Catholic Junior College
JC2 Preliminary Examinations
Higher 2

CANDIDATE NAME	MARK SCHEME
CLASS	2T

PHYSICS **9749/02**

Paper 2 Structured Questions

23 August 2024

2 hours

Candidates answer on the Question Paper.

READ THESE INSTRUCTIONS FIRST

Write your name and class in the spaces at the top of this page.
Write in dark blue or black pen on both sides of the paper.
You may use an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.
Answer **all** questions.

The number of marks is given in brackets [ ] at the end of each question or part question.

FOR EXAMINER'S USE		
Q1		/ 6
Q2		/ 12
Q3		/ 5
Q4		/ 5
Q5		/ 7
Q6		/ 11
Q7		/ 8
Q8		/ 6
Q9		/ 20
PAPER 2		/ 80

DATA

speed of light in free space	c	=	3.00×10^{8} m s^{-1}
permeability of free space	μ_0	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	ε_0	=	8.85×10^{-12} F m^{-1}
			$(1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge	e	=	1.60×10^{-19} C
the Planck constant	h	=	6.63×10^{-34} J s
unified atomic mass constant	u	=	1.66×10^{-27} kg
rest mass of electron	m_e	=	9.11×10^{-31} kg
rest mass of proton	m_P	=	1.67×10^{-27} kg
molar gas constant	R	=	8.31 J K^{-1} mol^{-1}
the Avogadro constant	N_A	=	6.02×10^{23} mol^{-1}
the Boltzmann constant	k	=	1.38×10^{-23} mol^{-1}
gravitational constant	G	=	6.67×10^{-11} N m^{2} kg^{-2}
acceleration of free fall	g	=	9.81 m s^{-2}

FORMULAE

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
work done on / by a gas	$W = p\,\Delta V$
hydrostatic pressure	$p = \rho g h$
gravitational potential	$\phi = -\dfrac{Gm}{r}$
temperature	$T/K = T/^{\circ}C + 273.15$
pressure of an ideal gas	$p = \dfrac{1}{3}\dfrac{Nm}{V}\langle c^2\rangle$
mean translational kinetic energy of an ideal gas molecule	$E = \dfrac{3}{2}kT$
displacement of particle in s.h.m.	$x = x_0 \sin \omega t$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$ $= \pm\omega\sqrt{x_0^{\,2} - x^2}$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \ldots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \ldots$
electric potential	$V = \dfrac{Q}{4\pi\varepsilon_o r}$
alternating current / voltage	$x = x_0 \sin \omega t$
magnetic flux density due to a long straight wire	$B = \dfrac{\mu_o I}{2\pi d}$
magnetic flux density due to a flat circular coil	$B = \dfrac{\mu_o N I}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_o n I$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \dfrac{\ln 2}{t_{\frac{1}{2}}}$

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

1 A car of mass 1700 kg travels over a curved hump in the road as shown in Fig. 1.1. The radius of curvature of the hump is 45 m.

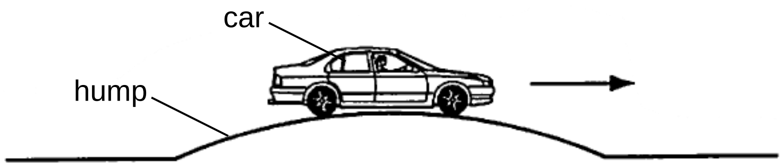


Fig. 1.1

(a) The speed of the car at the top of the hump is 19 m s^{-1}.

Determine, for the car at the top of the hump,

(i) the magnitude of the centripetal force acting on the car,

centripetal force = ………………….……………… N [1]

L1

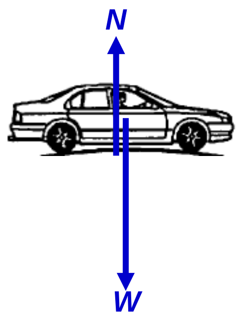
$$F_c = \frac{mv^2}{r} = \frac{(1700)(19)^2}{45} = 13638 = \mathbf{14000\ N}$$

A1

(ii) the magnitude of the normal contact force exerted by the road on the car.

normal contact force = ……………………………… N [2]

L2 Free body diagram:



The resultant force of the downward weight of the car *W* and the upward normal contact force exerted by the road *N* provide for the centripetal force required.

***W* – *N* = 13638**
(1700)(9.81) – *N* = 13638 **M1**

***N* = 3039 = <u>3000 N (magnitude)</u>**
Direction of *N*: vertically upwards **A1**

(b) Determine the maximum speed v_{max} that the car can travel at without losing contact with the top of the hump. Explain your working.

v_{max} = …………………………… m s^{-1} [3]

L2 **The resultant force of the downward weight of the car *W* and the upward normal contact force exerted by the road *N* provide for the centripetal force F_c required. Thus,** **B1**
$W - N = F_c$
$N = W - F_c$

For the car not to lose contact with the top of the hump, the normal contact force N with the road must be greater than zero, i.e. **B1**

$N > 0$

$W - F_c > 0$

$mg - \frac{mv^2}{r} > 0$

$v < \sqrt{rg}$

$v < \sqrt{(45)(9.81)}$

$v_{max} = 21.011 = 21 \text{ m s}^{-1}$ **A1**

[Total: 6]

2 A long, straight wire W carrying a direct current of 3.0 A flows in the direction as shown in Fig. 2.1.

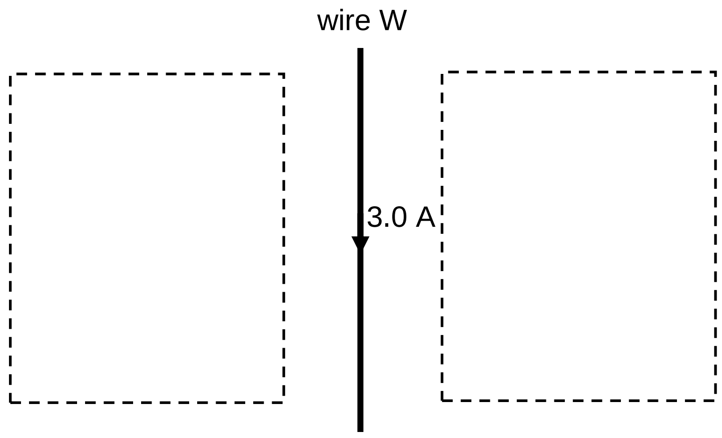
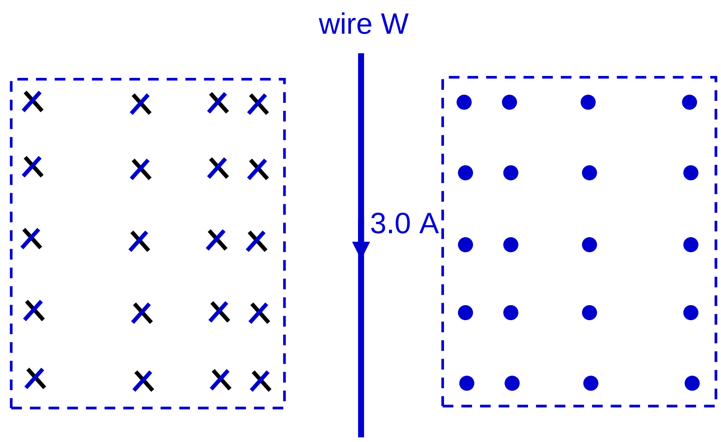


Fig. 2.1

(a) Draw on Fig. 2.1, the pattern of the magnetic field produced by wire W in the regions indicated by the dotted boxes. Use the symbol x to represent magnetic field directed into the page and use the symbol • to represent magnetic field directed out of the page. [3]

L1 Solution:



Marks scheme:

1 mark for: **B1**

- Correct direction of magnetic flux density on left side (into plane of paper) and right side (out of plane of paper) of wire W.

1 mark for: **B1**

- Increasing spacing with increasing distance from wire W.

1 mark for (Pattern shown sufficiently) **B1**

- At least 4 columns each of x and • shown to show the trend of increasing spacing between consecutive circular field lines.

- At least 3 rows each of x and • shown to show the trend of equal spacing parallel to the wire.

(b) A similar wire Y is placed parallel to wire W, separated by a distance of 40.0 cm as shown in Fig. 2.2. Initially, there is no current in wire Y.

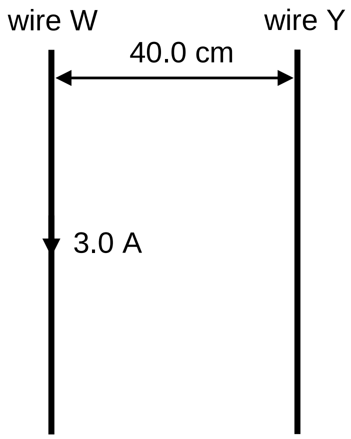


Fig. 2.2

(i) Show that the magnetic flux density at wire Y due to the current in wire W is 1.5×10^{-6} T.

[1]

L1

Magnetic flux density $B = \frac{\mu_0 I}{2\pi d}$ where I is the current in wire W and d the distance of Y from W.

$B = \frac{(4\pi \times 10^{-7})(3.0)}{2\pi(40.0 \times 10^{-2})}$ **M1**

$= 1.5 \times 10^{-6}$ T (Shown) **A0**

(ii) A current of 1.0 A is now switched on in wire Y and flows in the opposite direction as the direction of current flow in wire W.

Use your answer in **(b)(i)** to calculate the force per unit length acting on wire Y.

force per unit length = ………………………….. N m^{-1} [2]

L2

Magnetic force $F_{\text{on Y}} = B_{\text{at Y due to W}} I_{\text{in Y}} L_{\text{of Y}} \sin\theta$

where $\theta = 90°$ since B and I are perpendicular.

