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PHYWE

Operating Instructions

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Hall Effect, n-germanium Supporting plate 11802.00 and Hall Effect, p-germanium Supporting plate 11805.00

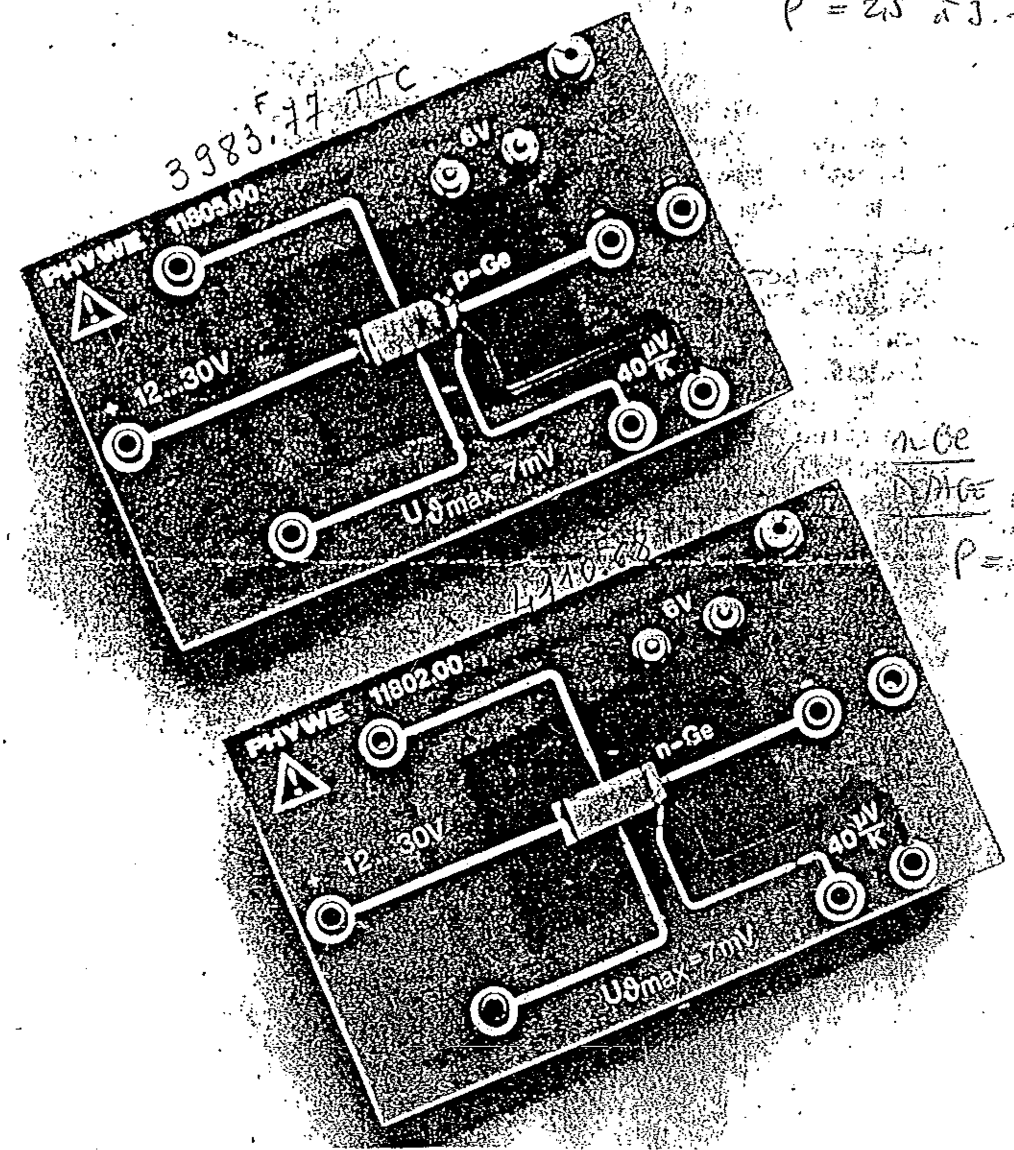


Fig. 1

Contents

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 supporting plates 11802.00 and 11805.00 (Fig. 1). The sign of the charge carriers responsible for the conduction process can be determined from the polarity of the Hall voltage.

