E and M fields MS

1. B

[1]

2. D

[1]

3. A

[1]

4. A

[1]

5. B

[1]

6. Use of *W=mg* — 1

Use of *F=BIL* — 1

B = 0.04 *T* — 1

[3]

7. (a) (Magnetic) Flux — 1

linkage — 1

(b) QWC (i and iii) – spelling of technical terms must be correct and the answer must be organised in a logical sequence

Lenz's law / conservation of energy — 1

<u>induced</u> current/emf (direction) — 1

Opposes the <u>change</u> (that produced it) — 1

[5]

8.	(a)	At least 3 parallel straight lines	1	
		<u>ALL</u> Equispaced (except ignore a large gap in middle) [be firm]	1	
		Arrow left to right	1	
	(b)	Use of eV [eg 1.6×10^{-19} or 2000/4000]	1	
		(=) ½ mv^2	1	
		Use of 2000	1	
	(c)	Use of $v = s/t$ [eg = 1.5 / 23 ($\times 10^{-6}$)]	1	
		(= 65000) Sub into previous equation	1	
		m = 1.5×10^{-25} kg	1	
	(d)	Some of the molecules in sample will travel further/less/not midway **(1)** Duration of laser pulse **(1)** Might emerge not horizontal **(1)** Molecules may be doubly/integer ionised **(1)** Time very small **(1)** Not perfect vacuum / collides with other molecules **(1)**	Max 2	
				[11]

9.	(a)		(Trace) always positive/not negative/not below 0/ if it was AC the graph would be positive and negative	1
			Indicating one/same direction	1
	(b)	(i)	Capacitor stores charge/charges up	1
			(If voltage is constant) capacitor doesn't discharge	1
		(ii)	Recall of E = ½ CV^2 or use of Q=CV and QV/2	1
			Substitution of C and any reasonable V [ignore power of 10 for C]	1
			eg = ½ $10 \times 10^{-6} \times 5.5^2/5.6^2$ = 1.5×10^{-4} - 1.6×10^{-4} J	1
	(c)	(i)	Capacitor charges up **(1)** From the supply **(1)** (then) Capacitor discharges **(1)** Through circuit / exponentially **(1)** Max 3	

(ii) Corresponding time interval for a change in V eg 6-7 ms for $\Delta V = 2V$ 1

$V = V_o\ e^{-t/RC}$ or rearrangement seen
[eg Ln 0.7 = 6×10^{-3} /RC] 1

R approx 1700 Ω (allow 1600 – 1800) 1

or

Time constant = 14 – 20 ms 1

T = RC seen 1

R approx 1700 Ω (allow 1600 – 1800) 1

or

Corresponding time interval for a change in V eg 6-7 ms for $\Delta V = 2V$ 1

Q = C V and I = Q/t seen 1

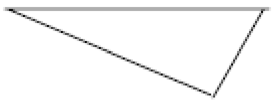
R approx 1700 Ω (allow 1600 – 1800) 1

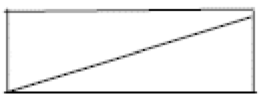
(iii) Use larger capacitor 1

[14]

10. (a) (Total / sum of) Kinetic energy conserved 1

(b) These diagrams could appear in part c and should be credited in (b) 1





1

[allow first mark for any triangle or parallelogram ie do not insist on right angle]
right angle labelled or approximately by eye / diagonal should be labelled "before" or "initial" or appropriately recognisable as incoming particle

(c) KE as formula eg $½ mu^2 = ½ mv^2 + ½ ms^2$ / p^2 /2m = p^2 /2m + p^2 /2m 1

Recognition of "Pythagoras" 1

(d) (i) Electric field 1

Does work on proton/applies a force /repel/attract 1

qV / Fd / Eq 1

(ii) Mass of incoming proton larger (than rest mass) **(1)**
Due to moving near speed of light/high speed/high energy/relativistic **(1)**

Alt answer : image not in plane of two protons after the event **(2)** — Max 2

(e) Out of the plane of paper — 1

[11]

11. C

[1]

12. C

[1]

13. Current in coil generates magnetic field **(1)**
Current drops/decreases **(1)**
Change of flux [accept flux cut] **(1)**
Rapid/quick/short time **(1)**
Large emf/200 V <u>induced</u>**(1)**
Field/flux linkage large due to many turns **(1)**

[4]

14. (a) Use of $E = V/d$ **(1)**
Answer = 1.5×10^5 V m^{-1} or N C^{-1} **(1)**

Eg $E = 1.5 / 10 \times 10^{-6}$ — 2

(b) Opposite forces (act on either end of molecule) **(1)**
Molecule rotates / aligns with field **(1)**
– at top / + at bottom **(1)** — 3

[5]

15. (a) Straight lines (at least 4) touching proton **(1)**
Equi spread (by eye) **(1)**
Arrow on at least one pointing away from proton **(1)** — 3

(b) Use of $F = k\,QQ/r^2$ [requires 2 subs to qualify as use] **(1)**
Know $Q_p = 1.6 \times 10^{-19}$ (C) eg $QQ=(1.6 \times 10^{-19})^2$ **(1)**
Answer = 7.9×10^{-8} N **(1)**
Eg $F = 8.99 \times 10^9 (1.6 \times 10^{-19})^2 / (5.4 \times 10^{-11})^2$ — 3

[6]

16. (a) Charges **(1)**
Movement of electrons from one plate to the other
OR one plate becomes + the other – OR until pd
across C equals V_{supply} **(1)** — 2

(b) (i) Use of $Q = It$ (both 0.74 and 0.1/0.2) **(1)**
Recognition of milli and Δt =0.1 **(1)**

Eg $Q = 0.74 \times 10^{-3} \times 0.1 = 74 \times 10^{-6}$ C — 2

(ii) Use of $V = Q/C$ **(1)**
Explains unit conversion **(1)**

Eg $V = 278 \times 10^{-6} / 100 \times 10^{-6} = 2.78$ [accept μ/μ] — 2

(c) (i) Recall of RC **(1)**
Answer = 0.3 (s) **(1)**
Eg $T = 3000 \times 0.0001$

plus either
1/e or 37% of initial **(1)**
=0.23 - 0.27 (s) **(1)**

or
sub in formula $I=Ioe^{-t/RC}$ **(1)**
= 0.23 - 0.27 (s) **(1)**

or
Initial Tangent drawn **(1)**
Time constant = 0.2-0.3 (s) **(1)** — 4

(ii) Plot Ln I / Log I **(1)**
Against t **(1)** (dependent on first mark)
or
Gradients of graph **(1)**
Against I **(1)** (dependent on first mark)

should be straight line **(1)** (dependent on previous 2) — 3

[13]

17. C **[1]**

18. D **[1]**

19. D **[1]**

20. A **[1]**

21. D **[1]**

22. A **[1]**

23. B **[1]**

24. (a) (i) Use of $E = ½\ CV^2$ **(1)**
Answer [0.158 J] **(1)**

$E = ½\ CV^2 = 0.5 \times 2200 \times 10^{-6}$ F × (12 V)^2
E = 0.158 J — 2

(ii) Correct substitution into $\Delta E_p = \Delta mgh$ **(1)**
Answer 0.75 [75%] **(1)**

ΔE_p = 0.05 kg × 9.8 N kg^{-1} × 0.24 m [= 0.12 J]
Efficiency = 0.12 ÷ 0.16 J = 0.75 [75%] — 2

(b) (i) ($t = CR$) = 2200 × 10^{-6} (F) × 16 (Ω) = 35.2 (ms) **(1)** — 1

(ii) Curve starting on I axis but not reaching t axis **(1)**

I_0 = 1.6 V / 16Ω = 100 mA shown on axis **(1)**

Curve passing through about 37 mA at t = 35 ms **(1)** 3

(c) (i) The vibrations of the air particles **(1)**
are parallel to the direction of travel of the wave (energy) **(1)** 2

(ii) $T = 1/f$ = 50 ms **(1)**

Sensible comment related to time constant of 35 ms **(1)** 2

[12]

25. (a) (i) $W = QV$ **(1)**

Correct answer 3.2 nJ [3.2×10^{-9} J, etc.] **(1)**

Example of answer:

$W = QV = 0.8 \times 10^{-9}$ C × 4.0 V = 3.2×10^{-9} J 2

(ii) +0.8 (nC) on top plate **and** –0.8 (nC) on bottom plate **(1)**
(**both** needed) 1

(b) Statement (E =) 'Area' **or** (E =) ½ QV **(1)**

See calculation ½ × 4.0 × 0.8 **or** ½ × base × height **(1)**

<u>OR</u>
C found from graph **(1)**
Use of W = ½ CV^2 **(1)**

Example of answer:

$$C = \frac{Q}{V} + \frac{8.0\times10^{-9}\ \text{C}}{4.0\ \text{V}} = 2.0\times10^{-10}\ \text{F}$$

$$\therefore\ W = ½CV^2 = \frac{2.0\times10^{-10}\ \text{F}\times(4.0\ \text{V})^2}{2} = 1.6 \times 10^{-9}\ \text{J}$$ 2

(c) (i) Correct answer 0.2 nC **(1)** 1

(ii) Graph is straight and through origin **(1)**

ends at 3.0V and their Q **(1)** 2

(iii) Attempt to **use** $C = Q/V$ or $C = \Delta Q/\Delta V$ **(1)**

Correct answer 0.067 nF / 67 pF **(1)**

Example of answer:

$$C = \frac{Q}{V} = \frac{0.2 \times 10^{-9}\ \text{C}}{3.0\ \text{V}} = 6.7 \times 10^{-11}\ \text{F}$$ 2

[10]

26. (a) (i) 1.2 keV = $1.2 \times 10^3 \times 1.6 \times 10^{-19}$ J
OR
Use of $e\Delta V$ with e as 1.6×10^{-19} C and V as 1200 V **(1)**

Use of $\Delta(\frac{1}{2}m_e v^2)$ with m_e as 9.1**(1)** × 10^{-31} kg. **(1)**

Correct answer 2.0 – 2.1 × 10^7 m s^{-1} **(1)** 3

(ii) 1200 × 8/100 = 96 (eV delivered per electron) **(1)**
96/2.4 = 40 **(1)**

Or
2.4 × 100/8 = 30 (incident eV needed per photon) **(1)**
1200/30 = 40 **(1)**

Or
1200 / 2.4 = 500 (photons per electron, ideally) **(1)**
500 × (8/100) = 40 **(1)** 2

(b) Electrons on screen repel electrons in beam / force opposes electron motion/decelerating force **(1)**

Electrons (in beam) decelerated /slowed /
velocity reduced/ work done by electrons (against force) **(1)**

Electron (kinetic) energy reduced (not ¯shared¯) **(1)**

Fewer photons (per electron, stated or implied) **(1)**

Trace less bright **(1)**

QoWC **(1)** Max 4

[9]

27. (a) Scale interval is 0.1 (V) **(1)** 1

(b) (i) **Use** of $\varepsilon = (–)N\Delta\varphi/\Delta t$ **(1)**

Correct answer 9.6×10^{-7} (Wb) / 0.96 (μWb) [ignore +/–] **(1)**

Example of answer:

$$\Delta\phi = \varepsilon \times \frac{\Delta t}{N} = 0.12\ \text{V} \times \frac{40 \times 10^{-3}\ \text{s}}{5000} = 9.6 \times 10^{-7}\ \text{Wb}$$ 2

(ii) **Use** of 'φ' or '$\Delta\varphi$' or 'flux' = BA, or B = ε Δt/NA **(1)**

Correct answer 0.012 T / 0.013 T **(1)**

Example of answer:

$\varphi = BA$

$$\therefore B = \frac{\varphi}{A} = \frac{9.6 \times 10^{-7}\ \text{Wb}}{\pi \times \left(\frac{1.0 \times 10^{-2}\ \text{m}}{2}\right)^2} = 0.012\ \text{T}$$

[N.B. φ = 0.96 μWb → 0.012T, φ = 1μWb → 0.013T] 2

[5]

28. (a) Lines **(1)**
[not crossing; minimum 2 lines starting from S pole of magnet]
Correct arrow(s) **(1)**
[minimum 1 arrow pointing towards S pole, any incorrect arrow scores 0] 2

(b) (i) Use of $F = BIl$ rearranged to $B = F/Il$ OR with two correct subs **(1)**
Leading to correct answer **(1)**

$B = F/Il = 0.008/(5.8 \times 0.012)$ (T)
$B = 0.11$ (T) 2

(ii) Assumption:
parallel field/uniform field/constant field for 12 mm then falls to zero / assume wire perpendicular to field (at all points)/θ = 90° (where F=Bil sinθ given earlier)/force same at all points on the wire **(1)** 1

(c) Experimental value less because field diverges
OR field strength decreases with distance
OR field could be 0.3 T at magnet surface and only 0.1 T at wire **(1)** 1

(d) Wire would levitate (again) **(1)**
Two reversals cancel/applying FLHR **(1)**
[wire moves downwards due to current OR field reversed scores 1] 2

[8]

29. (a) capacitors need d.c. **(1)**
OR Mains is a.c. / mains current changes direction constantly

Charge given in one half of cycle is removed the next half **(1)**
OR C charged then discharges 2

(b) (i) Voltage value for initial voltage × 1/e [or use of 37%] **(1)**
OR use 2 values where 2nd is 1/eth of first
OR draw tangent at time = 0 s
OR $V = V_o e^{-t/RC}$ with correct substitution of (t,V) from graph

T = 0.07 s [allow 0.065 s – 0.075 s] **(1)** 2

(ii) Recall time constant = *CR* **(1)**
Answer for *R* [allow ecf for T] **(1)**

$R = T/C = 0.07 \text{ s}/(100 \times 10^{-9} \text{ F})$
$R = 7 \times 10^5\ \Omega$ 2

(c) (i) Recall $Q = CV$ [equation or substitution] **(1)**
Answer for Q **(1)**

$Q = CV = 100 \times 10^{-6} \times 300$
$Q = 0.03$ C 2

(ii) Recall $W = 1/2\ CV^2$ OR $W = 1/2\ Q^2/C$ **(1)**
OR 2 correct subs into $W = 1/2\ QV$ [allow ecf]
Answer **(1)**

Eg: $W = 1/2\ QV = 0.5 \times 0.03 \times 300$ (J) = 4.5 J
OR $W = 1/2\ CV^2 = 0.5 \times 100 \times 10^{-9} \times 300 \times 300$ (J) = 4.5 J
OR $W = 1/2\ Q^2/C = 0.5 \times 0.03 \times 0.03/(100 \times 10^{-9})$ (J) = 4.5 J 2

[10]

30. (a) (i) <u>P.d. across capacitor</u>

Use of VR = I × R **(1)**

[allow one error of 10^3 in individual substitutions; disallow if V_R value is 6V]

VC = 6.0 V – 4.0 V (= 2.0V) **(1)**
[No ecf] 2

Example of answer:

$V_R = 20 \times 10^{-6}$ A × 2.0 × 10^5 Ω = 4.0 V

Hence V_c = 6.0 V – 4.0 V = 2.0 V

(b) <u>Calculation of charge</u>

Use of Q = C × V with 560 μF & 2.0 V **(1)**

[Check correct equation is being used; allow power of 10 error in capacitance value. If capacitance value mis-transcribed, allow this first mark only]

Answer 1.1 (2)mC (1120μC) [no ecf] **(1)** 2

(c) <u>Calculation of energy stored</u>

Use of $W = ½CV^2$ with given values, or $W = ½\ V$ with their Q, to get 1.1(2) mJ (1120μJ) or their correct answer. **(1)**
[same numerical value as in (b)] 1

(d) <u>Calculation of energy transferred</u>

Use of $E = QV$, with their Q and V = 6.0 V, to get 6.7(2) mJ (6720μJ) or their answer [6 × value at part c] correctly found. **(1)** 1

(e) <u>Main reason for energy difference</u>

Energy is transferred to thermal / heat energy in / work is done against, the resistance of the resistor in the circuit [NOT just ‘the resistance of the wires’, nor the ‘components’] **(1)**

[Do not credit vague reference to energy dissipation, nor ‘energy is lost to the surroundings’] 1

[7]

31. (a) Calculation of potential difference

Use of $\frac{1}{2}m_p v^2$ with $v = 2.77 \times 105$ m s–1
and mp = 1.67×10^{-27} kg **(1)**

Use of eV with e = 1.60×10^{-19} C **(1)**
[beware confusion of v and V]

Answer = 400(.4) / 401 V **(1)**
[If data used to 2 sf, → 380V, 384V or 364V, allow 2/3] 3

Example of answer:

eV = ½ $m_p v^2$

$$V = \frac{m_p v^2}{2e} = \frac{1.67 \times 10^{-27}\ \text{kg} \times (2.77 \times 10^5\ \text{m s}^{-1})^2}{2 \times 1.6 \times 10^{-19}\ \text{C}}$$

= 400V
[beware unit error of eV here]

(b) Add second path to diagram

Path at B stays equidistant from that at A [gauge by eye] **(1)** 1

(c) (i) Add α path to diagram

Added path at A [allow through letter A] also curves upwards **(1)**

But is less curved than the original, straight beyond plates and continues to diverge from it **(1)** 2

(ii) Explanation

Charge on a is double that on proton / α has 2 protons /
force on a is double force on proton. **(1)**

Mass of a particle is (approx) 4 times / more than double that of the proton. **(1)**

[hence acceleration is approximately halved].

[Ignore reference to F = Bqv; do not credit reference to ${}^{4}_{2}\text{He}$ unless implication of numbers 4 and 2 is made clear]. 2

[8]

32. (a) (i) Direction of current

Position 1 = Q to P / anticlockwise / to the left } **(1)**
Position 3 = P to Q / clockwise / to the right }
[both needed; arrows added to diagram may give current directions at 1 & 3]

Position 2 = no current **(1)** 2

(ii) Current calculation

Use of $\frac{\Delta\phi}{\Delta t} = \frac{\Delta(BA)}{\Delta t}$, or $\varepsilon = Blv$, = 2 × 10^{-2} T × 0.12 m × 0.05 m s^{-1} **(1)**

[ignore power of 10 errors in dimension and velocity values]

(Emf =) 1.2 × 10^{-4} V **(1)**

$I = \frac{V}{R}$ or $I = \frac{E}{R}$ seen or used **(1)**

Answer = 6.0 × 10^{-5} A or 60μA [ecf their emf] **(1)** 4

(b) <u>Uniform acceleration?</u>

QoWC **(1)**

Magnitude of current would be increasing as frame moves through position 1 (or position 3) **(1)**

Magnitude of current would be greater for position 3 than 1 [Beware comparison of position 3 with position 2 here] **(1)**

Reference to increased rate of flux cutting / increased rate }
of flux change / increased area swept out per second } **(1)**
(Beware suggestion that B or flux density is changing) }

So induced emf is greater **(1)**

Current for position 2 is zero }
[Do not credit equal and opposite }
currents cancelling] } Both needed **(1)**

Since flux linkage is constant / }
(net) rate of flux cutting is zero / }
Emfs in PS and QR are equal and opposite } Max 4

[10]

33. (a) use of Q = CV OR statement or use of $W = CV^2/2$ OR $Q^2/2C$ **(1)**
answer **(1)**

$W = CV^2/2$
= 0.5 × 2500 × 2 × 2 (J) = 5000 J 2

(b) 1 correct value **(1)**
All correct values; 1.62, 1.39, 1.16 **(1)**
(1 mark for one correct or inappropriate sig figs) 2

(c) graph of ln (y) v. time (x) **(1)**
appropriate scales and both axes labelled fully **(1)**
points plotted properly (+/– 1 mm) **(1)**
best fit line drawn **(1)** 4

(d) recognise that gradient = (–)1/RC **(1)**
evaluate gradient **(1)**
conversion days to seconds **(1)**
obtain appropriate value for R **(1)**

gradient = (–) 0.92/(40 (days))

R = 40 × 24 × 3600 (s) / 0.92 × 2500 (F)
= 1500 Ω

(OR method using graph of V v. t)
recognise that time to Vo/e = RC **(1)**
this time estimated (42–45 days) **(1)**
conversion days to seconds **(1)**
obtain appropriate value for R **(1)** Max 4

[12]

34. (i) <u>Add to diagram.</u>

Arrows at A and B, both pointing directly away from the nucleus. **(1)**
[Arrow end (head or tail) need not touch A /B, but direction must be correct.
Gauge by eye, accept dotted construction lines as indication of intent] 1

(ii) <u>Calculation of force</u>

Use of $F = \dfrac{Q_1Q_2}{4\pi\varepsilon_0 r^2}$ or $F = \dfrac{kQ_1Q_2}{r^2}$ **(1)**

[ignore error/omission of '2' and/or '79' or 'e' or '1.6×10^{-19}' for this first mark, providing numerator clearly has a product of charges and denominator a distance <u>value</u> squared. Ignore power of 10 errors in values of *Q* or *r*]

2 × 1.6 × 10^{-19} C **and 79** × 1.6 × 10^{-19} C seen (**consequential** mark, dependent upon correct use of equation previously) **(1)**

Correct answer = 1.6 – 1.7 N **(1)**

Example of answer:

$$F = \frac{Q_1Q_2}{4\pi\varepsilon_0 r^2} = \frac{(79\times16\times10^{-19}\ \text{C})\times(2\times1.6\times10^{-19}\ \text{C})}{4\pi\times8.85\times10^{-12}\ \text{F m}^{-1}\times(1.5\times10^{-13}\ \text{m})^2}$$

= 1.62 N 3

(iii) <u>Effect on motion of α</u>

Slows down [decelerates] and then speeds up again [accelerates].
(both needed)
[accept 'slows down **at** A and speeds up **at** B] **(1)** 1

[5]

35. (a) (i) <u>Direction of e.m.f.?</u>

Hub '–' and Rim '+'.

