UNIVERSITY OF NEBRASKA-LINCOLN
Physics & Astronomy

Hall Effect and its Measurements

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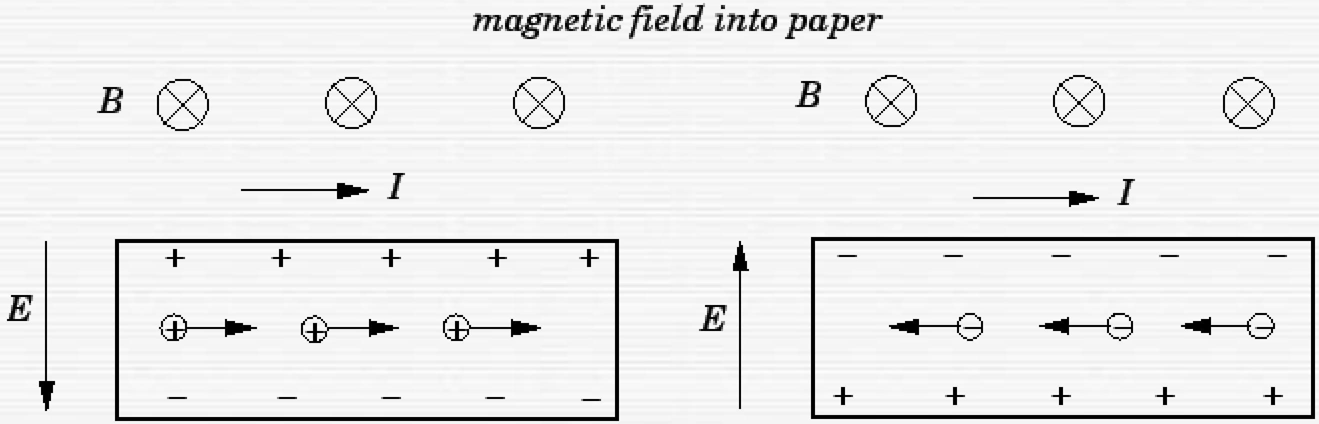
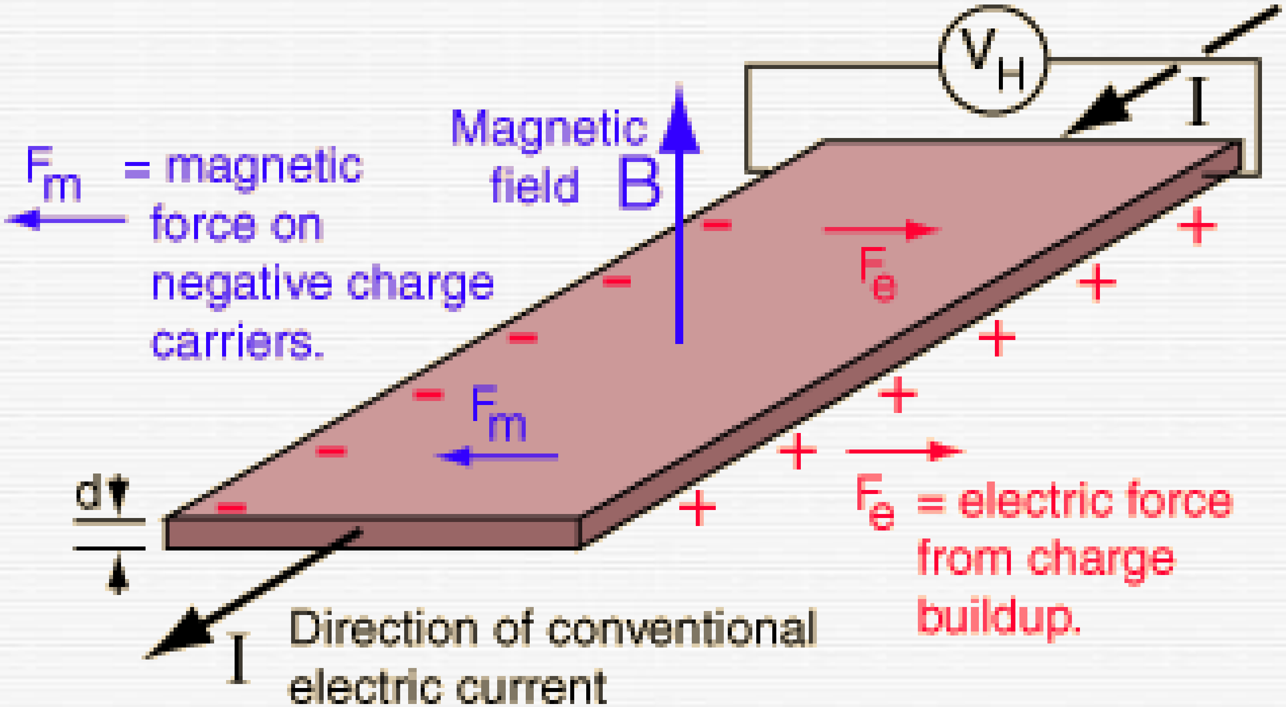
Hall effect

If an electric current flows through a conductor in a magnetic field, the magnetic field exerts a transverse force on the moving charge carriers which tends to push them to one side of the conductor.



