Related topics

Semiconductor, band theory, forbidden zone, intrinsic conduction, extrinsic conduction, valency band, conduction band, Lorentz force, magneto resistance, Neyer-Neldel rule.

Principle and task

The resistance and Hall voltage are measured on a rectangular strip of germanium as a function of the temperature and of the magnetic field. From the results obtained the energy gap, specific conductivity, type of charge carrier and the carrier mobility are determined.

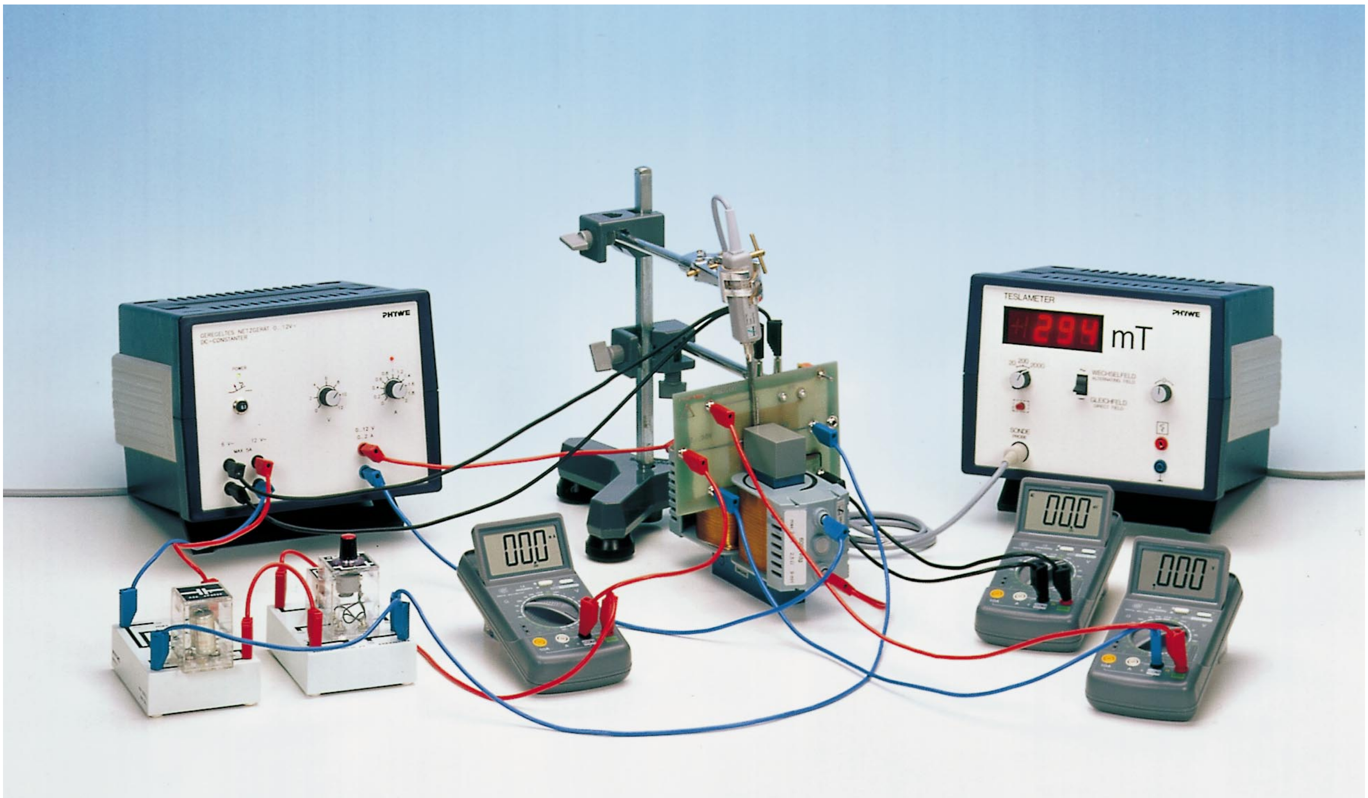
Equipment

Hall effect, n-Ge, carrier board	11802.00	1
Coil, 600 turns	06514.01	2
Iron core, U-shaped, laminated	06501.00	1
PEK carbon resistor 1 W 5 % 330 Ohm	39104.13	1
Pole pieces, plane, 30×30×48mm, 2	06489.00	1
Connection box	06030.23	1
Distributor	06024.00	1
Bridge rectifier 250 VAC/5 A	06031.11	1
PEK electro.capacitor 2000 mmF/25 V	39113.08	1
PEK potentiometer 560 Ohm lin 4 W	39103.18	1
Teslameter, digital	13610.93	1
Hall probe, tangent., prot. cap	13610.02	1
Power supply 0-12 V DC/6 V, 12 V AC	13505.93	1
Digital multimeter	07134.00	3
Tripod base -PASS-	02002.55	1
Support rod -PASS-, square, l 250 mm	02025.55	1
Right angle clamp -PASS-	02040.55	2
Universal clamp	37715.00	1
Connecting cord, 100 mm, red	07359.01	1
Connecting cord, 100 mm, blue	07359.04	1
Connecting cord, 500 mm, red	07361.01	6
Connecting cord, 500 mm, blue	07361.04	4
Connecting cord, 750 mm, black	07362.05	4

Problems

1. At constant room temperature and with a uniform magnetic field measure the Hall voltage as a function of the control current and plot the values on a graph (measurement without compensation for error voltage).
2. At room temperature and with a constant control current, measure the voltage across the specimen as a function of the magnetic flux density *B*.
3. Keeping the control current constant measure the voltage across the specimen as a function of temperature. From the readings taken, calculate the energy gap of germanium.
4. At room temperature measure the Hall voltage U_H as a function of the magnetic flux density *B*. From the readings taken, determine the Hall coefficient R_H and the sign of the charge carriers. Also calculate the Hall mobility μ_H and the carrier density *n*.
5. Measure the Hall voltage U_H as a function of temperature at uniform magnetic flux density *B*, and plot the readings on a graph.

Fig.1: Experiment set-up for Hall Effect Measurements.



Set-up and Procedure

Set up the apparatus as shown in Fig. 1.

Insert the semiconductor wafer into the magnet very carefully in order to avoid damaging the crystal. In particular, avoid bending the wafer.

