Q1.

3 (a) \( f_0 \) is at natural frequency of spring (system) ........................................ B1
this is at the driver frequency ................................................................. B1 (allow 1 mark for recognition that this is resonance) [2]

(b) line: amplitude less at all frequencies ............................................. B1
peak flatter ......................................................................................... B1
peak at \( f_0 \) or slightly below \( f_0 \) ...................................................... B1 [3]

(c) (aluminium) sheet cuts the magnetic flux/field .................................. B1
(so) currents/e.m.f. induced in the (metal) sheet ......................................... B1
these currents dissipate energy ............................................................. M1
less energy available for the oscillations ................................................ A1
so amplitude smaller ................................................................. A0 [4]
('current opposes motion of sheet' scores one of the last two marks)

Q2.

4 (a) e.g. amplitude is not constant or wave is damped
\[ \text{do not allow 'displacement constant'} \]
should be \((-\cos, \text{not sin})\) .......................................................................................................................... B1 [2]

(b) \[ T = 0.60 \text{ s} \]
\[ \omega = \frac{2\pi}{T} = 10.5 \text{ rad s}^{-1} \text{ (allow 10.4 } \rightarrow 10.6) \] C1 A1 [2]

(c) same period
displacement always less
amplitude reducing appropriately
for 2nd and 3rd marks, ignore the first quarter period

Total [7]

Q3.

4 (a) acceleration proportional to displacement (from a fixed point)........ M1
or \( a = -\omega^2 x \) with \( a, \omega \) and \( x \) explained
and directed towards a fixed point
or negative sign explained

(b) for s.h.m., \( a = (-\omega^2 x) \)
identifies \( \omega^2 \) as \( A_g/M \) and therefore s.h.m. (may be implied)
\[ 2\pi f = \omega \]
hence \[ f = \frac{1}{2\pi} \sqrt{\frac{A_g}{M}} \] B1 B1 B1 A0 [3]

(c) (i) \[ T = 0.60 \text{ s or } f = 1.7 \text{ Hz} \]

\[ 0.60 = \frac{2\pi\sqrt{M}}{\sqrt{\pi \times (1.2 \times 10^{-2})^2 \times 950 \times 9.81}} \]
\[ M = 0.0384 \text{ kg} \] C1 C1 A1 [3]

(ii) decreasing peak height/amplitude

B1 [1]
Q4.

4 (a) (i) 1.0 B1 [1]

(ii) 40 Hz B1 [1]

(b) (i) speed = \(2\pi fa\)
\[
= 2\pi \times 40 \times 42 \times 10^{-3} \\
= 10.6 \text{ m s}^{-1}
\]
C1

(ii) acceleration = \(4\pi^2 f^2 a\)
\[
= (80\pi)^2 \times 42 \times 10^{-3} \\
= 2650 \text{ m s}^{-2}
\]
A1 [2]

(c) (i) S marked correctly (on 'horizontal line' through centre of wheel) B1

(ii) A marked correctly (on 'vertical line' through centre of wheel) B1 [2]

Q5.

7 (a) (i) oscillations are damped/amplitude decreases as magnet moves, flux is cut by coil e.m.f./current is induced in the coil causing energy loss in load OR force on magnet energy is derived from oscillations of magnet OR force opposes motion of magnet B1 [5]

(ii) \(T = 0.60 \text{ s}\) \(\omega_b \left(= 2\pi/T\right) = 10.5 \text{ rad s}^{-1}\)
\[
\]
C1

A1 [2]

(b) sketch: sinusoidal wave with period unchanged or slightly smaller same initial displacement, less damping M1 A1 [2]

(c) (i) sketch: general shape – peaked curve peak at \(\omega_b\) and amplitude never zero M1 A1 [2]

(ii) resonance B1 [1]

(iii) useful: e.g. child on swing, microwave oven heating avoid: e.g. vibrating panels, vibrating bridges (for credit, stated example must be put in context) B1 [2]

Q6.
Q7.

