Mutual Induction

If we place two coils near each other and pass electric current in one of them, or change the current already passing through it, or stop the current, then an emf is induced in the second coil. This phenomenon of electromagnetic induction is called "mutual induction". The first coil is called the primary coil and the second is called the secondary coil.

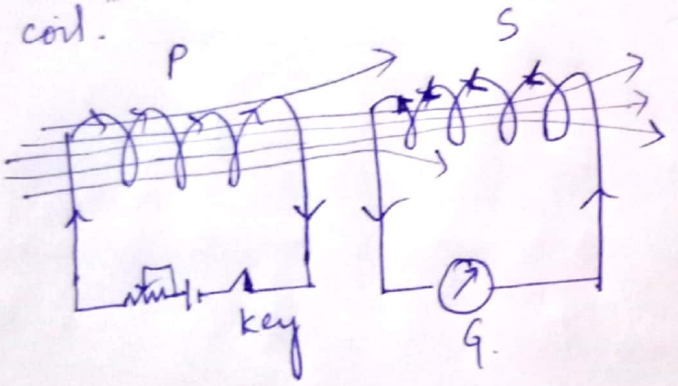

fig a

On pressing the key

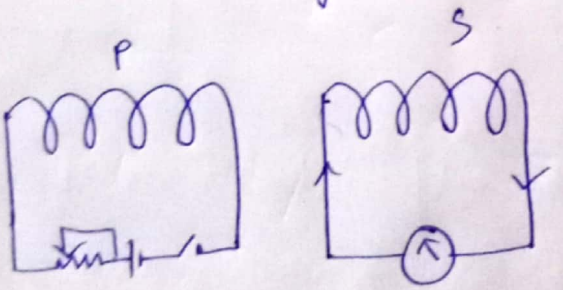

fig b

On leaving the key.

In figure a, a primary coil P and a secondary coil S are placed near each other. The coil P is connected to a battery, a rheostat and a tapping key. The secondary coil S is connected to a galvanometer. As

the key is pressed, a momentary deflection is produced in the galvanometer. The reason is that when the key is pressed, a current passes in the coil P and a magnetic field is produced around it. Some lines pass through the coil 'S' also. Thus, on pressing the key, the number of flux lines passing through the coil S increases from 0 to a definite value. Due to this change in the number of flux-lines, i.e in the magnetic flux, an emf is induced in the coil S and a current flows through it. Hence, a momentary deflection is produced in the galvanometer. According to Lenz's law, the induced current opposes the creation of flux-lines. Hence, its direction is opposite to the direction of current in coil P.

Similarly, again when the key is left open, a momentary deflection is produced in the galvanometer in the opposite direction, this is again due to change in magnetic flux. Hence again an emf is induced in the coil S and a current flows. This current opposes the disappearance of flux lines, so now the direction of current is same as in P.

Similarly, when the current through P is varied with the help of rheostat, there is a change in the number of flux lines passing through S, thus an induced current flows in S.

* Induction coil and transformers are based on this principle

Coefficient of Mutual Induction

Let a current i_1 ampere flows in the primary coil, P. Let, due to this current, the magnetic flux linked with each turn of the secondary coil be Φ_2.

If N_2 be the number of turns in coil S, then the number of flux linkages in the coil will be $N_2\Phi_2$.

This number is proportional to the current i_1 flowing in the primary coil, that is —

$$N_2\Phi_2 \propto i_1$$

$$\boxed{N_2\Phi_2 = Mi_1}$$

Here, 'M' is a constant called the "coefficient of mutual induction" or "mutual inductance" of the two coils.

$$M = \frac{N_2\Phi_2}{i_1}$$

If $i_1 = 1$, $M = N_2\Phi_2$. Hence, Coefficient of mutual inductance of two coils is equal to the number of magnetic flux-linkages in one coil when a unit current flows in the other.

If e_2 be the induced emf in secondary coil, then from Faraday's law,

$$e_2 = -N_2\frac{\Delta\Phi_2}{\Delta t} = -\frac{\Delta(N_2\Phi_2)}{\Delta t}$$

$$\Rightarrow e_2 = -\frac{\Delta(Mi)}{\Delta t} = -M\frac{\Delta i}{\Delta t} - M\frac{\Delta i}{\Delta t}$$

$$M = -\frac{e_2}{\Delta i_1/\Delta t}$$

The -ve sign indicates that the direction of emf induced in the secondary coil is such that it opposes any change in current in the primary coil.

If $\Delta i_1/\Delta t = 1$, then $M = e_2$.

Hence, The coefficient of mutual induction of two coils is equal to the numerical value of the induced emf in one coil when the rate of change of current in the other coil is unity.

The SI unit of coefficient of mutual induction is Henry.

Thus, 1 Henry is the mutual inductance of two coils when an induced emf of 1 volt is set up in one of them due to a current changing at the rate of 1 ampere per second in the other.

$$1\,H = 1\,Wb\,A^{-1} = 1\,VsA^{-1}$$

Q) (a) The current in the primary of a circuit is reduced from 10 A to zero uniformly in 1 ms. Calculate the emf induced in the secondary if the coefficient of mutual induction is 3 H.

(b) Also calculate the change in flux linked with each turn of the secondary which has 600 turns.

Ans: $e_2 = 30,000$ V

$\Delta\phi = -0.05$ Wb

Q) In a car spark-coil, when the current in the primary is reduced from 4.0 A to 0 in 10 μs, an emf is 40,000 V is induced in the secondary. Find the mutual inductance M of the primary and the secondary windings of the spark coil.

Ans: $M = 0.1$ H