Q1. (

a) (mark should be at the equilibrium position) since this is where the mass moves with <u>greatest speed</u> [transit time is least] ✓

1

(b) (i) mean time for 20T (from sum of times ÷5) = 22.7 (s)$_1$ ✓ (minimum 3sf)

uncertainty (from half of the range) = 0.3 (s) $_2$ ✓ (accept trailing zeros here)

percentage uncertainty

$(\text{from } \frac{0.3}{22.7} \times 100)[\frac{100}{5} \times \sum \frac{0.3}{20T}] = 1.3\,(22)\%_3$ ✓

(allow full credit for conversion from 20T to T, e.g. 1.135 = $_1$✓ 0.015 =$_2$ ✓ ecf for incorrect $_1$ ✓ and / or $_2$ ✓ earns $_3$ ✓

3

(ii) natural frequency $(\text{from } \frac{20}{22.7} \text{ and minimum 2 sf}) = 0.88\,(1)\text{Hz}$ [accept s^{-1}] ✓

(ecf for wrong mean 20T; accept ≥ 4 sf)

(c) (i) linear scale with at least 3 evenly-spaced convenient values (i.e. not difficult multiples) marked; the intervals between 1 Hz marks must be 40 ± 2 mm (100 ± 5 mm corresponds to 2.5 Hz) ✓

1

(ecf for wrong natural frequency: 100 ± 5 mm corresponds to $\frac{2.5f}{0.88}$ Hz)

(ii) 4 mm [allow ± 0.2 mm] ✓

1

(d) (i) student decreased intervals [smaller gaps] between [increase frequency / density of] readings (around peak / where A is maximum) ✓ ✓

1

[student took more / many / multiple readings (around peak) ✓]
(reject bland 'repeated readings' idea; ignore ideas about using data loggers with high sample rates)

(ii) new curve starting within ± 1 mm of A = 4 mm, f = 0 Hz with peak to right of that in Figure 3
(expect maximum amplitude shown to be less than for 2 spring system but don't penalise if this is not the case; likewise, the degree of damping need not be the same (can be sharper or less pronounced)

2

Peak at $\sqrt{2}$ value given in **(b)(ii)**; expect 1.25 Hz so peak should be directly over 50 ± 5 mm but take account of wrongly-marked scale ✓

2

[11]

Q2. (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 ≡ 0.64% ✓

same for the ¼ 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^{-2}) ✓

Allow 9.98 (m s^{-2}) if 0.39 used

Ecf if anomaly included in mean in (d)

percentage uncertainty in distance = 1.7%✓

Total percentage uncertainty =

1.7 + 2 x 0.64 = 3.0%

Absolute uncertainty = 0.30 (m s^{-2}) ✓

[g = 10.0 ± 0.3 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]

4 **Planning (15 marks)**

Defining the problem (3 marks)

P *V* is the independent variable, or vary *V* **and** *f* is the dependent variable, or measure *f*.
Or *f* is the independent variable, or vary *f* **and** *V* is the dependent variable, or measure *V*. [1]

P Change *f* (allow *V*) until the mass leaves/gap between plate. [1]

P Keep the position of the mass constant. (Do not allow keep mass constant.) [1]

Methods of data collection (5 marks)

M Labelled diagram showing signal generator/a.c. supply connected to vibrator with two wires with mass on plate. At least two labels needed. [1]

M Voltmeter/c.r.o. connected in parallel with vibrator in a workable circuit. [1]

M Measure *f* or *T* from signal generator/c.r.o. (Allow detailed use of motion sensor/stroboscope.) [1]

M Detail regarding mass leaving the plate: listen to noise, look for gap. [1]

M Repeat each experiment for the same value of *V* (allow *f* if consistent with above) and average. [1]

Method of analysis (2 marks)

Plot a graph of:

A

f^2 against $1/V$	$1/V$ against f^2	f against $1/\sqrt{V}$	$1/\sqrt{V}$ against f	$\lg V$ against $\lg f$	$\lg f$ against $\lg V$
or	*or*	*or*	*or*		
V against $1/f^2$	$1/f^2$ against V	$\sqrt{V}$ against $1/f$	$1/f$ against $\sqrt{V}$		

[1]

A $k = \text{gradient} \times \pi^2$ $\quad k = \dfrac{\pi^2}{\text{gradient}}$ $\quad k = \text{gradient}^2 \times \pi^2$ $\quad k = \dfrac{\pi^2}{\text{gradient}^2}$ $\quad k = \pi^2 \times 10^c$ $\quad k = \pi^2 \times 10^{2c}$ [1]

Safety considerations (1 mark)

S Precaution linked to mass leaving vibrating plate, e.g. use safety screen/goggles/sand tray. [1]

Additional detail (4 marks)

D Relevant points might include [4]
1 Wait for vibrator to oscillate evenly
2 Method to determine period of oscillation from c.r.o., i.e. one time period × time-base
3 Method to determine *f* from c.r.o. having determined *T*, i.e. $f = 1 / T$
4 Method to determine *V* from c.r.o, i.e. amplitude (height) × *y*-gain
5 Relationship is valid if the graph is a straight line passing through the origin
[For lg – lg graph the gradient must be correct (–2 or –0.5)]
6 Determine *f* (allow *V* if consistent with above) by increasing and decreasing *V* or *f*
7 Clean surfaces of metal plate/small mass
8 Spirit level to keep plate horizontal/eye level to look for gap

Do not allow vague computer methods.

Q4.

<table>
<tr><th>Question</th><th>Answer</th><th>Marks</th></tr>
<tr><td>4(a)</td><td>gradient = $4\pi^2 M$</td><td>1</td></tr>
<tr><td rowspan="5">(b)</td><td>
<table>
<tr><th>T / s</th><th>T^2 / s^2</th></tr>
<tr><td>1.12 or 1.120</td><td>1.25 or 1.254</td></tr>
<tr><td>0.950 or 0.9500</td><td>0.903 or 0.9025</td></tr>
<tr><td>0.815 or 0.8150</td><td>0.664 or 0.6642</td></tr>
<tr><td>0.655 or 0.6550</td><td>0.429 or 0.4290</td></tr>
<tr><td>0.570 or 0.5700</td><td>0.325 or 0.3249</td></tr>
<tr><td>0.47 or 0.470</td><td>0.22 or 0.221</td></tr>
</table>
</td><td></td></tr>
<tr><td>Values of T as above.</td><td>1</td></tr>
<tr><td>Values of T^2 as above.</td><td>1</td></tr>
<tr><td>Uncertainties in T increase from ±0.01 to ±0.02.</td><td>1</td></tr>
<tr><td>Uncertainties in T^2 about ±0.02.</td><td>1</td></tr>
<tr><td rowspan="2">(c)(i)</td><td>Six points plotted correctly.
Must be accurate to the nearest half a small square. Diameter of points must be less than half a small square.</td><td>1</td></tr>
<tr><td>Error bars in T^2 plotted correctly.
All error bars to be plotted. Length of bar must be accurate to less than half a small square and symmetrical.</td><td>1</td></tr>
<tr><td rowspan="2">(c)(ii)</td><td>Line of best fit drawn.
If points are plotted correctly then lower end of line should pass between (0.048, 0.5) and (0.052, 0.5) and upper end of line should pass between (0.098, 1.0) and (0.104, 1.0).</td><td>1</td></tr>
<tr><td>Worst acceptable line drawn (steepest or shallowest possible line that passes through all the error bars).
All error bars must be plotted.</td><td>1</td></tr>
</table>

