CHAPTER 6

Electromagnetic induction

Answers to revision questions

1. See Chapter 6.
2. (a) When the switch is first switched on, the current will take a brief moment to reach the maximum. This is a period of changing current, hence a changing magnetic flux for a brief moment. This changing magnetic flux will induce an EMF in the secondary coil according to Faraday's law. The galvanometer in the secondary coil registers a current flow.

   However, soon after, the DC current becomes steady, hence there is no more changing magnetic flux and no more induced EMF. The needle of the galvanometer drops to zero. Hence a flicker!

   (b) Turn the switch on and off so the magnetic flux will always be changing.

   (c) The soft iron core intensifies the magnetic flux in the coil, therefore making the induced EMF bigger.
3. Changing the circle into the square will change the area. To calculate the new area of the square we need to first determine the length of its sides. The perimeter of the square equals the circumference of the circle.

   Perimeter $= 2\pi r$ ($r =$ radius)

   Side $= \dfrac{2\pi r}{4}$ (all sides equal)

   Area of the square: $\left(\dfrac{\pi r}{2}\right)^2 = \dfrac{\pi^2}{4} \cdot r^2 (A_s)$

   Area of the circle: $\pi r^2 (A_c)$

   $A_s = (\pi r^2) \cdot \dfrac{\pi}{4} = \dfrac{\pi}{4}(A_c)$

   Since $\dfrac{\pi}{4} < 1$, the area of the square is smaller than the circle. Hence the area decreases.

   According to $\phi = BA$, when the area decreases, the magnetic flux changes to induce an EMF in the coil (according to Faraday's law).

   Using Lenz's law, since the change in flux can be minimised by an increase of the magnetic strength into the page, the induced EMF will need to flow in a clockwise direction in order to produce a magnetic field that will point into the page (right-hand grip rule).
4. (a) Since the magnet is in relative motion to the coil, an EMF current will be induced. The direction of the current is one that will induce a magnetic field that opposes the external field according to Lenz's law, that is, field leaving on the left side (a north pole). Hence the current will be flowing into the solenoid on the right side, and out on the left (right-hand grip rule).

   (b) The induced EMF will double.

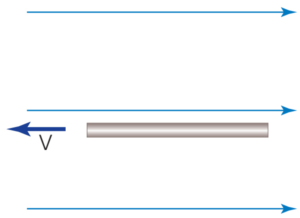
(c) The EMF will last twice as long.

(d) The induced EMF will reduce by a half.

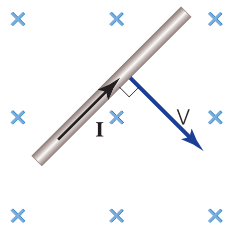
(e) The size of the induced EMF will remain the same but now goes in the opposite direction.

(f) The induced EMF will increase by 10 times.

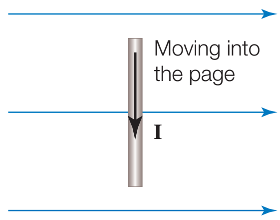
5. (a) There will be no EMF induced since the conductor is moving parallel to the magnetic field (not cutting the field lines).



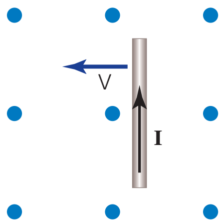
(b) Since the conductor is pushed down towards the right hand corner, we want the induced current to oppose this motion by moving it towards the top left corner. Hence the direction of current: from bottom left to top right. (Palm: top left corner; fingers: into the page; thumb: along the rod pointing to top right.)



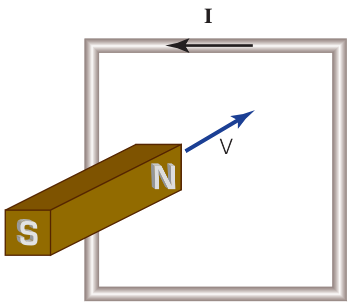
(c) Since the conductor is moving into the page, we want to induce a current which will try to move it out of the page. Hence the current will be down the page. (Use the right-hand palm rule. Palm: out of the page; fingers: to the right; thumb: down the page.)