3  (a) (i) amplitude = 0.5 cm  
     A1 [1] 
     period = 0.8 s  
     A1 [1]

(b) (i) \( \omega = \frac{2\pi}{T} \)  
     = 7.85 rad s\(^{-1}\)  
     C1
     correct use of \( v = \omega \sqrt{(x_0^2 - x^2)} \)  
     = 7.85 \times \sqrt{(0.5 \times 10^{-2})^2 - (0.2 \times 10^{-2})^2}  
     = 3.6 \text{ cm s}^{-1}  
     A1 [3]
     (if tangent drawn or clearly implied \( (B1) \)  
     3.6 \pm 0.3 \text{ cm s}^{-1} \quad \text{\( (A2) \)  
     but allow 1 mark for \( \pm 0.3 \) but \( \approx \pm 0.6 \text{ cm s}^{-1} \))

(ii) \( d = 15.8 \text{ cm} \) 
     A1 [1]

(c) (i) (continuous) loss of energy / reduction in 
     amplitude (from the oscillating system) 
     caused by force acting in opposite direction to the motion / friction / 
     viscous forces  
     B1 [2]

(ii) same period / small increase in period 
     line displacement always less than that on Fig.3.2 (ignore first \( \frac{1}{4} \) 
     peak progressively smaller  
     M1
     A1 [3]

Q7.

3  (a) (i) to-and-fro / backward and forward motion (between two limits)  
     B1 [1]

(ii) no energy loss or gain / no external force acting / constant energy / constant amplitude  
     B1 [1]

(iii) acceleration directed towards a fixed point 
     acceleration proportional to distance from the fixed point / displacement  
     B1 [2]

(b) acceleration is constant (magnitude) 
     so cannot be s.h.m.  
     M1
     A1 [2]

Q8.
Q9.

2 (a) (i) reduction in energy (of the oscillations) (B1)
reduction in amplitude / energy of oscillations (B1)
due to force (always) opposing motion / resistive forces (B1) [2]
any two of the above, max 2

(ii) amplitude is decreasing (very) gradually / oscillations would continue (for a long time) / many oscillations (M1)
light damping (A1) [2]

(b) (i) frequency $= \frac{1}{0.3}$
$= 3.3 \text{ Hz}$ (A1) [1]
allow points taken from time axis giving $f = 3.45 \text{ Hz}$

(ii) energy $= \frac{1}{2} m v^2$ and $v = \omega a$
$= \frac{1}{2} \times 0.085 \times (2\pi/0.3)^2 \times (1.5 \times 10^{-2})^2$ (M1)
$= 3.2 \text{ mJ}$ (A0) [2]

(c) amplitude reduces exponentially / does not decrease linearly (M1)
so will not be 0.7 cm (A1) [2]

Q9.

3 (a) acceleration / force proportional to displacement from a fixed point (M1)
acceleration / force (always) directed towards that fixed point / in opposite direction to displacement (A1) [2]

(b) (i) $A/g / m$ is a constant and so acceleration proportional to $x$ (B1)
negative sign shows acceleration towards a fixed point / in opposite direction to displacement (B1) [2]

(ii) $\omega^2 = (A/g) / m$
$\omega = 2\pi f$
$(2 \times \pi \times 1.5)^2 = (4.5 \times 10^{-4} \times 1.0 \times 10^3 \times 9.81) / m$
$m = 50 \text{ g}$ (C1)

Q10.

