Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1	a	i	**Method 1** $d = 8.5 – 3.2$ (= 5.3(cm)) ($F = kd$ so) F = 0.62 × 5.30 (= 3.3 (N)) $a = \frac{F}{m}$ so $a = \frac{3.3}{0.20}$ a = 17(m s^{-2}) **Method 2** ($F = kd$ so) F = 0.62 × 8.50 (= 5.27(N)) F_R = (0.62 × 8.50) – (0.20 × 9.81) (= 3.3 (N)) $a = \frac{F}{m}$ so $a = \frac{3.3}{0.20}$ **Method 3** ($F = kd$ so) F = 0.62 × 8.5 (= 5.27(N)) $\left(a = \frac{F}{m} \text{ so}\right) a = \frac{5.27}{0.20}$ = 26 (m s^{-2}) $a_{initial}$ = 26.35 – 9.81 = 17 (m s^{-2})	C1 C1 A1 (C1) (C1) (A1) (C1) (C1) (A1)	**Mark whichever method leads to the most marks** d = 5.3cm does not need to be calculated explicitly but seeing 5.3 implies first C1 mark F = 3.3N does not need to be calculated explicitly but seeing 3.3 implies both C1 marks **Allow** k = 0.61 (N cm^{-1}) leading to F = 3.2 (N)... ... and a = 16 (m s^{-2}) F = 5.27(N) does not need to be calculated explicitly but seeing 5.27 or 5.3 implies first C1 mark **Allow** k = 0.61 (N cm^{-1}) leading to F = 5.19 (N) F = 3.3(N) does not need to be calculated explicitly but seeing 3.3 implies both C1 marks **Allow** k = 0.61 (N cm^{-1}) leading to F = 3.2 (N)... ... and a = 16 (m s^{-2}) F = 5.27(N) does not need to be calculated explicitly but seeing 5.27 or 5.3 implies first C1 mark **Allow** k = 0.61 (N cm^{-1}) leading to F = 5.19 (N) Note: a= 26 (ms^{-2}) is an intermediate calculation for $a_{initial}$ in this method only and is **not** the A1 mark **Allow** k = 0.61 leading to F = 5.19 and a = 16 **Examiner's Comments** There are two measurements for extension given here: an extension of 3.2cm under a load of (0.2 × 9.81) N and an extension of 8.5cm under a force of F + (0.2 × 9.81)

					The easiest way to approach the question is to recognise that the extension due to *F* alone must be (8.5 – 3.2) = 5.3cm. *F* = *kx* then becomes *F* = 0.62 × 5.3 (since *k* is given in N cm^{-1}) and so we can use *F* = *ma* with *m* = 0.2kg to find the acceleration *a*. However, other valid methods were also given credit.
		ii	Use of $a = (-)\omega^2 x$ Use of $f = \frac{\omega}{2\pi}$ *f* = 2.8 (Hz) **<u>Alternative method:</u>** (*a* = *F* / *m* = *kx*/ *m* and *a* = (-) $(-)\omega^2 x$ gives) $\omega^2 = \frac{k}{m}$ $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$ $= \frac{1}{2\pi}\sqrt{\frac{0.62 \times 100}{0.2}}$ *f* = 2.8 (Hz)	C1 C1 A1 (C1) (C1) (A1)	The two C1 marks are independent and XP in one does not imply XP in the other **Not** just formula alone Expect *a* = 17 but **allow** ECF of *a* from **(b)(i)** **Allow** any value for *x* **Not** just formula alone Use of $a = (-)(2\pi f)^2 x$ scores both C1 marks **Allow** *f* = 2.9 (Hz) **Allow** $T = 2\pi\sqrt{\frac{m}{k}}$ $f = \frac{1}{T}$ **Allow** *f* = 2.9 (Hz) **<u>Examiner's Comments</u>** The answer to this question is frequency = 2.8Hz, since ω depends only on *k* and *m* ($\omega^2 = k/m$). However, most candidates used the formula $a = (-)\omega^2 x$ together with appropriate values for *a* and *x*.
	b	i	(motion of magnet M causes) a change of flux (linkage) in coil Y (inducing an e.m.f.) there is an (induced) <u>current</u> in (or through) coil X alternating current / field / flux in coil X interacts with the field of magnet L (causing an alternating force)	B1 B1 B1	**Allow** field (lines of M) cuts (turns of) coil Y **Allow** the coil or Y or solenoid for coil Y **Allow** the coils or the wire(s) or X for coil X **Ignore** (induced) e.m.f. **Not** changing or varying or oscillating for alternating **Allow** current / field / flux in coil X

