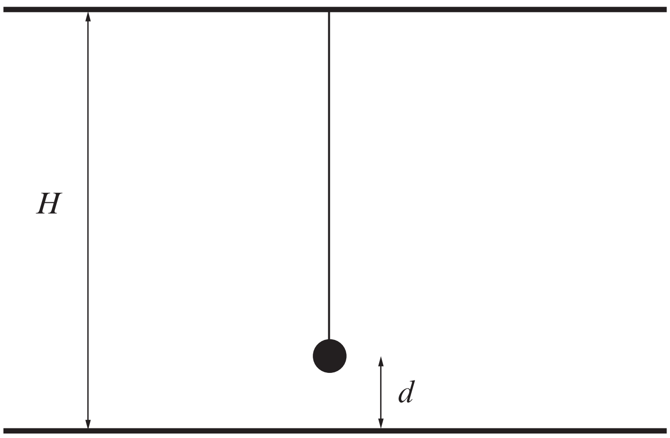
Examiner only

Data Analysis Task

A Physics student designs an experiment to measure the height of the laboratory using a simple pendulum. (This is a mass placed on the end of a light string and made to oscillate). The string is attached to the ceiling and its length is varied.

The student does not measure the length of the string. Instead the distance, *d*, from the floor to the mass is measured as shown below.



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The period of oscillation of the pendulum *(T)* is given by the equation:

$$T = 2\pi\sqrt{\frac{H - d}{g}}$$

where H is the height of the laboratory and g is the acceleration due to gravity.

(a) If values of T^2 are plotted against d a straight line graph is obtained.
Explain why the intercept on the T^2 axis of the graph is equivalent to $\frac{4\pi^2}{g}H$ and the gradient is equivalent to $-\frac{4\pi^2}{g}$. [2]

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The results obtained by the student are tabulated below.

Distance *(d)* (m)	Mean time for 20 oscillations (s)	Period of one oscillation (T) (s)	Period of oscillation squared (T^2) (.....)
0.100	62.2		±0.1
0.200	60.8		±0.1
0.300	59.4		±0.1
0.400	58.2		±0.1
0.500	56.6		±0.1
0.600	55.4		±0.1
0.700	53.8		±0.1
0.800	52.4		±0.1
0.900	50.6		±0.1
1.000	49.2		±0.1

(b) Complete the third and fourth columns giving an appropriate unit for T^2. [3]

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(c) Plot a graph of T^2 (vertical axis) against d (horizontal axis) including error bars for T^2. Draw a line of maximum gradient and a line of minimum gradient through the data. [5]

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(d) Explain whether or not your graph is in good agreement with the equation:

$$T = 2\pi\sqrt{\frac{H - d}{g}}$$

[3]

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(e) (i) Calculate the maximum and minimum gradients for your graph. [3]

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(ii) Hence determine the mean gradient and its **percentage** uncertainty. [2]

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(iii) Calculate a value for g and comment on its accuracy. [3]

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(f) (i) Calculate the mean value of the intercept on the T^2 axis and its **percentage** uncertainty. [2]

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(ii) Hence determine the height of the laboratory giving a value for its **absolute** uncertainty. (Assume $g = 9.81\,\mathrm{m\,s^{-2}}$.) [2]

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END OF PAPER

DATA ANALYSIS TASK – Mark Scheme

<table>
<tr><th>Question</th><th></th><th>Marking details</th><th>Marks Available</th></tr>
<tr><td>(a)</td><td></td><td>
Re-arrange the equation as $T^2 = \frac{4\pi^2 H}{g} - \frac{4\pi^2 d}{g}$ (1)

The re-arrangement should be explicit, i.e. the initial squaring step shown, e.g.

$T^2 = (2\pi)^2 \frac{H-d}{g}$ or $T^2 = 4\pi^2 \frac{H-d}{g}$

Explicit comparison with $y = mx + c$ (1), e.g.

$T^2 = \frac{4\pi^2 H}{g} - \frac{4\pi^2}{g}d$
</td><td>2</td></tr>
<tr><td>(b)</td><td></td><td>
Unit for T^2 given as s^2. (1)
Third column correct with all values to 3 sig figs (1) [see below].
Fourth column correct with all values to 2 (or 3) sig figs (1) [see below].

<table>
<tr><th>Period of one oscillation (T) (s)</th><th>Period of oscillation squared (T^2) (s^2)</th></tr>
<tr><td>3.11</td><td>9.67 ± 0.10</td></tr>
<tr><td>3.04</td><td>9.24 ± 0.10</td></tr>
<tr><td>2.97</td><td>8.82 ± 0.10</td></tr>
<tr><td>2.91</td><td>8.47 ± 0.10</td></tr>
<tr><td>2.83</td><td>8.01 ± 0.10</td></tr>
<tr><td>2.77</td><td>7.67 ± 0.10</td></tr>
<tr><td>2.69</td><td>7.24 ± 0.10</td></tr>
<tr><td>2.62</td><td>6.86 ± 0.10</td></tr>
<tr><td>2.53</td><td>6.40 ± 0.10</td></tr>
<tr><td>2.46</td><td>6.05 ± 0.10</td></tr>
</table>
</td><td>3</td></tr>
<tr><td>(c)</td><td></td><td>
Axes labelled with units – correct orientation [ecf on incorrect units in table – if no units are given in the table there is no ecf here]. (1)
Suitable scales (not involving awkward factors, e.g. 3 / over ½ each axis used). (1)
All points plotted correctly to within ½ small square division. (1)
All error bars plotted correctly. (1)
Correct steepest and least steep lines consistent with the error bars. (1)
See exemplification on pages 6-11 for additional guidance on marking this section.
</td><td>5</td></tr>
</table>

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Turn over.