[Allow mark for either on its own, but not if contradicted.] **(1)** 1

(ii) <u>Why a constant e.m.f.?</u>

Reference to flux cutting / rate of change of flux / change of flux linkage due to spoke motion / spokes moving at right angles to field / Reference to Faraday's Law **(1)**

Constant rate of spin implies constant rate of flux cutting. [Link made clear] **(1)**

[continuous process does not mean constant rate] 2

(iii) <u>The time for one revolution</u>

Use of $\varepsilon = \frac{BA}{t}$ with 'A' recognisable as area of a circle **(1)**

[ignore power of 10 errors for e.m.f. and radius values, and inclusion of N = 24]

Correct substitution of all values [but only N = 1 acceptable here] **(1)**

Correct answer 0.31 – 0.32 s **(1)**

[t = 7.6s scores 1/3; t = 1.12s scores 0/3, t = 0.64s scores 1/3 here]

Example of answer:

$$\varepsilon = \frac{\varphi}{t} = \frac{BA}{t} \rightarrow t = \frac{BA}{\varepsilon}$$

$$\therefore t = \frac{2.8 \times 10^{-5}\ \text{T} \times \pi \times (30 \times 10^{-2}\ \text{m})^2}{25 \times 10^{-6}\ \text{V}} = 0.317\ \text{s}$$ 3

<u>Alternative answer</u>

Use of ε = Blv with v = (mean) velocity of spoke. (**(1)**)

→ v = 2.98 m s^{-1} (**(1)**)

Hence rim velocity = 2.98 × 2 = 5.96 m s^{-1}.

$$\rightarrow t = \frac{2\pi r}{v_{RIM}} = \frac{2\pi \times 0.3\ \text{m}}{5.96\ \text{m s}^{-1}}$$ = 0.316s. (**(1)**)

[t = 0.63s scores 2/3 here]

(b) <u>What effect?</u>

(i) Reduced [accept 'halved'] **AND**

Rate of flux cutting is reduced / Fewer field lines are being cut / Component of Earth's field perpendicular to the wheel is less / Flux through wheel is less / Area of wheel perpendicular to field is less / Wheel is no longer perpendicular to the field **(1)**

[do not credit answers suggesting changes in the field strength itself] 1

(ii) Increased / increasing **AND**
Rate of flux cutting [etc.] would be increasing **(1)** 1

(iii) (Reduced to) zero [but not 'very small' / 'negligible', etc.] **AND**

No flux cut by spoke(s) / No component of the Earth's field perpendicular to the wheel / No flux through wheel / Wheel is spinning parallel to the field / in plane of field **(1)**
[but not just '$\Delta\Phi = 0$', nor 'motion is not perpendicular to field']

[Allow 1/3 for three correct statements of 'ε' outcome without any explanation, but **only** if score would otherwise be zero.]

[Disallow 'breaking' for 'cutting' on first occasion in entire question, but allow, ecf, thereafter] 3

[9]

36. (a) (i) arrow towards centre of curvature **(1)** 1

(ii) Use of formula with correct *q* OR *v* subbed **(1)**
correct answer **(1)**

$F = Bqv$
$= 0.5 \times 1.6 \times 10^{-19} \times 800\,000$ N (correct *q* or *v*) **(1)**
$= 6.4 \times 10^{-14}$ N **(1)** 2

(iii) Use of formula: EITHER correct *m* subbed OR *d* identified with *r* **(1)**
correct answer

$r = p/Bq = 1.67 \times 10^{-27} \times 800\,000/0.5 \times 1.6 \times 10^{-19}$ (m) **(1)**
$= 0.017$ m **(1)**
[Penalise factor 1000 error once only in question] 2

(iv) derive formula for *T* **(1)**
correct answer **(1)**

$T = \pi\, r/v$ (OR $T = 2\pi r/v$ for **(1)**x) **(1)**
$= \pi \times 0.017/800\,000$ (s) (ecf)
$= 6.6\ (6.5 – 6.7) \times 10^{-8}$ s **(1)** 2

(v) correct statement of force = change of momentum/time **(1)**
correct use of factor 2 **(1)**
correct answer **(1)**

F = change of momentum/time **(1)**
$= 2 \times 1.67 \times 10^{-27} \times 800\,000/6.7 \times 10^{-8}$ (N) (ecf) **(1)**
$= 4.1\ (4.0) \times 10^{-14}$ N [errors in *m* are self-cancelling] **(1)** 3

(b) Recall of formula **(1)**
correct answer **(1)**

$F = k\, q_1\, q_2/r^2$ OR $F = q_1\, q_2/4\pi\varepsilon_0 r^2$ OR $k = 1/4\pi\varepsilon_0$ **(1)**
$= 1.6 \times 10^{-19} \times 1.9 \times 10^{-6}/4 \times \pi \times 8.85 \times 10^{-12} \times 5 \times 5$ (N)
$= 1.1 \times 10^{-16}$ N **(1)** 2

[12]

37. (i) magnetic field <u>changing</u> **(1)**
field cuts across conductor/flux linkage changes **(1)**
Faraday/V induced **(1)** (any 3)
V causes I **(1)** 3

(ii) Direction of induced current has an effect tending to cancel its cause OR [reasonable attempt at putting Lenz into words – not just “Lenz”] **(1)** 1

[4]

38. (a) (i) recall of formula **(1)**
correct answer **(1)**

$C = Q/V$ (stated or implied) [this way round] **(1)**
= (appropriate pair of values, eg 4 C/4.8 V)
= 0.83 (0.82 – 0.84) F **(1)** 2

(ii) strip width ΔQ **(1)**1
$\Delta W = V.\, \Delta\, Q$ **(1)**2
add strips => area under graph **(1)**3
area = $1/2Q\ V$ **(1)**4
energy stored = work done **(1)**5
showing $1/2QV$ has unit J/joule **(1)**6 (any 3)
[integration answer – max **(1)(1)**]
[answer in words – max **(1)(1)**] 3

(iii) derive or recall $E = 1/2\ C\ V^2$ OR use correct Q value from graph **(1)**
OR line across graph at 4 V
correct answer **(1)**

$E = 1/2\ Q\ V$
= 1/2 × 3.3 (3.3–3.35) C × 4 V **(1)**
= 6.6 (6.6–6.7) J **(1)**

OR $E = 1/2\ C\ V^2$ **(1)**
$= 1/2 \times 0.83$ F $\times (4\text{ V})^2 = 6.6$ J **(1)** 2

(b) (i) Q decreases $\Rightarrow$ V decreases OR I decreases **(1)**
mention of $P = VI$ **(1)** 2

(ii) 125–145 s **(1)** 1

[10]

39. (a) (i) Recall of $Q = CV$ **or** $W = 1/2\ CV^2$ **(1)**
Correct calculation of W **or** V **or** C **(1)**
$\Rightarrow$ Conclusion [must be consistent] **(1)**

eg $W = 1/2\ CV^2$
$\Rightarrow C = 2\ W/V^2 = 2 \times 0.045 / (30{,}000)^2$ (F)
$= 1 \times 10^{-10}$ (F) = 100 (pF) ($\Rightarrow$ NOT COMPATIBLE)
or $\Rightarrow W = 1/2 \times 10 \times 10^{-12} \times (30{,}000)^2$ (J)
= 0.0045 (J) ($\Rightarrow$ NOT COMPATIBLE) 3
[no mark for conclusion; but ue for saying 100pF ~ 10 pF]

(ii) Sub of one appropriate value into $Q = CV$ **or** $W = 1/2QV$ **(1)**
Correct value **(1)**

eg Charge = $1 \times 10^{-10} \times 30{,}000$ (C)
$= 3 \times 10^{-6}$ C 2

(b) (i) Use of $E = V/d$ [Rearranged or subbed into] **(1)**
Correct value **(1)**

eg $d = V/E = 30{,}000/3 \times 10^6$ (m)
= 0.01 m 2

(ii) Use of $E = F/q$ [Rearranged or subbed into – any charge value] **(1)**
Correct value **(1)**

eg $F = Eq$ = 3 × 106 × 1.6 × 10–19 (N)
$= 4.8 \times 10^{-13}$ N 2

(c) Correct use of 1 mm in $W = Fd$ **or** $V = Ed$ [ecf from(b)(ii)] **(1)**
$\Rightarrow$ 3000 (V or eV)) **(1)**
$\Rightarrow$ correct value **(1)**

eg $W = Fd = 4.8 \times 10^{-13}$ N $\times$ 0.001 m (= 4.8×10^{-16} J)
$\Rightarrow$ 3000 (eV)
3000/35 = 85/86/85.7
or $V = Ed$ **=** (3×10^{6} V/m) $\times$ 0.001 (m)
$\Rightarrow$ 3000 (V)
3000/35 = 85/86/85.7 — 3

[12]

40. (a) emf/voltage **(1)**
induced / created / caused by flux change **(1)** — 2

(b) Lenz **(1)**
effect opposes change producing it **(1)** — 2

(c) dynamo generates emf **(1)**
lights off $\Leftrightarrow$ no current **(1)**
lights on $\Leftrightarrow$ current flowing **(1)** **Any 4**
If current, then force on dynamo rotor/$F = BIl$ **(1)**
[**or** field acting against field in dynamo]
This force opposes rotation **(1)** — 4

[8]

41. (a) Shape [lines not crossing] **(1)**
arrow(s) **(1)** — 2

(b) [reference to] changing B field/ flux cuts coil / changing flux (linkage) **(1)**1
induces emf **or** current [NOT "output"] /EM induction **(1)**2
emf α rate of change / Faraday's law stated **(1)**3
output is gradient of flux graph **(1)**4
signal +ve while ϕ increases / –ve while ϕ decreases **(1)**5
max emf for max dϕ / dt / steepest gradient **(1)**6 **(Any 5)**
Emf 0 when gradient = 0 **(1)**7
[**(1)**5 **(1)**6 **(1)**7 can be gained by annotations on graph] — 5

(c) (Binary / 1 or 0 / 2^{10}
maximum number =) 1024 **(1)** — 1

(d) 10010 **(1)** 1

(e) Attempt to calculate circumference (formula or numbers) **(1)**
dividing by 0.83×10^{-6} (m) **(1)**
correct value **(1)**□

eg $C = \pi d = \pi \times 0.089$ m (= 0.2796 m)
No of bits along circumference = $C \div (0.83 \times 10^{-6}$ m) 3
(= 3.37×10^5)

Rate = $3.37 \times 10^5 \times 120$ (7200 revs/min = 120 Hz)
= 4.04×10^7 s^{-1}
[2.43×10^9 min^{-1} is OK]

[12]

42. (a) <u>Formula in words</u>

(The force between two charged particles is directly) proportional to the **product** of their charges [plural] and **(1)**

inversely proportional to the square of their separation [not just ‘radius’]. **(1)**

<u>OR</u> Either equation for F*, with valid word replacements for Q_1, Q_2 **(1)**
and r or r^2 symbols. One mark for numerator, one for denominator. **(1)**

$$\left[\text{* i.e. words in } F = \frac{kQ_1Q_2}{r^2} \text{ or in } \frac{Q_1Q_2}{4\pi\varepsilon_0 r^2} \right]$$

[If equation given in symbol form, followed by a key to the symbol meanings, then 1/2.] 2

(b) <u>Base units of constant</u>

[Either k or $(4\pi)\varepsilon_0$, be sure which]
[ecf from part a if power of Q or r wrong]

$F = \frac{kQ_1Q_2}{r^2}$ **or** $F = \frac{Q_1Q_2}{4\pi\varepsilon_0 r^2}$ [OR using k units N m^2 C^{-2}]

Q_1Q_2 (*or* C^2) → A^2s^2 **(1)**

F (*or* N) → kg m s^{-2} **(1)**
→ (units of) k = kg m^3 A^{-2} s^{-4} OR (units of) ε_0 = kg^{-1} m^{-3} A^2 s^4 **(1)**

OR using ε_0 units F m^{-1}:

C = As **and** either F = CV^{-1} or V = JC^{-1} **(1)**
J = kg m^2 s^{-2} or N = kg m s^{-2} **(1)**

→ (units of) ε_0 = kg^{-1} m^{-3} A^2 s^4 **(1)** 3

[5]

43. (a) <u>Electron speed</u>

Substitution of electronic charge and 5000V in eV **(1)**
Substitution of electron mass in ½ mv^2 **(1)**

Correct answer [4.2 (4.19) × 10^7 (m s^{-1}), no ue] to at least 2 sf **(1)** 3
[Bald answer scores zero, reverse working can score 2/3 only]

