Classical Hall Effect and Magneto Resistance

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Abstract

It is discussed here the classical Hall effect and developed the basic ides starting with Drude's model of electrical conducting. Then Hall coefficient and magneto resistance is mentioned.

Keywords: *Hall effect, Drude's model, magneto resistance.*

Introduction

In 1879, Edwin H. Hall discovered an unexpected phenomena that if a thin gold plate is placed in a magnetic field at right angles to its surface, an electric current flowing along the plate can cause a potential drop at right angles both to the current and magnetic field, which is known as Hall effect (figure on below). This happens because electrically charged particles i.e. electrons moving in a magnetic field are influenced by a force and deflect laterally.

1.1 Hall Effect:

When a magnetic field is applied perpendicular to a conductor carrying current, a voltage is developed across the specimen in the direction perpendicular to both the current and the magnetic field. This phenomenon is called the **Hall effect**.

Now let us consider the case when a magnetic field is applied in a direction to the electric field.

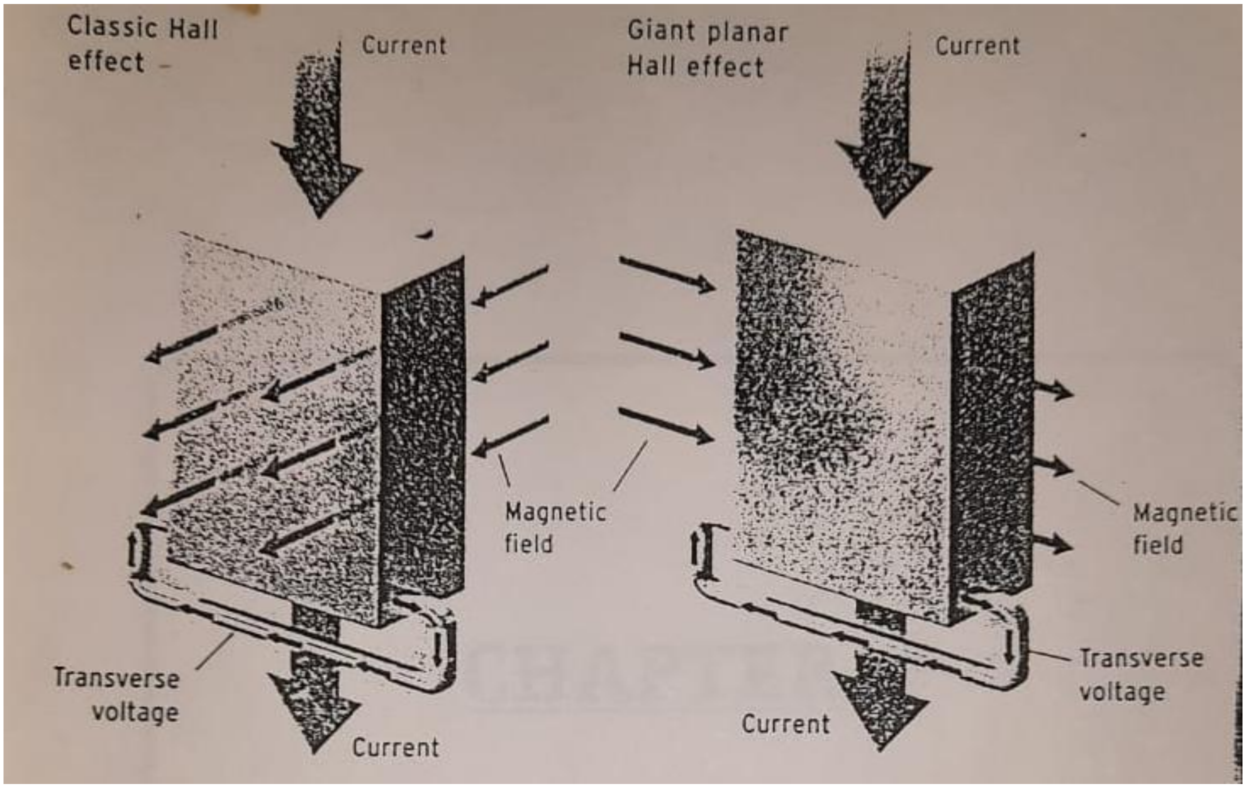
For this, consider a rectangular slab of a conductor subjected to an electric field E along x-direction and the applied magnetic field H is in the z-direction. Before we apply the magnetic field, a current density i, flows in the x-direction due to E A Lorentz force

$$F = \frac{-e}{c} V * H \qquad \text{…….1.1}$$

acts on the electrons to deflect them in the negative y direction. and therefore the lower surface collects a negative charge and the upper surface a positive ion excess. This sets up an electrostatic field inside the conductor in y-direction. But the electrons can move only upto the edge of the slab as they cannot leave the slab due to high potential barrier at the boundaries.

As the electrons accumulate there, the charge on the surfaces of the specimen continues until the force on moving charges due to the electric field associated with the accumulated charge itself is large enough to cancel the force exerted by the magnetic field. Ultimately a steady state is reached in which the net force on the moving charges in y-direction vanishes and the electrons can again move freely along the conductor.

Hence the transverse field (called Hall Field) E, will balance the Lorentz force due to H and current will flow only in the x-direction. The potential difference causing E_y is known as the Hall potential.



