Mark schemes

1. (a) Magnetic flux density at 0.070 m = 0.07 ± 0.005 T ✓

(use of flux linkage $N\Phi = BAN$
= 0.07 × 3.5 × 10^{-5} × 200)

Flux linkage = 4.9 ± 0.2 × 10^{-4} (Wb-turns) ✓

shown calculated to at least 2 sig figs

2

(b) (As the coil moves) there is a rate of change of flux through the coil ✓$_1$ (owtte)

The induced emf is proportional to the rate of change of flux (linkage) so the (magnitude) of the emf decreases ✓$_2$ (owtte)

✓$_1$ The first part ie the induced emf is proportional to the rate of change of flux linkage may be given in a number of ways eg emf = $N\frac{\Delta\Phi}{\Delta t}$ or $N\frac{\Delta(BA)}{\Delta t}$ or simply saying 'because of Faraday's law'.

Ignore the sign of the emf

✓$_2$ It's not enough to say the emf decreases

Connection between rate of change of flux and change of flux with distance must be made

2

(c) Finding a gradient from a tangent ✓[1]

Attempting to use Faraday's law

emf = $N\frac{\Delta(BA)}{\Delta t}$

OR incorporating velocity into Faraday's law $NA\left(\frac{\Delta B}{\Delta x}\right)v$

emf = (200 × 3.5 × 10^{-5}(0.693) × 0.80)
emf = 3.6 to 4.2 × 10^{-3} (V) ✓[3]

The maximum emf (in the range considered) is the greatest at x = 0.10 m (as the gradient is the greatest)
So No ✓[4] owtte

✓[1] This can be calculated at any x
eg at x = 0.10 m gives $\frac{\Delta B}{\Delta x} = \left(\frac{0.095}{0.137}\right)$ *= 0.69(3) (T m^{-1})*

✓[2] The mark is given for an attempt to use Faraday's law. Allow errors provided the form of the equation remains correct.

✓[3] The expected value is 3.8(8) × 10^{-3} V {range to be decided at standardisation}

✓[4] No and an indication that the emf at x = 0.10 m is the maximum available. This could come earlier in the answer and can be inferred by a reference to the maximum gradient in the range considered.
No ecf.
If no marks are awarded allow 1 mark if candidate states that the largest emf is expected at x = 0.10 m
If only the second mark is awarded allow a mark for finding $\frac{\Delta B}{\Delta t}$ or $N\frac{\Delta\phi}{\Delta t}$ *between x = 0.07 and 0.10 m (e.g.* $\frac{200\times3.5\times10^{-5}(0.07-0.024)}{0.0375}$*)*

4

[8]

2. A

lift upwards away from the wires.

[1]

3. A

one

[1]

4. D

The peak-to-peak voltage is 650 V.

[1]

5. (a) Force due to uniform <u>magnetic</u> field (is constant and always) at 90º to direction of travel ✓

Identifies this force as the centripetal force for circular/semicircular motion ✓

Reference to velocity will be taken as the velocity of the proton

2

(b) (1 electron through 10 kV = 10000 eV
14 MeV by 10000 eV)
= 1400 (times) ✓

1

(c) $F = Bev$ AND $F = m_p v^2/R$ ✓

Equates forces giving $v = eBR/m_p$ ✓

$E_k = ½m_p v^2 = ½m_p(eBR/m_p)^2$ ✓

$E_k = e^2B^2R^2 / 2m_p$

1st mark for either or both

2nd mark for expression for v

3rd mark for substituting in $½m_p v^2$

Condone use of Q *or* q *for* E

3

(d) Uses = $\dfrac{e^2B^2R^2}{2m_p}$

to calculate E_k for any one cyclotron in J or eV ✓ Calculates E_k for 3 cyclotrons or argues that as **X** is just OK, **Y** will be greater and Z will be less than 11 MeV ✓

<u>So</u> reasoned choice of **X** ✓

cost/$11.7^{1.5}$ = £2.3 million/$10^{1.5}$
cost = £2.9 million ✓

For ***X*** $E_k = \dfrac{(1.6 \times 10^{-19})^2 \times 1.3^2 \times 0.38^2}{2 \times 1.67 \times 10^{-27}}$

= 1.87×10^{-12} J or 11.7 MeV

For ***Y*** *$E_k = 2.32 \times 10^{-12}$ J or 14.5 MeV* ***or Y*** *must have higher energy because BR and hence B^2R^2 must be greater*

For Z $E_k = 6.89 \times 10^{-13}$ J 4.3 MeV ***or*** *by inspection B^2R^2 will be too low to give 11 MeV*

Or other appropriate method

4

[10]

6. B

$\frac{9}{2}P$

[1]

7. B

200 0.45

[1]

8. (a) Arrow pointing up labelled magnetic force or F_M and arrow pointing down labelled electric force or F_E ✓

As location A is given in the question the base of the arrows do not need to sit exactly on A but arrows, if extended, should pass through A.

