

## Mark schemes

## Q1.

- (a) (C because the ohm-meter) reading is 2 dp

OR

explains where the decimal point is ✓

*must refer to the decimal places displayed or the position of the decimal point:*

*allow 'displays 2 figures before decimal point' / 'displays 2 figures after decimal point' / decimal point between 2<sup>nd</sup> and 3<sup>rd</sup> digit / 'in format XX.XX' or WTTE;*

*condone 'resolution (shown) is 0.01' / 'decimal point is after the second digit' / 'decimal point is in the middle' /*

*reject 'because of where the decimal point is' / 'decimal point is in the same place' / 'decimal places are the same' / 'reading is between maximum and minimum for the range on C setting' / 'readings have same resolution' / 'reading is 3 sf'*

1

- (b) valid attempt to determine  $E_v$  using  $R = 2840$  1✓

$$E_v = 132 \text{ (lx)} \quad 2✓$$

*> 3 sf that rounds to 132 get both marks*

*for 1✓ expect 3.45(3) in a calculation;*

*allow 12✓ = 1 MAX for use of 2.84 leading to  $1.01 \times 10^6$  (lx) OR*

*allow use of  $\ln(2840)$  leading to  $2.46 \times 10^{-2}$  (lx)*

2

- (c) reads off from at least **three** different points on the line / graph 1✓

*for 1✓ allow 'get' / 'obtain';*

*must specify 3 or more; condone 'several' / 'many' / 'numerous' / 'quite a lot' / 'quite a few';*

*'multiple' is neutral*

suggests a valid test of **Figure 2** that confirms the inverse square law 2✓

*for 2✓ eg calculates  $E_v \times x^2$  for each point;*

*shows that '(percentage) differences (between results) are 'small' / 'insignificant'*

OR

*shows that values are 'close' / 'same' / 'similar' / 'consistent'*

*condone values should be 'close' / 'see if values are*

*/ should be constant' / 'agree' etc  
allow a reverse-working approach*

OR

proposes a valid graph (using data from **Figure 2**)  $1\checkmark$

a valid test to confirm the inverse square law based on their graph  $2\checkmark$

OR

**plot** of  $\log E_V$  against  $\log x$   $1\checkmark$

*gradient is  $\approx -2$*   $2\checkmark$  OR

**plot** of  $E_V$  against  $\frac{1}{x^2}$   $1\checkmark$

*linear graph through (0, 0)*  $2\checkmark$

2

(d) result in range 627(.0) to 646(.0) mm  $1\checkmark$

*use result on answer line*

*for  $1\checkmark$  accept 630 and 640 but not  $6.3 \times 10^2$  OR  $6.4 \times 10^2$*

result in range 634(.0) to 639(.0) mm  $2\checkmark$

2

(e) 1645 AND 1.73 correctly added to **Table 2**  $1\checkmark$

*for  $1\checkmark$  do not insist on units;*

*condone extra sf that round to these values*

Setting	Min $R$	Max $R$
range B	1645 ( $\Omega$ )	1717 $\Omega$
range C	1.63 k $\Omega$	1.73 (k $\Omega$ )

valid reasoned judgement to support use of range;

allow ECF for incorrect values in **Table 2**  $2\checkmark$

*for  $2\checkmark$  states that **B** should be used because*

*(half) range is smaller / (percentage) difference between max and min  $R$  is smaller*

OR

***any** valid and correct quantitative comparison between **both** settings, eg*

	Range ( $\Omega$ )	Uncert. ( $\Omega$ )	% Diff.	% Uncert.
<b>B</b>	72	( $\pm$ )36	$\approx 4\%$	$\approx 2\%$
<b>C</b>	100	( $\pm$ )50	$\approx 6\%$	$\approx 3\%$

allow 'resolution is smaller' not 'better';  
'more precise' / 'more accurate' / '(percentage)  
uncertainty is smaller' are neutral

2

(f) ANY 2 OF  $_1\checkmark$  to  $_3\checkmark$  below:

light level / brightness / intensity in the room OR WTTE  $_1\checkmark$

for  $_1\checkmark$  allow 'background lighting' / 'external light sources' / 'maintain blackout';  
'temperature' is neutral

voltage (across) / current in / power of / brightness of the lamp  $_2\checkmark$

for  $_2\checkmark$  allow 'intensity of (light from) the lamp' / 'luminosity of lamp' / 'pd of power supply';  
allow  $_{12}\checkmark$  for light incident on slides = 400 (lx)  
do not allow unqualified 'light intensity'

thickness of the **glass** / slides  $_3\checkmark$

for  $_3\checkmark$  allow 'transparency / opacity / colour of the glass / slides';

condone 'surface of slides must be clean'

the following are neutral:

$\mu$  / refractive index / density / 'type' of glass 'type' / 'size' / 'width' / 'area' / 'shape of slide'

(vertical) distance between the lamp and the LDR' / 'ohm-meter setting'

type of power supply / lamp / LDR / ohmmeter / connecting wires / shape of bulb

positions of equipment

2

(g) **plot**  $\ln E_V$  against  $N$

OR

plot **implied** by comparison between **correct algebra**  $\ln E_V = -\mu N + \ln 400$   
and  $y = mx + c$   $_1\checkmark$

for  $_1\checkmark$  allow plot  $\ln\left(\frac{E_V}{400}\right)$  against  $N$ ;

must clearly imply that  $N$  is the abscissa;

allow aligned expressions eg

$$\ln E_V = \ln 400 \text{ OR } 5.99 - \mu N$$

$$y \quad (=) \quad c \quad (+) \quad mx$$

$\mu$  is -gradient  $2\checkmark$

allow  $2\checkmark$  for '-  $\mu$  is gradient' / ' $\mu$  is absolute value of gradient' / ' $\mu$  is modulus of gradient value' where  $\ln E_V = -\mu N + \ln 400$  without comparison with  $y = mx + c$  seen;

**plot**  $\ln E_V$  against  $N$  with incorrect algebra is talk out for  $1\checkmark$

allow ECF if linking  $\mu$  to **gradient** based on their incorrect algebra for  $2\checkmark$

use of 'log-linear graph paper' is only acceptable with further explanation

use of 'logarithmic graph paper' is neutral

OR

allow **plot**  $\log E_V$  against  $N$  OR plot **implied** by  $\log E_V = -\mu \log(e) N + \log 400$  compared with  $y = mx + c$   $1\checkmark$

$$\mu \text{ is } \frac{-\text{gradient}}{\log(e)} \quad 2\checkmark$$

2

(h) evidence for any workable method that would lead to EITHER  $N_{1/2} \approx 7.7$

OR

a final integer answer that is appropriate to their calculated value  $1\checkmark$

$N_{1/2} = 8$  slides CAO  $2\checkmark$

for  $1\checkmark$  expect use of  $\ln 0.5 = -9.0 \times 10^{-2} N_{1/2}$  or similar (including trial and improvement)

2

[15]

**Q2.**

- (a) (use of a ruler to) **measure** height **from bench to rod** at (minimum of two) different points  $_{1}\checkmark$

*for  $_{1}\checkmark$  points may be **anywhere** along rod;*

*allow 'measure height of rod at each end' / 'at both clamps' / 'measure height from ground'*

*do not allow 'find height' / 'measure on both sides of the rod / wire'*

explains how the **ruler** is made vertical  $_{2}\checkmark$

*for  $_{2}\checkmark$  expect to see a set-square in **contact with the bench AND in contact with the upright ruler**;*

checks heights are the same  $_{3}\checkmark$  (contingent on  $_{1}\checkmark$ )

*allow use of a spirit level / T-square / plumb line / **large** protractor to make ruler vertical;*

*use of set-square between the ruler and the rod OR between stand and rod is neutral;*

*for  $_{1}\checkmark$  and  $_{2}\checkmark$  allow annotation to **Figure 1***

OR

use of a metre ruler placed on the rod with a spirit level placed on the ruler; check no gap between ruler and rod  $_{12}\checkmark$

check bubble is at centre  $_{3}\checkmark$  (contingent on  $_{12}\checkmark$ )

*allow  $_{12}\checkmark$  for use of a set-square in contact with the bench that reaches the rod (ie no ruler mentioned) as long as **measuring** is being done with it*

OR

use of metre ruler placed with no gap on top of nested set-squares so the metre ruler can be compared with rod  $_{12}\checkmark$

lower set-square in contact with the bench (no gaps)  $_{3}\checkmark$  (contingent on  $_{12}\checkmark$ )

*for  $_{3}\checkmark$  allow 'compare heights to check rod is parallel to bench / level'*

*allow 'measurements match' / 'contingent' etc*

*'straight' for horizontal or for vertical / 'heights are constant' is neutral*

3

- (b) force on **rod** is down(wards)  $_{1}\checkmark$

*'force down' & 'current to right' & 'field out of page by left-hand rule' earns  $\checkmark\checkmark\checkmark = 3/3$ ;*

*for  $_{1}\checkmark$  allow use of  $F \downarrow$  for force on rod down; may be indicated on **Figure 2***

allow unqualified 'force';  
 condone force = 'motion' / rod = 'wire'  
 'force **on balance** / **yoke is up**' is neutral

the current (in rod) is from left / to right / rightwards  $_{2}\checkmark$   
 for  $_{2}\checkmark$  allow  $I \rightarrow$  for current from left / to right;  
 may be indicated on **Figure 2**  
 condone 'current clockwise';  
 'from positive to negative' is neutral

predicts direction of field based on their force and their current using valid (left-hand) rule or WTTE  $_{3}\checkmark$

$_{3}\checkmark$  is contingent on seeing  $_{1}\checkmark$  force up or down and on seeing  $_{2}\checkmark$  current left or right etc;  
 for  $_{3}\checkmark$  allow use of B for field and LHR for left-hand rule;  
 allow B  $\odot$  by LHR;  
 for reversed F OR for reversed I allow  $\otimes$  by LHR,  
 eg 'force upwards' / 'current to right' / 'field into page' etc earns  $\times\checkmark\checkmark = 2/3$

3

(c) MAX 2 from:

- **any** valid expression to demonstrate homogeneity of terms  $_{A}\checkmark$   
 $B = \frac{F}{IL}$  OR  $BI = \frac{F}{L}$   $_{B}\checkmark$
- identifies the base units of F as  $\text{kg m s}^{-2}$   $_{C}\checkmark$   
 correct units for k earns 3 marks unless evidence of incorrect working seen  
 for  $_{A}\checkmark$  and  $_{B}\checkmark$  allow any valid expression or statement that contains both units AND quantities  
 for  $_{A}\checkmark$  idea that  $k B I$  has units of **mass**  
 any subject eg  $k \equiv \text{kg T}^{-1} \text{A}^{-1}$   
 allow 'M OR mass OR  $g = k B I$ '  
 condone words for **units**, eg 'amps' / 'tesla';

the units for k are  $\text{s}^2$   $_{3}\checkmark$

accept use of dimensional analysis, M (mass), L (length) and T (time)

$$\text{for }_{B}\checkmark \text{ allow } T \text{ (OR } B) \equiv \frac{N}{A m} \equiv \frac{N s}{C m}$$

$$\text{for }_{B}\checkmark \text{ allow } TA \text{ (OR } B I) \equiv \frac{N}{m}$$

$$\text{for }_{AB}\checkmark\checkmark \text{ allow } k \equiv \text{kg} \frac{(A)m}{N} (\text{A}^{-1})$$

$$\text{for }^{BC}\checkmark\checkmark \quad \text{allow T (OR B)} \equiv \frac{\text{kg (m) s}^{-2}}{\text{A (m)}} \equiv \frac{\text{kg}}{\text{C s}}$$

$$\text{for }^{BC}\checkmark\checkmark \quad \text{allow TA (OR B I)} \equiv \frac{\text{kg (m) s}^{-2}}{\text{(m)}}$$

3

- (d) records **two** vertical intercepts to 2 dp with at least one intercept correct to  $\pm 0.05$  (g)

OR

M1 and M2 read off to 2 dp for the same value of  $l$  with at least one read off correct to  $\pm 0.05$  (g)<sub>1</sub>✓

$$M1 \text{ intercept} = 134.85 \pm 0.05 \text{ (g)}$$

$$M2 \text{ intercept} = 181.85 \pm 0.05 \text{ (g)}$$

*allow either value seen in working*

derives **two** valid equations using their M1 and M2 that can be solved to determine Y

OR

their Y min 1 dp, consistent with their intercepts to  $\pm 0.1(0)$  (g) <sub>2</sub>✓

*for <sub>2</sub>✓ mark is for method OR for their Y*

*equations [A] and [B] seen:*

$$134.85 = (0 +) 2Z + Y \dots\dots\dots [A]$$

$$181.85 = (0 +) 4Z + Y \dots\dots\dots [B]$$

OR

$$Y = 2 \times M1 \text{ intercept} - M2 \text{ intercept};$$

*<sub>2</sub>✓ not contingent on <sub>1</sub>✓ so allow their Y correctly deduced using two incorrect intercepts including intercepts rounded to 1 dp*

$$Y = 87.85 \pm 0.1(0) \text{ (g) CAO } \textsubscript{3}\checkmark$$

*<sub>3</sub>✓ is contingent on <sub>1</sub>✓*

*for <sub>3</sub>✓ min 1 dp;*

*only allow 1 dp 87.8 OR 87.9*

3

- (e) identifies that B is less <sub>1</sub>✓

*for <sub>1</sub>✓ allow 'field' / '(magnetic) flux density' for B;*

*allow 'B weaker' / 'less field lines through the rod' / '(rod) not affected by field as much';*

*'B is not uniform' / '(rod) cuts less flux' / 'cutting less field lines' are neutral <sub>1</sub>✓*

**states and explains** why the intercept is the same <sub>2</sub>✓

for  $2\checkmark$  allow intercept is the same **because**  
 'intercept is the mass of yoke **and** magnets' /  
 'intercept = 2Z AND Y' / 'Z AND Y don't change' /  
 'there is the same initial mass'

**states and explains** why the line is less steep  $3\checkmark$

for  $3\checkmark$  allow 'gradient is smaller' / 'gradient is **less**  
 negative' / 'line is flatter' **because**

**allow**  $23\checkmark$  for **stating** that the line is less steep **AND** that the intercept is  
 the same without a valid explanation for either statement

'**change in** M1 / balance reading / force is less for  
 each (**change in**) I ' OR 'force won't **change as**  
**much** with current' OR 'less force per unit current'  
 OR gradient is  $kB$  / gradient  $\propto B$

allow  $13\checkmark$  for  $B = 0$  or WTTE (reject 'rod not in field');

'less force for same current' is neutral

intercept same as in **Figure 4** AND gradient = 0 or WTTE;

then mark  $2\checkmark$  as above

take account any sketch graph that correctly  
 compares the new graph of M1 against I with  
**Figure 4**

3

[15]

**Q3.**

- (a)  $4.5 \times 10^{-2}$  ✓  
 CAO

1

- (b) (short  $T_1$ )

so images are not blurred (or wtte)

*must refer to quality / property of images, eg  
 'images are sharp' / 'focused' / 'clear' / 'defined';  
 allow '(images of) ball are circular' / 'spherical' / 'not  
 elongated' or wtte: accept sketch  
 'increasing distance between images' / 'image is  
 accurate' are neutral*

OR

to determine position of the ball (in each image or wtte) ✓

*allow 'to see (point) where ball is' / idea that (centre  
 of) ball needs to be a 'single point' / 'ball does not  
 move during each flash ( $T_1$ )'  
 comments about the motion / trajectory of ball eg  
 'see a clear pattern' are neutral  
 comments about the duty cycle / flash rate are  
 neutral*

1

- (c) correct rearrangement to a three-term equation;

1

$\frac{H-h}{n}$  as the subject eg  $\frac{H-h}{n} = \frac{u_0}{f} + \frac{gn}{2f^2}$  ✓

valid suggestion for quantity plotted on x-axis;

allow use of  $y = mx + c$  aligned with  $\frac{H-h}{n} = \frac{u_0}{f} + \frac{gn}{2f^2}$

suitably annotated to identify  $x$  ✓

explains how  $g$  found using the gradient for **their** x-axis;

insist on  $g$  as subject whether explanation is in words or expressed as an equation ✓

for ✓ condone  $\frac{H-h}{n} = \frac{u_0}{f} + \frac{g}{2n} \left(\frac{n}{f}\right)^2$

✓ is contingent on ✓;

for a correct equation or if no equation is seen mark

${}_2\checkmark$  and  ${}_3\checkmark$  as below:

for ${}_2\checkmark$	for ${}_3\checkmark$
$n$	$g = \text{gradient} \times 2f^2$
$\frac{n}{2}$	$g = \text{gradient} \times f^2$
$\frac{n}{f}$	$g = \text{gradient} \times 2f$
$\frac{n}{2f}$	$g = \text{gradient} \times f$
$\frac{n}{f^2}$	$g = \text{gradient} \times 2$
$\frac{n}{2f^2}$	$g = \text{gradient}$

for an incorrect equation with  $n$  in the 'mx' term  
allow ECF for  ${}_2\checkmark$  and  ${}_3\checkmark$

2

(d)  $n = 17 \pm 1 \quad {}_1\checkmark$

${}_1\checkmark$  expect integer  $n = 17 \pm 1$  but see valid unusual approach below

