KLINGER SCIENTIFIC

Bringing You Science Since 1955

Hall Effect Apparatus KSCIHLEF

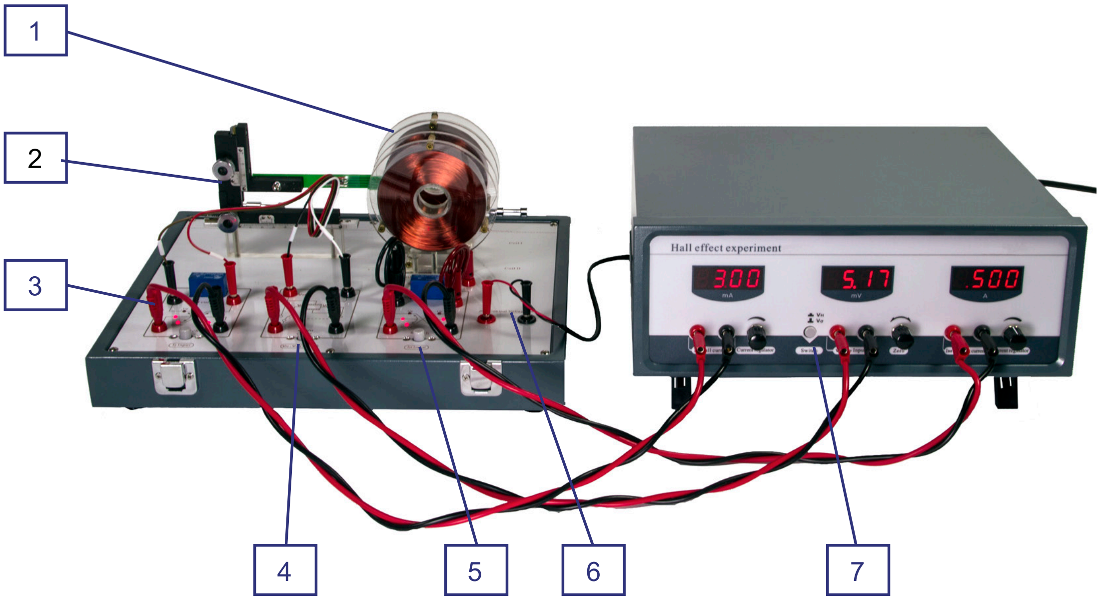


Figure 1

DESCRIPTION OF THE INSTRUMENT

The HLEF01 Hall Effect Apparatus is an integrated unit for investigating the basic characteristics of the Hall Effect in a n-type semiconductor.

The apparatus consists of an integrated Hall effect unit and a separate measurement and control unit. The Hall Effect unit contains a gallium arsenide chip held inside a pair of coils (1, Figure 1) by a two-axis traverse mechanism (2). The chip is connected to a reversing relay and switch (3) through which the drive current is supplied, and the resulting Hall voltage is fed to a connection block (4) for measurement. The magnet coils are energized via a second reversing relay and switch (5). The control and measurement unit is connected to the Hall Effect unit by three pairs of cords and a two-conductor control cable (6). Three digital displays indicate the magnitude and polarity of the drive current, the Hall effect voltage and the magnet current. Multi-turn potentiometers associated with the displays control the drive and magnet current magnitudes and the zero point of the Hall effect voltage measurement. An additional switch (7) allows the conductivity of the Hall effect chip to be measured.

SPECIFICATIONS

- Hall sensor chip: n-type GaAs, 1.5mm x 1.5mm x 0.2mm (length x width x thickness)
- Helmholtz coil pair: 1400 turns each, 72mm effective diameter.

  Magnetic induction at center:

Current (A)	0.1	0.2	0.3	0.4	0.5
Magnetic Induction (mT)	2.25	4.50	6.75	9.00	11.25

- Two-axis mechanical traverse with verniers for field plotting.

  Ranges: 0–75mm horizontal, 0-30mm vertical
- Constant current sources:

  For magnet 0—0.50A, resolution 1mA

  For Hall drive current 0—3.0mA, resolution 0.01mA
- Reversing switches for both currents for exploring the elimination of systematic error
- 3-1/2 digit current and voltage meters, 0.5% accuracy
- Switch to select voltage display between the Hall signal and the drive current voltage drop across the chip.
- Metal storage case for the Hall Effect unit

