Please check the examination details below before entering your candidate information

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Centre Number: 2 7 1 8 2 | Candidate Number: 8 1 8 2

Pearson Edexcel Level 3 GCE

Wednesday 24 May 2023

Afternoon (Time: 1 hour 45 minutes) | Paper reference: **9PH0/01**

Physics

Advanced

PAPER 1: Advanced Physics I

ALevelPhysicsOnline.com
/edexcel-advanced-physics-1

You must have:
Scientific calculator, ruler, protractor

Total Marks

Instructions

- Use **black** ink or ball-point pen.
- If pencil is used for diagrams/sketches/graphs it must be dark (HB or B).
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions.
- Answer the questions in the spaces provided – *there may be more space than you need.*

Information

- The total mark for this paper is 90.
- The marks for **each** question are shown in brackets – *use this as a guide as to how much time to spend on each question.*
- In the question marked with an **asterisk** (*), marks will be awarded for your ability to structure your answer logically, showing how the points that you make are related or follow on from each other where appropriate.
- The list of data, formulae and relationships is printed at the end of this booklet.

Advice

- Read each question carefully before you start to answer it.
- Try to answer every question.
- Check your answers if you have time at the end.
- You are advised to show your working in calculations including units where appropriate.

Turn over

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N:1/1/1/

P 7 1 9 1 5 A 0 1 2 8

Pearson

Answer ALL questions.

All multiple choice questions must be answered with a cross in the box ☒ for the correct answer from A to D. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 One isotope of oxygen is $^{17}_{8}O$. p+n p $\therefore n = 17 - 8 = 9$

Which row of the table shows the number of neutrons and the number of protons in a nucleus of $^{17}_{8}O$?

		Number of neutrons	Number of protons
☐	**A**	~~8~~	~~9~~
☐	**B**	~~8~~	~~17~~
☒ ✓	**C**	9	8
☐	**D**	~~17~~	8

(Total for Question 1 = 1 mark)

2 A subatomic particle consists of the quark combination u $\bar{s}$.

Which of the following is the classification for this particle?

☐ **A** baryon

☐ **B** lepton

☒ ✓ **C** meson

☐ **D** nucleon

quark - antiquark pair
Baryon no. = 0
Lepton no. = 0

(Total for Question 2 = 1 mark)

3 A charged capacitor is discharged through a resistor. The potential difference across the capacitor halved in a time *t*. The time constant is *T*.

Which of the following is the equation for *t*?

☐ **A** $t = \frac{\ln 2}{T}$

☐ **B** $t = \ln \frac{1}{2T}$

☐ **C** $t = T \ln \frac{1}{2}$

☒ ✓ **D** $t = T \ln 2$

$V = V_0 e^{-t/RC} = V_0 e^{-t/T}$ $\quad \frac{V}{V_0} = e^{-t/T}$

$\frac{V}{V_0} = \frac{1}{2} \quad \therefore \ln \frac{1}{2} = -\frac{t}{T}$

$\frac{t}{T} = \ln 2 \quad t = T \ln 2$

(Total for Question 3 = 1 mark)

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4 Muons created in the upper atmosphere can travel towards the Earth's surface at speeds close to the speed of light. Changes to the mass and average lifetime of the muons can then be observed.

Which row of the table describes these changes when muons travel at speeds close to the speed of light?

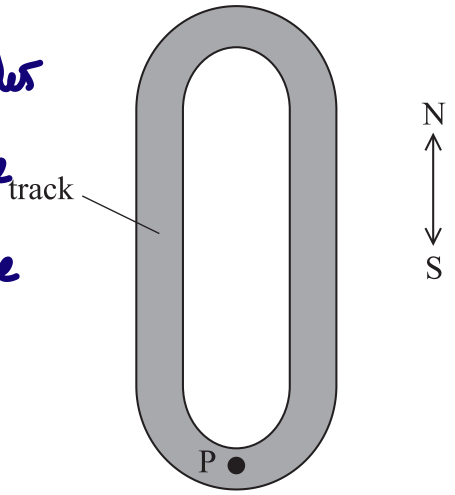
	Mass	Average lifetime
☒ ✓ **A**	increases	increases
☐ **B**	increases	~~decreases~~
☐ **C**	~~decreases~~	increases
☐ **D**	~~decreases~~	~~decreases~~

Time dilates (increases)
$t = \gamma t_0$
Mass also increases
$m = \gamma m_0$

(Total for Question 4 = 1 mark)

5 The plan view of a model racing car track is shown. Friction acts between a model racing car and the track. A car is moving round the track with a constant speed and reaches point P. Arrows indicating directions North and South are also shown.

The friction provides the centripetal force which is towards the centre of rotation.



The car then slides off the track at P.

Which of the following is the reason why the car slides off the track?

☐ **A** The centripetal force is acting in the N direction.

☐ **B** The centripetal force is acting in the S direction.

☐ **C** The frictional force is equal to the centripetal force.

☒ ✓ **D** The frictional force is not large enough. (to provide the centripetal force)

(Total for Question 5 = 1 mark)

6 In a boiler, energy is transferred to water at a rate of 40 kW. The corresponding power loss from the boiler to the surroundings is 4.0 kW.

Which of the following is the efficiency of this boiler?

$$\eta = \frac{\text{useful}}{\text{total}} = \frac{40}{40+4.0} = 0.909$$

☐ **A** 0.10

☐ **B** 0.11

☐ **C** 0.90

☒ ✓ **D** 0.91

(Total for Question 6 = 1 mark)

7 A car is fitted with an airbag which will inflate if the car stops very suddenly.

(Source: © KAIROS, LATIN STOCK/SCIENCE PHOTO LIBRARY)

Which of the following is increased if the airbag inflates because the car suddenly stops?

$$F \Delta t = \underbrace{m \Delta v}_{\text{constant}}$$

F: decreases

Δt: increases

☐ **A** change in momentum of the driver

☐ **B** change in velocity of the driver

☐ **C** force on the driver

☒ ✓ **D** time that the driver takes to stop

(Total for Question 7 = 1 mark)

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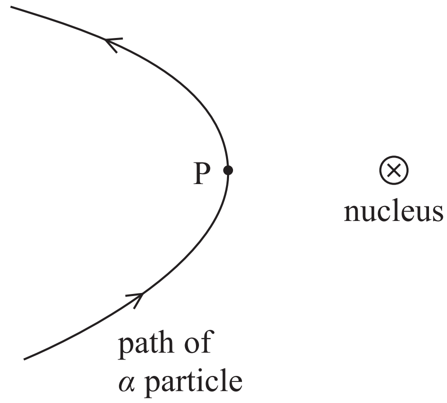
Questions 8 and 9 refer to the information below.