Question		Marking details	Marks Available
(d)		N.B. There is no mark for Yes / No only. Comment regarding straight line, e.g. it's a straight line! (1) Mention of negative gradient. (1) Mention of positive intercept [accept clear implication, e.g. 'intercept as expected']. (1)	3
(e)	(i)	Large triangles used (should be close to the extremities of the lines) or 2 equivalent suitable points clearly indicated on each line or clearly implied by calculation [see below]. (1) Both gradients calculated correctly (ignore unit and significant figures). (2) Allow **ecf** for incorrect max/min lines. Example of clear implication [from graph on page 7]. Max gradient = $\frac{5.97 - 10.14}{1.00 - 0.00}$ = [–]4.17[$s^2\,m^{-1}$]✓ Min gradient = $\frac{6.12 - 9.96}{1.00 - 0.00}$ = [–]3.84[$s^2\,m^{-1}$]✓ N.B. No penalty for positive gradient here. Marking tips: First check: The value of m_{max} should be ~ [–]4.2 [$s^2\,m^{-1}$] and the value of m_{min} should be about [–]3.85 [$s^2\,m^{-1}$]. Candidates who have drawn lines which are too extreme may obtain >4.25 and <3.80. This is penalised in *(c)*, so apply **ecf**. Candidates who have drawn 'tram lines' will have two nearly identical values of ~[–]4.02. Again **ecf** should be applied.	3
	(ii)	Mean gradient correct (1) [expected value ~[–]4.01[5] $s^2\,m^{-1}$ but apply **ecf** from *(c)* and *(e)*(i)] (no sig fig penalty). % uncertainty correct (1) [expected value ~± 5%. – Allow 2 sig figs. Apply **ecf** from *(c)* and *(e)*(i)].	2
	(iii)	g calculated correctly (1) (by whatever means including using points from the line of **best** fit) and quoted to 1 or 2 d.p. (if answer in $m\,s^{-2}$). % difference calculated on the comparison with 9.81 $m\,s^{-2}$. (1) [Typical difference = 0.03 $m\,s^{-2}$ → 0.3%, apply **ecf**]. Comment on accuracy. (1) [Expected answer for ~ 0.3% difference is that the result is accurate]. **Alternative approach:** 1st mark as above (✓). Calculation of % uncertainty from *(e)*(ii), typical value 5% (✓). Comment that the accepted value of g is within the 5% uncertainty of the calculated value (✓).	3

Question		Marking details	Marks Available
(f)	(i)	Mean value correct (1) [expected value ~ 10.05 s^2] (no sig fig or unit penalty). Percentage uncertainty correct to 1 or 2 sig figs (1) [expected value ~ 1%]. Intercept values 10.14 s^2 and 9.96 s^2 give a value of 10.05 ± 0.09 s^2, i.e. a % uncertainty of ~ 0.9%.	2
	(ii)	*H* calculated correctly (1) **ecf**. Uncertainty correct and values quoted to appropriate significant figures. (1) **ecf** The expected values are 2.50 ± 0.03 m also accept 2.500 ± 0.025 m.	2
		Total	**25**