Hall Voltage for Positive Charge Carriers



$$V_H = \frac{IB}{ned}$$

Charge Carriers in the Hall Effect

- The Hall effect is different for different charge carriers.
- In most common electrical applications, the conventional current is used partly because it makes no difference whether you consider positive or negative charge to be moving.
- The Hall voltage has a different polarity for positive and negative charge carriers, and it has been used to study the details of conduction in semiconductors and other materials which show a combination of negative and positive charge carriers.

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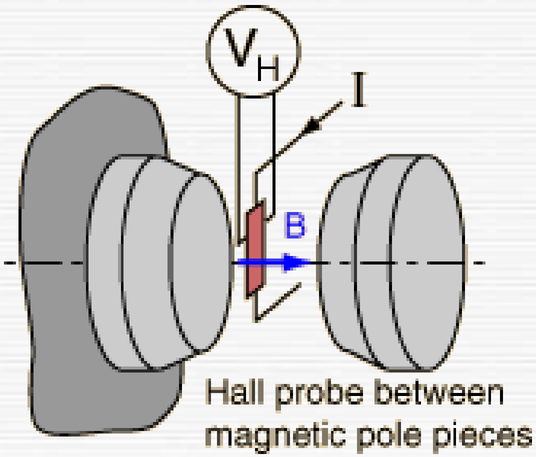
Charge Carriers in the Hall Effect

- The Hall effect can be used to measure the average drift velocity of the charge carriers
- Mechanically moving the Hall probe at different speeds until the Hall voltage disappears, showing that the charge carriers are now not moving with respect to the magnetic field.
- Other types of investigations of carrier behavior are studied in the quantum Hall effect.

Hall Probe

The measurement of large magnetic fields on the order of a Tesla is often done by making use of the Hall effect. A thin film Hall probe is placed in the magnetic field and the transverse voltage (on the order of microvolts) is measured.

Sometimes a thin copper film of thickness d on the order of 100 micrometers is used for a Hall probe.



The polarity of the Hall voltage for a copper probe shows that electrons are the charge carriers.

New Discoveries

- Quantum Hall Effect
- Spin Hall Effect
- Anomalous Hall Effect

Quantum Hall Effect

- Quantization of normal Hall Effect
- Seen at low temperature, high magnetic field
- Very precise, magnitude determined by Landau levels and electron interaction