Alpha particle scattering investigations were first carried out in the early part of the 20th century.

The diagram shows the path of an α particle that is being deflected by the nucleus of a gold atom. The closest distance of approach of the α particle to the nucleus is at point P.



8 Which row in the table describes the speed and potential energy of the α particle at point P on this path?

		Speed at P	Potential energy at P
☐	**A**	~~greatest~~	greatest
☐	**B**	~~greatest~~	~~least~~
☒ ✓	**C**	least	greatest
☐	**D**	least	~~least~~

$E_k \rightarrow E_p$

$\therefore E_k$ min $\therefore V_{min}$

but E_p max

(Total for Question 8 = 1 mark)

9 Which of the following can be concluded about a gold atom from the deflection of this α particle?

☐ **A** The atom contains electrons. ✗

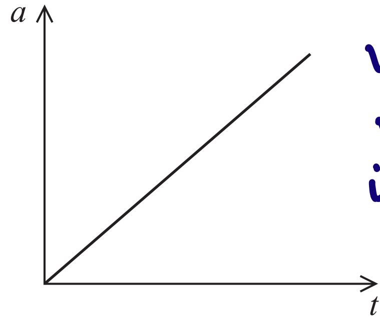
☐ **B** The atom has zero charge. ✗

☐ **C** The nucleus is very small compared to the atom. ✗

☒ ✓ **D** The nucleus of the atom is positively charged. ✓

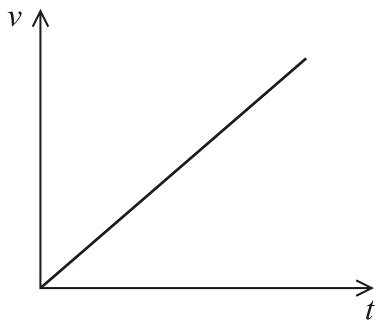
(Total for Question 9 = 1 mark)

10 An object moves from rest. The graph shows how the acceleration a varies with time t.

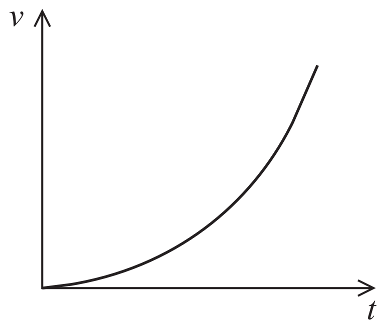


v = area under line, which increases at an increasing rate with t

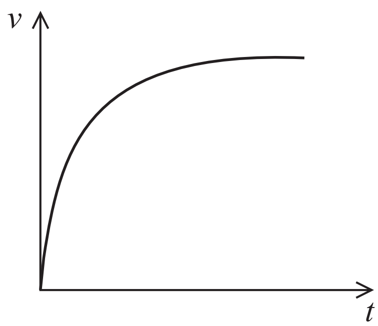
Which of the following graphs best shows how the velocity v of the object varies with t over the same time interval?



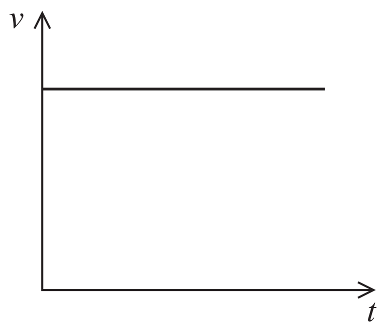
☐ **A**



☒ ✓**B**



☐ **C**



☐ **D**

(Total for Question 10 = 1 mark)

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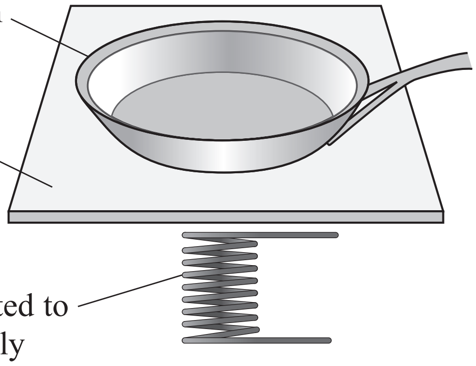
11 An induction hob consists of a coil beneath a sheet of ceramic material. The coil is connected to an alternating current (a.c.) supply as shown.



(a) A steel pan containing water is placed on the induction hob.

Explain why the pan becomes hot when the supply is switched on.

(4)

An alternating current in the coil produces a changing magnetic field ✓ through the pan ✓, which induces an emf ✓, leading to a current in the pan and an associated heating effect. ✓

(b) The a.c. supply to the coil in an induction hob has a much higher frequency than normal mains frequency.

Explain why this is an advantage in this case.

(2)

A higher frequency means that the field changes more quickly ✓, inducing a greater emf ✓ ∴ a greater current.

(Total for Question 11 = 6 marks)

12 An electrical conductor XY carries a current I as shown.

$$X \xrightarrow{I} Y$$

The current density j is defined as $j = \dfrac{I}{A}$ where A is the cross-sectional area of the conductor.

(a) Current density is a vector quantity.

State what is meant by a vector quantity.

(1)

A quantity that has both magnitude and direction.

(b) I is constant but A decreases towards end Y.

Explain how this affects the drift velocity of the free electrons in the conductor.