In particular, we shall 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 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. We shall show also 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 with a constant control current the Hall voltage rapidly falls as the temperature rises.

In addition to this, a series of quantitative measurements is possible (see literature), such as charge-carrier drift velocity, charge-carrier concentration, and defect concentration or doping level.

2. DESCRIPTION

2.1 Functional and control units

The supporting plates, which are identical except for different doping of the germanium crystals, 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 1 mm.

A DC voltage of 12 to 30 V 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

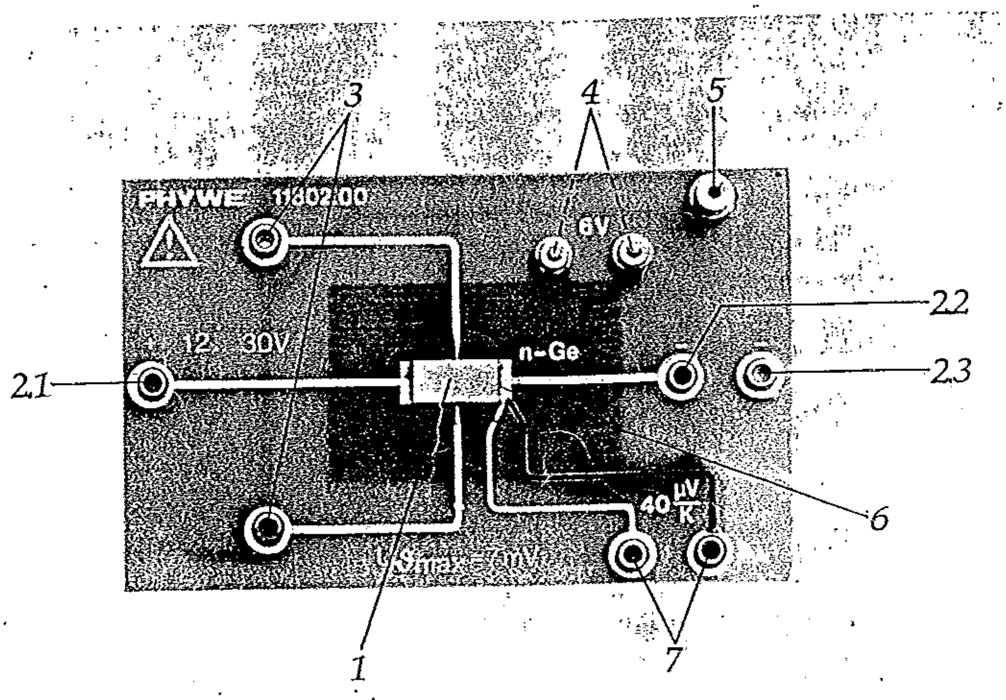


Fig. 2

keeps the control current constant (at about 30 mA) 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 its resistance.

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

Interfering voltages superimposed on the Hall voltage (voltage drop between Hall voltage terminals on the crystal due to the control current; thermoelectric voltages) can be compensated by use of adjusting knob *5* - see also Para. 2.2.

The two plugs *4* on the back of the plate serve not only to give mechanical support to the supporting plate, e.g. in multisocket distributor 06024.00, but also for carrying the heating current (heating time limited, see Operation).

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

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

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 being 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 (which cannot be entirely avoided in manufacture), the control current produces a drop in voltage along this tolerance range, even in the absence of a magnetic field. This interfering voltage can be 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 (adjusting knob *5*).

