

Experimental determination of the Hall coefficient of an unknown metal sample

by Martin Müller, The Open University, 27 December 2025

Abstract

This report presents an online experiment to determine the Hall coefficient and the free charge carrier density of an unknown metal sample. Using a remote-controlled toroidal electromagnet and measurement circuit the Hall voltage across a sample was measured under varying magnetic field strengths at a fixed transverse current. Careful calibration accounted for the non-linear relationship between coil current and magnetic field. Demagnetisations of the electromagnet, zeroing of sensors and repeated measurements minimized further systematic and random errors. The experimentally determined Hall coefficient was $|R_H| = 9.45 \times 10^{-11} \text{ m}^3 \text{ C}^{-1}$ with an uncertainty of $\pm 2.65\%$, slightly exceeding the literature value of $8.9 \times 10^{-11} \text{ m}^3 \text{ C}^{-1}$. The corresponding free-electron density, $n = 6.61 \times 10^{28} \text{ m}^{-3}$, agreed with literature within the errors. The positive Hall voltage measured in the specific setup indicated electrons as charge carriers, allowing the sample to be identified as silver.

The results show the expected linear relationship between Hall voltage and magnetic field, underline the importance of precise calibration and enable reliable identification of the sample. Overall, the results confirm the theoretical description of the Hall effect and demonstrate the reliability of the method for material identification.

Introduction

This report describes the methods used, the results obtained and the conclusions drawn of an online experiment to determine the Hall coefficient of an unknown metal sample, executed by the author, Martin Müller and his partner Wai Chung on December 13th, 2025. The experiment was conducted under the guidance of The Open University study materials, which provided the theory behind the Hall effect (The Open University, 2025a), the remote apparatus (The Open University, 2025b) and instructions for its online use (The Open University, 2025c), advice on how to plan the experiment properly (The Open University, 2025d) and data analysis resources, including a Python script (The Open University, 2025e).

The Hall coefficient is a material-specific proportionality constant related to the Hall effect, which is widely used in industry, for example to probe materials and in Hall sensors for measuring magnetic field strengths. The Hall effect is a consequence of the Lorentz force law in a particular setup, that is, it is the response of free charge carriers to mutually perpendicular electric and magnetic fields. When charge carriers (electrons or holes) are accelerated by an electric field and a magnetic field is applied perpendicular to their direction of motion, the charges are forced into a cycloidal trajectory in a direction perpendicular to both the electric and magnetic fields (see Figure 1). In a metal strip under these conditions, charge carriers, whether negative or positive, accumulate on one side of the sample until an equilibrium is established between the magnetic force and the induced electric force. Measuring the potential difference between the two sides of the strip reveals the Hall voltage.

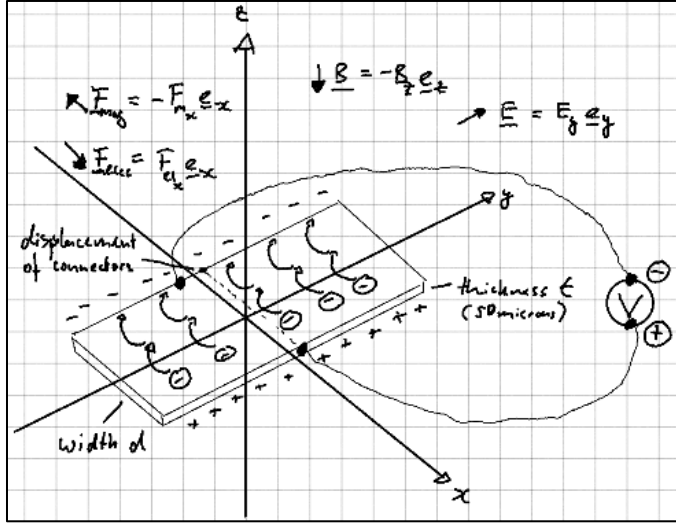


Figure 1: Depiction of the experimental setup, in which a thin metal strip of thickness 50 microns is placed in the gap (xy -plane) of a toroidally shaped electromagnet. An electric field is applied along the positive y -direction by a DC power supply, producing a conventional current. An uniform magnetic field is applied along the negative z -direction by the electromagnet. In this illustration, the metal contains free electrons that are accelerated by the electric field in the negative y -direction and therefore experience a magnetic force component in the negative x -direction. As a result, free electrons accumulate on the side with negative x -coordinate, inducing an electric field in the negative x -direction and an associated electric force on the electrons in the positive x -direction. An equilibrium is established when the electric force in the positive x -direction balances the magnetic force component in the negative x -direction. A voltmeter is connected

both sides of the sample, allowing the measurement of the total voltage, consisting of the Hall voltage and an additional resistive voltage caused by a possible geometrical displacement of the connectors.

