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Investigation of the Effect of Hall, Hall Constant and Density on Conductors (Silver, Copper and Tungsten)

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ABSTRACT

Effect of Hall is the most applied issue in materials science. The purpose of this paper is to investigate the effect of Hall on conductive metals such as silver, copper, and tungsten. Dimensions of the copper sheet (83mm × 25mm × 20μm) and dimensions of the silver sheet (25mm × 83mm × 43μm) and dimensions of the tungsten sheet (82mm × 20mm × 30μm) were investigated, as a result, the Hall voltage sign was positive in silver and tungsten and negative in copper. The reason for the negative sign of Hall voltage in silver and tungsten is that the hole carriers overcome the electron carriers and in copper, the electron carriers overcome the hole carriers. Due to the magnetic field of 200mT, then the Hall constant is $8 \times 10^{-3} \frac{mV}{TA}$for silver and $-6.56 \times 10^{-3} \frac{mV}{TA}$for copper. According to the symbol, the constant of Hall in silver and tungsten are p-type and for copper is n-type. Also, due to the current passing through the semiconductor in the amount and changing the magnetic field for the silver and copper samples, the Hall constant is obtained $7.84 \times 10^{-3} \frac{mV}{TA}$ and $-7.24 \times 10^{-3} \frac{mV}{TA}$, respectively. The carrier densities are $7.89 \times 10^{20} \frac{1}{m^3}$ for silver and $9.06 \times 10^{20} \frac{1}{m^3}$ for copper obtained.

KEYWORDS: *Hall Effect, Hall constant, Density, Copper, Silver, Tungsten*

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1. INTRODUCTION

The Hall effect is one of the most important transport experiments that give us good information about the scatter and the nature of the interactions that occur in the system (Dadras et al., 2010). Investigation of electrical and electronic properties of thin metal layers on semiconductor and insulation substrates plays a very important role in the development and technology of electrical and electronic components (Ashtiani & Khashyari, n.d.) .It is widely used by using magnetic sensors with the help of Hall effect sensors (Tse & Sarma, 2006).These sensors, while simple and inexpensive to build due to linear changes in the output of the Hall effect sensor due to changes in the field around it (Paul et al., 2021; Steinberg, 1921), can show acceptable linear properties with proper design (Mirzanejad et al., 2017).Hall effect thrusters are a promising type of electric thrusters for spacecraft and have recently set a significant record in many government space agency missions on commercial satellites (Ashtiani & Khashyari, n.d.). Magnetic semiconductors are gaining traction because of their potential use for spintronics, a new technology that integrates electronics and manipulates electron rotation (Manyala et al., 2004).Magnetic transport properties and Hall effect in polycrystalline single-phase samples $Gd_{0.9}Pr_{0.1}Ba_2Cu_3O_{7-\delta}$ show that the resistivity, Hall effect and resistance Magnets have a superconducting transition (Yue et al., 2005), (Khosravabdi et al., 2002). Hall effects are one of the most well-known family of phenomena in basic physics and applied microelectronics (Azimi Pana et al., 2006).It should be acknowledged that a complete and comprehensive study of the electrical properties of thin films has been done when the Hall effect is also studied in order to understand the density and mobility of carriers (Amo et al., 2009).Copper due to its high electrical and thermal conductivity and many potentials in the field of manufacturing electrical and electronic components in the form of mounds as well as thin layers is very important (Maqul & Khjir, 2017; Tse & Sarma, 2006).Effect of silver ions on $RbAg_4I_5$ monocrystals, the mobility of the Hall at room temperature is about 0.05 $cm^2V^{-1}sec^{-1}$, which is approximately 30 times greater than the ions in NaCl at 780 ° C previously obtained by Read and Katz (Kaneda & Mizuki, 1972) .Hall Effect for electrons in silver chloride, the room mobility of photoelectrons up to 5°C was measured in silver chloride monocrystals (Khosravabdi et al., 2002; Nazerzada et al., 2010). The results show that the mobility of the electron chamber increases to high values, 6000 cm^2 / vol. At very low temperatures (Kim & Flanagan, 1967; Wedler & Wiebauer, 1975), on the other hand, the drift mobility is strongly affected by multiple trapping and the microscopic mobility of these crystals is not characteristic of low temperatures (Kobayashi & Brown, 1959).The Spin Hall Effect (SHE) tungsten films experimentally using measurement-based scanning tunneling microscope (STM) is investigated (Hao et al., 2015). These measurements were performed using tungsten and iron-clad tungsten tips (Manyala et al., 2004; Wunderlich et al., 2005). Regarding tungsten points, it has been observed that the current flowing through the tungsten film leads to a significant asymmetry in the tunnel current due to the change in the tunnel voltage polarity (Xie et al., 2018).