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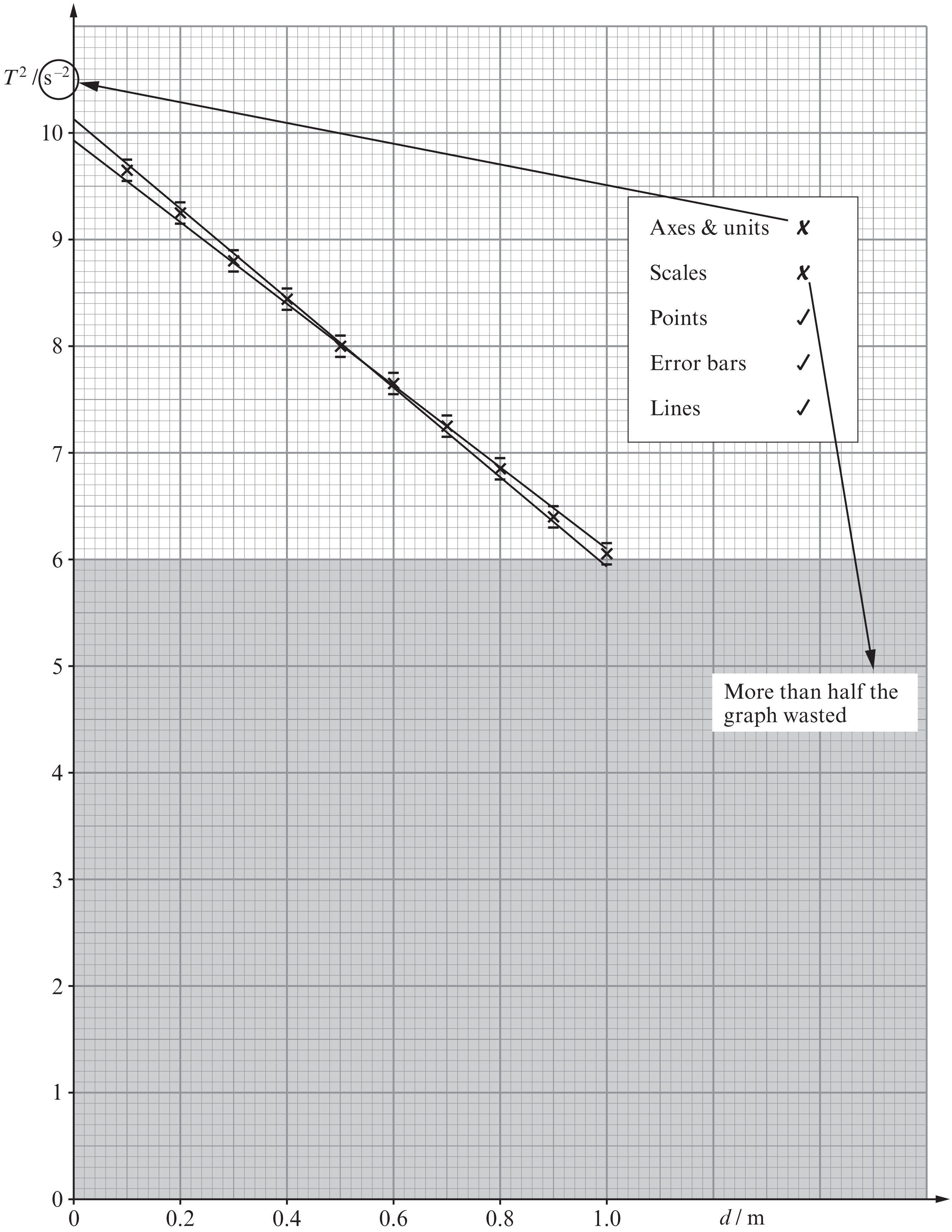