1

use of  $H = \frac{u_0 n}{f} + \frac{g}{2} \left(\frac{n}{f}\right)^2$

OR

use of  $H = u_0 t + \frac{1}{2} g t^2$  (eg with  $t$  from  $\frac{n}{31}$ )  ${}_2\checkmark$

$u_0$  correctly evaluated to (minimum) 2 sf  ${}_3\checkmark$

for  ${}_2\checkmark$  either approach 'use of' means full substitution without error (with  $h = 0$  shown or implied by omission) so that  $u_0$  is the only unknown;

condone  $g = \pm 9.79$  OR  $\pm 9.8(1)$ ;

condone POT error / mixed units for  $H$  and  $g$

1

valid alternative method:

use of **Figure 1** to determine non-zero  $h$  for integer  $n > 0$

for  ${}_1\checkmark$  a valid  $h$  for their integer  $n (\leq 16)$

eg when  $n = 5$ ,  $h = \frac{89 \text{ (mm)}}{99 \text{ (mm)}} \times 1550 \text{ (mm)} = 1393 \text{ (mm)}$

for  ${}_2\checkmark$  full sub including a valid  $h$  for their  $n$

for  $\sqrt[3]{u_0}$  correct for their  $n$  and  $h$

eg for  $n = 5$  and  $h = 1393$ ,  $u_0 = 0.18(4)$  ( $\text{m s}^{-1}$ )  $\sqrt[3]{}$

for  $\sqrt[3]{}$  see table for  $u_0$  with  $n = 16$  OR  $18$  AND/OR for the (intermediate) rounding of  $t$ ;  
accept  $> 3$  sf that rounds to values in table:

	subs $n, f$	truncates $t$	
expected	$t = 17/31$	3 sf	2 sf
$t / \text{s}$	(0.548387)	0.548	0.55
$u_0 / \text{m s}^{-1}$	0.14	0.15	0.13

ECF	$t = 16/31$	3 sf	2 sf
$t / \text{s}$	(0.516129)	0.516	0.52
$u_0 / \text{m s}^{-1}$	0.48	0.48	0.44

ECF	$t = 18/31$	3 sf	2 sf
$t / \text{s}$	(0.580645)	0.581	0.58
$u_0 / \text{m s}^{-1}$	-0.17	-0.18	-0.17

1

(e) calculates the horizontal velocity;

divides a valid horizontal displacement  $s_2 - s_1$  by a time  $\sqrt[1]{}$

for  $\sqrt[1]{s_2 - s_1}$  in range 490 to 1000 (mm);

expect time to be found from counting intervals between flashes but allow use of **their (f)** result;

condone use of distance between contacts with

time of  $\frac{19}{31}$  and  $\frac{20}{31}$ ;

horizontal velocity in range 1550 and 1650 ( $\text{mm s}^{-1}$ )  $\sqrt[2]{}$

$\sqrt[2]{}$  is not contingent on  $\sqrt[1]{}$

allow 2 sf  $1.6 \times 10^3$  ( $\text{mm s}^{-1}$ )

2

(f) determines  $h_{\text{max}}$  (at top of bounce) using an annotation to **Figure 3**  $\sqrt[1]{}$

eg



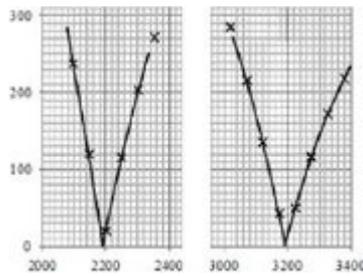
valid attempt to find time  $t$  between contacts by using *suvat* with  $u = 0$ , eg

$$\text{time} = (2 \times) \sqrt{\frac{2 \times \text{their } h_{\text{max}}}{9.81 \text{ OR } 9.79}} \sqrt[2]{}$$

OR

determines  $s$  for both contacts OR determines  $s_2 - s_1$  using annotations to **Figure 3**  $\sqrt[1]{}$

eg



valid attempt to find  $t$  by =  $\frac{\text{their } s_2 - s_1}{\text{their horizontal velocity in 01.5}}$   $_{2\checkmark}$

time in range 0.61(0) to 0.65(0) (s)  $_{3\checkmark}$

for  $_{1\checkmark}$  annotation should be a smooth curve through (at least) top 4 points,  $n = 51$  to  $54$ ; don't insist on seeing a horizontal line to the  $h$  axis

for  $_{2\checkmark}$  accept mixed units / POT in substitution / time to maximum height calculated / valid working in (e)

OR

for  $_{1\checkmark}$  annotation should be at least one smooth (allow straight) line to define each contact; eg (at least) through  $n = 41/42$  OR  $43/44$  to  $h = 0$  AND through  $n = 61/62$  OR  $63/64$  to  $h = 0$

for  $_{1\checkmark}$  or  $_{2\checkmark}$  accept valid working in (e); accept use of horizontal distance = 1000 (mm)

for  $_{2\checkmark}$  do not condone use of integer number

of intervals, eg  $t = \frac{19}{31} = 0.61(3)$  OT

$t = \frac{20}{31} = 0.645$

$_{3\checkmark}$  is contingent on  $_{2\checkmark}$ ;

exception: award  $_{3\checkmark}$  for  $t$  in range if obtained by estimating a **non-integer** number of intervals, eg  $t =$

$\frac{19.5}{31}$

**Q4.**

(a) rate = 1.40 to 1.75 ( $V s^{-1}$ ) <sub>1✓</sub>

*for <sub>1✓</sub> accept 2 sf 1.5, 1.6 and 1.7 ( $V s^{-1}$ )*

rate = 1.50 to 1.65 ( $V s^{-1}$ ) <sub>2✓</sub>

*for <sub>2✓</sub> accept >3 sf rounding to value in range;*

*accept 2 sf 1.6;*

*expected answer is 1.57(2) ( $V s^{-1}$ )*

2

(b) maximum 1 mark per marking point (see <sub>1✓</sub> to <sub>4✓</sub> below)

reduces impact of statistical error (involved in reading and recording data manually) <sub>1✓</sub>

data can be collected at a high(er) rate or wtte <sub>2✓</sub>

idea that data (in digital form) may be easily processed <sub>3✓</sub>

two (or more) sets of data ( $I$  and  $V$ ) can be made simultaneously or wtte <sub>4✓</sub>

treat suggestions that data logging improves 'precision' / 'resolution' / reduces 'uncertainty' / eliminates 'systematic' / 'parallax errors' / 'anomalous readings' as neutral

*for > 2 ideas mark as a list*

*for <sub>1✓</sub> allow reducing 'human error' / 'random error' / 'improving accuracy' as same idea;*

*idea that random error / uncertainty can be eliminated is talk out;*

*condone 'no human error / reaction';*

*for <sub>2✓</sub> condone 'quickly' / 'works faster'*

*'collect data at a steady rate' / 'saves time' / comments about 'reaction time' are neutral*

*for <sub>3✓</sub> eg can be transferred to / graphed with / analysed using a digital device or application eg computer / spreadsheet*

*allow 'can be processed automatically'*

*treat the following as neutral since they are not specifically applicable to this experiment:*

*can carry out experiment 'remotely' / 'in inaccessible or dangerous environments' / 'automatically' / 'without any human (being present)' or wtte;*

*can 'start / stop data collection at some suitable (future) time' / 'collect large amount of data' or wtte;*

*'a wide variety of sensors are available' / 'data logging is (increasingly) cheap'*

Max 2

- (c) identifies that **circuit 2** can produce the data because the pd can be varied between 0 V and 12 V <sub>1</sub>✓

*for <sub>1</sub>✓ allow 'can achieve 12 V range' or wtte; reject 'can produce 0 V and 12 V'*

identifies that **circuit 1** cannot produce (all of) the data shown on **Figure 2**

<sub>2</sub>✓

*for <sub>2</sub>✓ allow 'circuit 1 is not suitable' / 'not circuit 1';*

*award <sub>1</sub>~~<sub>2</sub>~~✓ for 'neither can produce the data'*

2

for **circuit 1** with **X** set to maximum resistance

calculates (minimum) *I*

OR

calculates (minimum) *V* <sub>3</sub>✓

*for <sub>3</sub>✓ (at least one) result should be evaluated to min 2 sf but condone '≈ 0.7' if decimal intermediate result is ok;*

*do not accept rounding to 0.69;*

*allow use of 17.2 without justification;*

$$\text{minimum } I \left( = \frac{12}{17.2} \right) = 0.70 \text{ A OR}$$

$$\text{minimum } V \left( = 12 \times \frac{2.3}{17.2} \right) = 1.6 \text{ V}$$

their minimum *I* or minimum *V* for **circuit 1** compared with value of first (or second) point in **Figure 2** <sub>4</sub>✓

*for <sub>4</sub>✓ could say their minimum *I* > 0.36 / *I* for first data point < 0.7(0) / 0.70 > 0.36 etc*

*allow 'cannot produce *I* < 0.7(0) in Fig 2';*

*'cannot produce all the values' is not enough*

2

- (d)  $P = 6.82$  in row 2 <sub>1</sub>✓

$I = 1.77$  in row 4 <sub>2</sub>✓

$P = 17.0$  in row 4 <sub>3</sub>✓

	$V/V$	$I/A$	$P/W$
	3.30	1.07	3.53
$1\checkmark$	5.17	1.32	<b>6.82</b>
	7.69	1.59	12.2
$2\checkmark$ $3\checkmark$	9.58	1.77	17.0
	11.47	1.94	22.3

for  $1\checkmark$  CAO

for  $2\checkmark$  allow  $1.77 \pm 0.01$

for  $3\checkmark$  ECF for their (incorrect)  $I \times 9.58$ ;

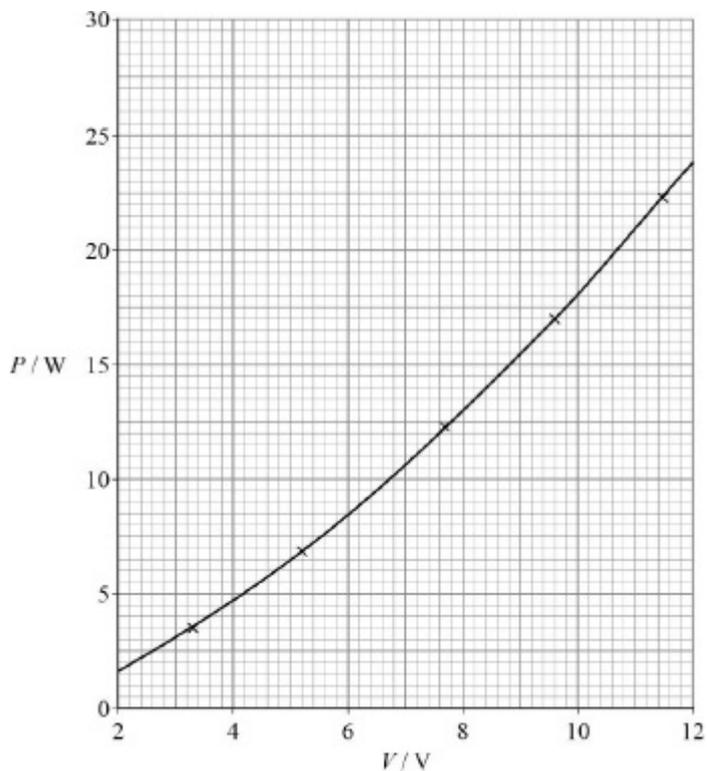
deduct MAX 1 mark if any are **not** to 3 sf

3

(e) vertical axis labelled  $P/W$   $1\checkmark$

suitable vertical scale for their data  $2\checkmark$

5 points plotted AND smooth curve of increasing gradient  $3\checkmark$



for  $1\checkmark$  allow  $P (W)$ ,  $P$  in  $W$ ;

reject comma separator, eg  $P, W$ ;

allow words, eg power for  $P / \text{watt(s)}$  for  $W$

for  $2\checkmark$  expect 1 cm interval = 2 W OR 2 cm intervals

= 5 W

vertical scale must

- be linear
  - be marked in integer values
  - be marked with a frequency of not less than 4 cm intervals
  - cover the range of plotted points
- assume  $P = 0$  at unmarked origin

2

for  $\checkmark$  check the plotting of any obviously suspect point;

points must **not** be thick / faint / dots / blobs;

line must

- be a continuous **curve**
- be neither thick or faint
- (at least) extend from the first to the fifth point
- be a reasonable best-fit for their data; withhold mark if line deviates by  $\geq 2$  minor squares from examiner's best line (by eye)

if  $I / A$  is plotted award  $\checkmark$  if the effective range of vertical scale is  $\geq$  half height of grid

1

- (f) evidence that  $P_r$  read-off to  $\pm 1$  minor grid square  $\checkmark$   
 for  $\checkmark$  best-fit line must be extrapolated to  $V = 12$  V (at the right-hand margin of the grid);  
 $P_r$  correct to  $\pm$  half a minor grid square;  
 expect  $P_r = 23.8$  W for a curve but accept a read-off obtained from a straight best-fit line

reads off  $P_2$  corresponding to 6 V;

evaluates  $\frac{2 \times \text{their } P_2}{\text{their } P_r} \times \checkmark$

$\checkmark$  is not contingent on  $\checkmark$

for  $\checkmark$  expect  $P_2 = 8.5$  W for a curve;

expected % in range 70% to 73%

if no read-off evidence is seen on **Figure 3** check for the possibility that **Figure 1** was used to obtain  $P_r$  and  $P_2$  eg by drawing a curve through points to intersect at  $V = 12$  V, then

using  $V (= 12) \times I (= 1.98) P_r = 23.7$

using  $V (= 6) \times I (= 1.42) P_2 = 8.5(2)$

would lead to 72%

2

[16]

**Q5.**

- (a) search coil is not suitable or wtte:

no emf (would be induced in a search coil)  $1\checkmark$

$1\checkmark$  and  $2\checkmark$  can be earned independently but are contingent on a statement that the search coil is not suitable;

insist on suitable use of the appropriate underlined term

for  $1\checkmark$  condone 'potential difference' OR 'voltage' for emf

1

a search coil needs (to be cut by) changing flux

OR

search coil is not cut by changing flux

OR

flux (cutting coil) is constant or wtte  $2\checkmark$

for  $2\checkmark$  accept  $\phi$  for flux;

do not insist on 'flux linkage';

do not allow 'field' for 'flux';

'current (in the coil on frame) must be ac' is neutral;

the suggestion that a search coil cannot be connected to a data logger is neutral

1

alternative approach:

search coil **is** suitable or wtte:

suggests a valid method that changes the flux cutting the search coil eg rotate either coil / turn (dc) current off / move either coil relative to other coil  $1\checkmark$

states their method changes flux through search coil

OR if search coil is cut by changing flux or wtte  $2\checkmark$

alternative approach:

$1\checkmark$  and  $2\checkmark$  can be earned independently but are contingent on a statement that the search coil is suitable

- (b) use of
- $1 - \cos 25^\circ$
- or
- $1 - \sin 65^\circ$
- in a calculation of percentage change
- $1\checkmark$

for  $1\checkmark$  expect either  $\geq 3$  sf rounding to  $1 - 0.906$  OR  $1 - 0.91$  seen in working

OR  $100 - 90.6$  or  $100 - 91$  seen in working;

(-) 9.4 (%) CAO <sub>2</sub>✓

for <sub>2</sub>✓ expect min 2 sf rounding to (-) 9.4;  
allow (-) 9.0 if 1 - 0.91 seen in working;  
do not insist on minus sign or 'decrease' on answer line

allow <sub>2</sub>✓ for unsupported answer of (-) 9.4;  
if no other mark is awarded allow 12✓ use of 1 - sin 25° or 1 - cos 65° in a % difference calculation leading to 58%

2

(c) uncertainty (in a single reading / judgement) is ½° <sub>1</sub>✓

for <sub>1</sub> ✓ accept 0.5 seen in numerator of % calculation OR absolute uncertainty is 2×0.5;  
allow a larger uncertainty up to 3° if justified with a comment about difficulty in judging the reading due to parallax, thickness of frame etc

1

(measurement of)  $\theta$  is based on (difference between) two readings / judgements

OR

absolute uncertainty in  $\theta$  (or  $\Delta\theta$ ) = 2 × uncertainty in each reading / judgement <sub>2</sub>✓

for <sub>2</sub> ✓ accept 2×0.5 OR 2 × their uncertainty in (a single) reading seen in numerator OR evidence for use of 2 × their uncertainty in result of % calculation;  
'measured twice' is ambiguous

correct percentage uncertainty calculation based on 100 × their absolute uncertainty divided by 25 <sub>3</sub>✓

for <sub>3</sub> ✓ allow 1 sf result;

$$\frac{2 \times 0.5}{25} \times 100 = 4\% \text{ (use of } 0.5^\circ \text{ ) earns } 1\sqrt{2}\sqrt{3}\checkmark$$

$$\frac{0.5}{25} \times 100 = 2\% \text{ (missing } 2\times \text{ ) earns } 1\sqrt{2}\times 3\checkmark$$

$$\frac{2 \times 1}{25} \times 100 = 8\% \text{ (} 1^\circ \text{ unexplained) earns } 1\times 2\sqrt{3}\checkmark$$

$$\frac{1}{25} \times 100 = 4\% \text{ (} 1^\circ \text{ unexplained) earns } 1\times 2\times 3\checkmark$$

