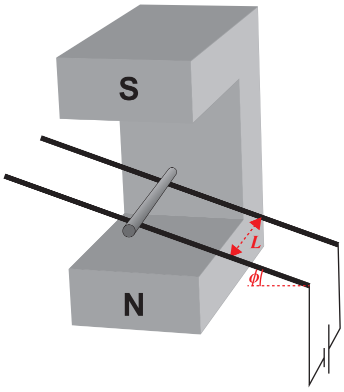
QUESTION ONE: THE MAGNETIC ROLLER

A pair of parallel, conducting metal rails are connected to a voltage source, as shown in the diagram. The fixed rails slope down at angle ϕ to the horizontal between the poles of a large magnet. The force on a current carrying conductor in a magnetic field is given by the relationship $F = BIL$. The voltage induced when a conductor moves through a magnetic field is given by $V = BvL$. Both of these relationships apply in the case where the magnetic field and the conductor are at right angles to each other, and when the velocity is at right angles to both.



(a) Show that a conducting roller can be placed across the rails and remain stationary in the position shown, if the magnetic field strength is given by $B = \dfrac{mg\tan\phi}{IL}$,

where m = mass of the roller, I = current through the roller, and L = the separation of the rails.

(b) The voltage source is now replaced with a small-valued resistor, of resistance R. The metal roller moves down the rails and enters the magnetic field. It slows down and continues at a constant velocity while it is inside the magnetic field.

Explain why this occurs.

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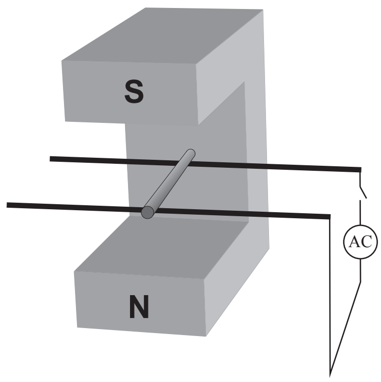
(c) Show that the constant velocity achieved by the roller through the magnetic field is given by:

$$v = \frac{mgR\tan\phi}{B^2L^2\cos\phi}$$

(d) With the rails now horizontal, they are connected to an AC (50 Hz) power supply, as shown in the diagram. When the switch is closed, the motion of the roller may be any one of a variety of different motions.

Explain how this is possible.



(8)

QUESTION TWO: INDUCTANCE (8 marks)

A 75 W electric light bulb (with zero inductance) is designed to run from a 50 Hz AC supply of 120 V_{rms}. If the only supply available is 240 V_{rms} and 50 Hz, the bulb can be operated at the correct power by placing in series with it, either:

(i) a resistance R, or

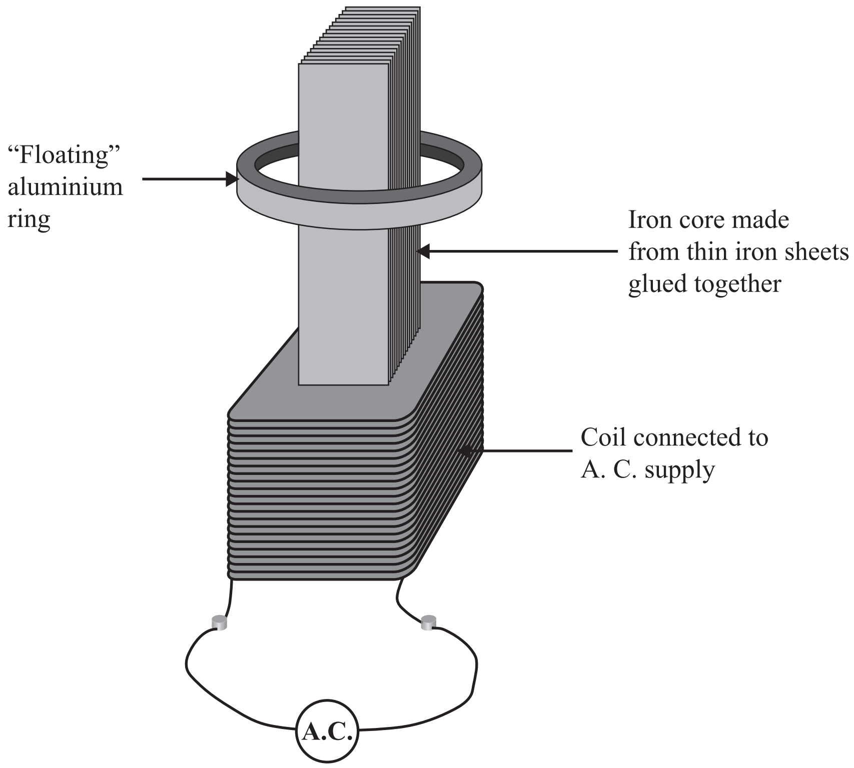
(ii) an inductance L.

(a) Find the values of R and L and the power drawn from the supply in each case.

(i)

(ii)

(b) When an alternating voltage is applied across a coil wrapped around an iron core, an aluminium ring around the core will "float" at some height above the coil.



Explain why this happens.

(c) Explain, possibly with the aid of a diagram, how such a coil could be wound so that this effect would not take place.