Example of answer:
$v^2 = (2 \times 1.6 \times 10^{-19}\text{C} \times 5000\text{ V})/(9.11 \times 10^{-31}\text{ kg}) = 1.76 \times 10^{15}$
$v = 4.19 \times 10^7$ m s^{-1}

(b) (i) <u>Value of E</u>

Correct answer [2.80 × 10^4 V m^{-1}/N C^{-1} or 2.80 × 10^2 V cm^{-1}] **(1)** 1

Example of answer:
$E = V/d$ = 1400 V / 5.0 × 10^{-2}
= 28 000 V m^{-1}

(ii) <u>Value of force F</u>
Correct answer [4.5 × 10^{-15} N, ecf for their E] **(1)** 1

Example of answer:
$F = Ee$ = 2.80 × 10^4 V m^{-1} × 1.6 × 10^{-19} C
= 4.48 × 10^{-15}N

(c) Calculation *of h* 4

See a = their F / 9.11 × 10^{-31} kg **(1)**
[→ a = 4.9 × 10^{15} m s^{-2}]

See t = 12 (× 10^{-2}) m / 4 × 10^{7} m s^{-1} (or use 4.2 × 10^{7} m s^{-1}) **(1)**
[$t = d/v$, with d = plate length; 12 cm]
[→ t = 3.0 × 10^{-9} s, or 2.86 × 10^{-9} s]

See substitution of a and t values [**arrived at by above methods**] into ½ at^2 **(1)**

Correct answer [h = 0.020 m – 0.022 m] **(1)**

[Full ecf for their value of F **if** methods for a and t correct **and** their $h \leq 5.0$cm]

Example of answer:
$h = ½\, a\, t^2$
= ½ × 4.9 × 10^{15} m s^{-2} × (2.86 × 10^{-9} s)^2
= 2.0 × 10^{-2} m

(d) (i) Path A of electron beam
Less curved than original **(1)** 1

(ii) Path B of electron beam
More curved than original, curve starting as beam enters field [started by H of the Horizontal plate label] **(1)** 1

[For **both** curves:
- ignore any curvature beyond plates after exit
- new path must be same as original up to plates]

[No marks if lines not identified, OK if either one is labelled]

[11]

44. (a) (i) Additional force
Correct answer [3.9 × 10^{-3} N] **(1)** 1
Example of answer:
0.4 × 10^{-3} kg × 9.81 N kg^{-1} = 4 × 10^{-3} N

(ii) Explanation
Quality of written communication **(1)**
(Current produces) a magnetic field around the **rod (1)**
[Do not accept in the rod]

There is an interaction between the two magnetic fields / fields combine to give catapult field **(1)**

Fleming's Left Hand Rule/ Fleming's Motor Rule **(1)**
The rod experiences an upward force **(1)**

Using Newton 3 → downward force on magnet — Max 4

(b) (i) Diagram
Lower pole labelled North/N and upper pole labelled South/S **(1)** — 1

(ii) Calculation of current in rod
Use of $F = BIl$. (Ignore 10^x. F is their force and l is 5cm) **(1)**
See conversions; mT to T and cm to m **(1)**
Correct answer [2.6/2.7 A] **(1)** — 3

Example of answer:
$I = 3.9 \times 10^{-3}$ N / (30×10^{-3} T $\times 5 \times 10^{-2}$ m) = 2.6 A

(iii) New reading on the balance
Value < 85g [not a negative value] **(1)**
84.6 g **(1)** — 2

[11]

45. Calculation of voltage

Use of $E=V/d$ [could be rearrangement] **(1)**

Correct answer [1.5×10^9 V] **(1)** — 2

Example of calculation:

$V = Ed = 3 \times 10^5 \times 5000$ V
$V = 1.5 \times 10^9$ V

Calculation of capacitance

Recall $Q = CV$**(1)**

Correct answer [2.7×10^{-8} F]**(1)** — 2

Example of calculation:

$C = Q / V$
$= 40$ C / 1.5×10^9 V
$= 2.7 \times 10^{-8}$ F

Resistance

Use of RC = 20 ms, or an appropriate time (eg, 20 ms ÷ 5 = 4 ms)**(1)**
OR attempt to find current from $I = Q/t$

Correct answer [7.5×10^5 Ω (1.5×10^5 Ω)]**(1)**

Example 1:

$\Rightarrow R = 20 \text{ ms} \div 2.7 \times 10^{-8} \text{ F}$ ($4\text{ms} \div 2.7 \times 10^{-8}$ F)

$= 7.5 \times 10^5$ Ω (1.5×10^5 Ω)

Example 2:

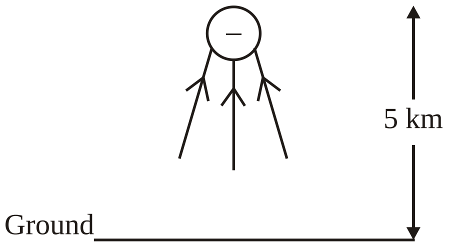
I = 40 C / 20 ms = 2000 A**(1)**

$$\Rightarrow R = \frac{V}{I} = \frac{1.5 \times 10^9 \text{ V}}{2000\text{A}}$$

$\Rightarrow 7.5 \times 10^5$ Ω **(1)** 2

[Also give credit for using "average" pd which is less than 1.5 GV say $V/2 \rightarrow 3.75 \times 10^5$ Ω]

Drawing of electric field region



≥ 2 radial lines **(1)**

Arrow(s) **(1)** 2

Electric field

Recall $E = \dfrac{q}{4\pi\varepsilon_0 r^2}$ OR $k = \dfrac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \text{ m F}^{-1}$) **(1)**

Correct answer [1.44×10^4 V m^{-1}] **(1)** 2

[Use of $\dfrac{V}{d}$ scores 0]

Example of calculation:

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

$$= \frac{40}{(4\pi \times 8.85 \times 10^{-12} \times 5000^2} \text{ V m}^{-1}$$

$= 1.44 \times 10^4$ V m^{-1}

Lightening strike

Field stronger near cloud OR Greater force/acceleration on charges
OR Mention of force on charges OR Mention of ionising atoms by collision **(1)** 1

[11]

46. How electron gun creates beam of electrons

Any four from:

1. hot filament **(1)**
2. thermionic emission / electrons have enough energy to leave **(1)**
3. anode and cathode / ± electrodes [identified] **(1)**
4. E–field **OR** force direction **OR** cause of acceleration **(1)**
5. collimation [eg gap in anode identified as causing beam] **(1)**
6. need for vacuum **(1)** Max 4

Speed of electrons

(eV =) ½ mv^2 **(1)**

Use of eV [ie substituted or rearranged] **(1)**

Answer [1.09×10^7 m s^{-1}] **(1)**

$1.6 \times 10^{-19} \times 340$ (J) = ½ × 9.11×10^{-31} (kg) × v^2

$v = 1.09 \times 10^7$ m s^{-1} 3

Definition of term electric field

Region/area/space in which **charge** experiences **force (1)** 1

ertical acceleration of electrons due to field

[Bald answer =0]

Use of equation $E = V/d$ **(1)**

$E = V/d$ = 2500 V ÷ 0.09 m = 28 (kV m^{-1})

Rearranged equation $E = F/q$ or substitution into it **(1)**

$F = Eq$ = 28 000 × 1.6 × 10^{-19} (N) 4.4 × 10^{-15} (N)

Equation $F = ma$ seen or substitution into it **(1)**

$$A = F/m = \frac{4.4 \times 10^{-15} (N)}{9.11 \times 10^{-31} (hg)}$$

= 4.9 × 10^{15} (m s^{-2}) **(1)** 4

[at least 2 sig fig needed] [No u.e.] [Reverse calculation max 3]

[12]

47. (a) Advantage of avoiding metal contacts

Any one from:

- makes possible a sealed unit
- avoids electrocution
- stops corrosion (by water)
- water cannot enter/short contacts **(1)** 1

(b) How arrangement is able to charge the battery

Any six from:

1. current (in X) produces magnetic field
2. field links second coil
3. metal = iron
4. metal core increases field
5. field changes/alternates
6. changing ϕ/B or $d\phi/dt$ or Faraday induces/causes V
7. V causes I
8. diode needed (or a.c. so won't charge)
9. field penetrates plastic
10. like a transformer / X is a primary and Y is a secondary
11. electromagnetic induction — Max 6

[7]

48. (a) Direction of field lines

Downwards **(1)** — 1

(b) (i) Calculation of force

Use of V/d i.e. 250 V/0.05 m [if 5 used mark still awarded] **(1)**

Use of $\frac{V}{d}e$ [Mark is for correct use of 1.6×10^{-19} C] **(1)**

$= 8.0 \times 10^{-16}$ N **(1)** — 3

(ii) Direction and explanation

(Vertically) upwards / towards AB **(1)**

No (component of) force in the horizontal direction OR because **(1)** — 2
(the force) does no work in the horizontal direction

(c) Calculation of p.d.

Use of $\Delta E_K = \frac{1}{2} m\upsilon^2$ / ½ 9.11×10^{-31} (kg) × $(1.3 \times 10^7)^2$ **(1)**

Use of Ve / $V \times 1.6 \times 10^{-19}$ (C) **(1)**

= 480 V **(1)** — 3

(d) <u>Beam of electrons</u>

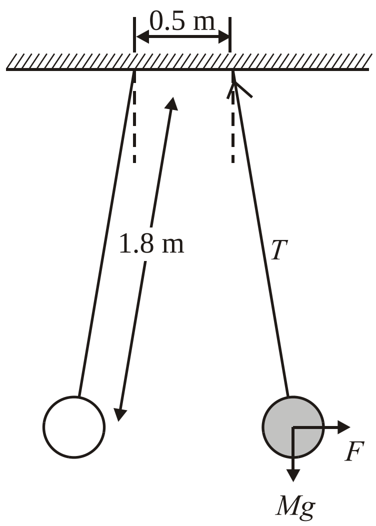
Diagram showing:

Spreading out from one point **(1)**
fastest electrons labelled **(1)**

2

[11]

49. <u>Minimum charge on balloon</u>



any 2 forces correct **(1)**
T 3rd force correct **(1)** 2

$F = kq_1q_2/r^2/F = kq^2/r^2$ **(1)**

$mg = T\cos\theta/T = 1.8 \times 10^{-2}$ N **(1)**

$F = T\sin\theta/F = mg\tan\theta/F = 4.6 \times 10^{-4}$ N **(1)**

$r = 0.5 + 2 \times 1.8 \sin 1.5°$ (= 0.594 m) **(1)**

$\Rightarrow q^2 = Fr^2/k = Fr^2 \times 4\pi\varepsilon_0$ **(1)** Max 3

$= 0.0018 \times 9.81 \times \tan 1.5° \times 0.594^2 \times 4\pi\,\varepsilon_0$

$\Rightarrow q = 1.36 \times 10^{-7}$ C **(1)**

[NB 2 for diagram, maximum 3 for intermediate parts, and final 1 for the answer] 1

[6]