$\frac{F}{L} = BI$

$\frac{F}{L} = (1.5 \times 10^{-6})(1.0)$ **M1**

$= 1.5 \times 10^{-6}$ N m^{-1} **A1**

(iii) Explain why the force that the two wires exert on each other is repulsive.

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

			....	
			....	
			....	
			....	[3]
		L2	**By Right Hand Grip Rule (*or,* using Fig. 2.1), the magnetic field produced by the current in wire W acts perpendicular to wire Y and out of the plane of paper.**	**M1**
			By Fleming's Left Hand Rule, the direction of the magnetic force on Y by W acts to the right / away from wire W.	**M1**
			By Newton 3rd law of motion, the direction of the magnetic force on W by Y is opposite to that on wire Y / towards the left / away from wire Y. [OR, Apply Fleming's Left Hand Rule a second time to determine the force on W.]	**M1**
			Therefore there is a repulsive force acting between the two wires.	**A0**
		(iv)	Determine a possible position, other than at infinity, where the resultant magnetic flux density due to the magnetic fields of both wires is zero.	
			position:	[3]
		L2	First, consider **directions** of the two fields in different regions: • Net *B* cannot be zero between W and Y, since their fields point in the same direction. • **On the left of both wires, and, on the right of both wires, their fields point in opposite directions**.	**M1**
			Secondly, consider **magnitude** of *B*: • Since $\lvert B\rvert = \dfrac{\mu_0 I}{2\pi d} \Rightarrow \lvert B\rvert \propto \dfrac{I}{d}$. Hence Net B can only be zero **on the side *further away* from the *larger* current**. Thus, **Net B is zero on the *right side of wire Y***.	
			Let *y* be the distance to the right of wire Y.	**M1**

			$\lvert B_{\text{due to Y}} \rvert = \lvert B_{\text{due to W}} \rvert$ $\frac{\mu_0 (1.0)}{2\pi y} = \frac{\mu_0 (3.0)}{2\pi (40.0 \times 10^{-2} + y)}$ $\frac{(1.0)}{y} = \frac{(3.0)}{(40.0 \times 10^{-2} + y)}$ $40.0 \times 10^{-2} + y = 3.0y$ $2.0y = 40.0 \times 10^{-2}$ $y = 20.0 \times 10^{-2}$ m $= 20.0$ cm position: **20.0 cm to the *right* of wire Y.** *(For marking: 'right' of wire Y can be stated either in the final answer space, or, working. Award A1 mark as long as this understanding that it must be right of Y be seen.)*	**A1**

[Total: 12]

3	A uniform spherical star has a mass of 6.0 x 10^{30} kg. The mass of the star may be assumed to be a point mass at the centre of the star. The star may be considered to be isolated in space.		
	(a)	Show that the gravitational field strength at a point 3.0 x 10^9 m from the centre of the spherical star is 44.5 N kg^{-1}.	
			[1]
	L1	$g = \frac{GM}{r^2} = \frac{(6.67 \times 10^{-11})(6.0 \times 10^{30})}{(3.0 \times 10^9)^2}$ $= 44.467 = 44.5\ N kg^{-1}$	**M1** **A0**
	(b)	The radius of the star is 1.0 x 10^9 m. On the axes of Fig. 3.1, sketch a graph to show the variation with distance *x* from the centre of the star of the gravitational field strength *g* of the star for values of *x* from *x* = 1.0 x 10^9 m to *x* = 4.0 x 10^9 m.	

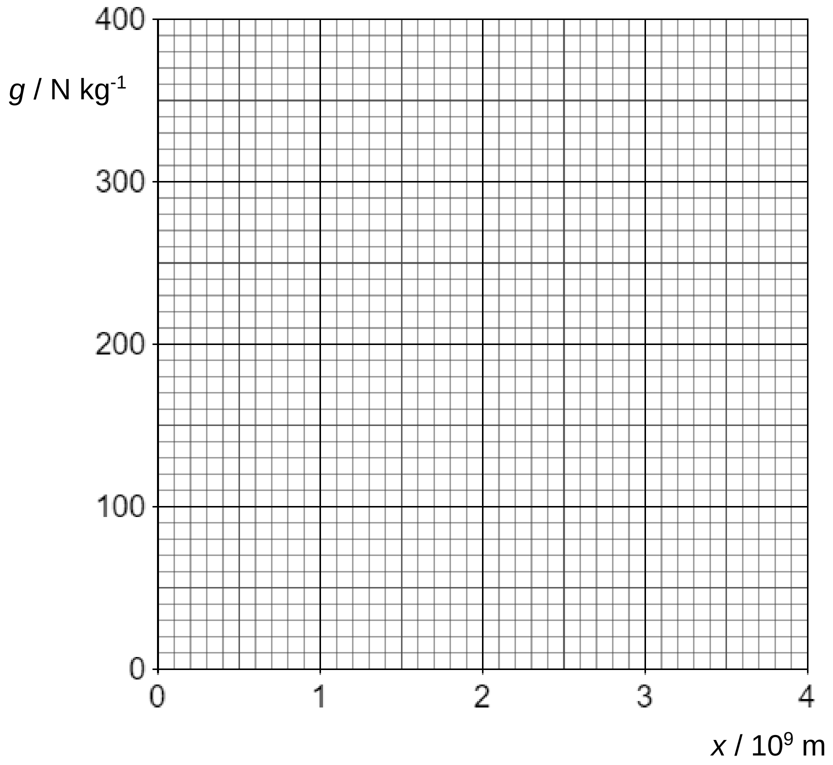


Fig. 3.1

[3]

L2

$g = \frac{GM}{x^2}$

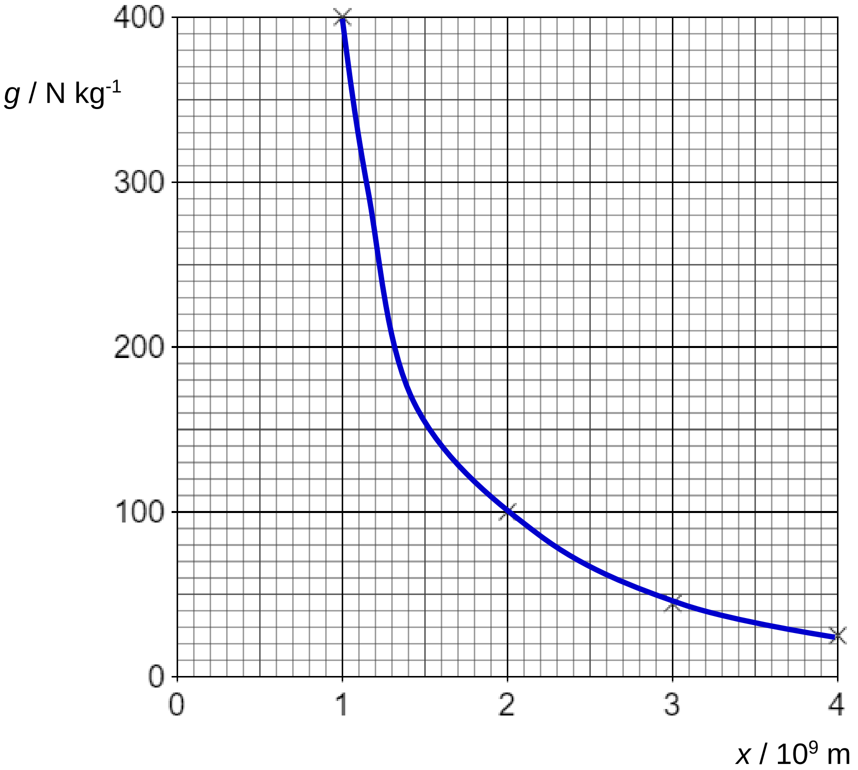
Thus **g is inversely proportional to r². **

When x = 1.0 x 10^9 m,

$$g = \frac{GM}{x^2} = \frac{(6.67 \, x \, 10^{-11})(6.0 \, x \, 10^{30})}{(1.0 \, x \, 10^9)^2} = 400.2 \, N \, kg^{-1}$$

OR, using (a), $g = (3^2)(44.467) = 400.2 \, N \, kg^{-1}$

x / m	**g / N kg^{-1}**
$\mathbf{1.0 \, x \, 10^9}$	**400.2**
$\mathbf{2.0 \, x \, 10^9}$	¼ x 400.2 = **100.1**
$\mathbf{3.0 \, x \, 10^9}$	From (a): **44.5**
$\mathbf{4.0 \, x \, 10^9}$	¼ x 100.1 = **25.0**



B2

2 marks – At least 4 correctly plotted points in the required range from x = 1.0 x 10^9 m to x = 4.0 x 10^9 m, and 4 points relatively well spaced out.

- [1 mark if 1 point wrongly plotted.]
- [0 mark if 2 or more points wrongly plotted or no point plotted.]

1 mark – Smooth hyperbolic curve drawn in the required range from x = 1.0 x 10^9 m to x = 4.0 x 10^9 m.

B1

	(c)	State what the area under the graph in Fig. 3.1 represents.	
		…………………………………………………………………………………………………..	
		………………………………………………………………………………………………	[1]
	L1	**Change in gravitational potential** (from x = 1.0 x 10^9 m to x = 4.0 x 10^9 m). OR **Work done per unit mass by an external agent in moving a small mass from x = 1.0 x 10^9 m to x = 4.0 x 10^9 m.**	**B1**

[Total: 5]

4	Two parallel plates are in a vacuum. One plate is positively charged and the other plate is earthed. A rectangular conductor of width x is placed in between the plates so that one of its faces is at a distance 0.5x from the positively charged plate and the opposite face is at 1.5x from the earthed plate as shown in Fig. 4.1.