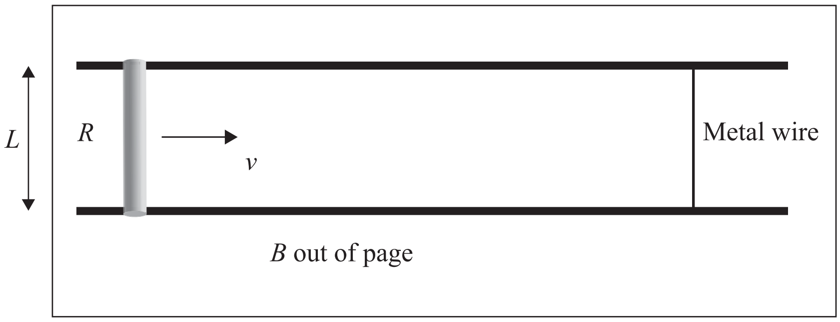
(d) To reduce the heating of the iron core, thin sheets of iron are glued together. The glue that holds the thin iron sheets together must have some specific electrical properties.

Suggest at least one electrical property of the glue, and state why it is important.

(8)

QUESTION THREE: ELECTROMAGNETIC INDUCTION (8 marks)

A metal roller of resistance R is placed on two long metal rails, which are connected via a metal wire. The whole system is placed in a uniform magnetic field, as shown in the diagram below. Initially the metal roller is given a small impulse towards the right.

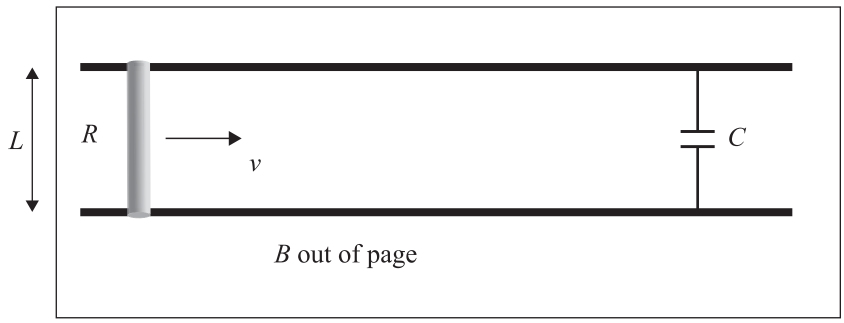


(a) Explain physically why the metal roller cannot continue to move with constant velocity towards the metal wire.

(b) By applying a constant force to the right, the roller can be made to move with constant velocity.

By applying Faraday's Law, derive a relationship for the voltage across the roller.

The metal wire is replaced by a capacitor, as shown below. The roller is again given a small impulse to the right.



(c) Explain why the roller eventually travels at a constant velocity.

(d) Derive an expression for the charge on the capacitor when the roller has reached constant velocity. Show that the expression you have derived is dimensionally correct.

(e) Explain what would be the effect of initially charging the capacitor before releasing the roller onto the rails.

(8)

QUESTION FOUR: A MAGLEV TRAIN

Theory

A current-carrying wire produces a magnetic field of magnitude B at a distance r from the wire. The direction of B is given by a right-hand rule and the magnitude of B is given by the equation below where I is the current in the wire and $\mu_0 = 4\pi \times 10^{-7}\,\text{N A}^{-2}$.

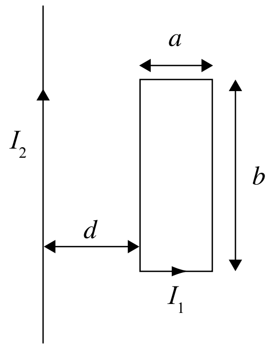
$$B = \frac{\mu_0 I}{2\pi r}$$

A wire carrying a current I in a magnetic field B experiences a force F. The direction of the force is given by an appropriate right-hand rule and the magnitude of F is calculated using the equation below, where l is the length of the wire.

$$F = BIl$$

Situation

A long wire with current I_2 lies in the plane of a rigid rectangular loop carrying current I_1. The rectangle has sides a and b and is a distance d from the long wire, as shown below.



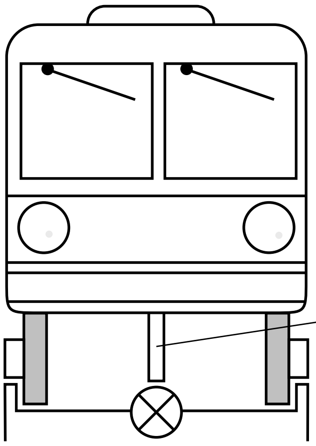
(i) Explain why there is a force acting on the loop.

(ii) Explain why the force on the loop acts to move the loop away from I_2.

(iii) Derive an expression for the magnitude of the force acting on the loop.

(iv) From your expression given above, it can be seen that the relative size of the variables a and d will have a strong influence on the size of the force. Discuss what would happen to the force in the limiting cases where $a<<d$ and $d<<a$.

Front view of Maglev train.



It is suggested that the force between a loop and a long current-carrying wire could be used in the design of a magnetically levitated train (Maglev). Many loops (a coil) are placed vertically in each carriage directly above a cable fixed to the track bed. If the dimensions are chosen so that $a >> d$ and N is the number of loops in a coil then the force produced will be given by:

$$F = \frac{\mu_0 N I_1 I_2 b}{2\pi d}$$

where $\mu_0 = 4\pi \times 10^{-7}$ N A^{-2} and the acceleration due to gravity = 9.80 m s^{-2}.

(v) A carriage used to investigate this concept is 20 m long with a mass of 2×10^4 kg and a maximum allowed current in the cable and coil of 100 A. The coil has 5000 loops.

Calculate the distance d between the lower side of the coil and the cable.

distance = ______________

(vi) One of the designers is concerned that the distance d will change considerably when people get on the train. Estimate the value of d for a full carriage holding 70 people.

(vii) Discuss at least one advantage and at least one disadvantage with the design of this type of train. Your discussion should be relevant and linked to the physics of the situation.