<sub>123</sub>✓✓✓ for two-judgement explanation leading to 1° used in a correct % uncertainty calculation

2

- (d)  $r$  in range 67 to 69 mm

OR

$x_{0.5}$  in range 50 to 55 mm  $_1 \checkmark$

$\frac{x_{0.5}}{r}$  in *in range gets both marks*

*for  $_1 \checkmark$  either value can be seen in working OR on (along horizontal axis in) **Figure 5***

$\frac{x_{0.5}}{r}$  in *in range 0.73 to 0.81  $_2 \checkmark$*

*for  $_2 \checkmark$  answer with no unit and minimum 2 sf*

2

- (e) **use of Figure 5:**

adds  $B_{H1}$  for experiment 1 to  $B_{H2}$  for experiment 2 at any point between  $x = 17$  and  $x = 51$  (mm);

resultant  $B_H$ , minimum 2 sf, in range 0.91 to 0.99 (mT)  $_1 \checkmark$

resultant  $B_H$ , minimum 2 sf, in range 0.93 to 0.97 (mT)  $_2 \checkmark$

*ignore any sign given with result*

2

- (f) for more than 2 ideas mark as a list

(field lines are) parallel or wtte  $_1 \checkmark$

*for  $_1 \checkmark$  accept 'in the same direction' / 'uniform-direction';*

*'horizontal' / 'directed to the right' / 'straight' / 'linear' / 'perpendicular to the coil' are neutral*

evenly-spaced or wtte  $_2 \checkmark$

*for  $_2 \checkmark$  accept 'equally-spaced' / 'equidistant' / 'uniform-spacing' / 'equal distance between lines' or wtte;*

*'close together' / 'do not touch' are neutral;*

*'uniform field' / 'field lines are uniform' / 'they are uniform' are neutral*

2

- (g) a vertical axis drawn (at any point between  $x = 0$  and  $x = r$ );

continuous line (accept poorly-marked) between  $x = 0$  and  $x = r$  (by eye);

intersecting or meeting horizontal axis /  $B_{(H)} = 0$  at  $x = \frac{r}{2}$   $_1 \checkmark$

vertical axis drawn, labelled with symbol  $B$ ;

negative gradient, line continuous between  $x = 0$  and  $x = r$ ; 2-quadrant graph  $_2\checkmark$

vertical axis drawn with symbol and unit eg  $B_{(H)} / \text{mT}$ ;

continuous line between  $x = 0$  and  $x = r$ ;

$B_{(H)} = 0.43 \pm 0.01$  at  $x = 0$  OR  $B_{(H)} = -0.43 \pm 0.01$  at  $x = r$   $_3\checkmark$

2-quadrant graph, continuous line between  $x = 0$  and  $x = r$ ; approximately correct shape: see below;

their  $y$ -value at  $x = 0$  equal and **opposite** to their  $y$ -value at  $x = r$  (by eye)

$_4\checkmark$

for  $_1\checkmark$  use checkmark on axis for guidance;

for  $_2\checkmark$  allow 'magnetic flux density' in words;

condone any flat section  $\leq r/4$  (judge by eye);

allow (always) positive gradient

for  $_1\checkmark$  and  $_2\checkmark$  allow a straight line;

single quadrant can score  $_1\checkmark$  or  $_3\checkmark$

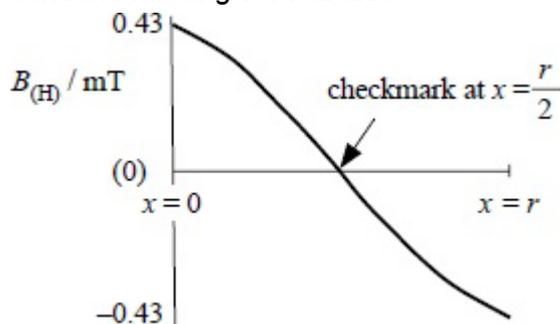
for  $_3\checkmark$  apply usual symbol-separator-unit convention

/ allow  $B_{(H)} = 4.3 \times 10^{-4}$  etc;

adjust criteria for positive gradient graph

for  $_4\checkmark$  if no values are marked on the axis, assume  $B_{(H)} = 0$  is aligned horizontally with the  $x$ -axis (judge by eye);

condone missing vertical axis



Max 3

[16]

## Q6.

(a) Y-shift ✓

*auto-marked: CAO*

1

(b) use of (transit distance) =  $2 \times 0.870$  ✓*for 1✓ allow 1.74*

1

use of (contact time) =  $6 \pm 0.2$  major divisions  $\times 50 \times 10^{-6}$  ✓*for 2✓ allow POT error in time-base value;**allow 2.9, 3(.0) or 3.1 ( $\times 10^{-4}$  s) seen in working*

1

speed in range 5600 to 6000 ( $\text{m s}^{-1}$ ) ✓*for 3✓ no credit for  $c = f \times \lambda$  approach;**speed in range 2800 to 3000 ( $\text{m s}^{-1}$ ) from*

$$\frac{0.870}{3 \times 10^{-4}}$$

*valid calculation eg  $3 \times 10^{-4}$  award 2✓ 13✓ = 2;**speed in range 1120 to 1200 ( $\text{m s}^{-1}$ ) from valid calculation (using minor divisions) eg*

$$\frac{2 \times 0.870}{5 \times 3 \times 10^{-4}}$$

*award 1✓ 23✓ = 2;**for speed = length of rod / (0.5  $\times$  time-base) 1✓ 2X3X**no credit for speed = length of rod / timebase**speed correct from valid calculation earns 1✓ 2✓ 3✓*

1

(c) quantitative effect on contact time ✓

*for 1✓ expect '(contact) time is doubled' / '600  $\mu\text{s}$ '*

quantitative effect on waveform ✓

*for 2✓ expect 'double the number of cycles would be produced' / 'would require 12 divisions';**accept 'waveform extended horizontally  $\times 2$ ' 'waveform is twice as long' or wtte;**condone 'number of wave(length)s doubled';**reject 'trace is twice as long' / 'wavelength doubled' / 'waveform stretched';**allow 'increased (contact) time so more waves / longer waveform seen' for 12✓ = 1 MAX*

waveform extends beyond screen / scale or wtte ✓

*for 3✓ consequences eg waveform could not be (fully) displayed / would not fit;*

*only penalise 'trace' once*

**Max 2**

adjustment to time-base control  $4\checkmark$

*for  $4\checkmark$  allow (any) change time-base;*

*allow 'time (per) div';*

*condone 'X-scale'*

**1**

to 0.1 ms (div<sup>-1</sup>)  $5\checkmark$

*for  $5\checkmark$  CAO*

**1**

**[8]**

**Q7.**

- (a) callipers may **reduce** the (reading of the) diameter ✓  
*treat 'change reading' / 'give incorrect reading' as neutral;*  
*accept the idea that the callipers may 'distort' / 'deform' / 'push in' the putty, eg*  
*'change the shape' / 'crush' / 'squash' / 'cut into' / 'squeeze'*  
*reject implication that density could change, eg*  
*'volume will change' / 'will compress';*  
*reject 'putty will move' / 'not able to grip the putty hard enough'*

1

- (b) average  $d$

OR

uncertainty in  $d$  ✓percentage uncertainty  $\geq 3$  sf ✓

*answers to >3sf rounding to 2.37(%) earns both marks*

*for ✓ either average = 33.8(0) (mm) OR  
 uncertainty from half range = 0.8(0) (mm);  
 allow  $1/2 \times (34.5 - 32.9)$  seen in working;  
 credit if seen in a percentage uncertainty calculation*

1

percentage uncertainty 2.37(%) ✓

*for ✓ percentage uncertainty to > 3 sf;  
 reject decimal answer or incorrect rounding to 2.36%;  
 reject answers if either 32.9 or 34.5 are (wrongly)  
 rejected as anomalous (leading to 1.62% and 1.64% respectively)*

1

- (c) % uncertainty in length correct ✓

*for ✓ minimum 2sf CAO; 2.8(2)%*

1

calculates % uncertainty in volume ✓

*for ✓ % uncertainty in  $V = 2 \times$  their % uncertainty  
 in  $d +$  their % uncertainty in  $L$ ; allow 2.4% for %  
 uncertainty in  $d$   
 minimum 2 sf; expect 7.6 %*

1

evidence for volume evaluated

OR

evidence for  $\Delta$  volume evaluated  $_{3}\checkmark$

for  $_{3}\checkmark$  accept answers including:

sub of **all data** in to  $V = \frac{\pi \times (\text{theird})^2 \times L}{4}$

OR

sub of **all data** in to

$$\Delta V = \frac{\pi \times (\text{theird})^2 \times L}{4} \times \text{their \% uncertainty}$$

$\Delta V = \text{their volume} \times \text{their \% uncertainty}$

OR

recognisable  $\Delta V$  with POT error

1

$\Delta$  volume between  $4.8$  and  $4.9 \times 10^3 \text{ (mm}^3)$   $_{4}\checkmark$

answers that round to  $4.8$  or round to  $4.9$  are acceptable;

$_{34}\checkmark$  for  $\Delta$  volume in range and correct POT

1

(d) ruled line  $_{1}\checkmark$

for  $_{1}\checkmark$  line passing below  $5^{\text{th}}$  AND above  $4^{\text{th}}$  ie no overlap between line and either +;

line passing through or extrapolated to  $(0, 0)$  to half a minor grid square;

withhold this mark if line is poorly-marked (if doing so annotate clip to explain)

1

gradient calculated  $_{2}\checkmark$

for  $_{2}\checkmark$  gradient calculated from  $\Delta R$  divided by  $\Delta L^2$ ;

minimum  $\Delta L^2 = 25 (\times 10^{-3} \text{ m}^2)$ ;

allow read-off errors in calculation / allow missing or incorrect POT

1

$\rho$  in range  $3.72$  to  $3.84 (\times 10^{-2})$   $_{3}\checkmark$

for  $_{3}\checkmark$  accept 2 sf  $3.8$

1

POT and unit correct  $_{4}\checkmark$

for  $_{4}\checkmark$  treat  $3.78 \times 10^{-2}$  and  $0.0378 \Omega \text{ m}$  as equally acceptable;

allow alternative valid answer, eg  $37.8 \Omega \text{ mm}$

1

**Q8.**

- (a) attempts two calculations that would lead to a conclusion  $1\checkmark$   
 for  $1\checkmark$  the result of at least one calculation of  $M \times y$   
 must be correct (see table) otherwise withhold both  
 marks;  
 allow use of  $y$  in  $m$  but reject POT error  
 allow use of correct read-offs from valid BFL;  
 condone use of two rows of data to show that when  
 $M$  doubles,  $y$  does not halve;  
 award of  $2\checkmark$  is contingent on valid  $1\checkmark$

1

a reasoned judgement explaining why  $y$  not inversely proportional to  $M$   $2\checkmark$

$M / \text{kg}$	$y / \text{mm}$	acceptable $M \times y$	min sf
0.5	89(.0)	44.5 / 45	2
1.0	82(.0)	82(.0)	
1.5	76(.0)	114(.0)	3
2.0	71(.0)	142(.0)	
2.5	66.5	166(.3)	
3.0	62.5	187.5 / 188	

for  $2\checkmark$  two correct calculations of  $M \times y$

see table for min sf in result for  $M \times y$

OR

one correct calculation of  $M \times y$  and an appropriate  
 reverse-working calculation;

statement rejecting inverse-proportion supported by  
 suitable quantitative reasoning, eg calculation of the  
 percentage difference between the results of their  
 calculations;

condone 'large' / 'significant differences' (between  
 calculation results) / use of  $\gg$  etc;

reject 'values are different' / 'not same' / 'not  
 constant' / 'not close enough' use of  $>$  etc;

reasoning must be based on the data points, eg  
 reject 'best-fit line crosses y-axis'

1

- (b) (as  $P$  moves down) trapped air expands so)  
 pressure (of trapped air) is reduced  $1\checkmark$

must address situation in **Figure 3**

for  $1\checkmark$  allow 'pressure reaches lower value' reject  
 'pressure is low'

pressure less than atmospheric pressure  $2\checkmark$

for  $2\checkmark$  allow 'there is a pressure difference across  $P$   
 ' / 'external pressure  $>$  pressure of trapped air'

award  $1\checkmark 2\checkmark$  for pressure of air reduced below

*atmospheric*

this leads to an upwards force balancing the weight of **P**

OR

pressure difference across **P** × area of piston = weight of piston <sub>3✓</sub>

*for <sub>3✓</sub> allow any **correct** idea about how two opposing forces act to produce equilibrium;*

*'no resultant force' is not enough*

*reject 'weight = gravity' / ideas about 'suction' / equating pressure with force*

why **P** falls when the valve is opened <sub>4✓</sub>

*for <sub>4✓</sub> idea of external and internal pressures equalising;*

*reject 'pressure released / returns to normal'*

Max 3

(c) smooth curve of decreasing negative gradient through all 6 points <sub>1✓</sub>

*for <sub>1✓</sub> must be a single continuous line for  $M > 0.5$  that overlaps with all 6 +;*

1

line with negative gradient extrapolated (backwards) to  $M \leq -0.35$  <sub>2✓</sub>

*condone poorly-marked line (note that poor line quality may only be penalised in (d))*

records *y* corresponding to  $M = -0.7$  <sub>3✓</sub>

*y* in range 108 mm to 116 mm <sub>4✓</sub>

*for <sub>2✓</sub> condone linear extension of curve with negative gradient for  $M < +0.5$*

1

OR

for incorrect  $M$  (3 MAX)

smooth curve etc <sub>1✓</sub>

*for <sub>3✓</sub> curve must extend to where read off is being made*

1

line with negative gradient extrapolated (backwards) to  $M \leq -0.35$  <sub>2✓</sub>

records *y* corresponding to  $M = -0.35$ ;

*y* in range 101 mm to 107 mm <sub>34✓</sub>

OR

for linear graph (2 MAX)

ruled line with negative gradient extrapolated (backwards) to  $M \leq -0.35$   
<sub>12</sub>✓

records  $y$  corresponding to  $M = -0.7$ ;

$y$  in range 101 mm to 107 mm <sub>34</sub>✓

*award of <sub>4</sub>✓ is contingent on valid <sub>3</sub>✓*

*for <sub>4</sub>✓ answers that round to nearest mm are acceptable*

1

(d) correctly identifies error <sub>1</sub>✓

*for <sub>1</sub>✓ reading has been taken at / from the top of the **meniscus** / top of coloured oil / top of liquid*  
 OR

*should have taken / did not take reading from the bottom / lowest point of the **meniscus** / lowest point on **surface** of coloured oil*

OR

*'(student thinks) sub-divisions are  $0.1 \text{ cm}^3$  and not (as question states)  $0.2 \text{ cm}^3$ '*

*reject 'should have read from bottom of coloured oil' / 'failed to read meniscus properly' / 'read at the top of the air' / 'has read divisions incorrectly' or wtte*

1

correct reading is 35.8 <sub>2</sub>✓

*for <sub>2</sub>✓ CAO*

1

(e) gradient from  $\Delta \log(V / \text{cm}^3)$  divided by  $\Delta \log(p / \text{MPa})$ ; evaluated to  $\geq 3$  sf result between  $-1.05$  and  $-1.01$  <sub>1</sub>✓

*don't insist on large steps / read off accuracy*

*accept result that rounds to 3sf between  $-1.05$  and  $-1.01$ ; sign essential*

1

relevant algebra enabling comparison with  $y = mx + c$  <sub>2</sub>✓

*for <sub>2</sub>✓ (eg Boyle's Law written as)*

*$\log V = -\log p + \text{constant}$*

*condone variation based on Ideal Gas Law in which case must establish that  $(nR)T / (Nk)T$  is constant (which then implies Boyle's Law) (recognisable data book symbols only)*

OR

*(Figure 5 shows)*

$\log V = \text{gradient} \times \log p + \text{constant}$ ;  
 accept  $(\log) k$ ,  $(\log) c$  etc as recognisable symbols  
 for the constant;  
 condone (any) numerical value given for the  
 constant eg  $10^{1.685}$ ;  
 accept  $m$  as recognisable symbol for the gradient

1

why gradient  $\approx -1$  confirms Boyle's Law  $3\checkmark$

for  $3\checkmark$  allow gradient is / equals / should be  $-1$   
 if  $2\checkmark$  not given accept 'gradient  $\approx -1$  demonstrates  
 inverse proportion or wtte

1

(f) reads off and attempts to make use of  $\log p_1$  AND  $\log V_1$  for any point on  
 the line  $1\checkmark$

for  $1\checkmark$  check  $\log V_1$  is within half a grid square of  
 correct position for their  $\log p_1$  or vice-versa;  
 'make use of' excludes use in a gradient calculation  
 $V_2$  in range 10.5 to 11.5 ( $\text{cm}^3$ ) earns  $1\checkmark 2\checkmark 3\checkmark$

1

applies a workable method  $2\checkmark$

for  $2\checkmark$  creditworthy examples are  
 a calculation of the intercept in **Figure 5**  
 eg  $\log V + \log p = 0.585$   
 OR

