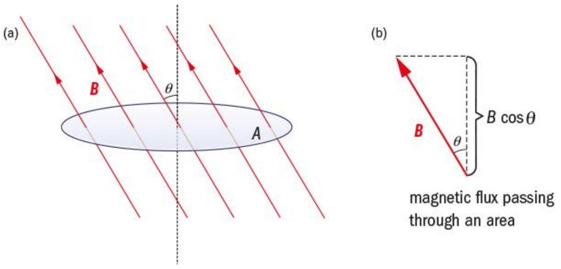
Electromagnetic Induction

A. MAGNETIC FLUX

- Magnetic flux ϕ is defined as the product of an area and the flux density perpendicular to the area.



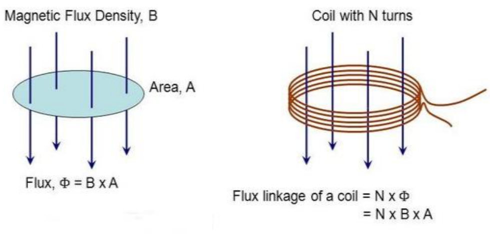
$$\phi = BA\cos\theta$$

* θ is the angel of the flux density B and the normal area, therfore If the flux density is perpendicular to the area:

$$\phi = BA$$

- Magnetic flux linkage is the product of the magnetic flux and number of turns (N turns of the coil) in a circuit.

Magnetic flux linkage $= N\phi = BAN$



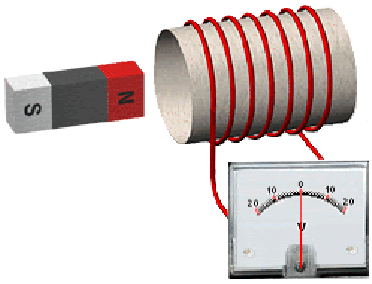
The unit of magnetic flux ϕ is weber (Wb)

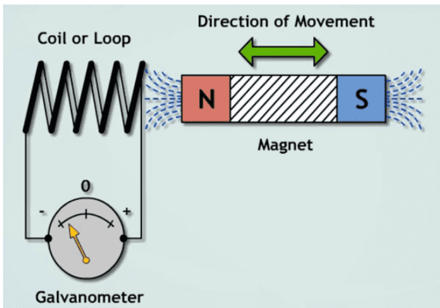
B. FARADAY'S LAW OF ELECTROMAGNETIC INDUCTION

- Faraday's law states that the e.m.f. induced in a closed circuit is proportional to the negative of the rate of change of flux linkage.
- From Faraday's experiment, current can be produced by change in magnetic field, and that phenomena is called an electromagnetic induction.

The equation is given by:

$$e.m.f = -\frac{Nd\phi}{dt}$$



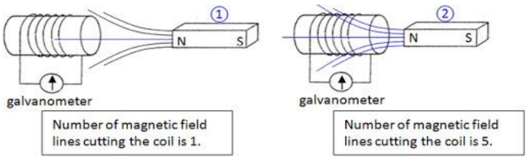


- The galvanometer will show how much current produced by the induced e.m.f. If the Galvanometer reads zero, there is no e.m.f. induced.
- Emf is induced when the magnet is moved forward and backward through the coiled wire (solenoid) because the lines of field that cut or pass through the coiled wire will change, hence there is a change in magnetic field as shown below.

Magnitude of the e.m.f. will increase:

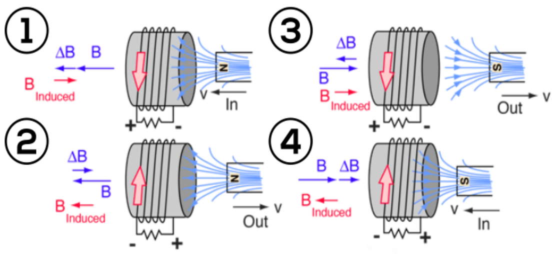
- as the speed of the magnet increase
- as the number of loop increase

- According to Faraday, when there is no relative motion between the magnet and the coil, magnetic flux within the coil remains constant (unchanged), so the galvanometer shows no deflection.
    - If the magnet is hold still inside the solenoid or outside the solenoid, the galvanometer will read zero.



C. LENZ'S LAW

Lenz's law states that the direction of the induced e.m.f. is such that it tends to oppose the flux change causing it.

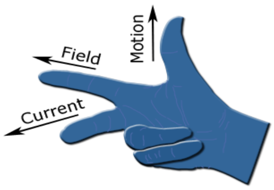


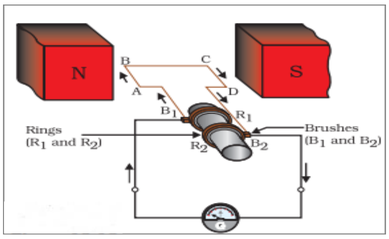
- The magnetic field is come from the north pole to the south pole of the magnet bar.
- Use the right-hand grip rule with thumb pointing the induced magnetic field and fingers grabbing the solenoid, the fingers will point the direction of current.
- For the induced current that enter galvanometer on positive side, the galvanometer will read positive current and vice versa.
- The galvanometer reads positive when the pointer is deflected to the right, and vice versa.
- The magnet bar that come towards or away from the solenoid, will change the magnetic field flowing through and must cause a change in magnetic flux, therefore it induces emf. The emf then creates a current in the loop, the induced current then produces the induced magnetic field (marked by the red B).

