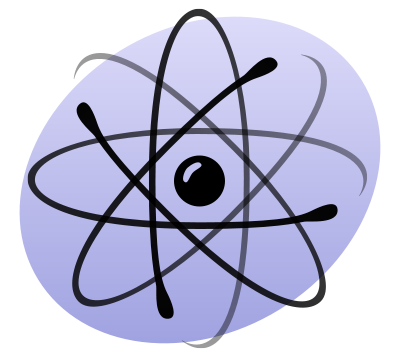
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PHYS2170: Electron Diffraction

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# Abstract

This report details the observation of electron diffraction through a graphite sample. Electrons were accelerated in a cathode ray tube and fired at a sample producing an interference pattern on a screen. Diffraction patterns from two crystal planes were observed. The spacing between the atoms in each plane were found to be 2.06 ± 0.25 Å and 1.37 ± 0.25 Å. This is in the same order of magnitude as credible values found, 1.54 Å [1].

# Introduction

Diffraction is a phenomenon where waveforms interacting with an obstacle are “bent” or redirected (see Figure 1). This occurs as when a waveform strikes an obstacle its path is changed and it is deflected in another direction (diffracted).

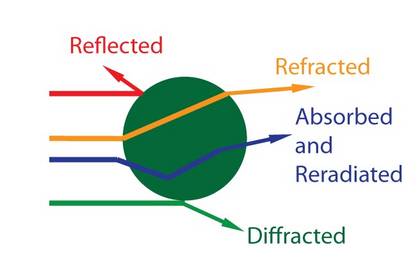


Figure : A waveform incident with an obstacle and the possible results.

By firing waveforms at a crystal lattice, the waves are diffracted and create an interference pattern. It is necessary for the waveform being diffracted to have a similar wavelength to the spacing it is being diffracted by in order to interact with it. The spacing is referred to as a “diffraction grating” (see Figure 2).

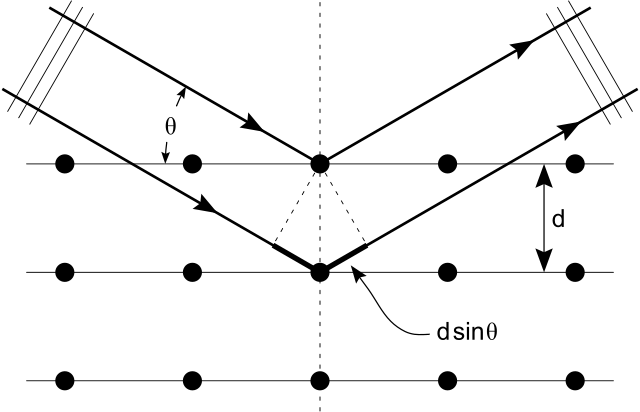


Figure : Diffraction of a waveform in a lattice structure.

The diffraction of a waveform in a crystal lattice is called “Bragg Diffraction” (also called “Bragg Reflection”) as it was first performed by Lawrence and William Bragg in 1913 who used X-rays. By observing the interference pattern of the light waves, they were able to determine the spacing of the diffraction grating (the molecules in the lattice). Each maxima of interference represents a “plane” of molecules in the lattice (the horizontal rows in Figure 2). The spacing between the interference maxima can then be used to calculate the spacing of the planes.

This phenomenon can be performed with electrons also, due to the wave-particle duality of quantum scale particles. Accelerating electrons using a potential difference and applying de’ Broglie’s wavelength relationship

Therefore, the wavelength of the electrons may be altered by changing the potential acting on them. By firing these electrons at a sample of graphite that consists of many different orientations of crystals an interference pattern of two rings is produced (see Figure 3). Each ring represents a plane in the lattice. Taking the diameter of each ring at each diameter and applying them to Equation 1.

By plotting the gradient is the constant in Equation 1. Therefore, d may be isolated from this value and the plane spacing be found.

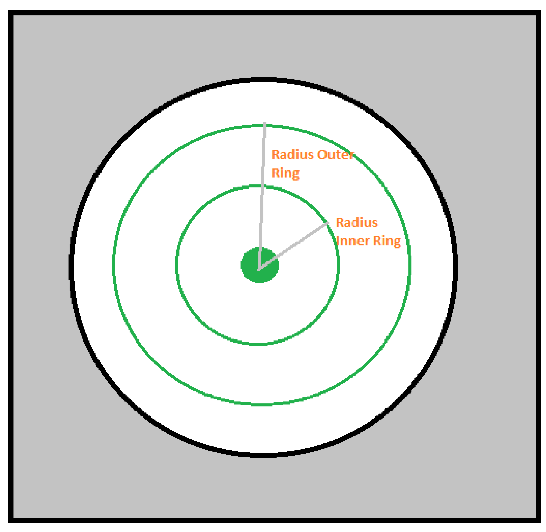


Figure : Electron interference pattern for graphite sample.

# Procedure

The smallest voltage whilst still being able to measure the ring radius was

# Results

Figure 4: Plot of magnetic field against offset hall voltage for germanium sample 3361 placed in an electromagnet and experiencing a current.

