Study of Hall effect and Magnetoresistance in Bismuth

Swaroop Ramakant Avarsekar*
School of Physical Sciences, National Institute of Science Education and Research, HBNI, Jatni -752050, India
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In this experiment, we study the magnetoresistance of Bismuth and also find the Hall coefficient of the sample. The increase in magnetoresistance is observed with increase in applied magnetic field. With two different probe current, we calculate the Hall coefficient of Bi. The Hall coefficient at probe current 190 mA is $(4.58 \pm 0.09) \times 10^{-7} m^3/C$. and at 150 mA is $(4.19 \pm 0.08) \times 10^{-7} m^3/C$, with average being $(4.38 \pm 0.12) \times 10^{-7} m^3/C$.

Keywords: Hall effect, Magnetoresistance, Gaussmeter

I. THEORY

A. Hall Effect

Hall effect is a phenomenon when a current carrying conductor/crystal where the direction of current is along x, with direction of magnetic field H from top gives the voltage across the ends 1 and 2 due to Hall effect, as shown in Figure(1). This magnetic field exerts a Lorentz force on charge carriers as given below:

$$\bar{F} = e(\bar{v} \times \bar{H}) \tag{1}$$

where e is charge of electron, v is drift velocity of charge carriers, H is magnetic field applied. This Lorentz force drags the electrons and holes towards opposite ends of the crystal, resulting a electric field, called Hall field (E_H), opposite to Lorentz force. Deflection of charge carriers takes place until Hall field cancels the Lorentz Force giving rise to a potential difference, called Hall voltage (V_H) .

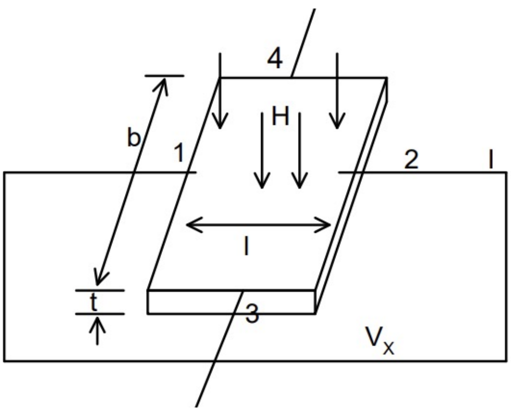

Figure 1: Hall effect in a crystal

The field along y-axis is given by

$$E_m = vH = \mu E_x H \tag{2}$$

This electric field is related to current density and conductivity as

$$\sigma E_x = J_x \tag{3}$$

The Hall coefficient R_H is defined as

$$R_H = E_m/J_x H = \mu E_x/J_x = \mu/\sigma = 1/ne \tag{4}$$

The Hall voltage is proportional to 1/n and $\mu = R_H \sigma$. Experimentally, the Hall coefficient is given by

$$R_H = \frac{V_y/b}{(I_x/bt)H} = V_y t/I_x H \tag{5}$$

where b and t are width and thickness of the sample.

If voltage across the input is kept constant, then Hall angle as the ratio of applied and measured voltages.

$$\phi = V_y/V_x = E_m b/E_x I = \mu b H/l \tag{6}$$

where l is the length of the crystal.

B. Magnetoresistance

Magnetoresistance is property of a material where resistivity changes with the magnetic field applied. This phenomena was discovered by Lord Kelvin. It is due to fact that the drift velocity of all charge carriers is not same. When magnetic field is applied, the Hall voltage compensates Lorentz force, with slower carriers being over compensated and faster ones with under compensated resulting in reduced mean free path, more collisions and increased resistivity.

Three cases of magnetoresistance depending on the structure of the electron orbitals at the Fermi surface In metals with closed Fermi surfaces, the electrons are constrained to their orbit in k-space and the effect of the magnetic field is to increase the cyclotron frequency of the electron in its closed orbit. For metals with equal numbers of electrons and holes, the magnetoresistance increases with H up to the highest fields measured and is independent of crystallographic orientation. Bismuth

* swaroop.avarsekar@niser.ac.in

falls in this class. Metals that contain Fermi surfaces with open orbits in some crystallographic directions will exhibit large magnetoresistance for fields applied in those directions, whereas the resistance will saturate in other directions, where the orbits are closed