$\frac{\Delta \log V}{\Delta \log p}$

use of gradient =  $\frac{\Delta \log V}{\Delta \log p}$  (eg similar triangles  
 idea)

OR

a calculation of  $p \times V$  (by any means)

OR

use of  $\log V = -1 \times \log 0.34 + \text{their intercept}$   
 no credit for claiming 1.685 (or 1.170) are  
 intercepts; this cannot earn  $2\checkmark$

1

further manipulation to determine unknown  $V_2$   $3\checkmark$

for  $3\checkmark$  accept result that rounds to 10.5 or 11.5;  
 accept 2sf 11 ( $\text{cm}^3$ )

1

(g) temperature (of air)  $1\checkmark$

for  $1\checkmark$  accept 'mean ke of air molecules' (or wtte) /  
 vapour pressure of air

*'keep mass of air constant' is neutral (this information is given below **Figure 5**)*

1

change the pressure of the gas slowly or wtte

OR

wait (after a change) between taking readings / until the oil level stabilises

<sup>2</sup>✓

*award of <sup>2</sup>✓ is contingent on valid <sup>1</sup>✓*

*for <sup>2</sup>✓ condone 'keep lab temperature constant';*

*'use a water bath' is neutral*

*reject 'do the experiment slowly' / 'do not heat the apparatus' / 'keep windows closed' etc*

1

**[19]**

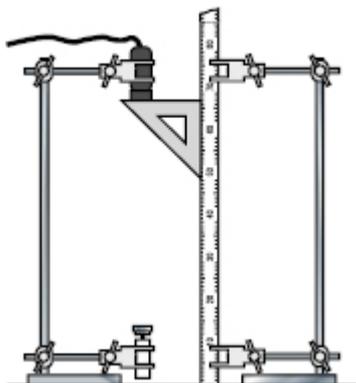
**Q9.**

- (a) finds  $d$  by reading position of (lower end of) detector;  
 subtracts 138 mm or wtte  $1\checkmark$

*for  $1\checkmark$  allow 'reads / measures height of detector' / 'distance from detector to bench';  
 reject 'measures height of clamp T'  
 if 'subtracts 138' is not seen; allow  
 'subtract distance from source to bench' / 'between source and bench' / 'height of source from ground' / 'position of top / open end / mouth of source';  
 allow 'measures height of the detector and the source and finds difference';  
 condone 'reversed' subtraction*

annotates **Figure 1** to show suitable use of a recognisable set-square  $2\checkmark$

*for  $2\checkmark$  expect a triangular  $90^\circ$  set-square in contact with a vertical edge of the ruler, top edge aligned with open end of the detector, eg*



*condone use of recognisable T-square in contact with vertical edge etc*

2

- (b) background count rate correct  $1\checkmark$

*for  $1\checkmark$  accept any of:*

*background count rate =  $0.7(0) / \frac{630}{900} \text{ (s}^{-1}\text{)}$*

*OR*

*background count in 100 s = 70*

*OR*

*background count in 300 s = 210*

1

working leading to correct  $R_C 2\checkmark$

*for  $2\checkmark$  [cao]  $\geq 2$  sf  $R_C = 0.33 \text{ (s}^{-1}\text{)}$*

*reject  $R_C = 0.30$  if their uncorrected count has been rounded to 1.0*

1

- (c) attempts two calculations that would lead to a conclusion  $1\checkmark$   
 for  $1\checkmark$  the result of at least one calculation of  $d^2 \times R_C$  or of  $d \times \sqrt{R_C}$  must be correct to 2 sf (see table) otherwise withhold both marks;  
 allow use of  $d$  in m but reject POT error;  
 allow 1 sf  $d^2 \times R_C$  for use of  $R_C = 0.3$ ;  
 allow  $530^2 \times$  their (b) result

a reasoned judgement that the evidence does not support the prediction  $2\checkmark$

$d / \text{mm}$	380	530	
$R_C / \text{s}^{-1}$	0.76	0.33	$\Delta\%$
$d^2 \times R_C$	$1.1(0) \times 10^5$	$9.27 \times 10^4$	18%
$d \times \sqrt{R_C}$	331 / 330	305 / 310	8.4%

$d / \text{mm}$	380	530	
$R_C / \text{s}^{-1}$	0.76	0.3 (1 sf)	$\Delta\%$
$d^2 \times R_C$	$1.1(0) \times 10^5$	$8(.43) \times 10^4$	29%
$d \times \sqrt{R_C}$	331 / 330	$3.(0) \times 10^2$	14%

for  $2\checkmark$  two correct calculations of  $d^2 \times R_C$  or  $d \times \sqrt{R_C}$ , both must be correct to 2 sf

OR

one correct calculation of  $d^2 \times R_C$  or of  $d \times \sqrt{R_C}$  correct to 2 sf and an appropriate reverse-working calculation;

the statement rejecting the prediction should be supported by a calculation of the percentage difference between the results of their calculations (see  $\Delta\%$  in table);

condone weaker 'large' / 'significant differences' (between calculation results);

reject 'prediction not correct' because 'values are different' / 'not constant' / 'not close enough'

2

- (d) lower / adjust the position of the detector / clamp  $T_1\checkmark$   
 for  $1\checkmark$  condone 'lower clamp' (this implies clamp  $T$  since  $B$  cannot be lowered further)  
 allow 'remove source using tongs while adjusting detector / clamp  $T$ ' otherwise  $2X$

1

to maximise distance between the experimenter and the source or wtte

OR

to reduce (limit) exposure (time) of the experimenter to radiation or wtte 2✓

for 2✓ allow 'not going (too) close (to source)'

reject 'don't touch / make contact with source'

suggesting using lead shielding is neutral

allow 12✓ for 'remove source or wtte using tongs to

maximise distance etc before moving **B** upwards'

changes to the position of source / clamp **B** without

the use of tongs loses both marks

1

- (e) determines  $10^a - 10^b$  where  $a$  and  $b$  are (any) plotted values of  $\log(d / \text{mm})$  1✓

use of  $\Delta d = \frac{10^a - 10^b}{n}$  where  $n$  is 1, 2, 3 or 4;

$\Delta d$  in range 47(.0) to 53(.0) (mm) 2✓

insist on  $a$  and  $b \geq 2$  dp; allow read-off errors  $\pm$  one square;

expect  $\frac{10^{2.52} - 10^{2.11}}{4} = 50(.6)$  (mm);

$\frac{e^a - e^b}{n}$

allow 12✓ for  $\frac{e^a - e^b}{n}$  leading to  $\Delta d$  correct for their values

2✓ is contingent on 1✓ i.e. there is no credit for an unsupported answer

2

- (f) suitable analysis 1✓

for 1✓  $\log R_C = -2 \log d + \log k$  seen; minus sign essential

1

appropriate use of **Figure 2** 2✓

for 2✓ draw best-fit line **and** measure gradient;

allow implication that a (linear) best-fit line is drawn and the gradient is being measured, eg 'check gradient of best-fit line';

condone  $m = \text{gradient}$

1

processing and conclusion 3✓

for 3✓ states that the prediction is confirmed if the gradient /  $m$  is  $\approx -2$

OR

prediction is **not** confirmed if the gradient is  $\neq -2$

condone 'the gradient should be  $-2$  (to confirm prediction)'

(no ECF for  $m = (+)2$  if denied in  $1\checkmark$  for missing – sign)

allow  $123\checkmark$  prediction is **not** confirmed if the best-fit line is a curve

reject 'prediction is confirmed if the best-fit line is straight' / 'there is a negative gradient' / 'because  $k$  is constant'

1

(g)  $t_d = 1.96 \times 10^{-4}$  (s)  $\checkmark$

minimum 2 sf; accept 196  $\mu$ s;

$$\frac{102 - 100}{102 \times 100}$$

calculation should be  $\frac{102 - 100}{102 \times 100}$  so only accept  $2.0 \times 10^{-4}$  (s) / 200  $\mu$ s only if **rounding up**

$$\frac{100 - 98}{100 \times 98}$$

( $100 \times 98$  gives  $t_d = 2.04 \times 10^{-4}$  (s))

1

(h) random nature of decay or wtte  $1\checkmark$

for  $1\checkmark$  condone 'the source emits (photons) sporadically' / 'unpredictably';

reject explanation based on exponential decay

reject 'decay occurs by chance' / 'source does not emit photons at a constant rate' / 'photons decay' / 'decay is spontaneous / inconsistent'

1

idea that more than one photon may arrive per 0.01 s interval

OR

idea that no photon may arrive during per 0.01 s interval

OR

photons 'arrive randomly' / 'do not arrive at a steady rate or wtte  $2\checkmark$

$2\checkmark$  is contingent on  $1\checkmark$

(if no other answer given) allow  $12\checkmark$  for:

'only counts 50 since detector still 'dead' at 0.01 s so only 'sees' odd-numbered photons';

use of formula to show  $R_1 = 50$  is neutral

1

[16]

**Q10.**(a) reads off  $\lambda_p$   $_{1}\checkmark$ *for  $_{1}\checkmark$  condone POT;**expect  $\lambda_p = 635 \pm 2$  (nm) /* *$635 \pm 0.02 \times 10^{-9} / 6.35 \pm 0.02 \times 10^{-7}$  (m)**allow evidence of working on **Figure 1***

1

use of  $n \times$  their  $\lambda_p = d \sin \theta$   $_{2}\checkmark$ *for  $_{2}\checkmark$  accept subject  $n$  with no / incomplete*

$$N = \frac{\sin \theta}{n \times \lambda_p}$$

*substitution, eg*

OR

*subject  $d$  and full substitution, eg*

$$d = \frac{5 \times \text{their } \lambda_p}{\sin 76.3} / 5.15 \times \text{their } \lambda_p \quad 5.15 \times \text{their } \lambda_p$$

OR

*correct result  $d = 3.27$  ( $\times 10^{-6}$  (m));**allow ECF in  $\lambda_p$  including POT;**allow recognisable  $d$  / 2 sf intermediate result*

3

$$N = \left( = \frac{1}{d} = \frac{1}{3.27 \times 10^{-6}} \right) = 3.06 \times 10^5 \quad _3\checkmark$$

*for  $_{3}\checkmark$  accept  $\geq 3$  sf in range  $3.05$  to  $3.07 \times 10^5$  OR*

$$N = \frac{0.194}{\text{their } \lambda_p} \quad (\text{allow ECF for } \lambda_p \text{ out of range but}$$

*not if due to POT)*

1

(b) identifies an appropriate physical characteristic that makes the measurement of the (5<sup>th</sup>) maximum more difficult  $\checkmark$ *take 'it' to be the 5<sup>th</sup> maximum / peak**(centre difficult to locate because)**(5<sup>th</sup>) 'maximum is wider' / 'peak less pronounced' / 'less defined' or wtte;**allow 'maximum more spread out' / 'less pronounced'*

OR

*maximum 'is fainter' / 'less bright' / 'intensity reduced';**reject 'not as clear'*

OR

*(cannot use edges to determine location of centre*

because)

'whole maximum (may be) not visible' / 'can't see edges'

OR

( $L_R$  produces a range of wavelengths so)

4<sup>th</sup> and 5<sup>th</sup> / adjacent fringes may overlap

1

- (c) extrapolation of linear region of the  $L_R$  characteristic  $1\checkmark$   
 for  $1\checkmark$  reads off where a ruled extrapolation to the linear region of the  $L_R$  characteristic reaches the horizontal axis  
 the line must be free from discontinuities; condone a ruled dashed line  
 condone tangent meeting curve at  $I \geq 10$  mA

$V_A$  for  $L_R$  in range 1.91 to 1.93 (V)  $2\checkmark$

for  $2\checkmark > 3$  sf acceptable if rounding to 3 sf

2

- (d) any fully correct calculation of the Planck constant  $1\checkmark$   
 for  $1\checkmark$  allow 2 sf  
 use of  $c = 3.00 \times 10^8$  AND  $e = 1.6(0) \times 10^{-19}$   
 AND EITHER  
 $V_A$  from (c) AND  $\lambda_p$  in range 620 to 650 nm / ECF  
 their  $\lambda_p$  from (a)  
 OR  
 $V_A = 2.00$  AND  $\lambda_p$  in range 550 to 580 nm;

calculates mean of two valid calculations of the Planck constant;

result in range  $6.10$  to  $6.50 \times 10^{-34}$  (J s)  $2\checkmark$

for  $2\checkmark$  Planck constant result rounding to correct 3 sf

(check very carefully working leading to data booklet value  $6.63 \times 10^{-34}$ )

1

- (e)  $V_F$  corresponding to  $I_F = 21$  mA read from  $L_R$  graph in **Figure 3**;  
 use of  $V_F = 2.01$  (V) leading to  $R = 195$  ( $\Omega$ ) earns both marks

calculates  $R$  from  $\frac{6.1 - \text{their } V_F}{21(0 \times 10^{-3})}$   $1\checkmark$

for  $1\checkmark$  accept evidence of working on **Figure 3**

condone 2 sf eg  $V_F = 2.0$  (V)

allow POT error for  $I_F$

1

$$R = 195 \text{ } (\Omega) \text{ from } \frac{6.10 - 2.01}{21(0) \times 10^{-3}} = 195 \text{ } 2\checkmark$$

195 2✓

for 2✓ evidence to show use of  $V_F = 2.01 \pm 0.01$  (V) must be seen, ie allow

$$\frac{6.10 - 2.00}{21(0) \times 10^{-3}} = 195 \text{ OR } \frac{6.10 - 2.02}{21(0) \times 10^{-3}} = 194$$

1  
[10]

**Q11.**

- (a) annotates **Figure 1** to identify equilibrium position; some (or all) of the mark should be below the bob

or

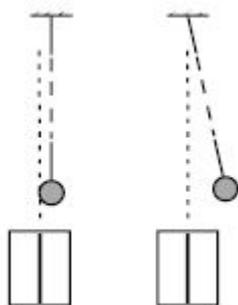
(bottom of mark) should be level with bottom of bob 1✓

this is where (the pendulum / bob) is moving fastest / (pendulum has) maximum kinetic energy

or

this is where the transit time is least 2✓

for 1✓ condone a poorly-annotated sketch if intention is clarified in 2✓; do not allow talkout do not insist on seeing the outline of the card as long as the vertical line is seen; condone arrows  $\uparrow \downarrow$  etc; blobs  $\bullet + \times$  are neutral allow vertical line of the mark to be aligned with either edge of the bob in the left-hand view or marked directly below point of suspension (within one-quarter of bob radius) in the right-hand view, eg



if marks are shown on each view of the pendulum, then each separately must satisfy the criteria for 1✓

**2✓ is contingent on award of 1✓**

for 2✓ comments about why the mark is not aligned with bob in right-hand view are neutral (at equilibrium) 'acceleration is zero' is neutral

2

- (b) use of appropriate horizontal scale or wtte 1✓

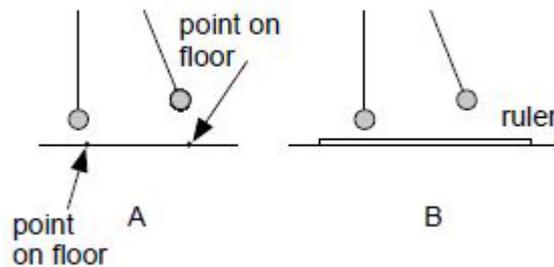
use of set-square with edge made vertical or other suitable equipment to eliminate parallax error in  $A_R$  2✓

measures  $A_R$  from (either) edge of displaced bob 3✓

*any of 1✓ 2✓ or 3✓ can be earned by suitable annotation to **Figure 2***

*for 1✓ ruler or 'mm scale' only;*

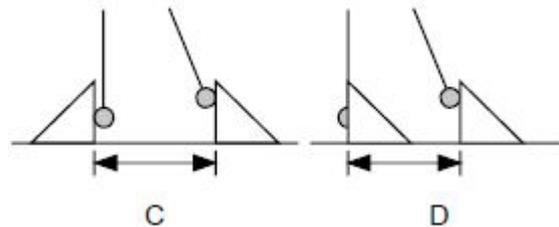
*'measuring with a ruler between points marked on the floor' is acceptable (see A below) or use of a 'ruler placed on floor' (see B)*



*for 2✓ allow use of plumb line, spirit level, video or photographic equipment; reject clamp stand*

*any use of the fiducial mark or the idea that the supporting beam is horizontal are neutral*

*withhold 3✓ unless candidates explains that allowance is being made for radius / diameter of bob (see C and D below)*



MAX 2

- (c) extrapolation of curve to (at least)  $x = 0.70$  m 1✓

*for 1✓ extrapolation must be continuous and smooth; allow (ruled) straight line; reject hairy, thick or dashed lines*

1

consistently-recorded min 3 dp values for  $T_{0.35}$  and  $T_{0.70}$  2✓

*for 2✓ allow values seen in working;*

*$T_{0.35}$  must round to 2.322; condone  $T_{0.70}$  by eye*

evidence of valid calculation (check denominator correct);

percentage increase in range 1.4(0) % to 1.8(0) % 3✓

*don't insist on horizontal or vertical lines between curve and vertical axis on **Figure 3***

