1)

a	i	elastic potential energy **and** gravitational potential energy ✓	1	For elastic pe allow "pe due to tension", or "strain energy" etc
a	ii	elastic pe → kinetic energy → gravitational pe → kinetic energy → elastic pe ✓✓ [**or** pe→ke→pe→ke→pe is ✓ only] [**or** elastic pe → kinetic energy → gravitational pe is ✓ only]	2	If kinetic energy is not mentioned, no marks. Types of potential energy must be identified for full credit.
b	i	period = 0.80 s ✓ during one oscillation there are two energy transfer cycles (or elastic pe→ke→gravitational pe→ke→elastic pe in 1 cycle) **or** there are two potential energy maxima per complete oscillation ✓	2	Mark sequentially.
b	ii	sinusoidal curve of period 0.80 s ✓ – cosine curve starting at t = 0 continuing to t = 1.2s ✓	2	For 1st mark allow ECF from T value given in 3(b)(i).
c	i	use of $T = 2\pi\sqrt{\frac{m}{k}}$ gives $0.80 = 2\pi\sqrt{\frac{0.35}{k}}$ ✓ $\therefore\ k\left(=\frac{4\pi^2 \times 0.35}{0.80^2}\right)$ = 22 (21.6) ✓ N m^{-1} ✓	3	Unit mark is independent: insist on N m^{-1}. Allow ECF from wrong T value from (b)(i): use of 0.40s gives 86.4 (N m^{-1}).
c	ii	maximum ke = (½ mv_{max}^2) = 2.0 × 10^{-2} gives $v_{max}^2 = \frac{2.0\times10^{-2}}{0.5\times0.35}$ ✓ (= 0.114 m^{2}s^{-2}) and v_{max} = 0.338 (m s^{-1}) ✓ $v_{max} = 2\pi fA$ gives $A = \frac{0.338}{2\pi\times1.25}$ ✓ and A = 4.3(0) × 10^{-2} m ✓ i.e. about 40 mm [**or** maximum ke = (½ mv_{max}^2) = ½ $m\,(2\pi fA)^2$ ✓ ½ × 0.35 × 4π^2 × 1.25^2 × A^2 = 2.0 × 10^{-2} ✓ $\therefore\ A^2 = \frac{2\times2.0\times10^{-2}}{4\pi^2\times0.35\times1.25^2}$ ✓ (= 1.85 × 10^{-3}) and A = 4.3(0) × 10^{-2} m ✓ i.e. about 40 mm] [**or** maximum ke = maximum pe = 2.0 × 10^{-2} (J) maximum pe = ½ $k\,A^2$ ✓ $\therefore$ 2.0 × 10^{-2} = ½ × 21.6 × A^2 ✓ from which $A^2 = \frac{2\times2.0\times10^{-2}}{21.6}$ ✓ (= 1.85 × 10^{-3}) and A = 4.3(0) × 10^{-2} m ✓ i.e. about 40 mm]	4	First two schemes include recognition that $f = 1/T$ i.e. f = 1/0.80 = 1.25 (Hz). Allow ECF from wrong T value from (b)(i) – 0.40s gives A = 2.15 × 10^{-2}m but mark to max 3. Allow ECF from wrong k value from (c)(i) – 86.4Nm^{-1} gives A = 2.15 × 10^{-2}m but mark to max 3.

2)

a		acceleration is proportional to displacement (from equilibrium) ✓ acceleration is in opposite direction to displacement **or** towards a fixed point/equilibrium position✓	2	Acceleration proportional to negative displacement is 1st mark only. Don't accept "restoring force" for accln.
b	i	$f\left(=\frac{1}{2\pi}\sqrt{\frac{g}{l}}\right)=\frac{1}{2\pi}\sqrt{\frac{9.81}{0.984}}$ ✓ = 0.503 (0.5025) (Hz) ✓ [**or** $T\left(=2\pi\sqrt{\frac{l}{g}}\right)=2\pi\sqrt{\frac{0.984}{9.81}}$ ✓ (= 1.9(90) (s)) $f\left(=\frac{1}{T}\right)=\frac{1}{1.990}$ = 0.503 (0.5025) (Hz) ✓] answer to **3SF** ✓	3	3SF is an independent mark. When g = 9.81 is used, allow either 0.502 or 0.503 for 2nd and 3rd marks. **Use of g = 9.8** gives 0.502 Hz: award only 1 of first 2 marks if quoted as 0.502, 0.503 0.50 or 0.5 Hz.
b	ii	$a\left(=-(2\pi f)^2 x\right)=(-)(2\pi\times0.5025)^2\times42\times10^{-3}$ ✓ = 0.42 (0.419) (m s^{-2}) ✓	2	Allow ECF from **any** incorrect f from (b)(i).