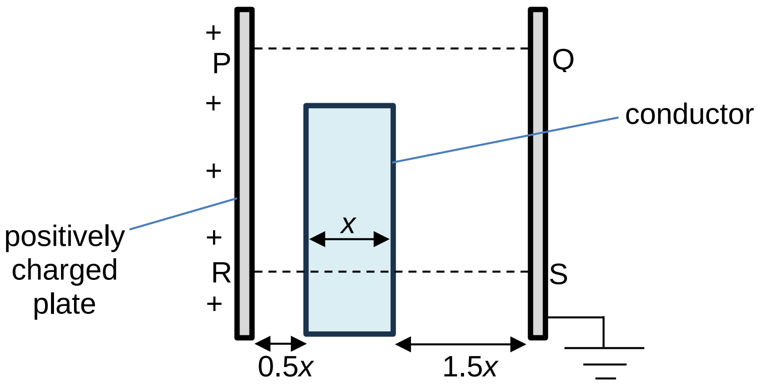


Fig. 4.1

The electric potential difference across the parallel plates is 3.00 V.

(a) The variation with distance from P to Q of the electric potential along line PQ is shown in Fig. 4.2.

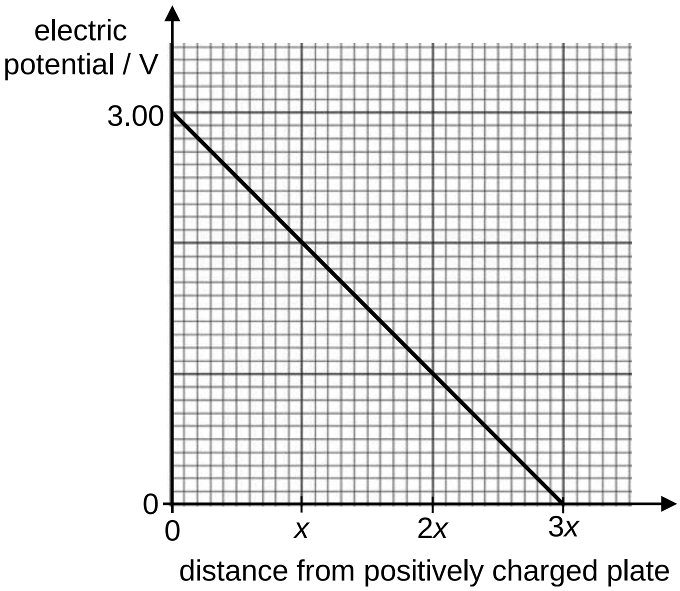
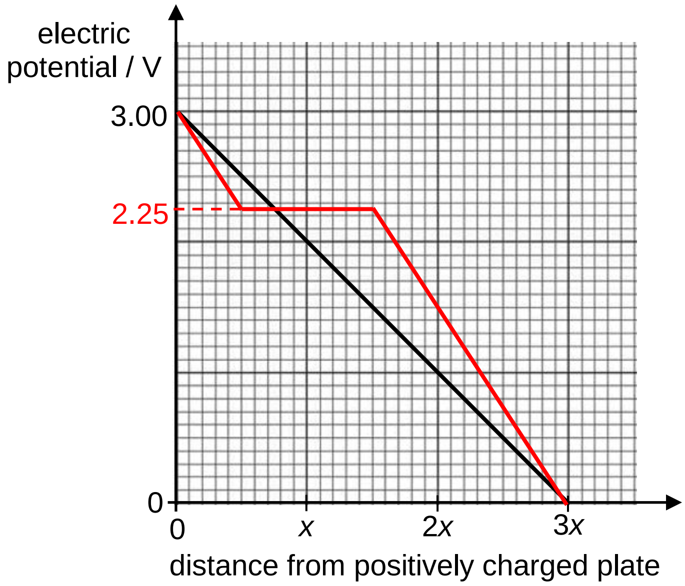


Fig. 4.2

On Fig. 4.2, draw a line to show the variation with distance from R to S of the electric potential along the line RS. [2]

L3 The electric potential **decreases proportionally** with distance in **between parallel plates**.
In addition, there is **no change in electric potential across the conductor**.
Therefore,

			B1 B1

1 mark – Horizontal line (at 2.25 V) **from 0.5*x* to 1.5*x*.**
1 mark – Straight line from 3.00 V to 2.25 V on the left of the conductor AND straight line from 2.25 V to 0 V to the right of the conductor, AND **both** of these lines must have **equal** gradients, i.e. equal electric field strength.

Working:
Since:
- Same uniform electric field strength outside the conductor, and,
- Zero p.d. within the conductor, and,
- Total p.d. between parallel plates equal to 3.00 V.

Thus:
- Effective distance over which potential decreases by 3.00 V is 2*x* (= plate separation – width of conductor),
- Electric field strength outside the conductor, $E_{outsdie} = 3.00 / 2x = 1.5x^{-1}$,
- To the left of the conductor, p.d. = $E_{outsdie}.0.5x = (1.5x^{-1})(0.5x) = 0.75$ V → potential of left face of conductor = 3.00 – 0.75 = 2.25 V.

(b) The variation with distance from P to Q of the electric field strength along line PQ is shown in Fig. 4.3.

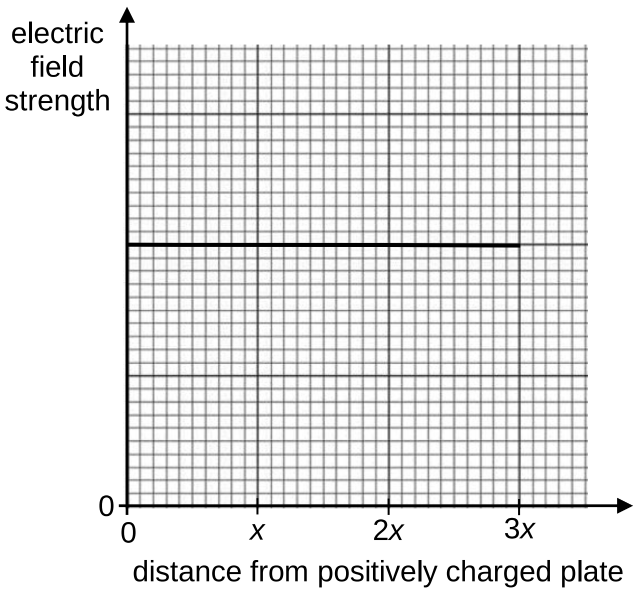
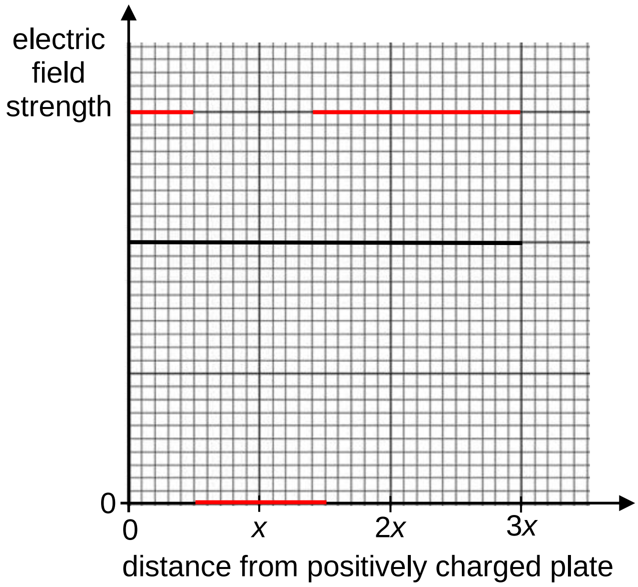


Fig. 4.3

On Fig. 4.3, draw a line to show the variation with distance from R to S of the electric field strength along the line RS. [3]

L3 The electric field strength is assumed to be constant in between parallel plates, and the electric field strength in a conductor is zero.

By observing the gradient of the graph in Fig. 4.2, the electric field strength is the same between 0 to 0.5*x* and from 1.5*x* to 3*x*.



1 mark – Horizontal straight line at **0** between **0.5*x* to 1.5*x*** **B1**

1 mark – Horizontal, **non-zero** lines to depict constant non-zero electric field strength between **0 to 0.5 *x*** and **1.5*x* to 3*x*, and at greater electric field strength** **B1**

1 mark – Magnitude of electric field strength outside the conductor is at **1.5 times** the value in PQ, and, the same between 0 to 0.5 *x* and 1.5*x* to 3*x* **B1**

Allow ECF from graph in part (a), showing understanding of E = -dV/dx.

Note to students: Phrasing of "draw a line..." follows A-level phrasing in 2020 P2 Q3, although one may argue that it is misleading since final answer has 3 separated lines not a single continuous line.

[Total: 5]

5 Fig. 5.1 shows a circular coil of 500 turns and radius 0.12 m.

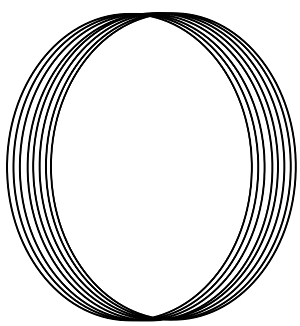


Fig. 5.1

A uniform magnetic field of flux density *B* is applied at right angles to the plane of the coil.

[Turn over

The magnetic flux density *B* changes with time *t* as shown in Fig. 5.2.