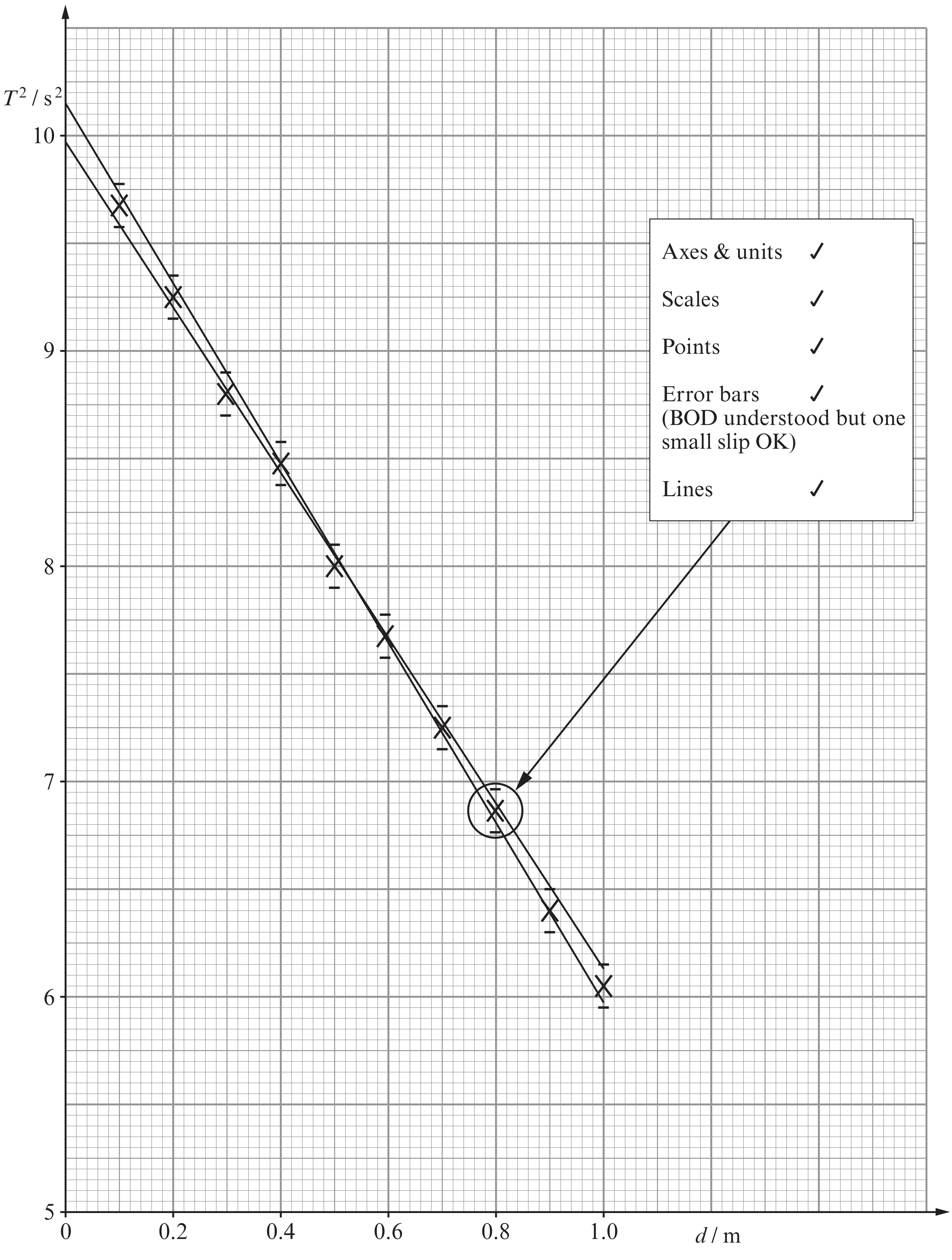
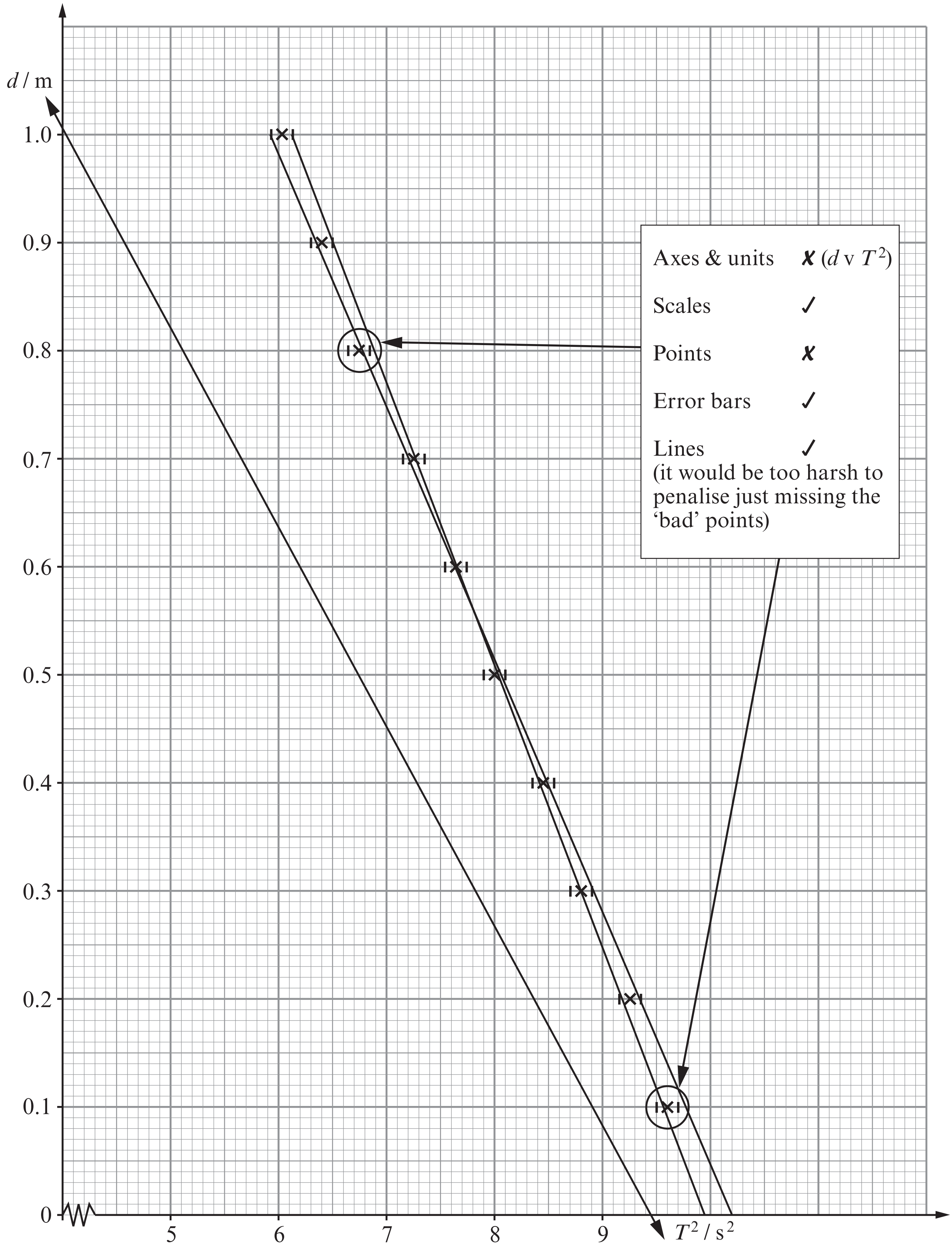
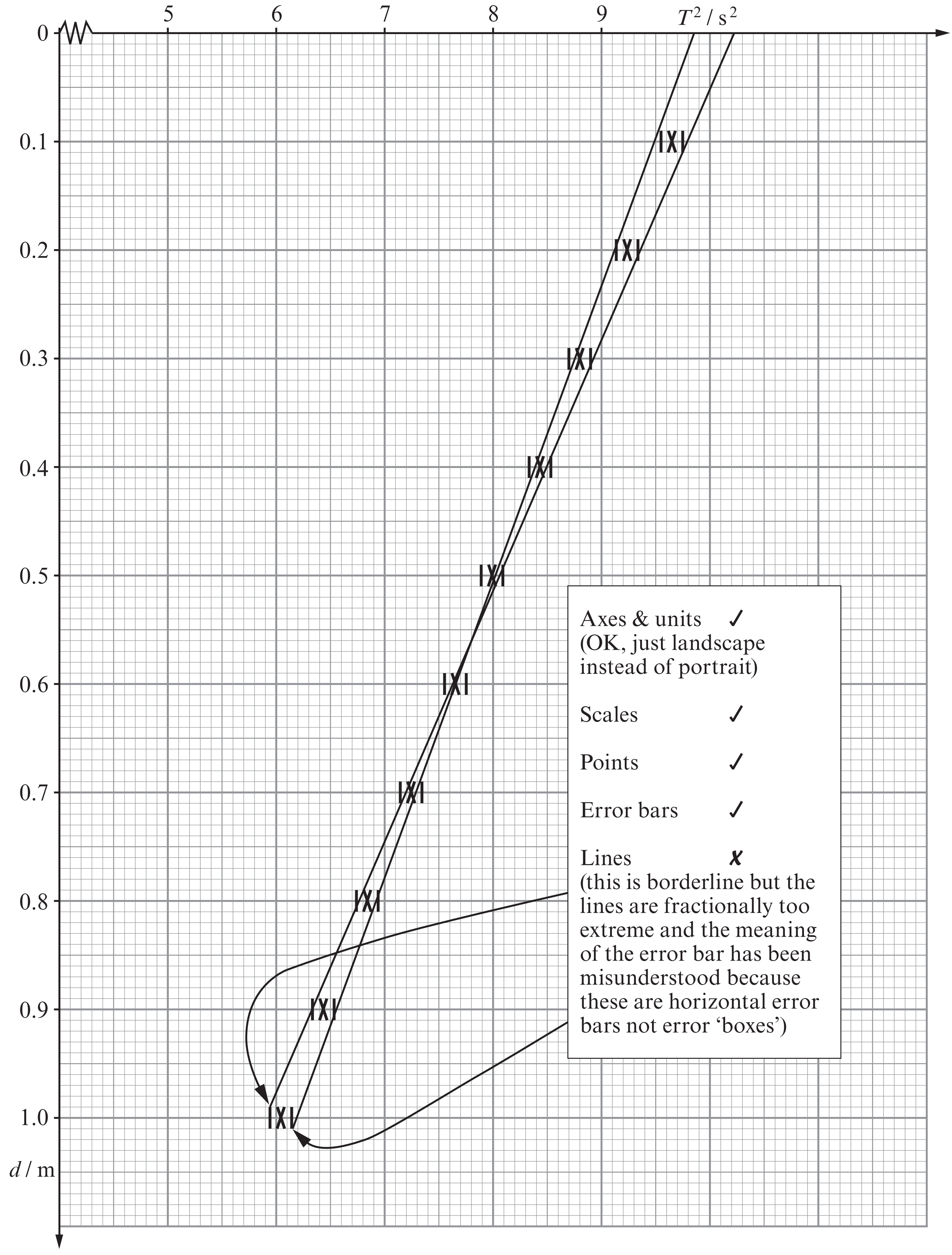