THE HALL EFFECT UNIT

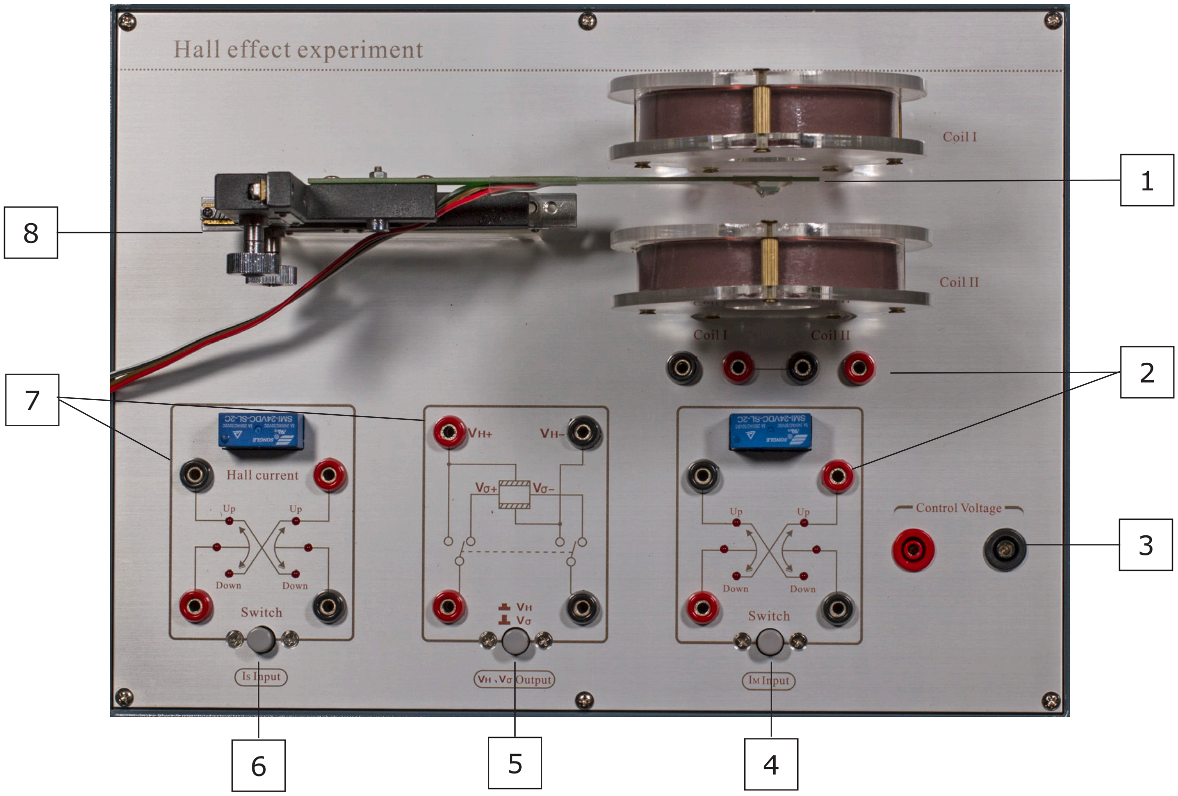


Figure 2

KEY TO THE PARTS (Refer to *Figure 2*)

1. Hall effect sensor mounted on printed circuit board
2. Connection sockets for Helmholtz coils
3. Connection sockets for reversing switch control cable
4. Reversing switch panel for the magnet current
5. Connecting panel for the Hall effect signal and conductivity measurement
6. Reversing switch panel for the Hall effect sensor drive current
7. Connecting sockets for the Hall effect sensor
8. Two-axis traversing mechanism.

MEASUREMENT AND CONTROL UNIT

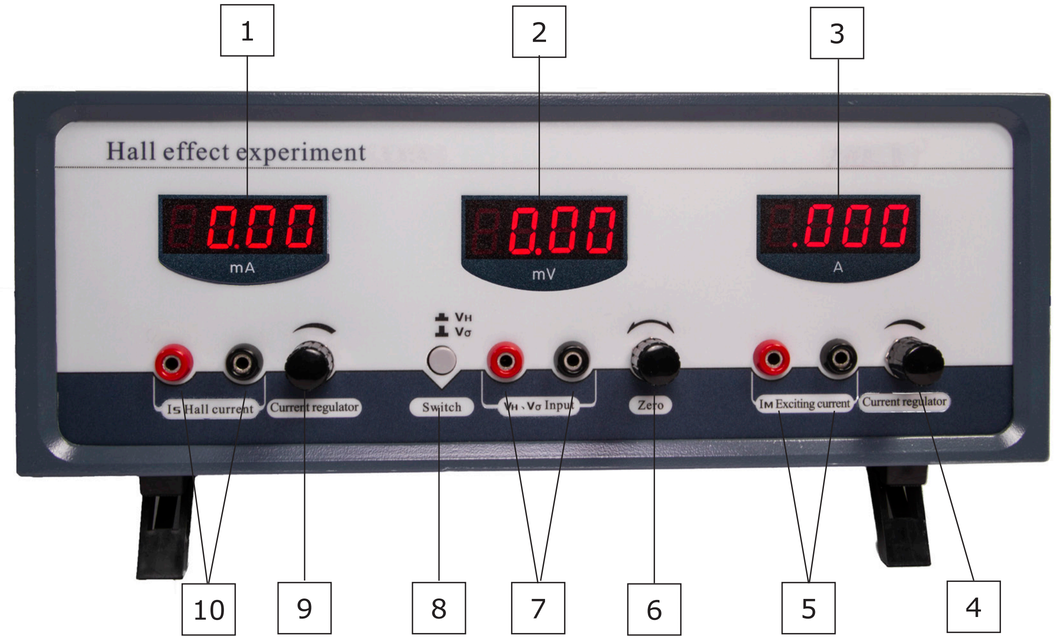


Figure 3

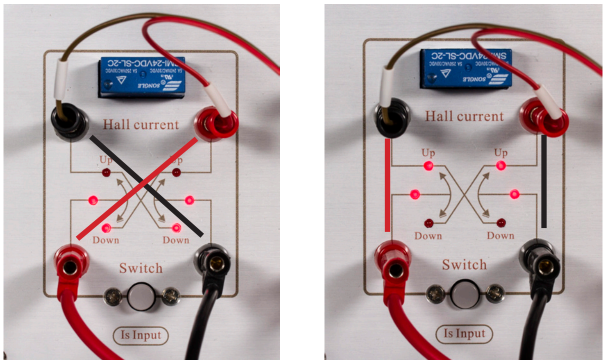
KEY TO THE PARTS (Refer to *Figure 3*)

1. Hall sensor driving current display, 3½ digits
2. Hall effect voltage & conductivity measurement display, 3½ digits
3. Magnet current display, 3½ digits
4. Magnet current regulating potentiometer, 10 turns, 0-0.50A
5. Magnet current output sockets
6. Hall effect sensor zero point adjustment potentiometer, 10 turns
7. Hall effect signal/conductivity measurement voltage input sockets
8. Hall effect signal/conductivity measurement voltage selection switch
9. Hall effect drive current regulating potentiometer, 10 turns, 0-3.0mA
10. Hall effect drive current output sockets

