New theory on the Hall effect

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Abstract

In Hall Effect first found by Edwin Hall in 1897, Plus Hall Effect has been measured that is not explained with electron movement only. As a method to explain this effect, a concept of positive holel has been introduced but it has an obvious physical error. Thus, this researcher proposes a new theory from a viewpoint that distribution of conductive electrons is varied by Lorentz Force with isotope centrifugal separation equation used in nuclear physics and in atom unit volume within solid and results in difference of level to generate Hall voltage.
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1. Introduction

The current Hall Effect theory explains generation of Hall voltage between both ends of a sample as difference of electric charge accumulation.

With current and magnetic field, Hall voltage between both ends of a sample refers to U_H = E · a and eE = F = e(v x B).
(E: Hall electric field, e: Electrical Charge, F: Force, v: Drift Velocity of Electron, B: Applied Magnetic Field, a: Distance between both Ends of a Sample)

This logic describes that as electrons are accumulated in one side of a sample in force direction by Lorentz force, F, force becomes balanced to appear as Hall electric field or Hall voltage.
On the other hand, as the current usually consists of electrons, it is naturally expected to have minus Hall voltage, but in the case that positive Hall voltage appears depending on materials, a concept of “Positive hole” is used against the electron [1].

As it is assumed that Positive Hole has plus charge and moves in opposite direction of the electron, “Electron” and “Positive Hole” are used as charge carrier. “Positive Hole” is explained as a state that electrons have escaped mainly from valence band of the semiconductor.

When the valence band is filled with electrons, net velocity of the entire electrons in the valence band refers to 0, and expressed as below;

$0=v_1+ \ v_2 + ...+ v_n$ (1)

When an electron v_2 has escaped from the valence band, total velocity of the all of remaining electrons becomes $-v_2$가 which is called as "Positive Hole" velocity and used as charge carrier.

When electron carrier is used for solid such as a metal, an expression below is derived from eE = F = e(v x B).

Hall electric fied $E = -\frac{1}{nec}(j\ B)$ (2)

where, n is free electron density, j is current and B is magnetic field.

In the case of a solid with electrons and positive holes mixed such as semiconductor,

Hall electric field $E = \frac{1}{e}\frac{(pv_p^2 - nv_n^2)}{(pv_p + nv_n)^2}\ (j\ B)$ (3)

is used. (where, p is positive hole density, n is free electron density, v_p is drift velocity of positive hole, and v_n is drift velocity of electron.)

2. Problem of the Current Theory

If a state with electrons escaped from valence band refers to $-v_2$, which is called as "Positive Hole", but the actual solid is an open system of thermodynamics that does not have electrons only but includes phonon, etc.

As it has electrons, phonon, etc. mixed, it is a normal physical state that summation of net velocity still becomes 0 even though one electron has escaped from the valence band.

$0=v_1+ ......+ v_n + ...+ (\text{Phonon Momentum}) + ...$ (4)

The reason is simple.

The fact that summation of velocity (momentum) becomes 0 through collision of electrons, phonon, etc. is line with law of entropy increase.

It is a natural principle that electrons change to increased randomness through collision with phonons.

In brief, it is a natural phenomenon that summation of velocity of the remained electrons becomes usually 0 through collision with phonons even though an electron has escaped from the valence band. It is a same law that when voltage is disconnected while current flows in a circuit, the current becomes promptly 0. It considers that a concept of Positive Hole is not in line with the Second Law of Thermodynamics.

3. New Theory

While Hall Effect theory considers that Hall voltage is determined by charge accumulation soley by Lorentz force, new theory considers that location of electron varies along equivalent level line in atom or molecule unit within an object by Lorentz force, which results in level difference between both ends of atom unit, and this difference is summated for all atoms between both ends of a sample to determine Hall voltage.

As an electron composing current in a sample with magnetic field (B) applied has Lorentz force (F=e(v x B)), when lattice ion and electron are located in parallel to this force direction, the level difference between this electron and lattice ion can be basically calculated with Schroedinger Equation if the electron is located along the equivalent level line.

Schrodinger Equation H = Kinentic Energy($\frac{p^2}{2m}$) + Potential Energy(V(y)) (5)

However, it is very difficult to express a phenomenon involving several electrons with Schrodinger Equation.

Quantitatively, though an electron is located anywhere in the unit volume as shown on the expression above, it may be regarded that levels made by the lattice ion and current (conductive band) electron are theoretically equivalent.