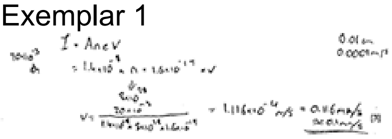
					interacts with field of magnet L **to** cause an alternating force **Allow** changing direction for alternating **Allow** combines for interacts **Allow** cuts across for interacts with **<u>Examiner's Comments</u>** Clarity in explanation was important here, as there are two magnets, M and L, plus two coils, X and Y. It is a change in flux linkage in coil *Y* which leads to an induced alternating current in coil *X*. This current creates an alternating magnetic field in coil *X* which interacts with the field of magnet *L* to create an alternating force on L. **Assessment for learning** Many explanations were too generalised: 'Faraday's Law states that there must be an induced emf which is proportional to the rate of change of flux linkage' or 'Fleming's left hand rule states there must be a force on the magnet' were often seen. Candidates should be encouraged to write in less general terms and to focus their answer on the specific question.
		ii	frequency of magnet L (always) equals (forcing/driving) frequency of vibration generator / magnet M resonance occurs at / close to 2.5 Hz amplitude is maximum at resonance	B1 B1 B1	**Allow** frequency of magnet increases with frequency of vibration generator May be seen from a **labelled** graph of amplitude against frequency **Allow** resonance occurs when forcing / driving frequency = natural frequency May be seen from a labelled graph of amplitude against frequency **<u>Examiner's Comments</u>** Many candidates did not realise that this was a question about resonance, presumably because of the unfamiliar context of the question.

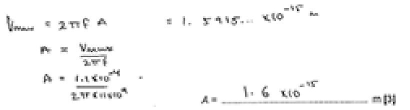
					Common problems in 4(c)(ii) • not answering every part of the question: most candidates forgot to describe how the frequency varied as well as the amplitude • not realising that the vibration generator is driving the oscillation of L, and that this is a question about resonance • not labelling the scales on the graph of amplitude against frequency (or just using letters such as *A* and *f*) • failing to mark the resonance frequency as 2.5Hz (instead calling it f_o)
•			**Total**	**12**	
2			**D**	1	**Examiner's Comments** Many candidates missed the third line of the question which states that the mass passes through the equilibrium point when t=0. This would indicate the correct function here is sine, rather than cosine. The argument of the function here (the expression inside the brackets) must be omega-t or 2πft. f here is 2 Hz, so the correct expression is 4πt.
			Total	**1**	
3			**B**	1	**Examiner's Comments** Option D is plainly false. Option A here is wrong by a factor of 10, as the correct period is 50 ms. Option C applies to stationary waves not in forced oscillations as in this case.
			Total	**1**	
4			**D**	1	**Examiner's Comments** When the initial displacement is doubled, then the amplitude and hence maximum speed is also