The Hall voltage V_H as a function of the applied magnetic field strength B for a fixed transverse current I_T and material specific Hall coefficient R_H can be derived mathematically and related to the setup chosen in Figure 1 as follows (The Open University, 2025a):

The potential difference V_H between the two sides of the sample arises from the induced electric field:

$$V_H = V\left(\frac{d_w}{2}\right) - V\left(-\frac{d_w}{2}\right) = - \int_{-\frac{d_w}{2}}^{\frac{d_w}{2}} \mathbf{E}_{ind} \cdot d\mathbf{l}$$

$$V_H = E_{ind} * d_w \quad (1)$$

where $\mathbf{E}_{ind} = E_{ind} (-\mathbf{e}_x)$, $d\mathbf{l} = dx (\mathbf{e}_x)$, and d_w is the width of the sample.

At equilibrium, the induced electric field strength E_{ind} establishes:

$$\mathbf{F}_{elec} = -\mathbf{F}_{mag}$$

$$(-e)(-E_{ind}\mathbf{e}_x) = -(-e)(-v_y\mathbf{e}_y \times -B_z\mathbf{e}_z)$$

$$E_{ind} = v_y B_z \quad (2)$$

where v_y is the drift velocity of the electrons in the negative y -direction and B_z is the applied uniform magnetic field strength.

Combining equations (1) and (2) yields:

$$v_y = \frac{V_H}{B_z d}$$

and inserting this into the definition of the current $I = nqvdt$, where n is the number density of free charge carriers q , and dt is the cross-sectional area of the conductor, gives

$$V_H = \frac{I_T}{nqt} B \quad (3)$$

where t is the thickness of the sample. The Hall coefficient R_H is defined as $1/nq$, that is, equation (3) can be written as

$$|V_H| = |R_H| \frac{I_T}{t} B \quad (4).$$

Since a small displacement of the voltmeter connectors perpendicular to the x -axis is possible, a resistive voltage V_0 must be taken into account. The measured total voltage V therefore becomes

$$V = |V_H| + V_0 = |R_H| \frac{I_T}{t} B + R_L I_T \quad (5)$$

where R_L is the resistance of the sample along the y-axis.

By measuring the voltage V across an unknown sample at varying magnetic field strengths, the main objectives of this experiment were to determine the Hall coefficient, the number density and polarity of the free charge carriers, and thereby identify whether the sample was silver or tungsten.

Methods

Figure 2 depicts the apparatus used in the experiment (The Open University, 2025b). It consisted of a toroidally shaped electromagnet (2) producing a uniform magnetic field in a narrow gap, in which the metal sample (1) was placed. The magnetic field strength could be varied by adjusting the DC power supply for the windings of the electromagnet between 0 and 10 A (4). However, an initial calibration was required due to a possible non-linear relationship between the coil current and the magnetic field strength. For this purpose, a magnetic field sensor connected to a magnetometer (7) could be inserted automatically in calibration mode by electric motors (the specific mechanism is not shown in the figure). A second DC power supply (3), adjustable between 0 and 20 A, was connected to the sample in order to generate an electric field and a conventional current in the y-direction. On the sides of the sample perpendicular to the x-direction, a sensor and voltmeter (6) were connected to measure the voltage resulting from the Hall effect and the resistive voltage of the metal.

All controllable parts of the device were connected to a control panel via an online interface, allowing the entire experiment to be conducted remotely over the internet. The experiment was performed by the author of this report, located in Germany, together with the student partner Wai Chung, located in Brunei, and took place on December 13, 2025, from 12:00 pm to 1:38 pm GMT, using experimental set 1. Detailed planning of the experiment was carried out jointly over a period of two weeks prior to execution, including an online meeting (The Open University, 2025d).