Calculation on distribution trend of electrons composing the current may be used as below with reference to an equation used for nuclear isotope separation. [2]

$$\text{Distribution Probability} = (\exp(\frac{e(v \times B) \cdot a}{\mathrm{N}kT}) - 1) \quad (6)$$

(where, e: charge amount, v: drift velocity, B: magnetic field, k: Boltzmann's constant, T: electromagnetic temperature, a: distance between both ends of a sample, N: Number of electrons in the conductive band of one row between both ends of a sample)

Measured Hall voltage can be earned from equations (5) and (6). Hall voltage is expressed by summating all of level values between both ends at each atom unit between both ends of a sample.

$$eV_h = -\sum_{1}^{N} (H_b - H_a)(\exp(\frac{e(v \times B) \cdot a}{\mathrm{N}kT}) - 1) \quad (7)$$

(where, H_b is electron level of electron at conduction band, H_a is electron level of electron at valence band electron level, V_h Hall voltage)

In equation (7), temperature of free electron gas in normal metal at eV degree, therefore coefficient ($\frac{e(v \times B) \cdot a}{\mathrm{N}kT}$) ≈ 0.

Then, it can be expressed as an approximate expression as below.

$$eV_h = -\sum_{1}^{N} (H_b - H_a)(\frac{e(v \times B) \cdot a}{\mathrm{N}kT}) \quad (8)$$

1) Hall Coefficient

It can be derived from equation (8) as below.

Hall Coefficient $R_h = -\frac{\Delta H}{kT} \cdot \frac{1}{nec}$ (9)

(where, $\Delta H = \sum_1^N (H_b - H_a)/N$, means $kT = \frac{2}{3}\langle\frac{p^2}{2m}\rangle$, $\langle\frac{p^2}{2m}\rangle$ is average energy of electrons in conductive band, n is electron density of conductive band, e is electron charge, c is light speed.)

2) Plus Hall Effect

New theory is in the case that plus Hall effect is $H_b < H_a$,

Level of electrons of valence band in lattice ions should be higher than that of current electrons (conductive band). It is possible on a phenomenon known as overlapping of the band. For any reason, when the conductive band has lower level than the balance band, plus Hall effect appears.

3) Extraction of Average Level Difference between Valence Band and Conductive Band of Pure Metal Solid

Equation (9) can be rewritten as below.

$$eV_h = -\frac{1}{N}\left(\sum_1^N H_b - \sum_1^N H_a\right)\left(\frac{e(v \times B) \cdot a}{NkT}\right) \quad (10)$$

$\left(\frac{1}{N}\sum_1^N H_b\right)$ term of Equation (10) refers to average energy level of conductive band, and

$\left(\frac{1}{N}\sum_1^N H_a\right)$ term to average energy level of valence band.

Thus, as it can be extracted from calculation of measured Hall Coefficient R_h, free electron gas' temperature T, free electron density n, etc., it may be useful for research of energy band in solid.

4. Conclusions

Though Positive Hole concept is widely used for Hall Effect, it has been determined to have no physical meaning. For the reason, other method is required to explain the Plus Hall Effect.

It is considered that Lorentz force does not directly work on the electrons in a solid, but electrons of conductive band in atom unit volume move along the equivalent level line in any direction at the center around the atom. Lorentz force is a mean to increase a trend that the electrons simply moving along the equivalent level line are distributed in the force direction, and this distribution trend exposes level difference between both ends of an atom to be summated and Hall voltage is measured between both ends of a sample.

A method to calculate distribution trend of electrons in conductive band by Lorentz force has completed new “Hall Effect Theory” using isotope centrifuge separation equation of the nuclear physics.

New theory shows that Hall voltage occurs due to level difference of electron cloud between both ends of atom in atom or molecule unit volume, this level difference is resulted in by Lorentz force, only the electrons in the conductive band are able to play a role of charge carrier, and no electron in the valence band can carry the charge event though a hole is created.

It has clarified that valence band is not a path to convey charge.

in the end, the holes in the Hall effect means the electron is empty, and charge carrier is only free electrons.

Refferens

[1] Charles Kittel, *Introduction to Solid State Physics* 7th ed. (john wieley & sons inc, newyork, 1996), pp.206-207

[2] I.Kaplan, *Nuclear Physics*. (Addison-wesley, inc,pub, 1955), pp.531-533