1. The control current is generated from the a. c. voltage output of the power supply with the aid of a bridge rectifier. To do this, connect the rectifier to the lower socket of the power supply unit and to the socket marked "12 V" (cf. Fig. 2).

   Connect the electrolytic smoothing capacitor to the output of the rectiffier (observe polarity!). Set the control current with the aid of a potentiometer. To avoid exceeding the maximum permissible current (50 mA) in advertently, connect a resistance (330 Ω) in series to limit the current.

   The crystal is connected directly for this experiment (sockets A and B, cf. Fig. 2); consequently, the constant-current source contained on the wafer and the error voltage compensation are not operative.

   The magnetic field is generated by the two series-connected coils which are supplied from the d.c. voltage output of the power supply unit. It is expedient to set the voltage to the maximum value and to set the desired magnetic field with the current adjustment knob. The power supply unit then functions as a constant-current source and hence the field strenght is not affected by changes of resistance caused by thermal effects. Measure the magnetic flux density with the Teslameter by positioning its Hall probe in the centre of the field (after balancing the instrument) Measure the Hall voltage with the high-impedance multimeter.

2. Now connect the control current supply to the outer contacts A and C (cf. Fig. 2) so that the built-in constant-current source is operative. Set the 560 Ω potentiometer to maximum voltage. The control current should now be approximately 30 mA. (If this is not the case, the value can be adjusted with the aid of the small trimmer on the supplementary wafer). Measure the voltage on the specimen across the terminals A and B (cf. Fig. 2) with the multimeter. Calculate the resistance of the specimen R_0 in the absence of a magnetic field, and

   and record the change of resistance

   $$\frac{R_B - R_0}{R_0}$$

   as a function of the magnetic flux density B. (R_B = resistance of the specimen in the presence of a magnetic field).

3. Heat the specimen to temperatures up to 175°C with the aid of the fitted heater coil. The necessary heating current is taken from the a. c. voltage output of the power supply unit. The temperature of the specimen can be determined by way of the fitted Cu/CuNi thermocouple using the mV meter 07019.00:

   $$T = \frac{U_T}{\alpha} + T_0$$

   (U_T = voltage across the thermocouple; α = 40 µV/K; T_0 = room temperature).