*for 3✓ expected answer is 1.51%*

2

(d) rejects anomalous 0.247;

average  $A_5 \geq 3$  sf (that rounds to) 0.221 (s) 1✓

correct uncertainty calculation or 0.004(0) (s) seen 2✓

**or**

does not reject 0.247;

average  $A_5 =$  (rounds to) 0.226 (s);

correct uncertainty calculation or 0.015 (s) seen 12✓

correct % uncertainty from  $\frac{\text{their half range}}{\text{their average}} \times 100 \geq 2$  sf 3✓

*0.221 and 1.8 % on answer lines earn 123✓✓✓*

*1✓ (0.247 rejected) full answer 0.2214 (s)*

*2✓ from half range; can be inferred from working*

*3✓ if 12✓✓ full answer 1.81 %; allow 1.8 % or 1 sf 2 %*

*when 0.247 is not rejected*

*12✓ full answer 0.2257 (s)*

*3✓ full answer 6.647 %; allow 6.64 / 6.65 % or 2 sf 6.6 / 6.7 %*

*for 3✓ allow ECF only if uncertainty is from half range*

3

(e)  $\ln(A_4 / m) = -1.492$  ✓

*CAO 3 dp only*

1

(f) vertical scale with one major (cm) grid square = 0.02 **or** 0.025;

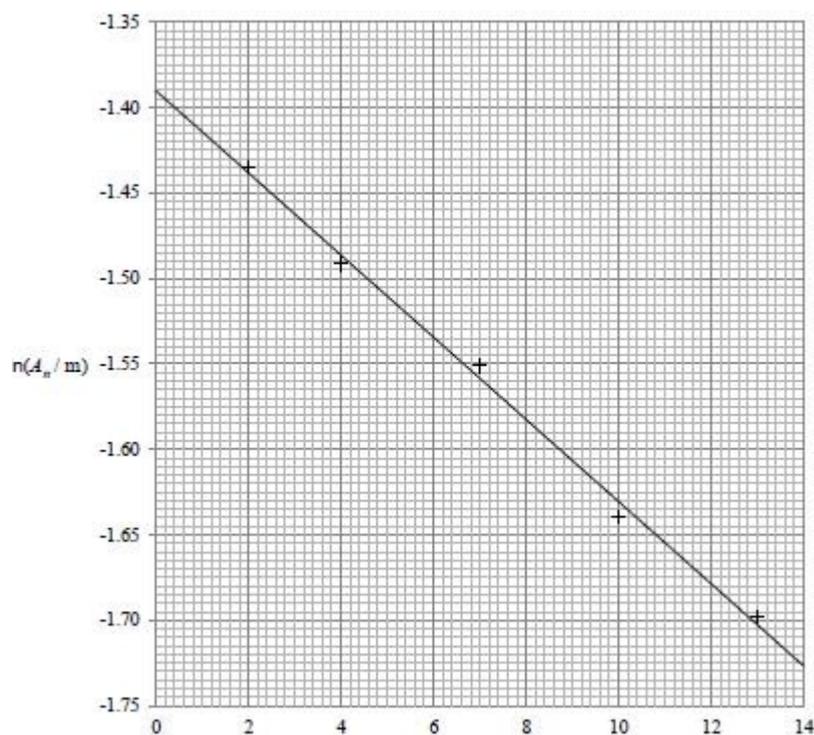
maximum spacing of values marked on the scale = 5 cm 1✓

points plotted for  $n = 2, 4, 7, 10$  and 13;

suitable continuous ruled line of negative gradient from  $n = 2$  to (at least)  $n = 13$ ;

line must pass above  $n = 4$  **and**  $n = 10$  points

**and** must pass below  $n = 7$  point 2✓



*withhold both marks for false plot*

*for 1✓ scale might go (down page) from -1.40 to -1.72 (1 square = 0.02) or from -1.30 to -1.70 (1 square = 0.025);*

*scale must cover range of plotted points; do not insist on use of broken scale convention*

*no credit for reversed values leading to graph with 'positive' gradient;*

*no credit for missing / inconsistent minus signs or for inconsistent dp in labelled values*

*for 2✓ allow ECF acceptable line based on accurate plot of incorrect  $n = 4$  point*

*allow ECF for graph with 'positive' gradient due to reversed scale, eg line must pass **below**  $n = 4$  and  $n = 10$  points and must pass **above**  $n = 7$  point*

*accept only 4 points if  $n = 4$  is not tabulated; line must pass **between**  $n = 7$  and  $n = 10$*

*ignore any plot of  $\ln(A_5 / m)$  based on part (d) data; withhold mark for poor points eg blobs or for thick / faint / non-continuous line*

(g) (any) correct expression with  $\ln A_n$  as subject 1✓

$$\delta = e^{-\text{gradient}} \text{ or write } 2✓$$

for 1✓  $y = mx + c$  idea is required

**either**  $\ln A_n = -n \ln \delta + \ln A_0$  ( $y = mx + c$ )

**or**  $\ln A_n = \ln A_0 - n \ln \delta$  ( $y = c + mx$ )

**not**  $\ln A_n = \ln A_0 - \ln \delta^n$

treat 'lg  $A$ ' as a slip

allow use of 'log  $A$ ' for 1✓ but no ECF in 2✓

for 2✓

$\delta$  must be the subject, reject  $\ln \delta = -\text{gradient}$  etc

allow ECF if 1✓ is withheld for missing - sign;

if gradient is evaluated accept  $\delta = e^{(+).024}$  or  $\delta = 1.02(4)$  etc

an explanation that  $\delta$  can be found using  $A_n = A_0$

$\delta^{-n}$  must rely on values of  $A_n$ ,  $A_0$  and  $n$  that are determined using the line in **Figure 4**

2

[15]

**Q12.**

(a) 37.8 ✓

CAO

1

(b) random (error)

condone 'statistical' ✓

*the following are neutral:**'parallax' / 'human (error)' / '(some) results are anomalous'*

1

(c) advantage (of using thinner beam):

(same load produces) larger (values of)  $s$  or wtte 1✓

so

the percentage uncertainty / error (in  $s$ ) is reduced 2✓*for 1✓ accept 'beam bends / deflects more'**'beam extends more' / 'easier to bend' are neutral**for 2✓ the following are neutral:**'easier to make readings' / 'values (of  $s$ ) are more accurate' / 'more precise' / 'less mass needed' / 'wider range of readings'*

disadvantage (of beam bending more):

idea that beam may undergo plastic deformation 3✓

so

the graph will be non-linear / curve or wtte 4✓

**or**beam 'may break' / 'slip off knife edges' **and** relevant comment about safety / health / hazard / 'cannot get unload data'**or**reduces range of  $m$  or wtte **and** relevant comment about the effect on the graph, eg increase scatter 34✓ = 1 MAX*for 3✓ accept / 'beam may become permanently**deformed' or wtte / 'necking may occur' / 'hysteresis may occur' / 'beam can reach (go past) elastic limit'**the following are neutral:**'causes systematic error' / 'beam may go past limit'*

*of proportionality' / 'need to increase height of supports' / 'beam may bend under own weight'*

MAX 3

(d)  $E \approx 10^9$

or

$1.14 \times 10^9$  seen 1✓

*for 1✓ accept  $10^9$  seen in working*

1

correct manipulation seen in **body of answer** of  $s = \frac{\eta m}{E}$  2✓

*for 2✓ either*

*substitution of their  $E$  and data from **Figure 8** leaving  $\eta$  as only unknown: allow POT in  $s$  but not in  $m$*

eg  $\eta = \frac{\text{their } E \times 25.5 (\times 10^{-3})}{0.25}$  or

*substitution of their  $E$  and result of a gradient calculation: allow POT in  $\Delta s$  but not in  $\Delta m$*

eg  $\eta = 1.14 \times 10^9 \times 1.02 (\times 10^{-1})$  or

*calculation involving orders of magnitude (expect  $10^{-1}$  but allow  $10^2$  for gradient)*

eg  $\eta \approx 10^9 \times 10^{-1}$

2

correct raw result (allow POT in  $E$ ) 3✓

*for 3✓ expect  $1.16 \times 10^8$  but allow 1 sf gradient eg leading to  $1.14 \times 10^8$*

(on answer line) order of magnitude consistent with their raw result 4✓

*for 4✓  $\eta = 10^8$  or 8 only; allow use of their  $E$*

*award 34✓ = 1 MAX for use of gradient  $\approx 100$  leading to order of magnitude =  $10^{11}$  or 11 only*

1

(e) identifies that  $s$  and  $L$  are linked by a power law ✓

*accept any correct expression (unless there is talk-out) with  $s$  or  $\log s$  as the subject;*

*treat any quantities other than  $s$  and  $L$  as constant except  $E$  and  $\eta$*

*possible answers are:*

$s \propto L^n$

*allow  $s \propto L^m$  if  $m$  identified as constant*

$s \propto L^3$

$$s = kL^n$$

$$\log s = n \log L + (\log) k$$

$$\log s = 3 \log L + (\log) k$$

$$\log s = \log L^3 + (\log) k$$

reject

$$s = L^n$$

$$\log s = n \log L$$

$$\log s \propto n \log L$$

$$10^s \propto 10^L$$

's and L are linked logarithmically'

's is directly proportional to L'

1

(f)  $(\log L =) -0.097$  seen

for 1✓ accept any  $\log L$  rounding to  $-0.097$ ;

1

or

working on **Figure 5** confirming a value of  $\log L$  between  $-0.095$  and  $-0.100$  1✓

uses **Figure 5** to obtain  $s$  in range  $2.9$  to  $3.1 \times 10^{-2}$  (m) 2✓

*working can be suitable ruled line or mark on the best-fit line / on graph axes*

for 2✓ accept 29, 30 or 31 mm etc

reject 1sf  $3 \times 10^{-2}$  (m)

1

use of wrong base

$\ln L = -0.22(3)$ ;

uses **Figure 5** to obtain  $s$  in range  $1.49$  to  $1.51 \times 10^{-1}$  or  $1.5 \times 10^{-1}$  (m) 12✓

accept 15 cm etc

(g) use of **Figure 4** to determine  $M$  ✓

*their (final answer to) (f)  $\times$  gradient of **Figure 4** (9.8  $\pm$  2.5%)*

*minimum 2sf*

*condone use of 1sf s*

1

[13]

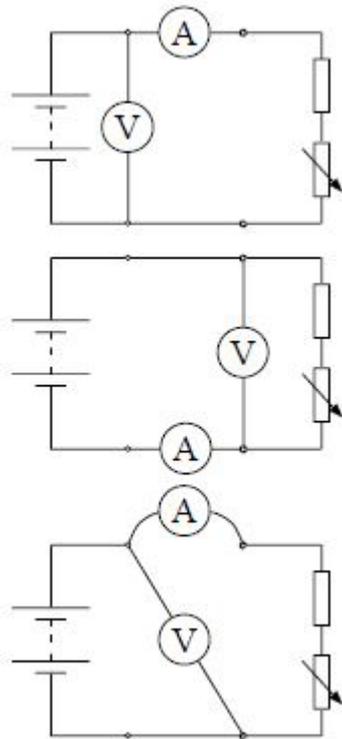
**Q13.**

- (a) valid continuous series circuit that includes ammeter, and one wire link  
(condone diagonal connections)

**and**

voltmeter between any two sockets that enable the terminal pd to be measured ✓

all of the following are acceptable:



**links and connections**

*reject broken / dashed lines*

*tolerate diagrams with diagonal or non-straight connections between sockets if these will produce a valid circuit*

*don't insist on connection blobs*

*circuit must be continuous unless a switch is included: otherwise no gaps wider than the thickness of their links*

*inclusion of a switch is neutral but the length of the open switch must be  $\geq$  length of the gap where the switch is connected: condone the whole gap between terminals vertically opposite the ammeter to be marked as an open switch*

**meters**

*correct ASE symbol for ammeter and correct ASE symbol for voltmeter are essential*

*one voltmeter and one ammeter only  
meters must not be 'transparent'  
positions of meters assume that the ammeter has negligible resistance and voltmeter has infinite resistance*

1

(b) (with any switch closed) read ammeter and voltmeter

**or**

record / measure  $I$  and  $V$ ;

adjust / vary / change resistance / (setting of) variable resistor / Q

and repeat (readings) 1✓

*for 1✓ must produce a range of  $I$ ,  $V$  values (>2 sets) and identify how this is achieved; it is not necessary to suggest range or number of sets*

plot  $V$  (against)  $I$  2✓

*mark 2✓ independently of 1✓*

2

$\varepsilon$  = (vertical / y-axis) intercept 3✓

$r$  = -gradient 4✓

2✓ 3✓ and 4✓ can be awarded for a suitable sketch graph

*condone 'use the (variable) resistor to vary current and read  $I$ ,  $V$ '*

*idea that  $R$  can be read from Q is neutral*

*for 2✓ (and further credit in 3✓ and 4✓) the ordinate and the abscissa must be identified;*

*allow 'plot  $V$  over  $I$ ' or 'plot  $V/I$ '*

*allow 2✓ for reverse plot ' $I$  (against)  $V$ '*

*then 4✓ for  $r = \frac{-1}{\text{gradient}}$  and 3✓ intercept =  $\frac{\varepsilon}{r}$*

*for 3✓ open circuit methods involving  $\varepsilon$  read directly using voltmeter are neutral*

*for 4✓ any subject but minus sign essential*

2

variation

*1✓ as above;*

*3✓ find  $R$  from  $V$  divided by  $I$ ; disconnect external circuit and measure  $\varepsilon$  directly;*

4✓ plot  $\frac{\varepsilon}{V}$  against  $\frac{1}{R}$   
 2✓ gradient =  $r$

- (c) gradient calculation seen with  $\Delta n^{-1}$  divided by  $\Delta I^{-1}$ ;

$\varepsilon$  from  $22 \times$  gradient 1✓

for 1✓ do not penalise one read off error, (allow use of 0, 0) or for small steps

expect gradient  $\approx 7.2(5) \times 10^{-2}$  leading to  $\varepsilon = 1.594$  (V)

do not allow reverse working based on answer to part (e)

1

$\varepsilon$  minimum 3 sf; in range 1.58 to 1.61 (V) 2✓

2✓ is contingent on award of 1✓

1

- (d) use of **Figure 3** to read off  $I^{-1}$  corresponding to  $n^{-1} = 0.25$ ;

calculates  $I$  in range 0.23(2) to 0.24(4) (A) ✓

do not insist on seeing evidence of working on **Figure 3**

expect  $I^{-1} = 4.2 \pm 0.1$  ( $A^{-1}$ ) leading to  $I = 0.238$  (A)

(should expect 1 more sf than in 0.25 for 'show that' but condone 0.23 and 0.24 since result based on 2 sf data)

do not allow reverse working based on answer to (e)

1

- (e) circuit resistance  $R = 5.5$  ( $\Omega$ ) seen in (e) working 1✓

minimum 2sf  $V$  from their  $I \times 5.5$

or

$V$  from their  $\varepsilon$  – their  $I \times r$  2✓

for 1✓ allow  $R = \frac{22}{4}$  or  $\frac{11}{2}$ ; allow  $R^{-1} = \frac{4}{22}$   
 etc

for 2✓ correct  $R$  only; expect  $V = 1.3(1)$  V; use of  $I = 0.25$  A gives  $V = 1.38$  V

do not allow  $V \geq$  their  $\varepsilon$

$r$  using lost volts divided by current; full substitution of their valid data

$$\text{eg } r = \frac{1.58 - 1.31}{0.238} \quad 3\checkmark$$

or

$r$  using formula for **Figure 3**; full substitution of their valid data

$$\text{eg } r = \frac{\varepsilon}{I} - \frac{22}{4} = \frac{1.58}{0.238} - 5.5 \quad 3\checkmark$$

or

$r$  using either intercept on **Figure 3**; full substitution of their valid data

eg their vertical intercept  $\times -22$  or

their horizontal intercept  $\times \varepsilon \quad 3\checkmark$

use of 'show that' or 2 sf data:

$$r = \frac{\varepsilon - V}{I} \quad \text{with } \varepsilon = 1.6 \text{ V, } V = 1.4 \text{ V and}$$

$$I = 0.25 \text{ A gives } r = 0.80 \Omega$$

$$\frac{22}{n} = \frac{\varepsilon}{I} - r \quad \text{with } \varepsilon = 1.6 \text{ V, } I = 0.25 \text{ A}$$

$$\text{and } n = 4 \text{ gives } r = 0.90 \Omega;$$

(can find  $r$  first, then  $V$  using  $\varepsilon - Ir$ )

a vertical intercept must be calculated; result is negative, eg vertical intercept =  $-0.053$ :

$$r = -1 \times -0.053 \times 22 = 1.17(\Omega)$$

$$\text{horizontal intercept} = 0.73:$$

$$r = 1.6 \times 0.73 = 1.18(\Omega)$$

minimum 2 sf result in range 0.80 and 1.3(0) ( $\Omega$ )  $4\checkmark$

allow  $4\checkmark$  only if there is clear evidence of a valid method leading to a result in range

4

(f)  $n = 2$  and  $n = 3 \quad 1\checkmark$

$n = 5$  or  $n = 6$  or  $n = 7 \quad 2\checkmark$

to improve distribution of points (along the line) or wtte  $3\checkmark$

for  $1\checkmark$  and  $2\checkmark$  if suggesting more than three values for  $n$  accept only the last three

for  $3\checkmark$  allow:

'spread out' / 'avoid concentrating' points'

where current /  $n$  is smaller' or wtte 'reduce distance between points (data)' / (add) detail

'most uniform distribution' / 'most equally spread

*out' / 'roughly evenly spaced'*

*reject:*

*'making points (data) 'equally' / 'evenly-spaced' /  
'even spread' (without qualification)*

*'easier to plot / draw line' / 'line more accurate' /  
'easier to see trend' are neutral*

3

- (h) both points move (by  $\geq$  half a grid square) to the right 1✓

both points move (by  $\geq$  half a grid square) causing the gradient of a straight line between them to be reduced 2✓

*allow badly-marked points / use of arrows*

*ignore any best-fit line added to **Figure 5***

*for 1✓ rightwards motion of each point must be  
parallel to gridlines  $\pm$  half small square*

*award of 2✓ mark is independent of 1✓ mark*

*for 2✓ the points do not need to move in the same  
direction*

2

[17]

**Q14.**

(a) <sup>1</sup>✓ idea of **maximising distance**

use tongs / tweezers / handling tool (when handling source to keep as far away from source as possible)

OR keep at least 2 metres away (if observing)

*award 1 mark for each valid procedure (unless contradicted)*

*do not award more than 1 mark for safety procedure 1 and do not award more than 1 mark for safety procedure 2*

*do **not** credit the same marking point for **different** do not award more than 1 mark for safety procedure 1 procedures*

*for <sup>1</sup>✓ treat as neutral: 'keep source at arm's length / far away' / 'use pliers' / don't go close (to the source)*

<sup>2</sup>✓ idea of **limiting exposure time during** experiment

remove source from lab / room when not in use / after experiment

OR idea of put / replace / keep source in a castle / container when not in use / in the open / after experiment or write

*for <sup>2</sup>✓ do not insist on 'lead'*

*treat as neutral: 'use a lead container'*

*treat as neutral: 'limit time of exposure' / 'work as quickly as possible' / 'don't keep source out of box for too long' / 'keep source sealed'*

<sup>3</sup>✓ is about **shielding** using a named absorber

stand behind a lead absorber / screen (when source is in the open)

*for <sup>3</sup>✓ accept aluminium or steel for lead; use of lead apron*

<sup>4</sup>✓ is safe use of source when removed from castle

never point (open end of) the source at anyone / at yourself

OR do not look directly at / look into the source

*for <sup>4</sup>✓ accept 'avoid eyes'*

*treat as neutral: 'avoid direct contact' / 'don't touch source' / 'always point source at ground'*

<sup>5</sup>✓ is about **good practice**

read local rules (about the use of radioactive sources) /

OR read / post warning / notice on the door

*for 5 ✓ accept 'report any damage to a source'  
treat as neutral: 'use safety screen' / 'don't stand in front' / 'don't ingest / swallow' / 'wash hands after use' / 'wear safety glasses / goggles / gloves / lab coats' / 'use film badge'*

*no credit for procedures that are the responsibility of the teacher / radiation protection adviser, eg 'obtained signed consent form'*

MAX 2

(b) 5 ✓

*correct answer only*

1

(c) **A**

OR  $^{222}_{86}\text{Rn}$  / radon 222 /  $\text{Rn}_{222}$  ✓

**B**

OR  $^{218}_{84}\text{Po}$  / polonium 218 /  $\text{Po}_{218}$  ✓

**I**

OR  $^{210}_{82}\text{Pb}$  / lead 210 /  $\text{Pb}_{210}$  ✓

*if candidates have provided more than 3 responses, each extra error / contradiction negates one correct response; if there are 3 or more errors / contradictions, award no marks*

*answers may be given **in any order***

*accept unnamed isotope with correct A, Z eg  $^{222}_{86}\text{X}$  eg while the suggestion that A, B and I are correct earns 3 the suggestion that A, B, I and J are correct earns 3 – 1 = 2*

3

(d) suitable procedures to eliminate systematic error are:

remove (all radioactive) source(s) (from the room)

OR

measure  $A_b$  before the source is present / in another room

OR

put source in (lead) castle / (lead) container / behind a (lead) absorber 1 ✓

zero / reset the counter AND/OR stopwatch (before use)

*do not insist on references to systematic or random*

*error but give no credit for explicit talk-out eg 'use a long integration time to eliminate systematic error'*

*for  $_{1}\checkmark$  treat as neutral: 'measure  $A_b$  with no source near' / 'check source is shielded / far away / out of range / sealed' / 'in another area' / 'point detector away from the source (or vice-versa)' / 'don't point source at counter' / 'put detector behind source'*

OR

check the counter AND/OR stopwatch has no zero error  $_{2}\checkmark$

*for  $_{2}\checkmark$  treat as neutral: 'zero / reset the equipment (before use)' / 'zero the detector'*

measure  $A_b$  on same day as experiment is carried out  $_{3}\checkmark$

*for  $_{3}\checkmark$  treat as neutral: 'measure  $A_b$  after experiment to double-check'*

measure  $A_b$  in same room / location / area as that where experiment is to be carried out  $_{4}\checkmark$

*for  $_{4}\checkmark$  treat as neutral: / 'keep detector in the same position' / 'measure  $A_b$  in different positions'*

suitable procedure to reduce percentage uncertainty in  $A_b$  is:

use long(er) (integration) time / prolonged time

OR

(total of) at least 100 s  $_{5}\checkmark$

*for  $_{5}\checkmark$  accept idea of a suggested total time, taking account of repeats, exceeding 100 s (eg 10 repeated 10 s counts and 1 single 100 s single count amount to the same thing) treat as neutral: 'repeat and average' ignore anomalous results' / 'use room with high background count / record large reading' / 'use more than one detector'*

MAX 3

(e) use of 5.5 MeV shown by **working** on **Figure 4**  $_{1}\checkmark$

minimum thickness MAX 3sf that rounds to 12 mm  $_{2}\checkmark_{3}\checkmark$

OR

minimum thickness MAX 3sf that rounds to 11 mm / MAX 3sf that rounds to 13 mm  $_{23}\checkmark$

*for  $_{1}\checkmark$  use of 5.5 MeV can be inferred from **Figure 4** as a (horizontal) **line**, a **mark** on the vertical axis or a **mark** on the curve / intersection between curve and a vertical line, **above 5 MeV and below 6 MeV**;*

a single line / mark between 5 and 6 MeV with no subsequent working can score 1✓

any line does not have to be ruled or perfectly parallel to the grid line;

allow a cross or a small blob as the mark on the curve;

do not insist on seeing a vertical line

if more than one line is drawn / mark is made then mark as per scheme if a clear decision has been made about which read-off has been used to provide the result for the **thickness**;

allow only one **thickness** given as final answer

2✓ 3✓ OR 23✓ can be earned without any working on the grid / other intermediate working

OR

use of 7.8 MeV shown by working on **Figure 4** AND minimum thickness is 16, 17 or 18 mm 123✓

for 123✓ use of 7.8 MeV can be inferred from **Figure 4** as a line, mark on axis / curve etc above 7 MeV and below 8 MeV; accept MAX 3 sf result that rounds to 16, 17 or 18 mm

1  
2

(f)  $d = \sqrt{k} \times \frac{1}{\sqrt{A}} - e$  OR  $d = \sqrt{k} \times \sqrt{\frac{1}{A}} - e$  OR  $d = \sqrt{\frac{k}{A}} - e$  seen 1✓

states  $\sqrt{k}$  = gradient OR  $k$  = gradient<sup>2</sup> 2✓

gradient from  $\Delta d$  divided by  $\frac{1}{\sqrt{A}}$  with  $\Delta \frac{1}{\sqrt{A}} \geq 0.5$  3✓

$k$  minimum 2 sf in range  $1.7(0) \times 10^5$  to  $1.9(5) \times 10^5$  4✓

unit for  $k$  = mm<sup>2</sup> Bq or mm<sup>2</sup> s<sup>-1</sup> 5✓

for **statement** that  $k$  = gradient mark as follows:

for  $d = k \times \frac{1}{\sqrt{A}} - e$  AND  $k$  = gradient 12✓ = 1 MAX;

award 3✓ as above

45✓ = 1MAX ecf for the following:

$k$  in range 410 to 450 or 2 sf  $4.1$  to  $4.5 \times 10^2$  mm Bq<sup>0.5</sup> or mm s<sup>-0.5</sup>

OR

$k$  in range 0.41(0) to 0.45(0) m Bq<sup>0.5</sup> or m s<sup>-0.5</sup>

OR

$k$  in range 41.(0) to 45.(0) cm Bq<sup>0.5</sup> or cm s<sup>-0.5</sup>

for  $_1\checkmark$   $d$  must be the subject;

allow obvious slips, eg  $D$  for  $d$

for  $_2\checkmark$  allow  $\sqrt{k} = m$  if  $y = mx + c$  is quoted so

inference that  $\sqrt{k} = \text{gradient}$  is clear; this mark is for **explaining** the step and **not** for performing the calculation

for  $_3\checkmark$  the mark is for the process, not the result; evidence of acceptable steps on grid with plausible result are enough; no credit if false origin missed allow working subsumed into calculation of  $k$

for  $_4\checkmark$  gradient based on  $d$  in mm (expected = 433 mm Bq<sup>0.5</sup>) POT 10<sup>5</sup> required

for  $_5\checkmark$  the unit given for  $k$  must be consistent with the POT of the result for  $k$  / gradient<sup>2</sup>

order not important Bq mm<sup>2</sup> is acceptable; do not accept incorrect symbol, eg bq for Bq

otherwise:

if for  $_4\checkmark$  gradient based on  $d$  in m (expected  $\approx 0.43$  m Bq<sup>0.5</sup>)  $k$  in range 0.17(0) to 0.19(5)

then for  $_5\checkmark$  m<sup>2</sup> Bq or m<sup>2</sup> s<sup>-1</sup>

if for  $_4\checkmark$  gradient based on  $d$  in cm (expected  $\approx 43$  cm Bq<sup>0.5</sup>)  $k$  in range  $1.7(0) \times 10^3$  to  $1.9(5) \times 10^3$

then for  $_5\checkmark$  cm<sup>2</sup> Bq or cm<sup>2</sup> s<sup>-1</sup>

2  
1  
2

(g) second mark ( $_2\checkmark$ ) is **contingent on** award of first ( $_1\checkmark$ )

an unsupported answer or an answer obtained by scale drawing or by extrapolation off the grid score zero

attempts to find  $e$  by calculation by any valid method using gradient or  $k$  with all data **correctly** substituted in **their** expression;

allow use of  $y$  for  $d$ ,  $x$  for  $\frac{1}{\sqrt{A}}$ ,  $m$  for  $\sqrt{k}$  and  $c$  for  $e$ ;

attempts to solve for  $e$   $_1\checkmark$

for  $_1\checkmark$  use of  $y = mx + c$  with recognisable data **correctly** substituted, eg

$e = \text{their gradient} \times \frac{1}{\sqrt{A}} - d$  with substitution of

their gradient and values of values of  $d$  and

$\frac{1}{\sqrt{A}}$  from a point on the line from **Figure 6**  
OR

$e = \sqrt{k} \times \frac{1}{\sqrt{A}} - d$  with substitution of their  $k$  etc  
OR

(-)  $e = \text{gradient} \times \text{horizontal intercept}$ , with  
substitution of their gradient and horizontal intercept  
ignore POT errors in their gradient / their  $k$ ;  
allow mixed units and read-off errors of 1 small  
square

1

$\geq 2$  sf result in range  $\geq 28(.0)$  and  $\leq 32(.0)$  (mm)  $_{2}\checkmark$

for  $_{2}\checkmark$  answer in range only (no ecf from 01.6) allow  
negative answer

1

[19]

**Q15.**

(a) general procedure

- collect water for a measured time;
- **divide** measured / calculated volume by time to determine rate  $1\checkmark$   
*static volume should be measured **after timing**, eg  
 reject 'measure time to fill cylinder' or  $1\checkmark = 0$   
 accept 'find V for different t, plot V against t,  
 gradient = Q' but not if by continuous flow method*

1

names 2 suitable instruments  $2\checkmark$ 

for time use stopwatch or stopclock;  
 treat as neutral: 'timer' or 'light gate / data logger'  
 for volume use measuring cylinder / graduated  
 beaker;  
 treat as neutral: 'measuring beaker' / 'burette'  
 OR

for mass use balance; use of  $V = \frac{m}{\rho}$  (any subject)  
 condone 'volume of 1 g is 1 cm<sup>3</sup>';  
 reject 'weigh'/'weighed'

1

method to reduce uncertainty in volume  $3\checkmark$ 

read water level at bottom of the meniscus (or wtte  
 or allow sketch); don't penalise further use of  
 'beaker' treat as neutral: 'dry cylinder before use'  
 OR

procedure to avoid systematic error in determining  
 mass, eg tare / reset / zero the balance with empty  
 beaker on pan / find mass of beaker empty and  
 subtract from mass of beaker plus water;  
 don't penalise further use of 'weigh'/'scales' allow  
 'use balance on a horizontal surface'

method to reduce uncertainty in time  $4\checkmark$ 

$\checkmark$  ensure stopwatch is zeroed / reset before use

added detail  $5\checkmark$   $6\checkmark$   $7\checkmark$ 

collect large(r) volume / for long(er) time /  $\geq 60$  s  $5\checkmark$   
 this reduces percentage / fractional uncertainty  $6\checkmark$   
 read at eye level or wtte, to reduce parallax  $7\checkmark$

MAX 2

(b) sensible mark identifying second box indicating (N m<sup>-2</sup> s) only  
**auto marked question**

1

- (c) 19.8% (from  $4 \times 2.9\% + 1.8\% + 6.4\%$ ) earns both marks ✓✓  
*don't insist on seeing '%' unless 0.198 etc*  
*allow final answer rounded to 20%*  
*allow 1 mark for 0.198 or 0.20 but reject 1 sf 0.2*  
*for incorrect answer the following can earn one mark:*  
*(percentage uncertainty in  $d$  =)  $4 \times 2.9\% / 11.6\% / 12\%$  seen in working but wrong final answer*  
*OR missing  $\times 4$  eg  $2.9\% + 1.8\% + 6.4\% = 11(.1)\%$*   
*OR incorrect multiplier applied to 2.9 eg  $2 \times 2.9\%$*   
*OR with  $\times 4$  applied wrongly eg*  
 $2.9 + (1.8 \times 4) + 6.4 = 16.5\%$  or  $17\%$  /  
 $2.9 + 1.8 + (6.4 \times 4) = 30(.3)\%$

2

- (d) appropriate use (ie close to and parallel with the vertical side of the tube, but not necessarily in contact with the tube) of:

a metre ruler made vertical using a set-square in contact with the bench / floor / (flat) surface

OR

a plumb line / weight on vertical string (reject 'pendulum')

OR

a spirit level ✓

*the mark can be awarded for a convincing sketch,*  
*eg use of a very large set square without ruler*  
*accept 'tri-square' for set square*  
*the only acceptable horizontal reference is the bench: don't allow use of horizontal T, eg set square placed on T even if sketch looks convincing*  
*no credit for attempt to show graduations on tube are horizontal / use of 'protractor' for set-square / 'each side of meniscus at same level' / use of clamp stand rod or wall as vertical reference*

1

- (e) attempted use of  $y = y_0 e^{-\lambda \Delta t}$  with substitution of values of  $y$ ,  $y_0$  and  $\Delta t$  obtained **directly** from **Figure 4** / plausible values obtained from **Figure 7**

OR

tangent drawn on **Figure 4** to find  $\frac{dy}{dt}$  ;

use of  $\frac{dy}{dt} = (-)\lambda \times y^*$  and  $y^*$  is where tangent meets the curve  $1\checkmark$

valid calculation **seen** leading to a result for  $\lambda$  that rounds to 3 sf in range  $4.45$  to  $4.55 \times 10^{-3} \text{ (s}^{-1}\text{)}$ ;

award if seen in body of answer  $2\checkmark$

for  $1\checkmark$  do not penalise  $y / y_0$  interchanged, read off

errors, manipulation errors /  $\Delta t = t / t_0 / \frac{t}{t_0}$  or use of incorrect symbols eg A, N for y;

no ecf for  $2\checkmark$

allow use of **Figure 7**

$y_0 = 60.0 \text{ cm}$ ,  $y = 52.2 \text{ cm}$ ;  $\Delta t = 60 - 29 = 31 \text{ s}$

$52.2 = 60 e^{-31\lambda}$ ;  $\therefore \lambda = 4.49 \times 10^{-3} \text{ s}^{-1}$

if the intermediate step is seen, eg

$$\lambda = \frac{1}{\Delta t} \times \ln\left(\frac{y_0}{y}\right) = \frac{1}{31} \times \ln\left(\frac{60}{52.2}\right)$$

accept 'log' for 'ln'

no credit allowed for reverse-working method in a 'Show that' problem

no credit for assuming straight line and  $y = mx + c$ , measuring the gradient then by determining the

equation of the line or by using  $m = \frac{y_2 - y_1}{t_2 - t_1}$

determines the half life; finds  $\lambda$  from  $\frac{\ln 2}{\text{half life}}$

no credit for common error  $\lambda = \text{gradient} \times 2$

for  $2\checkmark$  look for any answer in the body that deserves credit (for a 'Show that' we can overlook truncation in the value given on the answer line)

variation on use of use of  $y = y_0 e^{-\lambda t}$  for  $1\checkmark$ :

