cenco

OPERATING INSTRUCTIONS

Hall Effect in Germanium - Complete Set

Catalog No. 32020

Hall Effect in Germanium - Basic Set

Catalog No. 32030

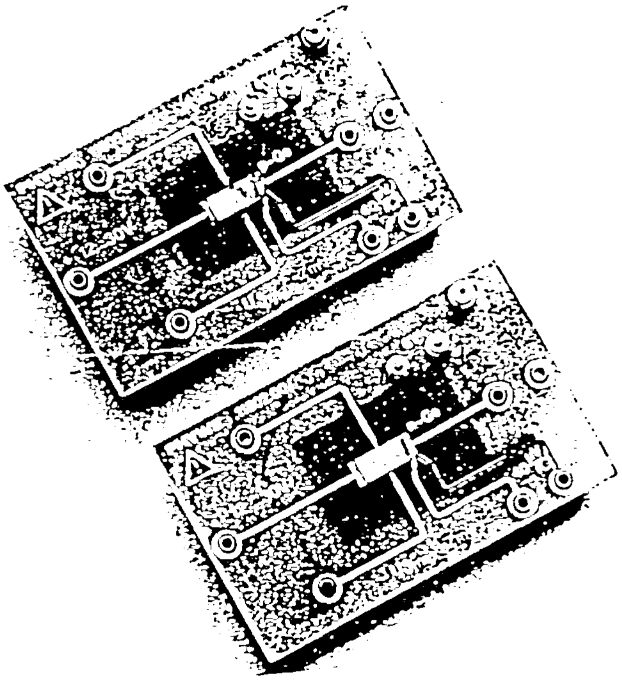

Fig. 1

P-Germanium Carrier Board
N-Germanium Carrier Board

Central Scientific Company

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OPERATING INSTRUCTIONS

Hall Effect in Germanium - Complete Set

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1. Purpose: The temperature dependence of the electrical conductivity and the Hall Effect in n-type or p-type semiconductors can be demonstrated with the included supporting plates or carrier boards that contain specimens of n-germanium and p-germanium (Fig. 1). The sign of the charge carriers responsible for the conduction process can also be determined from the polarity of the Hall voltage.

In particular, you will be able to demonstrate the two different conduction mechanisms in doped semiconductors, namely extrinsic and intrinsic conduction. For this purpose, the type of doping is so chosen that extrinsic conduction predominates over a certain temperature range above room temperature. Over this range, the resistivity increases with rising temperature, as it does in a metal. At higher temperatures, intrinsic conduction due to thermally produced electrons and holes predominates, being marked by a rapid fall in resistivity with rising temperature.

You'll also be able to show that the Hall voltage is substantially independent of temperature over the range where extrinsic or defect conduction predominates, whereas over the range of intrinsic conduction the Hall voltage rapidly falls as the temperature rises. Both types of conduction take place at a constant control current.

The resistance and Hall voltage is also measured at room temperature and a constant control current as a function of magnetic flux density. From these results one can determine the energy gap, the specific conductivity, the type of charge carrier, and the mobility of the charge carriers.

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2. Description:

2.1 . Functional and Control Units -- The 32030 Hall Effect in Germanium Basic Set comprises the following equipment items:

p-germanium carrier board

n-germanium carrier board

Multisocket distributor

Connection box

250VAC/5A bridge rectifier

2nF electrolytic capacitor

330 Ω carbon resistor

560Ω potentiometer

The 32020 Hall Effect in Germanium Complete Set comprises the following equipment items:

p-Germanium carrier board

n-Germanium carrier board

Multisocket distributor

Connection box

250VAC/5A bridge rectifier

2nF electrolytic capacitor

PEK carbon resistor, 1W, 330Ω 5%

Coil, 300 turns (2 included)

Pole pieces, plane, 30 x 30 x 48 mm, pair

Iron core, U-shaped, laminated

PEK potentiometer 560Ω, 4W

Universal power supply

The two carrier boards, or supporting plates, are identical except for different doping of the germanium crystals. They have the following functional and control units (see Fig. 2):

The semiconductor crystal *1* is an n- or a p-doped germanium crystal with dimensions 20 x 10 x 1mm.

A DC voltage of 12 to 30 volts is applied to the crystal via sockets *2.1* and *2.3*. The socket *2.1* marked "+" is connected directly to the crystal, while in the case of socket *2.3* a current stabilizer (on an extra plate at the back) is interposed. The current stabilizer keeps the control current constant (at about 30mA) in spite of the dependence of the crystal resistance on temperature.

The voltage drop across the crystal can be measured between sockets *2.1* and *2.2*, in order, for example, to determine the crystal's resistance.

The two sockets *3* are used to take off the hall voltage U_H.

Interfering voltages superimposed on the Hall voltage (voltage drops between Hall voltage terminals on the crystal due to the control current and thermoelectric voltages) can be compensated by use of adjusting knob *5*.

The two plugs *4* on the back of the plate give mechanical support to its supporting plate, for example the plate of the multisocket distributor, and carry the heating current. The heating time is limited -- see the Operation section.

Note: The copper-constantan thermocouple *6* generates a thermoelectric voltage of approximately 40µV/°K which can be taken from the two sockets *7*.