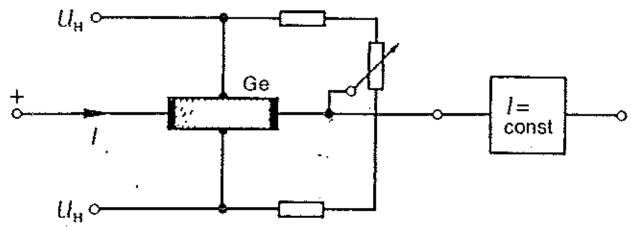


Fig. 3

3. OPERATION

Caution:
Germanium crystals are very brittle and consequently fragile. To prevent any bending of the supporting plate during assembly, the following points should be observed:

To affix the plate to the multisocket distributor 06024.00, the two plugs *4* are pushed into the distributor sockets by pressing on the front of the plate between the nuts securing these plugs. To remove the plate, the back of the plate near these plugs is pressed with two fingers and pulled away from the distributor.

When wiring up the individual sockets, these are each given support by pressing the hand against the back of the plate.

3.1 General design

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 approx. 30 mA at our works. If ever the measured value 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 (range multiplier 30 or 100 mV) is connected across sockets *3*.

The Hall voltage terminals must first be compensated. To do this, the control current is switched on between sockets *2.1* and *2.3*, but without the magnetic field. If the voltmeter connected across the Hall voltage terminals *3* should show a deflection, this is compensated by turning adjusting knob *5* (if need be, with the aid of a suitable screwdriver). When proper compensation has been applied, there should be no voltage across sockets *3* when there is no magnetic field.

The magnetic field is now switched on. To produce a Hall voltage of 50 mV, a magnetic field of some 300 mT is required.

To heat the crystal, a heating voltage of 6 V (current 5 A) is applied to the plugs *4* on the rear. The temperature is measured by a built-in thermocouple, a sensitive voltmeter (range multiplier not greater than 30 mV and preferably 10 mV) being connected across sockets *7*.

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 (range multiplier 300 mV or 1 V) across sockets *2.1* and *2.2*.

3.2 Experiment instructions

The supporting plate is suitably held by fixing a multisocket distributor 06024.00 on plugs *4* and mounting this on suitable supports. The heating voltage also can be provided simply by using a second pair of sockets on the distributor.

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 a suitable source.

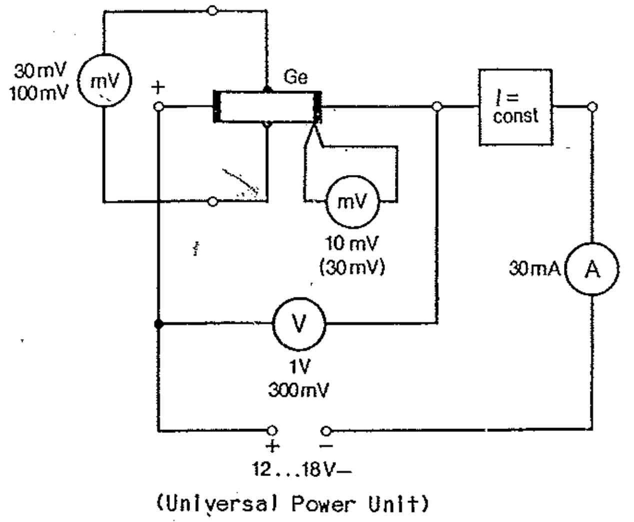


Fig. 4

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

Fig. 4 shows the complete circuit of the supporting plate.

Suitable voltmeters are, for example, moving-coil instruments with appropriate range-multiplier inserts. Current measurement is required to determine the resistance of the crystal and can be effected with a multi-range demonstration meter, for example.

Measurements of the voltage drop or the Hall voltage as a function of the thermoelectric voltage can alternatively be registered on any xy recorder.

If the experiment is intended as a students' practical exercise rather than for demonstration, the digital multimeter or the two multi-range meters with overload protection are available. In this case, a measuring amplifier should be inserted for the measurement of the thermoelectric voltages.