Care – in some cases A can look like an arrow head.

1

(b) Statement that electric and magnetic forces balance
OR
$qE = Bqv$
OR
$E = vB$
OR
$1.5 \times 10^5 \times 0.12$ ✓

electric field strength = $E = 1.8 \times 10^4$ (V m^{-1}) ✓

A correct final answer gains both marks

2

(c) (centripetal force or $F_c = \frac{mv^2}{r}$, equals force due to the magnetic field or $F_m = Bqv$)

$\frac{mv^2}{r}$ and hence $\frac{mv}{Bq}$ ✓

Condone use of F to represent both F_c and F_m

Allow an interchange between use of q and Q.

Note F = is required

1

(d) $r\left(=\frac{mv}{Bq}=\frac{1.0\times10^{-26}\times1.5\times10^{5}}{0.12\times1.6\times10^{-19}}\right) = 0.078(1)$ ✓

distance (= 2r) = 0.16 (m) ✓ (0.156 m)

ecf on second mark.

second mark given only if mv/Bq used in a calculation.

2

(e) (using an energy approach)

work done by field equals gain in KE $qV = \frac{1}{2} mv^2$ ✓1a

(so $v = \sqrt{\frac{2qV}{m}} = \left(\frac{2\times1.6\times10^{-19}\times\frac{6000}{2}}{1.2\times10^{-26}}\right)^{1/2}$)

mark for using the $V/2$ either in an equation or via a substitution ✓2a

$= 2.8(3) \times 10^5$ (m s^{-1}) ✓3a

OR

(using a force approach)

Force on ion $= ma = qE$ ✓1b

$$a = \frac{6000 \times 1.6 \times 10^{-19}}{1.2 \times 10^{-26} \times d} = 8.0 \times 10^{10}/d$$

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

Mark for using equation for E and equation of motion either in symbols or via a substitution ✓2b

$v = 2.8 \times 10^5$ (m s^{-1}) ✓3b

1a in words or equation which can be awarded even if the ion is not singly charged (candidates can wrongly think it has a charge of 3e)

2a for making use of half the pd ie 3000 V

3a Only allow ecf using 6000V giving

$v = 4.0 \times 10^5$ m s^{-1}

3

(f) A smaller mass gives a smaller time interval ✓1

(The explanation can come from a Force or a Work done approach)

The ions are given the same force ✓2a

(so) smaller mass has higher acceleration and smaller time interval ✓3a

OR

Work done on ions or kinetic energy gained is the same ✓2b

(so) smaller mass is given greater speed and smaller time interval ✓3b

Award any two of the three marks

condone use of 'lighter' for 'smaller mass'

3 max 2

[11]

9. A

[1]

10. D

[1]

11. C

[1]

12. C

[1]

13. (a) $N = \frac{\Phi}{AB}$ Or $N = \frac{1.5 \times 10^{-3}}{2.5 \times 10^{-2} \times 5.0 \times 10^{-4}}$

N = 120 (turns) ✓$_2$

✓$_1$ N must be the subject of the equation for the mark.

✓$_2$ A correct answer gains both marks.

If no mark is awarded a single mark can be given for Φ = BAN cos 30° being used to find

N = 139.

2

(b) Φ(= NAB cosθ = 1.5 × 10^{-3} cos 30°)

Flux linkage = 1.3 × 10^{-3} (Wb turns) ✓

1

(c) $f = \frac{1}{T} = \frac{1}{0.25}$ = 4.0 (Hz) or ω = 25.1 or 8π (rad s^{-1}) ✓$_1$

Peak emf (= $BAN\frac{2\pi}{T}$ = $1.5 \times 10^{-3} \times \frac{2\pi}{0.25}$)

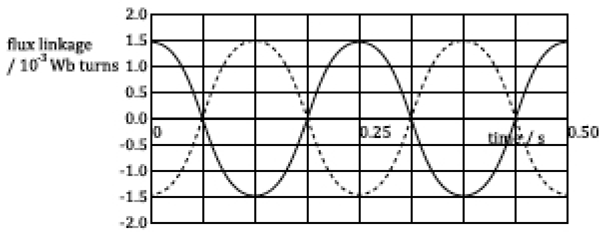
✓$_1$ Condone using 1 sig fig for f but not ω or T.