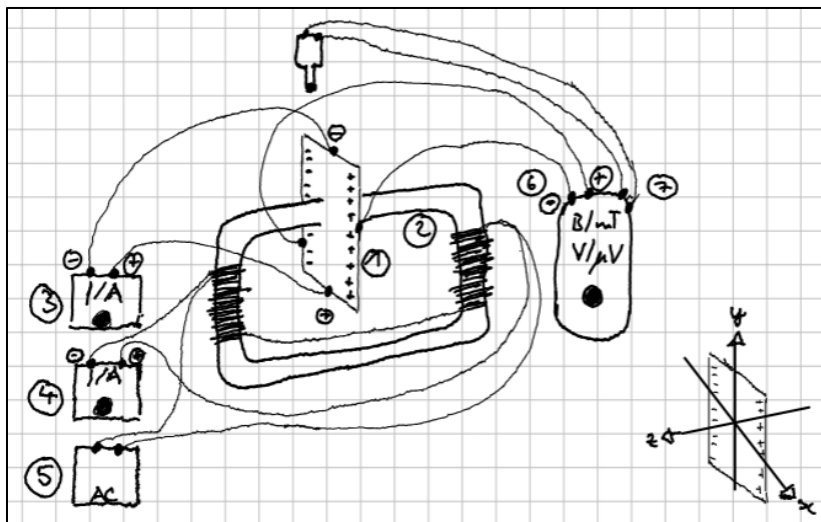


Figure 2: Depiction of the experimental apparatus. (1) The sample placed in the gap of the toroidally shaped electromagnet (2). (3) The adjustable DC power supply for the sample (0 to 20 A). (4) The adjustable power supply for the electromagnet (0 to 10 A). (5) The AC power supply used to demagnetise the iron core of the electromagnet. (6) The sensor and voltmeter used to measure the voltage between the sides of the sample. (7) The sensor and magnetometer used to calibrate the magnetic field. To simplify the depiction, the DC/AC relay switch connected to (4) and (5) was omitted.

The setup is oriented with respect to the Cartesian coordinate system in the same way as shown in Figure 1. For reference, a coordinate system is shown in the lower right corner. To present one surface of the sample, the depiction is slightly tilted. Charge carrier accumulation due to the Hall effect is included for illustrative purposes only and does not necessarily reflect the outcome of the experiment.

The potential hazards of this experiment were assessed. The main risk arose from high currents of up to 20 A, which could cause wire heating, posing a risk of fire and injury, as well as potential lethality upon direct contact. As this was a remote experiment, the experimenters were not exposed to these hazards. In the laboratory, warning signs were displayed, current flow was limited to short durations, and a fire alarm system was installed in accordance with laboratory standards.

The experiment was divided into two parts: (1) calibration of the magnetic field and (2) measurement of voltages across the sample with electric and magnetic fields applied (The Open University, 2025c).

Part 1: Calibration of the magnetic field

The magnetic field sensor was inserted into the electromagnet gap, and the iron core was demagnetised using an AC current for approximately one minute. The sensor was then zeroed and fluctuations were observed. The coil current was set to 0 A to identify offsets, and the magnetic field was recorded together with minimum and maximum live readings. The coil current was subsequently increased in steps of 1 A up to 10 A, with three measurements taken at each setting to allow averaging and reduce random errors. This part proceeded according to plan and within the allocated time.

Part 2: Voltage measurements

As applying a coil current magnetised the iron core, the electromagnet was demagnetised again before voltage measurements began. To minimise non-linear effects caused by temperature-dependent resistivity changes, the sample was warmed up by applying four consecutive transverse currents of 10 A. After the warm-up, the initial voltage drifted from approximately 3 microvolts to 0.2–0.3 microvolts over about five minutes, after which the voltmeter was zeroed.

Since no specific guidance was provided on selecting the transverse current, measurements were initially performed at five currents between 4 A and 20 A in steps of 4 A, with a fixed coil current of 7 A. A live analysis using a Python script showed an almost perfectly linear relationship between transverse current and voltage ($R^2 = 0.999995$). Based on this result and the warm-up conditions, a transverse current of 10 A was chosen for the main measurements.

The electromagnet was demagnetised once more, and the voltmeter was zeroed again after the voltage decayed from approximately 7 microvolts to 0.1–0.2 microvolts over a period of about seven minutes. To determine the resistive voltage contribution, measurements were taken at a coil current of 0 A and a transverse current of 10 A, with each measurement repeated four times. Finally, the total voltage was measured for coil currents from 1 A to 10 A in steps of 1 A, with three measurements performed at each data point.

Zeroing the voltmeter exceeded the planned duration, but available time buffers allowed completion twelve minutes before the session ended.