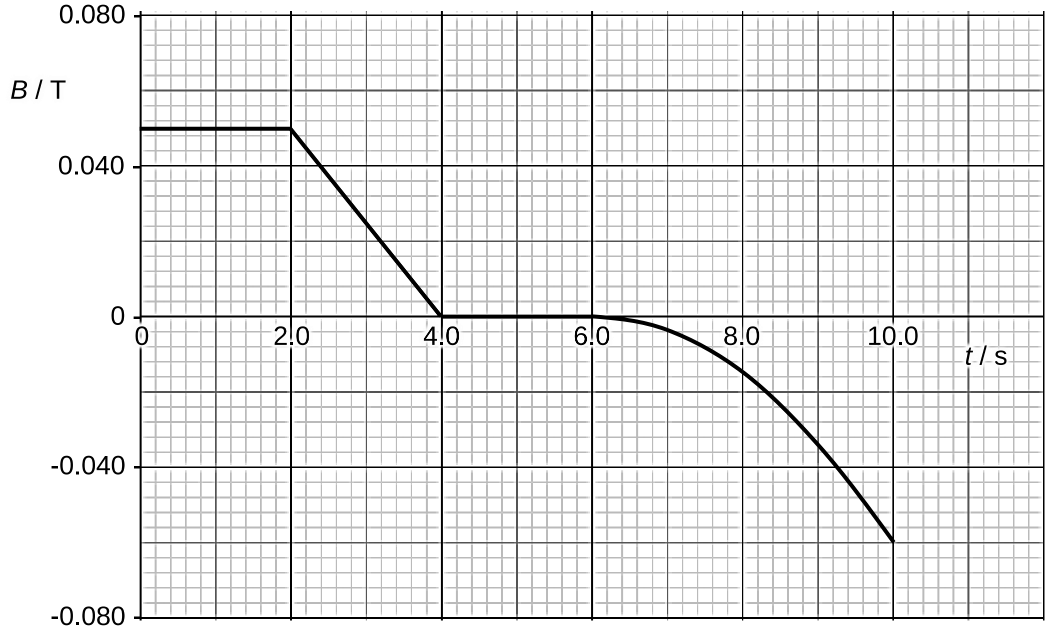


Fig. 5.2

From *t* = 6.0 s to t = 10.0 s, the gradient of the graph of *B* against *t* changes at a constant rate.

	(a)	Calculate the magnetic flux linkage of the coil at *t* = 10.0 s.	
		magnetic flux linkage = ……………..………………….…… Wb	[2]
	L2	Magnetic flux linkage $\Phi = NBA$, where *A* is the area and *N* is the number of the coil. $\Phi = NBA = (500)(0.060)\left[\pi(0.12^2)\right]$ = 1.3572 Wb = 1.4 Wb (2 s.f.)	**M1** **A1**
	(b)	Show that the magnitude of the induced e.m.f. in the coil between *t* = 2.0 s and *t* = 4.0 s is 0.57 V.	
			[2]
	L2	Applying faraday's law of electromagnetic induction, $\lvert E \rvert = \left\lvert -\frac{d\Phi}{dt} \right\rvert = \left\lvert \frac{d(NBA)}{dt} \right\rvert = NA\left\lvert \frac{dB}{dt} \right\rvert$ where $\frac{dB}{dt}$ is the gradient of the B-t graph $= (500)\left[\pi(0.12^2)\right]\left\lvert \frac{(0.050-0)}{(2.0-4.0)} \right\rvert$ = 0.56549 V = 0.57 V (Shown)	**C1** **M1** **A0**
	(c)	On Fig. 5.3, sketch a graph to show the variation with time *t* of the induced e.m.f. *E* in the coil for time *t* = 0 to *t* = 10.0 s.	

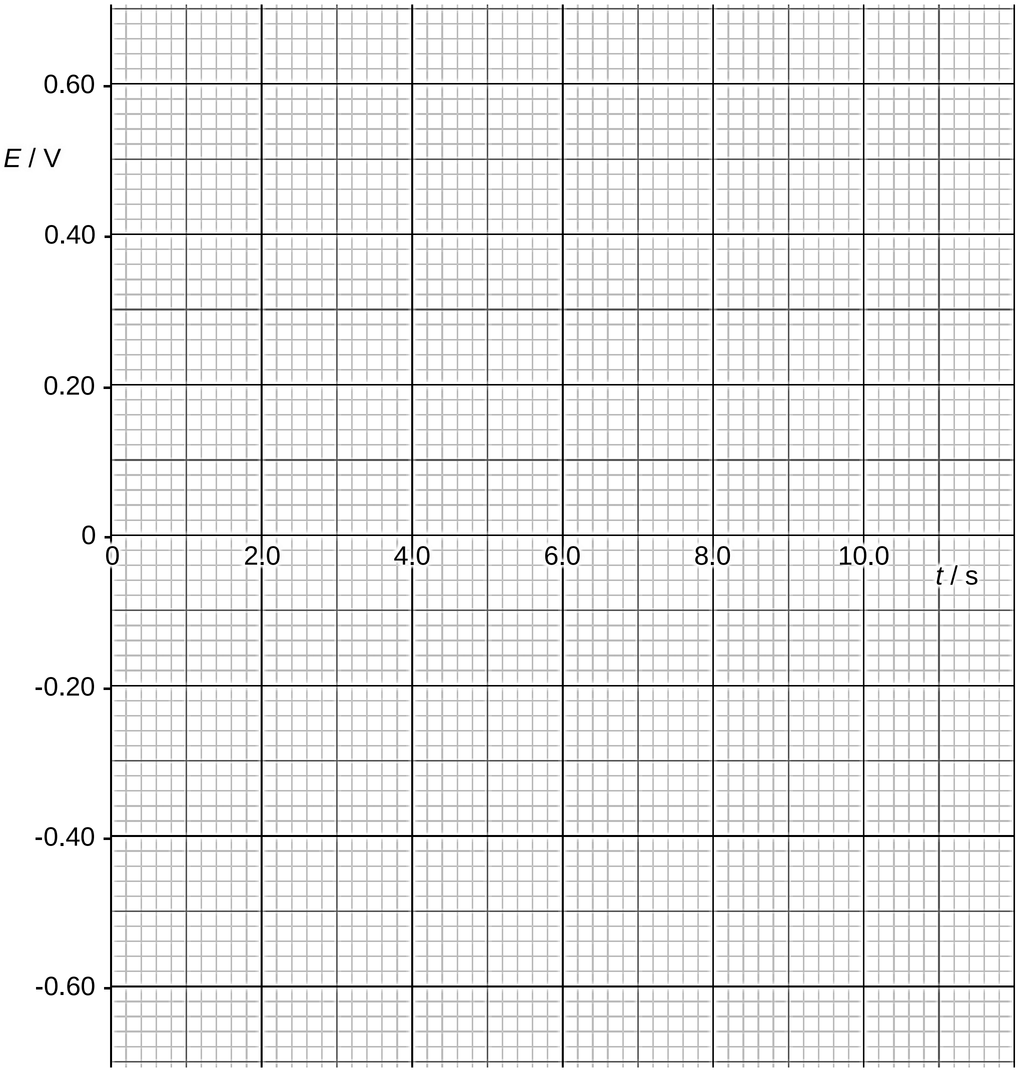
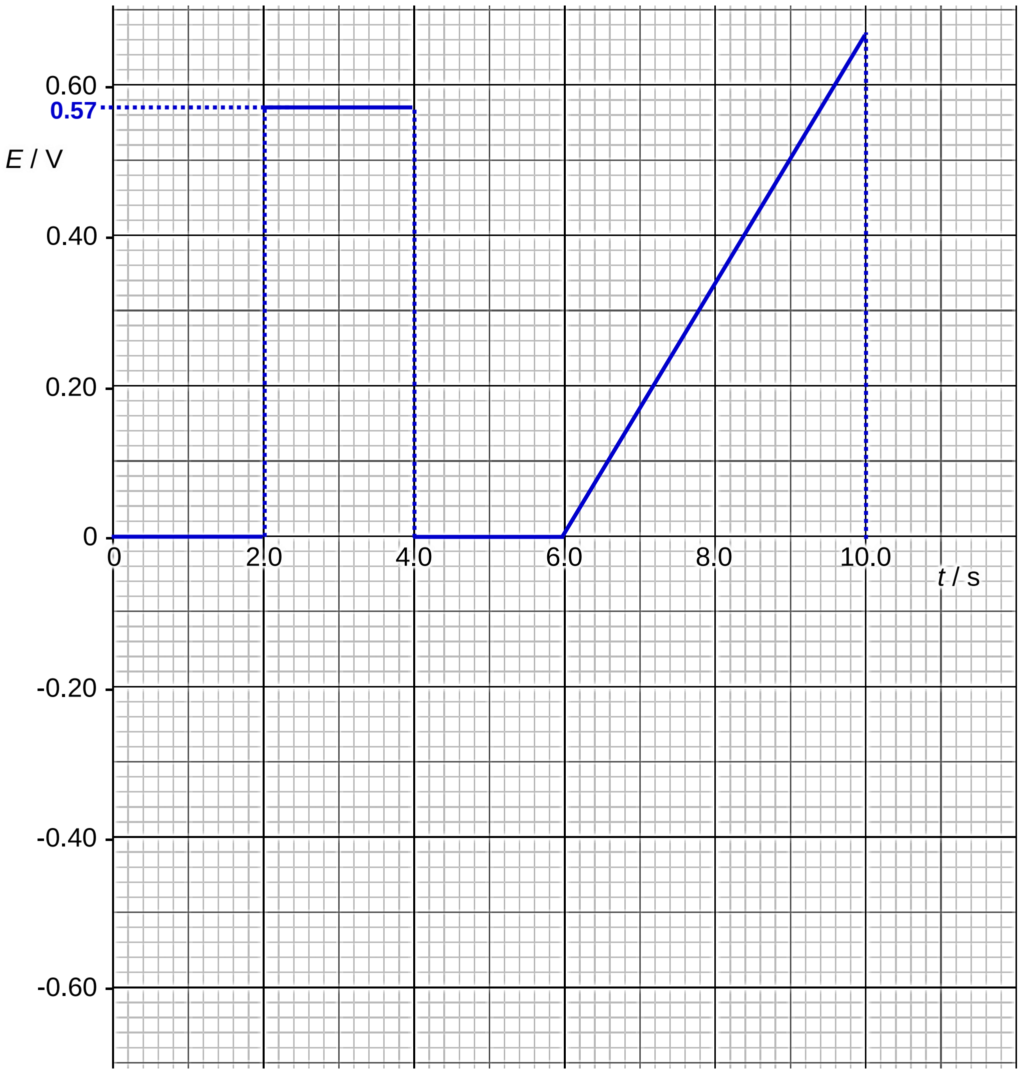