The mark can be gained from seeing f or ω or T given explicitly or from a substitution in the peak emf equation in the second mark.

✓$_2$ A correct answer gains both marks.

2

(d)



Either solid or dashed line gains mark ✓

The mark is dependent on the exact crossing of the time axis which has a tolerance of ± 1 small square.

The vertical axis figures is not expected.

Also ignore errors in height and the exact positions of the peaks.

Only a rough sinusoidal shape is expected. A triangular shape with very slightly rounded edges would be acceptable.

1

[6]

14. D

[1]

15. **A** **[1]**

16. **B** **[1]**

17. **C** **[1]**

18. (a) The direction of the induced emf (when there is a change of flux linkage) is such that it will (try) to oppose the change (of flux) that is producing it ✓ owtte

A reference to emf is needed rather than induced current as this is dependent on a circuit. Ignore reference to current if emf is given.

1

(b) (The reading shows a dc) current flow which then becomes zero (when the magnet stops moving) ✓

The reading does not have to be steady. So reading increasing or pulsing up before falling to zero is okay. There should be no hint that the reading changes direction.

1

(c) (The induced current produces) a north pole on the right hand side of the coil ✓

which opposes the motion of the bar magnet

OR

and the two north poles repel each other

OR

to try to maintain the (small) magnetic field as the magnet approaches the coil (without this the magnet would increase the magnetic field beside the coil) ✓

The polarity of the coil may be shown on the diagram.

The two marks are independent but the second mark does not stand completely alone as it has to be said in context. EG 'Two North poles repel' on its own will not gain a mark.

2

(d) (Use of $\varepsilon = Blv$ as the straight leading edge of the coil is the only conductor that cuts the magnetic flux lines. Also using $v = s / t$)

$t = Bls/\varepsilon$ ✓

(There must be some evidence of use for the mark but the mark can come from substituting numbers, eg $t = 0.38 \times 0.032 \times 0.032 / 2.9 \times 10^{-4}$)

$t = 1.3(4)$ (s)✓

OR

(Using $\varepsilon = (-)N\ \Delta\varphi/\Delta t$ then $\Delta t = \Delta(BA)/\varepsilon$)

$t = BA/\varepsilon$ ✓

(There must be some evidence of use for the mark but the mark can come from substituting numbers, eg. $t = 0.38 \times .032^2 / 2.9 \times 10^{-4}$)

t = 1.3(4) (s) ✓

Useful numbers $BA = 3.89 \times 10^{-4}$

Although the first mark can come from substituting numbers the equation mark may be lost if it is obvious that the equation is not understood by the way substitutions are made (this does not include a simple AE slip). This loss of a mark is directed at the candidate who quotes several equations and happens to hit on the correct equation but fails to use it properly.

Failure to square the side length is a PE.

Answer only gains 2 marks.

2

(e) (using $\varepsilon = BAN\omega \sin \omega t$ which give a maximum value of $\varepsilon_{max} = BAN\omega$)

ω (= ε_{max}/BAN) = $5.1 \times 10^{-3} /(0.38 \times (0.032)^2$. ✓

ω = 13(.1) (rad s^{-1}) ✓

Candidates who cannot maximise/remove sin ωt gain no marks.

{may see $\omega = 5.1 \times 10^{-3} / 3.9 \times 10^{-4}$}.

2

[8]

19. **D**

[1]

20. **B**

[1]

21. **A**

[1]

22. (a) attempt to apply principle of moments either about pivot or (LH) end of ruler $_1$✓

mass = 127(.04) (g) $_2$✓

assumption is that ruler is <u>uniform</u> / <u>mass</u> evenly distributed **OR**

<u>weight</u> acts at the centre/mid-point/middle **OR**

<u>centre of mass</u> / gravity is at the centre/mid-point/middle $_3$✓

for $_1$✓ for evidence of moments taken expect clockwise and anticlockwise moment;

for moment about pivot expect to see either 29 or 49; for use of LH end of ruler expect 30 or 50

don't insist on seeing masses in kg, distances in m or the inclusion of 9.81 or g in the working; condone g seen on one side only

rounding to 127 g earns $_1$✓ and $_2$✓

3

(b) <u>force</u> on wire is <u>upwards</u> **OR** ↑ $_1$✓

<u>current</u> is <u>from **P** to **Q**</u> **OR** <u>rightwards</u> **OR** (left) to (the) right **OR** → $_2$✓

states direction of force and direction of current (or $_3$✓= 0) and makes a suitably justified deduction, eg

using <u>left-hand rule</u> **OR** LH rule

AND

B is <u>into the page</u> **OR** into plane of **Figure 3 OR** ⊗ $_3$✓

for $_1$✓ condone 'motion is upwards'