In a highly sensitive ferromagnetic semiconductor (right), with controllable magnetic and electronic properties, a voltage develops transverse to the current when a magnetic field is applied in its plane. In the classic Hall effect [left], the transverse voltage is created when a magnetic field is applied perpendicular to the current.

1.2 Hall Coefficient (Rh)

It can be defined as -

$$R_H = \frac{E_y}{j_x H} \qquad \text{…….1.21}$$

Since E_y balances the Lorentz Force it would be proportional to both the applied field H and the current J_x along the x-axis.

To calculate the Hall Coefficient, let us consider the applied electric field E_x and E_y in the presence of a magnetic field H along the z-axis causing current densities J_x and J_y. The force acting on electrons situated anywhere in the sample is -

$$F = -e\left(E + \frac{V * H}{c}\right) \qquad \text{…….1.22}$$

Hall coefficient can be written as

$$R_H = \frac{-1}{ne} \qquad \text{……1.23}$$

which is constant for a metal.

The Hall Coefficient depends only on the concentration of in the metal. That means the lower the carrier concentration, the greater the magnitude of the Hall Coefficient. It is negative for electrons positive for many metallic and semiconducting substances.

1.3 Magneto Resistance

If the specimen consists of two type carriers i.e. electrons and holes, then for each of the carrier the equation becomes.

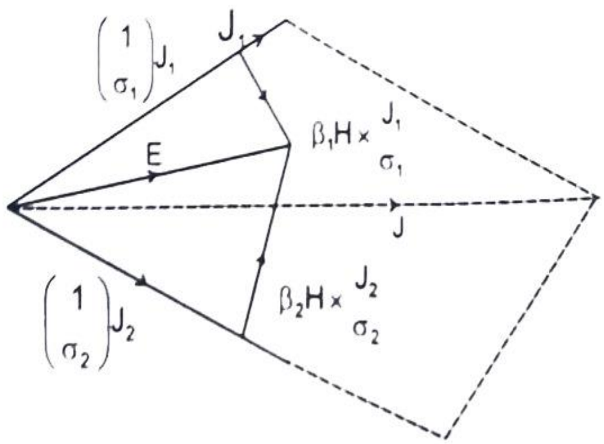
$$E = \frac{1}{\sigma_1} J_1 + \beta_1 H * \frac{J_1}{\sigma_1}$$

and $$E = \frac{1}{\sigma_2} J_2 + \beta_2 H * \frac{J_2}{\sigma_2}$$

where $$\beta_1 = \frac{e\tau}{m_1 C}$$

Both the equation represents the relation between their contributions the current and the applied electric field.

And the total current, J = J, + J,



(contributions to the Hall effect from two bonds of carriers) ……..3.23

which breaks up the current to longitudinal, in the direction of E, and transverse, in the direction of applied H. So

$$J = \frac{\sigma E}{1+\beta^2 H^2} - \frac{\sigma E}{1+\beta^2 H^2} H * E$$

……..1.32

Thus for two type of carriers

$$J = \sum_{i=1,2}\left[\left(\frac{\sigma_i}{1+\beta_i^2 H^2}\right)E - \left(\frac{\sigma_i \beta_i}{1+\beta_i^2 H^2}\right)H * E\right]$$

or $$\alpha E - \lambda H * E$$

……..1.31 ….1.33

Where α and λ are the coefficient of E and H E in the above equation. For finding the Hall Coefficient one has to invert this expression to get E in terms of J and HE then

$$E = \frac{J}{\sum\left(\frac{\sigma_i}{1+\beta_i^2}\right)} + \frac{\sum\left(\frac{\sigma_i \beta_i}{1+\beta_i^2 H^2}\right)}{\sum\left(\frac{\sigma_i}{1+\beta_i^2 H^2}\right)} H * E$$

….1.34

In low magnetic field this reduces to

$$E = \frac{J}{\sigma_1 + \sigma_2} + \frac{\sigma_1 \beta_1 + \sigma_2 \beta_2}{(\sigma_1 + \sigma_2)^2} H * E$$

…….1.35

Comparing we find the Hall Coefficients as

$$R_H = \frac{e\tau}{mc\rho_o} = \frac{\sigma_1 \beta_1 + \sigma_2 \beta_2}{(\sigma_1 + \sigma_2)^2}$$

or $$R_H = \frac{\sigma_1^2 R_{H_1} + \sigma_2^2 R_{H_2}}{(\sigma_1 + \sigma_2)^2}$$ …….1.36

Where RH and R, are the corresponding Hall Coefficients for each type of carriers.

Comparing J with the components of E along J we have

$$\rho = \frac{J.E}{J^2} \qquad \ldots\ldots 1.37$$

But

$$J.E = \left(\frac{\sigma_1}{1+\beta_1^2 H^2} + \frac{\sigma_2}{1+\beta_1^2 H^2} \right) E.E = \alpha E.E \qquad \ldots\ldots 1.38$$

Conclusion

So an electrical potential develops across the current flowing conductor in the presence of magnetic fields, besides electric field, this effect can also be found in ordinary magneto resistance. However, experimentally it is found that the Hall Coefficient generally does depend on the Magnetic Field, the temperature and the method of preparation of the sample. At very low temperatures and for very pure and carefully prepared samples placed in very high magnetic fields, it is seen that the measured Hall Coefficient appear to approach a limiting value.

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