FUNCTION OF THE REVERSING SWITCHES

The reversing switch panels contain relay-actuated switches that reverse the directions of the Hall sensor drive current and the magnet current respectively without changing their magnitude settings. They are energized via the control cable (inputs 3 in Figure 2) and controlled by pushbutton switches on each of the panels. The images below indicate the connection paths in each switch state, also shown by the red status lights:

Figure 4



Switch DOWN "+"
(+ to +, - to -)

Switch UP "-"
(+ to -, - to +)

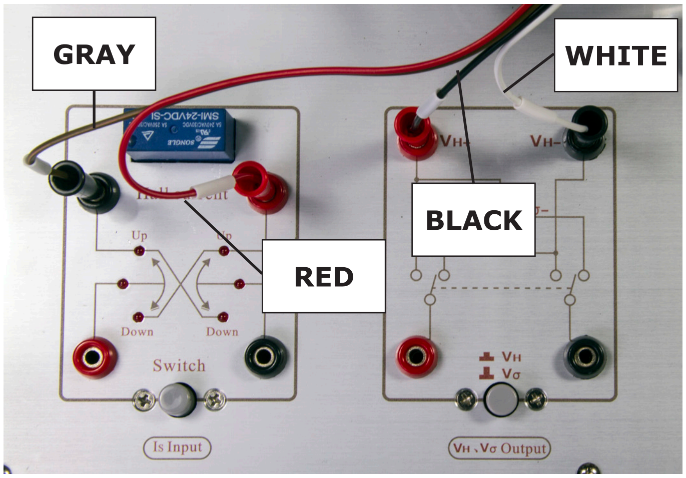
CONNECTIONS

NOTE: COMPLETE ALL CONNECTIONS BEFORE APPLYING POWER TO THE APPARATUS

- **THE HALL SENSOR LEADS**

Connect the four leads of the Hall sensor assembly to the “I_S Input” and “V_H, V_σ Output” switch panels on the Hall effect unit as indicated in the image below. [*red plug to red socket, black plug to black socket*] Pay close attention to the indicated wiring colors.

Figure 5



- **CONNECTING THE HALL EFFECT UNIT TO THE MEASUREMENT & CONTROL UNIT**

ALL CONNECTIONS IN THIS SECTION ARE MADE “RED-TO-RED, BLACK-TO-BLACK”

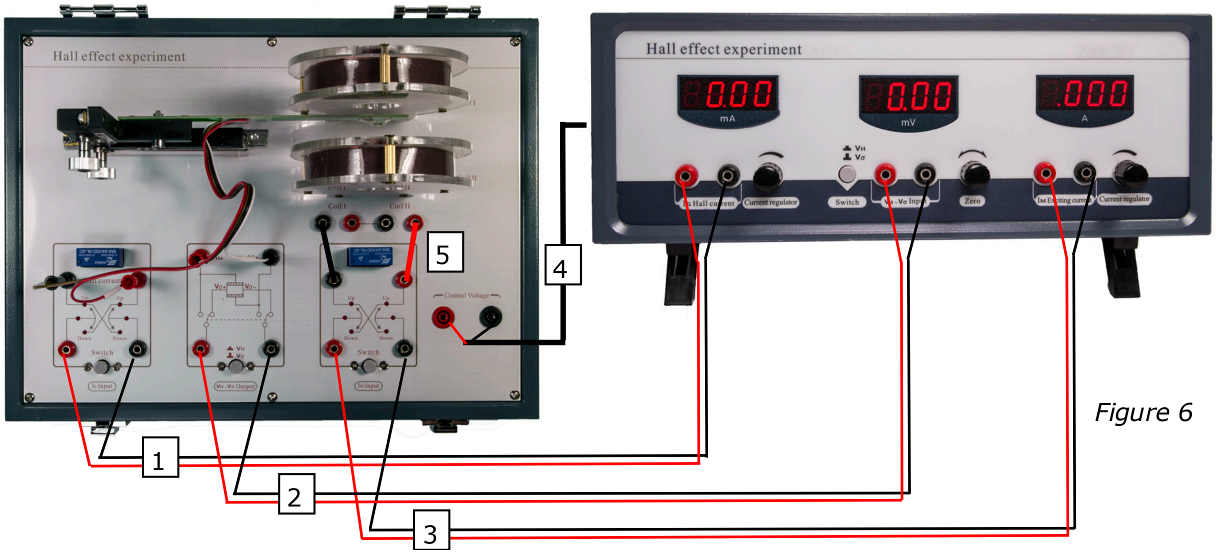


Figure 6

Refer to *Figure 6*:

- With the supplied red and black banana plug cords, connect:
  1. “I_S Hall Current” output sockets on the control unit to “I_S Input” sockets on the Hall unit;
  2. “V_H, V_σ Output” sockets on the Hall unit to “V_H, V_σ Input” sockets on the control unit;
  3. “I_M Exciting Current” output sockets on the control unit to “I_M Input” sockets on the Hall unit;

- With the supplied two-conductor cable with a microphone plug and two banana plugs, connect:

    4. The "Control Voltage" sockets on the Hall unit to the microphone socket on the rear panel of the control unit.

- With two short USER-SUPPLIED banana plug cords, connect:

    5. The Helmholtz coil connecting sockets on the Hall unit to the "I_M" reversing switch sockets.

- Connect the supplied power cord to the socket on the rear panel of the control unit, ensure that the power switch next to the power cord socket is in the "off" position ("O" symbol depressed), and connect the power cord plug to a 110VAC outlet.