II. EXPERIMENT & ANALYSIS

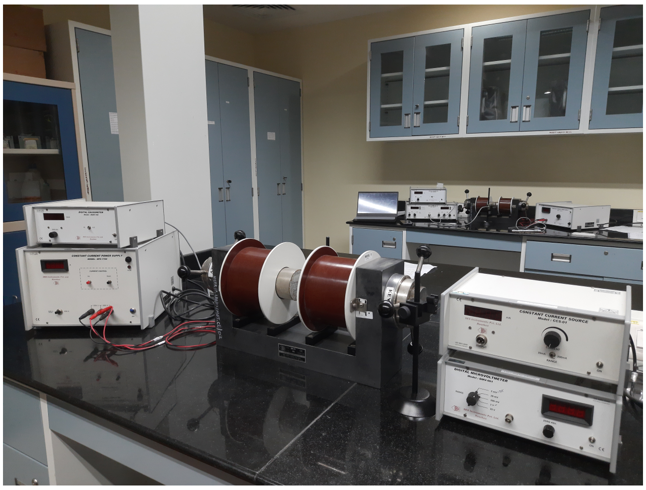

Figure 2: Experimental setup in laboratory

Magnetoresistance, Four probes, and Hall probes with Bi sample and constant current source and power supply. Gaussmeter to measure magnetic fields. Electromagnets , microvoltmeter and multipurpose stand will be required for this experiment. The setup is shown in Figure (2).

Table I: Magnetoresistance Table for probe current 190 mA

Magnetic field (G)	Hall Voltage (mV)	$R_m(\Omega)$	ΔR/R	Log (H)	Log ($\Delta R/R$)
0	0.301	0.00158	0.0000		
594	0.303	0.00159	0.0093	2.773786445	-2.030252657
858	0.304	0.00160	0.0127	2.933487288	-1.897627091
1223	0.304	0.00160	0.0127	3.087426457	-1.897627091
1557	0.305	0.00161	0.0160	3.192288613	-1.796169451
1932	0.308	0.00162	0.0260	3.286007122	-1.585316085
2340	0.31	0.00163	0.0326	3.369215857	-1.486184612
2740	0.311	0.00164	0.0360	3.437750563	-1.443986932
3020	0.314	0.00165	0.0460	3.480006943	-1.337531602
3330	0.316	0.00166	0.0526	3.522444234	-1.278753601
3690	0.32	0.00168	0.0660	3.567026366	-1.180745498
3990	0.321	0.00169	0.0693	3.600972896	-1.159347353
4280	0.321	0.00169	0.0693	3.631443769	-1.159347353
4610	0.322	0.00169	0.0726	3.663700925	-1.138954194
4870	0.327	0.00172	0.0893	3.687528961	-1.049275894
5050	0.326	0.00172	0.0859	3.703291378	-1.065790982
5330	0.327	0.00172	0.0893	3.726727209	-1.049275894
5550	0.33	0.00174	0.0993	3.744292983	-1.003194424
5740	0.331	0.00174	0.1026	3.758911892	-0.9888599714
5970	0.333	0.00175	0.1093	3.775974331	-0.9615368442
6090	0.334	0.00176	0.1126	3.784617293	-0.9484939876
6130	0.335	0.00176	0.1159	3.787460475	-0.935831444

Table II: Magnetoresistance Table for probe current 150 mA

Magnetic field (G)	Hall Voltage (mV)	$R_m(\Omega)$	ΔR/R	Log (H)	Log ($\Delta R/R$)
0	0.222	0.00148			
861	0.224	0.00149	0.0090	2.935003151	-2.045322979
1143	0.224	0.00149	0.0090	3.05804623	-2.045322979
1497	0.225	0.00150	0.0135	3.1752218	-1.86923172
1785	0.228	0.00152	0.0270	3.25163822	-1.568201724
2100	0.228	0.00152	0.0270	3.322219295	-1.568201724
2360	0.229	0.00153	0.0315	3.372912003	-1.501254934
2590	0.231	0.00154	0.0405	3.413299764	-1.392110465
2850	0.232	0.00155	0.0450	3.45484486	-1.346352974
3110	0.233	0.00155	0.0495	3.492760389	-1.304960289
3330	0.235	0.00157	0.0586	3.522444234	-1.232409622
3610	0.236	0.00157	0.0631	3.557507202	-1.200224939
3860	0.238	0.00159	0.0721	3.586587305	-1.142232992
4130	0.24	0.00160	0.0811	3.615950052	-1.091080469
4340	0.241	0.00161	0.0856	3.63748973	-1.067599373
4640	0.242	0.00161	0.0901	3.666517981	-1.045322979
4920	0.244	0.00163	0.0991	3.691965103	-1.003930294
5120	0.245	0.00163	0.1036	3.709269961	-0.9846251384
5380	0.246	0.00164	0.1081	3.730782276	-0.9661417327
5620	0.248	0.00165	0.1171	3.749736316	-0.9313796265
5800	0.25	0.00167	0.1261	3.763427994	-0.8991949431
6110	0.251	0.00167	0.1306	3.78604121	-0.8839549766