$$\sigma = \nu \frac{e^2}{h}$$

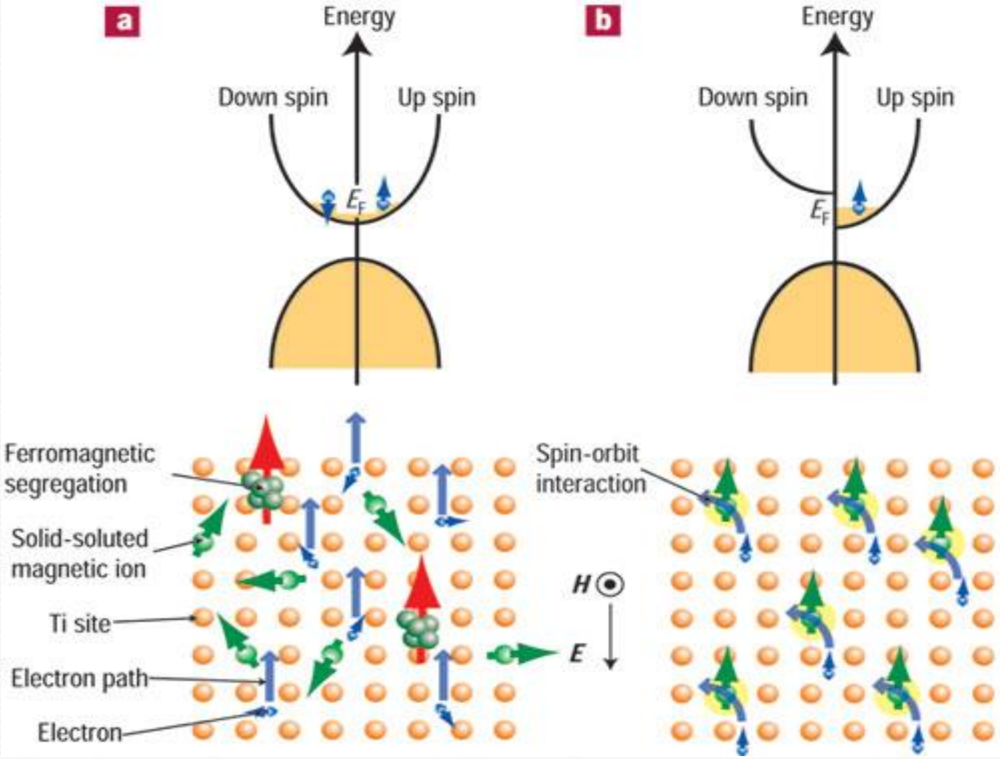
Spin Hall Effect

- Separation of electron spins in current-carrying object, no magnetic field needed
- Predicted in 1971, observed in 2004 via emission of circularly polarized light
- Universal, present in metals and semiconductors at high and low temperature

Anamolous Hall Effect

- Ferromagnetic materials have internal magnetic field

Via Toyosaki et al. 2004



- Much larger than normal Hall Effect, but not well understood ; Possible Berry-phase effect

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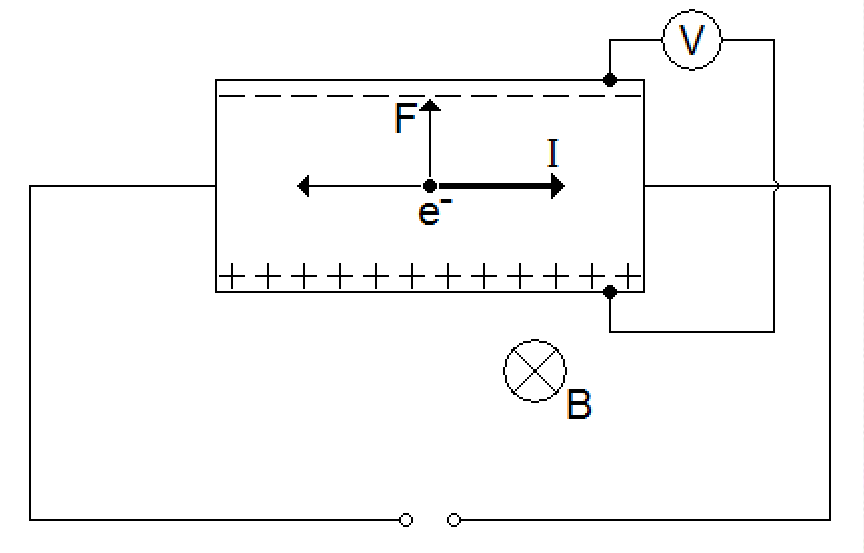
Hall Effect Measurements

This transverse voltage is the Hall voltage VH and its magnitude is equal to IB/qnd, where I is the current, B is the magnetic field, d is the sample thickness, and q (1.602 x 10^{-19} C) is the elementary charge.

In some cases, it is convenient to use layer or sheet density (n_s = nd) instead of bulk density. One then obtains the equation:

$$n_s = \frac{IB}{q|V_H|}$$



Hall Effect Measurements

Thus, by measuring the Hall voltage V_H and from the known values of *I*, *B*, and *q*, one can determine the sheet density n_s of charge carriers in semiconductors. If the measurement apparatus is set up as shown, the Hall voltage is negative for *n*-type semiconductors and positive for *p*-type semiconductors. The sheet resistance R_S of the semiconductor can be conveniently determined by use of the Van der Paw resistivity measurement technique. Since sheet resistance involves both sheet density and mobility, one can determine the Hall mobility from the equation