4 (a) $a = (-) \omega^2 x$ and $\omega = 2\pi / T$ (C1)
$T = 0.60 \text{ s}$ (C1)
a $= (4\pi^2 \times 2.0 \times 10^{-2}) / (0.6)^2$
$= 2.2 \text{ ms}^{-2}$ (A1) [3]

(b) sinusoidal wave with all values positive (B1)
all values positive, all peaks at $E_k$ and energy = 0 at $t = 0$ (B1)
period $= 0.30 \text{ s}$ (B1) [3]

Q11.
2 (a) energy $= \frac{1}{2} m \omega^2 a^2$ and $\omega = 2 \pi f$
   $= \frac{1}{2} \times 37 \times 10^{-3} \times (2 \pi \times 3.5)^2 \times (2.8 \times 10^{-3})^2$
   $= 7.0 \times 10^{-3}$J
   (allow $2 \pi \times 3.5$ shown as $7 \pi$)
   Energy $= \frac{1}{2} m v^2$ and $v = r \omega$
   Correct substitution
   Energy $= 7.0 \times 10^{-3}$J

   (b) $E_K = E_P$
   \[ \frac{1}{2} m \omega^2 (a^2 - x^2) = \frac{1}{2} m \omega^2 x^2 \] or $E_K = E_P = 3.5$ mJ
   $x = a/\sqrt{2} = 2.8/\sqrt{2}$ or $E_K = \frac{1}{2} m \omega^2 (a^2 - x^2)$ or $E_P = \frac{1}{2} m \omega^2 x^2$
   $= 2.0$ cm
   (Allow $E_K$ or $E_P = 7.0$ mJ scores 0/3)

   Allow:
   \[ k = 17.9 \]
   \[ E = \frac{1}{2} kx^2 \]
   \[ x = 2.0 \text{ cm} \]

   (c) (i) graph: horizontal line, y-intercept = 7.0 mJ with end-points of line at +2.8 cm and −2.8 cm
   \[ B_1 \] [1]

   (ii) graph: reasonable curve
   with maximum at (0,7.0) end-points of line at (−2.8, 0) and (+2.8, 0)
   \[ B_1 \] [2]

   (iii) graph: inverted version of (ii)
   with intersections at (−2.0, 3.5) and (+2.0, 3.5)
   (Allow marks in (iii), but not in (ii), if graphs K & P are not labelled)
   \[ M_1 \] [2] \[ A_1 \] [2]

   (d) gravitational potential energy
   \[ B_1 \] [1]

Q12.
Q13.

3. (a) (i) 1. amplitude = 1.7 cm
   2. period = 0.36 cm
      frequency = 1/0.36
      = 2.8 Hz

   (ii) \( a = (-\omega^2 x \text{ and } \omega = \frac{2\pi}{T} \)
      acceleration = \((2\pi/0.36)^2 \times 1.7 \times 10^{-2} \)
      = 5.2 m s\(^{-2}\)

(b) graph: straight line, through origin, with negative gradient
   from \((-1.7 \times 10^{-2}, 5.2)\) to \((1.7 \times 10^{-2}, -5.2)\)
   (if scale not reasonable, do not allow second mark)

(c) either kinetic energy = \(\frac{1}{2} m \omega^2 (x_0^2 - x^2)\)
    or potential energy = \(\frac{1}{2} m \omega^2 x^2\) and potential energy = kinetic energy

\[ \frac{1}{2} m \omega^2 (x_0^2 - x^2) = \frac{1}{2} \times \frac{1}{2} m \omega^2 x_0^2 \text{ or } \frac{1}{2} m \omega^2 x^2 = \frac{1}{2} \times \frac{1}{2} m \omega^2 x_0^2 \]

\[ x_0^2 = 2x^2 \]
\[ x = x_0 / \sqrt{2} = 1.7 / \sqrt{2} \]
\[ = 1.2 \text{ cm} \]

A1 [3]

Q14.
Q15.

