Q	Evidence	1-4 marks	5-6 marks	7-8 marks
ONE (a)	The magnetic force on the roller is up the rails (to the left). The gravity force component must be equal and opposite to the magnetic force component. $F_g = mg\sin\phi = F_m = B\cos\phi \times IL$	Thorough understanding of these applications of physics. OR Partially correct mathematical solution to the given problems. AND / OR Partial understanding of these applications of physics.	(Partially) correct mathematical solution to the given problems. AND / OR Reasonably thorough understanding of these applications of physics.	Correct mathematical solution to the given problems. AND Thorough understanding of these applications of physics.
(b)	The moving conductor (the roller) will have a potential difference (pd) induced between its ends by the movement through the magnetic field. This pd will drive a current around the circuit. (This is why a resistor needs to be connected.) The current will produce a magnetic field around the roller, which will react against the permanent magnetic field, causing the roller to slow down. Slowing down will reduce the induced voltage, therefore reduce the current, therefore reduce the retarding force. Once the retarding force (initially larger than the gravity component) becomes equal to the accelerating component of the gravity force on the roller, with no net force now acting on the roller, it will continue moving at some small constant velocity.			
(c)	$V = B\cos\phi \times v \times L$ $I = \frac{V}{R}$ $I = \frac{B\cos\phi \times v \times L}{R}$ At constant velocity $mg\sin\phi = B\cos\phi \times I \times L$ (from part(a)) $mg\sin\phi = B^2\cos^2\phi \times L^2 \times \frac{v}{R}$ $v = \frac{R \times m \times g\tan\phi}{B^2\cos\phi \times L^2}$			
(d)	The movement of the roller will depend on the phase state of the supply when the power is turned on. If the voltage is rising from zero to its peak, the roller will move in a series of jerks in one direction (if the frequency is high enough, the movement will appear to be continuous). If the voltage is decreasing from zero towards its negative maximum, then the roller will move in the opposite direction. And if the voltage is falling from its peak value (or rising from its negative maximum), then the roller will vibrate in place.			

Q	Evidence	1-4 marks	5-6 marks	7-8 marks
TWO (a)(i)	Operating resistance of bulb $= \dfrac{V^2}{W} = \dfrac{120^2}{75} = 192\ \Omega$ Put a 192 Ω resistor in series with the bulb. The voltage drop across each will be 240 /2 = 120 V (the required operating voltage for the bulb) The power drawn by this configuration will be $240 \times \dfrac{75}{120} = 150\text{ W}$	Thorough understanding of these applications of physics. OR Partially correct mathematical solution to the given problems. AND / OR Partial understanding of these applications of physics.	(Partially) correct mathematical solution to the given problems. AND / OR Reasonably thorough understanding of these applications of physics.	Correct mathematical solution to the given problems. AND Thorough understanding of these applications of physics
(ii)	With the inductor (L) , the V_R will be 90° out of step with V_L. $V_S^2 = V_L^2 + V_R^2$ $V_L = \sqrt{240^2 - 120^2} = 120\sqrt{3}$ $X_L = \dfrac{V_L}{I} = \dfrac{120\sqrt{3}}{\left(\dfrac{75}{120}\right)} = 192\sqrt{3}$ $L = \dfrac{X_L}{w} = \dfrac{192\sqrt{3}}{2\pi \times 50} = 1.06\text{ H}$ Power drawn is just the 75 W dissipated by the bulb. The inductor dissipates no power.			
(b)	The AC in the coil creates a strong and fluctuating magnetic field around the iron core. This moving magnetism induces a current in the aluminium ring (an eddy current). The eddy current produces its own magnetic field, which acts in the opposite direction (is repelled by) the coil's magnetism. The repulsive force between the two can be larger than the force of gravity on the ring so the ring is moved away from the coil until it reaches a distance at which the upward magnetic repulsive force is equal to the downward gravitational force.			
(c)	Make the coil "non-inductive" by reversing the direction of the windings after half have been completed in one direction. Reverse the direction of half the windings so that the amount of clockwise current is balanced by an equal amount of anticlockwise current.			
(d)	The glue must be non conducting (and must be permeable to magnetic fields). The core must be laminated to reduce the induction of eddy currents, which would both waste a lot of energy and produce a lot of potentially damaging heat.			