					doubled. If the maximum speed is doubles, the maximum KE is quadrupled, since KE = ½ m v^2.
			Total	**1**	
5	a	i	newton in base units is kg m s^{-2} Substitution and cancelling of kg and m arriving at s^2 –> s^2	C1 A1	
		ii	One force is increased by kx and one is reduced by kx /AW Some working to include kx − (-kx)	B1 B1	reject 2 springs in series or 2 springs in parallel idea XP accept one extension is reduced by x and one is increased by x / AW **<u>Examiner's Comments</u>** Question 21 (a) (ii) is considerably more challenging. The two springs are not in series nor are they in parallel. When there is a displacement *x* one spring is extended by an *extra* amount *x* i.e. an extension of (*e* + *x*) and the other is extended by a reduced amount *x i.e.* an extension of (*e* − *x)* where *e* is the equilibrium extension. This meant that the resultant force was *k*(*e* + *x*) − k(*e* − x), which is clearly 2*kx*. Neither spring goes into compression, although we condoned candidates who suggested that a reduction in extension meant the same as a compression.
		iii	period is independent of <u>amplitude</u> / AW No effect	M1 A1	Allow isochronous **<u>Examiner's Comments</u>** A reasonably large proportion of candidates did not link the idea of initial displacement to the amplitude of this motion. Those that did often scored both marks as they also recalled that SHM is isochronous. **Assessment for learning**

					Merely repeating the words in the question, in this case 'the initial displacement' instead of 'amplitude', is unlikely to give access to full marks. Think about which piece or pieces of technical language on the specification are the likely target of each question.
	b	i	Units omitted from T **and** T^2 Valid statement about significant figures	B1 B1	allow correct statement about individual data points or decimal place or "precision" e.g. sf of T does not match sf of 20T or sf of T not consistent throughout column or idea that 1 sf never enough **Examiner's Comments** Most candidates spotted the two different errors namely the lack of units for both *T* and T^2 and the inconsistent presentation of the digits in the data. **Assessment for learning** The Practical Skills handbook has a section dedicated to the treatment of data in tables and how to get the number of significant figures (or decimal places) correct, even if there is a logarithmic column.
		ii	Correct plotting within half a small square Correct line of best fit	B1 B1	ECF for incorrect plotting. NB Same number of points above and below the line AND fair distribution of distances from line
		iii	Gradient between 1.22 and 1.44 $k=2\pi^2 \div$ gradient k between 13.7 and 16.2	C1 C1 A1	reject use of data table ECF use of candidate's line ECF use of candidate's gradient as per rubric **Examiner's Comments** Almost all candidates correctly plotted the data point at (0.200, 0.372). Most candidates constructed an acceptable line of best fit with a minority insisting that the best fit line should go through

					the origin. Best fit lines are judged on two criteria: the number of points above and below the proposed line and a fair distribution of points away from the line. Consider the line that starts at the origin and has three points above and below it. The first and last points are some distance away from the line and the points get progressively closer towards the middle. This cannot happen with the best fit line. Most candidates used the relationship correctly, recognising that the gradient = $2\pi^2/k$. Nearly all candidates correctly calculated the gradient, going on to evaluate *k*. Gradients from incorrect best fit lines were acceptable under error carried forward rules for all 3 marks. A minority of candidates misread their graphs or made algebraic errors.
	c		maximum four from: EPE gain (in stretched spring) > EPE lost (in relaxed spring) EPE is dependent on x^2 Total energy increases (and so KE increases since EPE −> KE) Max KE when the system has minimum EPE / at equilibrium position/when x=0 Minimum EPE is unchanged Omega is same, amplitude has increased v_{max} when x=0 so v_{max} has increased (omega^2 = sqrt(A^2-x^2)) v_{max} increased so KE_{max} increased	4 x B1	Allow EPE max is dependent on A^2 NOT EPE dependent on x alone Allow EPE dependent on x and F which is dependent on x (EPE = ½ Fx idea) KE = ½ kx^2 is XP **<u>Examiner's Comments</u>** The language around energy and energy transfers is challenging and this question was pitched as a high demand question. Once more, the technical language needed to be relatively accurate for marks to be given. As soon as the glider is displaced, the total elastic potential energy (EPE) is increased. The spring that is longer than at equilibrium stores more energy than before and the spring that is shorter than at equilibrium stores less. Since the amount of EPE is given by ½ kx^2, the increase in EPE in the longer spring is larger than the decrease in EPE for the shorter