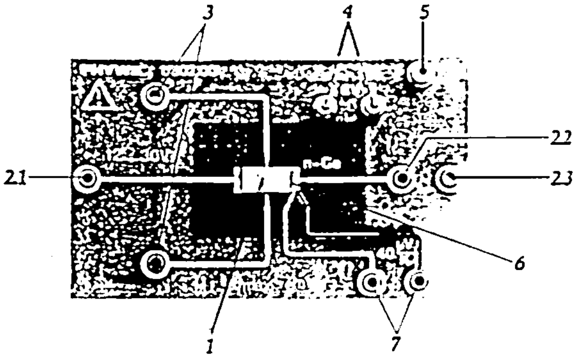


Fig. 2
Carrier Board Components

> Note: Since germanium crystals are fragile, it is advisable to use the original packing when storing the supporting plate.

Specifications:

Crystal dimensions	20 x 10 x 1 mm
Crystal material	germanium, doped
Crystal resistivity	approx. 3 Ω/cm
Maximum permissible steady current through crystal	50 mA
Operating voltage to produce control current	12 to 30 VDC
Constant current from stabilizer	approx. 30 mA
Maximum temperature	175°C
Thermocouple	Cu-CuNi
Thermoelectric voltage coefficient	approx. 40 µV/°K
Heating current	6 VDC or AC/5 A

2.2 Compensation of Interfering Voltages -- In the Hall Effect, a voltage due to Lorentz forces is produced in a conductor traversing a magnetic field; the direction of this voltage is at right angles to the control current I and to the direction of the magnetic field. The Hall voltage U_H is tapped off at the side edges of the conductor. If the two tappings are even only slightly displaced from one another in the direction of the control current, the control current produces a drop in voltage along this tolerance range, even in the absence of a magnetic field. This displacement cannot be entirely avoided during the manufacturing process, so a slight interfering voltage is produced.

The interfering voltage is compensated by a balancing potentiometer connected as in Fig. 3. The present apparatus is fitted with such a potentiometer, with which all interfering voltages can be electrically compensated (by adjusting knob 5).

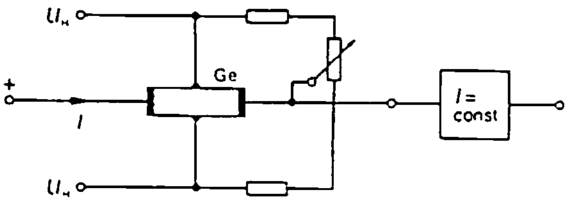


Fig. 3
Potentiometer Connection

3. Setup:

Caution! Germanium crystals are very brittle and consequently fragile. To prevent any bending of the supporting plate during assembly, use the following methods:

To affix the plate to the multisocket distributor push the two plugs *4* into the distributor sockets by pressing on the front of the plate between the nuts securing these plugs.

To remove the plate, press the back of the plate near these plugs with two fingers and pull the plate away from the distributor.

Press your hand against the back of the plate to support the individual sockets when you are wiring them.

3.1 General design and method of use --

The supporting plate is supported between the pole pieces of an electromagnet so that the magnetic field passes through the germanium.

A direct voltage between 12 and 30 V is applied with the correct sign to sockets *2.1* and *2.3* (current level approx. 30 mA). Thanks to the built-in current stabilizer, current limiting resistors are unnecessary.

Note: The value of the control current delivered from the current stabilizer is adjusted to approximately 30mA at our place of manufacture. If the measured value ever departs substantially from this value, it is possible that the trimming potentiometer on the small extra plate accessible from the side has been moved. In this case, the desired current level can be easily set with a suitable screwdriver.

To measure the Hall voltage, a sensitive voltmeter (such as our 31884 Digital Multimeter), capable of measuring up to at least 100 mV in 1 mV steps, is connected across sockets *3*.

Before the Hall voltage can be measured, the Hall voltage terminals must first be compensated. To do this, switch on the control current between sockets *2.1* and *2.3*, but do not turn on the magnetic field. If the voltmeter connected across the Hall voltage terminals *3* shows a deflection, compensate for it by turning the adjusting knob *5* (if necessary, with the aid of a suitable screwdriver). When proper compensation has been applied, there shouldn't be any voltage across sockets *3* when there is no magnetic field.

Now switch on the magnetic field. To produce a Hall voltage of 50 mV, a magnetic field of some 300 mT is required.

Apply a heating voltage of 6 V (current 5 A) to the plugs *4* on the rear to heat the crystal. The temperature is measured by means of a built-in thermocouple. Connect a sensitive voltmeter with a range multiplier not greater than 30 mV and preferably 10 mV across sockets *7*. The 31884 Digital Multimeter is a suitable meter)

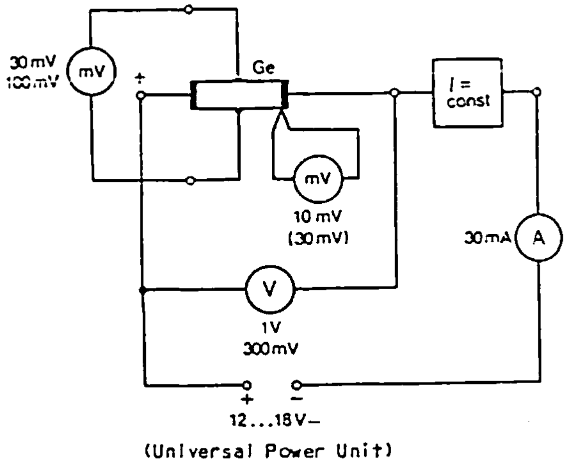
Caution! Disconnect the heating current as soon as the thermoelectric voltage reaches 5 mV (heating time about 2 minutes), in order to prevent overheating of the supporting plate.