(2)

$I = nqvA$ $\quad$ I, n and q all constant

$\therefore v \propto \dfrac{1}{A}$ $\quad$ $\therefore$ drift velocity increases

(c) The resistivity ρ of the conducting material is given by $\rho = \dfrac{E}{j}$

where E is the electric field strength.

Show that the units are the same on both sides of this equation.

(4)

$\rho = [\Omega m]$ ✓

$\dfrac{E}{j} = \dfrac{[Vm^{-1}]}{[Am^{-2}]} = [VA^{-1}m]$ ✓ ✓

$R = \dfrac{V}{I}$

$[\Omega] = [VA^{-1}]$

$\therefore \rho = \dfrac{E}{j} = [VA^{-1}m]$ ✓

$\rho = [VA^{-1}m]$

(Total for Question 12 = 7 marks)

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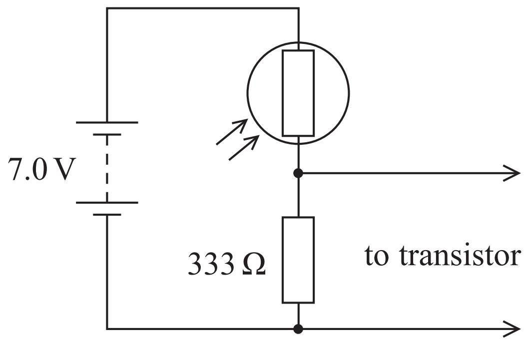
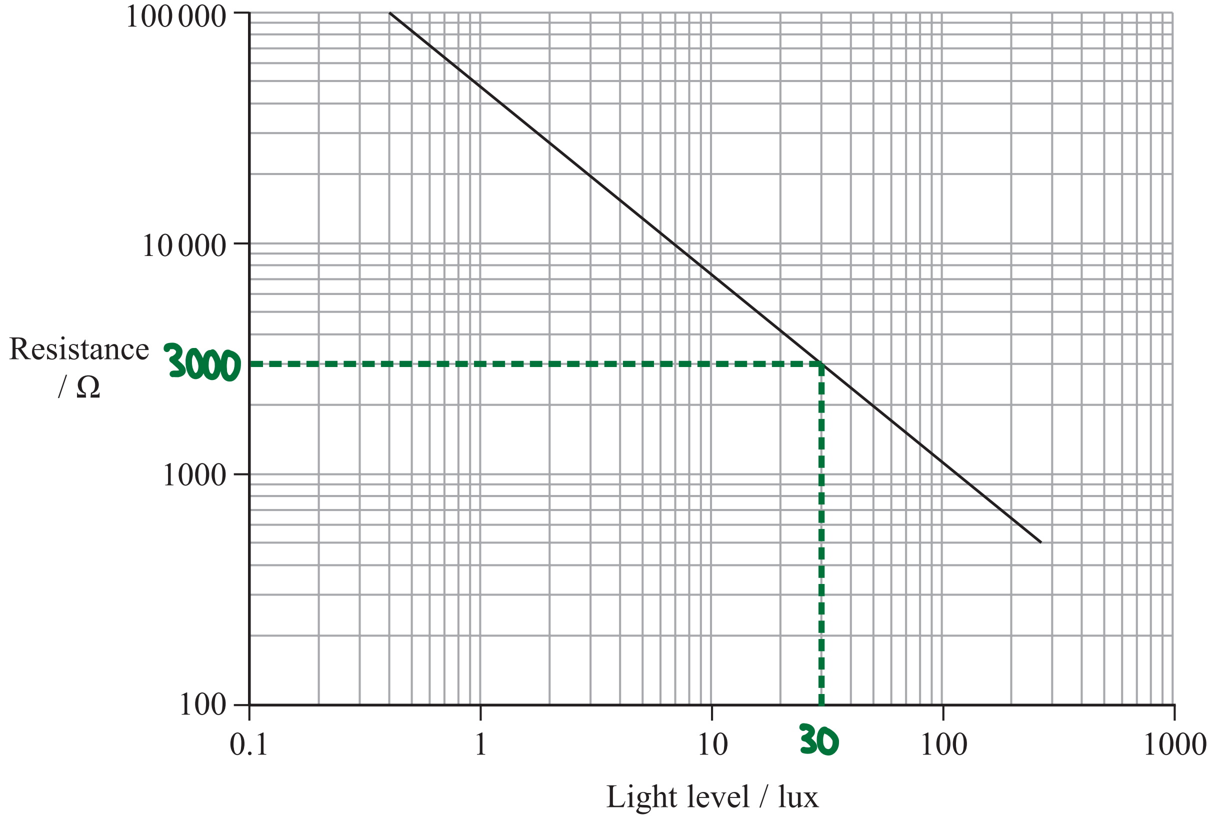
13 The circuit shown provides an input to a transistor. A transistor is a type of electronic switch and in this circuit it can be assumed to have infinite resistance.



The resistance of the LDR varies with light level as shown below.



The transistor switches on when the potential difference across the input increases above 0.7 V. This should happen as the light level reaching the LDR increases above 30 lux.

(a) Deduce whether this circuit responds as required.

(6)

When lux = 30, R = 3000 Ω ✓

$\frac{V_R}{V_T} = \frac{R_R}{R_T}$ ✓✓ ∴ $V_R = V_T \frac{R_R}{R_T} = 7.0 \times \frac{333}{3000 + 333}$

$= 0.699 = 0.70\ V$ ✓

As light > 30 lux, R_{LDR} decreases ✓, therefore the potential difference across the resistor will be greater than 0.70 V ∴ the circuit responds as required. ✓

(b) Explain how the resistance of the LDR changes as the light level increases.