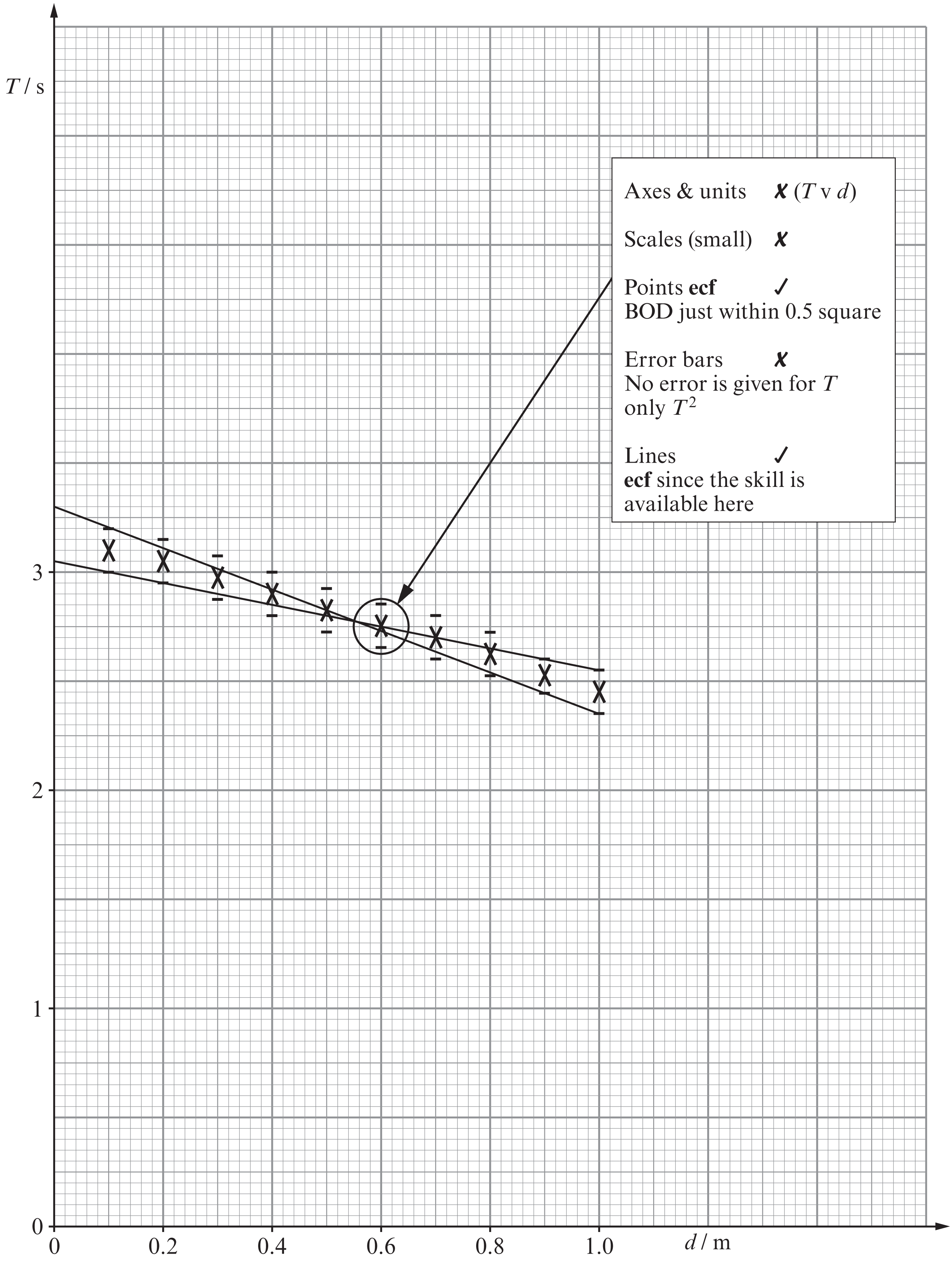
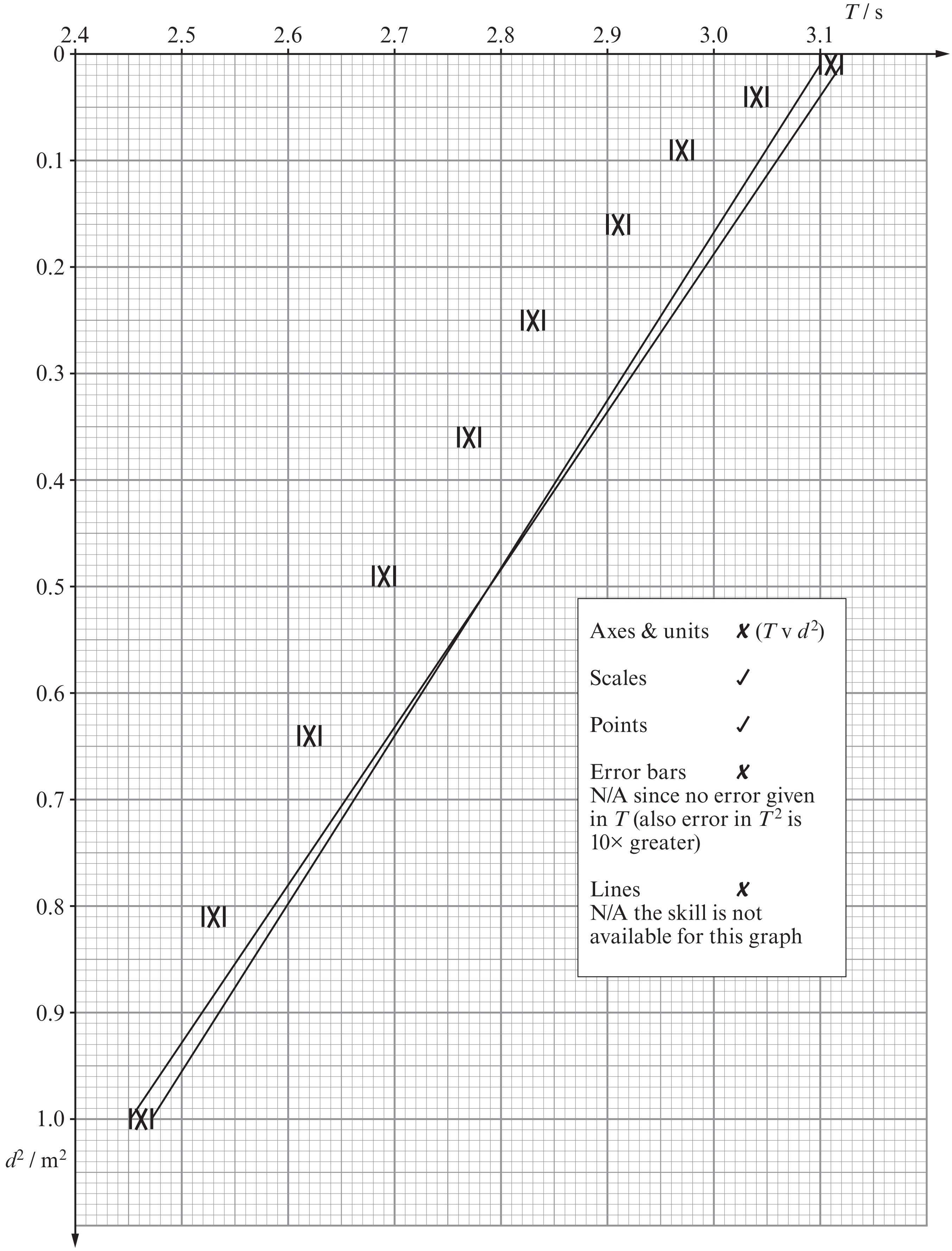