Important On no account allow the temperature of the specimen to exceed 190°C.

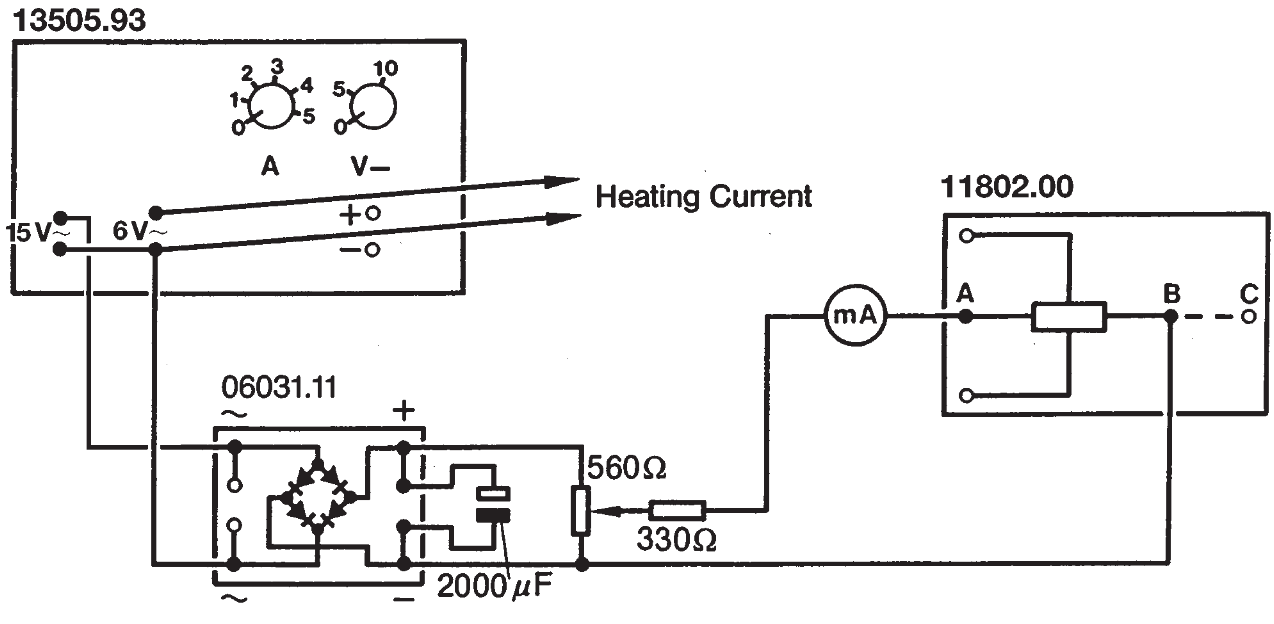
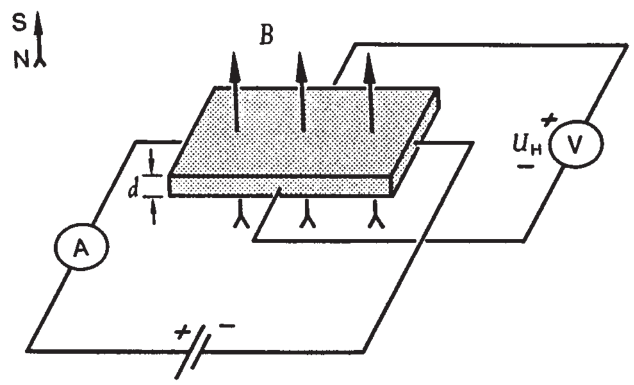


Fig. 2: Wiring Sketch for Producing the Control Current.

Fig. 3: Hall effect on a rectangular specimen. The polarity of the Hall voltage indicated is for negative charge carriers.



4. With the magnetic field switched off and the pole shoes detached (residual magnetism!), switch on the control current (terminals A and C, cf. Fig.2) and set the Hall voltage to zero using the compensating potentiometer. Refit the pole shoes and measure the Hall voltage as a function of the magnetic flux density for both field directions.