List of experiment equipment recommended in the text:

Description	Order No.	No. off
Multisocket distributor	06024.00	1
Coil, 300 turns	06513.00	2
Pole pieces, plane, 30 x 30 x 48 mm, pair	06489.00	1
Iron core, U-shaped, laminated	06501.00	1
Power supply, universal	11704.93	1
Variable transformer with rectifier	11709.93	1
Moving-coil instrument	11100.00	2
Range multiplier, 30 mV DC	11104.13	1
Range multiplier, 100 mV DC	11104.21	1
Range multiplier, 300 mV DC	11104.23	1
Range multiplier, 1 V DC	11104.31	1
Range multiplier, amplifier*	11110.01	1
Demonstration multi-range meter	11000.11	1

Alternatively, instead of the moving coil instrument and associated range multipliers, use

xyt Recorder	11408.93	1

Instead of the demonstration multi-range meter, the following special instruments can be used in practicals:

For measurement of Hall voltage:

- Multi-range meter with overload protection B — 07026.00

  or

- Digital multimeter — 07029.00

* For this range multiplier, four 9 V batteries 07496.10 are required.

For measurement of thermoelectric voltage

- Measuring amplifier — 11761.93
  in conjunction with any chosen meter (including demonstration meter) with 10 V DC range multiplier

For measurement of the voltage drop along the crystal and of the control current, the following instruments are suitable in addition to those mentioned above:

- Voltmeter, 0.3 to 300 V DC, 10 to 300 V AC — 07035.00
- Ammeter, 1 mA to 3 A DC/AC — 07036.00
- Multi-range meter with overload protection — 07021.01

4. EXPERIMENT LITERATURE

PHYWE Experimental Units in Physics, Solid-state physics, last published 1982

5. TECHNICAL DATA

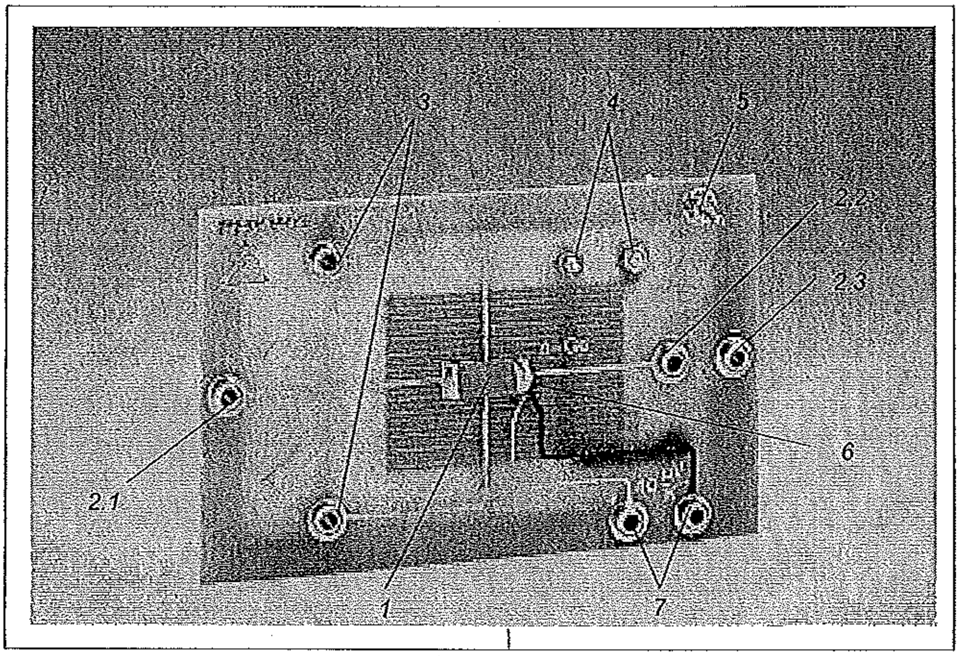
Dimensions of crystal	20 x 10 x 1 mm
Crystal material	germanium, doped
Resistivity of crystal material	approx. 3 Ω.cm
Maximum permissible steady current through crystal	50 mA
Operating voltage to produce control current	12 to 30 V DC
Constant current from stabilizer	approx. 30 mA
Maximum temperature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