Results and analysis

Table 1 shows the raw data obtained in the calibration. Three measurements were taken at each current setting and averaged. In addition, the lowest and highest values observed in the live readings were recorded. A brief data analysis using orthogonal distance regression in Python showed no significant increase in uncertainty beyond that already accounted for by averaging the three measurements. Therefore, these additional values were not used in the subsequent analysis.

I_c/A	B_1/mT	B_2/mT	B_3/mT	B_{avg}/mT
0	0.0	n/a	n/a	0.0
1	43.6	43.6	43.6	43.6
2	87.8	88.0	88.1	88.0
3	130.9	131.0	131.0	131.0
4	173.4	173.4	173.4	173.4
5	214.0	214.0	214.0	214.0
6	249.9	249.9	249.9	249.9
7	276.4	276.4	276.4	276.4
8	293.3	293.3	293.3	293.3
9	305.2	305.2	305.2	305.2
10	314.6	314.3	314.0	314.3

Table 1: Raw magnetic field calibration data for each coil current setting, as returned by the magnetometer, together with the calculated average magnetic field value B_{avg}

Plotting the average magnetic field strength B_{avg} as a function of the applied coil current I_c (The Open University, 2025e) revealed a non-linear relationship as can be seen in Figure 3. However, the curve was smooth and exhibited no outliers, allowing all coil current values to be used.

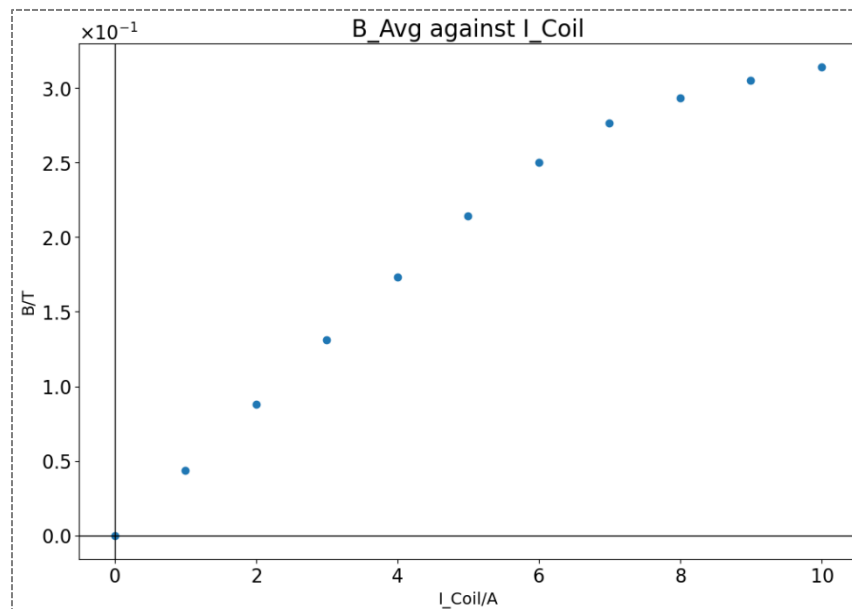


Figure 3: Plot of the magnetic field strength B_{avg} as a function of the applied coil current

Table 2 shows the raw data of the voltage measurements, together with their averages, the relation of I_c and B and the calculation of the Hall voltage. The average resistive voltage V_0 of $-23.50 \mu V$ was subtracted from all other measured averaged voltages to obtain the Hall voltages. As in the calibration part, due to insignificance the lowest and highest values observed in the live readings were not taken into account.

I_c/A	B_{avg}/mT	$V_1/\mu V$	$V_2/\mu V$	$V_3/\mu V$	$V_4/\mu V$	$V_{avg}/\mu V$	$V_{Hall}/\mu V$
0	0.0	-23.50	-23.52	-23.48	-23.50	-23.50	0.00
1	43.6	-22.80	-22.67	-22.56	n/a	-22.68	0.82
2	88.0	-21.77	-21.73	-21.68	n/a	-21.73	1.77
3	131.0	-20.95	-20.87	-20.83	n/a	-20.88	2.62
4	173.4	-20.08	-20.08	-20.14	n/a	-20.10	3.40
5	214.0	-19.54	-19.50	-19.54	n/a	-19.53	3.97
6	249.9	-18.96	-18.87	-18.79	n/a	-18.87	4.63
7	276.4	-18.43	-18.32	-18.19	n/a	-18.31	5.19
8	293.3	-17.91	-17.91	-17.95	n/a	-17.92	5.58
9	305.2	-17.67	-17.65	-17.61	n/a	-17.64	5.86
10	314.3	-17.40	-17.46	-17.33	n/a	-17.40	6.10

Table 2: Raw potential difference data for each coil current setting, as returned by the voltmeter, together with the calculated average total voltage V_{avg} . The first row contains measurements of the resistive voltage, yielding an average value of $-23.50 \mu V$, which was then subtracted from all other total voltages to obtain the Hall voltages V_{Hall} .