The voltage drop in the semiconductor crystal, and from this the resistance of the crystal and its dependence on temperature, can be determined by connecting a voltmeter with a range multiplier of 300 mV or 1 V (31884 Digital Multimeter) across sockets *2.1* and *2.2*.

3.2 Experiment Instructions --

The supporting plate (carrier board) is held by fixing the multisocket distributor on plugs *4* and mounting the setup on suitable supports. Use the second pair of sockets on the distributor to provide the heating voltage.

The magnetic field is generated by an electromagnet with two 300-turn coils mounted on a U-shaped laminated core, and fitted with two plane pole pieces. The electromagnet is fed with a direct current of some 4 A which does not have to be smoothed. A variable transformer with rectifier is included with this apparatus for this task. ~~(See Fig. 4.)~~



Use as is circuit

Fig. 4
Carrier Board/Complete Circuit

The control current and heating voltage can both be supplied from the included universal power unit.

The following items are recommended as measuring instruments:

Description	Catalog No.
Digital Multimeter	31884
Hall Effect Gaussmeter	78562-02

Measurements of the voltage drop or the Hall voltage as a function of the thermoelectric voltage can alternatively be registered on any *xy* recorder, such as our 32111 One-Pen Chart Recorder.

4. **Operation:** Procedures for the following experiments are given:

- The Hall voltage is measured at room temperature and constant magnetic field as a function of the control current and plotted on a graph. (Because the measurement is a function of the control current, there is no compensation for defect voltage.)
- The Hall voltage U_H is measured as a function of the magnetic flux density B at room temperature and constant control current. From the readings taken the Hall coefficient R_H and the sign of the charge carriers are determined. The Hall mobility μ_H and the carrier density n (n-germanium) and p (p-germanium) are calculated.
- The Hall voltage U_H is measured at constant control current as a function of temperature at constant magnetic induction B and the values are plotted on a graph. The energy gap, or the band spacing of germanium, is calculated from the measurements.

Refer to Fig. 4.

4.1 Experiment 1: Measuring the Hall voltage at room temperature and constant magnetic field as a function of the control current --

Insert either the n-germanium or the p-germanium semiconductor wafer into the magnet very carefully in order to avoid damaging the crystal. In particular, avoid bending the wafer.

The control current is derived from the alternating voltage output of the power unit, using a bridge rectifier. Connect the rectifier to the lower socket of the power supply unit and to the socket marked "15V" on the selector ring (socket cross) located above the lower socket.

Connect the electrolytic smoothing capacitor to the output of the rectifier, observing polarity. Set the control current with the aid of the potentiometer. To avoid inadvertently exceeding the maximum permissible current of 50mA, connect a resistance of 330Ω in series to limit the current.

In this experiment, the crystal is connected directly (see Fig. 5, terminals A and B), so the constant-current source on the wafer and the defect voltage compensation are inactive.

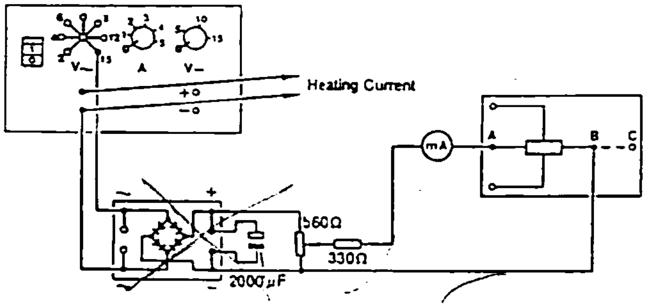
The magnetic field is produced by the two series-connected coils fed from the DC voltage output of the power supply unit. Set the voltage to the maximum value and adjust the magnetic field to the desired value, using the current control knob. The power supply unit then functions as a constant-current source, so ensuring that the field strength is not affected by changes of resistance caused by thermal effects. Measure the magnetic flux density with the 78562-02 Hall Effect Gaussmeter by positioning its Hall probe in the center of the field. Measure the Hall voltage with the 31884 Digital Multimeter.

4.2 Experiment 2: Measuring the voltage across the sample at room temperature and constant control current as a function of the magnetic flux density --

Now connect the control current supply to the outer contacts *A* and *C* (see Fig. 5) so that the built-in constant-current source is operative. Set the 560Ω potentiometer to maximum voltage. The control current should now be about 30mA. (If it is not, the value can be readjusted using the trimmer on the supplementary board). Measure the voltage on the specimen across the terminals *A* and *B* (see Fig. 5) with the 31884 Digital Multimeter. Calculate the resistance of the specimen R_0 in the absence of a magnetic field, 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).



We'll use separate DC supply

Fig. 5
Wiring Sketch for
Producing the Control Current

4.3 Experiment 3: Measuring the voltage across the sample at a constant control current and constant magnetic flux density as a function of temperature --

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 AC voltage output of the power supply unit: Connect the heater coil at the two lower sockets and select the heater filament voltage by inserting the shorting plug into the corresponding sockets of the socket cross.