50. Results of experiments and conclusions

Most pass straight through/undeflected **(1)**

A few deflect/reflect (at large angles) **(1)**

Small nucleus/mostly empty space **(1)**

Concentrated mass and/or positive charge **(1)** 4

How to determine x graphically

Plot log N v. log (sin $\theta / 2$) [OR ln on both sides] [Any base] **(1)**

Gradient = x **(1)** 2

Meaning of numbers in the symbol for the gold nucleus

Bottom number: 79 protons **(1)**

Top number: 197 ns + ps)
OR)
197 nucleons) **(1)**
OR)
197 – 79 = 118 ns) 2

Mass of alpha particle

Mass of alpha particle ≈ $4 \times m_p$

$= 4 \times 1.67 \times 10^{-27} = 6.7$ [or 6.68] $\times 10^{-27}$ kg **(1)** 1

Calculation of electric force

$F = kq_1q_2/r^2$ OR $q_1q_2/4\pi\varepsilon_o r^2$ **(1)**

$q_1 = 79 \times 1.6 \times 10^{-19}$ C *and* $q_2 = 2 \times 1.6 \times 10^{-19}$ C **(1)**

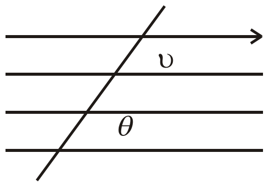
[stated or subbed]

$\rightarrow F = 14.56$ N **(1)** 3

[12]

51. <u>Situation to which equation refers</u>

F = force <u>on particle</u> **(1)**



B = (magnetic) flux density/field strength **(1)**

υ = velocity/speed of particle }
q = charge of particle } **(1)**

θ = angle between *B* and υ/motion /current **(1)**

F is perpendicular to *B* <u>and</u> *υ* **(1)**

[Some of these may be shown by diagram] Max 4

<u>Description of situation modelled by equation</u>

Curved/circular motion of particle **(1)**

p = momentum **(1)** 2

<u>Why path of a particle is curved</u>

Charged particles **(1)**

with (component of) motion perpendicular to field **(1)**

Force perpendicular to motion/ Fleming's L.H. rule **(1)** Max 2

<u>Why spiralling path decreases as it nears North Pole</u>

Nearer pole → field stronger **(1)**

Reference to $r = p(m\upsilon)/Bq$ OR $r \propto 1/B$

OR B increasing → centripetal/inward *F* increases

Alternative: $\upsilon \downarrow$ due to resistive force **(1)**

Reference to $r = p(m\upsilon)/Bq$ OR $r \propto p/\upsilon$ 2

[10]

52. <u>Explanation of why resultant flux in iron core is zero</u>

Same current (in both coils) OR same turns **(1)**

Wound opposite ways **(1)** 2

OR leading to cancelling of <u>magnetic</u> effects

<u>Explanation of how RCCB breaks circuit</u>

Any five from:

Different currents give different (noncancelling) effects **(1)**

$\therefore$ net B OR ϕ/B $\neq 0$ **(1)**

Faraday/changing ϕ/B **(1)**

$\Rightarrow$ *V* induced in third coil [“*I* induced” is 4th **(1)** only] **(1)**

$\Rightarrow$ *I* in third coil/relay coil **(1)**

$\Rightarrow$ relay coil magnetized **(1)**

$\Rightarrow$ relay contact opens **(1)** Max 5

[7]

53. <u>What happens in circuit after switch closed then opened again</u>

Any seven from:

S closed $\rightarrow$ C charges **(1)**

up to V_S **(1)**

Instantly/very quickly **(1)**

S open: discharge starts **(1)**

Exponential discharge **(1)**

$(V_c = V_s\, e^{-t/RC})$

$\frac{3}{4} V_s = V_s\, e^{-t/RC}$ **(1)**

$\Rightarrow \ln \frac{3}{4} = -t/RC$ **(1)**

$\Rightarrow t = 29.7$ s OR $RC = 103$ s [if no other calculation] **(1)**

Buzzer sounds for 29.7 s [ecf] **(1)** Max 7

[Marks 1-5 and mark 9 are available via appropriate graph. For mark 5 graph must have axes labelled with a *V/Q/I* and same *t,* and a recognisable exponential curve.]

54. Meaning of uniform magnetic field

Magnetic flux density constant / magnetic field lines parallel / **(1)**
magnetic field strength is constant/ does not vary 1

Sizes and directions of forces on LM and NO

Force on LM: 2.4×10^{-4} N/ 0.24 mN **(1)**
Direction:
Downwards/into (paper) **(1)**

Force on NO:)
2.4×10^{-4} N / 0.24 mN [No unit penalty]) Must have both **(1)** 3
Direction:)
Upwards / out of (paper))

Why no forces on MN and OL

Wires/current and B field directions are parallel [allow 'same direction'] / field due to current and B field of magnet are perpendicular to each other **(1)** 1

The effect on the square

A (turning) moment will be applied / it will (begin) to turn / spin / rotate **(1)** 1

Moving the pole pieces further apart

Reduces the size of the forces, **(1)**
Because the flux density is reduced/ magnetic field (strength) reduced / B (field) reduced **(1)** 2

[8]

55. <u>Charge on capacitor</u>

220 μF × 5 V [use of CV ignore powers of 10] **(1)**
= 1100 μC **(1)** 2

<u>Energy on capacitor</u>

$\frac{220}{2}$ μF × (5 V)^2 / $\frac{1100}{2}$ μC ×5 V / $\frac{1100^2\ \mu C^2}{2 \times 220 \mu F}$ [ignore powers of 10] **(1)**

= 2750 μJ (2.8 × 10^{-3} J) **(1)** 2

<u>Experiment</u>

Method 1 (constant current method):

- Circuit **(1)**
- For a given *V* record time to charge capacitor at a constant rate **(1)**
- for a range of values of *V* **(1)**
- Use $Q = It$ to calculate *Q* **(1)**
- Plot $Q \rightarrow V$– straight line graph through origin / sketch graph / dive *Q/V* and obtain constant value **(1)**

Method 2:

- Circuit **(1)**
- For a given value *V* measure I and t **(1)**
- Plot $I \rightarrow t$ find area under graph *Q* **(1)**
- Repeat for a range of values of *V* **(1)**
- Plot $Q \rightarrow V$ for straight line graph through origin/ sketch graph / dive *Q/V* and obtain constant value **(1)**

Method 3 (joulemeter method):

- Circuit **(1)**
- Record V and energy stored **(1)**
- For range of V **(1)**
- Determine Q from ½ QV or $\frac{Q^2}{2C}$ **(1)**
- Plot $Q \rightarrow V$– straight line graph through origin / sketch graph / divide *Q/V* and obtain constant value **(1)** 5

[Coulombmeter (will not work with this value of capacitor)
circuit **(1)** ; record charge *Q* on colombmeter **(1)**; for a range of values of *V* **(1)**; Plot $Q \rightarrow V$ for straight line through origin **(1)** – Max 3]

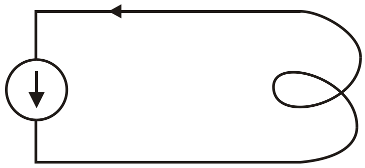
[9]

56. Lenz's law

The direction of an induced current/emf/voltage is such as **(1)**
to oppose the change (in flux) that produces it **(1)** 2

Polarity at top of coil

North **(1)**
Direction of current



Only ONE arrow required **(1)** 2

Graph

Magnet is moving faster / accelerating (under gravity) **(1)**

(Rate of) change/ cutting of flux is greater **(1)**

Induced emf is greater **(1)** Max 2

[6]

57. Explanation of what has happened in circuit

Charging process **(1)**

Plates oppositely charged OR charge moves from one plate to another **(1)**

Charge flows anticlockwise OR electrons flow clockwise OR left plate becomes positive OR right plate becomes negative **(1)**

Build up of Q/V reduces flow rate **(1)** Max 3

Explanation of what would have been seen

Same as ammeter 1 **(1)**

Reason: Same I everywhere OR series circuit OR same I/Q in each component **(1)** 2

Estimate of charge

Attempt to find area under correct region of graph **(1)**

= 52 μC **(1)** 2

[Allow 45 – 65 μC]

Estimate of capacitance

p.d. across resistor at t = 10 s = 100 × 10^3 Ω × 3 × 10^{-6} A = 0.3 V **(1)**

(hence p.d. across capacitor = 1.5 V – 0.3 V = 1.2 V)

$C = \frac{Q}{V} = \frac{5\times10^{-5}\,\text{C}}{1.2\text{V}}$ (equation or sub) [ecf] **(1)**

C = 42 μF [If 1.5 V is used to obtain C = 33 μF, then 2/3] **(1)** 3

Alternative method using $e^{-t/RC}$

Correct answer appropriate to set of values **(1)**

Correct ln line **(1)**

Correct answer (40–44uF) **(1)**

Alternative method using $T = RC$

Using $T = RC$ **(1)**

Appropriate T value **(1)**

⇒ correct answer **(1)**

Observations

Same picture as before **(1)**

since same ΔV **(1)** 2

[OR C now carries twice the previous charge]

[12]

58. Meaning of E

Voltage/e.m.f. **(1)**

Induced/caused/created (when magnetic field/flux changes) **(1)** 2

Definition of ϕ

$\phi = BA$ **(1)**

(Magnetic) flux OR magnetic field lines **(1)** 2

Additions to diagram of paths of currents

Joined up, and one each side and wholly on disk **(1)** 1

Explanations

(i) Disc cuts B/ϕ [relative motion implied] ($\Rightarrow$ V/I induced) **(1)**

(ii) $B + I$ [or two interacting magnetic fields] $\Rightarrow$ force **(1)**

Lenz or LH rule ($\Rightarrow$ opposing force) OR energy argument **(1)** 3

Explanation of reasoning

Mention of $F = BIl$ **(1)**

$B \propto I_b$ **(1)**

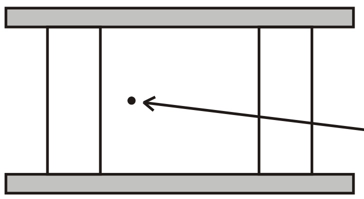
I (in disc) $\propto B/\phi$ **(1)** 3

[11]

59. Addition to diagram

2 lines or more, vertical **(1)**

Arrow downwards **(1)** 2



Electric field strength

$E = V/d$ OR $2000 \div (0.8 \times 10^{-2})$ **(1)**

$= 250\ 000\ \text{V m}^{-1}$ OR N C^{-1} [OR $2500\ \text{V cm}^{-1}$] **(1)** 2

(2.5×10^5)

Magnitude of charge

$F = ma$ OR $1.8 \times 10^{-7} \times 3.0 \times 10^{-7}$ (N) OR 5.4×10^{-14} (N) **(1)**
($F = Eq \Rightarrow$) $q = F/E$ OR $5.4 \times 10^{-14}/2.5 \times 10^5$ (C) **(1)**
$= -2.16$ (2, 2.2) $\times 10^{-19}$ C **(1)** **(1)** 4

[NB 1 mark for –, 1 mark for rest of answer]

Why a vacuum

Air/gas/molecules would **alter acceleration** OR provide another force OR collide with niobium sphere **(1)** 1

[9]

60. <u>F proportional to I</u>
Quality of written communication **(1)**
Any two from:
[In words or on diagram]

- Method of producing and measuring a varying direct current
- Wire perpendicular to B field
- Method of measuring/detennining forces, e.g. moments / acceleration **(1) (1)**

Graph of F - I straight line through origin for F = added weight **(1)** 4

[OR correct straight line if F is total weight OR $\frac{F}{I}$ constant]

<u>Calculation of Initial acceleration</u>

$F = BIl$
$= 0.20 \text{ T} \times 4.5 \text{ A} \times 5.0 \times 10^{-2} \text{ m}$
$= 4.5 \times 10^{-2} \text{ N}$
$a = F/m$
$= \frac{4.5 \times 10^{-2} \text{ N}}{50 \times 10^{-3} \text{ kg}}$
$= 0.90 \text{ m s}^{-2}$