Fig. 5.3 [3]

L3 Solution:



From Faraday's Law and Lenz's Law,

$$E = -\frac{d\Phi}{dt} = -\frac{d(NBA)}{dt} = -NA\frac{dB}{dt}$$

Therefore,

1 mark: **Zero induced e.m.f. from 0 to 2.0 s and from 4.0 s to 6.0 s.**	**B1**
1 mark: **Constant positive e.m.f. of 0.57 V from 2.0 s to 4.0 s.**	**B1**
1 mark: **E.m.f. increases with time (straight line, positive gradient) from 6.0 s to 10.0 s.**	**B1**

*Additional note to students (not marked for here): **At 10.0 s,** since the gradient dB/dt is **steeper** than the gradient from 2.0 s to 4.0 s, the magnitude of induced e.m.f. at 10.0 s is **greater than 0.57 V** (actual value not required since an accurate tangent cannot be constructed at the end of the graph in this case; if possible, the tangent should be drawn and gradient used to calculate the e.m.f. at 10.0s).*

*Note: There is **no reversal** of direction of induced e.m.f. at 6.0 s because the magnitude of B is increasing from 6.0 s to 10.0 s. So by Lenz's Law, in an attempt to oppose the change in flux linkage when B is reversed in direction and increasing in magnitude, the induced e.m.f. remains in the same direction as from 2.0 s to 4.0 s where B was of opposite direction and decreasing in magnitude.*

[Total: 7]

6 A cylinder that contains a fixed amount of an ideal gas is shown in Fig. 6.1.

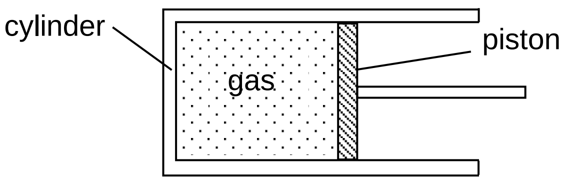


Fig. 6.1

The cylinder is fitted with a piston that moves freely.

(a) Use the kinetic theory of gases to explain

(i) the origin of the pressure of the gas in the cylinder,

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.... [3]

L2

Gas atoms are in constant random motions, and they continually collide with the walls of the cylinder.

When a gas atom collides with the wall of the cylinder, it rebounds and its velocity changes direction, hence there is a change in momentum of the gas atom. **B1**

By Newton's second law of motion, there is a resultant force exerted by the wall on the gas atom which is proportional to the rate of change in momentum. **B1**

By Newton's third law, the gas atom exerts a force of equal magnitude and opposite direction on the wall. **B1**
The pressure exerted by the gas is the total force per unit area of the container walls exerted by all the gas atoms on the walls of its container.

***An answer referring to kinetic theory of gases (i.e. referring to the movement of the gas atoms) is expected. No mark awarded if candidate explains with reference to macroscopic properties.*

(ii) why the mean velocity of the atoms of the gas is zero.

....

[Turn over

		……………………………………………………………………………………………………	
		……………………………………………………………………………………………………	
		……………………………………………………………………………………………………	
		……………………………………………………………………………………………………	[2]
	L2	The **gas atoms are in random motion** and this means that **every atom has equal probability of moving in every direction.** **Also, the mean speed in all directions are equal.**	B1
		Consequently, the **vector sum of all their velocities is equal to zero**. Hence, the mean velocity is zero.	B1
(b)		Fig. 6.2 shows the variation of pressure and volume of the monoatomic ideal gas in the cylinder. The gas is initially at state W.	

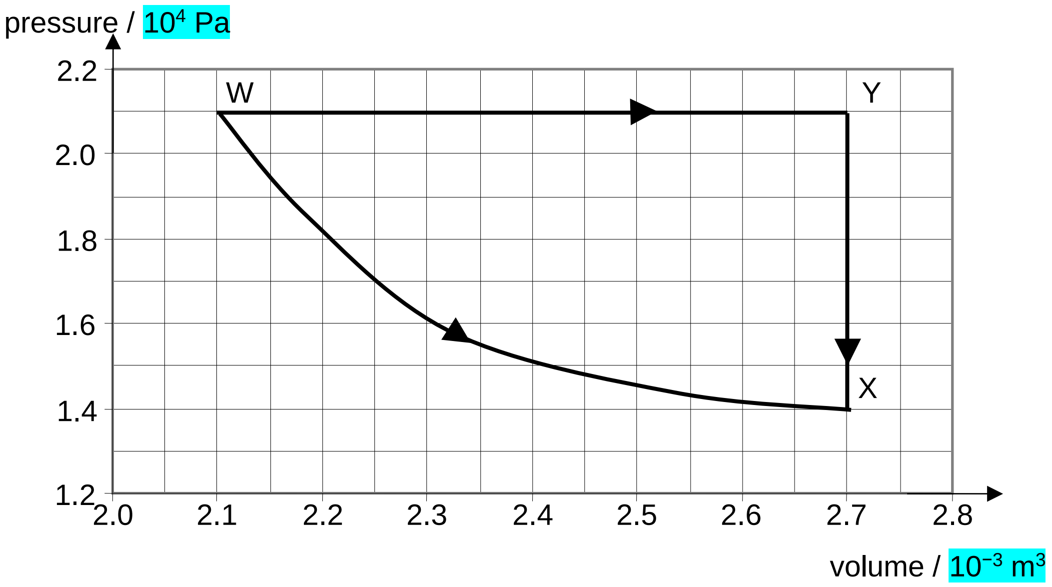
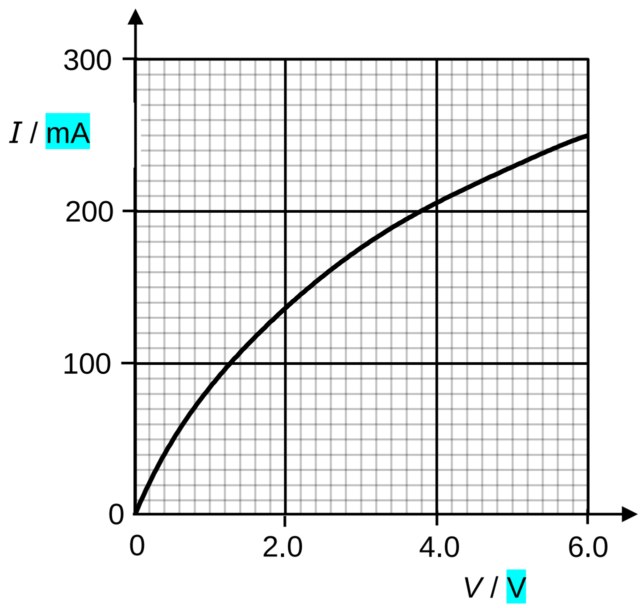


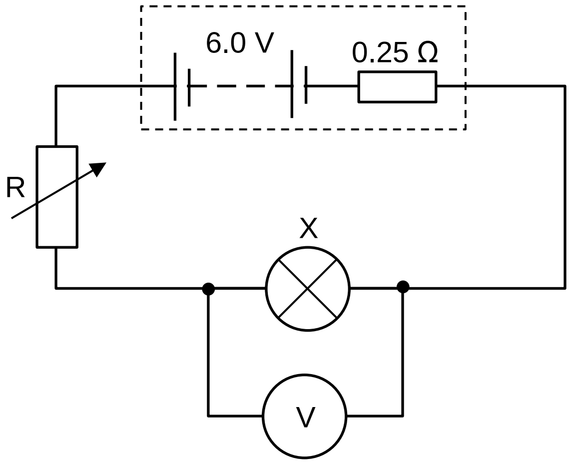
Fig. 6.2

(i)	Determine the change in internal energy of the gas when it is taken from state W to state X along the curved path.		
	change in internal energy = ……………………………… J	[2]	
L2	For a monoatomic ideal gas,		
	$\Delta U_{WX} = \frac{3}{2}nR\Delta T = \frac{3}{2}\Delta(pV)$		
	$\Delta U_{WX} = \frac{3}{2}(p_X V_X - p_W V_W)$		
	$\Delta U_{WX} = \frac{3}{2}\left[(1.4x10^4)(2.7x10^{-3}) - (2.1x10^4)(2.1x10^{-3})\right]$	M1	
	$\Delta U_{WX} = -9.45$ J	A1	
(ii)	The same resultant change in state of the gas may be achieved by stages WY and YX.		
	Determine the net heat supplied to the gas during the change from W to Y to X.		