Question	Answer	Marks
(c)(iii)	Gradient determined with clear substitution of points from the line of best fit into $\Delta y / \Delta x$. Distance between points must be at least half the length of the drawn line.	**1**
	uncertainty = gradient of line of best fit – gradient of worst acceptable line **or** uncertainty = ½ (steepest worst line gradient – shallowest worst line gradient)	**1**
(d)(i)	*M* determined from gradient **and** given to 2 or 3 significant figures **and** with correct unit. $M = \frac{\text{gradient}}{4\pi^2} = \frac{\textbf{(c)(iii)}}{39.478}$	**1**
(d)(ii)	% uncertainty in *M* = % uncertainty in gradient	**1**

Question	Answer	Marks
(e)	*k* calculated. Correct substitution of numbers required. $k = \left(\frac{4\pi^2 M}{T^2} = \right)\frac{4\pi^2\textbf{(d)(i)}}{2.5^2}$ **or** $6.3165\times\textbf{(d)(i)}$ **or** $k = \left(\frac{\text{gradient}}{T^2}\right) = \frac{\textbf{(c)(iii)}}{2.5^2}$ **or** $\frac{\textbf{(c)(iii)}}{6.25}$	1
	Absolute uncertainty in *k*. Correct substitution of numbers required. Using *M*: $\text{uncertainty in } k = \left(\frac{\Delta M}{M} + 2\times\frac{\Delta T}{T}\right)\times k$ $\text{uncertainty in } k = \left(\frac{\textbf{(d)(ii)}}{100} + 0.008\right)\times k$ $\max k = \frac{4\pi^2 \times \max M}{\min T^2}$ **or** $\min k = \frac{4\pi^2 \times \min M}{\max T^2}$ Using gradient: $\text{uncertainty in } k = \left(\frac{\Delta\text{gradient}}{\text{gradient}} + 0.008\right)\times k$ $\max k = \frac{\max\text{gradient}}{\min T^2}$ **or** $\min k = \frac{\min\text{gradient}}{\max T^2}$	1

6 **Analysis, conclusions and evaluation (15 marks)**

	Mark	Expected Answer	Additional Guidance
(a)	A1	gradient = $\frac{-4\pi^2}{g}$ y-intercept = $\frac{4\pi^2}{g}k$	Gradient must be negative. Allow y-intercept = –gradient × k
(b)	T1	(mean) t/s, T/s and T^2/s^2	All column headings to be correct.
	T2	31.8 or 31.81 30.8 or 30.80 29.6 or 29.59 28.7 or 28.73 27.8 or 27.77 26.8 or 26.83	Check all values of T^2. Allow a mixture of significant figures.
(c) (i)	G1	Six points plotted correctly	Must be within half a small square. Penalise “blobs” Ecf allowed from table.
	U1	Error bars in d plotted correctly	All error bars to be plotted. Must be accurate to less than half a small square.
(c) (ii)	G2	Line of best fit	Lower end of line should pass between (1.60, 27.0) and (1.64,27.0) **and** upper end of line should pass between (0.44,31.8) and (0.48,31.8).

	G3	Worst acceptable straight line. Steepest or shallowest possible line that passes through <u>all</u> the error bars.	Line should be clearly labelled or dashed. Examiner judgement on worst acceptable line. Lines must cross. Mark scored only if all error bars are plotted.
(c) (iii)	C1	Gradient of best fit line	Must be <u>negative</u>. The triangle used should be at least half the length of the drawn line. Check the read offs. Work to half a small square. Do not penalise POT. (Should be about –4.)
	U2	Uncertainty in gradient	Method of determining absolute uncertainty: difference in worst gradient and gradient.
(c) (iv)	C2	*y*-intercept	FOX does not score. Check substitution into $y = mx + c$ Allow ecf from **(c)(iii)**. (Should be about 33.7.)
	U3	Uncertainty in *y*-intercept	Uses worst gradient and point on WAL. Do not check calculation. FOX does not score.
(d) (i)	C3	*g* between 9.20 and 9.90 given to 2 or 3 s.f. and correct unit ($m\,s^{-2}$) having used gradient.	$g = -\frac{4\pi^2}{m}$; allow $N\,kg^{-1}$
	C4	*k* determined correctly with correct unit (m)	$k = c\frac{g}{4\pi^2} = \frac{c}{-m}$ (*k* must be positive.)
(d) (ii)	U4	Percentage uncertainty in *g*	
	U5	Percentage uncertainty in *k*	Percentage uncertainty in *k* must be larger than the percentage uncertainty in *g*.