OPERATING PRECAUTIONS

- Before turning the power to the apparatus on or off, make sure that the two current-regulating potentiometers (I_S and I_M) are turned to zero (fully counterclockwise) to avoid damage to the Hall sensor from impulse voltages.
- **Before applying power, double-check** to make sure that the output from the I_M sockets of the control unit have not been erroneously connected to the I_S inputs of the Hall unit, as this would destroy the Hall sensor on applying power.
- The Hall sensor is fragile, do not handle it.
- Do not force the two-axis traverse controls beyond the built-in stops.

EXPERIMENT TOPICS

1. The Hall Effect and Hall sensor characteristics:
    - Zero potential (inequipotential) and inequipotential resistance of the Hall element
    - Relationship between the Hall signal, the drive current and the magnetic field
    - Determination of the Hall sensitivity of the sensor
    - Measurement of the conductivity of the Hall sensor and estimation of the charge carrier mobility
2. Elimination of systematic errors in the Hall effect signal:
    - Inequipotential Effect
    - Ettingshausen Effect
    - Nernst Effect
    - Righi-Du Leke Effect
3. Using the Hall effect to plot the field profile of the Helmholtz coil pair

BACKGROUND—THE HALL EFFECT

The Hall Effect results from the motion of charged particles within a solid in a magnetic field. The particles experience a Lorentz force directed perpendicularly to both the direction of the particles' motion and the magnetic field.

Figure 7 illustrates this.

With the conventional current oriented along the positive x-axis and the magnetic field along the positive z-axis, the Lorentz force is oriented along the negative y-axis for negatively-charged particles (electrons in a metal or n-type semiconductor) and the positive y-axis for positively-charged particles (holes in a p-type semiconductor.)

The deflection of the particles' path through the solid leads to an accumulation of positive charge on the positive-y side of the solid and a corresponding accumulation of negative charge on the negative-y side. The electric field thus established is oriented along the negative y-axis, and opposes the Lorentz force for both polarities of charged particles. Charge accumulation increases until the force due to the electric field balances the Lorentz force. A voltage can now be observed across the y-direction of the solid sample.

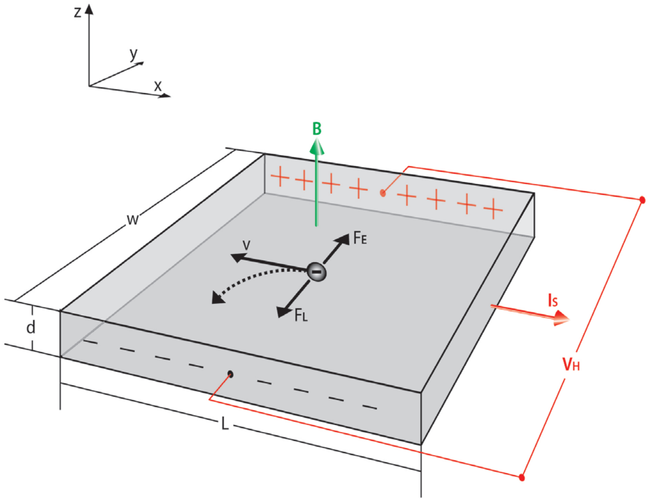


Figure 7

In the case of the n-type semiconductor used in this apparatus, the magnitude of the Lorentz force F_L experienced by the current-carrying electrons moving at an average velocity v in a magnetic field of induction B is:

$$F_L = -evB$$

where –e is the electronic charge.

The force F_E due to the electric field E_H is:

$$F_E = -eE_H = -V_H/w$$

where V_H is the observed voltage in the y-direction and w is the width of the sample.

When dynamic equilibrium is achieved,

$$F_L = -F_E \text{ , so } vB = V_H/w \qquad (1)$$

If the thickness of the sample is d and the concentration of charge carriers is n, the current through the sample (the working current) is:

$$I_S = nevwd \qquad (2)$$

Combining (1) and (2) yields:

$$V_H = vBw = I_SB/ned = (1/ne).(I_SB/d) = R_H.(I_SB/d) \qquad (3)$$

The quantity R_H = 1/ne is a characteristic of the material of the sample and is called the Hall coefficient.

More rigorous analysis for low intensity magnetic fields yields a modifying factor of $3\pi/8$:

$$R_H = 3\pi/8ne$$

The Hall coefficient is a measure of the strength of the Hall effect for a given material. Equation (3) indicates that the Hall voltage is proportional to the product of the working current and the magnetic induction, and inversely proportional to the thickness of the sample.

The conductivity σ of a conducting material is related to the mobility μ of the charge carriers by:

$$\sigma = ne\mu$$

μ represents the average velocity of the charge carriers in a unit electric field.

Using the simpler approximation for R_H, we can write:

$$R_H = \mu/\sigma \quad \text{or } \mu = \sigma R_H \qquad (4)$$

Since for a given current the mobility of the charge carriers in a semiconductor is much larger than in a metal, semiconductors are used for practical Hall effect sensors.

To take the thickness d of the sample into account, we define:

$$K_H = R_H/d = w/ned \qquad (5)$$

Combining (5) and (3):

$$V_H = K_H I_S B \qquad (6)$$

K_H is the sensitivity of the Hall sample used, the Hall voltage generated with unit current in a field of unit magnetic induction. The usual units are [mV/mA.T]

For an effective Hall sensor, K_H should be as large as possible. In metals, the electron concentration is very high, which for a given current results in a low mobility. This means that for metals R_H, and therefore K_H, is very small. This is why metals are unsuitable for constructing Hall sensors. K_H is also larger for thin sensors than for thick ones, but making the sensor extremely thin increases the input and output resistances of the sensor too much for practical purposes. The sensor dimensions in this apparatus are 1.5mm x 1.5 mm x 0.2mm thick.