5. Keeping the magnetic field constant, gradually increase the temperature of the specimen to the maximum value and measure the Hall voltage. During the heating-up period, remove the Hall probe of the Teslameter from the heating zone.

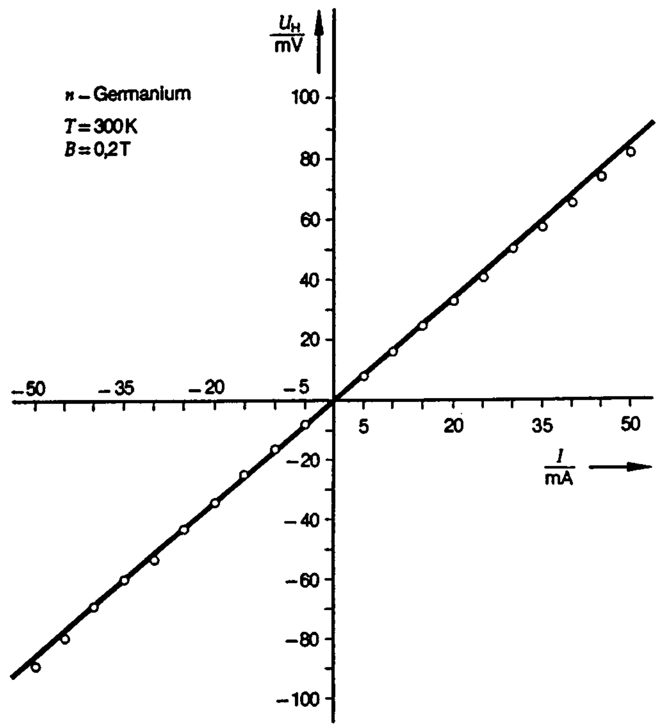


Fig. 4: Hall voltage as a function of current (T = 300 K, B = 0.2 T).

Theory and evaluation

When a current-carrying conductor in the form of a rectangular strip is placed in a magnetic field with the lines of force at right angles to the current, a transverse e. m. f. – the so called Hall voltage – is set up across the strip.

This phenomenon is due to the Lorentz force: the charge carriers which give rise to the current flow through the specimen are deflected in the magnetic field B as a function of their sign and of their velocity v:

$$\vec{F} = e\,(\vec{v} \times \vec{B})$$

(F = force acting on carrier, e = elementary charge).

Since negative and positive charge carriers have opposite directions of motion in the semiconductor, both are deflected in the same direction.

If the directions of the current and magnetic field are known, the polarity of the Hall voltage tells us whether the current is predominantly due to the drift of negative charges or to the drift of positive charges.

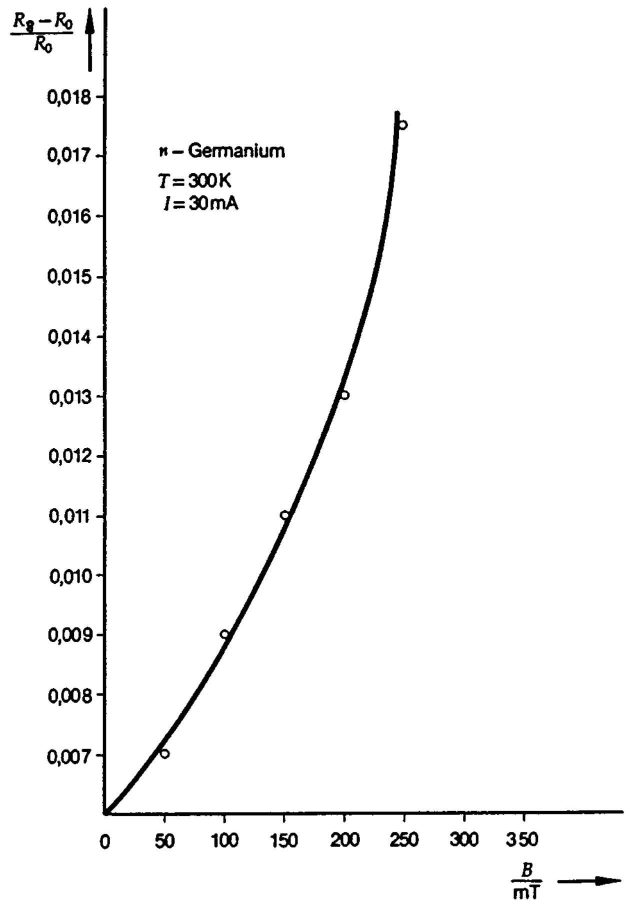


Fig. 5: Change of resistance as a function of the magnetic flux density.