From the picture above,

- On the first case, north pole is pointing to the left, the magnetic field from the bar that is pointing to the left increases as the bar is moving towards (in) the coil. In other word, the change in magnetic field (and also magnetic flux) is pointing to the left, therefore the induced magnetic field will oppose that change (Lenz's law) by pointing to the right.
- On the third case, north pole is pointing to the right, the magnetic field from the bar is pointing to the right. When the bar is moving away (out) from the coil, the magnetic field will decrease. In other word, the change is pointing to the left, hence the induced magnetic field is pointing to the right.

C. FLEMING'S RIGHT-HAND RULE





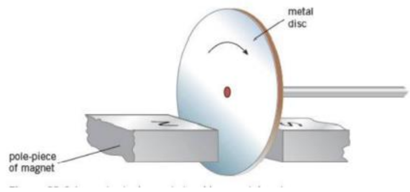
The Fleming's is used to determine the direction of induced current when moving coil or wire in a magnetic field.

The picture above illustrates an AC generator,

- If the wire AB is given a push upward, from the Fleming's right-hand rule we can know that the current will go from A to B (as shown on the picture)
- If the wire CD is pushed upward by a force, then the current will go from D to C (opposite the current in the picture)

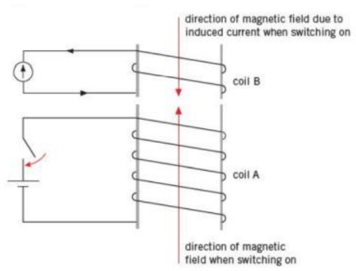
D. APPLICATIONS OF ELECTROMAGNETIC INDUCTION

Eddy current damping



- As the disc spins, it cuts through the flux lines of the magnet.
- An e.m.f. (electromotive force) will be induced in the disc but, since the rate of cutting of flux varies, the e.m.f. will have different magnitudes in different regions of the disc.
- Since the disc is made of metal, electrons will move between regions within the disc that have different e.m.f. values.
- Various currents are induced. Since these currents varies in magnitude and direction, they are called **eddy currents.**
- The eddy currents cause heating in the disc and the dissipation of the energy of rotation of the disc is referred to **eddy current damping.**

E.m.f. induced between two coils



- As the current in coil A is being switched on, the magnetic field in this coil grows. The magnetic field links with the turns on coil B, as a result, there is a change in flux linkage in coil B and an e.m.f. is induced in this coil.
- The change of a current was a growth in the magnetic flux in coil A. The induced current in coil B will give rise to a magnetic field in coil B. Consequently, since the field in coil A is vertically upwards, the field in coil B will be vertically downwards.
- When the current in coil A is switched off, the magnetic field in coil A will decay. Therefore, the magnetic field in coil B will try to prevent thdecay and hence it will be vertically upwards.

E. EXERCISE

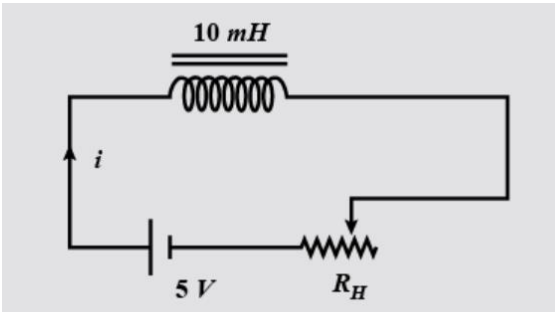
- Find out the e.m.f. produced when the current changes from 0 to 1A in 10 second, given $L = 10\mu H$.

Solution

$L = 10\mu H$
$t = 10A$
$i_i = 10A$
$i_f = 1A$

$|e| = L\frac{di}{dt}$
$|e| = 10 \times 10^{-6} \times \frac{1}{10} = 1\mu V$

- The resistance in the following circuit is increased at a particular instant. At this instant the value of resistance is 10Ω. The current in the circuit will be now?



Solution

If resistance is constant (10Ω) then steady current in the circuit

$i = \frac{5}{10} = 0.5\ A$

But resistance is increasing, it means current through the circuit start decreasing. Hence, inductance comes in picture which induces a current in the circuit in the same direction of main current.

So, $i > 0.5A$

- which one is the correct statement:

  (i) only current is induced when the flux linked with a closed circuit changes.

  (ii) only e.m.f. is induced when the flux linked with a closed circuit changes.

  (iii) both e.m.f. and current are induced when the flux linked with a closed circuit changes.

  (iv) both e.m.f. and current are induced when the flux linked with an open circuit changes.

  Solution

  Faraday's First Law of Electromagnetic Induction states that whenever a conductor is placed in varying magnetic field e.m.f. are induced which is known as induced e.m.f. if the conductor circuit is closed current are also induced which are called induced current.

  So, the answer is (iii)

- A hundred turns of insulated copper wire are wrapped around an iron cylinder of area $1 \times 10^{-3}\ m^2$ and are connected to a resistor. The total resistance in the circuit is 10Ω. If the longitudinal magnetic induction in the iron changes from $1\ weber\ m^{-2}$, in the direction to $1\ weber\ m^{-2}$ in the opposite direction, how much charge flows through the circuit?

  Solution

  $$dQ = \frac{d\phi}{R} = \frac{nAdB}{R}$$

  $$Q = \frac{nA\Delta B}{R} = \frac{100 \times 1 \times 10^{-3} \times 2}{10} = 2 \times 10^{-2} C$$

- **Assertion:** Faraday's Laws are consequences of conservation of energy.
  Reason: in a purely resistive ac circuit, the current lags behind the e.m.f. in phase.

  Solution
  According to Faraday's Laws, the conversion of mechanical energy into electrical energy. This is in accordance with the law of conservation of energy. It is also clearly known that in pure resistance, the e.m.f. is in phase with the current.
  So, assertion is correct but reason is incorrect.