T^2 / s^{-2}
10
9
8
7
6
5
4
3
2
1
0
0
0.2
0.4
0.6
0.8
1.0
d / m
Axes & units ✗
Scales ✗
Points ✓
Error bars ✓
Lines ✓
More than half the graph wasted


T^2 / s^2
10
9
8
7
6
5
0
0.2
0.4
0.6
0.8
1.0
d / m
Axes & units ✓
Scales ✓
Points ✓
Error bars ✓
(BOD understood but one small slip OK)
Lines ✓


d / m
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5
6
7
8
9
T^2 / s^2
Axes & units ✗ (d v T^2)
Scales ✓
Points ✗
Error bars ✓
Lines ✓
(it would be too harsh to penalise just missing the 'bad' points)


5
6
7
8
9
T² / s²
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
d / m
Axes & units ✓
(OK, just landscape instead of portrait)
Scales ✓
Points ✓
Error bars ✓
Lines ✗
(this is borderline but the lines are fractionally too extreme and the meaning of the error bar has been misunderstood because these are horizontal error bars not error 'boxes')


T / s
3
2
1
0
0
0.2
0.4
0.6
0.8
1.0
d / m
Axes & units ✗ (T v d)
Scales (small) ✗
Points ecf ✓
BOD just within 0.5 square
Error bars ✗
No error is given for T
only T²
Lines ✓
ecf since the skill is
available here



Axes & units ✗ (T v d^2)

Scales ✓

Points ✓

Error bars ✗
N/A since no error given in T (also error in T^2 is 10× greater)

Lines ✗
N/A the skill is not available for this graph

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SECTION B

Task B4 (45 minutes)

You are going to use a pendulum to determine a value for the acceleration due to gravity, g.