1. Fig. 4 shows that a linear relation exists between the current land the Hall voltage U_H:

   $$U_H = \alpha \cdot I$$

   (α = proportionality factor)

2. The change of resistance of the specimen in a magnetic field is connected with a decrease of the mean free path of the charge carriers. Fig. 5 shows a non-linear, obviously quadratic change of resistance with increasing field strength.

3. For intrinsic conduction, the relationship between the conductivity σ and the absolute temperature T is:

   $$\sigma = \sigma_o \cdot \exp\left(-\frac{E_g}{2kT}\right)$$

   where E_g is the energy gap between the valency and conduction bands, and k is Botzmann's constant.

   A graph of $\log_e$ a against $1/T$ will be linear with a slope of

   $$b = -\frac{E_g}{2k}.$$

   Hence E_g is obtained.

   With the measured values in Fig. 6, the regression formulation

   $$\log_e \sigma = \log_e \sigma_0 + \frac{E_g}{2kT}$$

   gives slope

   $$b = -\frac{E_g}{2k} = -3.2 \cdot 10^3 \text{ K}$$

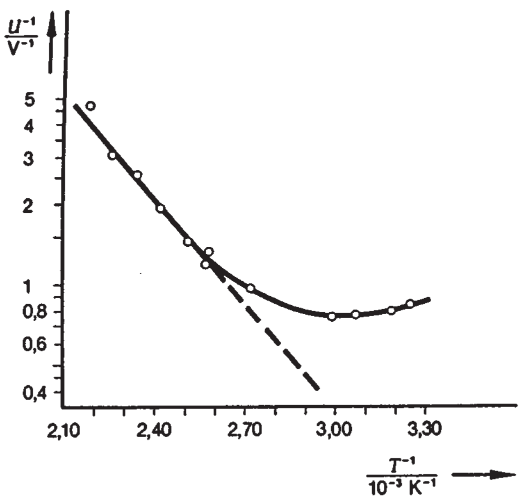
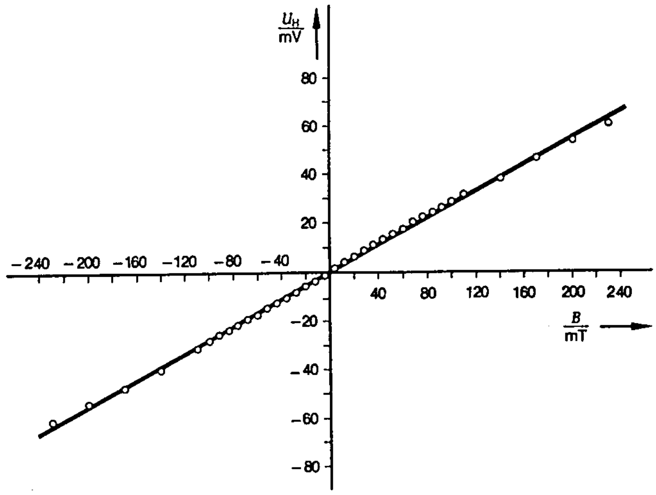


Fig. 6: The reciprocal specimen voltage as a function of the reciprocal absolute temperature (Since I was constant during the experiment, U^{-1} is approximately equal to σ; the graph is therefore the same as a plot of the conductivity against the reciprocal temperature.)

Fig. 7: Hall voltage as a function of the magnetic flux density.



with the standard deviation

$$s_b = \pm 0.2 \cdot 10^3 \text{ K}.$$

(Since the experiment was performed with a constant current, σ can be replaced by U^{-1} [U = voltage across the specimen]).