[Total: 15]

Uncertainties in Question 6

(c) (iii) Gradient [U2]

Uncertainty = gradient of line of best fit – gradient of worst acceptable line

Uncertainty = $\frac{1}{2}$ (steepest worst line gradient – shallowest worst line gradient)

(c) (iv) [U3]

Uncertainty = *y*-intercept of line of best fit – *y*-intercept of worst acceptable line

Uncertainty = $\frac{1}{2}$ (steepest *y*-intercept – shallowest *y*-intercept)

(d) (ii) [U4]

Percentage uncertainty in g = $\frac{\Delta m}{m} \times 100 = \frac{\Delta g}{g} \times 100$

[U5]

Percentage uncertainty in k = $\frac{\Delta k}{k} \times 100 = \frac{\Delta g}{g} \times 100 + \frac{\Delta c}{c} \times 100$

max k = $\frac{\text{max } g \times \text{max } y\text{-intercept}}{4\pi^2}$ = $\frac{\text{max } y - \text{intercept}}{\text{min gradient}}$

min k = $\frac{\text{min } g \times \text{min-intercept}}{4\pi^2}$ = $\frac{\text{min } y - \text{intercept}}{\text{max gradient}}$

Q6.

6 **Analysis, conclusions and evaluation (15 marks)**

<table>
<tr><th>Part</th><th>Mark</th><th>Expected Answer</th><th>Additional Guidance</th></tr>
<tr><td>(a)</td><td>A1</td><td>Gradient = b
y-intercept = lg a</td><td>Allow log a but not ln a</td></tr>
<tr><td>(b)</td><td>T1
T2</td><td><table>
<tr><td>1.9777</td><td>0.292 or 0.2923</td></tr>
<tr><td>1.9294</td><td>0.265 or 0.2648</td></tr>
<tr><td>1.8751</td><td>0.241 or 0.2405</td></tr>
<tr><td>1.8129</td><td>0.210 or 0.2095</td></tr>
<tr><td>1.7404</td><td>0.170 or 0.1703</td></tr>
<tr><td>1.6532</td><td>0.127 or 0.1271</td></tr>
</table></td><td>T1 for lg l column – ignore rounding errors; min 2 dp.
T2 for lg T column – must be values given
A mixture is allowed</td></tr>
<tr><td></td><td>U1</td><td>From ± 0.004 or ± 0.005 to ± 0.006 or ± 0.007</td><td>Allow more than one significant figure.</td></tr>
<tr><td>(c) (i)</td><td>G1</td><td>Six points plotted correctly</td><td>Must be within half a small square; penalise ≥ half a small square. Penalise ‘blobs’ ≥ half a small square. Ecf allowed from table.</td></tr>
<tr><td></td><td>U2</td><td>Error bars in lg (T/s) plotted correctly.</td><td>All error bars must be plotted. Check first and last point. Must be accurate within half a small square; penalise ≥ half a small square.</td></tr>
<tr><td>(ii)</td><td>G2</td><td>Line of best fit</td><td>If points are plotted correctly then lower end of line should pass between (1.65, 0.124) and (1.65, 0.128) and upper end of line should pass between (2.00, 0.300) and (2.00, 0.306). Allow ecf from points plotted incorrectly; five trend plots needed – examiner judgement.</td></tr>
<tr><td></td><td>G3</td><td>Worst acceptable straight line. Steepest or shallowest possible line that passes through <u>all</u> the error bars.</td><td>Line should be clearly labelled or dashed. Should pass from top of top error bar to bottom of bottom error bar or bottom of top error bar to top of bottom error bar. Mark scored only if all error bars are plotted.</td></tr>
<tr><td>(iii)</td><td>C1</td><td>Gradient of best fit line</td><td>The triangle used should be at least half the length of the drawn line. Check the read offs. Work to half a small square; penalise ≥ half a small square.</td></tr>
<tr><td></td><td>U3</td><td>Uncertainty in gradient</td><td>Method of determining absolute uncertainty
Difference in worst gradient and gradient.</td></tr>
<tr><td>(iv)</td><td>C2</td><td>y-intercept</td><td>Must be negative. Check substitution of point from line into c = y – mx.
Allow ecf from (c)(iii).</td></tr>
</table>