Recall/state/use $F – ma$ and $F = BIl$ **(1)**
Use $5.0 \times (10^{-2} \text{ m})$ for length **(1)**
Conversion of g to kg 50×10^{-3} **(1)**
$a = 0.90 \text{ m s}^{-2}$ **(1)** 4

[8]

61. <u>E.m.f.</u>
Motion of magnet **(1)**
produces changing magnetic field over the coil **(1)** 2
OR
Field lines (of magnet) cut across coil
OR
Produces changes in flux linkage between coil and magnets
<u>Diagram</u>
X at both ends of path **(1)**
X in middle of path **(1)** 2

Rate of change of flux

$\frac{\Delta\phi}{\Delta t} = \frac{3 \times (10^{-3})(V)}{500}$ **(1)**

= 6.0 ×10^{-6} wb s^{-1}/V/T m^2 s^{-1} **(1)** 2

Changes to apparatus

Any three from:

- more coils
- stronger magnet [Accept 'more powerful']
- decrease length of suspension) [Not just 'increase'
- larger amplitude) speed of magnet]
- larger cross sectional area of coil
- iron core within coil **(1) (1) (1)** 3

[9]

62. Diagram

Electric pattern:

Straight, parallel, reasonably perpendicular to plates and equispaced [Minimum 3 lines] **(1)**

Correct direction labelled on one line [Downwards arrow] **(1)** 2

Equipotential lines:

Any two correct equipotentials with any labelling to identify potentials (rather than field lines) **(1)** 1

[Arrows on electric field lines – none on equipotential being sufficient labelling]

Force

$E = \frac{3000V}{25 \times (10^{-3})\text{m}}$ [Correct substitution] **(1)**

Use of $F = Ee$ even if value of "e" is incorrect **(1)**

F = 120 ×(10^3) V m^{-1} × 1.6 × 10^{-19} C

= 1.9 (2) × 10^{-14} (N) **(1)** 3

Graph

Straight horizontal line [Even if extending beyond 25 mm] **(1)**

Value of F marked [e.c.f. their value] provided graph begins on force axis and is marked at this point **(1)** 2

Speed

Use **(1)**

eV = ½ mv^2 v^2 = 2 eV/m	$v^2 = 2\left(\frac{F}{m}\right)s$	Fd = ½ mv^2 $v^2 = 2Fd/m$

Substitution **(1)**

$$V^2 = \frac{2 \times 1.6 \times 10^{-19}(\mathrm{C}) \times 3000(\mathrm{V})}{9.11 \times 10^{-31}\,\mathrm{kg}}$$

$$= 2\ \frac{(1.92 \times 10^{-14}\,\mathrm{N})}{9.11 \times 10^{-31}\,\mathrm{kg}} \times 25\ 10^{-3}\ \mathrm{m}$$

$$= \frac{2 \times 1.92 \times 10^{-14}\,\mathrm{N} \times 25 \times 10^{-3}\,\mathrm{m}}{9.11 \times 10^{-31}\,\mathrm{kg}}$$

Answer: $V = 3.2 \times 10^7\ \mathrm{ms^{-1}}$ **(1)** 3

[If $F = 2 \times 10^{-14}$ N, then $V = 3.3 \times 10^7\ \mathrm{ms^{-1}}$]

[11]

63. Formula for magnitude of force

$F = Eq$ **(1)** 1

Direction

Down page **(1)** 1

Calculation

$Eq = Bq\upsilon$ **(1)**
$\rightarrow \upsilon = E/B$ (*)
$= 1.2 \times 10^4/0.4\ \mathrm{ms^{-1}}$ (*)
(*) [Equation or substitution] **(1)**

$\upsilon = 3 \times 10^4\ \mathrm{ms^{-1}}$ **(1)** 3

Explanation

$mg << eE$ and/or $Bq\upsilon$ **(1)** **(1)**

[OR gravity force << E and/or B force	2 marks	
OR m very small	1 mark only	
OR gravity is a weak force	1 mark only	2
OR ion moving fast	1 mark only]	

[7]

64. <u>Alpha particle: diagram</u>

Curving path between plates	1
Towards 0 V plate	1
Emerging from plates and carrying on straight	1

<u>Calculation</u>

Electric field = $\dfrac{2000\text{ V}}{10 \times (10^{-3})\text{ m}}$

Substitution	1

Force = EQ

$= \left(\dfrac{2000}{10 \times 10^{-3}}\right) \text{Vm}^{-1} \times (2) \times 1.6 \times 10^{-19}\text{ C}$

Substitution [ecf their E]	1

$= 6.4 \times 10^{-14}$ N

Correct answer	1

[6]

65. <u>Horizontal component</u>

4.8×10^{-5} T × cos 66°

$= 1.95\ [2.0] \times 10^{-5}$ T

Use cos 66°/sin 24°	1
Answer	1

<u>Calculation of induced voltage</u>

Speed after 2 seconds = 9.81 m s^{-2} × 2 s	1
[ecf their B]	
Induced e.m.f. = 1.95×10^{-5} T × 2.5 m × [9.81 m s^{-2} × 2 s]	1
$= 9.6 \times 10^{-4}$V	1

<u>North-south rod</u>

Induced emf = 0 (V)	1
Rod does not cut magnetic field lines/no flux cutting/no change in flux	1

[7]

66. (i) Protons are positively charged / like current 1

refer to Fleming or motor rule / *Rev* / *Bqv* / perpendicular *F* and υ 1

[**not** right hand rule]

(ii) $m\frac{\upsilon^2}{r} = Be\upsilon$ $\qquad$ $mr\omega^2 = Be\upsilon$ 2

[accept *q* for *e*]

$\upsilon = \frac{2\pi r}{T} / \frac{\pi r}{t}$ $\qquad$ $\omega = \frac{2\pi}{T} / \frac{\pi}{t}$ 1

(iii) Quality of written communication 1

Each time it crosses gap/between dees it accelerated / is attracted / is given *E* 1

Idea that p.d. between the dees reverses while the proton completes half a revolution / c.e.p. 1

As energy becomes large the mass/inertia of the proton increases 1
[**not** protons hit edge]

so it cannot exceed the speed of light [i.e. ref to *c*]/synchronous property breaks down/formula no longer gives constant *f* 1

(iv) $\Delta E = (1.6 \times 10^{-19}$ C) (12000 V) [allow × 12] 1

$= 1.9/1.92 \times 10^{-15}$ (J) [no e.c.f.] 1

(v) $r^2 = 2m \times$ k.e. $\div B^2e^2r = \sqrt{\text{same}}$

Substitute 1.66 / 1.7×10^{-27} kg /1860 m_e /2000 m_e *and* 1.6×10^{-19} C 1

Use of k.e. = $(1.9 \times 10^{-15}$J) × 850 1
[e.c.f. for 1.9×10^{-15} J e.g. 2×10^{-15}J ⇒ 1.7×10^{-12}J]

⇒ $r = 0.575$ m /57.5 cm 1

[2×10^{-15}J ⇒ 0.59 m]
[9.1×10^{-31} kg ⇒ 0.0137 m e.o.p. max 1/3]

[15]

67. Energy stored in a capacitor

Justify area: $W = QV$
OR
work/area of thin strip = $V \times \Delta Q$ **(1)**

Area under graph **(1)** 2

<u>Energy stored when capacitor charged to 5000 V</u>

$W = \frac{1}{2} QV = \frac{1}{2} \times 0.35 \times 5000$ J

= 875 J **(1)** 1

<u>Time constant for circuit</u>

5000/*e* or 3 = 1840/1667 V **(1)**

⇒ T.C = 3.3 m s [3.1 – 3.6 m s] **(1)**

OR

Initial tangent → *t*-axis **(1)**

Accept between 3.5 and 4.0 m s **(1)** 2

[Also allow use of exponential formula with appropriate substitution of correct *V* and *t*, e.g. 2000 and 3 ms]

<u>Capacitance</u>

$C = \frac{T}{R}$ or as numbers **(1)**

3.3 m s → 7.0×10^{-5} F [Allow e.c.fs.]

4.0 m s → 8.5×10^{-5} F **(1)** 2

[OR using graph: $C = Q/V$ **(1)**
= 0.35/5000 = 7.0×10^{-5} F **(1)**]

<u>Energy left in capacitor</u>

At 2 ms, V = 2700 V [2600 – 2800] **(1)**

$\Rightarrow E = \frac{1}{2} CV^2$ *OR* $\frac{1}{2} QV$

= 255 J [e.c.f, depends on method] **(1)** 2

Energy setting

Energy leaving capacitor = (875 – 255) J

= 620 J [e.c.f] **(1)**

Energy delivered = 620 × 60/100 J

= 372 J

⇒ 380 J setting [Allow e.c.f] **(1)** 2

[11]

68. Electric field

$$\frac{100\,(\text{V})}{300 \times 10^{-6}\,(\text{m})}$$ **(1)**

= 3.3×10^5 V m^{-1} **(1)** 2

Force

$F = Eq = 3.3 \times 1.6 \times 10^{-19}$ (N)

= 5.3×10^{-14} N [Allow e.c.f] **(1)** 2

Why force has this direction

Vertical line ↑ **(1)**

Attracted to positive plate
OR in terms of field direction } **(1)** 2

How much energy hole gains

$W = F \times d = 5.3 \times 10^{-14} \times 2.8 \times 10^{-10}$ (J) **(1)**

= 1.5×10^{-23} J [Allow e.c.f] **(1)** 2

[8]

69. How torch works and factors which affect brightness

At least two lines leaving N and S pole, diverging and crossing wires **(1)**

Arrow leaving N pole/towards S pole **(1)**

Field/flux lines cut wires **(1)**

→ changing B/ϕ OR $\frac{d\phi}{dt}$ OR Faraday's law causes *V or I* **(1)**

If causes *V* followed by causes *I* **(1)**

Any two of rotation, field strength, number of coils **(1)**

Appropriate direction e.g. faster rotation brighter/more *V*/*I* **(1)**

$R\downarrow \Rightarrow$ brighter **(1)**

[Max 6]

70. <u>Reason</u>

Even a very small resistance (in series) with 2000 A through it would generate much heat

[Answer must refer to where heating effect occurs]

OR

Such a big current would need thick wires in the meter design

OR

Have to break circuit to insert meter **(1)** 1

<u>Explanation</u>

Any four from:

- I_1causes flux (in iron ring and coil)
- (flux) in iron ring/coil
- changing $I_1 \Rightarrow$ changing flux
- $\therefore V$ in coil induced / $V = N\frac{d\phi}{dt}$ /cutting flux /Faraday's law in context/ *I* induced **(1) (1)**
- *V* in coil $I \Rightarrow$ I in coil **(1) (1)** 4

[5]

71. <u>Observations of circuits</u>

Any six from:

- capacitor is charged
- energy stored in C/goes to lamps...
- → heat and light in lamp
- as *I*/*Q* passes through lamp/discharges through lamp
- $E = ½ CV^2$
- $\Rightarrow V \times 2 \Rightarrow E \times 4$
- (hence) 4 lots of energy/4 lamps lit similarly

-
- 5 V across 1 lamp ≡ same Q through each lamp as before
- discussion of $T = RC$
- R same for both circuits
- flash is bright and dies exponentially **(1) (1) (1)**
- $V \times 2 \rightarrow Q \times 2$ **(1) (1) (1)**
- $\rightarrow$ same Q or I as before alone each parallel branch