Equation (6) is derived assuming that the orientation of the magnetic induction B is normal to the plane of the sample, and thus to the direction of the drive current I_S. If instead the direction of B makes an angle θ with the normal to the plane of the sample, then only that component of B which is parallel to the normal, Bcosθ, is effective in generating a Hall voltage, since charged particles moving parallel to the component of B in the plane of the sample experience a Lorentz force directed normal to the sample plane. Equation (6) becomes:

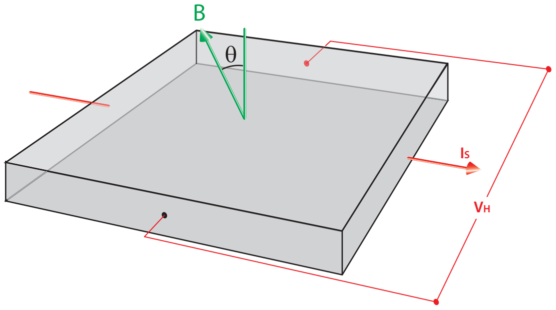


Figure 7

$$V_H = K_H I_S B\cos\theta \qquad (7)$$

In using a Hall effect probe to measure the strength of a magnetic field, it is therefore important to adjust the orientation of the probe so that the plane of the measuring chip is normal to the field to be measured.

Figure 8 shows the connection scheme for a commercial Hall element. The drive current I_S is applied through opposite edges of the rectangular chip and its magnitude is controlled by a constant current source. The Hall voltage V_H is measured across the other two edges of the chip.

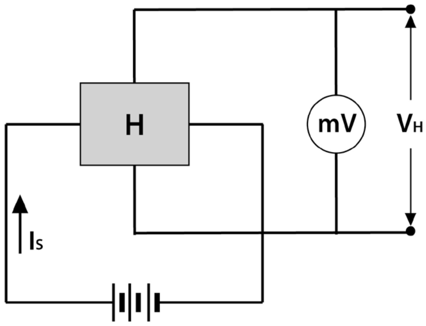


Figure 8

SYSTEMATIC ERRORS IN THE HALL SIGNAL

In order to use the Hall effect for practical measurements of magnetic field strengths, a number of factors that cause erroneous measurements of V_H must be taken into account. These include:

1. The Inequipotential Effect
2. The Ettingshausen Effect
3. The Nernst Effect
4. The Righi-Du Leke Effect

1. The Inequipotential Effect.

This is an effect that arises due to the mechanical limits on the precision of the manufacturing process.

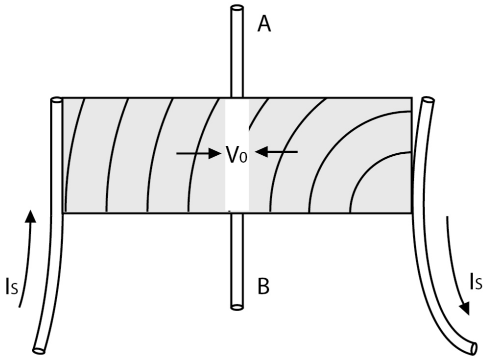


Figure 9a

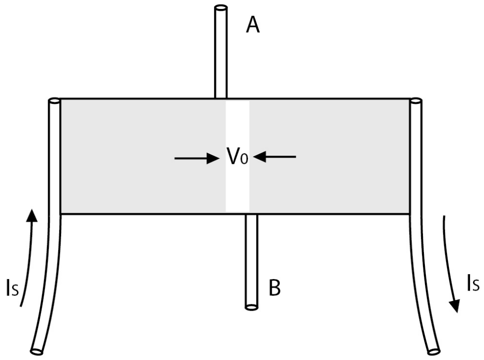


Figure 9b

Figure 9 illustrates schematically two manufacturing problems that arise in manufacturing a Hall effect chip. The drive current I_S is applied through two metallic leads attached to the sides of the semiconductor chip and the Hall voltage V_H is sampled by two wires, labeled A and B, attached at the centers of the other two chip sides. *Figure 9a* shows that imperfectly attached current leads result in equipotential lines that do not lie exactly parallel to the line of the Hall voltage wires so that the A and B wires lie on different equipotential lines. Figure 9b shows that due to manufacturing tolerance limits the A and B wires may not be connected exactly opposite one another, which also results in them lying on different equipotential lines, even if the current leads are perfectly connected.

These problems result in there being an *inequipotential voltage* V_0 between wires A and B when the drive current is applied, even in the absence of a prependicular magnetic field.

Since the magnitude of V_0 depends on the magnitude of I_S, the influence of the inequipotential effect for an individual chip sample is characterized by its *inequipotential resistance*, R_0:

$$R_0 = V_0/I_S \qquad (8)$$

The erroneous voltage V_0 for a given chip is therefore $R_0 I_S$.

2. The Ettingshausen Effect

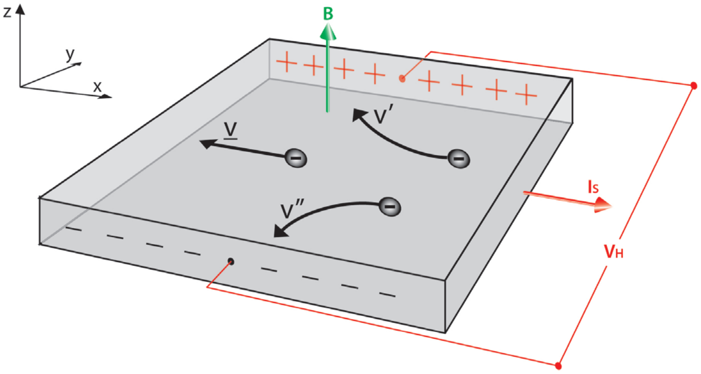


Figure 10

The population of current carriers in the Hall semiconductor chip is not uniform, but has a thermodynamic statistical distribution of drift speeds when the driving voltage is applied. If the mean drift velocity of the population is $\underline{v}$ then we can see from equation (1) that when the magnetic field B is applied, only those particles moving exactly at $\underline{v}$ are perfectly adjusted to continue on a straight path. Some particles will be either slower (v' in *Figure 10*) or faster (v" in *Figure 10*) than $\underline{v}$ and will be deflected from the straight path in opposite directions.

