HALL EFFECT: THEORY AND DERIVATION

Hall Effect Principle explains the behavior of charge carriers when it is exposed to electricity and magnetic fields. This principle can be regarded as an extension to Lorentz Force which is the force acting on the charge carriers (Electrons and Holes) passing through a magnetic field.

The Hall Effect Principle has been named after an American physicist Edwin H. Hall (1855–1938). It was first introduced to the world by him in 1879.

Hall Effect Principle says that when a conductor or semiconductor with current flowing in one direction is introduced perpendicular to a magnetic field a voltage could be measured at right angles to the current path. Before anything, we should understand what actually Electric current is. Electric Current is basically a flow of charged particles through a conductive path. These charged particles may be 'Negative Charged Electrons' or even 'Positive Charged Holes' (voids where electrons should be).

If we take a thin conductive plate and connect it in a circuit with a battery (voltage source) then a current will start flowing it. The charge carriers will flow in a straight line from one end of the plate to the other end.

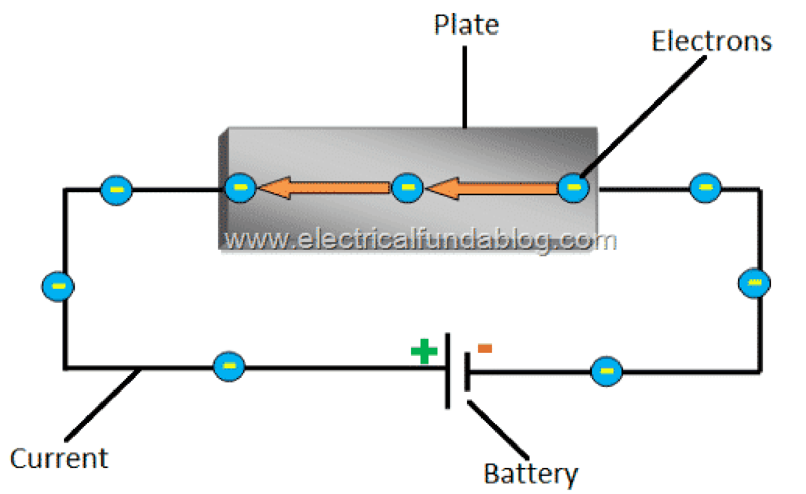


Fig. 1– Hall Effect Principle – Current Flowing Through a Plate

As the charge carriers are in motion, they will produce a magnetic field. Now when you place a magnet near the plate, its magnetic field will distort the magnetic field of the charge carriers. This will upset the straight flow of the charge carriers. The force which upsets the direction of flow of charge carriers is known as Lorentz force. Due to the distortion in the magnetic field of the charge carriers, the negative charged electrons will be deflected to one side of the plate and positive charged holes to the other side. That is why a potential difference (also called as Hall Voltage) will generate between both sides of the plate which can be measured using a meter.