2. Methods and experiments:

2.1. Methods:

Suppose a conductive sheet with thickness d as shown in Figure (1) is in a uniform field with magnetic intensity B, so that the field lines are perpendicular to the surface of the conductor. If current I is passed along the length of the conductor, a force $\vec{F} = q\vec{V} \times \vec{B}$will be applied to each of the current-carrying electrical charges. If the type of charge is positive, it flows from left to right, and if the type of charge carrier is negative, it flows in the opposite direction of current I, ie from right to left. Also, assuming that the thickness of the samples is 1 mm and the magnetic field is equal to 200 mT or the current passing through the semiconductor is 20 mA, then the Hall constant in the samples is examined.

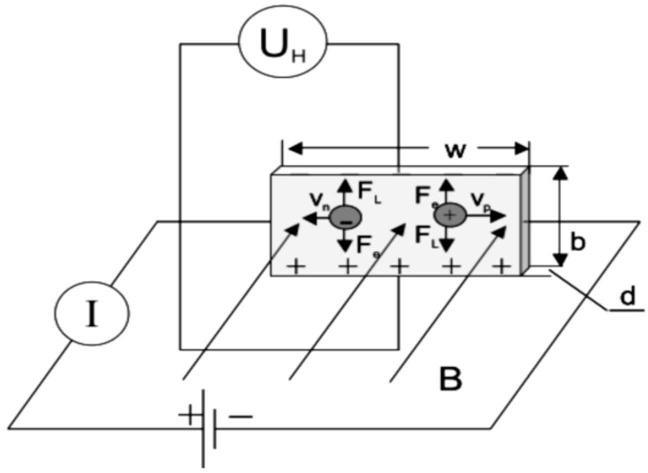

Figure 1: F_L represents the Lorentz force and F_e due to the electric field of the Hall voltage.

Due to the compression of electric charges of the same name on one side of the width of the sheet, the repulsive force between them has increased so that this force is equal to the force caused by the magnetic field, i.e.:

$$F_L = F_e \ (1)$$

$$qv_dB = Eq \ (2)$$

Where v_d is the velocity of electrical charges. The equivalent potential difference is equal to

$$V_H = Eb = v_dBb \ (3)$$

V_H is the voltage of the hall and the width of the sheet b.

Since the electric current density are:

$$v_d = \frac{j}{\rho_n q} = \frac{I/A}{\rho_n d} \ (4)$$

The value of $R_H = \frac{1}{\rho_n q d}$ is called the Hall coefficient and can be written as:

$$V_H = R_H \frac{IB}{d} \ (5)$$

2.2. Experiment

Dimensions of copper sheet (83mm × 25mm × 20µm) and dimensions of silver sheet (25mm × 83mm × 43µm) and dimensions of tungsten (82mm × 20mm × 30µm). Placing a sheet of metal such as silver or copper in a uniform magnetic field and passing an electric current through it creates a transverse voltage called the Hall voltage, which is determined by determining the direction of this voltage, the type of charge carriers, and by measuring its density. Free charge carriers are obtained. It should be noted that the wires of the magnetic magnet should be connected to the power supply in such a way that the current passing through them is opposite to each other. The base of the hall board is then placed so that its plane is perpendicular to the field. Now install the two rectangular cores so that they are close to the sample plate (tungsten, silver and copper) on the board and their distance from each other is approximately equal to 10 mm. It now connects the positive and negative poles of the microvolt meter to the output voltage of the board, and also connects the positive and negative poles of the electrical current source to the two conductor connections installed on the board.

3. Results and Discussion:

The data is divided into three parts.