					spring. A few candidates attempted to prove this algebraically which was not required. Finally, the EPE at equilibrium position is not zero but a minimum. This is why the maximum KE occurs at this point. Some candidates attempted the slightly more accessible route of comparing v_{max} with the amplitude yet did not mention that the angular velocity was the same, although there was still some credit available.
			Total	**17**	
6			D	1	
			Total	**1**	
7		i	$I_{max} = nAv_{max}e$ $v_{max} = \frac{20 \times 10^{-3}}{8 \times 10^{28} \times 1.6 \times 10^{-19} \times 1.4 \times 10^{-8}}$ v_{max} = 1.1 × 10^{-4} (ms^{-1})	B1 M1 A1	**Allow** v for v_{max} throughout **Allow** I for I_{max} **Allow** q or Q for e / a for A / V for v but **not** N for n Substitution must be shown in full Answer must be given initially to 2 or more sf (but may later be rounded to 1sf) **<u>Examiner's Comments</u>** Since the answer is given here and candidates are being asked to show where it comes from, it is important to show every stage in the working. The following steps were necessary to gain full marks: write down the correct formula substitute the given values <u>and</u> the values of any physical constants (such as e) work out the answer to more significant figures than given in the question Exemplar 1 

					The exemplar above shows the type of response that gained full marks.
		ii	$\omega = 2\pi f$ $A\ (= v_{max}/\omega) = \frac{1.1 \times 10^{-4}}{2\pi \times 11 \times 10^{9}}$ **or** $A\ (= v_{max}/\omega) = \frac{1.1 \times 10^{-4}}{6.9 \times 10^{10}}$ $A = 1.6 \times 10^{-15}$ (m)	C1 C1 A1	May be inferred from working $\omega = 2\pi \times 11 \times 10^9 = 6.9 \times 10^{10}$ (rad s^{-1}) **Allow** use of $V_{max} = 1 \times 10^{-4}$ (m s^{-1}) **Allow** V_{max} from **(a)(i)** given to more than 2sf but **not ECF** from any value which does not round to 1×10^{-4} (ms^{-1}) **Allow** use of $v_{max} = 1 \times 10^{-4}$ (ms^{-1})[1] giving $A = 1.4 \times 10^{-15}$ (m) to 2sf or 1.45×10^{-15} (m) to 3sf Special case: **Allow** $A = 1 \times 10^{-15}$(m) to 1 sf if $v_{max} = 1 \times 10^{-4}$ (ms^{-1}) is used **<u>Examiner's Comments</u>** The formula sheet gives $v = \pm\omega(A^2 - x^2)^{½}$ as a starting point. The maximum velocity of the electrons has been given in (i) as 0.1 mm s^{-1}. The electrons are moving in simple harmonic motion, and so their maximum velocity occurs as they pass equilibrium i.e. when $x = 0$. This simplifies the formula to $v_{MAX} = \omega A$. Equal marks were given for using either the given value for v_{MAX} of 0.1 mm s^{-1} or the candidate's own value from (a)(i). **Exemplar 2**  The exemplar above shows the type of response that gained full marks.
		iii	($a_{max} = \omega^2 A$ and $v_{max} = \omega A$) $a_{max} = 2\pi f\ V_{max}$ Since V_{max} is constant, $a_{max} \propto f$	M1 A1	**Allow** $a_{max} = \omega\ v_{max}$ **Allow** a for a_{max} and V for V_{max} **<u>Examiner's Comments</u>** This was a difficult question; hard to visualise and involving some challenging algebra.