A pendulum has been set up for you. Pull the mass to one side and release it. The pendulum swings backwards and forwards in an oscillating motion.

(a) (i) Clearly describe the energy changes when the pendulum is in motion. [2]

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(ii) Explain why the pendulum eventually comes to rest. [1]

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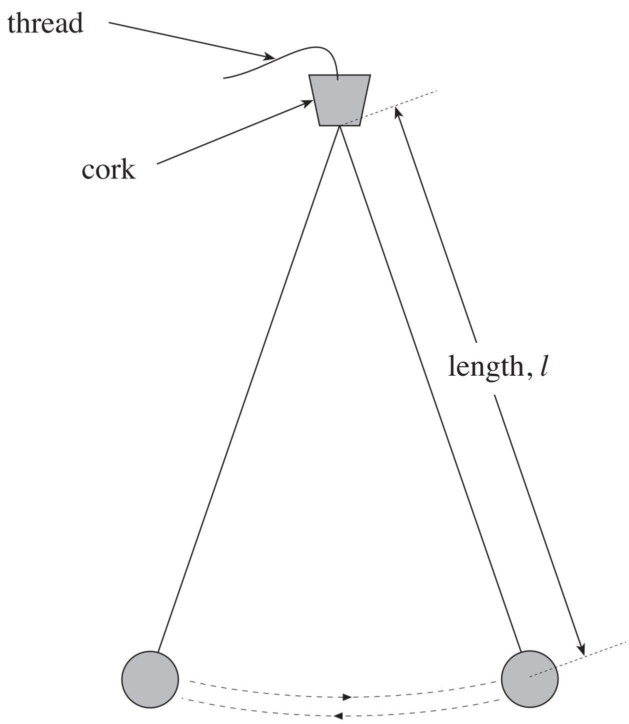
(b) The period T of the pendulum is the time taken for one oscillation. This is the time taken for the pendulum to swing from one side to the other **and back again** as shown in the following diagram.



The pendulum has been set up for you with a length of 0·200 m.
Take a series of measurements for the time taken for 10 oscillations for 5 different lengths in the range 0·200 m to 1·200 m.
The length can be changed by adjusting the thread through the cork. To set the pendulum in oscillation you should pull the mass to the side a small distance.

Examiner only

Record your results in a table and include and complete a column for the mean value of the time for 10 oscillations. [5]

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(c) (i) Using your results in part *(b)*, complete the following table for T^2 [where T is the period of **one** oscillation] against l, the length of the pendulum. [3]

length, l (.........)	Mean time for 10 oscillations (.........)	Mean time for **one** oscillation, T (.........)	T^2 (.........)

(ii) Plot a graph of T^2 (vertical axis) against l (horizontal axis) on the grid below. [5]

Examiner only

(iii) Calculate a value for the gradient of the graph and include appropriate units. [3]

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(d) The period, T, of one oscillation is given by the equation:

$$T^2 = \left(\frac{4\pi^2}{g}\right)l$$

where g is the acceleration due to gravity.

(i) By using your answer to part *(c)*(iii) and comparing the above equation with that of a straight line ($y = mx + c$), calculate a value for g. [3]

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(ii) The accepted value for acceleration due to gravity, $g = 9{\cdot}81\ \text{ms}^{-2}$ and your answer can be considered accurate if it is within 5% of this value. Comment on your answer. [2]

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SECTION B

TASK B4

Candidates will be expected to make measurements on the oscillation of a simple pendulum.

Test 1
Apparatus required:

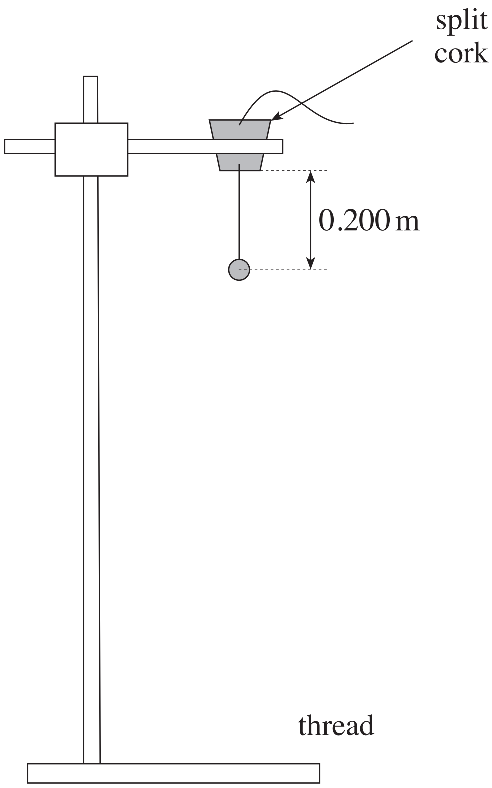
- Simple pendulum mass in the form of either a lead or brass bob.
- Length of cord - approx. 1·4 m
- Stand, clamp and boss - the height of the stand should enable the candidate to adjust the length of the pendulum to 1·20 m
- Stopwatch - Resolution ±0·01 s
- Metre rule
- Either a rubber or cork bung split to clamp the cord and enable the candidates to change the length easily
- G-clamp to secure the stand

The apparatus should be assembled and the pendulum should be set to a length of 0·200 m.