<table>
<tr><th>Question</th><th>Evidence</th><th>1-4 marks</th><th>5-6 marks</th><th>7-8 marks</th></tr>
<tr><td>3(a)</td><td>The induced voltage drives a current around the circuit. The current induces a magnetic field in the roller. This induced magnetism is opposed by the external magnetic field – felt as a retarding force on the roller which slows down and stops.

Alternative:
The metal wire completes the circuit so a current exists. As the current exists, energy is lost to the system as heat energy, so the kinetic energy of the roller is converted to heat energy, and it will slow down.</td><td rowspan="5">Shows good understanding of the fundamental processes involved in producing induced voltages

AND/OR

Shows moderate understanding of application of fundamental ideas in a new context.</td><td rowspan="5">Shows good understanding of the fundamental processes involved in producing induced voltages

AND

Shows moderate understanding of application of fundamental ideas in a new context.

OR

Shows clear understanding of application of fundamental ideas in a new context.</td><td rowspan="5">Shows good understanding of the fundamental processes involved in producing induced voltages

AND

Shows clear understanding of application of fundamental ideas in a new context.</td></tr>
<tr><td>(b)</td><td>$\varepsilon = -\frac{\Delta\phi}{\Delta t}$
$\phi = BA \Rightarrow \Delta\phi = B\Delta A$ (B const)
$A = L \times d$
$\varepsilon = -BL\frac{\Delta d}{\Delta t}$
$\varepsilon = -BLv$</td></tr>
<tr><td>(c)</td><td>The original induced voltage will drive a current, which will charge up the capacitor. The voltage across the capacitor will oppose the induced voltage, and when this results in the current ceasing, there will be no opposing force to further slow the roller, and it will continue at a steady speed.</td></tr>
<tr><td>(d)</td><td>At constant velocity, no current exists in the circuit.
Kirchhoff's voltage rule:
Voltage across capacitor = voltage produced by roller
$BLv = Q / C$
$\Rightarrow Q = BLvC$
Units: B has units of kg s^{-1} C^{-1}
L has units of m
v has units of m s^{-1}
C has units of F (equivalent to $C\ V^{-1}$)
Final units are kg m^2 s^{-2} V^{-1} but units of V are J C^{-1} which is kg m^2 s^{-2} C^{-1}
So this shows final unit C on both sides.</td></tr>
<tr><td>(e)</td><td>The capacitor would discharge a current through the roller. This current would result in the roller experiencing a force either towards or away from the capacitor, depending on the current direction. If the induced force is against the direction of the push, then the roller will move in the direction of the greater force. If the induced force is in the direction of the push, the roller will accelerate rapidly towards the capacitor, then the acceleration will reduce until the roller reaches a steady velocity.</td></tr>
</table>

Question	Type 1 (explanatory) or Type 2 (problem)	B Evidence	A Evidence
4(i)	1		The current in the wire generates a magnetic field. The loop of wire carries a current and is in this magnetic field. These interact to produce a force.
4(ii)	1	The direction of the magnetic field is into the paper (right-hand grip rule). The direction of the force on the loop is given by the right-hand rule. The side nearest the long wire experiences a force away from the long wire.	The direction of the magnetic field is into the paper (right-hand grip rule). The direction of the force on the loop is given by the right-hand rule. Each side of the loop experiences a force towards the centre of the loop. The magnitude of the force on the sides of the loop is given by $F = BIl$, where B is the magnetic field produced by the wire ($B \propto \frac{1}{r}$). The forces at the top and bottom of the loop cancel as B is the same, so the forces are equal and opposite. The force is greater along the side of the loop nearest the wire than the opposite side, so the net force will be acting away from the wire.
4(iii)	2		Magnetic field produced by wire: $B = \frac{\mu_0 I_2}{2\pi r}$ where r is distance from wire. Force F_1 on side of loop nearest the wire: $F_1 = BI_1 l = \frac{\mu_0 I_1 I_2 b}{2\pi d}$

