IN 221 (AUG) 3:0
Sensors and Transducers
Lecture 9

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The Hall Effect

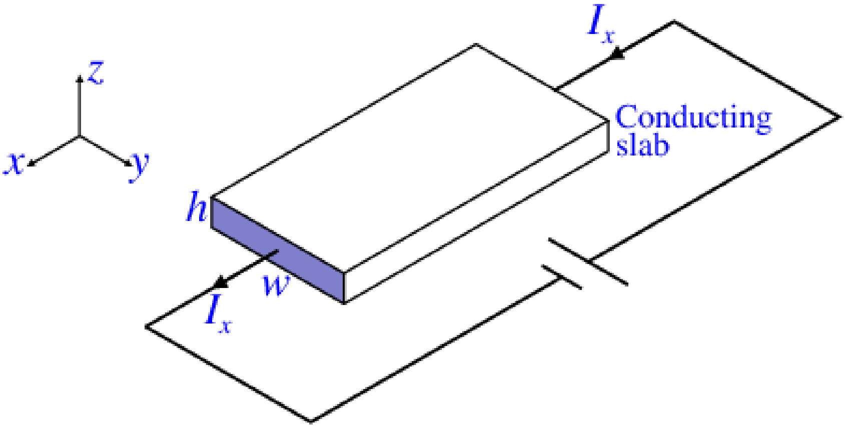
- A potential difference called the **Hall voltage** is produced that is transverse to an electric current in a conductor and to an applied magnetic field.
- Discovered in 1879 by Edwin Hall
- . . . before the discovery of the electron in 1897
- Provides information about the sign of charge carriers in conducting materials
- Used for sensing magnetic fields

Ideas and People Connected with Hall's Experiment

- Late nineteenth century: Electron was yet to be discovered.
- Not much was known about what actually was electric current.
- Edwin Herbert Hall (1855 – 1938)
- Henry Augustus Rowland (1848 – 1901)
- James Clerk Maxwell (1831 – 1879)

Please see
Hall, Edwin, "On a New Action of the Magnet on Electric Currents". *American Journal of Mathematics*, vol. 2 pp. 287–292, 1879

Current Density, Charge Density, Drift Velocity



Current Density, Charge Density, Drift Velocity

Charge density: Let the slab be filled with movable charge of density ρ, so that a volume V will contain movable charge $Q = \rho V$.
Drift velocity: Let it move in the x direction with velocity v_x.
Distance covered in time t: Then in time t it moves by a distance $\ell = v_x t$.
Volume: $V = wh\ell = whv_x t$.
Charge: $Q = \rho V = \rho whv_x t$.
Current: $I_x = Q/t = \rho whv_x$.
Drift velocity:

$$v_x = \frac{I_x}{\rho wh} = \frac{J_x}{\rho}, \qquad (1)$$

where,

$$J_x = \frac{I_x}{wh}, \qquad (2)$$

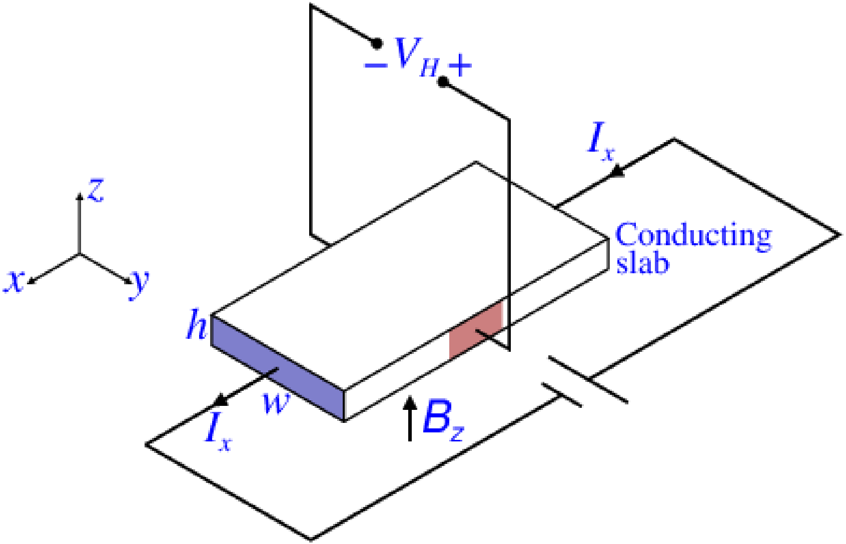
is the *current density*.
If ρ is really large, then v_x can be quite small.