2 (a) (i) \(a, \omega\) and \(x\) identified \(-1\) each error or omission \(\ldots B2\)

(ii) \(-\)ve because \(a\) and \(x\) in opposite directions
OR \(a\) directed towards mean position/centre \(\ldots B1\) [3]

(b) (i) forces in springs are \(k(e + x)\) and \(k(e - x)\) \(\ldots C1\)
resultant = \(k(e + x) - k(e - x)\) \(\ldots M1\)
\(2kx\) \(\ldots A0\) [2]

(ii) \(F = ma\) \(\ldots B1\)
\(a = -2kx/m\) \(\ldots A0\)
\(-\)ve sign explained \(\ldots B1\) [2]

(iii) \(\omega^2 = 2kl/m\) \(\ldots C1\)
\((2\pi)^2 = (2 \times 120)/0.90\) \(\ldots C1\)
\(f = 2.6 \text{ Hz}\) \(\ldots A1\) [3]

(c) atom held in position by attractive forces
atom oscillates
not just two forces OR 3D not 1D
force not proportional to \(x\)
any two relevant points, 1 each, max 2 \(\ldots B2\) [2]

Q16.
Q17.

4 (a) (i) \[ \omega = 2\pi f \]
\[ = 2\pi \times 1400 \]
\[ = 8800 \text{ rad s}^{-1} \]
\[ = 1.38 \times 10^{-3} \text{ m s}^{-1} \]
\[ = 8800 \times 0.080 \times 10^{-3} \]
\[ = 6200 \text{ m s}^{-2} \]

(ii) \[ \omega_0 = (\omega_0)^2 \]
\[ = 8800 \times 0.080 \times 10^{-3} \]
\[ = 6200 \text{ m s}^{-2} \]

(b) straight line through origin with negative gradient

(c) (i) zero displacement

(ii) \[ v = \omega x_0 \]
\[ = 8800 \times 0.080 \times 10^{-3} \]
\[ = 0.70 \text{ m s}^{-1} \]

Q18.

3 (a) use of \( a = -\omega^2 x \) clear

either \( \omega = \sqrt{(2k/m)} \) or \( \omega^2 = (2k/m) \)
\[ \omega = 2\pi f \]
\[ f = (1/2\pi)\sqrt{(2 \times 300)/0.240} \]
\[ = 7.96 \approx 8 \text{ Hz} \]

(b) (i) resonance

(ii) 8 Hz

(c) (increase amount of) damping

without altering \( (k \text{ or } m) \) ... (some indirect reference is acceptable)

sensible suggestion

B1 [1]
3. (a) (i) 0.8 cm .............................................................. B1 [1]

(ii) (max.) kinetic energy = 2.56 mJ ........................................... C1

\[ v(\text{max}) = \frac{1}{2} m \omega^2 \]
\[ (\text{max.}) \text{ kinetic energy} = \frac{1}{2} m \omega^2 a^2 \text{ or } \frac{1}{2} m \omega^2 (a^2 - x^2) \] ........................................... C1

\[ 2.56 \times 10^{-3} = \frac{1}{2} \times 0.130 \times \omega^2 \times (0.8 \times 10^{-2})^2 \] ........................................... M1

\[ \omega = 24.8 \text{ rad s}^{-1} \] ........................................... C1

\[ f = \frac{\omega}{2\pi} \] ........................................... M1

\[ = 4.0 \text{ Hz} \; (3.95 \text{ Hz}) \] ........................................... A0 [6]

(b) (i) line parallel to x-axis at 2.56 mJ ........................................... B1 [1]

(ii) 1.40 Hz .............................................................. B1

\[ 2.050 \text{ cm (allow } \pm 0.03 \text{ cm) } \] ........................................... B1 [2]

Q20.

3. (a) acceleration / force (directly) proportional to displacement and either directed towards fixed point or acceleration & displacement in opposite directions ........................................... M1

Either directed towards fixed point or acceleration & displacement in opposite directions ........................................... A1 [2]

(b) (i) maximum / minimum height / 8 mm above cloth / 14 mm below cloth ........................................... B1 [1]

(ii) 1. \( \Delta = 11 \text{ mm} \)

2. \( \omega = 2\pi f \)

\[ = 2\pi \times 4.5 \]

\[ = 28.3 \text{ rad s}^{-1} \; (\text{do not allow 1 s.f.)} \] ........................................... A1 [2]

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(c) (i) \( v = \omega a \)

\[ = 28.3 \times 11 \times 10^{-3} \]

\[ = 0.31 \text{ m s}^{-1} \; (\text{do not allow 1 s.f.)} \] ........................................... C1

(ii) \( v = \sqrt{\omega^2 - y^2} \)

\[ y = 3 \text{ mm} \]

\[ = 28.3 \times 10^{-3} \sqrt{11^2 - 3^2} \]

\[ = 0.30 \text{ m s}^{-1} \; (\text{allow 1 s.f.)} \] ........................................... A1 [3]

Q21.
Q22.

