A-Level Physics

Measurements and Their Errors

Mark Scheme

Time available: 99 minutes
Marks available: 72 marks

1.

(a) Spreading of pulse / parts of a pulse take different times to travel through the fibre / pulse broadening✓

Do not credit material dispersion.

owtte

Due to different paths through the optical fibre / due to entering the optical fibre at different angles ✓

Accept a diagram showing different paths.

2

(b) speed $(= \frac{distance}{time}) = \frac{10 \times 10^3}{5.225 \times 10^{-5}}$ ✓ (= 1.91 x 10^8)

1

(c) Reads off Sin θ_R = 0.3391

or

use of $n_1 \sin\theta_1 = n_2 \sin\theta_2$✓

Use of $n = \frac{c}{c_s}$ seen✓

With their Sin θ_R

(Refractive index of core = 1.47)

Allow use of their refractive index where cs is the subject of the formula

$cs = 2.03 \times 10^8$ ✓

Alternative:

Reads off Sin θ_R = 0.3391

or

$\theta = 19.8°$ ✓

$c_s \cos 19.8 = 1.9 \times 10^8$ ✓

$c_s = 2.03 \times 10^8$ ✓

Allow finding θ_R for their read off

Allow use of their θ_R

3

(d) The refractive index of core for blue light is greater than the refractive index for red / The refractive index of core for red light is less than the refractive index for blue✓

Max 1 mark for stating that the refractive indices are different because their speeds are different

MP1 can come from graph or prior knowledge

The speed of the blue light is less than the speed of the red light and travel the same distance / The speed of the red light is greater than the speed of the blue light and travel the same distance✓

2

(e) the blue now travels a shorter distance than the red light (compared to (d))✓

or

the red light now travels a greater distance than the blue light (compared to (d))✓

or

the difference between the blue's velocity parallel to the central axis and the red's velocity (parallel to the central axis) has decreased (compared to (d)). ✓

Allow: now travel different distances whereas previously travelled the same distance.

or

the difference between the horizontal velocity of the red light and the horizontal velocity of the blue light has decreased (compared to (d)).✓

1

[9]

2. (a) correctly deduces extension is 2.6 or 2.7 mm ✓

Should see $AC^2 = 1.50^2 + (6.34 \times 10^{-2})^2$;

(new) AC = 1.50134;

Extension of AC = (1.50134 − 1.50 =) 0.00134 m or 1.34 mm; and then doubles this

Final value must be to at least 2 sf

1

(b) evidence of correct working: ✓

$\sin\theta = \frac{6.34\times10^{-2}}{\text{their new AC}}$ or θ = 2.42° seen

OR

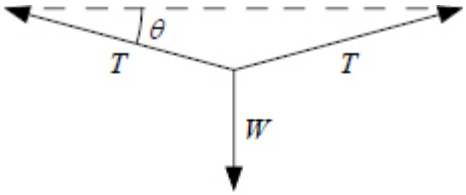
$W = 2T\sin\theta$ seen

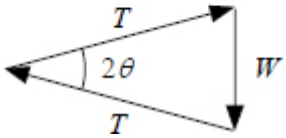
OR

suitable vector diagram with θ labelled

tension correctly calculated from $\frac{1.0}{2\times\text{their }\sin\theta}$ ✓

For 1✓ acceptable diagrams are shown below





Correct final answer of 11.8 N or 12 N earns both marks

2

(c) ruled best-fit line between first and sixth points;

line must pass above 2nd point

and

must pass below 4th point $_1$✓

for $_1$✓ withhold mark if line is thick, faint or discontinuous

gradient calculated from $\frac{\Delta(W/y)}{\Delta y^2}$ with $\Delta y^2 \geq 0.004$ $_2$✓