The Lorentz Force Law

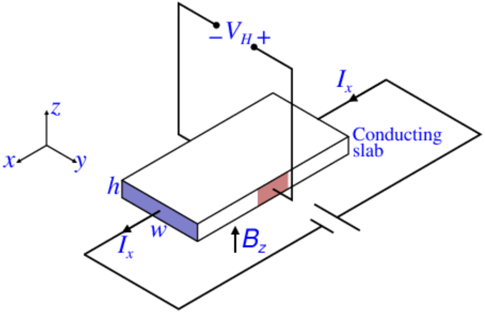
$$\mathbf{F} = q\left(\mathbf{E} + \mathbf{v} \times \mathbf{B}\right). \quad (3)$$

F: Force on the particle
q: Charge of the particle
E: Electric field
v: Velocity of the particle
B: Magnetic field
This formula will be used in the derivation that follows.

The Hall Effect: Diagram



The Hall Effect: Explanation



- The current is in the *x* direction.
- The magnetic field is in the *z* direction.
- The Hall voltage is generated in the *y* direction.

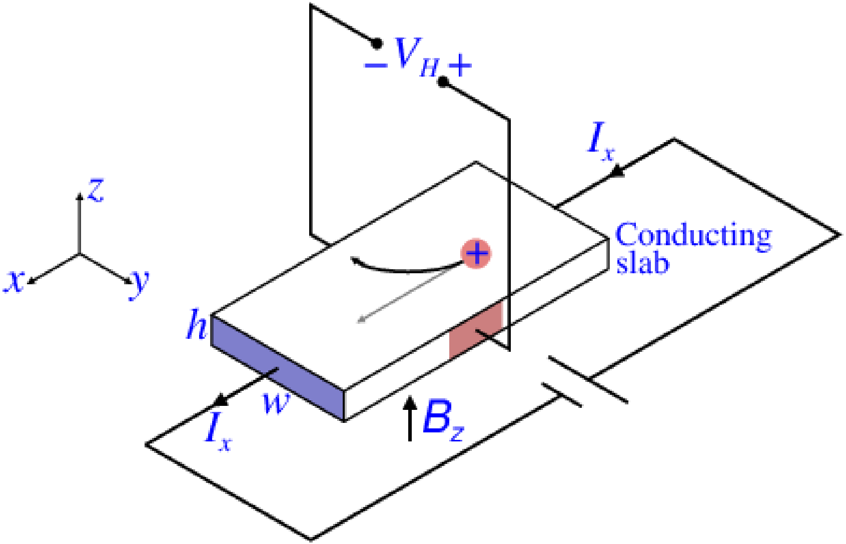
Assumption: One sign of carrier only

At the point we assume that the conduction in the slab is due to one type of charge carrier.
Either we have only positive charge carriers or only negative charge carriers, but *not both types*.

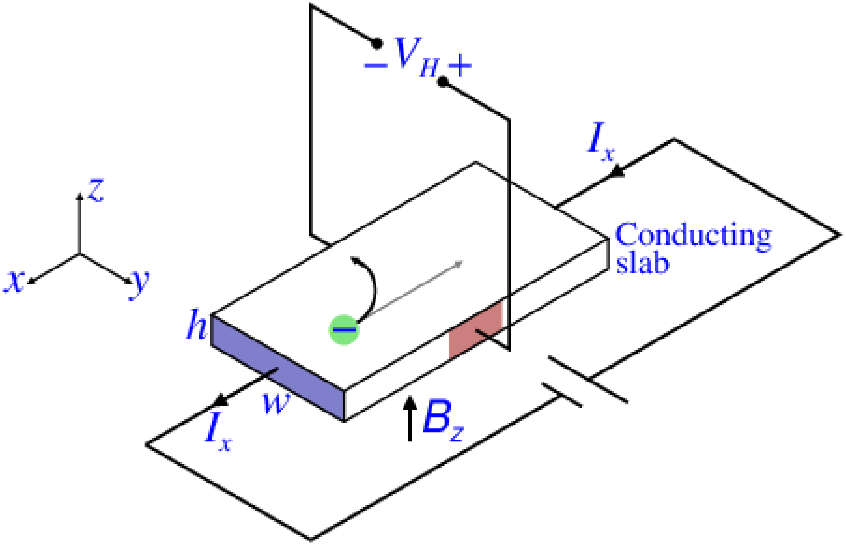
Force and deflection due to the magnetic field