c		recognition of 20 oscillations of (shorter) pendulum **and/or** 19 oscillations of (longer) pendulum ✓ *Explanation:* difference of 1 oscillation **or** phase change of 2π **or** Δt = 0.1 so n = 2/0.1 =20, **or** other acceptable point ✓ time to next in phase condition = 38 (s) ✓ [**or** (T = 1.90 s so) (n + 1) × 1.90 = n × 2.00 ✓ gives n = 19 (oscillations of longer pendulum) ✓ minimum time between in phase condition = 19 × 2.00 = 38 (s) ✓]	3	Allow "back in phase (for the first time)" as a valid explanation.

3)

a	i	for one spring, change in force $\Delta F = k\Delta L = 30 \times 60 \times 10^{-3} = 1.8$ (N) ✓ resultant force (= $[F + \Delta F] - [F - \Delta F]$) = $2\Delta F$ ✓ (= 3.6 N) **alternative** using answer from (b) (ii) $a = (2\pi f)^2 x = (2\pi \times 1.38)^2 \times 60 \times 10^{-3} = 4.51$ (m s^{-2}) ✓ resultant force = ma = 0.80 × 4.51 ✓ (= 3.6 N)	**2**
a	ii	acceleration $a \left(= \frac{F}{M}\right) = \frac{3.6}{0.8} = 4.5$ (m s^{-2}) ✓ to the right ✓ **alternative** for first mark using answer from (b) (ii) $a = (2\pi f)^2 x = (2\pi \times 1.38)^2 \times 60 \times 10^{-3} = 4.5$ (m s^{-2}) ✓	**2**
b	i	acceleration is proportional to displacement (from equilibrium position) ✓ acceleration is in opposite direction to displacement [**or** acceleration is towards a fixed point/equilibrium position] ✓	**2**
b	ii	$f = \frac{1}{2\pi}\sqrt{\frac{2 \times 30}{0.80}}$ ✓ (= 1.38 Hz) period $T \left(= \frac{1}{f}\right) = \frac{1}{1.38} = 0.73$ (0.726) ✓ [or 730] s ✓ [ms]	**3**
c	i	$f = \left(= \frac{1}{2\pi}\sqrt{\frac{2k}{m}}\right) = \frac{1}{2\pi}\sqrt{\frac{2 \times 200}{1.0 \times 10^{-25}}} = 1.0(1) \times 10^{13}$ (Hz) ✓	**1**
c	ii	v_{max} (= $2\pi fA$) = $2\pi \times 10^{13} \times 10^{-11}$ = 630 (628) (m s^{-1})✓	**1**
c	iii	max E_K (= ½ mv_{max}^2) = ½ × 1.0 × 10^{-25} × 628^2 = 2.0 × 10^{-20} (J) ✓ [or using ½ kA^2 approach]	**1**
		Total	**12**

4)

1(a)	*Forced vibrations*: repeated upwards and downwards movement ✓ vibrations at frequency of support rod ✓ amplitude is small at high frequency **or** large at low frequency ✓ correct reference to phase difference between displacements of driving and forced vibrations ✓ *Resonance*: frequency of support rod **or** driver is equal to natural frequency of (mass-spring) system ✓ large (or maximum) amplitude vibrations of mass ✓ maximum energy transfer (rate) (from support rod to mass-spring system) ✓ correct reference to phase difference between displacements of driving and driven vibrations at resonance ✓	Acceptable references to phase differences: *Forced vibrations* – when frequency of driver » frequency of driven, displacements are out of phase by (almost) π radians or 180° (**or** ½ a period) **or** when frequency of driver « frequency of driven, displacements are (almost) in phase. [Accept either] [Condone >, < for », «] *Resonance* – displacement of driver leads on displacement of driven by $\pi/2$ radians or 90° **or** ¼ of a period (or driven lags on driver by $\pi/2$ radians or 90° **or** ¼ of a period) [Condone phase difference is $\pi/2$ radians or 90°]	max 4	
1(b)(i)	cone oscillates without ring (*ticked*)	Only one box to be ticked.	1	
1(b)(ii)	damping is caused by air resistance ✓ area is the same whether loaded or not loaded ✓ loaded cone has more kinetic energy **or** potential energy **or** momentum (at same amplitude) ✓ smaller proportion (or fraction) of (condone less) energy removed per oscillation from loaded cone (or vice versa) ✓ inertia of loaded cone is greater ✓	Award marks for correct physics even when answer to 1(b)(i) is incorrect.	max 3	
Total			8	