Table III: Table for Hall effect

Probe current=190mA		Probe current=150 mA	
Magnetic field (G)	Hall Voltage (mV)	Magnetic field (G)	Hall Voltage (mV)
0	0	0	0
799	-0.008	1168	-0.006
1145	-0.01	1432	-0.008
1325	-0.012	1760	-0.01
1427	-0.013	1877	-0.011
1647	-0.015	1950	-0.011
1824	-0.017	2230	-0.013
1960	-0.018	2490	-0.015
2140	-0.019	2730	-0.015
2290	-0.02	2980	-0.017
2500	-0.022	3300	-0.018
2730	-0.023	3580	-0.02
2960	-0.026	3830	-0.021
3160	-0.027	4050	-0.022
3300	-0.028	4260	-0.025
3530	-0.03	4460	-0.026
3720	-0.031	4830	-0.027
3890	-0.032	5120	-0.028
4020	-0.033	5510	-0.029
4210	-0.034	5650	-0.03
4420	-0.036	5910	-0.031
4720	-0.038	6050	-0.032
4930	-0.04	6130	-0.032
5150	-0.041		
5310	-0.042		
5500	-0.042		
5670	-0.043		
5880	-0.043		
6070	-0.044		

A. Hall effect

To find the Hall coefficient of Bi, we plot Magnetic field versus Hall voltage for two different probe current as shown in Figure (3) and (4).

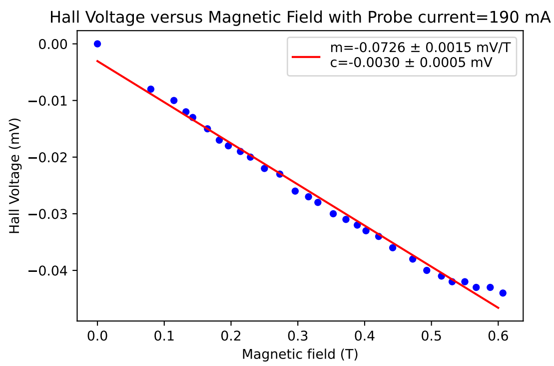

Figure 3: Hall voltage versus Magnetic field, I=190 mA

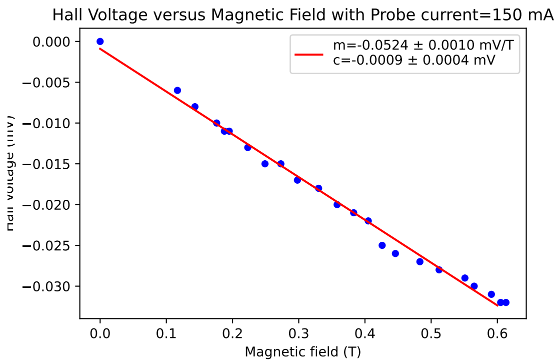

Figure 4: Hall voltage versus Magnetic field, I=150 mA

We know that from equation (5) and figures (3) and (4), Slope is V/H with t and I being known quantities. t is the thickness of the sample, t= 1.2 mm.

Therefore,

$$R_H = Slope.t/I \tag{7}$$

Hall coefficient from probe current=190 mA is,

$$R_H = -0.0726 \times 0.0012/190 = 4.58 \times 10^{-7} m^3/C \tag{8}$$

Hall coefficient from probe current=150 mA is,

$$R_H = -0.0524 \times 0.0012/150 = 4.19 \times 10^{-7} m^3/C \tag{9}$$

Error in R_H is:

$$\Delta R_H = R_H \times \Delta Slope/Slope \tag{10}$$

For probe current at 190 mA, we have

$$\Delta R_H = 4.58 \times 10^{-7} \frac{0.0015}{0.0726} = 0.09 \times 10^{-7} m^3/C \tag{11}$$

For probe current at 190 mA, we have

$$\Delta R_H = 4.19 \times 10^{-7} \frac{0.001}{0.0524} = 0.08 \times 10^{-7} m^3/C \tag{12}$$

The average Hall coefficient is $4.38 \times 10^{-7} m^3/C$

Error in average value is $\sqrt{(0.08)^2 + (0.09)^2} = 0.12 \times 10^{-7} m^3/C$

Therefore, average value of Hall coefficient of Bismuth is $(4.38 \pm 0.12) \times 10^{-7} m^3/C$