for $_2$✓ 'towards Q' ***OR*** *'positive to negative' are not enough*

*allow logically correct (using LH rule) $_3$✓ for either <u>downwards</u> force with correct current **AND/OR** <u>upwards</u> force with wrong current*

increased flux density below wire is acceptable alternative to LH rule

3

(c) gradient calculated from ΔM divided by ΔI, condone read off errors of ± 1 division; minimum I step ≥ 2.0 A $_1$✓

evidence of g = 9.81 or 9.8 correctly used in working for σ or B $_2$✓

$|B|$ in range 1.76×10^{-2} to 1.87×10^{-2} or 1.8×10^{-2} (T) $_3$✓

for $_1$✓ expect (–)0.28 (g A^{-1}); do not penalise for missing – sign

for $_2$✓ look for σ = their gradient × 9.81 (× 10^{-3} N)

OR *$B = \dfrac{\text{their gradient} \times 9.81(\times 10^{-3})}{15(\times 10^{-2})}$; condone POT*

errors

for $_3$✓CAO by correct method only; ignore – sign if provided; no limit on maximum sf

3

(d)

	Reduced	**No effect**	**Increased**
Force acting on wire		$_1$✓	
Force acting on prism	$_2$✓		
Gradient of graph	$_3$✓		
Vertical intercept	$_4$✓		

$_1$✓ = 1 mark

$_2$✓ = 1 mark

$_3$✓ and $_4$✓= 1 mark

allow any distinguishing mark as long as only one per row

for ✓ and ✗ in same row ignore ✗

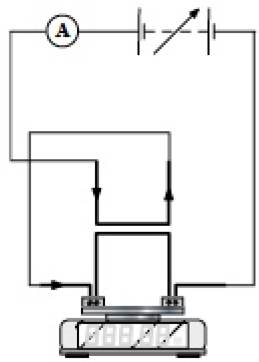
for ✓ and ✓ in same row give no mark

ignore any crossed-out response unless only distinguishing mark on row

3

(e) any complete circuit connecting the power supply in **Figure 6** to **X** and to **Y** that produces currents in **X** and in **Y** that travel left to right $_1$✓

wiring correct so that **X** and **Y** are in series (see below) $_2$✓



allow parallel circuit for $_1$✓ but reject use of additional power supply

*if **X** and/or **Y** is/are short-circuited award no marks;*

for impractical circuits eg voltmeter added in series, award no marks

ignore any current arrows added to diagram

2

(f) strategy:

states that readings of M (as the dependent variable) will be measured for different values of independent variable, I or d only $_1$✓

<u>clearly</u> identifies the correct control variable, d or I only;

condone $\frac{d}{L}$ = constant if I varied **OR** I^2L OR IL = constant if d varied;

it must be clear how the value of the control variable is known $_2$✓

states that L will be measured or gives value eg L = 5.0 cm $_3$✓

use of g to convert M reading to F; evidence may be found in expression for k $_4$✓

for $_1$✓ condone F identified as the dependent variable or as the balance reading;

reject 'measure change in mass / change in F'

failure to make M or F the dependent variable cannot score $_1$✓ or $_2$✓

for $_2$✓ if d is being varied and I = 5.0 A is stated, this can be taken to mean I is the control variable and the value is known

*for $_1$✓ and for $_3$✓ insist that M and L are being <u>read</u> **OR** <u>measured</u> **OR** <u>recorded</u>*

for $_4$✓ 'work out force' is not enough; reject 'acceleration' for g

MAX 3

analysis:

suggests a plot with M or F [by itself or combined with another factor] on the vertical axis and some valid manipulation of their independent variable on the horizontal axis $_5$✓

identifies correctly how k can be found using the gradient of their graph; k must be the subject of the expression given $_6$✓ **OR**

if suggesting a plot with log M or log F on the vertical axis etc identifying correctly how k can be found from the graph intercept $_6$✓

OR

suggesting a plot with M or F on the vertical axis etc and identifying correctly how k is found using the area under the line $_{56}$ ✓ = 1 MAX

the intention to plot M against I^2 is taken to mean that M is the dependent variable and is plotted on the vertical axis

examples: plot M against I^2 will earn $_5$✓

and then $k = \frac{g \times d \times \text{gradient}}{L}$ will earn $_6$✓

or plot F against $\frac{1}{d}$ will earn $_5$✓ and then

$k = \frac{\text{gradient}}{I^2 \times L}$ will earn $_6$✓ (note that when F is the dependent variable g will not appear in the expression for k)

2

[19]

23. **A**

[1]

24. **C**

[1]