$$\mu = \frac{|V_H|}{R_S I B} = \frac{1}{q n_S R_S}$$

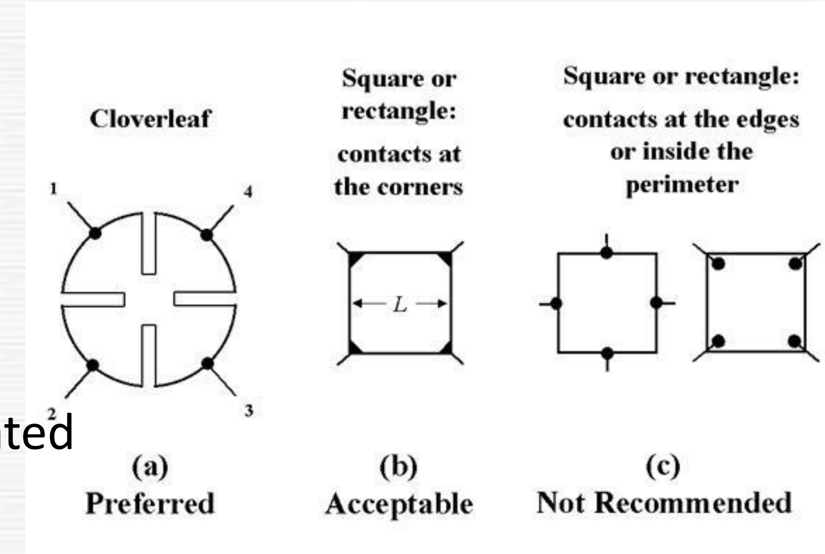
If the conducting layer thickness *d* is known, one can determine the bulk resistivity ($r = R_S d$) and the bulk density ($n = n_S/d$).

The Van der Pauw Technique

Van der Pauw equation:

$$e^{\frac{-\pi R_A}{R_S}} + e^{\frac{-\pi R_B}{R_S}} = 1$$

In which $R_A = \frac{V_{43}}{I_{12}}$ $R_B = \frac{V_{14}}{I_{23}}$



The bulk electrical resistivity ρ can be calculated

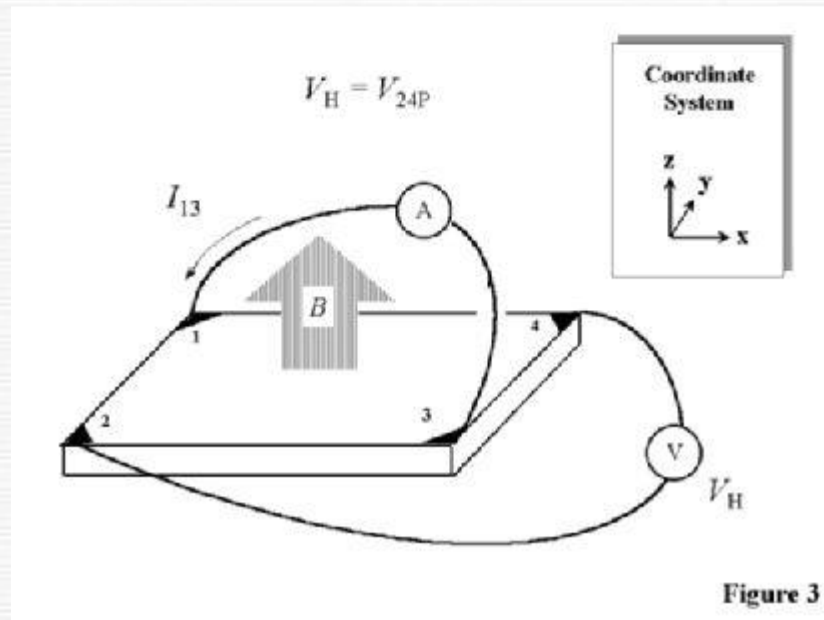
$$\rho = R_S d$$

Hall measurement in the Van der Pauw technique is to determine the sheet carrier density n_s by measuring the Hall voltage V_H

To measure the Hall voltage V_H,
current I contacts 1 and 3
the Hall voltage V_H (=V_{24}) contacts 2 and 4.

the sheet carrier density ns can be calculated

$$n_s = \frac{IB}{q|V_H|}$$



Summary

- ➢ Hall effect and the new phenomena
- ✓ Quantum Hall Effect
- ✓ Spin Hall Effect
- ✓ Anomalous Hall Effect
- ➢ Simple measurement of Hall effect

Next topic: Hall bar, normal Hall effect and Anomalous Hall Effect

Thank you for your time!

Density of Charge Carriers

Calculation of the density of free electrons in a metal like copper involves the basic physical data about the metal, plus the fact that copper provides about one free electron per atom to the electrical conduction process. A representative value can be calculated with the following data.

Molar mass of copper = $63.54\,gm/mol = 63.54x10^{-3}\,kg/mol = M$

Density of copper = $9\,gm/cm^3 = 9x10^3\,kg/m^3 = \rho$

Number of free electrons per mol = Avogadro's number = $6.02x10^{23}\,/mol = N_A$

Number of free electrons per unit volume = n

$$n = \frac{mass/m^3 x \; atoms/mol}{mass/mol} = atoms/m^3$$

$$n = \frac{\rho N_A}{M} = 8.5x10^{28} \; electrons/m^3$$

This is a nominal value because the density of copper in electrical wiring cables varies somwhat with processing.