					Most candidates did not notice that the question specified the <u>maximum</u> acceleration of a free electron. Therefore the most common response was that $a = (2\pi f)^2x$, showing that $a \propto f^2$. This gained no marks. Other candidates went further and said that the maximum acceleration occurs when $x = A$. This means that $a_{MAX} = (2\pi f)^2A$ and so $a_{MAX} \propto f^2$, since A is constant. However, the amplitude A of the oscillation is itself dependent on the frequency. If the maximum current remains constant then the maximum velocity v_{MAX} of the electron must also remain constant. In (a)(ii), we used the fact that $v_{MAX} = 2\pi fA$, so fA must remain constant. $a_{MAX} = (2\pi f)^2A = (2\pi)^2fA - f$ = constant × f. So we conclude that $a_{MAX} \propto f$. An easy way to see this algebraically is: $a_{MAX} = (2\pi f)^2A$ and $v_{MAX} = 2\pi fA$ Therefore $a_{MAX} = (2\pi f)\ v_{MAX}$ v_{MAX} remains constant and so $a_{MAX} \propto f$
			Total	**8**	
8	a		use of stopclock (**or** stopwatch **or** timer) time n oscillations **and** divide by n	B1 B1	If n is specified then $n \geq 5$ **<u>Examiner's Comments</u>** When asked to describe how to measure a physical quantity, it is important to include the correct measuring instrument as part of the response. A stopwatch or stop clock is the simplest, but any method is acceptable as long as a <u>timer</u> is mentioned. For example, 'I measured the time using my phone' would not be accepted, but 'I used my phone to record the event with a timer in view and then played it back/viewed it frame by frame' would be fine.

					Measuring the number of oscillations in a fixed time period (10 seconds, say) and then calculating *T* from the frequency was not accepted as it is a less accurate method than the one described in the mark scheme.
	b	i	$f = 1/T$ working shown to give $T^2 = \left(\frac{8\pi^2}{3g}\right)L$	B1 B1	**Allow** $T = 2\pi\left(\frac{2L}{3g}\right)^{\frac{1}{2}}$ **or** $f^2 = 1/T^2$ Subject must be T^2 **Allow** $T^2/L = 8\pi^2/3g$ **<u>Examiner's Comments</u>** The expected response here was to start from the given relationship $f = \frac{1}{2\pi}\sqrt{\frac{3g}{2L}}$ and then use $T = 1/f$ to manipulate the expression into the form $y = mx + c$. Candidates who recognised this generally had sufficient skill in algebra to arrive at the correct answer.
		ii	$g = \left(\frac{8\pi^2}{3 \times 2.64}\right)$ $g = 9.97$ (ms^{-2})	C1 A1	Answer must be given to at least 3sf **<u>Examiner's Comments</u>** Candidates needed to substitute gradient = 2.64 into the formula $g = \frac{8\pi^2}{3 \times \text{gradient}}$ This was arguably the easiest question on the paper. Although almost all candidates scored both marks, a few lost a mark through thinking that 9.97 = 10.0 to 3sf.
		iii	line of worst fit drawn	B1	Steepest or shallowest possible line that passes through all the error bars (allow ±½ small square tolerance vertically) If two lines are drawn then they must both be correct **<u>Examiner's Comments</u>** A line joining the top of the furthest right hand error bar to the bottom of the furthest left hand error bar (or vice versa) passed through all the error bars. Either was accepted. A tolerance of ±½ small square was allowed at either end.

					The most common misconception was that the worst fit line joined the top of the right hand error bar to the top of the left hand error bar (or vice versa).
		iv	gradient of worst line calculated with large triangle working to find percentage uncertainty in g answer consistent with candidate's worst line	B1 M1 A1	$\Delta L \geq 0.06$m Shallowest gradient ≈ 2.1($s^2\ m^{-1}$) and steepest ≈ 2.9 ($s^2\ m^{-1}$) $\frac{\text{worst value of g} - 9.97}{9.97}$ (x 100%) **Allow** % uncertainty in gradient = $\frac{\text{gradient of wfl} - 2.64}{2.64}$ (x 100%) Expect answer ≈ 10% (steepest wfl) and ≈ 27% (shallowest wfl) **Allow** a negative answer **<u>Examiner's Comments</u>** It is important to show all working in this type of question. Firstly, in checking the gradient of the worst fit line, the examiner needs to determine whether a large triangle has been used in the calculation. Therefore it is helpful if candidates draw the triangle they intend to use and write down all their read-offs. Secondly, the working to find the percentage uncertainty in g has to be shown in full because the correct answer is $\frac{\text{worst value of } g - 9.97}{9.97}$ and not $\frac{\text{worst value of } g - 9.97}{\text{worst value of } g}$ Although the percentage uncertainty in the gradient was not exactly the same as the percentage uncertainty in g, both methods were accepted.
		v	percentage difference = $\frac{9.97 - 9.81}{9.81} \times 100\%$ = 1.6% **or** absolute difference = 9.97 − 9.81 = 0.16 **or** absolute uncertainty = (9.97 − value of g from wfl) conclusion consistent with candidate's answer to **(b)(iv)**	M1 A1	Possible **ECF** from **(b)(ii)** Value for g is accurate if % uncertainty >% difference **or** if absolute uncertainty > absolute difference **or** if 9.81 lies within the uncertainty range for g **<u>Examiner's Comments</u>**

