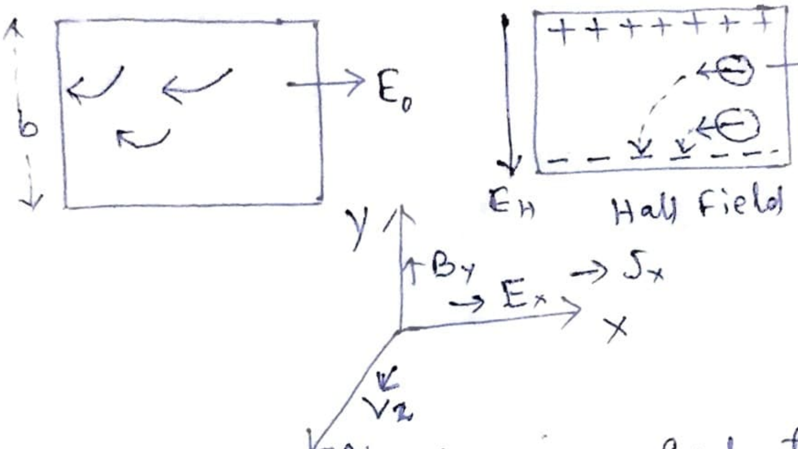
Free Electron Theory of Metals: Hall effect

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. It was discovered in 1879 by Hall.



Let us consider a thin slab of a conductor subjected to an electric field E_x along the x-axis. This will give rise to a current density J_x in the direction of E_x. For the moment, let us assume that the current is carried by electrons, each of charge '$-e$'. Now, let us suppose that superimposed on this field is a constant magnetic field B_z applied in the z-direction. The effect of the magnetic effect would be to force the electrons in 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 the Y-direction. The accumulation of 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 the Y-direction vanishes and the electrons

Can again move freely along the conductor. The electrostatic field E_y, which is set up inside the conductor, is given by

$$F_y = -e\left[E_y + \frac{1}{c}(\vec{v}\times\vec{B})_y\right] = 0$$

or, $$F_y = -e\left[E_y - \frac{1}{c} v_x \vec{B}_z\right] = 0$$

or, $$E_y = \frac{1}{c} v_x B_z \quad \text{———} (1)$$

Using the free electron theory result for current density,

$$J_x = -ne v_x$$

where v_x is the average drift velocity of the electrons,

eqn (1) is expressed as

$$E_y = -\frac{J_x B_z}{nec} = R_H J_x B_z \quad \text{———} (2)$$

with $$R_H = -\frac{1}{nec} \quad \text{———} (3)$$

R_H is called the Hall coefficient. It is a constant for a metal. E_y is the Hall field, and it is proportional to both J_x and B_z; the Hall coefficient R_H is thus merely the proportional constant between the Hall field and the product $J_x B_z$. Hall field can be obtained by measuring the Hall voltage V_H potentiometrically. The Hall field and Hall voltage are related by

$$V_H = E_y \times b$$

Where b is the width of the specimen. The Hall coefficient R_H can be determined if V_H, J_x and B_z are known.

If the charge carriers are electrons, R_H should always be negative. From experiment, it has been found that R_H is positive for many metallic and semiconducting substances (p-type).

Importance:→ The Hall effect is important in being the only simple way by which we can tell whether we have to deal with electrons or holes. Moreover, its magnitude gives the direct estimate of the number of carriers 'n' per unit volume.

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