The electrical resistance of the semiconductor material converts some of the carriers' energy of motion into heat. More heat is generated from the fast carriers than from the slower ones, so one side of the chip becomes slightly warmer than the other.

Since the wires sampling V_H are metal and the chip is a semiconductor, the combination forms a thermocouple which has a temperature gradient across it, generating a thermoelectric voltage V_E that varies as $I_S B$. Since the magnitude and sign of the *Ettingshausen voltage* V_E vary with the magnitudes and signs of the drive current and the magnetic induction, as does the Hall voltage itself (see equation (6)), there is no available technique for separating two effects and eliminating V_E from the measurements.

3. The Nernst Effect

In general, the bonds betweeen the drive current leads and the semiconductor will have different contact resistances at each end, so the resistance heating (Joule heating) caused by the passage of the drive current will also be different at each end. This temperature difference will cause a thermoelectric current Q to flow between the ends, modifying the magnitude of the drive current. The charge carriers of this current component will also experience the Lorentz force and contribute a quantity V_N to the measured V_H. This is the Nernst Effect. But V_N is proportional to QB, and so is independent of the direction of the drive current, providing an opportunity for a correction to eliminate its influence.

4. The Righi-Du Leke Effect

The temperature gradient parallel to the drive current described for the Nernst Effect above also has a secondary influence. It causes the spread of carrier velocities described for the Ettingshausen Effect to change from one end of the chip to the other, modifying the magnitude of the Ettingshausen Effect by an amount V_R. However, unlike the Ettingshausen Effect, the direction of V_N is not related to I_S, only to Q and B, so the same possibility of correction exists as for the Nernst Effect.

CORRECTING FOR THE SYSTEMATIC ERRORS

Except for the Ettingshausen Effect, the systematic errors in the measurement of V_H described above can be corrected by combining a series of measurements where the directions of the drive current and the applied magnetic field are sequentially reversed, with measurements made at each reversal.
Taking "+" and "-" to refer to opposite directions of the variable quantities, I_M to refer to the magnet curent, and V_{AB} to refer to the measured voltage across the Hall chip, we have:

For $+I_S$ and $+I_M$: $V_{AB1} = +V_H + V_0 + V_E + V_N + V_R$
For $+I_S$ and $-I_M$: $V_{AB2} = -V_H + V_0 - V_E - V_N - V_R$
For $-I_S$ and $-I_M$: $V_{AB3} = +V_H - V_0 + V_E - V_N - V_R$
For $-I_S$ and $+I_M$: $V_{AB4} = -V_H - V_0 - V_E + V_N + V_R$

Combining the above four equations yields:

$$V_H + V_E = (V_{AB1} - V_{AB2} + V_{AB3} - V_{AB4})/4 \qquad (9)$$

For small values of I_S and I_M, $V_H \gg V_E$, so we can write:

$$V_H \approx V_H + V_E = (V_1 - V_2 + V_3 - V_4)/4 \qquad (10)$$

EXPERIMENTS

1. The Hall Effect and Hall sensor characteristics:

- Zero potential (inequipotential) and inequipotential resistance of the Hall element
- Relationship between the Hall signal, the drive current and the magnetic field
- Determination of the Hall sensitivity of the sensor
- Measurement of the conductivity of the Hall sensor and estimation of the charge carrier mobility

Zero potential (inequipotential) and inequipotential resistance of the Hall element

This measures the indicated Hall voltage at zero magnetic field, V_0, with non-zero drive currents, I_S. Because V_0 varies with I_S, it is useful to characterize the Hall chip being measured by its inequipotential resistance, $R_0 = V_H/I_S$. This value characterizes the manufacturing imperfections of the chip.

- Chack that the Hall effect unit and the control unit are correctly wired according to *Figures 5 and 6*.
- Set the drive current and magnet current potentiometers (4 and 9, *Figure 3*) to their minimum positions (fully counterclockwise), turn on the control unit power switch, and allow 10 minutes for the circuits to warm up and stabilize.

- Set the switches on the Hall effect unit and control unit to V_H (5, *Figure 2* & 8, *Figure 3*), short circuit the V_H input sockets on the control unit (7, *Figure 3*) and use the zero potentiometer (6, *Figure 3*) to bring the indicated Hall voltage to 0.00mV
- Remove the short circuit and set the drive current to 3.00mA (potentiometer 9, *Figure 3*)
- Record the indicated Hall voltage, V_{01}.
- Reverse the direction of the drive current with the switch on the Hall efect unit (6, *Figure 2*) and record the new value of the indicated Hall voltage, V_{02}.
- Calculate the inequipotential resistances:

$$R_{01} = |V_{01}|/I_S \qquad R_{02} = |V_{02}|/I_S$$

The two values should be closely similar. Take their average for use in future calculation.