					Most candidates were able to calculate either the absolute or the percentage difference between the experimental result (9.97) and the true value of *g* (9.81). Many candidates wrongly called this the percentage uncertainty or the percentage error in the result, but their calculation was accepted anyway. A common misconception was that the relatively small percentage difference (1.6%) between the experimental result and the true values meant that the experiment was accurate. However, this is not necessarily the case. A result is only accurate if it is close to the true value and, unless we know the *uncertainty* in our result, we cannot judge whether or not this is the case. For example, suppose that the uncertainty in our result was 1% i.e. we found that g = 9.97±0.10. Then our result for *g* would *not* be accurate. Our result must be somewhere between 10.07 and 9.87, and the true value of *g* (9.81) lies outside this range.
			Total	**12**	
9	a		$\omega \rightarrow s^{-1}$ **or** $\omega^2 \rightarrow s^{-2}$ LHS = ms^{-2} **and** RHS = ms^{-2} clearly shown by unit algebra	M1 A1	**Allow** $\omega \rightarrow$ (radians) s^{-1} **Allow** $\omega^2 = (2\pi f)^2$ **or** $(2\pi/T)^2$ with some evidence of units afterwards e.g. RHS = m $(s^{-1})^2$ **<u>Examiner's Comments</u>** A large majority of candidates showed clearly that the units for acceleration were ms^{-2} and that the unit for angular frequency, in base units, was s^{-1}. Showing the resulting unit algebra clearly was often the only barrier to scoring both marks.

	b	i	$\Delta p = 0.10 \times 1000 \times 9.81$ $\Delta p = 980$ (Pa)	C1 A1	**Allow** 1 mark for 490 Pa; 5.0 cm used **Examiner's Comments** Most candidates thought that the height difference here was 0.05 m, because that is the difference between the final liquid level and the undisturbed level. The correct approach is to look at the difference between the liquid levels once the liquid has stopped moving.
		ii	**1** $\omega^2 = \frac{2\rho g A}{m}$ **or** $\omega^2 = 37.7$ (rad^2 s^{-1}) $\omega = 6.1$ $T = \frac{2\pi}{6.1}$ $T = 1.02$ (s) **2** Oscillation is isochronous starting from (0,5) Correct value(s) on the horizontal axis At least 2 oscillations shown **and** amplitude is decreasing **3** The (driving) frequency is close to the natural frequency (of the system) / resonance will occur (Level of) water will oscillate with large amplitude	C1 C1 C1 A0 B1 B1 B1 B1 B1	**NOT** $\omega = 37.7$ **Alternative route**: • Substitution of expression for omega • Re-arrangement to make T subject • Evidence of evaluation to T = 1.02 (s) Period same by eye. **Note** scale must be linear and increasing Amplitude of 2nd oscillation smaller by eye. **Allow** a description of consequence such as water leaving the tube or being unable to measure the height of liquid **Examiner's Comments** Very few candidates made the link that the gas pressure oscillating would cause a periodic force and so this would become a resonant system. The best way to describe a resonating system in this context is that the amplitude of vibrations becomes significantly larger.
			Total	**12**	
10			**B**	1	**Examiner's Comments**

					Most students answered this question correctly. Those that did not tended to refer to the mass at a point other than at the lowest point in its oscillations.
			Total	**1**	