8. In A Hall Experiment, A Current Of 25 A Is Passed Through A Long Foil Of Ag, Which Is 0.1 Mm Thick

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The Hall Effect is a fundamental phenomenon in electromagnetism that provides critical insights into the behavior of charge carriers within conductive materials. In a typical Hall experiment, a current is passed through a thin, flat conductor or semiconductor, and the resulting voltage developed across the material in the presence of a magnetic field is measured. This experiment not only elucidates the nature of charge carriers—whether electrons or holes—but also enables the determination of vital electrical properties such as carrier concentration, mobility, and type. In this particular scenario, a current of 25 amperes is passed through a long foil of silver (Ag), which has a thickness of 0.1 millimeters, to observe and analyze the Hall effect under these specific conditions.

Understanding the setup and parameters of this experiment is essential for comprehending the underlying physics and the significance of the measurements obtained. Let's explore this scenario in detail, examining the key concepts, the experimental procedure, the calculations involved, and the implications of the results.

Overview of the Experimental Setup

The core components of this Hall experiment include a silver foil, a magnetic field source, voltage measurement apparatus, and current supply. Each element plays a crucial role in ensuring accurate and meaningful data collection.

Silver Foil Specifications

- Material: Silver (Ag) – renowned for its high electrical conductivity.
- Thickness: 0.1 millimeters (mm) – a critical dimension influencing voltage and current distribution.
- Length and Width: Typically elongated and wide enough to facilitate uniform current flow and magnetic field application.

Electrical and Magnetic Components

- Current Source: Supplies a steady current of 25 A through the foil.
- Magnetic Field: Applied perpendicular to the plane of the foil, usually using electromagnets or permanent magnets.
- Voltage Probes: Placed across the width of the foil to measure the Hall voltage developed due to the magnetic field's influence.

Fundamental Principles of the Hall Effect

The Hall effect arises when a current-carrying conductor or semiconductor is placed within a magnetic field perpendicular to the current direction. The magnetic Lorentz force acts on the moving charge carriers, causing them to accumulate on one side of the material. This accumulation results in a transverse electric field and an observable Hall voltage.

Key Concepts

- Lorentz Force: $\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$, where q is charge, $\mathbf{v}$ is velocity, and $\mathbf{B}$ is magnetic flux density.
- Hall Voltage (V_H): The potential difference developed across the conductor due to charge

accumulation.

- Hall Field (E_H): Related to the Hall voltage by $V_H = E_H \times w$, where w is the width of the foil.

Calculations in the Silver Hall Experiment

Understanding the numerical aspects of this experiment involves calculating parameters such as the magnetic flux density, the Hall coefficient, and the carrier concentration. These calculations help infer the properties of the silver foil and the behavior of charge carriers within it.

1. Determining the Magnetic Field (B)

Assuming the magnetic field is known or controlled, it's essential to specify the flux density in Tesla (T). For typical laboratory setups:

- Magnetic field strength might be set at $B = 0.5\, \text{T}$.

If not specified, this value can be adjusted based on experimental conditions.

2. Calculating the Hall Voltage (V_H)

The Hall voltage can be derived using the relation:

$$
V_H = \frac{IB}{nqe t}
$$

where:

- I = 25 A (current passing through the foil),
- B = magnetic flux density,
- n = charge carrier density,
- q = elementary charge ($1.6 \times 10^{-19}\, C$),
- e = also the elementary charge (used interchangeably),
- t = thickness of the foil in meters.

Alternatively, the Hall coefficient R_H relates the Hall voltage to the current and magnetic field:

$$
V_H = R_H \times \frac{I B}{t}
$$

Given the high conductivity of silver, the experimental setup must account for the significant current and precise measurements.

3. Effect of Thickness on Measurements

The foil thickness directly influences the Hall voltage:

- Thinner Foil: Produces a larger Hall voltage for a given magnetic field and current, due to reduced cross-sectional area.
- Thickness Conversion: $t = 0.1\, \text{mm} = 1 \times 10^{-4}\, \text{m}$.

This small thickness makes the measurement of the Hall voltage feasible and sensitive.

Significance of Using Silver (Ag) in the Experiment

Silver is an excellent choice for the conducting material in this experiment because of its exceptionally high electrical conductivity ($\sigma \approx 6.3 \times 10^7\, \text{S/m}$). This property results in:

- Low resistivity, minimizing Joule heating.
- Large current-carrying capacity without significant temperature rise.
- Clear and measurable Hall voltages, facilitating precise calculations.

Additionally, the high purity of silver used in laboratory experiments ensures minimal scattering of charge carriers, improving the accuracy of measurements related to carrier density and mobility.

Expected Outcomes and Data Analysis

By passing a 25 A current through the silver foil in a magnetic field, the experiment aims to measure the resulting Hall voltage and analyze the electrical properties of silver.