Relationship between the Hall signal, the drive current and the magnetic field

Hall Signal - Drive Current Relationship

- Set up the apparatus as described above for the inequipotential measurement
- Use the adjustment knobs on the traversing mechanism (8, *Figure 2*) to precisely center the sensor chip between the magnet coils
- Adjust the reversing switches for the magnet and drive currents (4 and 6, *Figure 2*) to indicate the "UP" position. "+" will indicate the "UP" positions and "-" the "DOWN" positions of the reversing switches in the following (e.g. "$+I_S$", "$-I_M$")
- Set the magnet current I_M to 0.500A (potentiometer 4, *Figure 3*) and the drive current I_S to 0.5mA (potentiometer 9, *Figure 3*)
- Adjust the drive current I_S and the reversing switch positions to record the indicated values of V_H according to the following table:

I_S (mA)	**V_1 (mV)**	**V_2 (mV)**	**V_3 (mV)**	**V_4 (mV)**	**$V_H=(V_1-V_2+V_3-V_4)/4$ (mV)**
	$+I_S$ $+I_M$	**$+I_S$ $-I_M$**	**$-I_S$ $-I_M$**	**$-I_S$ $+I_M$**	
0.50					
1.00					
1.50					
2.00					
2.50					
3.00					

Hall Signal-Magnetic Field Relationship

- Return the reversing switches to the "UP" positions and reset the drive current and magnet currents to zero
- Set the drive current I_S to 3.00mV
- Adjust the magnet current I_M and the reversing switch positions to record the indicated values of V_H according to the following table

I_M (A)	**V_1 (mV)**	**V_2 (mV)**	**V_3 (mV)**	**V_4 (mV)**	**$V_H=(V_1-V_2+V_3-V_4)/4$ (mV)**
	$+I_S$ $+I_M$	**$+I_S$ $-I_M$**	**$-I_S$ $-I_M$**	**$-I_S$ $+I_M$**	
0.100					
0.150					
0.200					
0.250					
0.300					
0.350					
0.400					
0.450					
0.500					

- Plot the V_H-I_S and V_H-I_M curves to visualize the relationships.

Determination of the Hall sensitivity of the sensor

From equation (6) we have: $V_H = K_H I_S B$, so $K_H = V_H / I_S B$

Corresponding values of V_H and I_S are available from the above tables, and values of B at the center of the coils for various values of I_M are given in the specifications table on page 2.

I_M = 0.500A, B=11.25mT

I_S (mA)	**V_H (mV)**	**K_H ($VA^{-1}T^{-1}$)**
0.50		
1.00		
1.50		
2.00		
2.50		
3.00		

I_S = 3.00mA

I_M (A)	**B (mT)**	**V_H (mV)**	**K_H ($VA^{-1}T^{-1}$)**
0.100	2.25		
0.200	4.50		
0.300	6.75		
0.400	9.00		
0.500	11.25		

Measurement of the conductivity of the Hall sensor and estimation of the charge carrier mobility

The conductivity of the semiconductor material of the Hall effect chip is measured by measuring the voltage generated between the drive current connecting wires for various values of I_S.

The conductivity is expressed as reciprocal ohms (Siemens, S) per unit length, Sm^{-1}.

$$\sigma = I_S L/V_\sigma ld$$

Where L is the length of the chip, l is its width, and d its thickness. For this chip, L=l=1.5mm, d = 0.2mm

So $$\sigma = 5000 I_S/V_\sigma \ Sm^{-1}$$

- Reset the potentiometers for I_S and I_M until the corresponding displays read zero. Re-zero the displayed value of V_H with the zero potentiometer if necessary
- Select V_σ on the Hall effect unit and the control unit with the corresponding selection switches (5, *Figure 2* and 8, *Figure 3*) and set the direction of I_S so that the positive-positive and negative-negative poles are connected (switch in "Down" position)
- For the valuesof I_S in the table below, record V_σ and calculate σ.

I_S (mA)	V_σ (mV)	σ (Sm^{-1})
0.50		
1.00		
1.50		
2.00		
2.50		
3.00		

- From equation (4) we have the electron mobility $\mu = \sigma R_H$. We also have $R_H = K_H d$ from equation (5) and $K_H = V_H/I_S B$ from equation (6). Combining these three equations gives:

$$\mu = V_H d\sigma/I_S B \qquad (11)$$

- Use equation (11) with sets of corresponding measured values of V_H, I_S, and B, and the value of σ from the above table to calculate μ. The thickness d of the Hall chip is 0.2mm. Note that the units of σ above are Sm^{-1}, while mobilities are usually quoted in cm^2/Vs, so special attention must be paid to unit consistency ($1m^2/Vs = 10^4 \ cm^2/Vs$)

An approximation of the magnitude of the Nernst Effect and Righi-DuLeke Effects can be obtained from the previous measurements.

For the "$+I_S$ $+I_M$" values we have:

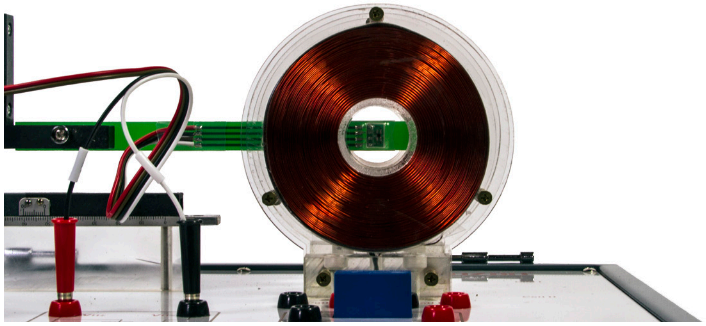
$$V_1 = V_H + V_0 + V_E + V_N + V_R$$

So $$V_N + V_R = V_1 - (V_H + V_E + V_0) = V_1 - (V_H + V_E + I_S R_0)$$

As explained above, the "V_H" measurements are really $V_H + V_E$ measurements, and since R_0 has been measured, $V_N + V_R$ can be estimated from values in the above tables. It will be found to be very small and can safely be ignored for routine measurements at low magnetic fields.

