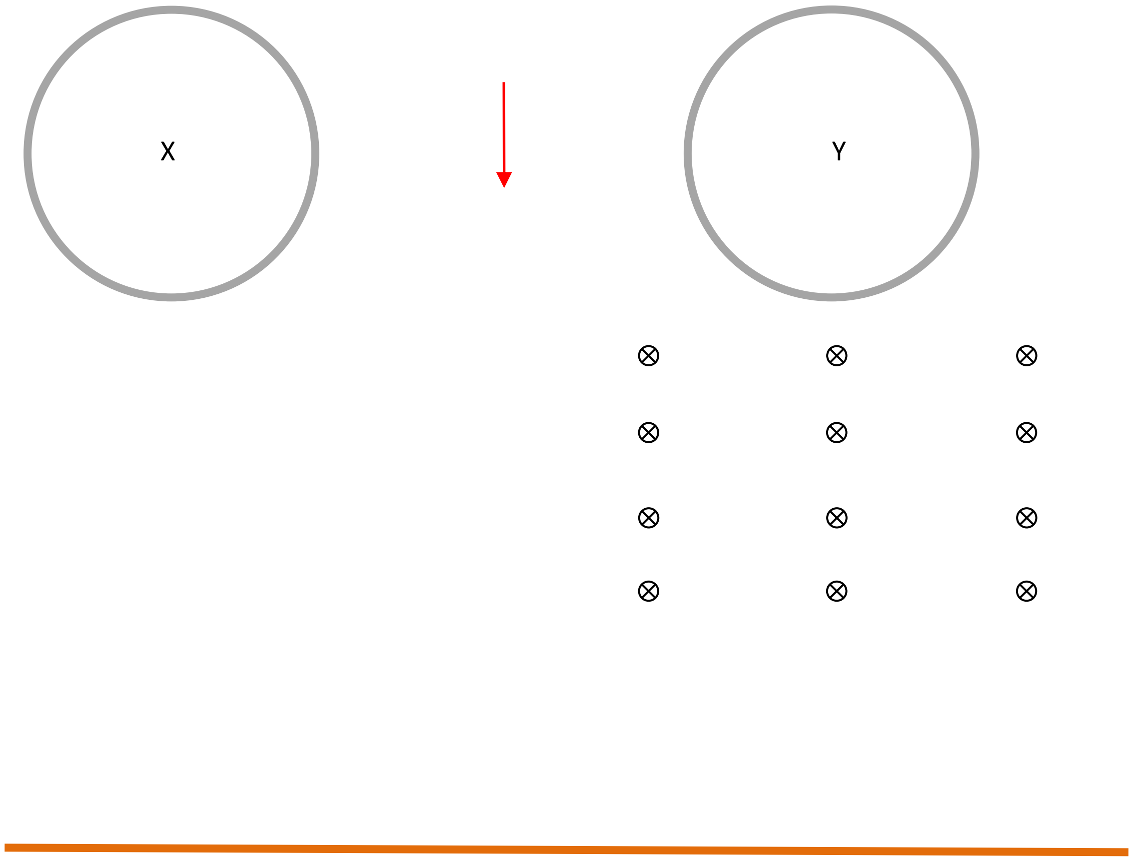
Problem of the week

EM Induction

(a) The flux through a single loop varies with time as shown in the graph.