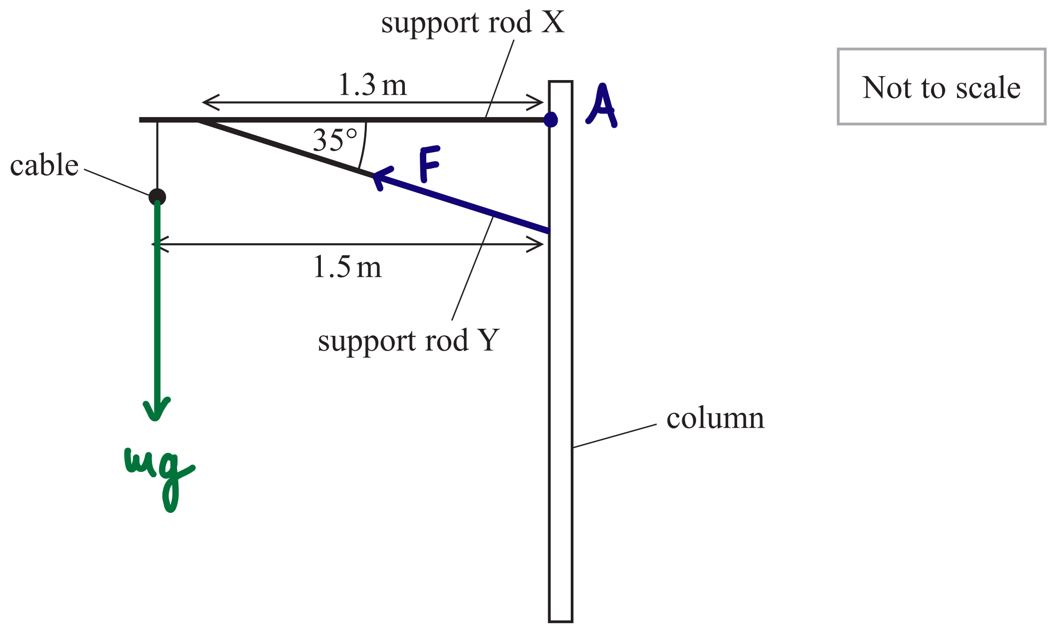
(2)

More electrons move into a conduction band as light level increases ✓ ∴ reduced resistance. ✓

(Total for Question 13 = 8 marks)

14 Overhead electricity cables for railway lines are supported by structures like the one shown.

An electric cable of mass 45 kg is suspended from a support rod X. A second support rod Y is attached to X. X and Y are attached at one end to a column.



The masses of support rods X and Y are negligible.

(a) (i) Determine, by taking moments, the force exerted on rod X by rod Y.

(4)

Take moments about A ✓

$\overset{\curvearrowright}{M} = F \sin 35 \times 1.3$ ✓

$\overset{\curvearrowleft}{M} = 45 \times 9.81$ ✓ $\times 1.5$

$\overset{\curvearrowright}{M} = \overset{\curvearrowleft}{M}$

$F \sin 35 \times 1.3 = 45 \times 9.81 \times 1.5$

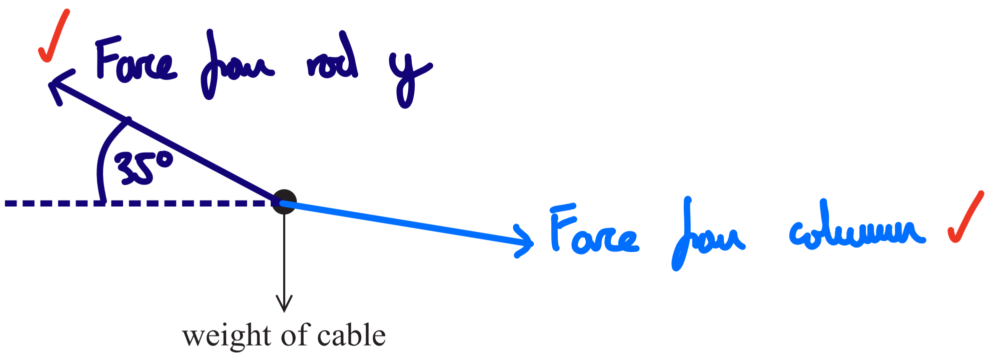
$F = 662.175 / 0.7456 = 888\text{ N}$

Force = 890 N ✓

P 7 1 9 1 5 A 0 1 2 2 8

(ii) Complete the free-body force diagram for support rod X.

(2)



(b) A website gives a value of the electric field strength *E*, at two distances from the electric cable.

Distance / m	***E* / N C^{-1}**
3	1200
25	100

Deduce whether these data are consistent with an inverse square law.

(3)

$E \propto \frac{1}{r^2} = \frac{k}{r^2}$ $\quad Er^2 = k$ ✓

$1200 \times 3^2 = 10,800$

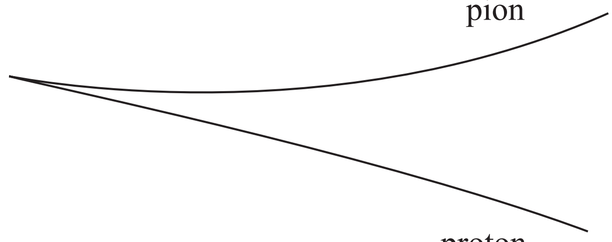
$100 \times 25^2 = 62,500$ ✓ $\therefore$ k not a constant

$\therefore$ not an inverse square law ✓

(Total for Question 14 = 9 marks)

15 A delta particle decays into a proton and a pion.

(a) The diagram shows tracks in a particle detector formed when the delta particle decays.



(i) State why it can be concluded from the diagram that the delta particle is neutral.

(1)

The delta particle leaves no track. ✓

(ii) Deduce the charge on the pion.

(2)

It must be negative ✓ as it curves the other way to a proton which is positive, and charge must be conserved in this interaction. ✓

(iii) Complete the particle equation for the decay of the delta (Δ^0) particle.

(1)

$\Delta^0 \rightarrow p^+ + \pi^-$ ✓

$B = 1 = 1 + 0$

(iv) State why the delta particle must be classified as a baryon based on the evidence of its decay.

(1)

Baryon number always conserved, and as the RHS of the equation above has B=1, delta must also = 1. ✓

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(v) Explain how the momentum of the proton compares with the momentum of the pion.

