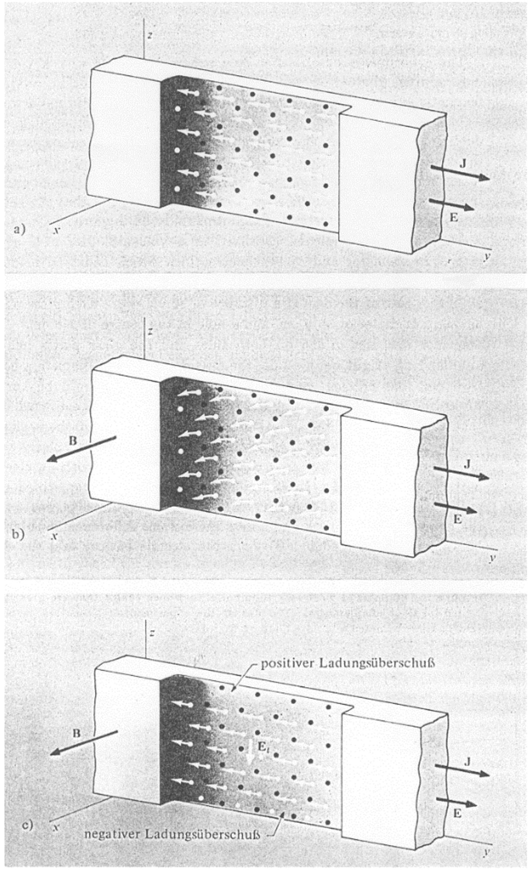

Subjects and Terminology

Electric field; *Coulomb force*. Magnetic field; *Lorentz force*.

Band theory; Semiconductors, Valence band, Conduction band, Band gap; Self conduction.

Doping; negative and positive charge carriers (electrons and holes); Impurity conduction.

HALL EFFECT	GP II

Normal and anomalous *Hall Effect*.

Special Aims of the Experiment

Observing the *Hall Effect* as the common action of electric- and magnetic fields on moving charge carriers in solids.

Investigation of the conduction mechanism and determination of the type and concentration of the charge carriers in metals and semiconductors.

Literature

The physical principles of the *Hall effect* und of the electrical properties of semiconductors are presented in basic physics text books. In particular, the following are recommended:

Skript *HALBLEITER* im allgemeinen Teil dieser Praktikumsanleitung.

/1/ E.M. Purcell; Berkeley Physik Kurs Band 2, Elektrizität und Magnetismus; Stichwort Hall-Effekt (gute Einführung).

/2/ Gerthsen·Kneser·Vogel, Physik; Springer-Verlag; Stichwort Halbleiter (gute Behandlung der Eigenschaften von Halbleitern, der Bandlücke und der Effekte von Störstellen).

/3/ R.W. Pohl; Einführung in die Physik, Zweiter Band, Elektrizitätslehre, 21. Auflage; Springer-Verlag; Literaturwerte der *Hall-Konstanten*.

Exercises

1. Observing the *Hall Effect* on germanium (n- or p-Ge) as a function of control current and magnetic field. Calculation of the *Hall constant* of germanium. Determining the type and concentration of the charge carriers.
2. Investigation of the temperature dependence of the *Hall voltage* in germanium and calculation of the band gap.
3. Common exercise for all students in a group: Observation of the *Hall Effect* in Cu and Zn. Estimating the *Hall constants* as well as the type and concentration of the charge carriers.

Physical Principles

In addition to the fundamentals found in the literature, two aspects should be pointed out, which are often neglected or not presented:

- The charge carriers contributing to the *Hall Effect* can be negative (electrons) or also positive (holes), depending on the material. This leads to different signs for the *Hall voltage* and the *Hall constant R* :
- In doped semiconductors at low temperatures, the charge carriers of the impurities are responsible for conduction (impurity conduction). In addition, electrons from the host semiconductor (host lattice) are lifted from the valence band into the conduction band through thermal excitation.
  At sufficiently high temperatures this intrinsic conduction dominates over the impurity conduction. In the region of intrinsic conductivity, however, practically only electrons contribute to the *Hall Effect* due to the different mobility's of the electrons and holes.

Presentation of the Physical Principles

(as preparation for part of the report): Presentation of the *Hall Effect* and derivation of the *Hall voltage*. Short statement and discussion of the temperature dependence of the *Hall voltage*.

Apparatus and Equipment

Printed circuit (pc) board with metal probes (n-Ge, p-Ge, Cu and Zn) to determine the *Hall Effect* and various additional components for the experimental investigation.

Electromagnet formed by two coils and a U-shaped iron core with pole shoes. Various power supply units. Digital multimeter and a microvolt meter for the measurement of currents and voltages.

Experiment and Evaluation

<u>Please handle the pc board with care</u>. Ge crystals are brittle and sensitive to breakage and a fracture of the crystal by bending makes the pc board unusable (cost of a pc board ≈ 1000 €). Proceed carefully when placing the pc board in the magnet and connecting the cables. Compensate the pressure used to plug in and pull out the banana plugs by firmly holding the pc board in the area of the sockets.

<u>Circuitry</u>

The required connections are inscribed on the pc board.