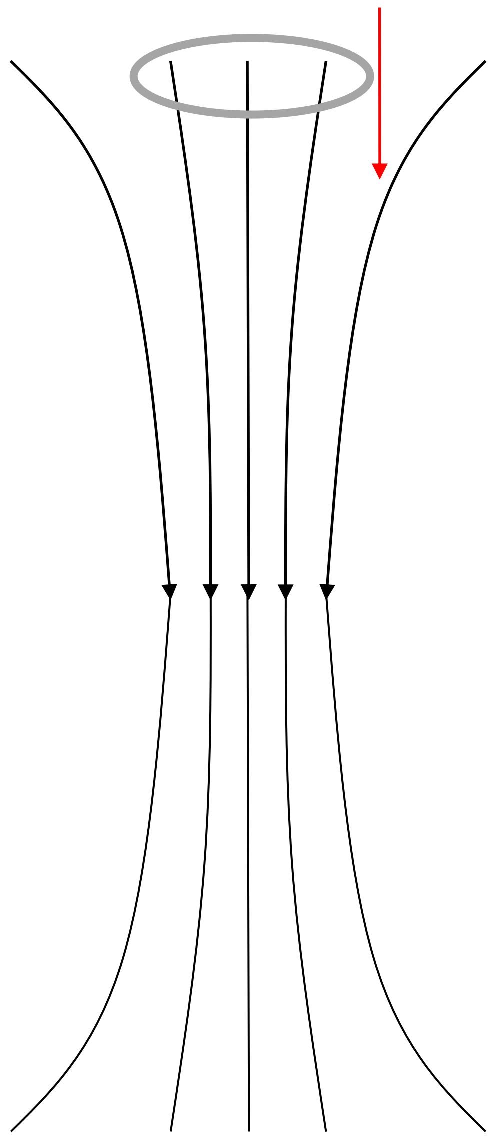
Sketch a graph to show the variation with time of the induced emf in the loop.

(b) Two identical conducting rings, X and Y, are falling vertically with their planes vertical. Y goes through a uniform horizontal magnetic field. X and Y start from rest at the same height from the ground.



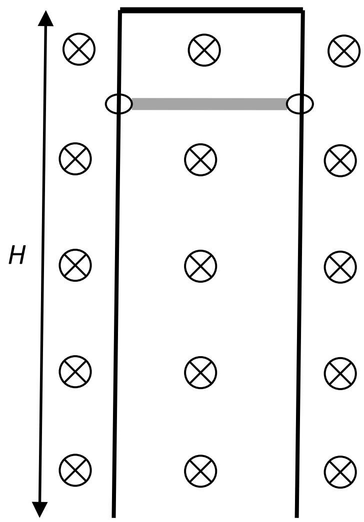
State and explain which ring falls to the ground first.

(c) A conducting ring falls vertically with its plane horizontal in a region of a non-uniform vertical magnetic field.



Describe the motion of the ring qualitatively.

(d) A conducting rod of length L, mass m and resistance R is attached to conducting rails by rings so that the rod can fall vertically without friction. The height H of the rails is very long. A uniform horizontal magnetic field B is established as shown. The rod is allowed to fall from rest.

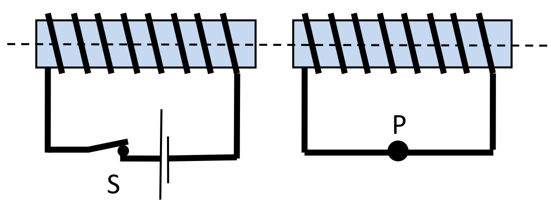


(i) Show that the potential difference at the ends of the rod when the rod has speed *v* is *BvL*.

(ii) Explain why the rod will reach terminal speed.

(iii) Show that the terminal speed is given by $v_T = \frac{mgR}{B^2L^2}$.

(e) Two coils wound on iron cores have a common axis as shown. Switch S was originally closed but it is now opened.