			heat supplied =................................... J	[4]
		L2	**The change in internal energy for both paths, W to X or W to Y to X are the same.** $\Delta U_{WX} = \Delta U_{WYX} = -9.45$ J Using Fig. 6.2, work done by the gas $= (2.1 \times 10^4)(2.7 - 2.1) \times 10^{-3} = 12.6$ J Using first law of thermodynamics, $\Delta U_{WYX} = Q + W_{WYX}$ $-9.45 = Q + (-12.6)$ $Q = +3.15$ J	**C1** **M1** **M1** **A1**

[Total: 11]

7	**(a)**	Fig. 7.1 shows the variation with potential difference *V* of the current *I* for a filament lamp X rated at 6.0 V and 1.5 W.  **Fig. 7.1**		
		(i)	Calculate the resistance of the filament lamp at 6.0 V.	
			resistance = ... Ω	[2]
		L1	*R is given by the RATIO of the coordinates (V, I) at the operating point of interest.* $R = \frac{V}{I} = \frac{6.0}{250 \times 10^{-3}}$	**M1** **A1**

			= **24 Ω**	
		(ii)	Explain how Fig. 7.1 shows that the resistance of the filament lamp increases as the potential difference across the filament lamp increases.	
			…………………………………………………………………………………………	
			…………………………………………………………………………………………	[1]
		L1	Fig. 7.1 shows that as *V* increases, the **ratio of *V* to *I* increases**. Since resistance is defined as the ratio of potential difference *V* to the current *I*, the resistance of the filament lamp increases as the p.d. increases.	**B1**
		(iii)	The filament lamp X is connected in series with a battery B and a variable resistor R, and, in parallel with a voltmeter, as shown in Fig. 7.2.  **Fig. 7.2** Battery B has electromotive force 6.0 V and internal resistance 0.25 Ω. The resistance of R is adjusted such that the voltmeter reads 5.0 V. Calculate the terminal potential difference (p.d.) across B. Show your working.	
			terminal p.d. across B = ………………………………… V	[3]
		L2	**From Fig. 7.1, when *V* = 5.0 V across lamp X,** **current through lamp X is *I* = 230 mA = 0.230 A.** ***Note: Resistance of X is not the same as that in (a)(i).*** ***Do not accept I = 5.0 V / 24 Ω = 0.208 A.*** Terminal p.d. across B, V_t $= E - Ir$ = **6.0 – (0.230)(0.25)** = 5.9425 = **5.9 V**	**M1** **M1** **A1**

			Note: Both M1 and A1 marks are not awarded if the wrong value of current I is substituted or if working is not shown clearly.	
	(b)	Fig. 7.3(a) and Fig. 7.3(b) show two circuits which can be used to act as a dimmer switch for a lamp.		

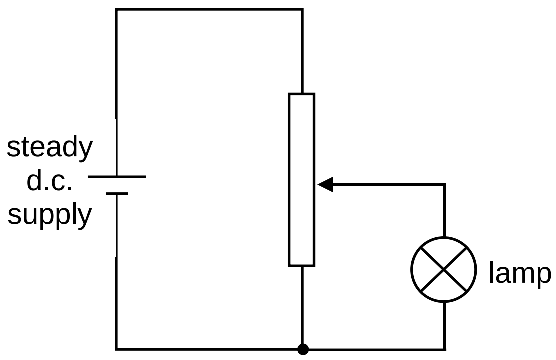


Fig. 7.3(a)

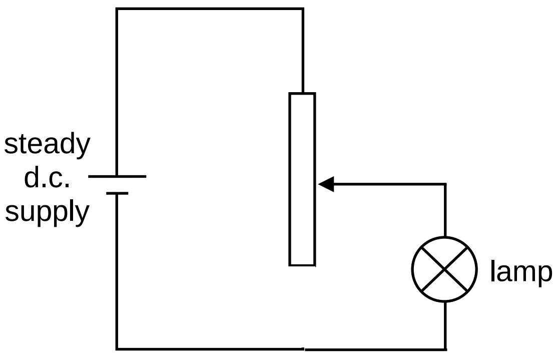


Fig. 7.3(b)

		State and explain one advantage the circuit in Fig. 7.3(a) has over the circuit in Fig. 7.3(b) in varying the brightness of the lamp.	
		…………………………………………………………………………………………	
		…………………………………………………………………………………………	
		…………………………………………………………………………………………	[2]
	L3	State: **The lamp in circuit in Fig. 7.3(a) can be fully switched off.** Explain: **In the circuit in Fig. 7.3(b), there is always p.d. across the lamp**. *Do not accept "waste less energy/power". Answer too generic and there is still current flowing through the fixed resistor hence there is still power dissipated in the resistor even when the lamp is off in Fig. 7.3(a).*	**B1** **B1**

[Total: 8]

8	A long horizontal tube, containing fine powder, is closed at one end. A loudspeaker connected to a signal generator is positioned at the other of the tube. At a particular frequency, a stationary wave is set up inside the tube and the powder forms heaps as shown in Fig. 8.1.	

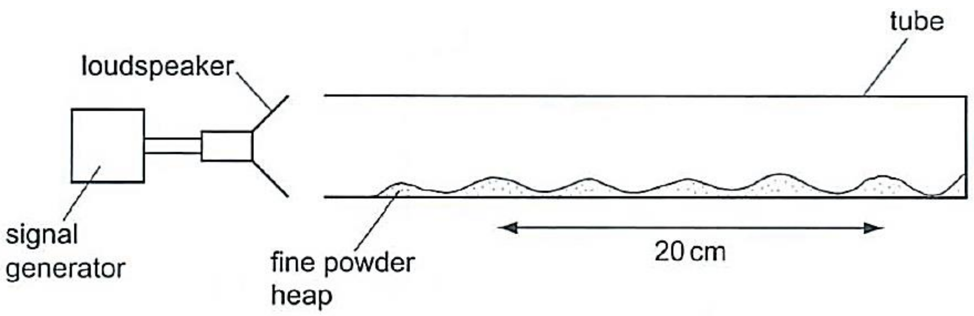


Fig. 8.1

The speed of sound is 330 m s^{-1}.

	(a)	Explain why, for a stationary wave to form inside the tube, it is usually necessary to adjust either the frequency of the signal generator or the length of the tube.

[Turn over

		…………………………………………………………………………………………	
		…………………………………………………………………………………………	
		…………………………………………………………………………………………	
		…………………………………………………………………………………………	
		…………………………………………………………………………………………	[2]
	L2	For stationary wave to form inside the tube, the **boundary conditions at both ends of the air column in the tube must be always satisfied: a displacement node must form at the closed-end and a displacement antinode must form at the open-end**. This implies that the **tube length must be equal to an odd integer multiple of one-quarter-of-a-wavelength**. Thus, to achieve this, either the frequency of the sound wave (which affects wavelength), or, the tube length must be adjusted.	B1 B1
	(b)	With reference to the motion of the air molecules in the tube, explain why the powder heaps form at the displacement nodes.	
		…………………………………………………………………………………………	
		…………………………………………………………………………………………	
		…………………………………………………………………………………………	
		…………………………………………………………………………………………	
		…………………………………………………………………………………………	
		…………………………………………………………………………………………	[2]
	L2	**Displacement nodes are where the air molecules in the tube remain at rest**. **At all other positions, the air molecules vibrate/oscillate *parallel* to the tube-axis, with maximum amplitude of vibration occurring at the displacement antinodes.** The **air molecules on either side of a displacement node vibrate in antiphase**, whereas **between any two successive nodes the air molecules vibrate in phase**. Thus the motion of the *air molecules* causes the powder to be pushed away from the displacement antinodes and settle at the displacement nodes.	B1 B1
	(c)	Using Fig. 8.1, calculate the frequency of the sound wave in the tube.	
		frequency = ………………………………… Hz	[2]
	L1	"heaps" are the locations of the displacement nodes. Distance between two successive nodes in a stationary wave = ½ wavelength **From Fig. 8.1,** **2 wavelengths = 20 cm** **1 wavelength = 10 cm** $v = f\lambda$	

		$330 = f (10 \times 10^{-2})$ f = 3300 Hz	C1 A1

[Total: 6]

9	Read the passage below and answer the questions that follow. When an object is moving in a fluid such as air and water, it experiences a force known as drag force which always opposes the motion of the object. The drag force on an object is dependent on a few factors such as the velocity of the object relative to the fluid, the drag coefficient, the frontal area of the object and the density of the fluid. When taking into accounts these factors, the drag force is given by $$D = kC\rho Av^2$$ where k is a constant; C is the drag coefficient; ρ is the density of the fluid; A is the frontal area of the object; v is the velocity of the object relative to the fluid. The frontal area A is the cross-sectional area of the object that passes through the fluid. The drag coefficient C is a dimensionless quantity with no unit. It is dependent largely on shape of the object and to a small extent on the velocity of the object relative to the fluid. In most cases, the drag coefficient may be considered to be independent of the speed of the object relative to the fluid. A parachute is an inflatable device which is used to slow down the speed of an object. Parachutes come in different shapes and sizes. Parachutes are made from strong and light weight nylon that has been treated to be less porous so that it does not let as much air through especially at high speeds. This allows the open parachute to create more air resistance and to achieve a lower terminal speed just before reaching the ground. The parachute is packed into a single backpack called the container. In a particular parachuting jumping, a parachutist with his parachute in the container leaps off from a helicopter. We may consider he falls straight down from rest when his initial horizontal speed is small and there is no wind which causes a horizontal motion. During the first few seconds of the fall, the parachutist falls under the action of gravity with his parachute in the container. His velocity increases from zero to a constant value known as the terminal velocity. The terminal velocity is dependent on the total mass of the parachutist and the parachute, the drag coefficient, the density of the air and the frontal area of the falling parachutist with his parachute. The parachutist may fall with his body vertical (known as feet first position) or with his body horizontal (known as spread eagle position). The frontal area of the parachutist depends on whether the parachutist is falling with feet first position or spread eagle position. In the feet first position, the frontal area is approximately 0.18 m^2 while the frontal area in the spread eagle position is about 4 times that of the feet first position. At a suitable altitude, he triggers the parachute to open by pulling on the ripcord and the velocity decreases rapidly. The parachutist will reach a lower terminal velocity before reaching the ground. Fig. 9.1 shows the arrangement of the parachute with the parachute fully open.	