The temperature of the specimen can be determined by way of the built-in Cu/CuNi thermocouple using the 31884 Digital Multimeter:

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

where U_T = voltage on the thermocouple
α = 40μV/°K
T_0 = ambient temperature

Caution! Never allow the temperature of the specimen to rise above 190°C.

With the magnetic field switched off and the pole shoes detached (to eliminate the influence of residual magnetism), switch on the control current (terminals A and C, see 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.

Note: Remove the Hall probe of the 78562-02 Hall Effect Gaussmeter from the heating zone during the following heating up period. Keeping the magnetic field constant, gradually increase the temperature of the specimen to the maximum value and measure the Hall voltage.

5. Theory:

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 emf -- the so-called Hall voltage -- is set up across the strip.

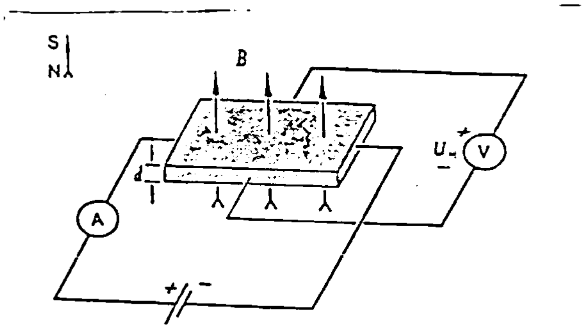


Fig. 6: Hall effect on a rectangular specimen. The polarity of the Hall voltage indicated is for negative charge carriers.

This phenomenon is described by 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:

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

where F = force on carrier

and e = elementary charge

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

Because 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. 7 shows that a linear relation exists between the current I and the Hall voltage U_H:

$$U_H = \alpha \cdot I$$

where α = proportionality factor.

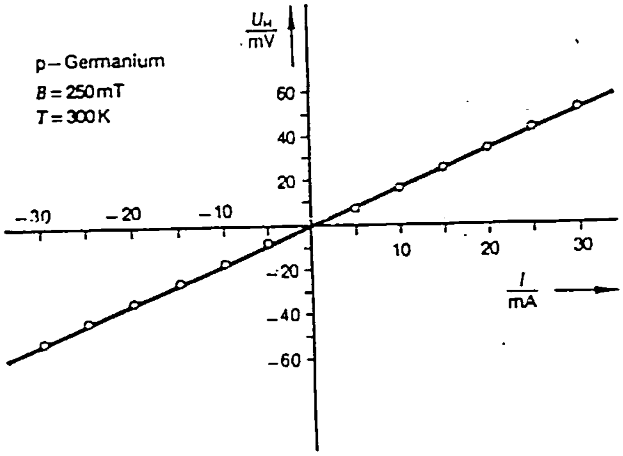


Fig. 7a:
Hall voltage as a function of current
p-Germanium specimen

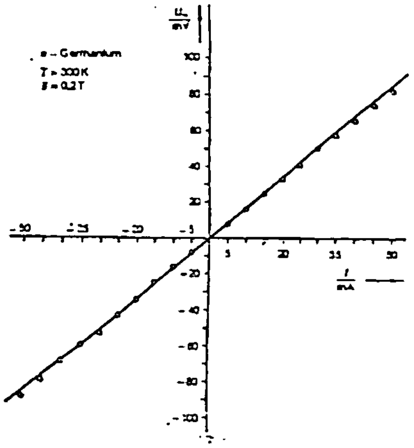


Fig. 7b:
Hall voltage as a function of current
n-Germanium specimen

The change in resistance of the specimen in a magnetic field is associated with a reduction in the mean free path of the charge carriers. Fig. 8a and 8b show the non-linear, clearly quadratic, change in resistance as the field strength increases.

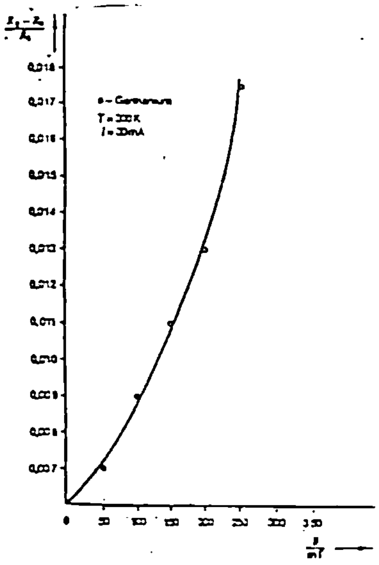


Fig. 8a
Change of resistance in n-germanium
as a function of the magnetic flux density

