Question	Answer	Marks
1	**Defining the problem**	
	x is the independent variable and *E* is the dependent variable, or vary *x* and measure *E.*	**1**
	Keep *B* or *m* constant and keep *k* or *N* constant.	**1**
	Methods of data collection	
	Labelled diagram of workable experiment including: • labelled spring supported by stand and clamp • labelled magnet • labelled coil positioned so that magnet is vertically above the coil by eye in the correct orientation.	**1**
	Circuit diagram showing voltmeter / multimeter set to p.d. range / oscilloscope connected to the ends of the coil. Do not accept other electrical components.	**1**
	Method to measure *x*, e.g. labelled ruler drawn parallel to spring/magnet and equilibrium position and displaced position indicated and *x* indicated or difference determined or description of use of ruler to measure equilibrium position and displaced position and difference determined.	**1**
	Method to measure mass of magnet e.g. use balance or use newton-meter to measure weight and divide by *g*.	**1**
	Method of Analysis	
	Plots a graph of *E* against *x* or equivalent. **Allow** lg *E* against lg *x.*	**1**
	Relationship valid if a straight line passing through the origin is produced. (for lg *E* against lg *x*: relationship valid if a straight line with gradient = 1).	**1**
	$\alpha = \frac{\text{gradient}}{BN}\sqrt{\frac{m}{k}}$ (for lg *E* against lg *x*: $\alpha = \frac{10^{y\text{-intercept}}}{BN}\sqrt{\frac{m}{k}}$)	**1**

Question	Answer		Marks
1	**Additional detail including safety considerations**	**Max 6**	**6**
	Use safety goggles / safety screen to prevent injury (to eyes) from (detached) spring/magnet; do not accept from oscillating magnet or use cushion / sand box in case magnet falls or use g clamp / weights on stand to prevent toppling.	D1	
	Keep distance between equilibrium position and coil constant.	D2	
	Check that the unstretched length of the spring has not changed or is not permanently deformed (after removing load / magnet).	D3	
	Expression to determine *k* from relevant experiment, e.g. $k = mg$ / extension or gradient of *F* – extension graph. Weight / force must be defined.	D4	
	Measure *B* using a (calibrated) Hall probe.	D5	
	Additional detail on use of Hall probe, e.g. adjust probe until maximum value or measure *B* using Hall probe first in one direction and then in the opposite direction and average.	D6	
	Method to maximise *E*, e.g. position magnet so that equilibrium position is at the centre of the coil or use a large number of turns.	D7	
	Explanation to determine max *E* e.g. use of video and slow-motion playback.	D8	
	Repeat experiment for each *x* and average *E*.	D9	
	Method to ensure clamped rule to measure *x* is vertical, e.g. correctly positioned set square indicated at right angles between the rule and the horizontal surface or plumb line supported on a surface shown in appropriate position.	D10	

Question	Answer	Marks
2(a)	Gradient = $\frac{-1}{CR}$ y-intercept = ln $\frac{E}{R}$	**1**
2(b)	3.83 or 3.829 3.69 or 3.689 3.53 or 3.526 3.33 or 3.332 3.18 or 3.178 3.00 or 2.996	**1**
	Absolute uncertainties in ln I from ± 0.04 to ± 0.1	**1**
2(c)(i)	Six points plotted correctly. Must be within half a small square. Diameter of points must be less than half a small square.	**1**
	Error bars in ln I plotted correctly. All error bars to be plotted. Total length of bar must be accurate to less than half a small square and symmetrical.	**1**
2(c)(ii)	Line of best fit drawn. Points must be balanced. Line must pass between (5.5, 3.75) and (8.0, 3.75) and between (56, 3.05) and (58, 3.05)	**1**
	Worst acceptable line drawn. Steepest or shallowest possible line that passes through all the error bars. Mark scored only if all error bars are plotted.	**1**

Question	Answer	Marks
2(c)(iii)	Negative gradient determined with clear substitution of data points into $\Delta y / \Delta x$; distance between data points must be at least half the length of the drawn line.	1
	Gradient determined of WAL uncertainty = (gradient of line of best fit – gradient of worst acceptable line) or uncertainty = ½ (steepest worst line gradient – shallowest worst line gradient)	1
2(c)(iv)	*y*-intercept read from *y*-axis to less than half a small square, or *y*-intercept determined from substitution into $y = m\,x + c$.	1
2(d)(i)	*C* determined using gradient and *C* given to two or three significant figures Correct substitution of numbers must be seen, $C = \frac{-1}{150 \times 10^3 \times \text{gradient}} = \frac{-1}{150 \times 10^3 \times \text{(c)(iii)}}$	1
	E determined using *y*-intercept Correct substitution of numbers must be seen, $E = R \times e^{y\text{-intercept}} = 150 \times 10^3 \times e^{\text{(c)(iv)}} \left(\times 10^{-6}\right)$ Or $\ln E = \ln R + y\text{-intercept}$	1
	C determined using gradient and *E* determined using *y*-intercept and dimensionally correct SI unit for C: F or s Ω^{-1} or C V^{-1} or A s V^{-1} and *E*: V or A Ω.	1

Question	Answer	Marks
2(d)(ii)	Absolute uncertainty in C. $\Delta C = \left(0.05 + \frac{\Delta\text{gradient}}{\text{gradient}}\right) \times C$ OR Correct substitution for max/min methods $\max C = \frac{-1}{142.5 \times 10^3 \times \text{minnumericalgradient}}$ $\min C = \frac{-1}{157.5 \times 10^3 \times \text{maxnumericalgradient}}$	**1**
2(e)	I determined from **(d)(i)** OR **(c)(iii)** and **(c)(iv)** with correct substitution and correct power of ten(s). Do not accept ecf for POT from **(c)(iii)**, **(iv)** or **(d)**. $I = \frac{E}{R} \times e^{\frac{-120}{CR}}$ OR $I = e^{y\text{-intercept}} \times e^{(\text{gradient} \times 120)} \times 10^{-6}$ OR $\ln I = 120 \times \text{gradient} + y\text{-intercept}$ $I = e^{120 \times \text{gradient} + y\text{-intercept}} \times 10^{-6}$	**1**