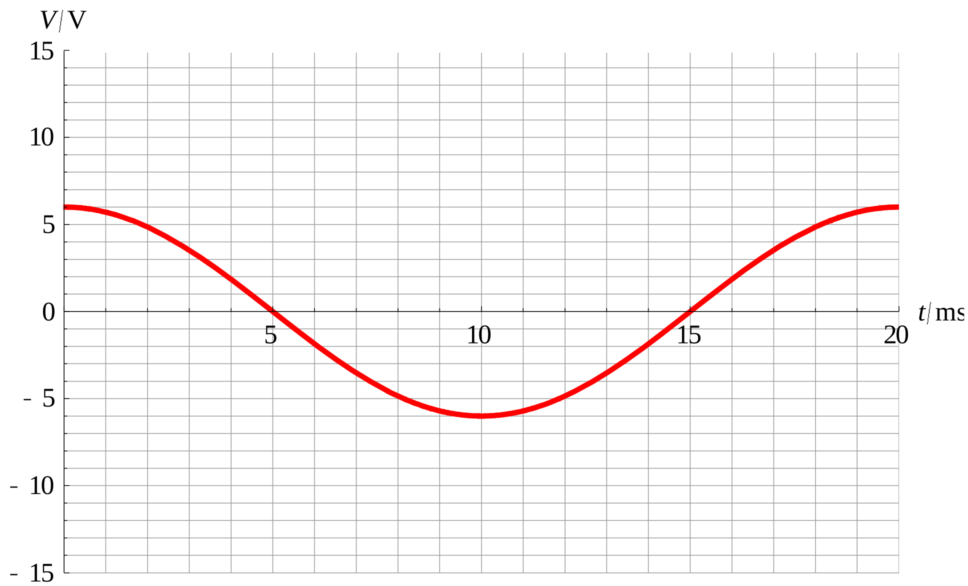


(i) Explain why a current will flow in the right-hand coil.

(ii) Explain why the current will flow for a short time interval only.

(iii) State and explain the direction of the current through P.

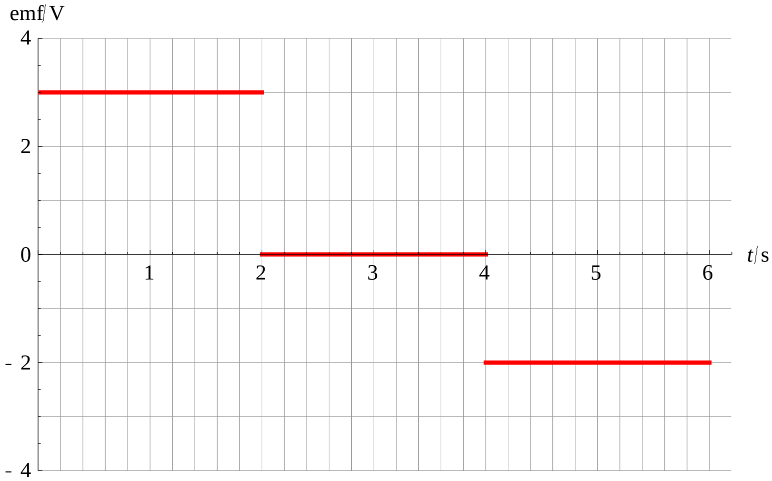
(f) The graph shows the variation with time of the voltage in a coil that rotates in a uniform magnetic field.



The frequency of rotation is doubled. Sketch, on the axes, a graph to show the new variation with time of the voltage.

Answers

(a)

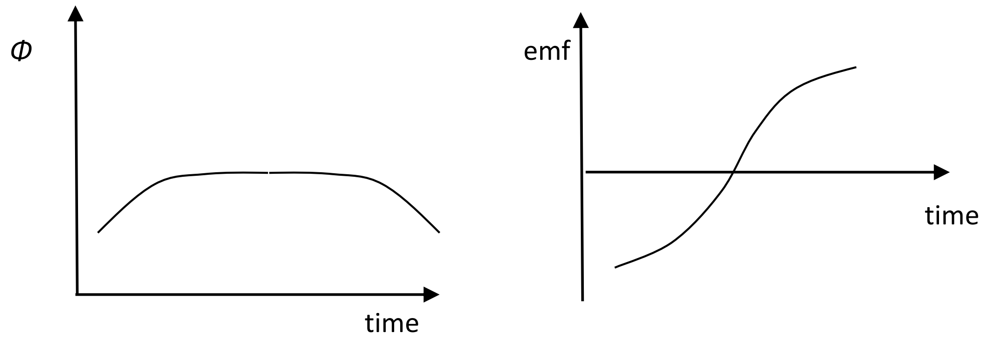


(b) When ring Y enters and then leaves the region of magnetic field the flux is changing and so an emf will be induced and a current will flow. This generates thermal energy in the ring and so the kinetic energy of the ring is less than ring X. Hence the average speed of Y is less than that of X and so X will arrive first.