3.1. Investigation of the effect of Hall on tungsten:

First, the tungsten was placed inside the device, and after turning on the I_m (transverse current) and IB (magnetic field generating current) generators and resetting the micro voltmeter device, the transverse current was set to a constant value of I_m = 5A. Then I_B was increased from 0 with intervals of 5A to 4A and the corresponding V_H values were recorded in Table 1. In the next step, I_B was set to 4 Amp and the corresponding V_H values obtained were recorded in Table 2.

Table 1 Constant transverse current intensity (I_m = 5A) and magnetic current intensity varying .from 0 to 4 amp

B (T)	I_B (A)	V_H (μV)
0	0	406
0.118	0.5	405
0.200	1	404
0.295	1.5	403
0.374	2	402
0.455	2.5	401
0.520	3	401
0.585	3.5	401
0.630	4	401

Table 2 Constant magnetic current intensity (IB = 5A) and transverse current intensity (Im) varying from zero to 5 amp.

I_m (A)	V_H (μV)
0	0
0.5	45
1	81
2	124
2.5	200
3	243
3.5	285
4	321
4.5	363
5	401

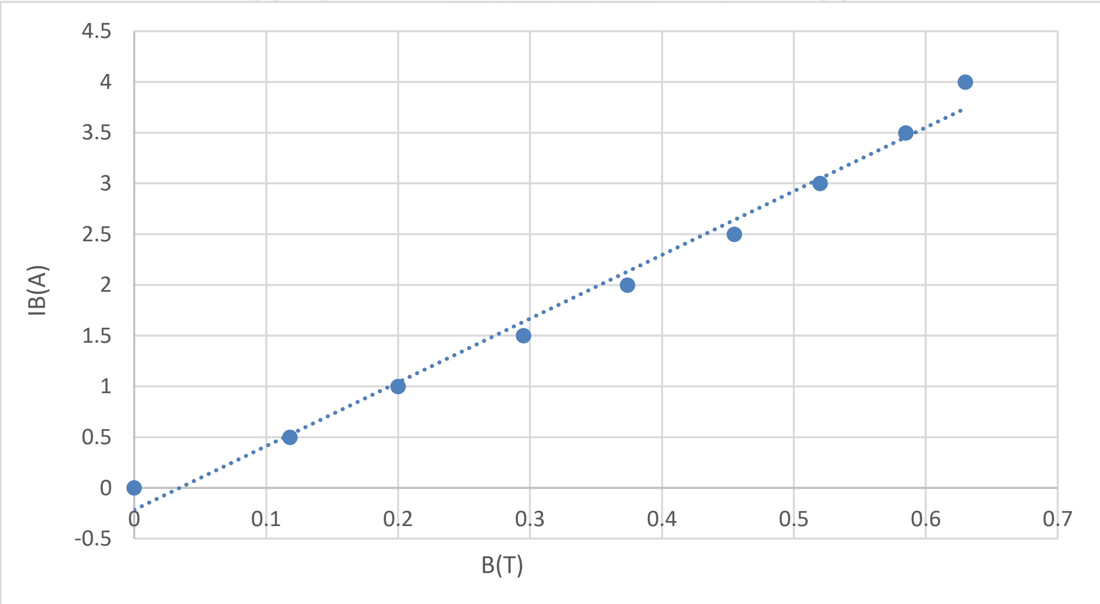

Figure 2: Magnetic field generating current I_B (A) in terms of magnetic field B (T) shows that it is directly related to increasing I_B (A). Magnetic field I_B (A) also increases and the graph is a straight line.

Figure (2) shows that if the Im transverse current is constant (5A), the current generating the magnetic field increases with respect to the magnetic field. This increase is in a range and it is in the current of 2 Amp. After 2 Amp the Hall potential remains constant (Table 1) and from the diagram (1) it can also be seen that the curve from 2 Amp onwards is a straight line. It can also be seen from Table (2) if the IB current is constant (5 Amp). Transverse flow is variable. With changes in transverse current, the hall voltage also changes. But the hall voltage remains constant in the transverse current after 5 Amp. As in Table (1), the Hall voltage in the current generating the magnetic field is constant after 5 Amp (401µV).

