The Hall Effect

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This experiment calculated the hall coefficient for a germanium crystal. A current created by a power supply was sent through the germanium crystal in a constant magnetic field. Through redistribution of charge carriers of current, a voltage was created perpendicular to the magnetic field and current. The current was varied and the Hall voltage was measured. The hall coefficient was calculated to be (0.0142 ± 0.0012) m^3/C. The published experimental value is $-8*10^{-2}$ m^3/C.[1] The number of charge carriers per unit volume was calculated to be $(5.17 \pm 0.44)*10^{20}$ carriers/m^3.

INTRODUCTION

When Edwin Herbert Hall sent a current across a metal strip contained in a magnetic field in 1879, he noticed a voltage was created[1]. Hall's experiment appeared to go against the idea of conduction. The current sent across the metal, the voltage created, and the magnetic field are perpendicular to each other. The voltage, called the Hall voltage, depends on the strength of both the magnetic field and the current. When semiconductors were discovered, they also displayed the Hall effect, just as metals. The Hall coefficients provided information about the density and sign of the charge carriers[2].

A germanium research group was assembled at Purdue University in March 1942. By May 1942, the group had produced p-type and n-type germanium. The Hall effect and thermo-electric power measurements determine the sign of the carrier charges. The negative carriers showed that the electrons have greater mobility than the holes, or p-type carriers[2]. This causes a negative Hall coefficient.

THEORY

When a current flows along a conductor in a magnetic field perpendicular to the direction of the current, a Hall voltage is created across the conductor and perpendicular to the magnetic field. Usually, the magnetic field, current, and voltage are all perpendicular to each other. The magnetic field, B travels in the y-direction. The current, I, travels in the x-direction.

The magnetic field causes the charge carriers to deviate from their original path and swerve towards the side. The Lorenz force causes the deflection of the charge carriers. The negative current carriers would move to one side of the crystal and the positive carriers would move to the opposite side. Using the left hand rule, we are able to see which way the electron current is deflected. The positive charges are deflected to one side, and the negative charges are deflected to the other.

The new position of the charge carriers creates an electric field in the z-direction. When the system reaches equilibrium, the force between the Hall field and the Lorenz force will be equal. Thus, the charge carriers can move along their original, unchanged path.

When the system reaches thermal equilibrium, the force due to the magnetic field is equal and opposite of the force due to the electrical field.

$$F_H = eE_H = Bev_x = F_B \tag{1}$$

where F_H is the force due to the electrical field, e is the charge of the current carriers, E_H is the Hall e.m.f , B is the flux density of the magnetic field, v_x is the velocity of the carriers in the x-direction, and, F_B is the force due to the magnetic field. Therefore, the Hall voltage will be

$$V_H = E_H w = Bv_x w \tag{2}$$

where w is the width of the sample, in the z-direction. The current density is J_x,

$$J_x = nev_x = \frac{I_x}{wt} \tag{3}$$

where n is the number of carriers and t is the thickness of the sample, in the y-direction[4]. Using Equations (2) and (3)

$$R_H = \frac{1}{ne} = \frac{V_H t}{BI_x} \tag{4}$$

Assuming that each current carrier had one electronic charge of the same sign, the number of carriers of electricity per unit volume will be

$$n = \frac{3\pi}{8eR_H} \tag{5}$$

where n is the number of current carriers per unit volume[5].

EXPERIMENT

In order to test the Hall effect in a semi-conductor, the power supply sends a current through a germanium crystal. The crystal is kept in a constant magnetic field perpendicular to the direction of current flow using a permanent magnet.

For the first two runs, a current is sent through the germanium sample in the x-direction. There are wires on either side of the germanium sample that are connected to a digital ampmeter, which is driven by the power supply. The strength of the magnetic field is measured with a gaussmeter probe. The strength of the magnet varied from 0.1760 Tesla in the center to 0.1785 Tesla and 0.1761 Tesla on either side. The average of the three values was taken and the standard deviation was calculated to be 0.1769±0.0014 Tesla, a constant throughout all of the runs. The power supply created a current through the germanium crystal for a few minutes before the data taking process began. This ensures that the system is in thermal equilibrium for all of the data points. For the first two runs, the current was started at -1.0 mA. The Hall voltage is measured after each decrease in current with a voltmeter. The current was decreased to approximately –10 mA on the first run and –15 mA on the second. During the runs, the current was brought below -6.0 mA, but the data points started to curve. The heating of the germanium crystal, which may change the Hall coefficient, could cause the change in slope. The direction of the current was switched for the third and fourth runs and data points were only taken from 1 mA to 6 mA.

In order to measure the thickness of the germanium crystal, a traveling telemicroscope was used. The crystal was placed at an angle with respect to the telemicroscope. The telemicroscope measured the depth between the two corners of the germanium crystal. By using the angle that the edge of the germanium crystal makes with the lens of the telemicroscope, the actual thickness of the crystal can be calculated. The actual thickness of the germanium crystal is 2.07±0.15 mm.

ANALYSIS AND INTERPRETATION

The data where the heating effects were not apparent were plotted in Igor and are pictured in Figure 1 below. The linear behavior of the data points is glaringly obvious. Also, the y-intercept is approximately zero for each of the runs. This shows there is not a systematic error that causes some offset in all of the data points. The slope for each data set is graphed and the slope is noted in Figure 1. The average of the slopes was calculated to be –1.218±0.034 V/A.

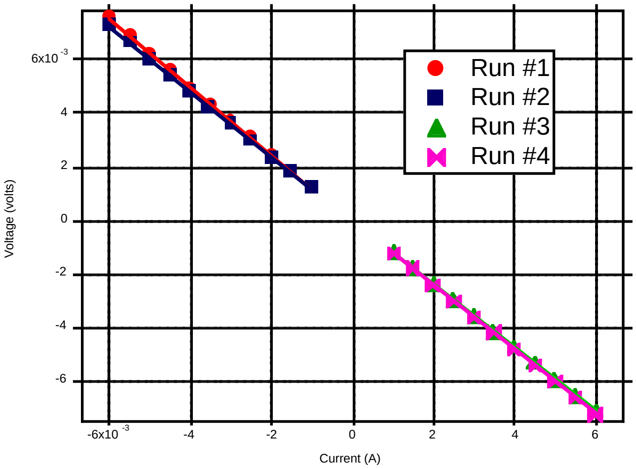

FIG. 1. The slopes for run #1, 2, 3, and 4 are –1.2665±0.0050, -1.218±0.005, -1.1875±0.0020, and –1.2031±0.0016 respectively.

Using equation 4, the Hall coefficient was calculated to be –0.0142±0.0012 m^3/C. The experimentally known value for the Hall coefficient for germanium at room temperature is $–8*10^{-2}$ m^3/C.[1] Using equation 6, the number of carriers of electricity per unit volume is (5.17±0.44)* 10^{20} carriers/m^3.

CONCLUSION

By calculating the Hall coefficient, important facts about how metals and semiconductors behave are displayed. The Hall coefficient for the germanium crystal was –0.0142±0.0012 m^3/C. This shows that a negative carrier of electricity was used to traverse the crystal. The charge carriers are electrons, just as the Purdue germanium group found. The number of carriers per meter cubed is (5.17±0.44)* 10^{20} carriers/m^3.

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