

Allow ECF from incorrect current

[2 marks]

17d. Cell X is replaced by a second cell of identical emf *E* but with internal resistance 2.0 Ω. Comment on the length of AC for which the current in the second cell is zero. *[2 marks]*

Markscheme

since the current in the cell is still zero there is no potential drop across the internal resistance

and so the length would be the same

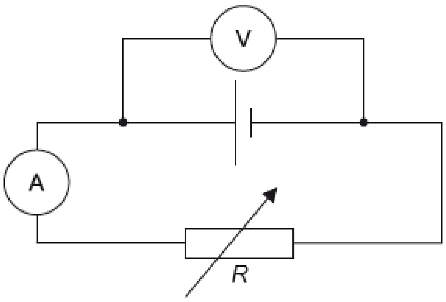
OWTTE

[2 marks]

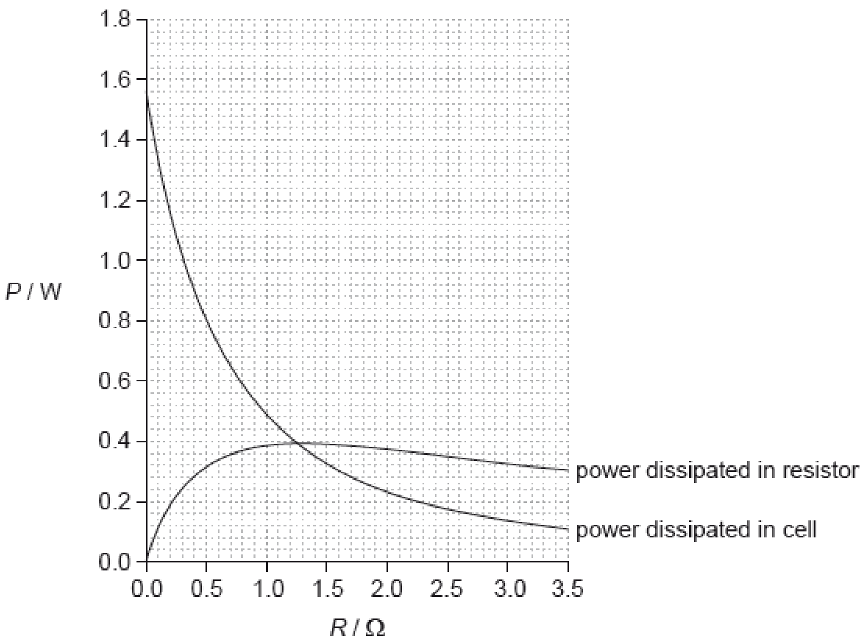
This question is in **two** parts. **Part 1** is about kinematics and Newton's laws of motion.

Part 2 Electrical circuits

The circuit shown is used to investigate how the power developed by a cell varies when the load resistance R changes.



The variable resistor is adjusted and a series of current and voltage readings are taken. The graph shows the variation with R of the power dissipated in the cell and the power dissipated in the variable resistor.



18a. An ammeter and a voltmeter are used to investigate the characteristics of a variable resistor of resistance R. State how the resistance of the ammeter and of the voltmeter compare to R so that the readings of the instruments are reliable. *[2 marks]*

Markscheme

ammeter must have very low resistance/much smaller than R;

voltmeter must have very large resistance/much larger than R;

*Allow **[1 max]** for zero and infinite resistance for ammeter and voltmeter respectively.*

*Allow **[1 max]** if superlative (eg: very/much/OWTTE) is missing.*

18b. Show that the current in the circuit is approximately 0.70 A when $R = 0.80\ \Omega$. *[3 marks]*

Markscheme

power (loss in resistor) $= 0.36\ (\mathrm{W})$; } *(accept answers in the range of 0.35 to 0.37 (W) – treat value outside this range as ECF (could still lead to 0.7))*

$I^2 \times 0.80 = 0.36$;

$I = 0.67\ (\mathrm{A})$ ***or*** $\sqrt{\left(\frac{0.36}{0.8}\right)}$; *(allow answers in the range of 0.66 to 0.68 (A).*

The cell has an internal resistance.

18c. Outline what is meant by the internal resistance of a cell. *[2 marks]*

Markscheme

resistance of the components/chemicals/materials within the cell itself; } *(not "resistance of cell")*

leading to energy/power loss in the cell;

18d. Determine the internal resistance of the cell. *[3 marks]*

Markscheme

power (in cell with 0.7 A) $= 0.58\ \mathrm{W}$; } *(allow answers in the range of 0.57 W to 0.62 W)*

$0.7^2 \times r = 0.58$;

$r = 1.2\ (\Omega)$; *(allow answers in the range of 1.18 to 1.27 (Ω))*

or

when powers are equal;

$I^2R = I^2r$;

so $r = R$ which occurs at 1.2(5) (Ω);

*Award **[1 max]** for bald 1.2(5) (Ω).*

18e. Calculate the electromotive force (emf) of the cell. *[2 marks]*

Markscheme

$(E = I(R + r)) = 0.7(0.8 + 1.2)$;

1.4 (V);

Allow ECF from (e) or (f)(ii).

or

when $R = 0$, power loss $= 1.55$;

$E = (\sqrt{1.55 \times 1.2} =)\ 1.4\ (\mathrm{V})$;