1. Calculation of Carrier Concentration (n)

Using the measured Hall voltage:

$$
n = \frac{I B}{q V_H t}
$$

This calculation reveals the density of free electrons in the silver foil, which is typically on the order of $5.9 \times 10^{28}\, \text{m}^{-3}$.

2. Determination of Mobility (μ)

Mobility indicates how quickly charge carriers move in response to an electric field:

$$
\mu = \frac{\sigma}{n q}
$$

where σ is the electrical conductivity.

Given silver's high conductivity, the mobility is also high, indicating efficient charge transport.

Implications of the Experiment

This experiment demonstrates the practical application of the Hall effect in determining fundamental electrical properties of materials. It is crucial for material science, semiconductor physics, and electronic engineering.

Applications include:

- Measuring carrier concentration and type—distinguishing between electrons and holes.
- Assessing material purity and quality—via mobility and conductivity measurements.
- Designing electronic devices—such as sensors, Hall probes, and magnetic field detectors.

Conclusion

Passing a 25 A current through a long foil of silver with a thickness of 0.1 mm in a Hall experiment provides valuable insights into the material's electronic properties. The high conductivity of silver ensures a significant and measurable Hall voltage, facilitating precise calculations of charge carrier density and mobility. Understanding these parameters is essential for advancing electronic materials science and developing sensitive magnetic field sensors. The experimental setup, parameters, and calculations discussed here serve as a fundamental example of how the Hall effect is utilized in physics and engineering research to explore the intrinsic properties of conductive materials.

Frequently Asked Questions

What is the significance of passing a 25 A current through a long foil of silver in a Hall experiment?

Passing a 25 A current through the silver foil generates a magnetic field perpendicular to the current, which is essential for measuring the Hall voltage and determining the Hall coefficient of the material.

How does the thickness of 0.1 mm of silver foil affect the Hall experiment results?

The thinness of 0.1 mm ensures a uniform current distribution and minimizes resistance, allowing more accurate measurement of the Hall voltage and better detection of the Hall effect.

What role does the silver material play in the Hall experiment with a current of 25 A?

Silver, being a good conductor with high electrical conductivity, facilitates a stable current flow and produces a measurable Hall voltage when subjected to a magnetic field, aiding in the study of charge carriers.

What are the typical applications of the Hall effect measured in such

experiments?

Hall effect measurements are used to determine carrier concentration, type of charge carriers (electrons or holes), and mobility in materials, which are crucial for designing electronic devices and understanding material properties.

How does increasing the current to 25 A influence the magnetic field and Hall voltage in the experiment?

Increasing the current enhances the magnetic field and the resulting Hall voltage proportionally, improving the sensitivity and accuracy of measurements related to charge carrier properties.

Additional Resources

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Introduction to the Hall Effect and Its Significance

The Hall effect, discovered by Edwin Hall in 1879, is a fundamental phenomenon in electromagnetism that reveals insights into the nature of charge carriers within a conducting material. When a current-carrying conductor is placed within a magnetic field perpendicular to the current, a transverse electric field develops, leading to a measurable potential difference known as the Hall voltage. This effect is instrumental in characterizing materials, determining carrier concentration, mobility, and even in practical applications such as magnetic field sensors.

In this detailed review, we analyze a specific Hall experiment involving a long silver (Ag) foil with a current of 25 A passed through it, and a thickness of 0.1 mm. We will delve into the physics principles, experimental setup, calculations, and implications of this scenario.

Fundamental Concepts Underlying the Experiment

1. Hall Effect Fundamentals

- When a current I flows through a conductor of width w, thickness t, and length l, and a magnetic field B is applied perpendicular to the current, charge carriers experience a Lorentz force, causing charge accumulation on the sides of the conductor.
- This accumulation results in an electric field E_H, giving rise to the Hall voltage V_H across the width of the sample.
- The Hall coefficient R_H relates the measurable Hall voltage to the magnetic field and current:

$$
V_H = R_H \frac{I B}{t}
$$

where t is the thickness of the foil.

2. Properties of Silver (Ag)

- Silver is a highly conductive metal with a high electrical conductivity ($\sigma \approx 6.3 \times 10^7 \, \text{S/m}$ at room temperature).
- It has a high density of free electrons, approximately $n \approx 5.86 \times 10^{28} \, \text{electrons/m}^3$, which influences the magnitude of the Hall voltage.
- The mobility of electrons in silver is also high, facilitating significant current flow with minimal resistance.