3.2. Investigation of the effect of Hall on Silver:

At this stage, the magnetic field produced by the electric magnet is fixed and the current passing through the sample is changed. To do this, first zero the microvolt meter with a potentiometer in it, then set the current of the electric magnet power supply (I_m) to 4 Amp. In order to achieve the goal, the experiment is performed in two stages. First, we keep the state of the magnetic field constant and change the intensity of the current flowing. With steps of about 0.5 Amp, the different voltages of the hall are read from the micro voltmeter in Table (3). In the second step, I keep the current intensity constant and record the hall voltage in Table (4).

Table 3: Results of Hall voltage measurements in a constant magnetic field for silver

$V(v)$	$I(mA)$	$V_H(\mu v)$
0.4	5	8.05
0.8	10	15
1.1	15	21.22
1.5	20	29.45
1.8	25	40.2
2.2	30	47.3

Table 4: Results of Hall voltage measurements on constant current flow for silver

(mA) B	mT	$V_H(\mu v)$
0.5	30	3.9
1	50	8.0
1.5	80	13.1
2	105	17.3
2.5	130	20.6
3	150	24.6
3.5	175	29.0
4	200	30.6
4.5	220	34.9
5	245	37.8

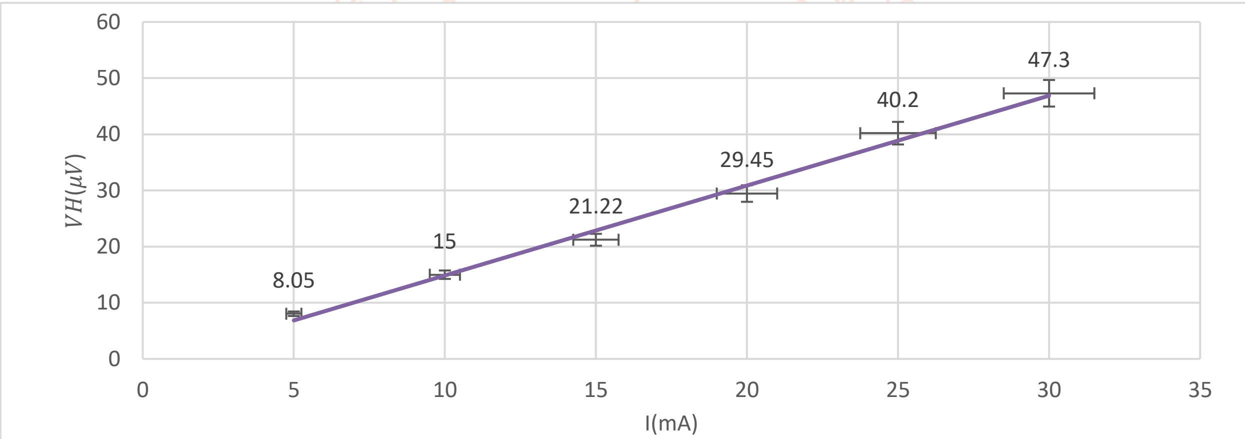

Figure 3: Diagram in terms of the current passing through silver with a constant magnetic field.

As can be seen from Table (3) and Figure (3), with increasing current, the voltage of the Hall in silver increases. Thus, if the magnetic field is constant, the voltage of the Hall increases with the intensity of the current flowing in Silver. If the current intensity is constant, the Hall voltage is directly related to the magnetic field, that is, as the magnetic field increases, the Hall voltage in silver also increases (Table 4 and Figure 4). From both tables (3) and (4) the hall voltage sign is positive. It turns out that silver is type P.