Figure 5: Plot of magnetic field against offset hall voltage for germanium sample 3375 placed in an electromagnet and experiencing a current.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sample** | **Majority Carrier Type** | **Hall Coefficient (cm3C-1)** | **Carrier Density (cm-3)** | **Carrier Mobility (cm2V-1s-1)** |
| 3361 | p-type | 20600 ± 1080 | 3.03 ± 0.16 x 1013 | 2.943 ± 0.17x 103 |
| 3375 | n-type | 20000 ± 1080 | 3.12 ± 0.16 x 1013 | 3.333 ± 0.17x 103 |

Table 1: Properties of the tested germanium samples as determined using Equations 1, 2 & 3.

# Discussion

## Inaccuracy

The experiment has a number of sources of inaccuracy. The instruments themselves have intrinsic inaccuracies. The voltmeter and current sources are accurate to ±0.1mV and ±0.1mA respectively. The Gauss probe had an accuracy of ±0.1 Gs.

The gradient of the plots in Figure 5 & 6 were not perfectly linear and so an inaccuracy of ±5% was applied to the gradient and carried through the results calculations. The inaccuracy for the Hall Coefficient is ±1080, the carrier density is ±0.16x10E13 and the carrier mobility is ±0.17x10E3.

Additional sources of inaccuracy are the misalignment of voltmeter probe terminals though this should have been accounted for by calculating the offset voltage (see Equation 4).

The Ettingshausen and Nernst (Righi-Leduc) Effects also contribute to errors in the data collected. The Ettingshausen Effect is where charge carriers with a greater velocity are deflected more than others creating a temperature gradient that induces an additional voltage which affects the hall voltage. The Nernst effect is also due to a temperature gradient which generates current perpendicular to the hall voltage and magnetic field, this also alters the reading of the hall voltage.

The Ettingshausen effect cannot be corrected by calculating an offset voltage for reversed magnetic field or current however the Nernst effect can be accounted for by reversing current. This process could be used to improve the experimental data in the future.

The magnitude of these effects on the data for this experiment have however been deemed negligible.

## Hall Effect Applications

The data obtained can and has been used to calculate the conductive properties of a semiconducting material. This is useful as the information can be used to determine the possible applications of a material for certain tasks, such transistors in small electronics.

The hall effect can also be used in sensors. Many pedal systems for vehicles use this effect to generate a voltage due to a moving magnetic field. A magnet is attached to a pedal and when the pedal moves the induced voltage magnitude determines the angle that the pedal has been pushed to. Often switches in integrated circuits are triggered by a moving magnetic field inducing a voltage i.e. the Hall Effect.

## Intrinsic Semiconductors

Intrinsic semiconductors do exhibit extrinsic conduction. Extrinsic conduction is caused by having free holes or electrons, intrinsic conduction is caused by thermal agitation exciting electrons from the valence band to the conduction band of a material (see Figure 7).

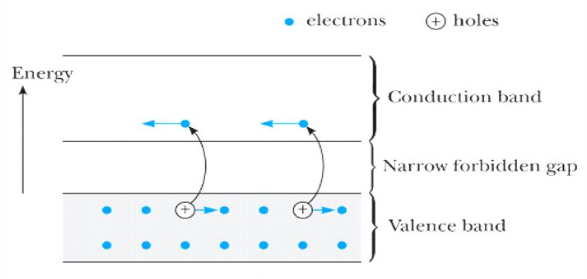


Figure 6: Thermal agitation of electrons in a semiconductor to the conduction band form the valence band (aka intrinsic conduction).

The samples of germanium in this experiment were kept at a relatively constant temperature. The increase in temperature due to heat dissipation in the material was negligible as the current was only 5mA. Therefore, the hall voltage generated must be attributed to extrinsic conduction and hence was observed for a intrinsic semiconductor.

Based on the analysis of force direction described in the introduction of this report (see Figure 2) the materials, though undoped, exhibited a clear majority charge carrier. This occurred despite pure semiconductors being modelled as having an equal number of holes and electrons. The results may be explained by crystallographic defects and imperfections in the material.

Furthermore, the change in hall voltage with increasing magnetic field in combination with the right-hand rule demonstrated that germanium sample 3361 had positive majority charge carriers. This is as it is known that both positive and negative charge carriers are deflected in the same direction and hence it could be determined which carrier was influences the change in voltage. Similarly, the sample 3375 was determined to be an n-type material.

# Conclusion

The hall effect was effectively used to determine the conductive properties of two samples of germanium. Most notably sample 3361 was found to be a p-type material with carrier density 3.03 ± 0.16 x 1013 cm-3, validating the presence of positive charge carriers. Sample 3375 was found to be an n-type material with carrier density 3.12 ± 0.16 x 1013 cm-3. This means that despite both samples being “intrinsic” materials there was a difference majority charge carrier for both hence even pure semiconductors exhibit extrinsic properties.

# Bibliography

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| [1] | P. A. Laboratory, “The Hall Effect and the Conductivity of Semiconductors,” 22 February 2006. [Online]. Available: http://instructor.physics.lsa.umich.edu/adv-labs/Hall/hall\_effect\_2005.pdf. [Accessed May 2018]. |
| [2] | M. Design, “Energy band structure of germanium,” materials design, 2018. [Online]. Available: http://www.materialsdesign.com/appnote/energy-band-structure-germanium. |