(3)

Radius of the circular path of the proton is larger. ✓ $r = mv/Bq$. ✓ B and q the same $\therefore$ $r \propto mv$ $\therefore$ momentum for proton is larger than that of the pion. ✓

(b) The mass of the delta particle is 1232 MeV/c^2.

(i) Calculate the mass of the delta particle in kg.

(3)

$$m = \frac{E}{c^2} ✓ = \frac{1232 \times 10^6 \times 1.60 \times 10^{-19}}{9.00 \times 10^{16}} ✓ = 2.19 \times 10^{-27}$$

Mass = 2.19×10^{-27} ✓ kg

(ii) The mass of the proton is 939 MeV/c^2 and the mass of the pion is 139 MeV/c^2.

Explain why the sum of the masses of the two particles after the decay is not equal to the mass of the delta particle.

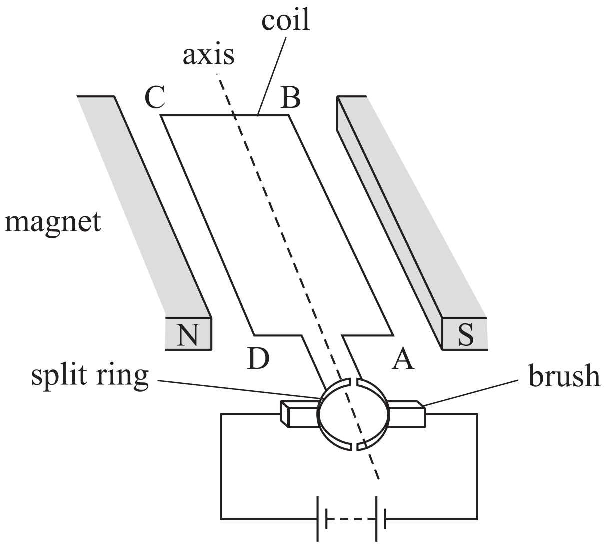
(3)

$939 + 139 = 1078 < 1232$ ✓. Mass of products is less, mass is converted to E_K of products ✓ as $E = mc^2$ ✓

(Total for Question 15 = 14 marks)

16 Electric vehicles use a direct current (d.c.) electric motor powered by a battery for propulsion. A simplified diagram of a d.c. electric motor is shown.

A split ring consists of two semi-circular sections that are attached to a coil. The coil is labelled ABCD. Two brushes, made of carbon, rub against and make electrical contact with the split ring.



*(a) Describe how this arrangement can lead to the coil rotating.

(6)

Direction of the current in the coil is from D to C, the force acting on side DC due to the interacting magnetic fields is vertically down. Using Fleming's left hand rule the force on BA is upwards as the current is in the opposite direction here. Moments of these forces causes rotation about the axis. ✓✓✓✓

After half a rotation, the direction of the current switches due to the split ring commutator ∴ coil continues to rotate in the same direction. ✓✓

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(b) An advert for an electric car has the following information:

- electric motor can develop up to 390 kW output power
- car achieves a velocity of $28\,m\,s^{-1}$ from rest in 4.0 s at maximum power

Calculate the work done by resistive forces when the car accelerates to a velocity of $28\,m\,s^{-1}$ from rest in 4.0 s.

mass of car = 1950 kg

(3)

Gain in $E_K = \frac{1}{2}mv^2 = 0.5 \times 1950 \times 28^2 = 764,400\,J$ ✓

E transferred by motor $= Pt = 390 \times 10^3 \times 4.0 = 1,560,000\,J$ ✓

E overcoming resistive forces $= 1,560,000 - 764,400$
$= 795,600\,J$

Work done by resistive forces = $8.0 \times 10^5\,J$ ✓

(c) A website suggests that 'fast-charging' the battery in an electric vehicle can increase the internal resistance of the battery.

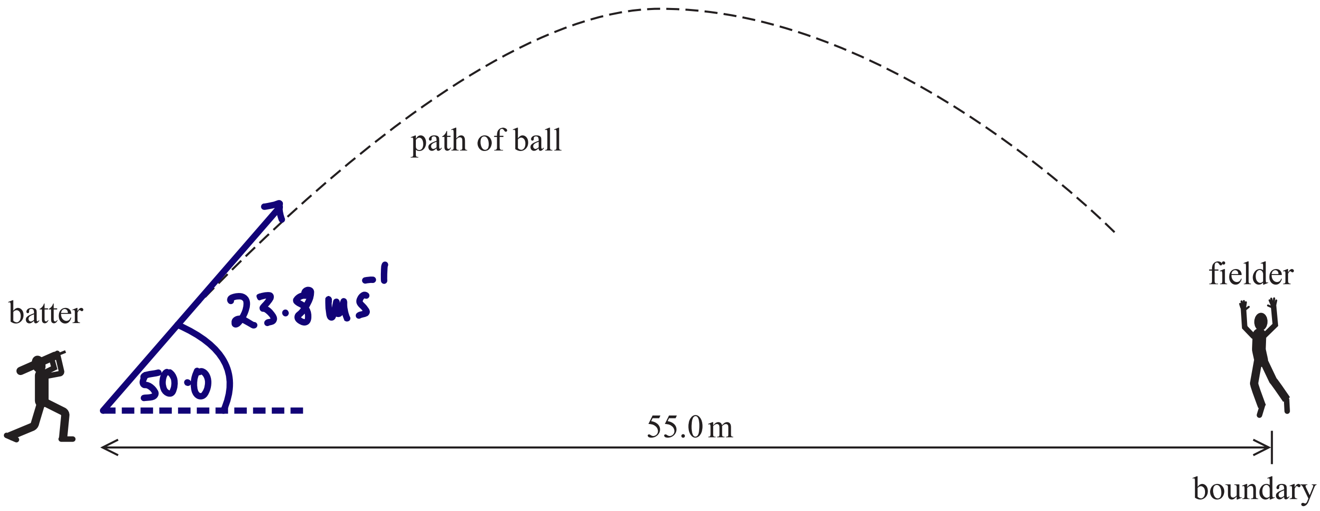
Explain why an increase in internal resistance of a battery is a disadvantage.