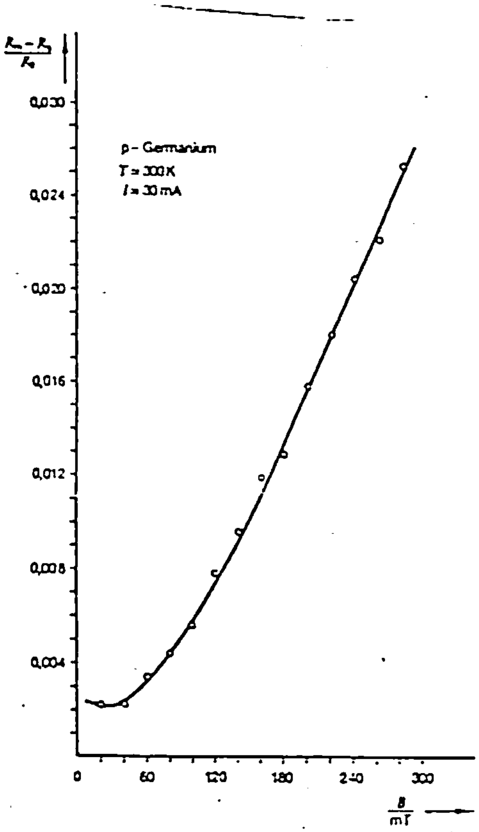


Fig. 8b
Change of resistance in p-germanium
as a function of the magnetic flux density

The conductivity of semiconductors is characteristically a function of temperature. Three ranges can be distinguished: At low temperatures we have extrinsic conduction, i.e., as the temperature rises charge carriers are activated from the impurities.

At moderate temperatures we talk of impurity depletion, since a further temperature rise no longer produces activation of impurities.

At high temperatures it is intrinsic conduction which finally predominates. In this instance charge carriers are additionally transferred by thermal excitation from the valence band to the conduction band.

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

$$\sigma = \sigma_0 \cdot \exp\left(-\frac{E_g}{2\,kT}\right)$$

where E_g = the energy gap between the valency and conduction bands, and k = Boltzmann constant.

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

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

from which E_g can be determined.

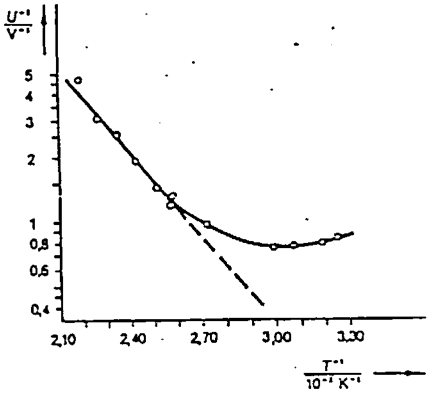


Fig. 9a
The reciprocal n-germanium specimen voltage as a function of the reciprocal absolute temperature.

From the measured values of n-germanium used in Fig. 9, the regression formulation

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

gives the slope

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

with the standard deviation

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

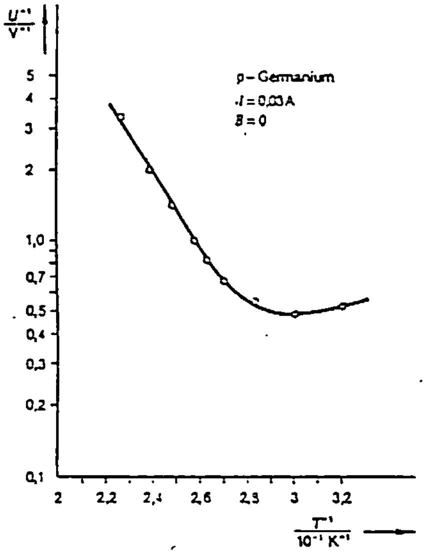


Fig. 9b
The reciprocal p-germanium specimen voltage as a function of the reciprocal absolute temperature.

Note: For both Fig. 9a and 9b, since I was constant during the experiment, U^{-1} is approximately equal to σ; the graph is therefore equivalent to a plot of conductivity against reciprocal temperature.

For the p-germanium specimen,

$$b = -3.62 \cdot 10^3\,\mathrm{K}$$

and the standard deviation is

$$\pm 0.09 \cdot 10^3\,\mathrm{K}$$

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

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

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

For p-germanium, $E_g = (0.62 \pm 0.02)$ eV

With the directions of control current and magnetic field illustrated in Fig. 6, 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 constant R_H:

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

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

$$n = \frac{1}{e \cdot R_H} \text{ and } p = \frac{1}{e \cdot R_H}$$

Fig. 10 shows a linear relation between the Hall voltage and the magnetic flux density B. Using the values from Fig. 10, regression with the formulation

$$U_H = U_0 + bB$$

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

For p-germanium, the slope of $b = 0.191\,\mathrm{VT^{-1}}$ has a standard deviation of $\pm 0.002\,\mathrm{VT^{-1}}$.

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 specimen thickness $d = 1 \cdot 10^{-3}$ m and $I = 0.03$ A, then

$$R_H = 8.9 \cdot 10^{-3}\,\frac{\mathrm{m^3}}{\mathrm{As}}$$

with the standard deviation

$$s_{RH} = 0.1 \cdot 10^{-3}\,\frac{\mathrm{m^3}}{\mathrm{As}}$$

The Hall coefficient for p-germanium (for the values used in Fig. 10) is

$$R_H = 6.37 \cdot 10^{-3}\,\frac{\mathrm{m^3}}{\mathrm{As}}$$

with the standard deviation

$$s_{RH} = 0.07 \cdot 10^{-3}\,\frac{\mathrm{m^3}}{\mathrm{As}}$$

The conductivity at room temperature is calculated from the length l of the specimen, its cross-sectional area A and its resistance R_0

$$\sigma_0 = \frac{l}{R_0 \cdot A}$$

With the measured values of

	n-Germanium	p-Germanium
l	0.02m	0.02m
R_0	45.7Ω	45.0Ω
A	$1 \cdot 10^{-5}\,m^2$	$1 \cdot 10^{-5}\,m^2$

we have

$\sigma_0 = 43.8\ \Omega^{-1}\,m^{-1}$ for n-germanium,

and

$\sigma_0 = 44.4\ \Omega^{-1}\,m^{-1}$ for p-germanium.