(gradient ~ 3850)

for $_2$✓ condone read off errors of ± 1 division

for $_3$✓ note that $1.50^3 = 3.375$ so allow sub of 3.38

for $_4$✓ reject 2 sf 1.2×10^{11}

evidence of using E = $\frac{\text{their gradient} \times 1.50^3}{1.11 \times 10^{-7}}$ $_3$✓

for $_3$✓ note that $1.50^3 = 3.375$ so allow sub of 3.38

E in range 1.10×10^{11} to 1.24×10^{11} (Pa) $_4$✓

for $_4$✓ reject 2 sf 1.2×10^{11}

4

(d) kg s^{-2} ✓

no credit for N m^{-1}

correct answer only

1

[8]

3. (a) 28 (°C) ✓

1

(b) The energy transferred reduces the number of nearest atomic neighbours

First alternative must not imply total loss of intermolecular forces or neighbours.

A reference to 'breaking the bonds' implies all the bonds and does not gain the mark.

No mark for saying bonds weaken.

However these errors in discussing the bonds does not prevent a mark coming from another point

OR

allows atoms to move their centre of vibration

Last alternative might be expressed as 'atoms change from fixed positions to them being able to slide around each other'.

Ignore any references to changes in separation.

OR

breaks some of the (atomic) bonds

OR

crystalline to amorphous ✓ (owtte)

An explanation that involves increasing the kinetic energy will lose the mark.

So will any description that implies it becomes a gas.

1

(c) The (total or mean) kinetic energy remains constant. ✓

The (total or mean) potential energy increases. ✓

2

(d) The mean speed/mean kinetic energy increases ✓

Ignore references to larger separation (because it's not always true): collisions (as it is not a gas) or measures of randomness (which are usually too vague).

Condone use of average for mean.

Don't allow velocity instead of speed.

During this time interval the atoms are all in the liquid form so no credit for references that indicate a change of state.

1

(e) Using both $\Delta Q = mc\Delta\theta$ **and** $\Delta Q = P\Delta t$ ✓

$$\left(c = \frac{P\Delta t}{m\Delta\theta} = \frac{35 \times (14.8 - 11.2) \times 60}{0.25 \times (110 - 28)} = 369\right)$$

c = 370 ✓ (allow 365–375)

J kg^{-1} K^{-1} ✓ (or J kg^{-1} C^{-1})

First mark can be given by seeing the substitution which may have some errors for example not using exactly 28. These will be penalised in the second mark.

Correct answer gains first two marks NB 400 J kg^{-1} K^{-1} shows candidate has wrongly made calculations for the solid. No mark for the unit if a solidus is used because of the uncertainty of whether the K is on the top or bottom line. (which is correct J / kg / K or J / kg K ?)
However allow a prefix if kilojoules are used for example.

3

(f) (Using both $\Delta Q = ml$ and $\Delta Q = P\Delta t$)

$$l\left(=\frac{P\Delta t}{m}\right) = \frac{35 \times ((11.2-1.8) \times 60)}{0.25} = 79 \text{ kJ kg}^{-1}$$ ✓

hence M = gallium ✓ (condone an ecf consistent with the calculation provided a comment is made if the value falls outside the range of the table)

The calculation yields1.3 kJ kg^{-1} if the 60 seconds is omitted.

Interim stage heat supplied = 19.7 kJ

A valid calculation must be shown to gain this second mark.

2

[10]

4.

(a) general procedure

- collect water for a measured time;
- **divide** measured / calculated volume by time to determine rate $_1$✓

***static** volume should be measured **after timing**, eg*

*reject 'measure time to fill cylinder' **or $_1$✓ = 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 $_2$✓

for time use <u>stopwatch</u> or <u>stop</u>clock;

treat as neutral: 'timer' or 'light gate / data logger'

for volume use <u>measuring cylinder</u> / graduated beaker;

treat as neutral: 'measuring beaker' / 'burette'

OR

for mass use <u>balance</u>; use of $V = \frac{m}{\rho}$ *(any subject)*

condone 'volume of 1 g is 1 cm ^{3}*';*

reject 'weigh'/'weighed'