(3)

An increased internal resistance results in a lower terminal pd ✓ ∴ reducing the current ✓ ∴ acceleration of the car is reduced. ✓

(Total for Question 16 = 12 marks)

17 In cricket a fielder is often placed at the boundary edge as shown. If the fielder catches the ball, the batter is out.



The fielder is 55.0 m away from the batter. The fielder can catch the ball providing the ball is less than three metres above the height at which it was hit.

The ball is hit with a velocity of 23.8 m s^{-1} and at an angle of 50.0° to the horizontal.

(a) Deduce whether the fielder can catch the ball in this case.

(5)

$\rightarrow$ $s = 55.0\,m$

$u = 23.8 \cos 50.0\ ms^{-1}$ ✓

$v =$ "

$a = 0\ ms^{-2}$

$t = ?$

$t = \frac{s}{u} = \frac{55.0}{23.8 \cos 50.0}$ ✓

$t = 3.595\,s$

$\uparrow$ $s =$

$u = 23.8 \sin 50.0\ ms^{-1}$

$v =$

$a = -9.81\ ms^{-2}$

$t = 3.595\,s$

$s = ut + \frac{1}{2}at^2$ ✓

$s = (23.8 \sin 50.0 \times 3.595)$
$- (0.5 \times 9.81 \times 3.595^2)$ ✓
$= 2.15\,m < 3\,m$ ✓

$\therefore$ can catch the ball

P 7 1 9 1 5 A 0 1 8 2 8

(b) The ball was bowled. Just after the bat hit the ball, the ball had a velocity of 23.8 m s^{-1} at an angle of 50° to the horizontal.

(i) Show that the magnitude of the momentum of the ball, after it was hit, was about 3.3 N s.

mass of cricket ball = 0.140 kg

(1)

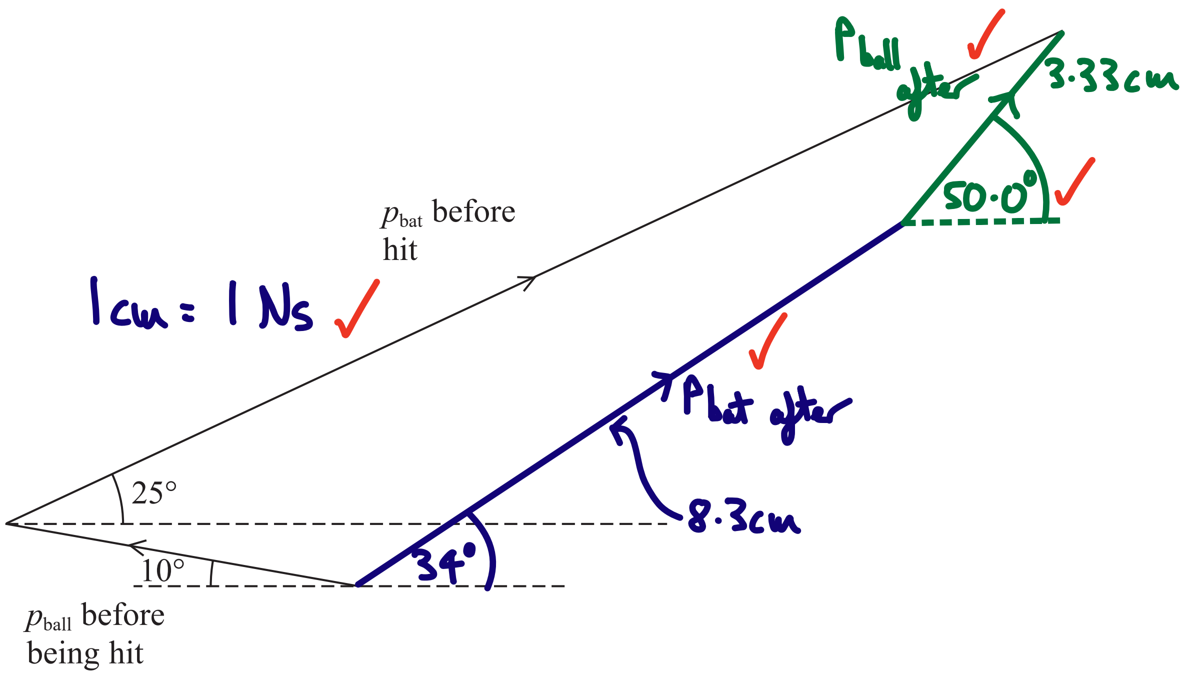
$p = mv = 0.140 \times 23.8 = 3.332$ kg m s^{-1} ≈ 3.3

(ii) The vector diagram below shows, accurately to scale, the momentum of the ball and the momentum of the bat before the hit.

Determine, by completing the vector diagram, the momentum of the bat after it hit the ball.

momentum of bat before hitting ball = 15.0 N s at 25° to the horizontal
momentum of ball before hitting bat = 4.6 N s at 10° to the horizontal

(5)

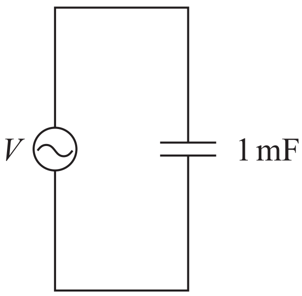


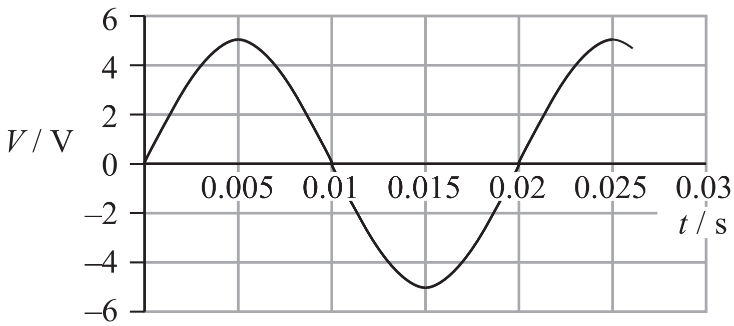
Momentum of bat after hitting ball = 8.3 kg m s^{-1}

at an angle of 34° to the horizontal

(Total for Question 17 = 11 marks)

18 The circuit shows a 1 mF capacitor connected to an a.c. supply. The graph shows how the potential difference V varies with time t.