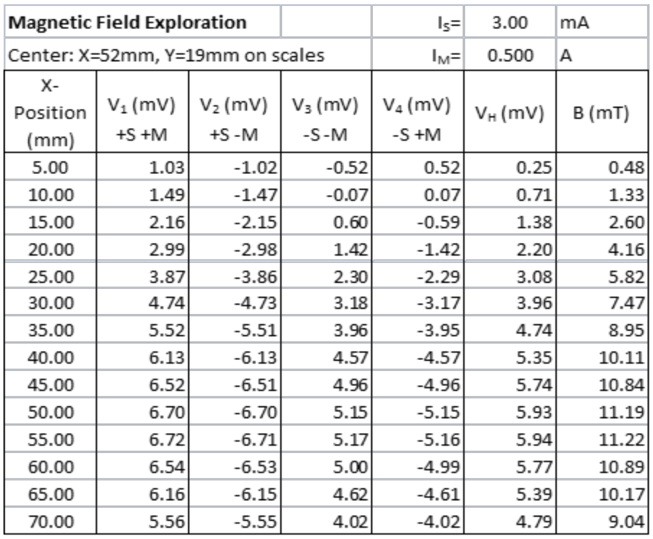
2. Using the Hall effect to plot the field profile of the Helmholtz coil pair

- The horizontal and vertical traverse mechanisms (8, *Figure 2*) can be used to allow the Hall sensor to sample the magnetic field at various points between the field coils.
  DO NOT FORCE THE MECHANISMS BEYOND THE STOPS AT THE LIMITS OF TRAVEL.
- Center the sensor visually between the coils by viewing horizontally through the holes in the coil bobbins

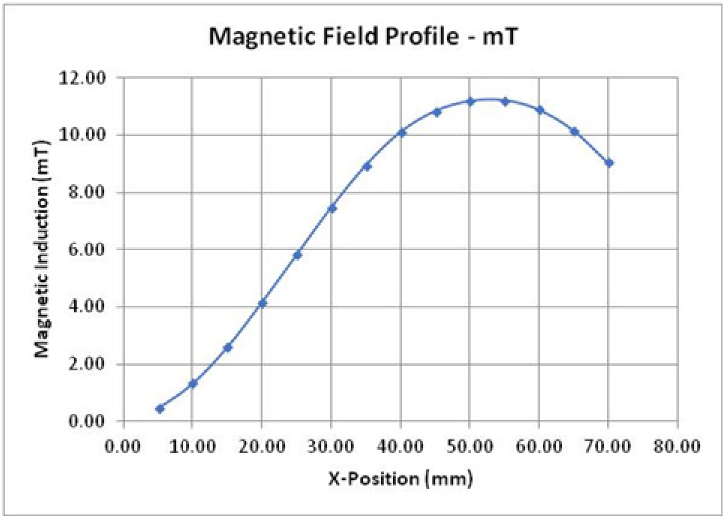


- The sensor may be tracked through 65 mm horizontally and 30 mm vertically.
  - for horizontal tracking start with the sensor centered vertically and at zero mm horizontally (fully right)
  - for vertical tracking,start with the sensor centered horizontally and at zero mm vertically (lowest)
- Set I_S and I_M to zero, short circuit the V_H inputs on the electronic control unit, and adjust the zero potentiometer to display zero mV. Remove the short circuit.
- Set I_S to 3.00 mA, then I_M to 0.500 A.
- Track in increments of 5.0 mm, measuring V_1 through V_4 for each increment and calculating V_H as before.
- Plot the V_H values against the sensor position for the horizontal and vertical tracks to reveal the magnetic field profile of the coil pair.

Sample Results



Magnetic Field Exploration				I_S=	3.00	mA
Center: X=52mm, Y=19mm on scales				I_M=	0.500	A
X-Position (mm)	V_1 (mV) +S +M	V_2 (mV) +S -M	V_3 (mV) -S -M	V_4 (mV) -S +M	V_H (mV)	B (mT)
5.00	1.03	-1.02	-0.52	0.52	0.25	0.48
10.00	1.49	-1.47	-0.07	0.07	0.71	1.33
15.00	2.16	-2.15	0.60	-0.59	1.38	2.60
20.00	2.99	-2.98	1.42	-1.42	2.20	4.16
25.00	3.87	-3.86	2.30	-2.29	3.08	5.82
30.00	4.74	-4.73	3.18	-3.17	3.96	7.47
35.00	5.52	-5.51	3.96	-3.95	4.74	8.95
40.00	6.13	-6.13	4.57	-4.57	5.35	10.11
45.00	6.52	-6.51	4.96	-4.96	5.74	10.84
50.00	6.70	-6.70	5.15	-5.15	5.93	11.19
55.00	6.72	-6.71	5.17	-5.16	5.94	11.22
60.00	6.54	-6.53	5.00	-4.99	5.77	10.89
65.00	6.16	-6.15	4.62	-4.61	5.39	10.17
70.00	5.56	-5.55	4.02	-4.02	4.79	9.04



MAINTENANCE AND STORAGE

The Hall Effect Apparatus needs no special maintenance.

Replace the fuse in the control unit only with the same type - 20mm miniature fuse, F1A/250V.

When storing the apparatus, ensure that the I_S and I_M potentiometers are turned to the minimum position (fully counterclockwise) and that all connecting cords are disconnected. Store the apparatus with the Hall effect unit protected by the supplied metal cover.

Store the apparatus in a dry location protected from bright sunlight and excessive temperatures.

To clean, wipe with a dry cloth. Do not use any solvents, as these could damage the finish.