Supervisors should instruct candidates not to use extreme swings of the pendulum if this occurs during the test.

The length of the pendulum needs to be reset to 0·200 m at change over.

Apparatus set-up:



Test 2
The apparatus is as for **Test 1**, with the base of the cork/bung at a height of 1·400 m above the bench and the pendulum bob at a height of 1·200 m above the bench.

SECTION B

Task B4 (45 minutes)

You are going to use a pendulum to determine a value for the acceleration due to gravity, *g*.

A pendulum has been set up for you. Pull the mass to one side and release it. The pendulum swings backwards and forwards in an oscillating motion.

(a) (i) Clearly describe the energy changes when the pendulum is in motion. [2]

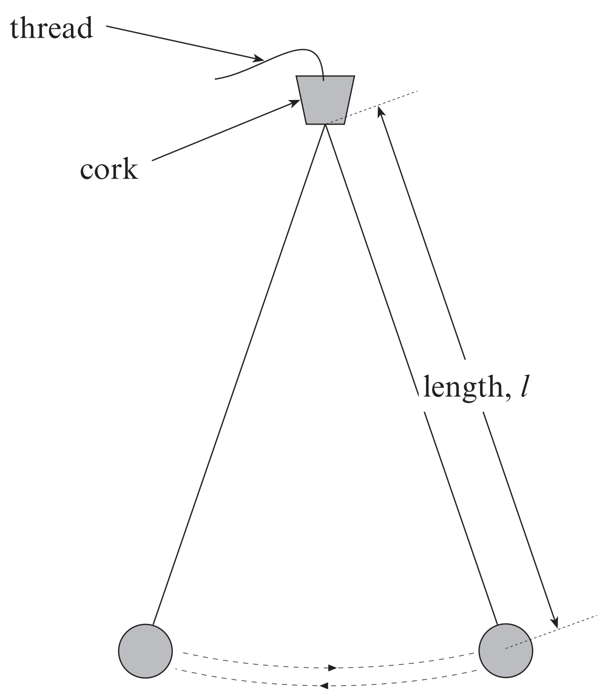
Potential to kinetic energy (or kinetic to potential energy) (1 mark)

This is continuous e.g. potential to kinetic and then potential energy (1 mark)
(can be deduced from a diagram)

(ii) Explain why the pendulum eventually comes to rest. [1]

Energy is lost against air resistance
or equiv by collision with air molecules
or energy lost due to friction at top of the string
(Energy lost due to friction or resistance is not enough)

(b) The period *T* of the pendulum is the time taken for one oscillation. This is the time taken for the pendulum to swing from one side to the other **and back again** as shown in the following diagram.



The pendulum has been set up for you with a length of 0·200 m.
Take a series of measurements for the time taken for 10 oscillations for 5 different lengths in the range 0.200 m to 1.200 m.
The length can be changed by adjusting the thread through the cork. To set the pendulum in oscillation you should pull the mass to the side a small distance.

Record your results in a table and include and complete a column for the mean value of the time for 10 oscillations. [5]

Clear headings and units for columns (1)
At least 1 repeat reading at each length (1)
Correct values for the mean time (1)
All time values quoted to 0.01s (1) [accept 0.1s]
Full range of length used, expressed to 1mm i.e. 60.0 cm not 60 cm
(no 2 values closer than 15cm used) (1)

(c) (i) Using your results in part *(b)*, complete the following table for T^2 [where T is the period of **one** oscillation] against l, the length of the pendulum. [3]

length, l (.........)	Mean time for 10 oscillations (.........)	Mean time for **one** oscillation, T (.........)	T^2 (.........)

T calculated correctly (1)
T^2 calculated correctly (accept 2 or 3 significant figures) (1)
Units correct (1)
(Do not penalise for significant figures for length and T)

(ii) Plot a graph of T^2 (vertical axis) against l (horizontal axis) on the grid below. [5]

***Do not penalise** incorrectly-orientated graph*

- *Title and units on both axes (1)*
- *Sensible scales (over half page used to plot the points, not multiples of 3) (1)*
- *All points plotted correctly to within ½ division (2 marks)*
  (Penalise 1 mark for each incorrect plot to a maximum penalty of 2)
- *Good line of best fit consistent with data (1)*

(iii) Calculate a value for the gradient of the graph and include appropriate units. [3]

- *Large triangle used (should be close to the extremities of the line of best fit)*
  [or 2 equivalent suitable points indicated on graph] (1)
- *Gradient calculated correctly (1)*
- *Units of gradient correct (s^2m^{-1}) (1)*
  (ecf on axis orientation ms^{-2})

(d) The period, T, of one oscillation is given by the equation:

$$T^2 = \left(\frac{4\pi^2}{g}\right)l$$

where g is the acceleration due to gravity.

(i) By using your answer to part *(c)*(iii) and comparing the above equation with that of a straight line ($y = mx + c$), calculate a value for g. [3]

- *Equating gradient to* $4\pi^2/g$ (1) (ecf on axis orientation)
- *Re-arrange equation to give g =* $4\pi^2$ *gradient (1) [can be awarded by implication if answer correct]*
- *Calculation correct (No unit penalty) (1)*
  (ecf on incorrect value of gradient from (c) (iii)*)*

(ii) The accepted value for acceleration due to gravity, g = 9·81 ms^{-2} and your answer can be considered accurate if it is within 5% of this value. Comment on your answer. [2]

Calculation correct for 5% of 9.81 [0.49] ms^{-2} (1)

Suitable comment (allow ecf if calculation incorrect) (1)