B. Magnetoresistance

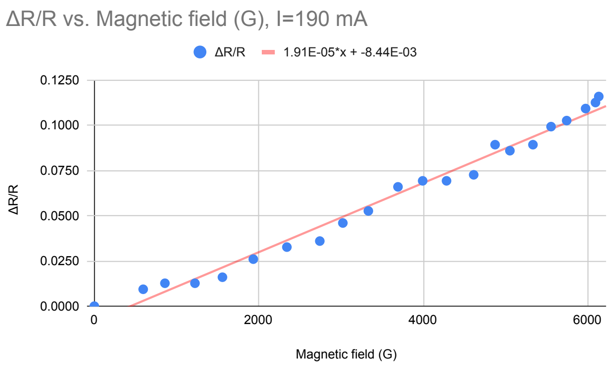

Figure 5: Plot for magnetoresistance for 190 mA of current

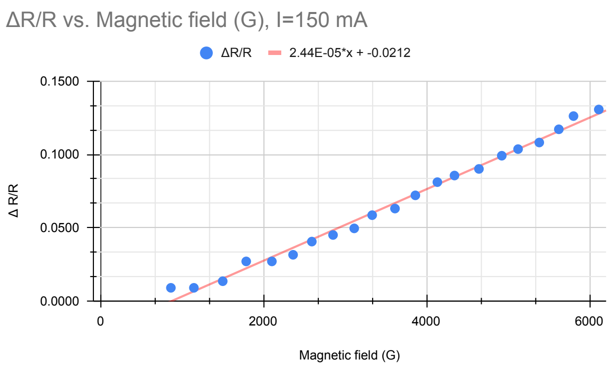

Figure 6: Plot for magnetoresistance for 150 mA of current

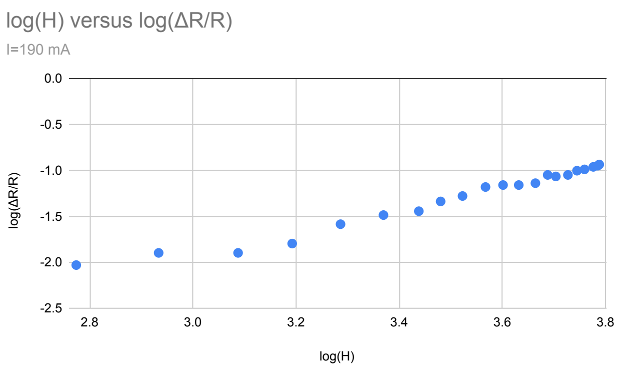

Figure 7: Plot for log(H) versus log(ΔR) for 190 mA

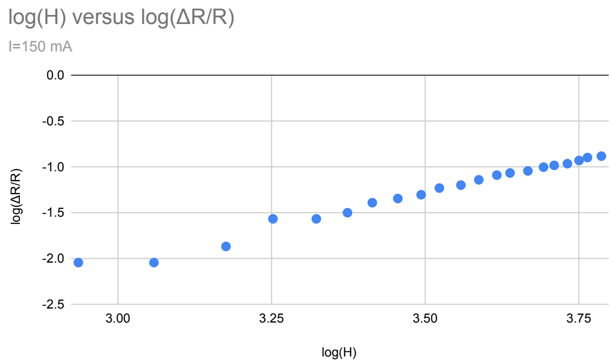

Figure 8: Plot for log(H) versus log(ΔR) for 150 mA

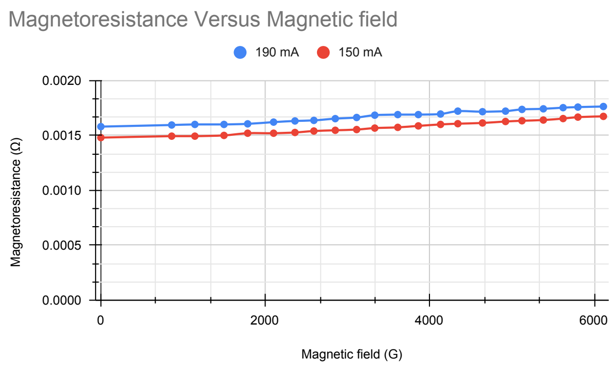

Figure 9: Magnetoresistance dependence for different current

It is observed from the figures (5), (6), (7), (8) and (9), that magnetoresistance of Bismuth linearly increases with the magnetic field applied. We supplied the probe current with 190 mA and 150 mA and magnetoresistance is studied. It is also seen that with higher probe current magnetoresistance increases, where the curve for 190 mA is seen higher than 150 mA.

III. CONCLUSION

In this experiment we studied the properties of Bi, which is semi-metal. Hall coefficient and Magnetoresistance at different probe current was studied. The Hall coefficient of Bismuth at probe current 190 mA is $(4.58 \pm 0.09) \times 10^{-7} m^3/C$. and at 150 mA is $(4.19 \pm 0.08) \times 10^{-7} m^3/C$, with average being $(4.38 \pm 0.12) \times 10^{-7} m^3/C$. It is expected that Hall coefficient should not change with different probe current, but here it arises due to Nernst effect, irregular power supply, heating, etc. Current through the probe should not be excess. It was also seen that magnetoresistance increases with increase in magnetic field in a linear fashion. Much of the error to this experiment have been contributed by the instruments used, some random errors may have crept into the data.

IV. REFERENCES

1. SPS NISER Lab Manual
2. `https://en.wikipedia.org/wiki/Hall_effect`