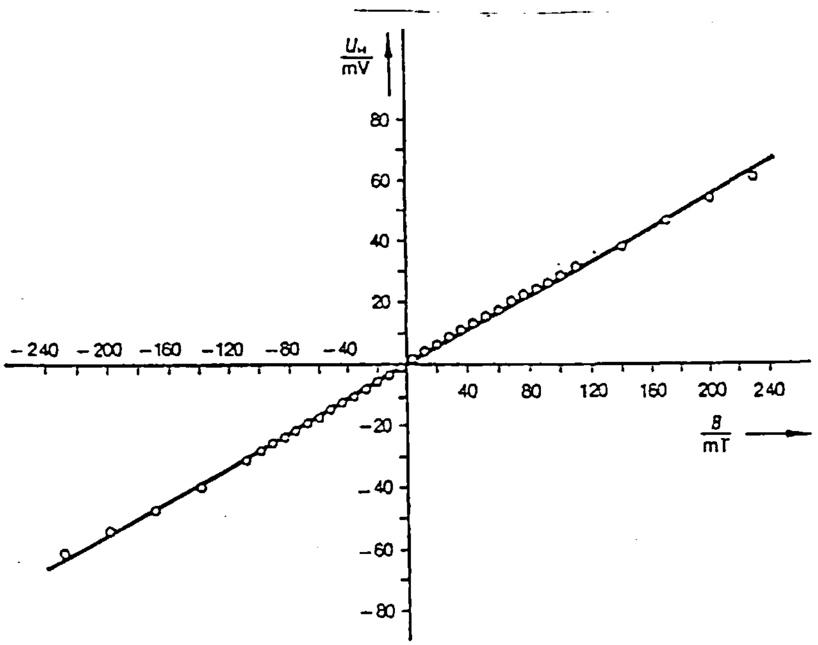


Fig. 10a
Hall voltage as a function of B
n-germanium specimen

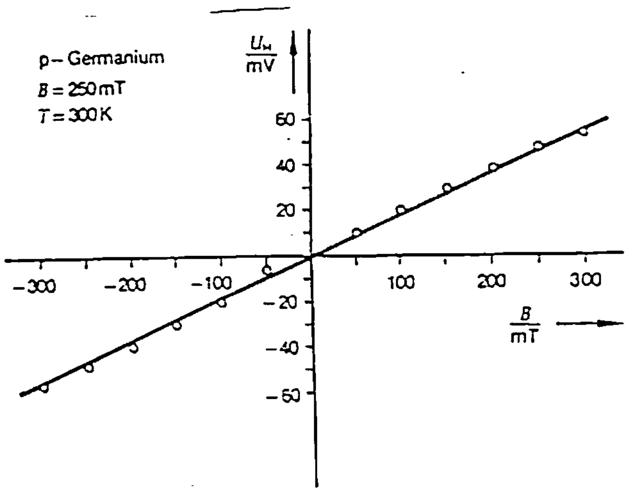


Fig. 10b
Hall voltage as a function of B
p-germanium specimen

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

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

Using the same measurements given in the table above, we get:

$$\mu_H = (0.389 \pm 0.004)\ \frac{m^2}{Vs} \text{ for n-germanium, and}$$

$$\mu_H = (0.283 \pm 0.003)\ \frac{m^2}{Vs} \text{ for p-germanium.}$$

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

$$n = \frac{1}{e \cdot R_H} \quad \text{and}$$

The hole concentration p of the p-doped specimen is calculated from

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

Using the value of the elementary charge =

$$e = 1.0602 \cdot 10^{-19} \text{ As}$$

we obtain

$n = 7.0 \cdot 10^{20} \text{ m}^{-3}$ and $p = 9.7 \cdot 10^{-20} \text{ m}^{-3}$

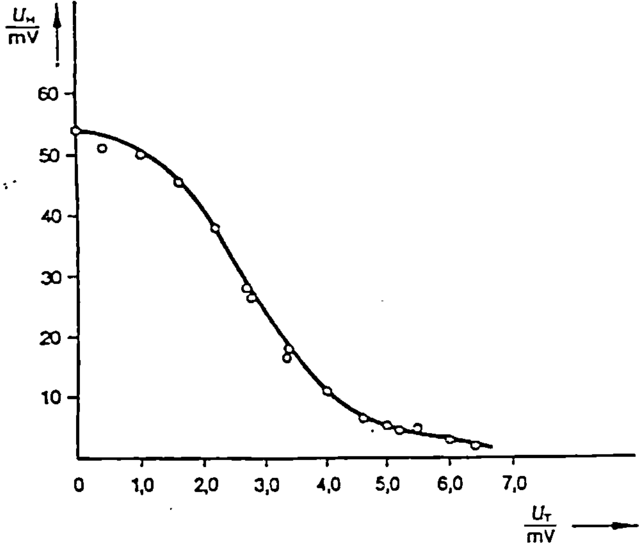


Fig. 11
Hall voltage as a function of temperature
Specimen of n-Germanium

Fig. 11 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.