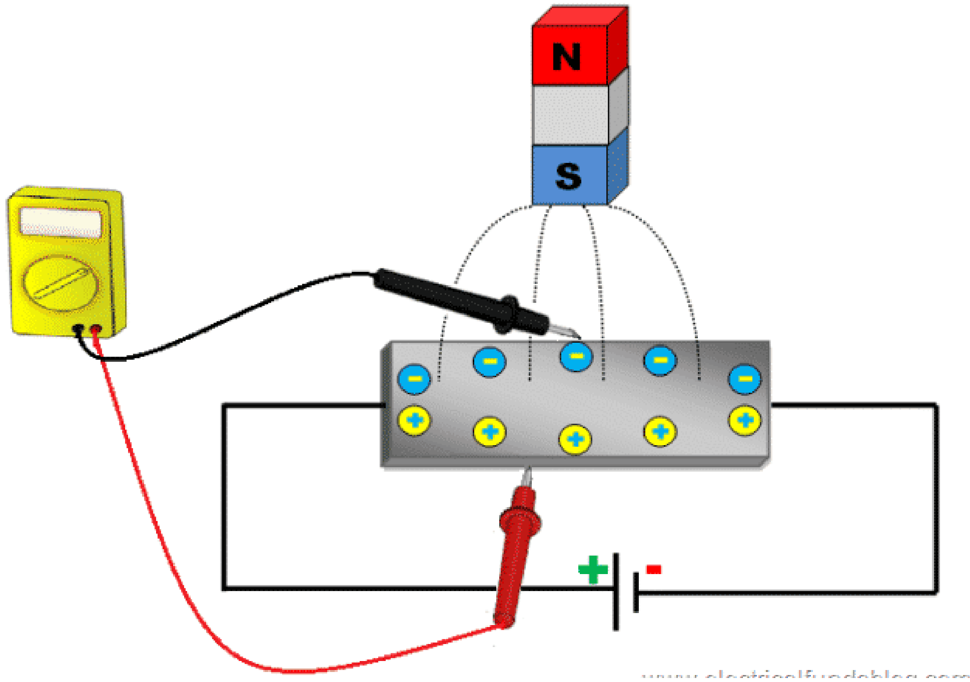
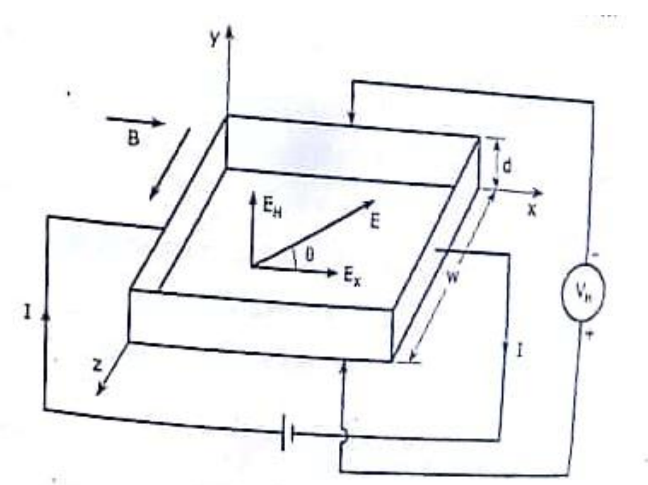


Fig. 2 – Hall Effect Principle – Deflection of Electrons and Holes

This effect is known as Hall Effect. The stronger the magnetic field, the more the electrons will be deflected. This means that the higher the current, the more the electrons will be deflected. And, the more the electrons will be deflected, the more the potential difference will be observed between both sides of the plate. Therefore we can say that:

- Hall Voltage is directly proportional to Electric Current, and
- Hall Voltage is directly proportional to the applied magnetic field.

As shown consider a rectangular plate of a p-type semiconductor of width ‘w’ and thickness ‘d’ placed along x-axis. When a potential difference is applied along its length ‘a’ current ‘I’ starts flowing through it in x direction.



As the holes are the majority carriers in this case the current is given by

$I = n_h A e v_d$ ....(1)

where n_h = density of holes

A = w × d = cross sectional area of the specimen

v_d = drift velocity of the holes.

The current density is

J= I/A =$n_h e v_d$ ....(2)

The magnetic field is applied transversely to the crystal surface in z direction. Hence the holes experience a magnetic force

$F_m = e v_d B$ ....(3)

In a downward direction. As a result of this the holes are accumulated on the bottom surface of the specimen.

Due to this a corresponding equivalent negative charge is left on the top surface.

The separation of charge set up a transverse electric field across the specimen given by,

$E_H = V_H / d$ ....(4)

Where V_H is called the HALL VOLTAGE and E_H the HALL FIELD.

In equilibrium condition the force due to the magnetic field B and the force due to the electric field E_H acting on the charges are balanced. So the equation (3)

$eE_H = e v_d B$

$E_H = v_d B$ ....(5)

Using equation (4) in the equation (5)

$V_H = v_d B d$.............................(6)

From equation (1) and (2), the drift velocity of holes is found as

$v_d = I/(en_h A) = J/(en_h)$ ....(7)

Hence hall voltage can be written as

$V_H = IBd/(en_h A) = (J_x Bd)/(en_h)$

An important parameter is the hall coefficient defined as the hall field per unit current density per unit magnetic induction.

$R_H = E_H/(J_x B)$

Applications of Hall effect

Hall effect finds many applications.

- It is used to determine if the given material is a semiconductor or insulator.
- It is used to measure the magnetic field and is known as a magnetometer
- They find applications in position sensing as they are immune to water, mud, dust and dirt.
- They are used in integrated circuits as Hall effect sensors.

Link to Video Lecture:

https://www.youtube.com/watch?v=Hnnl9vefZmA