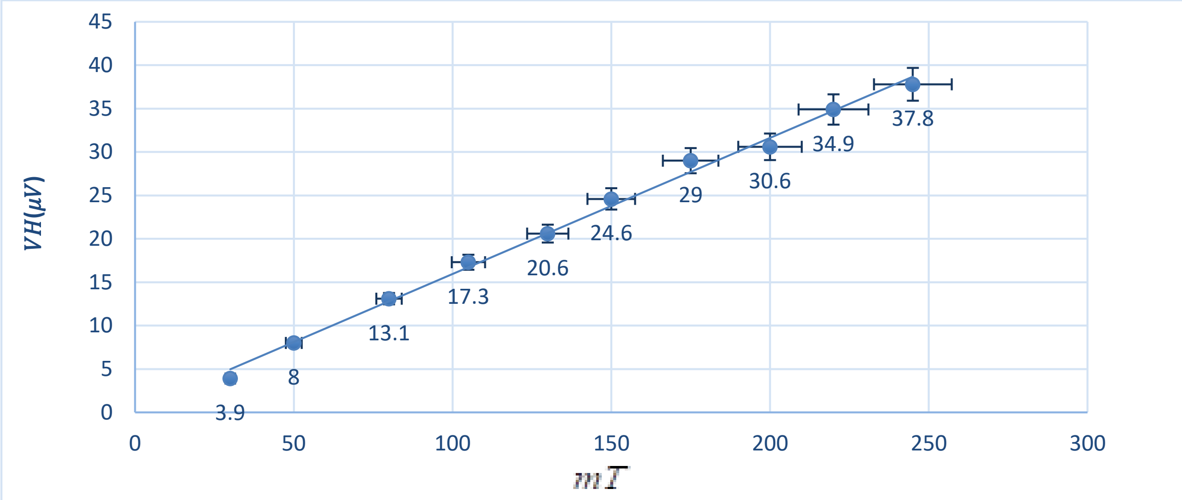

Figure 4: Diagram in terms of magnetic field (silver) with a current passing through a fixed semiconductor.

3.3. Investigation of the effect of Hall on Silver:

We do the Hall Effect on copper in the same way as the experience in the silver section. I use two parts to get the results. Once the magnetic field is kept constant and the current intensity with the Hall voltage is noted in Table (5). Later, the current intensity is fixed and the voltage changes of the hall with the magnetic field are recorded in Table (6).

Table 5: Results of Hall voltage measurements in a constant magnetic field for copper

$V(v)$	$I(mA)$	$V_H(\mu v)$
0.3	5	-9.1
0.6	10	-14.5
0.8	15	-21.1
1.1	20	-27.9
1.4	25	-35.5
1.6	30	-41.1

Table 6: Results of Hall voltage measurements on constant current flow for copper

(mA) B	mT	$V_H(\mu v)$
0.5	30	-4.3
1	50	-6.9
1.5	80	-10.6
2	105	-14.4
2.5	130	-17.9
3	150	-21.6
3.5	175	-25.4
4	200	-28.8
4.5	220	-31.4
5	245	-34.7

It can be seen from Table (5) that the voltage of the Hall increases with increasing current intensity. As can be seen from Table (6), the voltage of the Hall increases with the increase of the magnetic field. The negative sign of the Hall voltage indicates type n. This means that electron carriers outperform hole carriers. From both Figures (5 and 6) it can be seen that the Hall voltage graph is linear because the Hall voltage is directly related to the current intensity and the magnetic field.

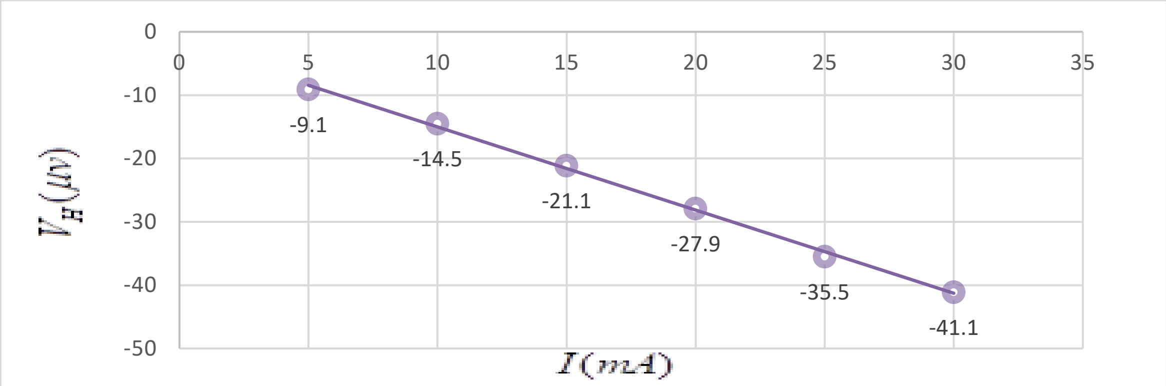

Figure5: Graph in terms of the current passing through the sample (copper) with a constant magnetic field.