A plot of the Hall voltage against the applied magnetic field showed a linear relationship (see Figure 4). A least squares regression analysis using the 'Python SciPy linregress' function was performed (The Open University, 2025e), creating a linear fit and yielding the following results:

Gradient: $1.89e-05 \pm 2.68e-07$
Intercept: $3.83e-08 \pm 5.83e-08$
R-squared value: 0.998

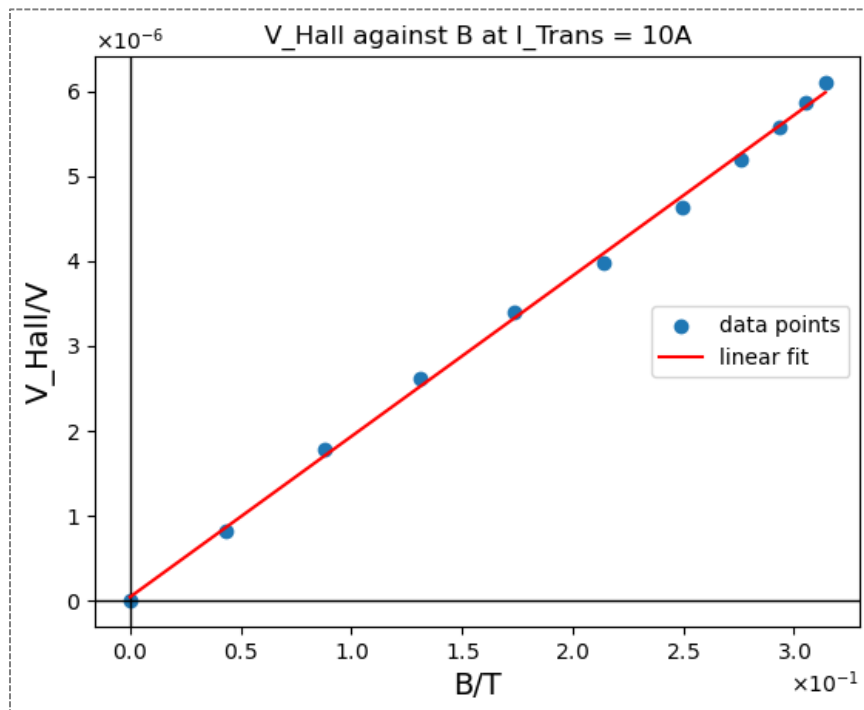


Figure 4: Plot of the Hall voltage V_{Hall} as a function of the applied magnetic field strength. A least squares regression was performed and is shown here as a linear fit.

The least squares regression analysis showed an experimental linear relationship between the Hall voltage $V_{H,Exp}$ and the applied magnetic field strength B at a fixed transverse current $I_T = 10 A$ and fixed sample thickness $t = 50 \text{ microns}$. The constant of proportionality was found to be $1.89 * 10^{-5} VT^{-1}$ (2 d.p.) with an error of $2.68 * 10^{-7} V$ (2 d.p.). The y-intercept could be considered 0 within the error. Thus,

$$V_{H,Exp}(B) = 1.89 * 10^{-5} VT^{-1} * B \pm 2.68 * 10^{-7} V \text{ (2 d.p.)}$$

Referring to equation 5 and after correcting for the resistive voltage V_0 , the theoretical relationship is

$$|V_H(B)| = |R_H| \frac{I_T}{t} * B$$

where $|R_H|I_T/t$ is the constant of proportionality. Defining $R_{H,Exp}$ as experimental Hall coefficient,

$$|R_{H,Exp}| \frac{I_T}{t} = 1.89 * 10^{-5} VT^{-1} \pm 2.68 * 10^{-7} V \text{ (2 d.p.)}$$

and therefore

$$|R_{H,Exp}| = 1.89 * 10^{-5} VT^{-1} * \frac{t}{I_T} \pm 2.68 * 10^{-7} V \text{ (2 d.p.)} \quad (6)$$

The quantities I_T and t introduced additional uncertainties. As these uncertainties were not explicitly documented, they were estimated from the last digit of the recorded values. The transverse current was $I_T = 10.0 A$, giving a percentage error of 1.0% (0.1 divided by 10.0). The sample thickness was $t = 5.0 * 10^{-5} m$, resulting in a percentage error of 2.0% (0.1 divided by 5.0). The percentage error obtained from the linear regression was 1.42% ($2.68 * 10^{-7}$ divided by $1.89 * 10^{-5}$) (2 d.p.). Combining these errors in quadrature yielded (The Open University, 2025f) a total percentage error of 2.65% (2 d.p.).