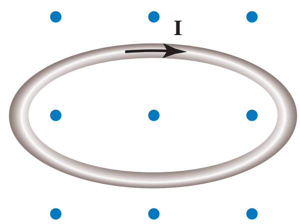
(d) Since the conductor is moving to the left, we want to induce a current which will try to push it to the right. Hence, the current will be up the page. (Palm: to the right; fingers: out of the page; thumb: up the page.)



(e) The bar magnet is moving into the square coil, thus the induced current will flow in a direction which opposes the movement of this magnet. Hence the current will move in an anti-clockwise direction. Use the right-hand grip rule. (thumb: out of the page; fingers: anti-clockwise.)

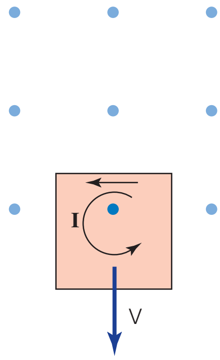


(f) When the magnetic field strength changes, the magnetic flux also changes, thus a current is induced. The induced current will flow in a direction which produces a magnetic field that opposes the change in the original magnetic field, that is, into the page. Hence the current will flow in a clockwise direction (right-hand grip rule – thumb: into the page; fingers: clockwise).

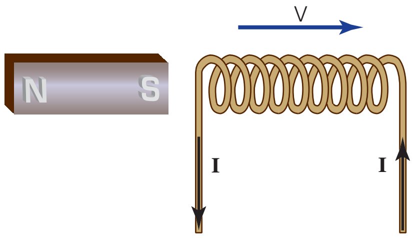


Magnetic field strength increases

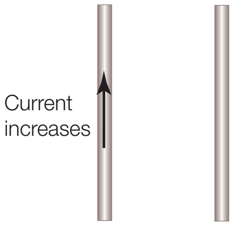
(g) Since it is a metallic sheet moving in a magnetic field, eddy currents will be induced. The upper portion of the plate will be induced with a current going from the right to the left (palm: up the page; fingers: out of the page; thumb: to the left). Hence the eddy currents will travel in an anti-clockwise direction.



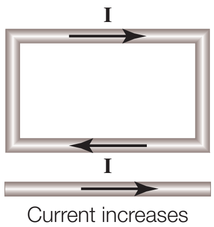
(h) As the solenoid moves away from the bar magnet, a current will be induced in the coil to produce a magnetic field opposing the change in the external magnetic field. Therefore, a north pole will be established on the left side of the solenoid. Hence, the current will enter into the right side and leave from the left side. (Right-hand grip rule – thumb: to the left; fingers: anti-clockwise when viewed from the left.)



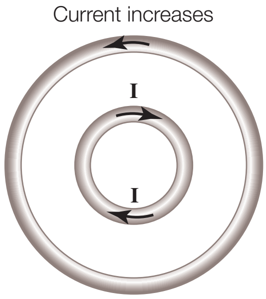
(i) The current in the wire will produce a magnetic field which goes into the page at the point where the conductor is. Although there is a change in the magnetic flux, the conductor is not linked to the changing magnetic flux, hence a current will not be induced.



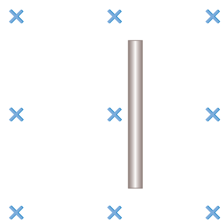
(j) The magnetic field generated by the wire at the site of the square loop is out of the page, since the current is increasing the magnetic flux is also changing (increasing). Using the right hand grip rule, the induced current will be going in a clockwise direction to oppose the increase in the magnetic field out of the page (thumb: into the page; fingers: clockwise).



(k) The magnetic field generated by the outer loop is coming out of the page at the centre. Since the current is increasing, the magnetic flux is also increasing. This will induce a current in the conductor. This current will flow in a direction to oppose the increasing magnetic flux out of the page. Hence the current will go in a clockwise direction (thumb: into the page; fingers: clockwise).



(l) The magnetic flux is changing since the magnetic field strength is increasing, but the conductor is not linked to this change of magnetic flux, thus no current will be induced.



6. See Chapter 6.

7. (a) When the ends of the solenoid are not connected an EMF will still be induced due to the changing magnetic flux (moving magnet), but a current will only be induced momentarily, as the circuit is not completed. Hence the magnet will be slowed down briefly before resuming to a constant velocity once again.