$\lambda$  can be found if points  $t_1, y_1$  and  $t_2, y_2$  are used and the values

substituted into  $\frac{y_1}{e^{-\lambda t_1}} = \frac{y_2}{e^{-\lambda t_2}}$ ;

$$\lambda = \frac{1}{\Delta t} \times \ln\left(\frac{y_0}{y}\right)$$

if this approach is used substitute the data into to confirm that the result for  $\lambda$  is correct before awarding  $2\checkmark$

1  
1

(f) use of  $T_{1/2} = \frac{\ln 2}{\lambda}$  OR  $\frac{\ln 0.5}{-\lambda}$  with substitution of **recognisable**  $\lambda$ ;

evaluated to  $\geq 2$  sf in range 140 s to 170 s  $\checkmark$   
*calculation can have any subject;*  
*accept use of 2 sf  $\lambda = 4.5 \times 10^{-3}$  usually leading to*  
*154 but allow correctly truncated to 150 or  $1.5 \times 10^2$*

1

(g) (mostly) continuous line drawn on **Figure 7**;

below dashed line and with negative gradient between  $t = 0$  and  $t = 120$ ;

do not penalise linear line or shaky / thick / hairy line or slight

discontinuities; accept  $\approx$  horizontal after 100 s  $1\checkmark$

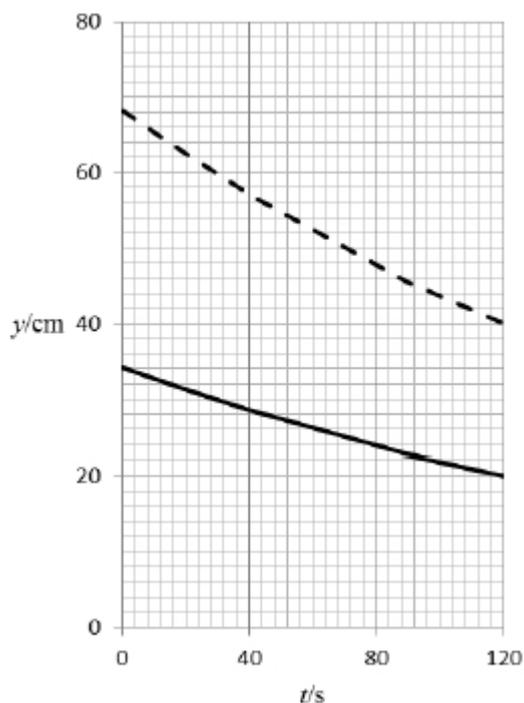
line passes through:

t/s	y/cm	
	min	max
0	33	35

AND through EITHER of

t/s	y/cm	
	min	max
60	24	28
120	17	23

$2\checkmark$



2

[13]

**Q16.**

- (a) attempt to apply principle of moments either about pivot or (LH) end of ruler  $_1\checkmark$

mass = 127(.04) (g)  $_2\checkmark$

assumption is that ruler is uniform / mass evenly distributed **OR**

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

centre of mass / gravity is at the centre/mid-point/middle  $_3\checkmark$

*for  $_1\checkmark$  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  $_1\checkmark$  and  $_2\checkmark$*

3

- (b) force on wire is upwards **OR**  $\uparrow$   $_1\checkmark$

current is from P to Q **OR** rightwards **OR** (left) to (the) right **OR**  $\rightarrow$   $_2\checkmark$

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

using left-hand rule **OR** LH rule

**AND**

B is into the page **OR** into plane of **Figure 3** **OR**  $\otimes$   $_3\checkmark$

*for  $_1\checkmark$  condone 'motion is upwards'*

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

*allow logically correct (using LH rule)  $_3\checkmark$  for either downwards force with correct current **AND/OR** upwards force with wrong current*

*increased flux density below wire is acceptable alternative to LH rule*

3

- (c) gradient calculated from  $\Delta M$  divided by  $\Delta I$ , condone read off errors of  $\pm 1$  division; minimum  $I$  step  $\geq 2.0$  A  $_1\checkmark$

evidence of  $g = 9.81$  or  $9.8$  correctly used in working for  $\sigma$  or  $B$   $_2\checkmark$

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

*for  $_1\checkmark$  expect  $(- )0.28$  ( $g A^{-1}$ ); do not penalise for*

missing – sign

for  $2\checkmark$  look for  $\sigma = \text{their gradient} \times 9.81 (\times 10^{-3} \text{ N})$

$$B = \frac{\text{their gradient} \times 9.81 (\times 10^{-3})}{15 (\times 10^{-2})}$$

**OR** ; condone POT errors

for  $3\checkmark$  CAO by correct method only; ignore – sign if provided; no limit on maximum sf

3

(d)

	Reduced	No effect	Increased
Force acting on wire		$1\checkmark$	
Force acting on prism	$2\checkmark$		
Gradient of graph	$3\checkmark$		
Vertical intercept	$4\checkmark$		

$1\checkmark = 1$  mark

$2\checkmark = 1$  mark

$3\checkmark$  and  $4\checkmark = 1$  mark

allow any distinguishing mark as long as only one per row

for  $\checkmark$  and  $X$  in same row ignore  $X$

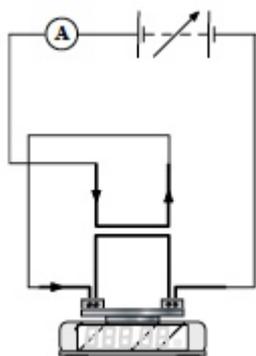
for  $\checkmark$  and  $\checkmark$  in same row give no mark

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  $1\checkmark$

wiring correct so that **X** and **Y** are in series (see below)  $2\checkmark$



allow parallel circuit for  $1\checkmark$  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  $_{1}\checkmark$

clearly identifies the correct control variable,  $d$  or  $I$  only;

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

it must be clear how the value of the control variable is known  $_{2}\checkmark$

states that  $L$  will be measured or gives value eg  $L = 5.0 \text{ cm}$   $_{3}\checkmark$

use of  $g$  to convert  $M$  reading to  $F$ ; evidence may be found in expression for  $k$   $_{4}\checkmark$

*for  $_{1}\checkmark$  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  $_{1}\checkmark$  or  $_{2}\checkmark$*

*for  $_{2}\checkmark$  if  $d$  is being varied and  $I = 5.0 \text{ A}$  is stated, this can be taken to mean  $I$  is the control variable and the value is known*

*for  $_{1}\checkmark$  and for  $_{3}\checkmark$  insist that  $M$  and  $L$  are being read **OR** measured **OR** recorded*

*for  $_{4}\checkmark$  '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  $_{5}\checkmark$

identifies correctly how  $k$  can be found using the gradient of their graph;  $k$  must be the subject of the expression given  $_{6}\checkmark$  **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  $_{6}\checkmark$

**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  $56 \checkmark = 1 \text{ MAX}$

*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  $5 \checkmark$*

*and then  $k = \frac{g \times d \times \text{gradient}}{L}$  will earn  $6 \checkmark$*

*or plot  $F$  against  $\frac{1}{d}$  will earn  $5 \checkmark$  and then*

*$k = \frac{\text{gradient}}{I^2 \times L}$  will earn  $6 \checkmark$  (note that when  $F$  is the dependent variable  $g$  will not appear in the expression for  $k$ )*

2

[19]

### Q17.

class="var"

(a) technique:

at least one instance seen where a metre ruler is made vertical using a set-square in contact with the floor  $1 \checkmark$

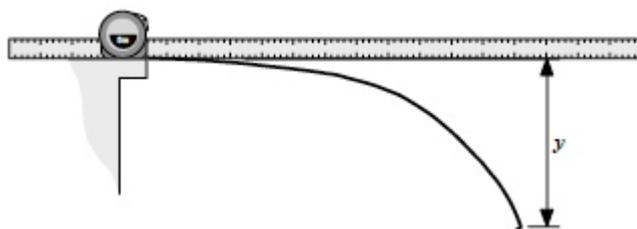
strategy:

(use a metre ruler to) measure the height of the free end of the tape (above the floor) and the height of the tape at the bench [height of the bench];

$y = \text{difference}$  between these heights  $2 \checkmark$

**OR**

use a metre ruler or straight edge placed alongside the tape measure and overhanging the (horizontal) bench, eg



$y$  is measured directly using this method using **additional** ruler  $1 \checkmark$

using **additional** ruler made vertical (as before) or using set-square placed against horizontal ruler  $2 \checkmark$

*for  $1 \checkmark$  allow use of plumb line or spirit level;*

*don't insist on the set-square being used against*

*two mutually perpendicular faces of the metre ruler  
the floor is assumed to be horizontal if the  
deflection is found from the difference between two  
vertical measurements*

*for  $_{2}\checkmark$  allow metre ruler B made horizontal by use of  
set-square against vertical ruler A; ruler B  
establishes vertical position of free end of tape;  
ruler A is used to measure  $y$  directly*

*either or both marks can be earned for suitable  
annotation to **Figure 1***

*reject suggestions that  $y$  can be found without  
making at least one vertical measurement*

2

- (b) (for  $x \leq 70$  cm  $y$  is small so) percentage/fractional uncertainty in  $y$  is (too) large **OR**

(for  $x > 70$  cm) percentage/fractional uncertainty in  $y$  not (too) large  $\checkmark$

*percentage or fractional and in  $y$  are essential;  
accept 'error' for 'uncertainty';*

*reject 'small distances are hard to measure'*

1

- (c) **continuous ruled** best-fit line drawn (at least) between 1st and 6th points;

line **must** pass below 2nd point and above 5th point;

line **must** pass above 1st point and below 6th point  $_{1}\checkmark$

gradient calculated from their best-fit line;

result, minimum 2 sf, in range 3.5 to 4.7  $_{2}\checkmark$

result for  $n$  correctly rounded from their gradient to the nearest integer  
(expect  $n = 4$ )  $_{3}\checkmark$

*for  $_{1}\checkmark$  'pass below' is taken to mean below the  
intersection of the cross-hairs defining the position  
of a point; a line that intersects (any of) the  
cross-hairs of the 1st, 2nd, 5th or 6th points loses  
this mark*

*for  $_{1}\checkmark$  the line must not be thicker than half a grid  
square, must not vary in thickness and must not be  
too faint; do not allow two lines unless these are  
drawn to calculate maximum and minimum  
gradients from which an average is then calculated*

*for  $_{2}\checkmark$  accept answers to greater than 2 sf which  
round to 2 sf in range 3.5 to 4.7*

*do not penalise for small steps or read off errors*

*for  $_{3}\checkmark$  it must be clear that final result is for  $n$  if this*

*is not on the answer line*  
*allow ecf for unexpected gradient result that is then correctly rounded to the nearest integer*  
*if no line is drawn (losing 1✓ and 2✓) allow 3✓ if n given as nearest integer to a gradient result obtained using two points on **Figure 2***

3

(d)  $\log A = (y)$  intercept seen

**OR**

$\log A = \log y$  when  $\log x = 0$

**OR**

$\log y = n \log x + \log A$  (or correctly rearranged) seen 1✓

indirect method to find (vertical) intercept described, eg

using (values for) a point on line;

substitute into equation (for the line); allow 'into  $y = mx + c$ ';

find  $\log A$  (don't penalise incorrect algebra) 2✓

$A = 10^{(y \text{ intercept})}$

**OR**

$A = 10^{(\log y - n \log x)}$  3✓

treat  $\ln A = (y)$  intercept in 1✓ as a slip and don't penalise but then insist that following work is consistent, eg insist on use of  $\ln y = n \ln x + \ln A$  (if seen) to earn 2✓

and

$A = e^{(y \text{ intercept})}$  to earn 3✓

*for 1✓ allow sensible use of  $y = mx + c$  idea;*

*reject 'log A is where line crosses y axis'*

*for 2✓ allow 'use a point on line to find x and y then sub into equation etc';*

*accept valid similar triangles idea;*

*reject anything such as extrapolating the line to suggest that the intercept can be found directly;*

*for 3✓ accept '(take/find) anti-log of (log y) intercept';*

*condone 'inverse log of (log y) for anti-log'; reject 'convert'*

accept  $A = 10^{(\log A)}$  providing 1✓ awarded

accept substitution of  $n$ , eg  $A = 10^{(\log y - 4 \log x)}$

reject  $A = 10^{(-y \text{ intercept})}$

alternative method:

using a point on line find  $\log x$ ,  $\log y$ ;

anti-log to find  $x$ ,  $y$  1✓

use  $A = \frac{y}{x^n}$  (equation seen with  $A$  the subject or equivalent description of process) 2✓

repeat (to find  $A$ ) using a different point on line;

calculate average ( $A$ ) 3✓

reject averaging of  $x$  and  $y$  or of  $\log x$  and  $\log y$

3

(e)  $A$  evaluated using  $A = \frac{y}{x^n}$  OR using  $A = 10^{(\log y - n \log x)}$  ;

correct substitution of  $n$  (from part (c)) and of  $y$  and  $x$  in cm from any row in the table (likely values shown opposite),

$A$  evaluated correctly to minimum 2 sf and correct POT 1✓

order of magnitude of  $A = -7$  OR  $10^{-7}$  (accept index or of power of ten) 2✓

$\text{cm}^{-3}$  3✓

**OR**

$\text{cm}^{(1-n)}$  where  $n$  is result given for part (c)

for 1✓ ECF for non-integer  $n$

values that may be seen in working:

$x/\text{cm}$	$y/\text{cm}$	$A$ when $n = 4$	$A$ when $n = 3.879$ *
132.4	61.2	1.99E-07	3.60E-07
116.8	33.7	1.81E-07	3.22E-07
105.1	24.3	1.99E-07	3.50E-07
94.5	15.6	1.96E-07	3.39E-07
84.3	11.0	2.18E-07	3.72E-07
73.2	5.7	1.99E-07	3.34E-07

\*equation of best-fit line gives vertical intercept = 3.879

for 2✓ accept  $1 \times 10^{-7}$  ( $\text{cm}^{-3}$ ) but reject  $1.0 \times 10^{-7}$  or  $2 \times 10^{-7}$  etc;

ECF order of magnitude correct for their value of  $A$ ;  
POT must be consistent with unit given eg if  $\text{cm}^{-3}$  is converted into  $\text{m}^{-3}$ ;

for  $\sqrt[3]{}$  CAO;

use of non-integer, eg  $n = 3.6$  requires  $A$  in  $\text{cm}^{-2.6}$

withhold  $\sqrt{}$  and  $\sqrt[3]{}$  if  $A$  is not evaluated

alternative approaches:

$A$  evaluated from  $A = \frac{y}{x^n}$  **OR** from  $A = 10^{(\log y - n \log x)}$  ;

correct substitution of  $n$  (from part (c)) and of  $y$  and  $x$  in (in m) etc;

$A$  evaluated correctly to minimum 2 sf and correct POT  $\sqrt{}$

order of magnitude of  $A = -1$  **OR**  $10^{-1}$   $\sqrt{}$

$\text{m}^{-3}$   $\sqrt[3]{}$

$x/\text{m}$	$y/\text{m}$	$A$ when $n = 4$	$A$ when $n = 3.879$ *
1.324	0.612	1.99E-01	2.06E-01
1.168	0.337	1.81E-01	1.85E-01
1.051	0.243	1.99E-01	2.00E-01
0.945	0.156	1.96E-01	1.94E-01
0.843	0.110	2.18E-01	2.13E-01
0.732	0.057	1.99E-01	1.91E-01

alternative approaches:

$A$  evaluated from  $A = \frac{y}{x^n}$  **OR** from  $A = 10^{(\log y - n \log x)}$  ;

correct substitution of  $n$  (from part (c)) and of  $y$  and  $x$  in (in mm) etc;

$A$  evaluated correctly to minimum 2 sf and correct POT  $\sqrt{}$

order of magnitude of  $A = -10$  **OR**  $10^{-10}$   $\sqrt{}$

$\text{mm}^{-3}$   $\sqrt[3]{}$

$x/\text{mm}$	$y/\text{mm}$	$A$ when $n = 4$	$A$ when $n = 3.879$ *
1324	612	1.99E-10	4.75E-10
1168	337	1.81E-10	4.26E-10
1051	243	1.99E-10	4.62E-10
945	156	1.96E-10	4.48E-10
843	110	2.18E-10	4.92E-10
732	57	1.99E-10	4.41E-10

ecf for wrong or non-integer value of  $n$ , ie for  $\text{cm}^{(1-n)}$

[12]

**Q18.**

- (a) pressure (of air) in **Figure 1c** is greater than (pressure of air) in **Figure 1d**

**OR**

pressure in **Figure 1d** is lower than pressure in **Figure 1c**  $_{1}\checkmark$

(since) temperature is the same

**OR**

Boyle's Law applies

**OR**

$PV = \text{constant}$ ;  $_{2}\checkmark$

any suggestion that pressure is constant **OR** the volume is constant **OR** the temperature changes **OR** the amount of air in the flask increases as flask is raised loses both marks

*for  $_{1}\checkmark$  must refer to either of the relevant figures or give other detail, eg 'when flask is lifted' so their meaning is unambiguous;*

*allow 'when volume decreases pressure increases' but must be comparing 1c with 1d*