Taking $k = 8.625 \cdot 10^{-5} \frac{\text{eV}}{\text{K}}$ we obtain

$$E_g = b \cdot 2k = (0.55 \pm 0.03) \text{ eV}.$$

4. With the directions of control current und magnetic field illustrated in Fig. 3, the charge carriers which produce the current are deflected to the front edge of the specimen. If, therefore, the current is due mainly to electrons (as in the case of an n-doped specimen), the front edge becomes negatively charged. In the case of hole conduction (p-doped specimen) it becomes positively charged.

   The conductivity σ_0, carrier mobility μ_H, and the carrier density n are all connected by the Hall coefficient R_H:

   $$R_H = \frac{U_H}{B} \cdot \frac{d}{I}$$

   $$\mu_H = R_H \cdot \sigma_0$$

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

   Fig. 7 shows alinearrelationbetween the Hall voltage and the magnetic flux density B. Using the values from Fig. 7, regression with the formulation

   $$U_H = U_0 + bB$$

   gives the slope $b = 0.268 \text{ VT}^{-1}$, with the standard deviation s_b + 0.003 VT^{-1}.

The Hall coefficient R_H is then given by

$$R_H = \frac{U_H}{B} \cdot \frac{d}{I} = b \cdot \frac{d}{I}.$$

Thus, if the thickness of specimen $d = 1 \cdot 10^{-3}$m and $I = 0.030$ A, then

$$R_H = 8.9 \cdot 10^{-3} \frac{\text{m}^3}{\text{As}}.$$

with the standard deviation

$$s_{RH} = \pm 0.1 \cdot 10^3 \frac{\text{m}^3}{\text{As}}.$$

The conductivity at room temperature is calculated from the length l of the specimen, its cross-sectional area A and its resistance R_0 (cf. Experiment 2):

$$\sigma_o = \frac{l}{R \cdot A}.$$

Thus, if $l = 0.02$ m, $R_0 = 45.7\ \Omega$, $A = 1.10^{-5}$m, then

$$\sigma_o = 43.8\ \Omega^{-1}\ \text{m}^{-1}.$$

The Hall mobility μ_H of the charge carriers can now be determined from the expression

$$\mu_H = R_H \cdot \sigma_o.$$

Using the same values above, this gives

$$\mu_H = (0.389 \pm 0.004) \frac{\text{m}^2}{\text{Vs}}.$$

The electron concentration n of the n-doped specimen is given by

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

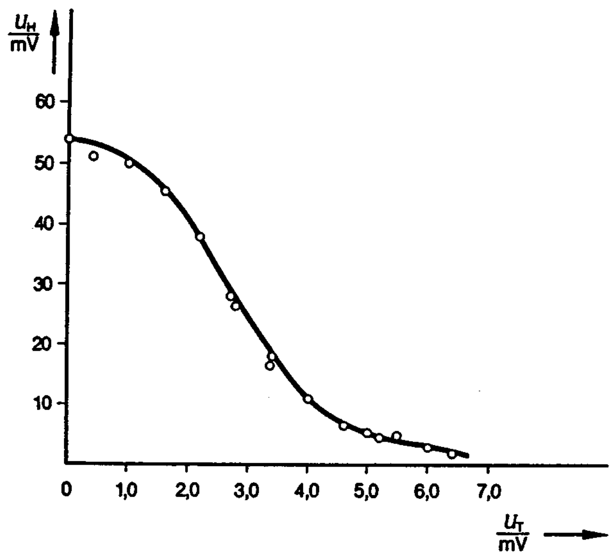
Taking e = elementary charge = 1 .602 · 10^{-19} As, we obtain

$$n = 7.0 \cdot 10^{20}\ \text{m}^{-3}.$$

5. Fig. 8 shows that the Hall voltage decreases with increasing temperature. Since the experiment was performed with a constant current, it can be assumed that the increase of charge carriers (transition from extrinsic to intrinsic conduction) with the associated reduction of the drift velocity v is responsible for this.

   (The same current for a higher number of charge carriers means a lower drift velocity). The drift velocity is in turn related to the Hall voltage by the Lorentz force.

Fig. 8: Hall voltage as a function of temperature.



Note

For the sake of simplicity, only the magnitude of the Hall voltage and Hall coefficient has been used here. These values are usually given a negative sign in the case of electron conduction.