	U4	Uncertainty in *y*-intercept	Method of determining absolute uncertainty Difference in worst *y*-intercept and *y*-intercept. Do not allow ecf from false origin read-off (FOX). Allow ecf from **(c)(iv)**.
(d)	C3	$a = 10^{y \text{ intercept}}$	*y*-intercept must be used. Expect an answer of about 0.19. If FOX expect answer of about 1.3.
	C4	*b* = gradient <u>and</u> in the range 0.495 to 0.520 <u>and</u> to 2 or 3 sf	Allow 0.50 to 0.52 to 2 sf Penalise 1 sf or ≥4 sf
	U5	Absolute uncertainty in *a* and *b*	Difference in *a* and worst *a*. Uncertainty in *b* should be the same as the uncertainty in the gradient.

[Total: 15]

Uncertainties in Question 6

(c) (iii) Gradient [U3]

1. Uncertainty = gradient of line of best fit – gradient of worst acceptable line
2. Uncertainty = ½ (steepest worst line gradient – shallowest worst line gradient)

(c) (iv) [U4]

1. Uncertainty = *y*-intercept of line of best fit – *y*-intercept of worst acceptable line
2. Uncertainty = ½ (*y*-intercept of steepest worst line – *y*-intercept of shallowest worst line)

(d) [U5]

1. Uncertainty = $10^{\text{best } y \text{ intercept}} - 10^{\text{worst } y \text{ intercept}}$

Q7.

implementing

accuracy: T from nT where n or $\Sigma n \geq 3$ *
L in range 95 to 105 cm *
* **(1)**

tabulation: y / m T / s **(1)**

readings: 5 sets, y range ≥ 20 cm **(1) (1) (1)**

significant figures: all T to 0.01 s *
s to 1.0 mm *
* **(1)**
all $\sqrt{\frac{L}{L-y}}$ and $\frac{1}{T}$ values tabulated to 3 s.f. **(1)**

quality: at least 4 points to ± 2 mm of straight line, suitably scaled graph **(1)**

analysis

axes: marked $\sqrt{\frac{L}{L-y}}$ / no unit (vertical), $\frac{1}{T}$ / s^{-1} (horizontal) (1)

scale: suitable (e.g. 8 × 8) **(1)**

points: 5 plotted correctly (check at least one) **(1)**

line: straight, positive gradient, best-fit **(1)**
Δ suitable size **(1)**
to 3 s.f, in s **(1)**
in range 1.90 to 2.10 s $m^{-1/2}$ [1.80 to 2.20 s $m^{-1/2}$ **(1)]** **(1)**

G: **(1)**

result:

(16)

evaluating

(i) check that (horizontal) distance between vertical strings is the same at two places **(1)** check that the string is aligned with the longer pendulum [the string passes through the hole in the stripboard without touching the sides] **(1)**

(ii) wide range, even distribution **(1)** in order to define the shape of the graph **(1)**
unlikely to significantly improve the evidence (don't allow additional readings improve the best-fit line):

(iii) when y is small T is very large: **(1)**
it is difficult to judge exactly when the pendulums are moving in phase **(1)**

(6)

[22]