*allow 'water pressure decreased in 1d'*

*treat 'air was compressed' (in 1c) as neutral*

*reject 'pressure released (in 1d)'*

*for  $_{2}\checkmark$  allow mean KE of molecules is the same*

*accept  $P \propto \frac{1}{V}$  ;*

*allow  $nRT = \text{constant}$ ;*

*reject  $PV = k$  (unless  $k = \text{constant}$  is also seen)*

2

- (b) same (air) pressure  $_{1}\checkmark$

same mass of air  $_{2}\checkmark$

any suggestion that temperature is constant **OR** that volume is constant **OR** that pressure has changed **OR** the amount of air in the flask decreases as flask is moved from H to C loses both marks

*for  $_{1}\checkmark$  and  $_{2}\checkmark$  accept constant/unchanged = same and condone 'assume same pressure/mass of gas'*

*for  $_{2}\checkmark$  accept same (number of) moles or same amount of gas*

*no credit for stating 'volume increases as*

*temperature increases'*  
*'temperature is in equilibrium' is neutral*

2

(c) relevant quantity and instrument seen:

volume(s) (of liquid) measured using a measuring cylinder **OR** graduated beaker <sub>1</sub>✓

reject 'measuring beaker' and 'burette'

eye level with the bottom of the meniscus (allow suitable sketch showing eye) <sub>2</sub>✓

'measure at eye level' **OR** 'eye level with graduation' **OR** 'eye perpendicular to graduation' are not enough to avoid parallax error <sub>3</sub>✓

see alternative opposite; if both approaches are given record the mark to whichever scores most

*alternative*

*for <sub>1</sub>✓ mass (of liquid/flask) measured using a balance*

*reject 'scales' and reject 'weigh/find weight/weigh the mass'*

*for <sub>2</sub>✓ valid method to account for the mass of flask eg tare/zero balance (ECF 'scales') with (same) empty flask on balance and then measure mass of flask with liquid **OR***

*subtract mass of empty flask from mass of flask containing liquid; don't penalise 'weigh' twice **OR** ensure the balance is on a horizontal surface for*

*<sub>3</sub>✓ find volume(s) using  $V = \frac{m}{\rho}$  ; V must be subject*

3

(d) suitable vertical scale for their data points covering at least half the grid;

false origin on the vertical scale correctly marked;

vertical scale marked at sensible intervals, based around intervals of 1, 2, 4 or 5 etc; graduations no further than 2 major divisions apart <sub>1</sub>✓

19, 207 plotted to nearest  $\frac{1}{2}$  grid square <sub>2</sub>✓

86, 255 plotted to nearest  $\frac{1}{2}$  grid square <sub>3</sub>✓

*for <sub>1</sub>✓ the two correct data points a suitable scale is  $10 \text{ cm}^3$  for each major division*

*an unmarked origin is be assumed to be (0, 0); if a broken scale symbol is not used and the V scale becomes non-linear, withhold the mark*

*award <sub>23</sub>✓ = 1 MAX for thick or poorly-marked points eg thicker than half a grid square;*

reject blobs, dots and circles

3

- (e) **continuous ruled** best-fit line of positive gradient through intersection of cross-hairs of their points ✓

*apply same criteria for judging line quality as in part (c); don't penalise thick line if thick points are penalised in part (d)*

1

- (f) legitimate method to calculate horizontal intercept

eg gradient calculated from  $\Delta V$  divided by  $\Delta\theta$  ie numerical evidence of 2 steps required; don't penalise read off errors or small steps

reads (to within 1 grid square) **OR** uses a point on the line to calculate (with correct use of  $y = mx + c$ ) the vertical intercept; sensible values are shown on the right  $_{1}\checkmark$

correct use of their vertical intercept and their gradient to calculate the horizontal intercept using  $-1 \times$  vertical intercept divided by gradient  $_{2}\checkmark$

**OR**

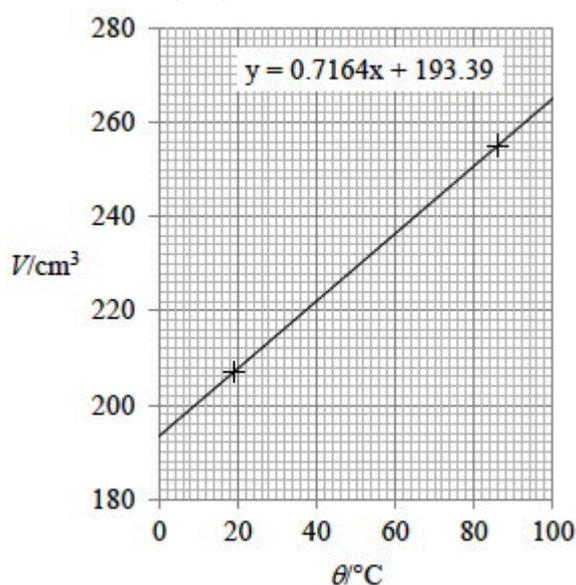
similar triangles, eg

$$\frac{255 - 207}{86 - 19} = \frac{207 - 0}{19 - \theta} \text{ or similar seen } _{1}\checkmark$$

minimum  $\Delta\theta = 86 - 19 (= 67)$  as in example above)  $_{2}\checkmark$

result in range  $-260^{\circ}\text{C}$  to  $-285^{\circ}\text{C}$   $_{3}\checkmark$

withhold mark for missing sign; no credit for unsupported answer



*in  $_{1}\checkmark$  condone V changed to  $\text{m}^3$  when calculating gradient and finding intercept values*

for a graph with a negative gradient allow credit for  
 $1\checkmark$  only = 1 MAX

no credit for non-linear graph = 0 MAX

data which may be seen in working include

$V = 193 \text{ cm}^3, \theta = 0 \text{ }^\circ\text{C}; V = 265 \text{ cm}^3, \theta = 100 \text{ }^\circ\text{C};$

$V = 207 \text{ cm}^3, \theta = 19 \text{ }^\circ\text{C}; V = 255 \text{ cm}^3, \theta = 86 \text{ }^\circ\text{C}$

3

[14]

**Q19.**

- (a)  $\theta_1 = 61.0 \pm 0.5 \text{ }^\circ\text{C} \checkmark$   
 reject 2 sf  $\theta_1$

1

- (b) sensible tangent drawn at  $t = 190 \text{ s}$ ; correct read-offs for points ( $\pm 1 \text{ mm}$ )  
 from triangle with step sizes at least  $8 \times 8_1 \checkmark$

$$G_1 = -9.57 \times 10^{-2} \text{ }_3\checkmark$$

for  $3\checkmark$  insist on correct sign and POT; accept result  
 in range  $1.05 \times 10^{-1}$  to  $-9.0 \times 10^{-2}$

3

- (c) substitution correct leading to  $\theta_R = 17.3 \pm 2.0 \text{ }^\circ\text{C} \checkmark$   
 allow ECF

1

- (d)  $\theta_0 - \theta_R$  correctly evaluated to  $\pm 1 \text{ }^\circ\text{C}$  for  $\theta_0$  at suitable reference time  $1 \checkmark$

evaluates  $\frac{\theta_0 - \theta_R}{e} \text{ }_2\checkmark$

evaluates  $\theta$  from  $\frac{\theta_0 - \theta_R}{e} + \theta_0$ ; time constant deduced from graph with  
 evidence of working (read offs to both axes are required)  $3\checkmark$

time for object to reach room temperature in range 1900 to 2000 s  $4\checkmark$

example for  $1\checkmark$ :  $\theta_0 = 89 \text{ }^\circ\text{C}$  at  $t = 0$  gives  $\theta_0 - \theta_R =$   
 $89 - 21 = 68 \text{ }^\circ\text{C}$

allow ecf for failure to take account of  $\theta_R$  in  $1 \checkmark$

example for  $2\checkmark$ :  $\frac{\theta_0 - \theta_R}{e} = \frac{68}{2.718} = 25$ ; allow ecf  
 for failure to take account of  $\theta_R$  in  $1\checkmark$

example for  $3\checkmark$ :  $\theta = 25 + 21 = 46$ ; time constant =  
 390 s

example for  $4\checkmark$ : time to reach room temperature =  
 $5 \times 390 = 1950 \text{ s}$ ; no ecf for errors in  $1\checkmark$  or in  $3\checkmark$

4

- (e) the starting temperature was lower <sub>1</sub>✓  
 the starting temperature was 86.5 °C compared to 89.0 °C <sub>2</sub>✓  
 the room temperature was higher <sub>3</sub>✓  
 the draught was less <sub>4</sub>✓  
 the water had only cooled to 38.0 °C after 600 s <sub>5</sub>✓  
 the sample rate of the data logger was lower <sub>6</sub>✓  
 samples were recorded every 20 s (rate for original experiment was much higher) <sub>7</sub>✓  
*other approaches are possible*  
*allow ± 0.3 °C for any temperature quoted for <sub>2</sub>✓ or for <sub>5</sub>✓*

MAX 5

[14]

**Q20.**

(a)  $w$  from  $\frac{R2 - R1}{6} = 0.408\text{mm} = 4.08 \times 10^{-4}\text{m}$  ✓

3 sf answer ✓

2

(b) double slit formula rearranged to give  $d = \frac{\lambda \times D}{w}$  <sub>1</sub>✓

$$d = \frac{589.3 \times 10^{-9} \times 0.395}{0.408 \times 10^{-3}} = 5.7(1) \times 10^{-4}\text{m}$$
 <sub>2</sub>✓

*allow ecf in <sub>2</sub>✓ for wrong  $w$  but not for POT error*

2

(c) use of  $PQ = \frac{d \times (D + L)}{L} = 5.46 \times 10^{-3}\text{m}$  <sub>1</sub>✓

*allow ecf for wrong  $d$  in <sub>1</sub>✓*

$$\text{number of fringes seen} = \frac{PQ}{w} = \frac{5.46}{0.412}$$
 <sub>2</sub>✓

number of fringes seen = 13 (integer only) <sub>3</sub> ✓

*allow 12 or 14 fringes*

3

(d) close jaws using ratchet ✓

confirm that instrument reads zero ✓

2

- (e) mean = 0.57(0) mm; uncertainty = 0.5 × range ✓

$$\text{percentage uncertainty} = 100 \times \frac{0.5 \times (0.574 - 0.566)}{0.570} = 0.70(2)\% \quad \checkmark$$

2

[11]

**Q21.**

- (a) Clear identification of distance from centre of sphere to right hand end of mark, or to near r.h.end of mark ✓

1

- (b) 0.393 (s) ✓

*Accept 0.39 (s)*

1

- (c) For 10 oscillations percentage uncertainty =  $\frac{0.1}{15.7} = 0.00637 \equiv 0.64\%$  ✓

same for the  $\frac{1}{4}$  period ✓

2

- (d) Identifies anomaly [0.701] ✓ and calculates mean distance = 0.759 (m) ✓

*Allow 1 max if anomaly included in calculation giving 0.750 (m)*

2

- (e) Largest to smallest variation = 0.026 (m)

Absolute uncertainty = 0.013 (m) ✓

1

- (f) Use of  $g = \frac{2d}{t^2}$  leading to

9.83 (m s<sup>-2</sup>) ✓

*Allow 9.98 (m s<sup>-2</sup>) if 0.39 used*

*Ecf if anomaly included in mean in (d)*

percentage uncertainty in distance = 1.7% ✓

Total percentage uncertainty =

$$1.7 + 2 \times 0.64 = 3.0\%$$

Absolute uncertainty = 0.30 (m s<sup>-2</sup>) ✓

[ $g = 10.0 \pm 0.3 \text{ m s}^{-2}$ ]

*Expressed sf must be consistent with uncertainty calculations*

3

(g) suggests one change ✓

Sensible comment about change or its impact on uncertainty ✓

eg

Use pointed mass not sphere

Because this will give better defined mark OR because the distance determination has most impact on uncertainty

OR

Time more swings / oscillations

As this reduces the percentage uncertainty in timing

OR

longer / heavier bar would take a greater time to swing to the vertical increasing  $t$  and  $s$  and reducing the percentage uncertainty in each

*If data logger proposed, it must be clear what sensors are involved and how the data are used.*

2

(h)  $[s = \frac{g}{2}t^2]$

plot graph of  $s$  against  $t^2$  or  $\sqrt{s}$  against  $t$  ✓

calculate the gradient ✓

the gradient is  $g/2$  or  $\sqrt{g/2}$  ✓

*Accept: plot  $s$  against  $t^2/2$  or plot  $2s$  against  $t^2$ :*

*calculate the gradient*

*in both cases gradient gives  $g$*

*Allow 1 max for answer that evaluates  $g$  for each data point and averages*

3

[15]

**Q22.**

- (a) Capacitor must not lose charge through the meter ✓ 1
- (b) Position on scale can be marked / easier to read quickly etc ✓ 1
- (c) Initial current =  $\frac{6}{100000} = 60.0 \mu\text{A}$  ✓  
 100  $\mu\text{A}$  or 200  $\mu\text{A}$  ✓ (250 probably gives too low a reading)  
 Give max 1 mark if 65  $\mu\text{A}$  (from 2.6) used and 100  $\mu\text{A}$  meter chosen 2
- (d) 0.05 V ✓ 1
- (e) Total charge =  $6.0 \times 680 \times 10^{-6}$  (C) (= 4.08 mC) ✓  
 Time =  $4.08 \times 10^{-3} / 60.0 \times 10^{-6} = 68$  s ✓  
 Hence 6 readings ✓ 3
- (f) Recognition that total charge =  $65 t \mu\text{C}$  and final pd =  $0.098 t$   
 so  $C = 65\mu / 0.098$  ✓  
 660  $\mu\text{F}$  ✓  
*Allow 663  $\mu\text{F}$*  2
- (g) (yes) because it could lie within 646 – 714 to be in tolerance ✓  
 OR  
 it is 97.5 % of quoted value which is within 5% ✓ 1
- (h) Suitable circuit drawn ✓  
 Charge  $C$  then discharge through  $R$  and record  $V$  or  $I$  at 5 or 10 s intervals ✓  
 Plot  $\ln V$  or  $\ln I$  versus time ✓  
 gradient is  $1 / RC$  ✓  
 OR  
 Suitable circuit drawn ✓

Charge  $C$  then discharge through  $R$  and record  $V$  or  $I$  at 5 or 10 s intervals ✓

Use  $V$  or  $I$  versus time data to deduce half-time to discharge ✓

$$1 / RC = \ln 2 / t_{1/2} \text{ quoted } \checkmark$$

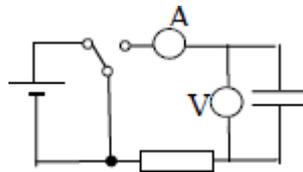
OR

Suitable circuit drawn ✓

Charge  $C$  then discharge through  $R$  and record  $V$  or  $I$  at 5 or 10 s intervals ✓

Plot  $V$  or  $I$  against  $t$  and find time  $T$  for  $V$  or  $I$  to fall to 0.37 of initial value ✓

$$T = CR \checkmark$$



*Either  $A$  or  $V$  required*

*For 2<sup>nd</sup> mark, credit use of datalogger for recording  $V$  or  $I$ .*

**Q23.**

- (a)
- $n$
- changes by 4 units, 2 units, 1 unit for each change in 100 nm ✓

OR

this is not half-life behaviour because graph has false origin for  $n$ 

OR

the magnitude of  $n$  does not halve every interval

1

- (b) Sensible long (
- $> 8$
- cm) tangent drawn, correct read-off for points from triangle at least half length of line and readings taken ✓

Substitution correct ✓

 $(-)(1.5 \pm 0.2) \times 10^4$  **and**  $m^{-1}$  ✓*Condone power of ten error in first two marks*

3

- (c) Column heading correct ✓

All calculations correct ✓

appropriate (3) sfs ✓

$1 / \lambda^2 / 10^{-12}$ $m^{-2}$
11.1
8.16
6.25
4.94
4.00
3.31
2.78

*Accept if calculated in  $nm^{-2}$  instead of  $m^{-2}$*  *$11.1 \times 10^{-6} nm^{-2}$  etc**Units as follows:  $1 / \lambda^2 / m^{-2}$ . Alternative acceptable labelling includes  $1 / \lambda^2 (m^{-2})$ ,  $1 / \lambda^2$  in  $m^{-2}$ . The  $10^{-12}$  can be in the body of the table or at top of column.*

3

- (d) Graph axes labelled correctly and sensible axes ✓

Plots correct to within half a square ✓

Best-fit line by eye ✓

*Suitably large graph scale (do not award if scale on axis could have been doubled) Scale must be sensible divisions which can be easily read. eg scales in multiples of 3, 6, 7, 9 etc are unsatisfactory.*

*2<sup>nd</sup> mark is independent mark i.e. if candidates have used an unsuitable scale they can still achieve marks for accurately plotting the points.*

*The line of best fit should have an approximately equal distribution of points on either side of the line.*

*Check bottom 3 plots.*

3

- (e) Intercept correct to within half a square ✓

*[1.6014]*

1

- (f) The value of refractive index at infinite / very long wavelength ✓

1

- (g) states that  $\log n = \log c + d \log \lambda$  ✓

plot  $\log n$  versus  $\log \lambda$  ✓

$d$  is the gradient of the graph ✓

3

**[15]**