1

method to reduce uncertainty in volume $_3$✓

read water level at <u>bottom of the meniscus</u> (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 <u>horizontal</u> surface'

method to reduce uncertainty in time $_4$✓

✓*ensure stopwatch is zeroed / reset before use*

added detail $_5$✓ $_6$✓ $_7$✓

collect large(r) <u>volume</u> / for long(er) <u>time</u> / ≥ 60 s $_5$✓

this reduces <u>percentage</u> / <u>fractional</u> uncertainty $_6$✓

read at <u>eye level</u> or wtte, to reduce <u>parallax</u> $_7$✓

MAX 2

(b) sensible mark identifying second box indicating (N m^{-2} s) only

auto marked question

1

(c) 19.8% (from 4 × 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 × 2.9% / 11.6% / 12% seen in working but wrong final answer

OR missing × 4 eg 2.9% + 1.8% + 6.4% = 11(.1)%

OR incorrect multiplier applied to 2.9 eg 2 × 2.9%

OR with × 4 applied wrongly eg

2.9 + (1.8 × 4) + 6.4 = 16.5 % or 17 % /

2.9 + 1.8 + (6.4 × 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 Δt 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 $_1$✓

valid calculation **seen** leading to a result for λ that rounds to 3 sf in range 4.45 to 4.55 × 10^{-3} (s^{-1});

award if seen in body of answer $_2$✓

for $_1$✓ do not penalise y / y_0 interchanged, read off

errors, manipulation errors / $\Delta t = t$ / t0 / $\frac{t}{t_0}$ or use of incorrect

symbols eg A, N for y;

no ecf for $_2$✓

*allow use of **Figure 7***

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

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

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 λ from $\frac{\ln 2}{\text{half life}}$

no credit for common error λ = gradient × 2

for $_2$✓ 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 $y = y_0 e^{-\lambda \Delta t}$ for $_1$✓:

λ can be found if points t_1, y_1 and t_2, y_2 are used and the values substituted into $\frac{y_1}{e^{-\lambda t_1}} = \frac{y_2}{e^{-\lambda t_2}}$;

if this approach is used substitute the data into $\lambda = \frac{1}{\Delta t} \times \ln\left(\frac{y_0}{y}\right)$ to confirm that the result for λ is correct before awarding $_2$✓

1
1

(f) use of $T_{½} = \frac{\ln 2}{\lambda}$ OR $\frac{\ln 0.5}{-\lambda}$ with substitution of **recognisable** λ;

evaluated to ≥ 2 sf in range 140 s to 170 s ✓

calculation can have any subject;

accept use of 2 sf λ = 4.5 × 10^{-3} usually leading to 154 but allow correctly truncated to 150 or 1.5 × 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 ≈ horizontal after 100 s $_1$✓

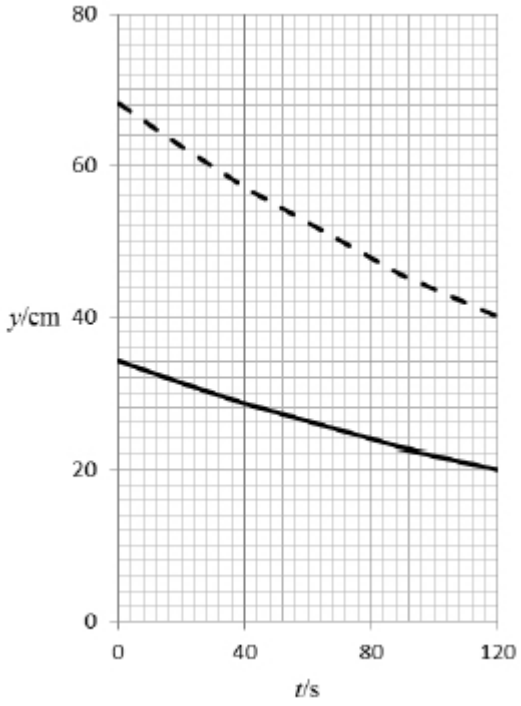
line passes through:

t/s	*y*/cm	
	min	max
0	33	35

AND through EITHER of

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

$_2$✓



2

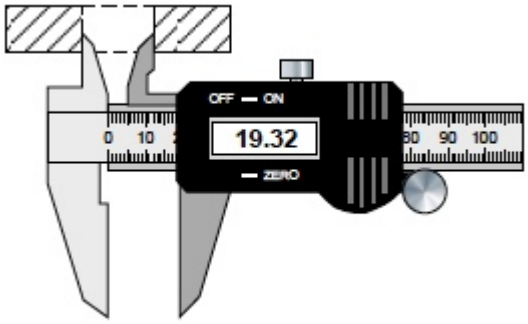
[13]

5. (a) to reduce the impact of systematic error: tare [zero] the callipers before use
OR
take reading with callipers fully closed (at some stage) and subtract from readings $_1$✓

to reduce the impact of random error: take measurement several times for different diameters/directions and calculate mean
OR
take measurement several times for different diameters to check for anomalies $_2$✓

2

(b) use of inside jaws on callipers required: must have a clear drawing with inside jaws in contact internal diameter$_1$✓



*A **sectional** view of the magnet must be given*

Jaws must be inside cavity (as here)

1

(c) Determines a cross-sectional area: (larger A=) 2.82

$\times 10^{-3}$ or (smaller area =) 2.932×10^{-4}

OR

states that the cross sectional area from Δ

$$A = \left(\frac{\pi D^2}{4} - \frac{\pi d^2}{4} \right)$$

OR

Calculates one volume correctly $_1$✓

Allow POT error $_1$✓ and $_2$✓

Where r is used must have an additional statement on how r relates to D (in the case where there is no correct substitution and no correct answer)

substitution of D = 59.90, d = 19.32 and t = 12.09 into

$$V = \left(\frac{\pi D^2}{4} - \frac{\pi d^2}{4} \right) \times t$$

OR

V = their $\Delta A \times 12.09$

OR

Correctly finds difference in ***their*** volumes $_2$✓

Or equivalent

Correct substitution into

$$V = \left(\frac{\pi D^2}{4} - \frac{\pi d^2}{4} \right) \times t$$

receives the first two marks (allow POT)

Expect values:

V_D *= 3.41 × 10^{-5} (m^3)*

V_d *= 3.54 × 10^{-6} (m^3)*

3.1×10^{-5} / 3.05×10^{-5} / 3.053×10^{-5} (m^3) $_3$✓

no limit on maximum sf

Correct answer scores 3

Allow 3rd sf round error where

answer rounds to 3.1 × 10^{-5}

when correct method seen

3

(d) ***Procedure:***

MAX 2

Take more measurement(s) of *h* for additional / different masses (of clay) ✓

More than one added mass, allow varies amount of clay

Convert (total) mass into weight (and equal to the repulsive force of magnet **A** on magnet **B**) ✓

Describe method to measure *h* using ruler or set square ✓

(in this case determination of k must be consistent with graph)

Analysis:

Plot a graph of *F* against $1/h^3$ ✓

Condone $1/h^3$ against F or equivalent

Should be a straight line of best fit ✓

This mark can be awarded if seen by drawing of straight line with positive gradient on sketch of graph

***Determination of k*:**

MAX 1

Measure gradient and set equal to *k* ✓

*Allow one mark for plot of F against h^3 and statement that area under graph is k. Mark **Procedure** as scheme*

Substitute (total) weight into formula and rearrange to find *k* ✓

Must be consistent with graph

5

[11]

6. (a) Mass of alpha particle = $\frac{2\times1.6\times10^{-19}}{4.81\times10^{7}}$ =6.6(53) × 10^{-27} (kg)

Allow mass = 2 × m_p + 2 × m_n = 6.696 × 10^{-27} kg

Allow mass = 4 × 1.66 × 10^{-27} kg = 6.64 × 10^{-27} kg

Allow mass = 4 × 1.67 × 10^{-27} kg = 6.68 × 10^{-27} kg

Allow slight rounding on mass (must be correct to 2 sf)