Experimental Setup and Parameters

1. Physical Dimensions

- Material: Silver foil
- Thickness t: 0.1 mm = 1×10^{-4} meters
- Length l: Typically several centimeters to meters; for calculations, assume $l = 1 \text{ m}$ for simplicity
- Width w: Not specified; assume $w = 1 \text{ cm} = 0.01 \text{ m}$ for illustration

2. Electrical Parameters

- Current I: 25 A
- Magnetic Field B: To be determined or assumed; typical laboratory magnetic fields are in the range of 0.1 – 1 Tesla
- Voltage across the length: Not specified; focus is on the Hall voltage across width

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Calculation of Current Density

Current density is a measure of how much current flows per unit area of the conductor:

$$
J = \frac{I}{A}
$$

where A is the cross-sectional area:

$$
A = w \times t = 0.01 \, \text{m} \times 1 \times 10^{-4} \, \text{m} = 1 \times 10^{-6} \, \text{m}^2
$$

Thus,

$$
J = \frac{25}{1 \times 10^{-6}} = 2.5 \times 10^{7} \, \text{A/m}^2
$$

This high current density emphasizes the importance of proper thermal management and material considerations to prevent damage.

Estimating the Hall Voltage

The Hall voltage V_H depends on the magnetic field B, the current I, and the material's Hall coefficient R_H:

$$
V_H = R_H \frac{I B}{t}
$$

1. Hall Coefficient R_H for Silver

For metals like silver, the Hall coefficient can be approximated as:

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

where:

- n: free electron density ($\approx 5.86 \times 10^{28} \, \text{electrons/m}^3$)

- e: elementary charge ($1.6 \times 10^{-19} \, \text{C}$)

Calculating:

$$
R_H = \frac{1}{(5.86 \times 10^{28}) \times (1.6 \times 10^{-19})} \approx 1.07 \times 10^{-10} \, \text{m}^3/\text{C}
$$

2. Assuming Magnetic Field B

Let's assume a typical laboratory magnetic field:

$$
B = 0.5 \, \text{Tesla}
$$

3. Calculating V_H

Plugging into the formula:

$$
V_H = R_H \times \frac{I \times B}{t}
$$

$$
V_H = (1.07 \times 10^{-10}) \times \frac{25 \times 0.5}{1 \times 10^{-4}}
$$

$$
V_H = (1.07 \times 10^{-10}) \times \frac{12.5}{1 \times 10^{-4}} = (1.07 \times 10^{-10}) \times 1.25

$$
\times 10^{5}
$$

$$
V_H \approx 1.34 \times 10^{-5} \, \text{V} = 13.4 \, \mu V
$$

This extremely small voltage indicates the necessity for sensitive measurement equipment to detect the Hall voltage in such experiments.

Thermal and Mechanical Considerations

1. Joule Heating

Passing 25 A through a thin silver foil causes significant heat:

$$
P = I^2 R
$$

where R is the resistance of the foil.

The resistance:

$$
R = \frac{\rho \times l}{A}
$$

with ρ being the resistivity of silver ($\approx 1.59 \times 10^{-8} \, \Omega \text{m}$):

$$
R = \frac{1.59 \times 10^{-8} \times 1}{1 \times 10^{-6}} = 0.0159 \, \Omega
$$

Hence,

$$
P = 25^2 \times 0.0159 \approx 9.94 \, \text{W}
$$

This power dissipation requires adequate cooling to prevent damage or deformation.

2. Mechanical Stability

The foil must withstand thermal expansion and electromagnetic forces. The Lorentz force acting on the current-carrying foil in the magnetic field may induce mechanical stress, especially at high currents.

Practical Aspects of the Experiment

1. Setup

- A long silver foil mounted securely with contacts for current injection.
- A uniform magnetic field perpendicular to the plane of the foil, provided by electromagnets or a superconducting magnet.
- Sensitive voltmeters or nanovoltmeters connected across the width to measure the Hall voltage.
- Proper insulation and cooling mechanisms to handle heat.

2. Measurement Procedure

- Pass the current of 25 A through the foil.
- Apply the magnetic field perpendicular to the current.
- Measure the transverse voltage V_H.
- Vary the magnetic field to verify the linearity of V_H with B.
- Calculate the Hall coefficient and verify consistency with theoretical values.

Significance and Applications

1. Material Characterization

- Determining carrier density, sign of charge carriers, and mobility.
- For silver, the negative Hall voltage confirms electrons as the dominant charge carriers.

2. Sensor Technology

- Hall sensors are widely used to measure magnetic fields with high precision.
- The experiment demonstrates the fundamental physics behind such sensors.

3. Fundamental Research

- Provides insights into the electron dynamics within metals.
- Helps in understanding phenomena like magnetoresistance and quantum Hall effects at low temperatures.

Limitations and Challenges

- Measurement Sensitivity: The tiny Hall voltages necessitate high-precision instrumentation.

- Thermal Effects: Significant heat generation at high currents requires effective cooling.

- Sample Quality: Surface imperfections, impurities, or non-uniformities can affect results.

- Magnetic Field Uniformity: Ensuring a uniform magnetic field across the sample is critical for accurate measurements.

Conclusion

This detailed exploration of a Hall experiment involving a 25 A current passing through a 0.1 mm thick silver foil illuminates the intricate interplay of electromagnetism, material properties, and experimental techniques. The calculations underscore the small magnitude of the Hall voltage in such a scenario, emphasizing the need for precise instrumentation and careful experimental design. Such experiments are not only vital for

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