PHYWE

Hall Effect, p-germanium, carrier plate

11805.00

Operating instructions



1 PURPOSE AND CHARACTERISTICS

The carrier plate allows to demonstrate the temperature dependence of conductivity and of the Hall effect of a p-conducting semiconductor. The sign of the charge carrier which causes conductivity can be assessed from the Hall voltage polarity.

As the probe temperature may be varied, the different conduction mechanisms - extrinsic and intrinsic conduction - can be demonstrated. It can furthermore be shown that the Hall voltage is approximately temperature dependent in the area of dominating extrinsic conduction, whereas it rapidly decreases with increasing temperature in the area of intrinsic conduction for constant current.

Furthermore, quantitative assessments concerning the drift velocity of the load carriers, the concentration of load carriers and of imperfections as well as the doping level can be made.

2 DESCRIPTION AND HANDLING

2.1 Function and control elements

A continuous voltage of 12 to 30 V is applied over the sockets *2.1* and *2.3* to the p-doped germanium crystal *1*. The socket marked „+" is directly connected to the crystal, whereas in the case of socket *2.3*, a current stabiliser is inserted (on the supplementary plate at the back), to assure a constant control current if the resistivity of the crystal changes with temperature.

Between sockets *2.1* and *2.2*, the voltage drop across the crystal may be measured, e. g. to determine the resistance. The two sockets *3* are used to tap the Hall voltage. Using control button *5*, defect voltages superimposed onto the Hall voltage - voltage drop across the Hall voltage taps due to the control current or to thermoelectric voltages - can be compensated (fig. 2). Because if the Hall voltage contacts on the crystal are only slightly shifted laterally in the direction of the control current, the latter will cause a drop of voltage, even in the absence of an exterior magnetic field,

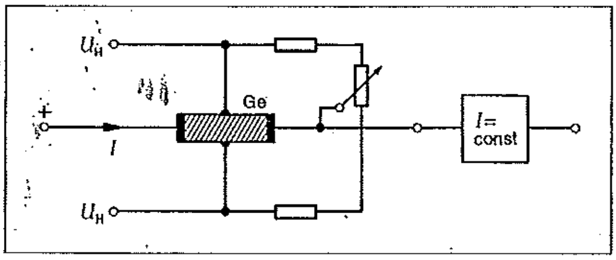


Fig. 2

which will distort the Hall voltage to be determined. The copper-constantan thermocouple *6* provides a thermoelectric voltage which may be tapped at the pair of sockets *7*.

Together with the corresponding PHYWE distributor, the pair of sockets *4* on the back side of the plate is used both for mechanical support of the carrier plate and to supply heating current.

2.2 General set-up

Attention! Germanium crystals are very brittle and thus can easily break. The following recommendations should be followed in order to avoid bending of the carrier plate and thus mechanical stress to the crystal:

- when plugging the carrier plate into the corresponding distributor, the pair of plugs 4 is pushed into the distributor sockets, pressing onto the front side of the plate, between the fastening nuts. To remove the plate, a finger is inserted behind the plate near the plug and the latter is carefully pulled off the distributor.
- When connecting the single sockets, they are supported with the hand at the back of the plate.