(a) (i) Calculate the root-mean-square potential difference.

(1)

$V_{rms} = V_0/\sqrt{2} = 5.0/\sqrt{2} = 3.536$

Root-mean-square potential difference = 3.5 V ✓

(ii) The formula used to generate this graph is $V = 5\sin(100\pi t)$

Explain why this formula leads to the graph above.

(3)

$-1 \leqslant \sin\theta \leqslant 1 \quad \therefore -5 \leqslant 5\sin\theta \leqslant 5$

$\therefore$ The 5 stretches the sine graph in the y-direction with scale factor of 5 to 5V. ✓

sin oscillates with $T = 2\pi$, as $\theta = 100\pi t$

100π is 50 times greater $\therefore$ graph is stretched by SF $1/50$ $\therefore T = 0.02$ s ✓✓

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(b) A spreadsheet is used to model how the current I in the 1 mF capacitor varies with t. Six rows of the spreadsheet are shown below.

	A	B	C	D	E	F	G
	t / s	Δt / s	V / V	$Q_{initial}$ / C	Q_{final} / C	ΔQ / C	I / A
7	0.0050	0.0010	5.00	0.00476	0.00500	0.00024	0.24
8	0.0060	0.0010	4.76	0.00500	0.00476	–0.00024	–0.24
9	0.0070	0.0010	4.05	0.00476	0.00405	–0.00071	–0.71
10	0.0080	0.0010	2.94	0.00405	0.00294	–0.00111	–1.11
11	0.0090	0.0010	1.55	0.00294	0.00155	–0.00139	–1.39
12	0.0100	0.0010	0	0.00155	0.00000	–0.00155	–1.55

(i) Explain how cell E10 has been calculated. **(2)**

$Q = CV$ ✓ ∴ cell $E_{10} = Q = CV$ where $C = 1\times10^{-3}$ F

and V = cell $C_{10} = 2.94$ V ✓

(ii) State the formula used to calculate cell G11. **(1)**

$I = \dfrac{\Delta Q}{\Delta t}$ ✓

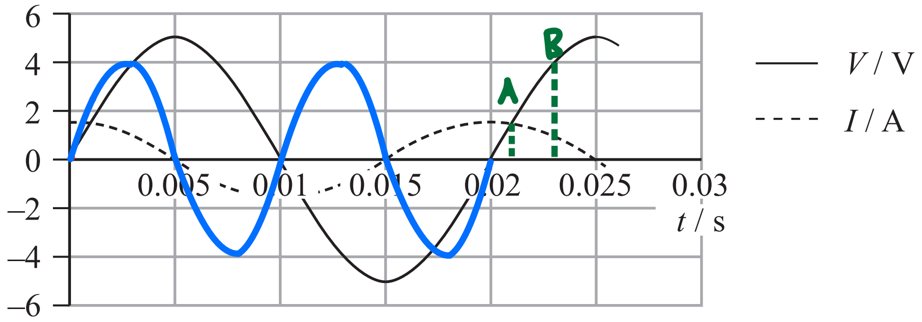
(iii) Calculate the maximum energy stored on the capacitor. **(2)**

$W = \frac{1}{2}CV^2 = \frac{1}{2} \times 1\times10^{-3} \times 5.00^2$ ✓

$= 0.0125$ J ✓

Maximum energy stored on the capacitor = ...

(c) The spreadsheet data are used to plot a graph to show how I varies with t. This is shown as a dashed line below.



The corresponding graph of V against t is also shown as a continuous line.

Deduce whether the capacitor dissipates power over one cycle of the a.c. supply.

(4)

Line in blue shows how the power varies with time, where $P = IV$.

At A : $P = IV = 1.5 \times 1.5 = 2.25$ W

B : $P = IV = 1.0 \times 4.0 = 4.0$ W

As this is both positive and negative the overall power dissipated is zero.

(Total for Question 18 = 13 marks)

TOTAL FOR PAPER = 90 MARKS

List of data, formulae and relationships

Acceleration of free fall	$g = 9.81\ \text{m s}^{-2}$	(close to Earth's surface)
Boltzmann constant	$k = 1.38 \times 10^{-23}\ \text{J K}^{-1}$	
Coulomb law constant	$k = \dfrac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9}\ \text{N m}^2\ \text{C}^{-2}$	
Electron charge	$e = -1.60 \times 10^{-19}\ \text{C}$	
Electron mass	$m_e = 9.11 \times 10^{-31}\ \text{kg}$	
Electronvolt	$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$	
Gravitational constant	$G = 6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$	
Gravitational field strength	$g = 9.81\ \text{N kg}^{-1}$	(close to Earth's surface)
Permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}\ \text{F m}^{-1}$	
Planck constant	$h = 6.63 \times 10^{-34}\ \text{J s}$	
Proton mass	$m_p = 1.67 \times 10^{-27}\ \text{kg}$	
Speed of light in a vacuum	$c = 3.00 \times 10^{8}\ \text{m s}^{-1}$	
Stefan-Boltzmann constant	$\sigma = 5.67 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^{-4}$	
Unified atomic mass unit	$u = 1.66 \times 10^{-27}\ \text{kg}$	