3 (a) straight line through origin .........................................................B1 [2]
    negative gradient .................................................................B1 [2]

(b) \( a = -\omega^2 x \) and \( \omega = 2\pi f \) ........................................C1
    \( 750 = (2\pi)^2 \times 0.3 \times 10^{-3} \) ...........................................C1
    \( f = 250 \text{ Hz} \) .................................................................A1 [3]

(c) straight line between(-0.3, +190) and (+0.3, -190) ..........................A2 [2]
    (allow 1 mark for end of line incorrect by one grid square or line does not extend to
    +/- 0.3 mm)

[Total: 7]

Q23.
Q24.

3 (a) (i) resonance
   (ii) amplitude 16 mm and frequency 4.6 Hz

(b) (i) $a = (-)\omega^2 x$ and $\omega = 2\pi f$
   $a = 4\pi^2 \times 4.6^2 \times 16 \times 10^{-3}$
   $= 13.4 \text{ m/s}^2$

(ii) $F = ma$
   $= 150 \times 10^{-3} \times 13.4$
   $= 2.0 \text{ N}$

(c) line always ‘below’ given line and never zero peak is at 4.6 Hz (or slightly less) and flatter

Q25.

3 (a) (i) 8.0 cm
   (ii) $2\pi f = 220$
        $f = 35$ (condone unit)
   (iii) line drawn mid-way between AB and CD (allow ±2 mm)
   (iv) $v = \omega a$
        $= 220 \times 4.0$
        $= 880 \text{ cm/s}$

(b) (i) 1. line drawn 3 cm above AB (allow ±2 mm)
      2. arrow pointing upwards

(ii) 1. line drawn 3 cm above AB (allow ±2 mm)
      2. arrow pointing downwards

(iii) $v = \omega \sqrt{(a^2 - \chi^2)}$
      $= 220 \times \sqrt{(4.0^2 - 2.0^2)}$
      $= 760 \text{ cm/s}$
      (incorrect value levy 0/2 marks)

Q26.

3 (a) (i) amplitude remains constant
   (ii) amplitude decreases gradually
        light damping
   (iii) period = 0.80 s
        frequency = 1.25 Hz (period not 0.8 s, then 0/2)
3. (a) acceleration proportional to displacement/distance from fixed point
   and in opposite directions/directed towards fixed point
   
   (b) energy \( \frac{1}{2}m\omega^2x_0^2 \) and \( \omega = 2\pi f \)
   \[ \begin{align*}
   = \frac{1}{2} \times 5.8 \times 10^{-3} \times (2\pi \times 4.5)^2 \times (3.0 \times 10^{-3})^2 \\
   = 2.1 \times 10^{-5} \text{ J}
\end{align*} \]

(c) (i) at maximum displacement
   above rest position
   
   (ii) acceleration \( (-\omega^2)x_0 \) and acceleration \( 9.81 \text{ or } g \)
   \[ \begin{align*}
   9.81 &= (2\pi \times 4.5)^2 \times x_0 \\
   x_0 &= 1.2 \times 10^{-2} \text{ m}
\end{align*} \]

Q27.

4. (a) straight line through origin
   shows acceleration proportional to displacement
   negative gradient
   shows acceleration and displacement in opposite directions
Q29.

3 (a) (i) any two from 0.3(0) s, 0.9(0) s, 1.50 s (allow 2.1 s etc.)  