OR

Correctly re-arranged k.e. equation (with v^2 or v as subject) with 8.1×10^{-13} (J) substituted correctly$_1$✓

1.56×10^7 seen $_2$✓

Condone ***incorrect mass*** *in otherwise correct substitution* ***with v or v²*** ***recognisable*** *as subject .*

Alternative approaches are:

$$v = \sqrt{\frac{E_k \times \text{specific charge}}{e}}$$

$$v = \sqrt{\frac{2 \times E_k}{m_\alpha}}$$

Must see answer to at least 2 sf

Must see attempt to use one of the alternative approaches to support correct answer

2

(b) Use of $W = Fs$, $F = 8.1 \times 10^{-13} \div 3.5 \times 10^{-2}$ $_1$✓

(F=) 2.3×10^{-11} (N) $_2$✓

Condone POT error

Correct answers gets 2 marks

OR

Use of an appropriate equation of motion to find a **and** $F = ma$

(allow their mass and their velocity in this sub) $_1$✓

Condone POT error

(F=) 2.3×10^{-11} (N) $_2$✓

Condone POT

OR

Use of an appropriate equation of motion to find t **and** $F = \Delta mv/t$

(allow their mass and their velocity in this sub) $_1$✓

(F=) 2.3×10^{-11} (N) $_2$✓

[answer is

$$\frac{(\text{their speed})^2 \times (\text{their } m_\alpha)}{0.070}$$

Using 2×10^7 m s^{-1} yields(5.71×10^{15} × their m_∞) – allow 1 sf answer in this case

Expect to see 3.8×10^{-11} (N) or 4×10^{-11} (N)]

2

(c) (Number of ions formed over range =)

$5.1 \times 10^4 \times 3.5$ seen **or** 1.785×10^5 (ions) seen

OR

8.1×10^{-13} converted to eV seen $_1$✓

$8.1 \times 10^{-13} \div 1.785 \times 10^5$

OR

$5.06 \times 10^6 \div 1.785 \times 10^5$ seen $_2$✓

Condone POT error in first mark

Ignore units

$8.1 \times 10^{-13} \div (5.1 \times 10^4 \times 3.5)$ is worth 1st and 2nd marks

Condone POT errors in second mark

Correct answer obtains 3 marks

28 (.4) (eV) $_3$✓

99(.3) (eV) scores 1 mark

3

(d) (Q =) $0.85 \times 10^{-3} \times 1.2 \times 10^{-9} = 1.02 \times 10^{-12}$

OR

n = (their Q) $\div 1.6 \times 10^{-19}$ $_1$✓

$n = 6.4 \times 10^6$ (c.a.o.) $_2$✓

Condone one POT error for one mark

2

(e) At 3.5 cm the pd drops / the current begins

OR

When the source is 10 cm away no ionisation occurs in the air gap (because the alpha particles have insufficient range to reach the air gap)

OR

When the radioactive source is close enough (approx. 5 cm) ionisation occurs ✓

OR

When beyond 3.5 cm no change in pd / current equals zero

Must be sense of abrupt change

MAX 3

When ionisation occurs / charge carriers are liberated in the air gap:

Allow more ionisation for second mark

resistance has decreased

OR

current increases (from zero)

OR

the potential difference decreases (with a maximum current) (to its minimum value) (across the air gap)✓

From 10 cm separation until 5 cm (approx) separation nothing changes / appreciates that pd is 4500 V / pd across gap = 4500 V until ionisation occurs ✓

Current is produced: the pd across 5 MΩ resistor is 4250 V / most pd is across the 5 MΩ resistor / small pd across air gap ✓

Current is produced and the pd across the air gap is 250 V✓

Current is produced and the pd across the air gap is 250 V✓

3

[12]

7. (a) To detect anomalies so these can be rejected

Reason for calculating a mean must be qualified.