<u>Control Current</u>

The current through the probe is called the *control current*. In semiconductors it is important to hold the control current constant during the experiment since the resistance is strongly dependent on the temperature.

For this purpose, the pc board incorporates a constant current source which delivers a constant current of about 30 mA independent of the external voltage (12 to 30 V). The constant current device is connected through outer socket of both (-) sockets for the control current. The constant current device is used to measure the *Hall voltage* as a function of the magnetic field sine it allows alignment of the resistance-voltage drop (see section on *Hall Voltage* below).

The constant current device cannot be used to measure the *Hall voltage* as a function of the control current (inner of both (-) sockets for the control current) and the power supply unit for the control current (*Voltcraft*) must be used as the constant current device (voltage limiter to maximum and the current adjusted with the current limiter). Proceed with care so that the maximum value of 50 mA for the control current is not exceeded (use the power supply unit with 200 mA limiting current).

With the metal probes, the control current is directly connected with a maximum current of 20 A.

<u>*Hall Voltage*</u>

The *Hall voltage* is tapped transverse to the probe dimension. Since both taps for the *Hall voltage* cannot lie directly opposite each other due to manufacturing constraints, a resistance voltage drop appears in addition to the *Hall voltage*. To compensate for this the voltage on one side is tapped slightly "above" and "below" the opposite point and aligned with the aid of a potentiometer. This zero-point correction of the *Hall voltage* is made in each case without applying the magnetic field.

This circuit is only effective in semiconductor probes when the constant current device (see above) is used. When the control current is directly connected to measure the *Hall voltage* as a function of the control current, the zero-point must be determined and the measured values accordingly computed.

<u>Heater and Thermocouple</u>

The probe (pc board) is equipped with a heater and thermocouple to investigate the temperature dependence of the *Hall voltage*.

<u>Magnet</u>

When connecting the magnet, pay attention to the correct series connection of the coils. A power supply unit (*Voltcraft* 0...30 V, 2 A) delivers the current for the magnet.

The lab bench script contains a calibration curve for the magnetic field in the center of the pole shoes as a function of magnetic current; the magnetic current must not <u>exceed 2 A</u>.

<u>Attention</u>: To check the polarity of *Hall voltage* with respect to the sign of the charge carriers one must very <u>carefully</u> take into account and document the orientation of all experimental quantities (magnetic field from the sense of the windings of the coil and the direction of the magnetic current, direction of the control current or polarity of the connection of the control current source, polarity of the *Hall voltage* or polarity of the connection of the voltage measuring instrument). A sketch of the experimental set-up is essential to clearly show the orientations and connections of the measuring instruments! When recording the values of the *Hall voltage* the sign must always be given!

To Exercise 1:

A second *Voltcraft* power supply unit ("200-mA" unit) is used as the control current source.

To investigate the *Hall voltage* as a function of the magnetic field one uses the constant current source on the pc board (outer (-) sockets) and the potentiometer (rotating pin) to align the resistance-voltage drop.

For the measurement as a function of the control current, the inner "direct" sockets must be connected; see the general information concerning the *Hall voltage* above.

- The control current must not exceed 50 mA.

The alignment potentiometer for the resistance-voltage drop is inhibited when the constant current source is not connected, and to correct the voltage values, the voltage drop for each control current value must be measured with the magnetic field switched off (switch off the magnetic current power supply at the mains switch) and the measured value computed with the correction.

The control current and the *Hall voltage* are measured with two digital multimeters.

To Exercise 2:

In addition to the circuitry for exercise 1, the heating current source and a further multimeter is connected to measure the thermo-voltage and the *Hall voltage* as a function of temperature.

The heater is operated with 6 V ac and the heating current is then about 5 A. The temperature coefficient of the thermocouple is 40 μV/K (temperature difference to room temperature).

- The temperature of the pc board must not exceed 150 °C corresponding to 5 mV thermo-voltage!

The heater (step transformer) should be used intermittently (momentary switch-on with pauses) so that the rate of heating is not too fast in order to ensure safe control and reliable recordings of the measured values.

The thermo-voltage can (still) be measured with the digital multimeters. The measuring accuracy is clearly limited by the low resolution (0.1 mV corresponding to 2.5 K) but may be considered as sufficient within the scope of the other measurement conditions (e.g., temperature gradients) and the aims of the experiment.

With a suitable logarithmic plot (see equation 1 in annex V „*HALBLEITER*“ in the lab script) the *Hall voltage* shows, in the high temperature range (intrinsic conduction), the expected linear progression from which one can determine the band gap ΔE .

To Exercise 3

A 10 A power supply unit is available to measure the *Hall Effect* on metal probes (copper and zinc) which require high control currents. The *Hall voltage,* however, remains comparatively small and must be measured with a sensitive microvolt meter (*KNICK*) or for comparison purposes with the digital multimeter (HP 3457A).

The measurements on the metal probes have only qualitative character with respect to the sign because of experimental difficulties (foils with large tolerances as thin probes; however, very small values for the *Hall voltage*). Since only one power supply unit for the high currents and one microvolt meter are available, the measurements shall be made as a common exercise for the whole group but reported and evaluated for each pair of students working together.