Velocity: $\mathbf{v} = v_x \hat{x}$.
B Field: $\mathbf{B} = B_z \hat{z}$.
Force due to the magnetic field is $q\mathbf{v} \times \mathbf{B} = -qv_x B_z \hat{y}$.
If the charges are positive, then they move in the $+x$ direction. If $q > 0$, then $v_x > 0$, and $qv_x > 0$.
If the charges are negative, then they move in the $-x$ direction. If $q < 0$, then $v_x < 0$, and still $qv_x > 0$.
If $B_z > 0$, as assumed, both positive and negative charges are deflected in the negative y direction.

The Hall Effect: Positive charge carriers



The Hall Effect: Negative charge carriers



The Hall Effect: Sign of V_H

Whether the charge carriers are positive or negative, the deflection is always in the $-y$ direction.
If the charge carriers are positive then they migrate to the $-y$ face to make $V_H < 0$.
If the charge carriers are negative then they migrate to the $-y$ face to make $V_H > 0$.

The Hall Field: Counterbalancing

The migration of charges to the lateral y plates develops a Hall voltage V_H.
The net effect is that a y directed electric field $\mathbf{E} = E_y \hat{y}$ now acts on the carriers to apply a force that is opposite to the magnetic force.
From the diagram,

$$E_y = -\frac{V_H}{w}. \tag{4}$$

The Lorentz force due both **E** and **B** must be zero.

$$\mathbf{F} = q\left(\mathbf{E} + \mathbf{v} \times \mathbf{B}\right) = q\left(E_y \hat{y} + v_x \hat{x} \times B_z \hat{z}\right) = q\hat{y}(E_y - v_x B_z) = 0.$$

Or,

$$E_y = v_x B_z.$$

Then

$$V_H = -wE_y = -wv_x B_z = -w\frac{I_x}{\rho w h} B_z = -\frac{B_z I_x}{\rho h}.$$

Observations

$$V_H = -\frac{B_z I_x}{\rho h}. \tag{5}$$

The Hall voltage

- V_H is proportional to both B_z and I_x.
- V_H is inversely proportional to both ρ and h.
- The sign of V_H can indicate the sign if ρ, indicating whether the charge carriers are positive or negative.
- In metals, ρ is so large that V_H is quite small.
- In semiconductors, ρ can be much smaller, making it possible to have practical Hall sensors.
- Main use: Measurement or detection of magnetic fields

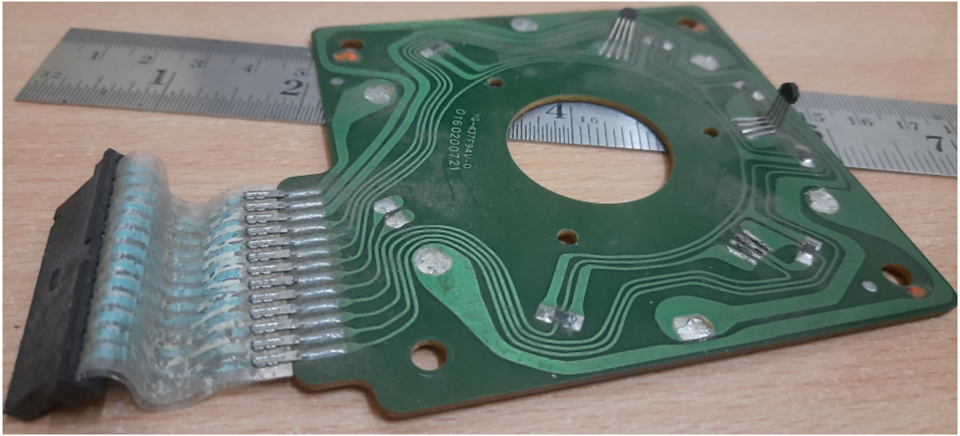
Uses

- Main use: Measurement or detection of magnetic fields
- Measurement of large direct currents
- Multiplier: Make B_z proportional to one signal, I_x proportional to the other.
- Wattmeter
- Brushless DC motors: Most computer fans

Types of Output

- Analogue: The Hall sensor output is amplified by a differential amplifier. Example: SS49E
- Digital: The Hall Sensor output is compared with a reference level and a logic output is given. Example: A3144

Hall Sensors in an old Floppy Drive Motor



Hall Current Sensor