   (b) When the ends are connected, part (a) will happen again, but this time, since there is a complete circuit, the current will flow continuously. Hence the magnet will be slowed down by a continuous deceleration.

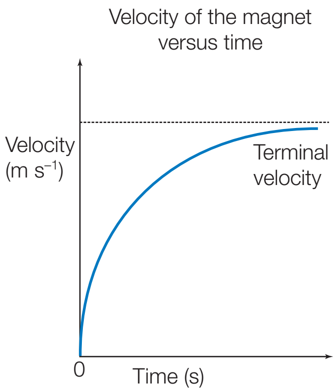
   (c) Part (b) will also happen, but with the soft iron core, it will enhance the induction process, hence the magnet will be slowed down at an even faster rate.

8. (a) Back EMF is the EMF induced as a result of the armature of a motor rotating inside the magnetic field. The nature of the back EMF according to Lenz's law is such that it opposes the initial forward EMF. As the motor spins faster, the size of the back EMF also increases. This opposes the forward EMF even more and therefore reduces the overall flow of current inside the coil. This means that when the motor reaches a certain high speed, the size of the back EMF will be so large such that the net current flowing in the coil is minimal; hence the torque acting on the armature (and therefore its acceleration) is minimal. This limits the speed of the motor.

   (b) When the drill is jammed inside the wall, because the armature is no longer rotating in between the magnetic field, the back EMF suddenly drops to zero. However, because the motor is not immediately turned off, the input EMF is still present. Consequently, the input EMF will not be opposed at all, and this leads to a very large net current flowing in the drill which can burn out the drill if it is sustained.

9. (a) Eddy currents will be induced in the copper tube to oppose the falling motion of the magnet.

   (b)



   The terminal velocity is reached because the opposing force due to the induced eddy currents is large enough to balance the weight force exerted by the magnet. (Assume there is no other friction force.)

   (c) The fact that the copper tube has holes will limit the flow of eddy currents, hence the opposing effect will be reduced and the magnet will be able to fall through it faster.

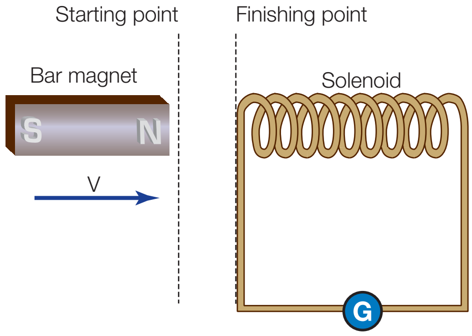
10. (a) Eddy current braking and induction cooktops

   (b) The soft iron core in armatures. The eddy currents flowing through them will produce heat, which is a source of energy loss, thus making the devices less efficient.

11. When choosing cooking wares for induction cooktops, it will be desirable to choose one that has high iron content since iron is one of the best materials for electromagnetic induction; electromagnetic induction is the basic principle of induction cooktops.

12. The basic principle for eddy current braking is to induce eddy currents in a moving object with magnetic fields. The induced eddy current will oppose the motion of the moving object, hence slowing it down very quickly, hence braking. The advantage of this kind of braking is that it is very efficient and also there is minimum friction, hence making the braking smoother, inflicting less wear and tear and as a result requiring less maintenance.

13. (a) A magnet and a solenoid are set up as shown in the following diagram.



(b) The magnet is moved from a fixed starting point into the solenoid at a constant speed. Stop the magnet at a fixed finishing point.

(c) Record the reading of the current in the solenoid while the magnet is moving.

(d) Repeat this three times and record the results.

(e) Bind two magnets together (hence doubling the magnetic field) and repeat step (b), (c) and (d). The factors that need to be controlled are the same solenoid, same starting and finishing points and the speed of the magnet as these factors can also affect the size of the induced EMF.

(f) Repeat step (e) with three, four and five magnets bound together respectively.

(g) Draw a table to display these results and make correlations between the strength of the magnetic field and the size of the induced EMF.

The data of this experiment is only semi-qualitative, hence it is difficult to plot any graph for the experiment. However, the results of the experiment should indicate that the strength of the magnetic field will directly influence the size of the EMF.