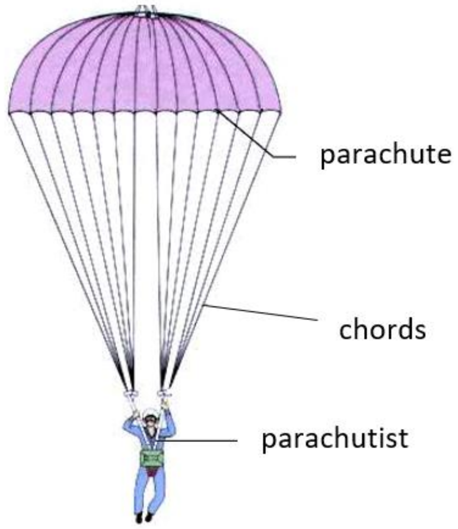


Fig. 9.1

Fig. 9.2 shows the variation with speed of the drag force per unit frontal area acting on a body with different drag coefficients.

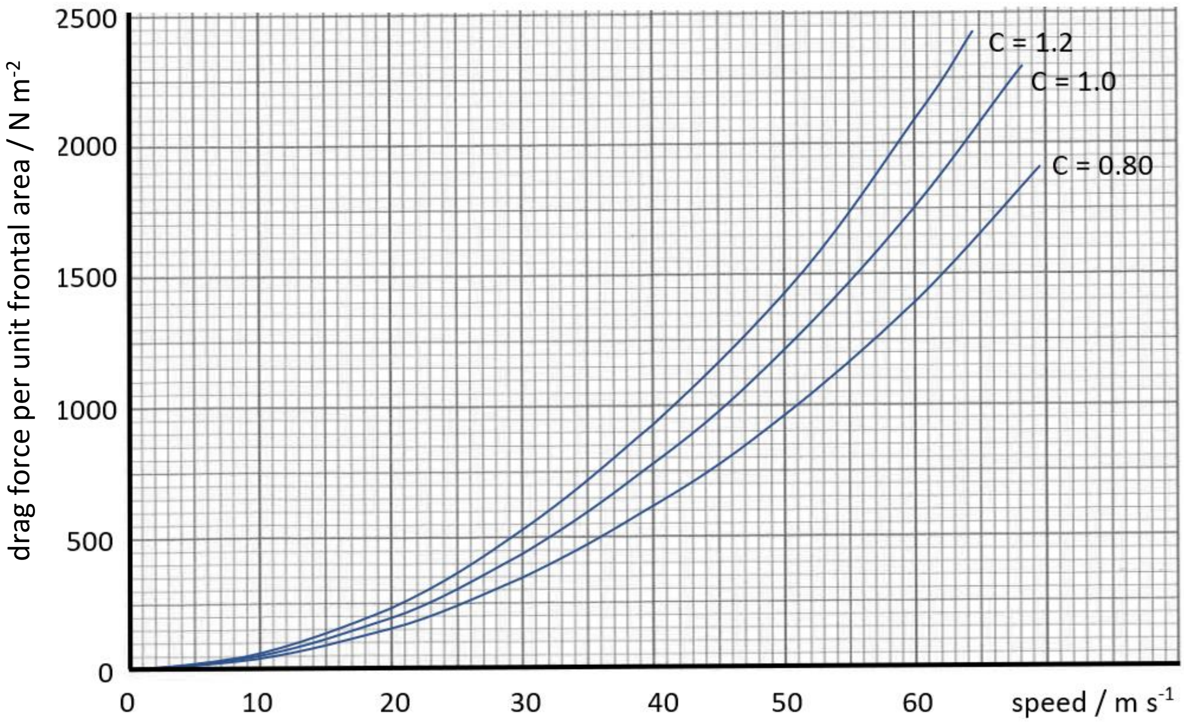


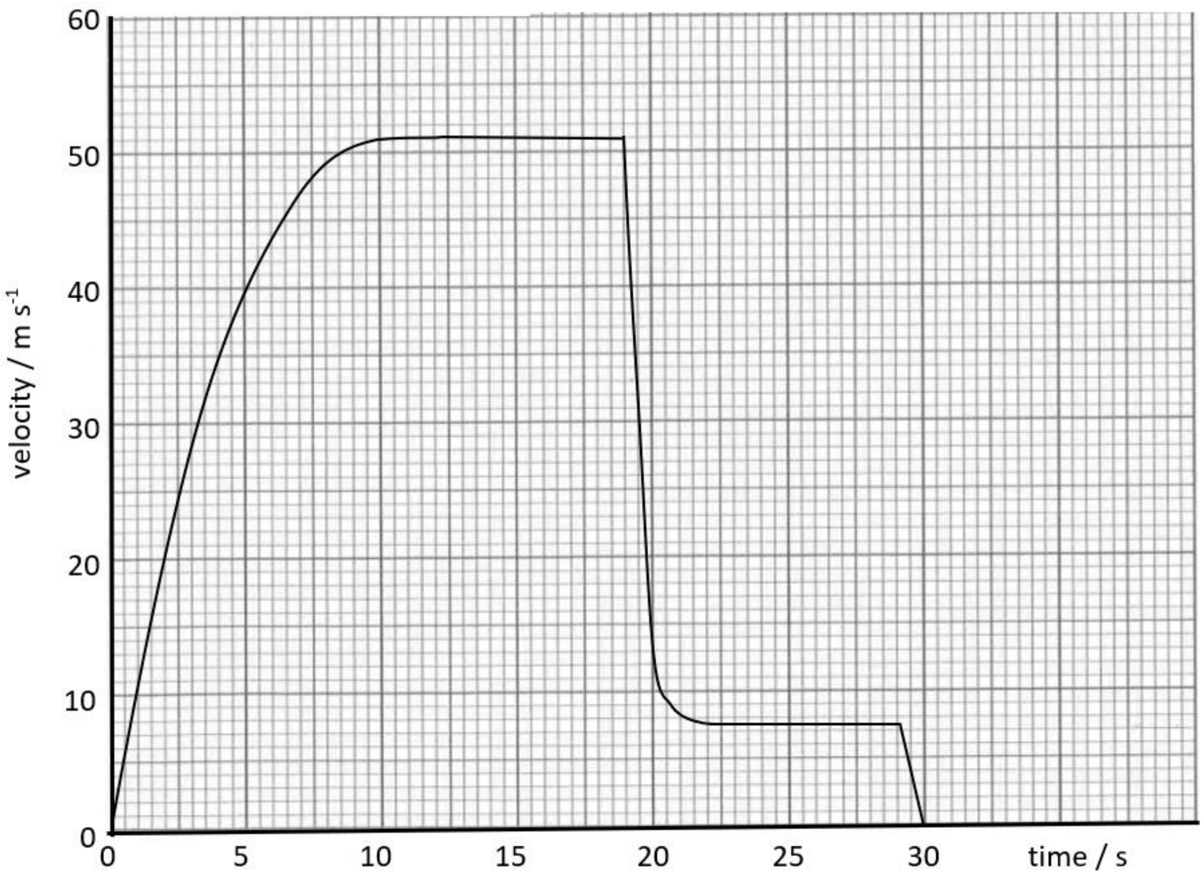
Fig. 9.2

Typical values of the drag coefficient *C* for a parachutist are as shown below:

Parachutist with parachute closed in feet first position	$C = 0.80$
Parachutist with parachute closed in spread eagle position	$C = 1.0$
Parachutist with parachute fully open	$C = 1.2$

The density of air may be assumed to be constant at 1.02 kg m^{-3} throughout the fall.