5)

a	i	speed at P, $v\ (= \sqrt{2gh}) = \sqrt{2 \times 9.81 \times 25}$ ✓ $= 22(.1)\ (\text{m s}^{-1})$ ✓	**2**
a	ii	use of $F = k\Delta L$ gives $d\left(=\frac{F}{k}\right) = \frac{58 \times 9.81}{54}$ ✓ $= 11\ (10.5)\ (\text{m})$ ✓	**2**
b	i	period $T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{58}{54}}$ ✓ (= 6.51 s) time for one half oscillation = 3.3 (3.26) (s) ✓	**2**
b	ii	frequency $f\left(=\frac{1}{T}\right) = \frac{1}{6.51}$ ✓ (= 0.154 (Hz)) use of $v = \pm 2\pi f\sqrt{A^2 - x^2}$ when $x = 10.5$ m and $v = 22.1\ \text{m s}^{-1}$ gives $22.1^2 = 4\pi^2 \times 0.154^2\ (A^2 - 10.5^2)$ ✓ from which $A = 25.1$ (m) ✓ [**alternatively**, using energy approach gives $\frac{1}{2} m v_P^2 + mg\Delta L = \frac{1}{2} k(\Delta L)^2$ ✓ $\therefore (29 \times 22.1^2) + (58 \times 9.81 \times \Delta L) = 27\ (\Delta L)^2$ solution of this quadratic equation gives $\Delta L = 35.7$ (m) ✓ from which $A = 25.2$ (m) ✓]	**3**

c		bungee cord becomes slack ✓ student's motion is under gravity (until she returns to **P**) ✓ has constant downwards acceleration **or** acceleration is not ∝ displacement ✓	**max 2**
d	i	when student is at **R** or at bottom of oscillation ✓	**1**
d	ii	at uppermost point **or** where it is attached to the railing ✓ because stress = *F*/*A* and force at this point includes weight of whole cord ✓ [accept alternative answers referring to mid-point of cord because cord will show thinning there as it stretches **or** near knots at top or bottom of cord where *A* will smaller with a reference to stress = *F*/*A*]	**2**
		Total	**14**

6)

(a)		(grav) potential energy → kinetic energy → (grav) potential energy → kinetic energy → gravitational potential energy ✓ energy lost to surroundings in overcoming air resistance ✓	**2**
(b)	(i)	period $T = \left(\frac{42}{15}\right) = 2.8$ s ✓ use of $T = 2\pi\sqrt{\frac{l}{g}}$ gives length $l = \left(= \frac{T^2 g}{4\pi^2}\right) = \frac{2.8^2 \times 9.81}{4\pi^2}$ ✓ giving distance from pt of support to c of m, l = 1.9 (m) or 1.95 (m) ✓ answer must be to **2 or 3 sf** only ✓	**4**
(b)	(ii)	$E_k = mg\Delta h$ stated or used ✓ gives E_k of girl at lowest point = 18 × 9.81 × 0.25 = 44 (J) ✓	**2**
(b)	(iii)	$\frac{1}{2}mv^2 = 44.1$ gives max speed of girl $v = \sqrt{\frac{2 \times 44.1}{18}} = 2.2$ (m s^{-1}) ✓ [**alternatively**: $A^2 = (3.9 - 0.25) \times 0.25$ gives $A = 0.955$ (m) and $v_{max} = 2\pi f A = (2\pi/2.8) \times 0.955 = 2.1$ (m s^{-1}) ✓]	**1**
(c)		graph drawn on **Figure 2** which: shows $E_k = 0$ at $t = 0$, $T/2$ and T ✓ has 2 maxima of similar size (some attenuation allowed) at $T/4$ and $3T/4$ ✓ is of the correct general shape ✓	**3**
		Total	**12**