Substituting the values for I_T and t into equation (6) and applying the calculated total error gave the experimentally determined Hall coefficient for the sample,

$$|R_{H,Exp}| = 1.89 * 10^{-5} VT^{-1} * \frac{5 * 10^{-5} m}{10 A} \pm 2.65\% \text{ (2 d.p.)}$$

and therefore,

$$|R_{H,Exp}| = (9.45 \pm 0.23) * 10^{-11} m^3 C^{-1} \text{ (2 d.p.)} \quad (7)$$

Equation (3) showed that the magnitude of the Hall coefficient is given by $|R_H| = 1/(n|q|)$, so that $n = 1/(|R_H||q|)$, where q is the charge of the carriers (electrons or electron holes). Substituting the values, gave the experimental value for the number density,

$$n_{Exp} = 6.61 * 10^{28} m^{-3} \pm 2.65\% \text{ (2 d.p.)} \quad (8).$$

Discussion and evaluation

Referring to Figure 1, the application of the Lorentz force law in the given setup shows, that both positive and negative charge carriers experience a magnetic force directed towards the side of the sample with negative x-coordinate. Since the measured Hall voltage was positive and the voltmeter was connected with its negative terminal to the sample side at negative x and its positive terminal to the sample side at positive x, the side of the sample at negative x must have been negatively charged. From this, it can be deduced that the charge carriers were electrons.

This fact shows that the sample must have been made of silver, since silver has free electrons as charge carriers, whereas tungsten has holes. Comparing the values obtained in this experiment with literature data (The Open University, 2025b), as shown in Table 3, reveals that the deviation of the Hall coefficient was slightly outside the estimated uncertainty, while the deviation of the charge carrier number density was zero within the stated precision.

Quantity \ Source	Literature	Experiment	Deviation (%)
$ R_H /m^3C^{-1}$ (1 d.p.)	8.9×10^{-11}	$9.5 \times 10^{-11} \pm 2.7\%$	+6.7%
n/m^{-3} (1 d.p.)	6.6×10^{28}	$6.6 \times 10^{28} \pm 2.7\%$	0.0%

Table 3: Comparison of literature with experimental values

Systematic errors affecting accuracy were addressed by calibrating the magnetic field as a function of coil current, demagnetising the iron core and zeroing both the magnetic field sensor and voltmeter. Random errors affecting precision, such as fluctuations due to sensor precision and environmental influences, were mitigated by repeated measurements for each data point. Additional uncertainties arising from equipment imprecision, such as the transverse current setting and the sample thickness, were accounted for by including appropriate errors in the final uncertainty calculations.

While the experimentally determined free-electron density agreed well with the literature value for silver, the Hall coefficient showed a small deviation of about 4% beyond the estimated uncertainty, which can plausibly be attributed to unaccounted systematic effects, such as a non-uniform magnetic field in the sample region, sample impurities or a non-uniform sample thickness. Including these additional sources of error could further improve the agreement with literature values.

Given the complexity of the experimental setup and the sensitivity of the Hall voltage to geometric and thermal effects, a deviation of a few percent is reasonable and does not affect the identification of the sample as silver.

Conclusions

The experiment successfully demonstrated the expected linear relationship between the Hall voltage and the applied magnetic field at a fixed transverse current. Calibration of the magnetic field was essential to account for the non-linear relationship between coil current and magnetic field strength and to minimise systematic errors.

The experimentally determined Hall coefficient was $|R_{H,Exp}| = 9.5 * 10^{-11} m^3 C^{-1}$ with an uncertainty of $\pm 2.7\%$, showing a deviation of $+6.7\%$ from the literature value of $8.9 * 10^{-11} m^3 C^{-1}$. The calculated free-electron number density of $n_{Exp} = 6.6 * 10^{28} m^{-3}$ agreed exactly with the literature value within the uncertainty.

Together with the positive Hall voltage and the experimental configuration, these results allow the sample to be identified with confidence as silver.

References and acknowledgements

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