OR

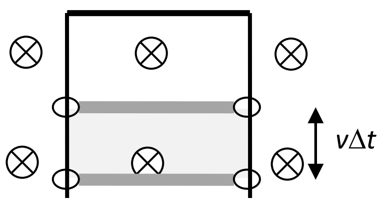
As Y enters the region of magnetic field an emf will be induced. The induced current will be counterclockwise and so a force will act on the ring upwards slowing it down. As Y leaves the region of magnetic field the flux is decreasing and so the induced emf will produce a clockwise current. The force will again be upward. Hence the ring is slowed down and so X arrives first.

(c) Initially the loop is moving towards a region of stronger magnetic field and so the flux is increasing. There will be an induced emf and an induced current. The current will be counterclockwise when looked at from above. There will be a force on the loop upward reducing the acceleration. In the middle of the magnetic field region the field appears uniform and so there will no force and the loop will fall with acceleration g. The ring then moves in a region of weakening magnetic field and so the flux is decreasing again inducing an emf and current. The current is clockwise looked at from above and there is an upward force on the loop again.
The flux and emf behave roughly as:



(d)

(i) In time Δt, the flux increases by $\Delta\Phi = BLv\Delta t$ because the area increased by the shaded amount below. Hence $V = \dfrac{\Delta\Phi}{\Delta t} = \dfrac{BLv\Delta t}{\Delta t} = BLv$.



(ii) There will be an induced emf and an induced current and so a magnetic force on the rod upwards. The induced emf is *BvL* and so increases as speed increases. Eventually the emf and the current will be large enough for the magnetic force to equal the weight.

(iii) $F_m = BIL$. $I = \dfrac{emf}{R} = \dfrac{BvL}{R}$. Hence $F_m = B\dfrac{BvL}{R}L = \dfrac{B^2L^2}{R}v$. $F_m = mg \Rightarrow v_T = \dfrac{mgR}{B^2L^2}$.

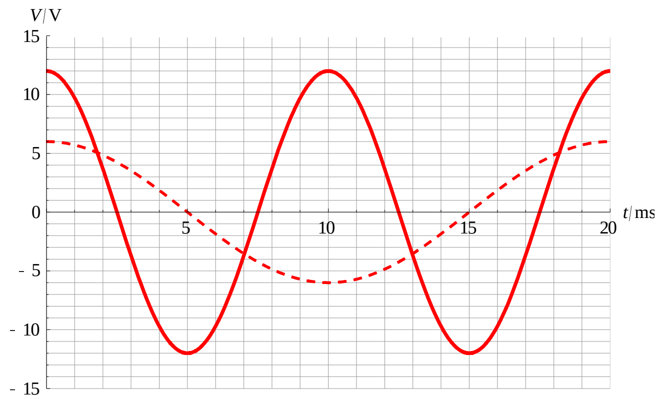
(e)

(i) The current in the left coil will be reduced from some non-zero value to zero. The magnetic field produced by this current is also reduced to zero. Hence the flux in the right coil is decreasing and so an emf and a current will be induced in the right coil.

(ii) The current will be reduced to zero in a very short interval of time and so the flux is changing only for this short time interval.

(iii) The flux in the right coil is decreasing so by Lenz's law the right coil will tend to attract the left coil to oppose the change in flux. The left coil behaves as a bar magnet with its N pole on the right. The right coli will then develop an S pole to the left. Hence the current in the right coil is to the left at P.

(f)


V / V
15
10
5
0
- 5
- 10
- 15
5
10
15
20
t / ms