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

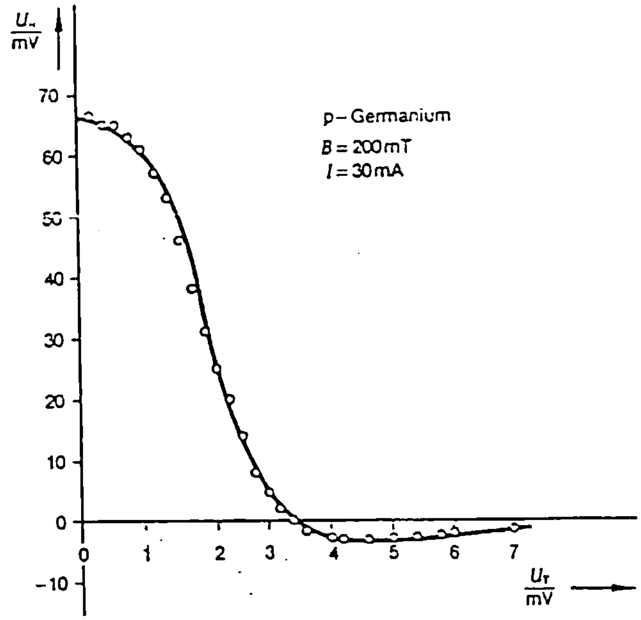


Fig. 12
Hall voltage as a function of temperature
Specimen p-Germanium

Fig. 12 shows first a decrease in Hall voltage with rising temperature. Since the measurements were made with constant current, it is to be assumed that this is attributable to an increase in the number of charge carriers (transition from extrinsic conduction to intrinsic conduction) and the associated reduction in drift velocity v.

(Equal currents with increased numbers of charge carriers imply reduced drift velocity). The drift velocity, in turn, is connected with the Hall voltage through the Lorentz force.

The current in the crystal is made up of both electron currents and hole currents

$$I = A \cdot e\,(v_n \cdot n + v_p \cdot p)$$

Since in the intrinsic velocity range the concentrations of holes p and of electrons n are approximately equal, those charge carriers will, in the end, make the greater contribution to the Hall effect which have the greater velocity or (since $v = \mu \cdot E$) the greater mobility.

Fig. 12 shows, accordingly, the reversal of sign of the Hall voltage, typical of p-type materials, above a particular temperature.

6 Maintenance: Pack the carrier boards in their original containers for storage. Other than this precaution against crystal breakage, the Hall Effect in Germanium Sets require no special maintenance. If you should experience any difficulty with a Hall Effect set, please contact Central Scientific Company, giving details of the problem. To ensure better service, please do not return any equipment to Central Scientific Company until you have received authorization.

Written 11/89

Central Scientific Company
11222 MELROSE AVENUE · FRANKLIN PARK, ILLINOIS 60131 (312) 451-0150

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OPERATING INSTRUCTIONS

11/95

Magnetic Field Detector

32391

1. Purpose: The Magnetic Field Detector is used in conjunction with the 12 VAC/DC Amplifier Power Supply (32386) and the Six-Range Meter (32381) to measure magnetic field strengths down to a level of 5 gauss.

2. Description: The unit consists of a Hall element mounted on the end of a 1 meter long probe which is fed to a voltage reference amplifier.

3. Operation: First connect the ~~32381 Six-Range Meter~~ voltmeter (SRM) into the output of the 32386 Amplifier Power Supply (APS), red to red and black to black. Turn the APS on. With the meter setting on the 0.1 volt scale, adjust the DC offset of the APS until the SRM reading is zero.

Now plug the MFD into the APS and select the 1000 gauss range. Change the SRM to the 2 volt range setting and, with the probe away from any strong magnetic fields, rezero the SRM by adjusting the APS DC offset.

To calibrate the detector, insert the probe into the "calibrate" slot so that the Hall element is on the upper side of the probe. Increase the APS gain setting until the appropriate field reading of 450 gauss (4.5 read on the middle 10V scale) is indicated on the SRM. With this calibration, the magnetic field strength sensed by the probe can be determined by multiplying the meter reading on the 10-volt scale by 100 to yield a reading in gauss.

The MFD can now be used to measure magnetic field strengths for experiments or demonstrations. The magnetic lines of flux perpendicular to the probe are actually measured. This is important to note when determining not only the strength but also the direction of the flux.

4. Maintenance: The Magnetic Field Detector needs no special maintenance. If you experience any problems with this unit or if you need more information about it, contact Central Scientific Company, giving details. To ensure better service, please do not return any apparatus to Central Scientific Company until we have sent you authorization.

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PART 1/2

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cenco

OPERATING INSTRUCTIONS

1/95

Cenco Electronic Module System

12 VAC/DC Amplifier Power Supply

Catalog No. 32386

1. **Introduction:** The 32386 12 VAC/DC Amplifier/Power Supply is the hub of the Cenco Electronic Modular System. It serves to power a variety of accessory units via a side port connector, provides variable low voltages for experiments from its output plugs, and is a variable gain (0-100) amplifier.