25. **D**

[1]

26. (a) Filament / metal is heated due to the current through it ✓

OR

Temperature of the filament rises due to the current through it

(Free / conduction) electrons gain sufficient/enough (kinetic) energy to leave (the metal surface)

OR

Work function (defines work function) ≤ energy supplied to an electron/electron energy ✓

Thermionic emission ✓

Not

Electrons are heated

Not heated due to the pd across it

Allow

By electrical power or electrically heated

Not allowed

Reference to electrons leaving <u>*atoms*</u> *or ionisation*

Allow

Energy supplied sufficient to overcome the work function

3

(b) Use one of $\frac{1}{2}mv^2 = eV$ and $r = \frac{mv}{Be}$ or $\frac{mv^2}{r} = Bev$

To arrive at

$\frac{Ber}{m} = v$ or $v = \sqrt{\frac{2eV}{m}}$ or $v^2 = \frac{2eV}{m}$

or $\frac{e}{m} = \frac{v}{Br}$ or $\frac{e}{m} = \frac{v^2}{2V}$ ✓

Substitution in the other equation and manipulates <u>correctly</u> and clearly to give $\frac{e}{m} = \frac{2V}{B^2r^2}$ ✓

Condone q for e

Substitution in other equation and correct manipulation

NB this is a show that so mark is not simply for stating the equation given

I presented such that v (velocity) and V (voltage) are indistinguishable in manipulation then award only first mark

2

(c) Correct substitution $\frac{e}{m} = \frac{2 \times 320}{(1.5 \times 10^{-3})^2 \times 0.040^2}$

And answer 1.8×10^{11} ✓

Answer to 2 sig figs ✓

Allow for incorrect answer following incorrect substitution in equation

As answer is on the data sheet must see correct substitution with all correct powers of ten

2

(d) The specific charge of the cathode rays/the particles was(much) larger/greater than the hydrogen ion/proton ✓

This provided evidence that cathode rays were composed of electrons/particles which have a (very) small mass / have a high (negative) charge

OR

Mass (much) smaller than the mass of a hydrogen (ion)/proton ✓

Not higher

If mark 1 not given then 0 for the question

Not lightest as substitute for mass

2

[9]

27. **C**

[1]

28. **C**

[1]

29. **B**

[1]

30. (a) It is not possible as the force (due to the magnetic field) is perpendicular to the motion / direction of travel / velocity ✓ (it can only change the charged particle's direction or alternatively no work is done on the proton)
Or
No component of force in the direction of motion.

The main part being examined is the reference to the force being perpendicular to the motion.

1

(b) $B\,Q\,v = m\,v^2 / r$ ✓

$t_{\text{semi-circle}}$ (= distance / speed) = $\pi\,r / v$
Or use of t_{circle} (= distance / speed) = $2\,\pi\,r / v$ ✓(this mark can only be awarded if it follows an attempt to answer the first mark)
combining gives

($t_{\text{circle}} = 2\pi\,m / B\,Q$ so)

$t_{\text{semi-circle}} = \pi\,m / B\,Q$

(which does not contain r / is independent of r) ✓

Accept 'e' if used instead of 'Q'

Alternatives can be given for the first two marks.

1st needs a centripetal force term.

2nd is a circular motion expression to enable r to be removed.

3

(c) (rearranging first equation in (b) or from data booklet $v = B Q r / m$)
$v = 0.44 \times 1.6 \times 10^{-19} \times 0.55 / 1.67 \times 10^{-27}$ ✓
$v = 2.3 \times 10^{7}$ (m s^{-1}) ✓

Correct answer scores both marks.

2

[6]

31. **B**

[1]

32. **C**

[1]

33. (a) Vertically up (third row of table) ✓

1

(b) (Using Flemings LHR) the configuration of the letters is S N ✓

Answer must be near / on the dashed lines.

1

(c) The tesla is the (strength) of the magnetic field / flux density that produces a force of 1 newton in a wire of length 1m with 1 ampere (flowing perpendicular to the field). ✓
(owtte but must contain 1N, 1A and 1m)

For mark a reference to 1N, 1A and 1m must be seen. However the word 'unit' is equivalent to '1'.

E.g. unit force = 1N.

Do not allow definitions based on $F = Bqv$.

1

(d) Use of ($B = F / I\,l$) $= m\,g / I\,l$ ✓ (mark may come from substitution as in next line)

Treat power of 10 error as an AE so lose one mark only.

$B = 0.620 \times 10^{-3} \times 9.81 / (3.43 \times 0.0500) = 0.035$ or 0.036 (T) ✓

Lack of use of 'g' is a PE and scores zero.

2

[5]