[6]

72. Faraday's law of electromagnetic induction
The induced e.m.f. **(1)**
in a conductor is equal to/proportional to
the rate of change of magnetic flux linkage **(1)**

OR

$E = (-)\dfrac{d\varphi}{dt}$ or $E \propto \dfrac{N\Delta\phi}{\Delta t}$ [Accept $\Delta\phi$ or dϕ]

E – induced voltage

dφ – change of magnetic flux **(1)**
dt – time

[All symbols defined] 2

Conversion of sound waves into electrical signals

Any four from:

- quality of language **(1)**
- sound waves make the diaphragm/coil vibrate/oscillate **(1)**
- coil: change in flux linkage/coil cuts field lines **(1)**
- induced voltage across coil **(1)**
- frequency of sound wave is frequency of induced voltage/current/ electrical wave **(1)** Max 4

[6]

73. Calculation of charge

6000 V × 20 × 10^{-6} F **(1)**
= 0.12 C **(1)** 2

Energy stored in capacitor

$$\left(\frac{CV^2}{2}\right) \frac{20 \times 10^{-6} \text{ C} \times (6000 \text{ V})^2}{2}$$ **(1)**

= 360 J **(1)** 2

Resistance

$\frac{6000 \text{ V}}{40 \text{ A}} = 150\ \Omega$ **(1)** 1

Time to discharge capacitor

Time = $\frac{0.12 \text{ C}}{40 \text{ A}}$ /their Q **(1)**

= 0.0030 s / 3.0×10^{-3} s [e.c.f.] **(1)** 2

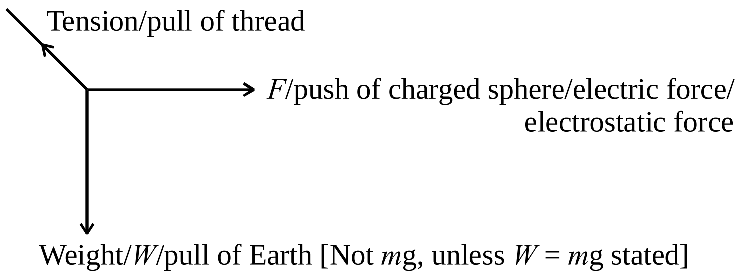
Reason

Time is longer because the rate of discharge decreases/ current decreases with time **(1)** 1

[8]

74. Free-body force diagram

Tension/pull of thread **(1)**
F/push of charged sphere/electric force/electrostatic force **(1)**
Weight/*W*/pull of Earth [Not *mg*, unless *W* = *mg* stated] **(1)** 3



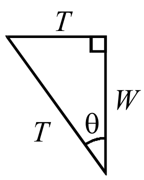
Force equation

$W = T\cos\theta$ (
(**(1)**
$F = T\sin\theta$ (

Processing mark, e.g. $F = \frac{W}{\cos\theta}\sin\theta$ OR $\tan\theta = \frac{\sin\theta}{\cos\theta}$ **(1)**

OR

F, T, W labelled **(1)**
both angles labelled **(1)** 2



Table

Distance $r = 36 \times 10^{-3}$ m
F = 35.5/36 [No u.e.] **(1)**
Distance $r = 27 \times 10^{-3}$ m

Using any pair of values **(1)**
Seeing correct constant for their pair of values **(1)**
$\rightarrow F$ = 63.1 [n.o u.e.] **(1)**

OR

Valid simple ratio calculation using a pair of values **(1)**
stating produce Q_1Q or kQQ_2 constant **(1)**
$\rightarrow F$ = 63.1 [no u.e.] **(1)** 4

Measurements taken quickly because

Leakage/discharge of charge [Allow dissipation or description of process] **(1)** 1

[10]

75. (i) $W_c = ½\, CV^2 = ½\,(0.0047 \text{ F})\,(25 \text{ V})^2$ [Ignore 10^n] **(1)**
= 1.5 J / 1.47 J [no e.c.f.] **(1)** 2

Quality of written communication
W_c is (very) small **(1)**
Even at 50 V it is only 6 J **(1)**
Any ΔT is difficult to measure/wire spread out/ **(1)**
something like a thermocouple is needed **(1)**
Wire (might) melt/fuse **(1)**
Heat/energy loss to air/surroundings [not to connecting wires] **(1)** Max 4

(ii) Exponential (decay) **(1)**
Radioactive decay/radioactivity [independent] **(1)**
Use of one of *five* approved methods [Name it] **(1)**
Data off graph appropriate to method [ignore 10^n] **(1)**
Use of RC/use of $R = V/I$ **(1)**
R = 7.2 Ω – 8.5 Ω [no e.c.f.] **(1)**
[7200 Ω – 8500 gets 3/4] 6

[12]

<u>Methods:</u>
M1 RC = time to $Q_0 \div e$ [35 – 39 ms]
M2 $RC \ln 2 = t_{1/2}$ [24 – 28 ms]
M3 RC = where initial tangent hits t axis [32 – 40 ms]
M4 Use of RC in $Q = Q_0e^{-t/RC}$ with numbers
[≈ correct]
M5 Calculation of T_0 initial current from gradient
[2.7 – 3.0 A]

76. How movement of magnet produces voltage shown on c.r.o screen

Any 4 from:

- Boxes correct
- Mention of Faraday's law/equation/word description
- Flux max when magnet vertical / box 1 / box 3
- Flux zero when magnet horizontal / box 2 / box 4
- When flux max, not changing, $V = 0$
- When flux changing fastest, V max
- Appropriate comment about sense of voltage, e.g., when poles reversed, V reversed — 4

Differences between figures (i) and (ii)

Qualitative points: (max 2)

(Faster turning, giving) $\frac{d\phi}{dt}\uparrow$ **(1)**

$= V\uparrow$ and $f\uparrow$ OR $T\downarrow$ **(1)**

OR

Quantitative points: (max 3)

($f \times 2 =$) $\frac{d\phi}{dt}$ (max) $\times 2$ **(1)**

$= V \times 2$ **(1)**

$f \times 2$ (OR $T \div 2$) **(1)** — 3

Flux at each end of magnet

Area 1 big square = 100 μ(Vs) or 100×10^{-6} (Vs)

OR area of 1 little square = 4 μ(Vs) or 4×10^{-6} (Vs)

OR area = 32 little squares (29 – 35)

OR area = 4/3 big squares (1.2 – 1.4) **(1)**

Area = 130×10^{-6} (Vs) (120 – 140) **(1)**

Φ = Area / 2×240

$= 2.7 \times 10^{-7}$ Wb (2.5 – 2.9) **(1)** — 3

Magnetic flux density at end of bar magnet

$B = \Phi/A$ OR $\Phi = BA$ OR $A = 0.01 \times 0.005$ OR $A = 5 \times 10^{-5}$ m^2 **(1)**

$= 3.0 \times 10^{-7} / 5.0 \times 10^{-5}$

$= 6.0 \times 10^{-3}$ T (accept Wb m^{-2}) **(1)** 2

[12]

77. Calculation of energy:

$E = ½ CV^2$ **(1)**

$= ½ \times 100 \times 10^{-6}$ F$\times$ (4 V)^2

$= 8 \times 10^{-4}$ J **(1)** 2

Parts of circuit which will transfer energy to surroundings:

S_s / the wires between it and C 1

Discussion:

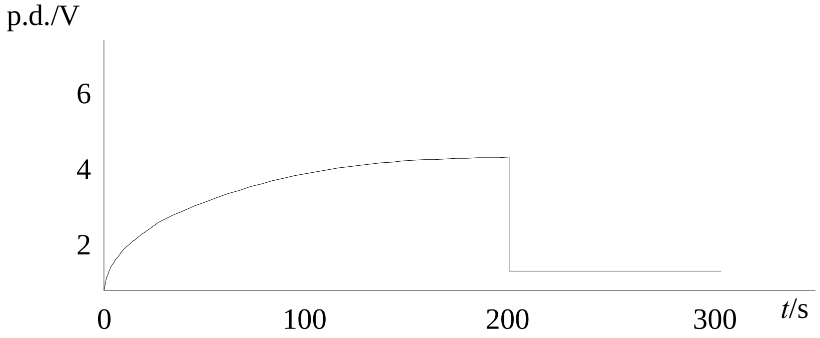
No – negligible energy 1

Completion of graph:

Convex curve up from 0 **(1)**

through (200, 4) **(1)**

Then drops to zero **(1)** 3



Approximate value for R:

Time constant = RC **(1)**

$\Rightarrow R = 200$ s/100μF

$= 2 \times 10^6\ \Omega$ [Allow 1.6 – 2.2 MΩ] **(1)** 2

Discussion of effect of increasing resistance, *R*:

R goes up ⇒ *T* goes up **(1)**

T goes up means longer toasting **(1)** 2

[11]

78. (a) The origin of the induced e.m.f:

Faraday's law **(1)**

As conductor cuts field lines **(1)**

Electrons experience force along wire **(1)**

⇒ move to one end ⇒ e.m.f. **(1)** 3

(b) Reduction in orbit height due to flow of current:

Current + field ⇒force OR Fleming L H rule **(1)**

Lenz's law: **(1)**

Force opposes motion **(1)**

Orbiting craft lose energy/speed **(1)** 3

[Max 5]

79. Relationship between current and charge:

Current is the rate of flow of charge/rate of change of charge OR current is charge per second

OR $I = Q/t$ (with or without d or Δ) but with symbols defined **(1)**

1

Explanation:

Since I is constant, Q *o* on capacitor ($= It$) increases at a steady rate OR charge flows at a constant rate **(1)**

Since $V \propto Q$, V also increases at a steady rate **(1)**

OR

$V = Q/C = It/C$ **(1)**

and $V = (I/C) \times t$ compared with $y = (m) \times x$

2

Determination of current, using graph:

Use of $Q = CV$	Attempt to get grad	**(1)**
Use of $I = Q/t$	Use of $I = C \times$ grad	**(1)**
= 1.1 mA	1.1 mA	**(1)**

3

Explanation:

Decrease [If increase, 0/3] **(1)**

As capacitor charges, V_R decreases **(1)**

R must decrease because I = V_R/R OR R must decrease to prevent I falling **(1)**

3

Second graph:

Line added to graph showing:

Any curve getting less steep with time [from origin; no maximum] **(1)**

And with same initial gradient as original straight line **(1)**

2

[11]

80. Calculation of potential difference:

Use of $E = V/d$ [d in m or cm] **(1)**

V = 90 kV **(1)**

Calculation of maximum kinetic energy:

Use of $\times 1.6 \times 10^{-19}$ [in $E = qV$ e.c.f. value of V] 1.4×10^{-14} (J) **(1)**

[e.c.f. their V $\times 1.6 \times 10^{-19}$] **(1)**

4

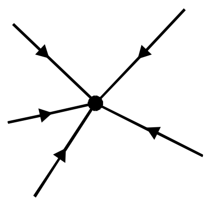
Maximum speed of one of these electrons:

Use of k.e. = ½ $m\upsilon^2$ with m = <u>9.1 × 10^{-31} kg</u> **(1)**

[Full e.c.f. their k.e. possible; make sure v is speed term]

= 1.8 × 10^8 m s^{-1} [u.e. but only once] **(1)**

Diagram:



2

At least 3 radial lines <u>touching</u> object **(1)**

Direction towards electron **(1)**

2

Expression for electric potential V:

$$V = \frac{1}{4\pi\varepsilon_0} \times \frac{1.6 \times 10^{-19}}{r} \quad \text{OR} \quad \frac{e}{4\pi\varepsilon_0} r \quad \text{OR} \quad \frac{1.44 \times 10^{-9}}{r}$$