Mechanics

Kinematic equations of motion

$$s = \frac{(u + v)t}{2}$$

$$v = u + at$$

$$s = ut + \tfrac{1}{2}at^2$$

$$v^2 = u^2 + 2as$$

Forces

$$\Sigma F = ma$$

$$g = \frac{F}{m}$$

$$W = mg$$

$$\text{moment of force} = Fx$$

Momentum

$$p = mv$$

Work, energy and power

$$\Delta W = F\Delta s$$

$$E_k = \tfrac{1}{2}mv^2$$

$$\Delta E_{grav} = mg\Delta h$$

$$P = \frac{E}{t}$$

$$P = \frac{W}{t}$$

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}}$$

$$\text{efficiency} = \frac{\text{useful power output}}{\text{total power input}}$$

Electric circuits

Potential difference

$$V = \frac{W}{Q}$$

Resistance

$$R = \frac{V}{I}$$

Electrical power and energy

$$P = VI$$

$$P = I^2R$$

$$P = \frac{V^2}{R}$$

$$W = VIt$$

Resistivity

$$R = \frac{\rho l}{A}$$

Current

$$I = \frac{\Delta Q}{\Delta t}$$

$$I = nqvA$$

Materials

Density

$$\rho = \frac{m}{V}$$

Stokes' law

$$F = 6\pi\eta rv$$

Hooke's law

$$\Delta F = k\Delta x$$

Young modulus

$$\text{Stress } \sigma = \frac{F}{A}$$

$$\text{Strain } \varepsilon = \frac{\Delta x}{x}$$

$$E = \frac{\sigma}{\varepsilon}$$

Elastic strain energy

$$\Delta E_{el} = \tfrac{1}{2}F\Delta x$$

Waves and particle nature of light

Wave speed

$$v = f\lambda$$

Speed of a transverse wave on a string

$$v = \sqrt{\frac{T}{\mu}}$$

Intensity of radiation

$$I = \frac{P}{A}$$

Power of a lens

$$P = \frac{1}{f}$$

$$P = P_1 + P_2 + P_3 + \ldots$$

Thin lens equation

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

Magnification for a lens

$$m = \frac{\text{image height}}{\text{object height}} = \frac{v}{u}$$

Diffraction grating

$$n\lambda = d \sin \theta$$

Refractive index

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$n = \frac{c}{v}$$

Critical angle

$$\sin C = \frac{1}{n}$$

Photon model

$$E = hf$$

Einstein's photoelectric equation

$$hf = \phi + \tfrac{1}{2}mv^2_{\text{max}}$$

de Broglie wavelength

$$\lambda = \frac{h}{p}$$

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Further mechanics

Impulse

$$F\Delta t = \Delta p$$

Kinetic energy of a non-relativistic particle

$$E_k = \frac{p^2}{2m}$$

Motion in a circle

$$v = \omega r$$

$$T = \frac{2\pi}{\omega}$$

$$F = ma = \frac{mv^2}{r}$$

$$a = \frac{v^2}{r}$$

$$a = r\omega^2$$

$$F = mr\omega^2$$

Fields

Coulomb's law

$$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$$

Electric field strength

$$E = \frac{F}{Q}$$

$$E = \frac{Q}{4\pi\varepsilon_0 r^2}$$

$$E = \frac{V}{d}$$

Electric potential

$$V = \frac{Q}{4\pi\varepsilon_0 r}$$

Capacitance

$$C = \frac{Q}{V}$$

Energy stored in a capacitor

$$W = \tfrac{1}{2}QV$$

$$W = \tfrac{1}{2}CV^2$$

$$W = \tfrac{1}{2}\frac{Q^2}{C}$$

Capacitor discharge

$$Q = Q_0 e^{-t/RC}$$

$$I = I_0 e^{-t/RC}$$

$$V = V_0 e^{-t/RC}$$

$$\ln Q = \ln Q_0 - \frac{t}{RC}$$

$$\ln I = \ln I_0 - \frac{t}{RC}$$

$$\ln V = \ln V_0 - \frac{t}{RC}$$

In a magnetic field

$$F = BIl \sin\theta$$

$$F = Bqv \sin\theta$$

Faraday's and Lenz's laws

$$\mathscr{E} = \frac{-d(N\phi)}{dt}$$

Root-mean-square values

$$V_{rms} = \frac{V_0}{\sqrt{2}}$$

$$I_{rms} = \frac{I_0}{\sqrt{2}}$$

Nuclear and particle physics

In a magnetic field

$$r = \frac{p}{BQ}$$

Thermodynamics

Heating

$$\Delta E = mc\Delta\theta$$

$$\Delta E = L\Delta m$$

Molecular kinetic theory

$$\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$$

$$pV = \frac{1}{3}Nm\langle c^2\rangle$$

Ideal gas equation

$$pV = NkT$$

Stefan-Boltzmann law

$$L = \sigma AT^4$$

$$L = 4\pi r^2\sigma T^4$$

Wien's law

$$\lambda_{max}T = 2.898 \times 10^{-3}\ \text{m K}$$

Space

Intensity

$$I = \frac{L}{4\pi d^2}$$

Redshift of electromagnetic radiation

$$z = \frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$$

Cosmological expansion

$$v = H_0 d$$

Nuclear radiation

Mass-energy

$$\Delta E = c^2\Delta m$$

Radioactive decay

$$A = \lambda N$$

$$\frac{dN}{dt} = -\lambda N$$

$$\lambda = \frac{\ln 2}{t_{½}}$$

$$N = N_0\, e^{-\lambda t}$$

$$A = A_0\, e^{-\lambda t}$$

Gravitational fields

Gravitational force

$$F = \frac{Gm_1m_2}{r^2}$$

Gravitational field strength

$$g = \frac{Gm}{r^2}$$

Gravitational potential

$$V_{grav} = \frac{-Gm}{r}$$

Oscillations

Simple harmonic motion

$$F = -kx$$

$$a = -\omega^2 x$$

$$x = A\cos\omega t$$

$$v = -A\omega\sin\omega t$$

$$a = -A\omega^2\cos\omega t$$

$$T = \frac{1}{f} = \frac{2\pi}{\omega}$$

$$\omega = 2\pi f$$

Simple harmonic oscillator

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

$$T = 2\pi\sqrt{\frac{l}{g}}$$

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