A discrete -6 volt output can be accessed via a front banana plug for a variety of low voltage applications. In addition, a variable output between -6 volts to +6 volts can be produced at the amplifier output by adjusting the gain knob to zero (to minimize noise), and adjusting the "DC offset" control knob.

2. **Description:** The control panel of the amplifier/power supply has the following connection plugs and control dials:

- Red and black input plugs
- Red and black output plugs, for the amplifier output or the variable DC output when the gain is set at "zero".
- "-6 volt" plug that provides -6 volts when referenced to either one of the black ground plugs.
- "Gain" control knob that provides amplifier gain adjustment between 0 and 100.
- "DC Offset" control knob, used to adjust DC component of amplifier input if the gain is above zero. It also adjusts the DC output voltage if the gain is set at "zero".
- "DC/AC" switch that blocks any DC voltage at the amplifier input when it is set to the AC position.
- "On/Off" switch.

The amplifier/power supply has its own 6-foot extension cord with a 3-prong plug and is housed in a 5 x 3-1/2 x 4-1/4" high sturdy aluminum box.

Specifications:

-6VDC Supply:

Voltage:	Discrete -6 volts
Current:	15mA

Amplifier output using DC Offset:

Voltage:	Variable, -6 to +6 volts
Current:	15mA

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3. Operation: Note – The input voltage and the input current must be limited to provide the maximum outputs of -6 to 8 volts and current levels below 120 milliamperes.

To amplify DC voltages, set the "DC Offset" knob to zero and the "AC/DC" switch to DC. Adjust the "Gain" control knob to the gain desired, keeping in mind that the maximum output voltage of 8 volts requires input voltages less than 8 volts divided by the gain setting. Any adjustments to the "DC Offset" knob will then change the level at which the input voltage causes the amplifier to overdrive.

Set the "AC/DC" switch to the AC position and otherwise follow the same procedure to amplify AC voltages.

4. Maintenance: The 12VAC/DC Amplifier/ Power Supply needs no special maintenance. If you should experience any difficulty with this piece of equipment, please contact Central Scientific Company, giving details of the problem. To ensure better service, please do not return any apparatus to Central Scientific Company until we have sent you authorization.

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the second pair of sockets on the distributor to provide the heating voltage.

The magnetic field is generated by an electromagnet with two 300-turn coils mounted on a U-shaped laminated core, and fitted with two plane pole pieces. The electromagnet is fed with a direct current of some 4 A which does not have to be smoothed. A variable transformer with rectifier is included with this apparatus for this task. ~~(See Fig. 4.)~~

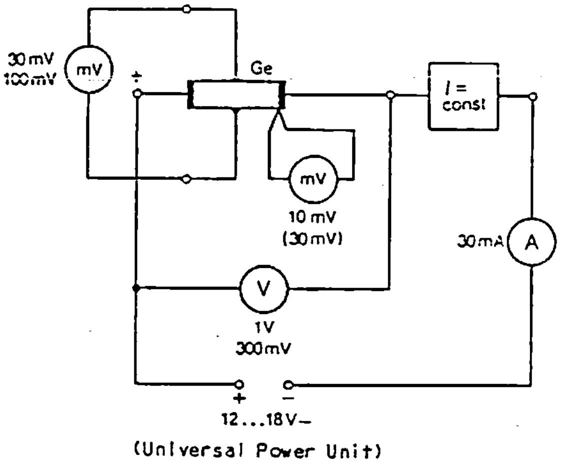

Fig. 4
Carrier Board/Complete Circuit

The control current and heating voltage can both be supplied from the included universal power unit.

The following items are recommended as measuring instruments:

Description	Catalog No.
Digital Multimeter	31884
Hall Effect Gaussmeter	78562-02

Measurements of the voltage drop or the Hall voltage as a function of the thermoelectric voltage can alternatively be registered on any *xy* recorder, such as our 32111 One-Pen Chart Recorder.

4. Operation: Procedures for the following experiments are given:

- The Hall voltage is measured at room temperature and constant magnetic field as a function of the control current and plotted on a graph. (Because the measurement is a function of the control current, there is no compensation for defect voltage.)

- The Hall voltage U_H is measured as a function of the magnetic flux density B at room temperature and constant control current. From the readings taken the Hall coefficient R_H and the sign of the charge carriers are determined. The Hall mobility μ_H and the carrier density n (n-germanium) and p (p-germanium) are calculated.

- The Hall voltage U_H is measured at constant control current as a function of temperature at constant magnetic induction B and the values are plotted on a graph. The energy gap, or the band spacing of germanium, is calculated from the measurements.

Refer to Fig. 4.

4.1 Experiment 1: Measuring the Hall voltage at room temperature and constant magnetic field as a function of the control current --

Insert either the n-germanium or the p-germanium semiconductor wafer into the magnet very carefully in order to avoid damaging the crystal. In particular, avoid bending the wafer.

The control current is derived from the alternating voltage output of the power unit, using a bridge rectifier. Connect the rectifier to the lower socket of the power supply unit and to the socket marked "15V" on the selector ring (socket cross) located above the lower socket.

Connect the electrolytic smoothing capacitor to the output of the rectifier, observing polarity. Set