[not k unless defined] $\left[\textit{Not } \frac{Q}{4\pi\,\varepsilon_0\, r} \text{ unless } Q \text{ defined} \right]$

[With or without "–" sign] **(1)**

1

[9]

81. Flux through closed window:

Flux = 20 × 10^{-6} T × (1.3 × 0.7) m^2

[if two equations, must use (1.3 × 0.7) each time] **(1)**

B_H chosen OR area correct **(1)**

= 1.8 × 10^{-5} Wb/T m^2

2

Average e.m.f. induced:

$E = \dfrac{1.8 \times 10^{-5}\ \text{Wb}}{0.8\ \text{s}}$ [e.c.f.] **(1)**

$= 2.3 \times 10^{-5}$ V [5.6×10^{-5} V if B_v used] **(1)**

2

Effect on induced e.m.f. of converting window: **(1)**

Zero induced e.m.f. [Not "very small"]

No change in flux linkage OR no flux cut OR e.m.fs. in opposite sides cancel out 2/2 [Consequential] **(1)**

2

[6]

82. Exponential shape **(1)**

Value at RC > 1.5 V [only if shape correct] **(1)**

Levels off at 3 V **(1)** 3

Why movement of diaphragm causes p.d:

No movement, no change in C, no signal **(1)**

OR moving diaphragm changes C

As C changes so V changes **(1)**

Vc + *IR* is constant **(1)**

Hence IR changes – signal **(1)** 4

OR for last 3 marks

As C changes Q changes

Q flows through R

hence V = *IR* for resistor as signal 7

83. Credit to be given for all good, relevant Physics

Examples of mark scoring points [each relevant formula is also worth 1 mark]:

Between plates field is uniform

Acceleration is constant

Energy gained = 2000e

All ions have same F or same energy

From hole to detector is zero field/force

Ion travels at constant speed

g negligible

time proportional to 1 /velocity

time proportional to 1 /mass

in a vacuum there are no collisions or friction forces

[Max 7]

„É „**84.** Estimation of charge delivered:

Charge = area under graph **(1)**

= a number of squares × correct calculation for charge of one square i.e. correct attempt at area e.g. single triangle **(1)**

= (3.5 to 4.8) × 10^{-3} C (A s, μA s) **(1)**

[Limit = triangle from 41 μA → 300 s]

OR

Charge = average current × time **(1)**

= (something between 10 and 20 μA) × 300 s **(1)**

= (3.5 to 4.8) × 10^{-3} C **(1)** 3

[But $Q = It$ → 0/3, e.g. 41 μA × 300 s]

Estimation of capacitance

C = calculated charge/9.0V time constant ≈100 s **(1)**

= 390 to 533 μF C = 100 s/220 k.Ω = 450 μF **(1)** 2

[5]

85. Estimate of time constant, using graph:

V/3	OR	V/e	OR	$t_{1/2}$
↓ 3 V		↓ 3.3 V		↓ 16 s
26 s		23.24 s		23 s

Method **(1)**

Value 23 → 26 s **(1)** 2

Calculation of resistance and hence capacitance:

$R = \frac{V}{i}$ OR $\frac{9}{0.19 \times 10^{-3}}$ **(1)**

Resistance = 47 kΩ [ue] **(1)**

Substitute in t = RC [e.c.f their t, their R] OR answer 300 μF

Capacitance = 500 μF **(1)** 3

Addition to graph of line showing how potential difference varies with time:

A curve of shape shown below, i.e. getting less steep **(1)**

Any convex curve ending at ≈ 7.5 V, crossing at ≈ 15 s **(1)** 2

[7]

86. Calculation of e.m.f. induced across falling rod:

Correct use of $E = Bl\upsilon$ **(1)**

$\upsilon = 25 \text{ m s}^{-1}$ **(1)**

e.m.f. = $7.3 - 7.4 \times 10^{-4}$ V **(1)** 3

Explanation of why magnitude of vertical component is not required:

Earth's field is parallel to direction of fall/body falls vertically **(1)**

Therefore no flux cut **(1)** 2

[5]

87. Forces acting on molecule, shown on diagram A:

Forces not collinear and sense correct **(1)** 1

Explanation of why molecules align with field:

Forces not in same line **(1)**

Hence turning effect [OR torque] 2

Field lines shown on diagram B:

At least three lines drawn equidistant**(1)**

Direction correct **(1)** 2

Calculations of electric field strength:

$E = \frac{V}{d} = \frac{1.5\text{V}}{1.0 \times 10^{-5}\text{m}}$ **(1)**

$= 1.5 \times 10^5$ V m^{-1} **(1)** 2

[7]

88. Capacitors and storage of energy:

$E = ½ cV^2$ **(1)**

$E_w = ½ \times 68 \times 10^{-3}$ F × (16 V)^2 = 8.7 J **(1)**

$E_2 = ½ \times 1 \times 10^{-3}$ F × (400 V)^2 = 80 J **(1)** 3

[Allow calculations in proportion using $\left(\frac{C}{\mu F}\right)\left(\frac{V}{V}\right)^2$

Range of actual value:

900 μF < C < 1500 μF **(1) (1)** 2

(i) Calculation of charge:

$Q = CV = 68 \times 10^{-3}$ F × 16 V= 1.1 C **(1)** 1

(ii) Demonstration that maximum leakage is about 3000 μA:

$I = 0.003 \times 10^{-6}$ A/μF V × 68 000 μF × 16 V **(1)**

$= 3.26 \times 10^{-3}$ A [3.3 mA] **(1)** 2

(iii) Estimate of time for capacitor to discharge with reasoning:

$\frac{Q}{I_0} = \frac{1.09\,\text{C}}{3.26 \times 10^{-3}\,\text{A}} = 334\,\text{s}$ [This is time constant] **(1)**

Numerical example such as: for less than 0.7% remaining $t = 5\tau$ =

1670 s OR well-reasoned estimate showing $t >> 300$ s **(1)** 2

[10]

89. Why large voltage is generated in secondary circuit:

Faraday's Law in words including 'flux linkage'

Current flow in primary **(1)**

causes magnetic flux in core **(1)**

Flux links secondary **(1)**

Opening switch S causes flux to reduce **(1)**

Changing flux in. secondary induces e.m.f **(1)**

Many turns on secondary means large flux linkage **(1)**

Hence rate of change of flux linkage is large

reduction time is short **(1)**

Hence induced e.m.f. is large **(1)** Max 6

[6]

90. Observations on voltmeter:

(a) Movement which implies brief or pulsed then V reads zero

(b) Negative reading with respect to direction above

(c) Alternating reading positive to negative and continuous

[5]

91. Total magnetic flux through the loop when 30 mm from end of magnet:
Flux = $B \times A$
= 1×10^{-3} T × 16×10^{-4} m^2 **(1)**

[Substitution of 1, 16. Ignore × 10 here]
= 1.6×10^{-6} Wb **(1)**

Total magnetic flux through the loop when 10 mm from end of magnet:
Flux = 30×10^{-3} T × 16 × 10^{-4} m^2
= 4.8×10^{-5} Wb [Unit penalty once only] **(1)** **3**

Average speed of movement of the loop:
$E = \Delta\phi / \Delta t$

$\Delta t = \dfrac{46.4 \times 10^{-6}\ \text{Wb}}{15 \times 10^{-6}\ \text{V}}$ **(1)**

= 3.1 s

Use of speed = distance ÷ time = 20 mm ÷ 3.1 s **(1)**
= 6.5 mm s^{-1} **(1)** **3**

Slow down nearer to the magnet **(1)** **1**

[Total 7 marks]

92. State Lenz's law of electromagnetic induction

Direction of induced emf is such as to oppose the charge producing it (2)

(2 marks)

An exhibit at a science centre consists of three apparently identical vertical tubes, T_1, T_2 and T_3, each about 2 m long. With the tubes are three apparently identical small cylinders, one to each tube.

When the cylinders are dropped down the tubes those in ~T, and ~T2 reach the bottom in less than I second, while that in ~T3 takes a few seconds.

Explain why the cylinder in T_3 takes longer to reach the bottom of the tube than the cylinder in T_1

In T_3 magnetic flux cuts copper tube (1)
induction occurs (1)
current in copper tube (1)
creates magnetic field (1)
opposite to magnet's which repels slows magnet

T_1 is plastic so no induction/no current forms (1)

(5 marks)

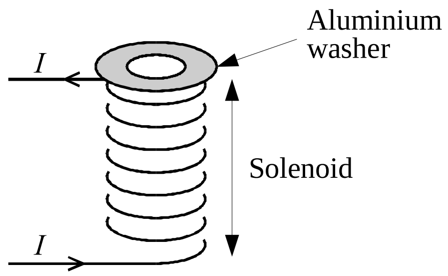
Explain why the cylinder in T_2 takes the same time to reach the bottom as the cylinder in T_1

In T_2 falling cylinder unmagnetised so no flux cut or no induction (1)

Both T_1 and T_2 have only force of gravity acting on them (1)

(2 marks)
[Total 9 marks]

93. A light aluminium washer rests on the end of a solenoid as shown in the diagram.



A large direct current is switched on in the solenoid. Explain why the washer jumps and immediately falls back.

B field produced by solenoid (1)

Flux lines CUT washer (1)

Induced current/e.m.f. in washer (1)

B field of solenoid opposite to B field washer (1)

Repulsive force lifts washer (1)

Steady current so no changing of flux/no induction (1)

OR explain by force on current carrying conductor in B field (LH rule)

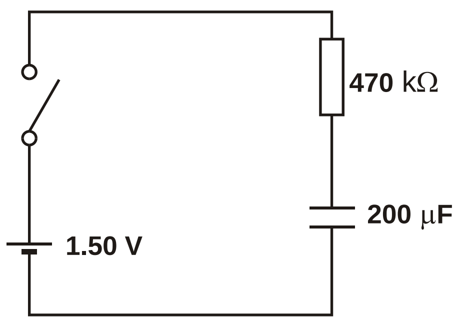
[Total 5 marks]

94. Define capacitance

Capacitance = Charge / Potential difference.

(2 marks)

An uncharged capacitor of 200 μF is connected in series with a 470 kΩ resistor, a 1.50 V cell and a switch. Draw a circuit diagram of this arrangement.



(1 mark)

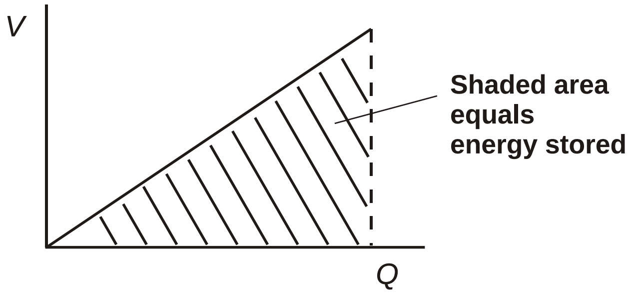
Calculate the maximum current that flows.

Current = 1.5 V/470 kΩ

Current = 3.2 μA

(2 marks)

Sketch a graph of voltage against charge for your capacitor as it charges. Indicate on the graph the energy stored when the capacitor is fully charged.



(4 marks)

Calculate the energy stored in the fully-charged capacitor.

$\frac{1}{2}CV^2 = \frac{1}{2}$ (200 μF) (1.5 V)^2

Energy = 2.25 μJ

(2 marks)
[Total 11 marks]