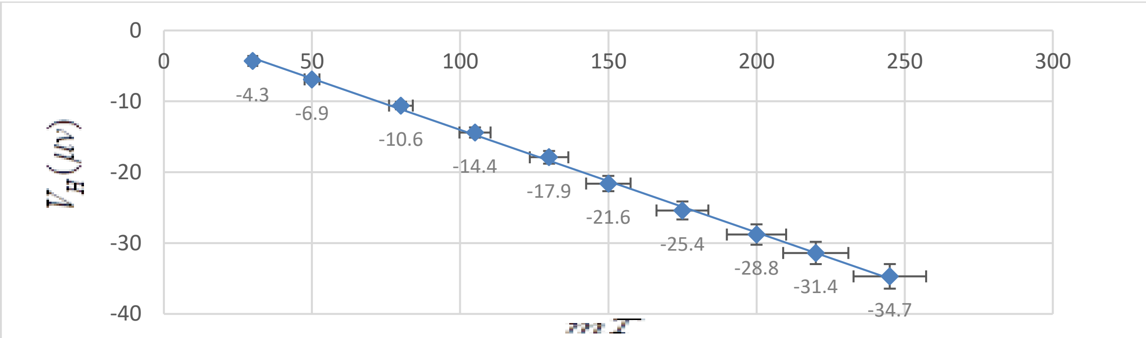

Figure6: Graph in terms of sample magnetic field (copper) with current passing through a fixed semiconductor.

Assuming that d = 1mm and the magnetic field is equal to 200mT, then the Hall constant is $8.00 \times 10^{-3}\frac{mV}{TA}$ for silver and $-6.56 \times 10^{-3}\frac{mV}{TA}$ for copper. According to the sign, the Hall constant in silver is of type P and for copper is of type n. Also, due to the current passing through the semiconductor 20mA and changing the magnetic field for the silver and copper samples, we obtained the Hall constant for Braille with $7.84 \times 10^{-3}\frac{mV}{TA}and-7.24 \times 10^{-3}\frac{mV}{TA}$,respectively. Now with averaging we will have:

$$For\ semiconductors\ p: R_H = 7.92 \times 10^{-3}\frac{mV}{TA}$$

$$For\ semiconductors\ n: R_H = -6.90 \times 10^{-3}\frac{mV}{TA}$$

For silver, because the constant value of the Hall is positive, then the semiconductor is p-type because the hole carriers outperform the electron carriers. And the density of cavities can be obtained as follows:

$$R_H = \frac{1}{e\rho_s}$$

The density of carriers for silverwas$7.89 \times 10^{20}\frac{1}{m^3}$. For copper, because the constant value of Hall is negative, then semiconductor is type n. Therefore, electron carriers overcome hole carriers and the density of carriers for it was$9.06 \times 10^{20}\frac{1}{m^3}$.

Conclusion:

From this experiment it was concluded that copper type n gave a negative Hall constant and silver and tungsten type p had a positive Hall constant. This sign difference is due to the difference in the direction of the drive of the hole and the electron in the electric field, or in other words, the difference in the direction of the force exerted on the electron and the hole in the same magnetic field. If Im is kept constant, the relationship of the Hall voltage (V_H) to the magnetic induction intensity (B) is a linear relationship, the slope of which is $\frac{1}{\rho_n q d}$, and if we keep B constant, the Hall voltage relationship (V_H)) Is linear with current intensity Im and its slope is equal to$\frac{1}{\rho_n q d}$. Experiments show that the line slope of the relation $V_H = R_H\frac{IB}{d}$d is negative for metals such as copper because of the presence of free electrons. This shows that the Hall Effect is

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normal. It is positive for conductors such as tungsten because of the presence of a hole (electron deficiency) as an electrical carrier in the conductor, which shows an abnormal Hall Effect.

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