Question	Type 1 (explanatory) or Type 2 (problem)	B Evidence	A Evidence
			Force F_2 on side of loop farthest from wire: $F_2 = BI_1 l = \frac{\mu_0 I_1 I_2 b}{2\pi(d+a)}$ Resultant force F: $F = \frac{\mu_0 I_2 I_1 b}{2\pi d} - \frac{\mu_0 I_1 I_2 b}{2\pi(d+a)}$ $F = \frac{\mu_0 I_1 I_2 b}{2\pi}\left[\frac{1}{d} - \frac{1}{a+d}\right]$
4(iv)	2	**Either:** When a<<d: $F \approx \frac{\mu_0 I_1 I_2 b}{2\pi}\left[\frac{1}{d} - \frac{1}{d}\right] = 0$ ie the forces on the two sides of the loop are approximately equal in magnitude and cancel each other out. **or:** When d<<a: $F \approx \frac{\mu_0 I_1 I_2 b}{2\pi}\left[\frac{1}{d}\right]$ ie this is the maximum possible force as the force on the side of the loop farthest from the wire is negligible.	When a<<d: $F \approx \frac{\mu_0 I_1 I_2 b}{2\pi}\left[\frac{1}{d} - \frac{1}{d}\right] = 0$ ie the forces on the two sides of the loop are approximately equal in magnitude and cancel each other out. When d<<a: $F \approx \frac{\mu_0 I_1 I_2 b}{2\pi}\left[\frac{1}{d}\right]$ ie this is the maximum possible force as the force on the side of the loop farthest from the wire is negligible.
4(v)	2	$d = \frac{\mu_0 N I_1 I_2 b}{2\pi F} = \frac{1.26\times10^{-6}\times5000\times100\times100\times20}{2\pi\times20000\times9.8} = 1.0\times10^{-3}\,m$	

Question	Type 1 (explanatory) or Type 2 (problem)	B Evidence	A Evidence
4(vi)	2		Estimate the mass of an average person – say 70 kg (accept estimates between 50 and 100 kg) The total mass of a full carriage = 20 000 + (70 x 70) = 24 900 kg Calculate new value of *d* d = 0.82 mm
4(vii)	1	Discussion of 1 advantage and 1 disadvantage required for credit. The discussion must involve the physics eg forces, energy, power etc. Some minor misconceptions or irrelevancies will be apparent. **Advantages:** Train can glide along the track without friction between the wheels and track so less force is needed to accelerate/decelerate, maintain constant velocity etc. **Disadvantages:** There is a high current in the wires (I=100A) and these wires will be long (5 000 turn coil, kms of track). We would expect significant heating of these wires ($P=I^2R$) and therefore they will require a lot of power.	Discussion of 1 advantage and 1 disadvantage required for credit. The discussion must involve the physics eg forces, energy, power etc. Response should not include any irrelevancies or misconceptions. **Advantages:** Train can glide along the track without friction between the wheels and track so less force is needed to accelerate/decelerate, maintain constant velocity etc. Very high speeds can be reached by levitating the train and using electromagnetic (or other) propulsion methods. This avoids the mechanical limitations of conventional motors and wheels where at high speeds there is a lot of friction, heating and stress on the mechanical components. **Disadvantages:** Friction between the wheels and track can be useful – eg when accelerating or braking. A different method of propulsion/braking could be used, or the train could rest on the track at times. There is a high current in the wires (I=100A) and these wires will be long (5 000 turn coil, kms of track). We would expect significant heating of these wires ($P=I^2R$) and therefore they will require a lot of power.