(ii) either \( v = ox \) and \( \omega = 2\pi/T \)  
\[ v = (2\pi/1.2) \times 1.5 \times 10^{-2} \]  
\[ = 0.079 \text{ m/s} \]  

or gradient drawn clearly at a correct position  
working clear  
to give \((0.08 \pm 0.01) \text{ m/s}\)  

(b) (i) sketch: curve from \((-1.5, 0)\) passing through \((0, 25)\)  
reasonable shape \((\text{curved with both intersections between } y = 12.0 \text{ to } 13.0)\)  

(ii) at max. amplitude potential energy is total energy  
total energy = 4.0 mJ  

Q30.
Q31.

4 (a) kinetic (energy) \( KE/E_k \)

(b) either change in energy = 0.60 mJ
   or \( \max E \propto \text{amplitude}^2 \) equivalent numerical working

   new amplitude is 1.3 cm
   change in amplitude = 0.2 cm

Q32.

1 (a) (i) either \( \omega = 2\pi/\tau \) or \( \omega = 2\pi f \) and \( f = 1/\tau \)

   \( \omega = 2\pi/0.30 \)
   = 20.9 rad s\(^{-1}\) (accept 2 s.f.)

   (ii) kinetic energy = \( \frac{1}{2}m\omega^2x_0^2 \) or \( v = \omega x_0 \) and \( \frac{1}{2}mv^2 \)

   \( v = \frac{1}{2} \times 0.130 \times 20.9^2 \times (1.5 \times 10^{-3})^2 = 6.4 \times 10^{-3} \) J

(b) (i) as magnet moves, flux is cut by cup/aluminium giving rise to induced e.m.f.
   (in cup)

   induced e.m.f. gives rise to currents and heating of the cup
   thermal energy derived from oscillations of magnet so amplitude decreases
   or
   induced e.m.f. gives rise to currents which generate a magnetic field
   the magnetic field opposes the motion of the magnet so amplitude decreases

   (ii) either use of \( \frac{1}{2}m\omega^2x_0^2 \) and \( x_0 = 0.75 \) cm or \( x_0 \) is halved so \( \frac{1}{2} \) energy
   to give new energy = 1.6 mJ

   either loss in energy = 6.4 – 1.6 or loss = \( \frac{1}{2} \times 6.4 \) giving loss = 4.8 mJ

(c) \( q = mc\Delta \theta \)

\( 4.8 \times 10^{-3} = 6.2 \times 10^{-3} \times 910 \times \Delta \theta \)

\( \Delta \theta = 8.5 \times 10^{-4} \) K

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Q33.

4. (a) acceleration/force proportional to displacement (from a fixed point)  
   either acceleration and displacement in opposite directions  
   or acceleration always directed towards a fixed point  
   M1  
   A1 [2]

(b) (i) zero & 0.625 s or 0.625 s & 1.25 s or 1.25 s & 1.875 s or 1.875 s & 2.5 s  
   A1 [1]

(ii) 1. \( \omega = \frac{2\pi}{T} \) and \( v_0 = \omega x_0 \)  
   \( \omega = \frac{2\pi}{1.25} \)  
   = 5.03 rad s\(^{-1}\)  
   C1

   \( v_0 = 5.03 \times 3.2 \)  
   = 16.1 cm s\(^{-1}\) (allow 2 s.f.)  
   A1 [3]

2. \( v = a \sqrt{x_0^2 - x^2} \)  
   either \( \frac{1}{2} \omega \theta = a \sqrt{(x_0^2 - x^2)} \)  
   or \( \frac{1}{2} \times 16.1 = 5.03 \sqrt{(3.2^2 - x^2)} \)  
   C1

   \( x_0^2/4 = x_0^2 - x^2 \)  
   \( 2.58 = 3.2^2 - x^2 \)  
   \( x = 2.8 \text{ cm} \)  
   A1 [2]

(c) sketch: loop with origin at its centre  
   correct intercepts & shape based on (b)(ii)  
   M1  
   A1 [2]