For safety reason, the terminal velocity of the parachutist must not be more than 7.5 m s^{-1} before reaching the ground. During a parachuting landing when the parachutist falls vertically, the parachutist must slightly bend his knees and clutch his body upon touching the ground, with the

	elbows tucked into the sides to prevent injury. The parachutist then allows his body to land on the ground before rolling his body. Fig. 9.3 shows the variation with time of the velocity of a parachutist who falls with parachute closed in spread eagle position. The parachutist reaches a terminal velocity at time 10 s. At 19 s, the parachutist opens the parachute and reaches a new terminal velocity of 7.5 m s^{-1} at 22 s.  **Fig. 9.3**	
	(a)	From Fig. 9.2, using the curve for the situation when the parachute is closed with the parachutist in the feet first position, show that the drag force is proportional to the square of the velocity.
		[4]

	L2	Since **frontal area A is fixed for the same starting position** (i.e. same feet first position), **if drag force is proportional to the square of the velocity then drag force per unit area, D/A = k v^2** **<u>Using Fig. 9.2, for curve C = 0.80,</u>** **When v = 20 m s^{-1}, $v^2 = 20^2 = 400$ m^2 s^{-2}, drag force per unit area = 150 N m^{-2}** **k = 150 / 400 = 0.38 N s^2** When v = 30 m s^{-1}, $v^2 = 30^2 = 900$ m^2 s^{-2}, drag force per unit area = 350 N m^{-2} k = 350 / 900 = 0.39 N s^2 **When v = 40 m s^{-1}, $v^2 = 40^2 = 1600$ m^2 s^{-2}, drag force per unit area = 625 N m^{-2}** **k = 625 / 1600 = 0.39 N s^2** When v = 50 m s^{-1}, $v^2 = 50^2 = 2500$ m^2 s^{-2}, drag force per unit area = 975 N m^{-2} k = 975 / 2500 = 0.39 N s^2 **When v = 60 m s^{-1}, $v^2 = 60^2 = 3600$ m^2 s^{-2}, drag force per unit area = 1400 N m^{-2}** **k = 1400 / 3600 = 0.39 N s^2** **Read values of v and D/A from curve C = 0.80** for **at least 3 points, and with range optimised/maximised (20 to 60 m s^{-1})**: M1 **Calculation of k, i.e. ratio of D/A to v^2**: M1 **Since the value of k remains constant,** D/A is proportional to the square of the speed. **Since the values of A is the same for the same start position (feet first),** D is proportional to the square of the speed.	M1 M1 B1 B1
	(b)	Explain why the acceleration of the parachutist is approximately 10 m s^{-2} when t = 0.	
		....	
		....	
		....	[1]
	L2	At t = 0, **velocity of the parachutist = 0, thus drag force = 0 and hence the net force = weight** = mg, acceleration = net force/mass = weight/mass = acceleration due to gravity ≈10 m s^{-2}.	B1
	(c)	Explain how Fig. 9.3 shows that the drag force increases with the velocity during the first 10 s of the motion.	
		....	
		....	
		....	
		....	
		....	[3]
	L2	***Note: Candidates must relate the relevant feature of the graph (e.g. gradient) to the phenomenon.***	

		During the first 10 s, **gradient of the v-t graph decreases, which shows that (downward) acceleration decreases. Hence** by Newton's 2nd law of motion, for a body of constant mass, the **downward net force on the parachutist decreases.** **Downward net force, F_{net} = (Downward weight, W) – (Upward drag force, D)** **Since W remains constant,** F_{net} decreases implies that D increases. OR **Gradient of v-t graph decreases, implies that acceleration decreases.** Net force = mass (m) x acceleration **Weight (mg) – Drag (D) = mass (m) x acceleration** **Since m and g are constants** ➔ D increases		M1 M1 M1 A0
	(d)	A parachutist falls with parachute closed from spread eagle position. Calculate the total mass of the parachutist and the parachute.		
		total mass = ... kg		[5]
	L3	From Fig. 9.3, **At terminal velocity (with parachute is still closed)**, v = 51 m s^{-1} From the passage, In the spread eagle position, C = 1.0 and A = 4 x 0.18 = 0.72 m^2 From Fig 9.2, for C = 1.0 and v = 51 m s^{-1} , D/A = 1250 N m^{-2} D = 1250 x 0.72 = 900 N **At terminal velocity, no net force, so** **D = mg** m = D / g = 900 / 9.81 = 92 kg		C1 C1 C1 M1 A1
	(e)	From time 19 s to 20 s, when the parachute is opened but before it is fully open, the velocity changes linearly with time and the acceleration is constant.		
		(i)	Using Fig. 9.3, calculate the acceleration during this motion.	
			acceleration = ... m s^{-2}	[2]
		L1	Acceleration = gradient = (13 – 51) / 1	

			= - 38 m s^{-2} *(Accept read-off of v at 20 s as 11 m s^{-1} to 15 m s^{-1}.)* Negative sign not marked for.	**M1** **A1**
		(ii)	Explain why drag force remains constant from 19 s to 20 s.	
			………………………………………………………………………………………	
			………………………………………………………………………………………	
			………………………………………………………………………………………	
			………………………………………………………………………………………	[2]
		L2	Acceleration is constant from 19 s to 20 s. (Given.) **Since** **Acceleration upward = net force / mass** **= (D – mg) / m** **= D/m – g** **And since m and g are constants,** therefore drag force D remains constant. OR **Acceleration upward = net force / mass = (D – mg)/m = D/m – g** Where D = k C ρ A v^2 **The area A of the parachute increases as it opens, while the velocity v decreases.** **When rate of *increase* in A equals the rate of *decrease* in v^2, the product of A and v^2 remains constant.** **Since D ∝ Av^2, drag force D remains constant.**	**B0** **B1** **B1**
	(f)	For safety reasons, when the parachutist falls vertically,		
		(i)	suggest a modification to the design of the parachute if the parachutist carries a heavy load,	
			………………………………………………………………………………………	
			………………………………………………………………………………………	
			………………………………………………………………………………………	[1]
		L2	He must not fall at a terminal velocity larger than 7.5 m s^{-1}. To ensure that the terminal velocity is not larger than 7.5 m s^{-1}, **EITHER:** • **increase the area of the parachute; OR** • **improve the design to increase the drag coefficient; OR** • **use material which is not so porous to increase the drag coefficient; OR** • **decrease the mass of the parachute using a less dense material.** Reason: Acceleration upward = net force / mass = (D – mg)/m = D/m – g	**B1**

			So to increase the retardation, increase D and/or reduce total mass m which includes the parachute's mass.	
		(ii)	explain why the parachutist needs to bend his knee and body upon touching the ground during landing and then roll his body.	
			…………………………………………………………………………………………	
			…………………………………………………………………………………………	
			…………………………………………………………………………………………	[1]
		L2	**To lengthen the time of impact with the ground so that the rate of change of momentum of the body and hence the net force on the parachutist is reduced. So the force of impact is reduced and the parachutist land without injuring his body.** Reason: net force = impact force – mg; impact force = net force + mg; when net force is reduced, impact force is reduced. **OR** **This increases the displacement moved by the body during the touch down.** **The work done by the impact force = average force x displacement moved.** **Work done by impact force to reduce the body's translational kinetic energy to zero is fixed for a given jump, so with a larger displacement moved, the average force is reduced.** **By rolling, the work done by the impact force is also reduced because part of the translational kinetic energy is converted into rotational kinetic energy.**	**B1**
	(g)	The same parachutist with the parachute attempts to trigger the parachute to open immediately after he leaps off the hovering helicopter. On Fig. 9.3, sketch a graph to show the expected variation with time of the velocity of the parachutist.		[1]
	L3	The **velocity will increase from zero and reach a terminal velocity of 7.5 m s^{-1}.** (Terminal velocity is still 7.5 m s^{-1} because at terminal velocity D = mg. Since mg unchanged, D unchanged. And since D = kCρAv^2, where kCρA is constant, speed v to produce the same D is unchanged at 7.5 m s^{-1}.) The **rate of change of velocity *at the start* is the same as that when he falls freely** with the parachute in the container before he triggers it 10 seconds later. **Due to the larger drag force, the rate of increase of speed is now lower than before.** Note: The time to reach the terminal velocity is not possible to be compared from the data given. **Solution:**		

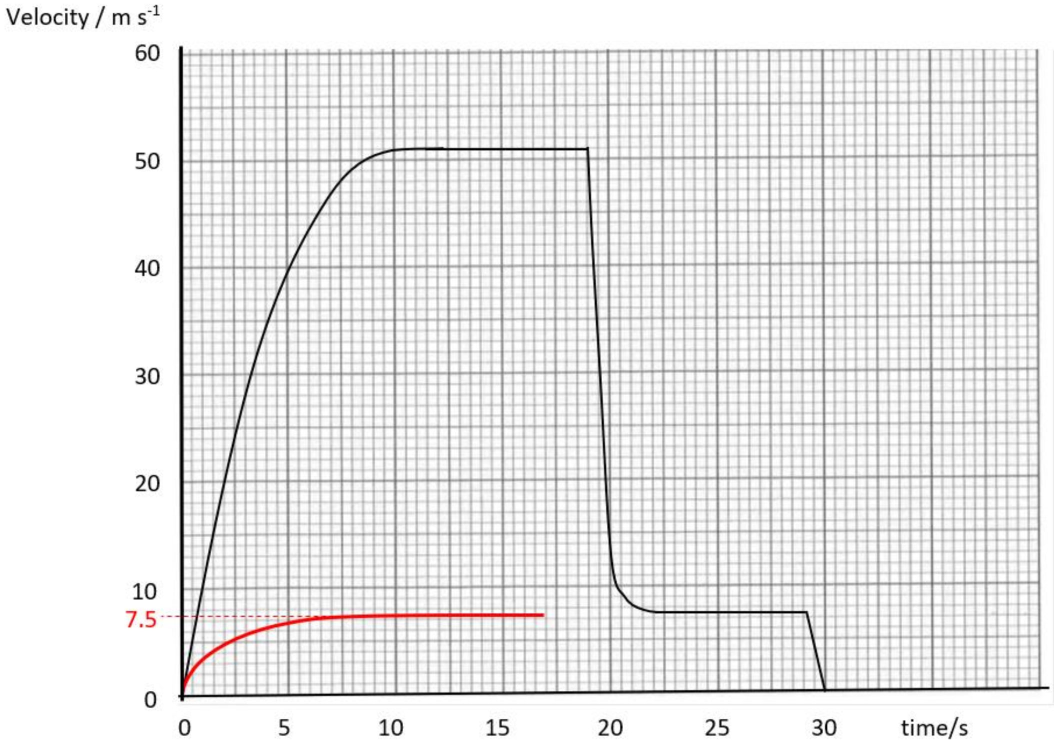


Fig. 9.3

B1

[Total: 20]

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