The carrier plate is fixed in such a way between the pole pieces of an electromagnet that the crystal is completely interspersed by the homogeneous magnetic field.
A continuous voltage between 12 V and 30 V (current requirement about 30 mA) is connected with the right polarity to sockets *2.1* and *2.3*. No current limiting resistors are required due to the integrated current stabiliser.
Indication: the current stabiliser is set to about 30 mA at the factory. If the measured value happens to be noticeably different, the required current can be set again with the trimming potentiometer on the small supplementary plate, with the assistance of a small screwdriver.
To start with, the Hall voltage tap is adjusted without applied magnetic field, by means of control button *5*.
If the adjustment is correct, and if control current is circulating, no voltage is present at sockets *3*. After that, the magnetic field is applied. A magnetic flux density of about 300 mT is required to generated a Hall voltage of 50 mV.
To heat the crystal, a heating voltage of 6 V at the utmost (current requirement 5 A) is applied over both plugs *4*. Temperature control is assured by means of the integrated thermocouple and by connecting a sensitive voltmeter (measuring range not larger than 30 mV).

Attention! As soon as the thermoelectric voltage has reached 5 V (heating time about 2 minutes), the heating current must be interrupted, to avoid overheating of the carrier plate. A possible brown discoloration of the plate, which may occur after heating to the maximum admissible temperature limit, has no effect on the function of the unit.

2.3 Hints for the performance of the experiment

The heating voltage can be applied as a supplementary voltage over the distributor sockets (cf. list of accessories). A U shaped iron core is fitted with 300 winding coils and with two plane pole pieces, to generate the magnetic field. A direct current of about 4 A is required to feed the coils.
Alternatively, an *xy* plotter may be used for the temperature dependent recording of the voltage drop for the determination of the resistance value or of the Hall voltage.
It must be made sure that the Hall probe does not touch the pole pieces. In critical cases, it is recommended to insulate the probe with a strip of transparent adhesive tape. The complete wiring of the carrier plate is depicted in fig. 3.

3 TECHNICAL SPECIFICATIONS

Crystal material	germanium, p doped
Crystal dimensions	(20 x 10 x 1) mm
Specific resistivity	approx. 3 Ωcm
Maximum control current	50 mA
Operating voltage	12V ... 30V
Constant stabiliser current	30 mA
Maximum crystal temperature	175 °C
Thermocouple	Cu-CuNi
Thermoelectric voltage coefficient	approx. 40 mV/K
Heating voltage	6 V≅/approx. 5 A

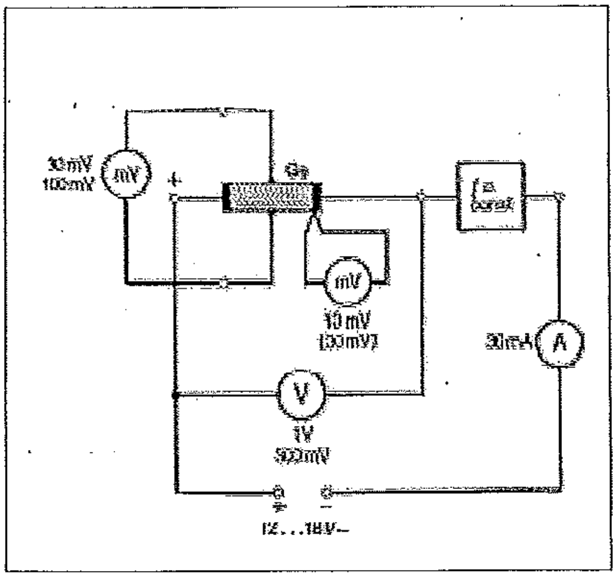


Fig. 3

4 LITERATURE REFERENCES

University Laboratory Course in Physics 1-3		16502.01

5 LIST OF ACCESSORIES

Distributor		06024.00
Coil with 300 windings	(2 x)	06513.01
Pole pieces, plane	(2 x)	06489.00
Iron core, U-shaped, laminated		06501.00
Universal power supply		13500.93
Controlled power supply 0-12 V/2 A		13505.93

To determine the magnetic flux density

Teslameter, digital	13610.93
Hall probe, tangential	13610.02

Furthermore, an ammeter and a voltmeter are required.