Ignore:

To decrease the percentage uncertainty

OR

Determine a mean thus producing a more accurate / repeatable / reproducible value

Ignore:

To make it more accurate (without reason why)

OR

To reduce the effect of random error / variations in width of pencil

Ignore:

To make the reading more reliable

OR

Readings from micrometer are more accurate / have a smaller (percentage) uncertainty (than using a ruler) because the micrometer has a greater resolution

Ignore:

To make it more precise

Condone 'sensitivity' for resolution

1

(b) $\%\ \text{uncertainty} = \frac{\frac{1}{2}\text{range}}{\text{mean}} \times 100) = 1.19\%$ ✓✓

1.19 % awarded 2 marks without supporting working

1 % or 1.2 % are permissible answers but must be supported by convincing working

Maximum of 3 sf permissible for answer

1 mark can be awarded for:

(Evidence for a calculated mean =) 7.15 (mm)

Reject 7.2 for calculated mean

OR

$(\frac{1}{2}\text{range} =) 0.085\text{(mm)}$

Reject $\frac{1}{2}\text{range} = 0.09\text{(mm)}$

OR

Use of % uncertainty = $\frac{uncertainty}{mean} \times 100$

OR

Use of % uncertainty = $\frac{\frac{1}{2}\text{range}}{\text{mean}} \times 100$

Allow their "½ range", their "uncertainty" and their "calculated mean" in use of...

But will need to see formula quoted on page and numbers or correct subject and equals sign and numbers for awarding use of...

2

(c) d = 2.2(1) mm ✓ ✓

Correct answer worth 2 marks

Condone 3rd sf rounding error if process correct

ECF from (b)

1 mark can be awarded for:

(Area of core = 0.09 × 42.43 or =) 3.8(2) seen

Penalise Talk Out on same line by use of a subject that is not an area

Allow $\frac{\pi d^2}{4}$ *as area of core or* πr^2

Allow any value of w from this list (7.06, 7.10, 7.15, 7.16, 7.20, 7.23, 7.1, 7.2, 7) or ECF from (b)

Allow any value of 0.83 w^2 *from this list (41.37, 41.84, 42.43, 42.55, 43.02, 43.39, 40.67) or ECF from (b)*

Allow any value of core from this list (3.72, 3.77, 3.82, 3.83, 3.87, 3.90, 3.66) or ECF from (b)

Condone power 10 error for 1 mark

OR

$$d = \sqrt{\frac{4 \times 0.09 \times 0.83w^2}{\pi}}$$

Accept their area (as a numerical value) for (0.09 × 0.83 w^2)

Do not allow *area of core = 0.83* d^2

OR

$$r = \sqrt{\frac{0.09 \times 0.83w^2}{\pi}}$$

Accept their area (as a numerical value) for (0.09 × 0.83 w^2)

Answers must be on answer line or clearly identified as answer by using correct subject and equals sign

2

(d) 85.3 **or** 85.4 (mm) ✓

General Marker

Must be 3 sf

1

(e) 83.8 **or** 83.9 (mm) ✓

General Marker

Mark together with (d)

*Where <u>both</u> (d) and (e) are incorrectly quoted as the **cm** value then award a compensatory 1 mark. Otherwise mark independently*

e.g: (8.53 <u>and</u> 8.39) or (8.53 <u>and</u> 8.38) or (8.54 <u>and</u> 8.39) or (8.54 <u>and</u> 8.38): award 1 mark

Must be 3 sf

1

(f) Answers 133.43, 142.33, 152.32, 142.16 ✓ ✓

(Allow 2 sf or more)

Allow **ECF**

One of these correct answers without working obtains two marks.

ECF must be supported by appropriate working

1 mark can be awarded for:

(Decrease in length per cm drawn found =)

$$\frac{\text{change in length (ans to (e) } - \text{ ans to (d))}}{20 \times 25} = 2.8 \times 10^{-3}$$

OR

$$\frac{\text{half pencil length (ans to (d)} \div 2)}{\Delta\text{length (ans to (e) - ans to (d))}}$$

Allow ecf from answers to (d) and (e),

condone any power of 10 errors on intermediate working seen

2

[9]