PHYWE

Operating instructions

Thermogenerator
04366.00

1. PURPOSE

The thermogenerator can be used to demonstrate two important complementary physical effects; the Seebeck effect and the Peltier effect. As a consequence of the Seebeck effect, the thermogenerator produces a voltage when a temperature difference is maintained. Conversely, if a voltage is applied externally to the device it functions as a heat pump in consequence of the Peltier effect and produces a temperature difference.

Apart from being able to demonstrate these effects clearly, it is also possible to carry out quantitative measurements (determination of the efficiency, the pumping capacity, the Seebeck coefficient and the Peltier coefficient). Furthermore, the thermogenerator can be used to cool substances down the ca. —15 °C and thus find use not only in Physics, but also in Chemistry and Biology.

2. MODE OF OPERATION

If the junctions of two dissimilar conductors which form part of an electric circuit (cf. schematic diagram, Fig. 2) are maintaind at different temperatures, then heat flows from the warmer area to the colder one. The charge carriers involved in the transportation of the heat distribute themselves inhomogeneously along the conductor. An internal field results which can be shown to be the original voltage U_0 on the open ends of the conductors (Seebeck effect, discovered in 1822 by Goethe's friend and adviser Thomas Seebeck). To a close approximation, the voltage is proportional to the temperature difference ΔT between the two junctions:

$$U_o = \alpha_{1,2}(T_h \quad T_c) = \alpha_{1,2}\Delta T$$

where $\alpha_{1,2}$ = Seebeck coefficient of the combination of materials used,

T_h = temperature of the hot side
T_c = temperature of the cold side

Conversely, if a current is passed through the thermocouple (cf. Fig. 3) in which the junctions are initially at the same temperature ($\Delta T = 0$), a temperature gradient is then produced between the junctions as a consequence of the effect discovered in 1834 by, and named after, the French watchmaker Peltier: the pumping capacity P (P = heat transported Q per unit time t) is proportional to the current I:

$$\frac{Q}{t} = P = \pi \cdot I$$

(π = Peltier coefficient)

For reasons of symmetry, both effects are reversible i.e. if the hot and cold sides are interchanged the polarity of the voltage on the terminal sockets also changes. If the

Fig. 1

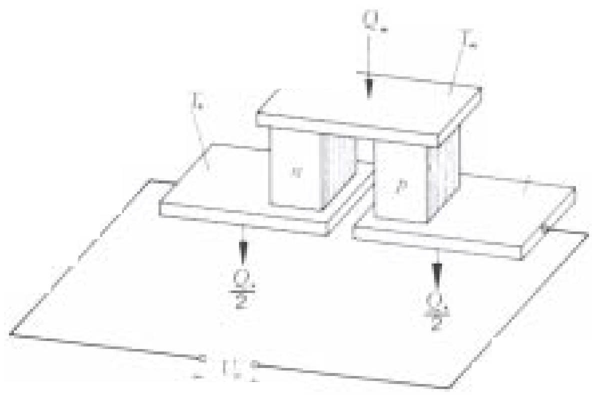

Fig. 2: Arrangement of a Seebeck semiconductor element

Q_h = quantity of inflowing heat on the hot side
Q_c = quantity of outflowing heat on the cold side
T_h = temperature of the hot side
T_c = temperature of the cold side
n = n-doped silicon
p = p-doped silicon

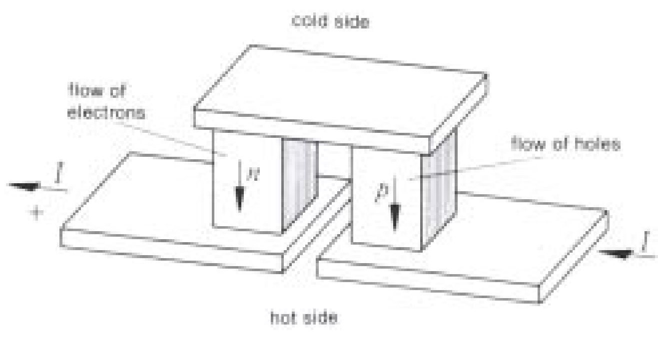

Fig. 3: Arrangement of the Peltier element

direction of the current in the heat pumping operation is reversed, the direction of pumping will also reverse, i.e. the hot and the cold side are interchanged.

It should be noted that the Seebeck and Peltier effects do not just occur on their own, but are always accompanied by other processes. In particular, these are:

- thermal conduction from the hot side to the cold side
- Joule heating, which occurs in the case of current flow at both junctions
- Thomson effect, heat pump effect in the homogeneous conductor in the presence of a temperature gradient
- Benedicks effect, voltage along the homogeneous conductor in the presence of a temperature gradient.

3. DESCRIPTION

142 semiconductor thermocouples are situated between two nickel-plated copper plates in the generator block (Fig. 4). The 10 mm thick copper plates *1*, which are used to transfer the heat, are each provided with a 7 mm borehole *2* to accommodate a thermometer. The thermocouples are connected electrically in series to increase the output voltage. Connection is made at the two 4 mm sockets *3* and *7* which have different colours. In the case of the Peltier effect, the direct current (max. 6 A DC) is also applied to these sockets.

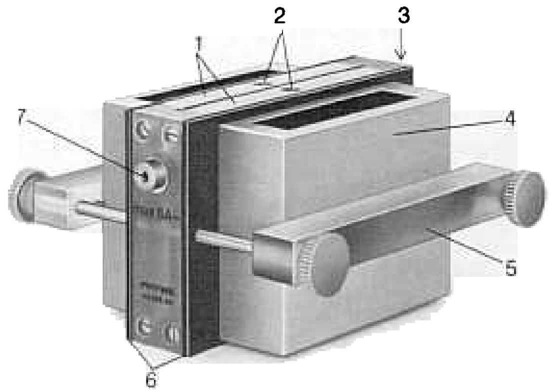

Fig. 4

Containers *4* for liquids can be attached to each side of the generator block. To ensure direct heat contact between the generator and the liquid, the containers — which are sealed by means of rubber gaskets *6* and secured using clamping jaws *5* and knurled screws — have no wall on the side which fits against generator block.

Two open-top containers are supplied with the thermogenerator. The following accessories are also available; cf. Fig. 5.

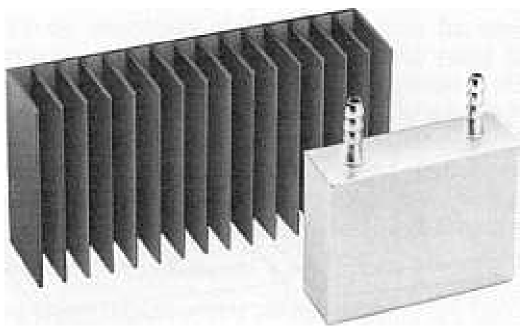

Fig. 5: Left: cooling body 04366.02,
Right: flow-type heat-exchanger 04366.01

flow-type heat-exchanger 04366.01; container closed at the top and provided with two tubing connections cooling body 04366.02; black anodised air heat-exchanger which is attached simple with knurled screws and does not require clamping jaws; cf. also Fig. 9.

4. HANDLING

The semiconductor elements housed in the generator block are drip- and splash-proof; in this respect, therefore, no particular precautions are required when using the apparatus.

Before the liquid containers are screwed on, the sealing surfaces should — if necessary — be cleaned with a cloth. To protect the rubber gaskets it is recommended that the containers be removed after use.

Precise polarity of the electrical connections is not specified since both the Seebeck and the Peltier effects are reversible. However, the semiconductor elements have been installed in such a way that the relation shown in Fig. 6 applies.

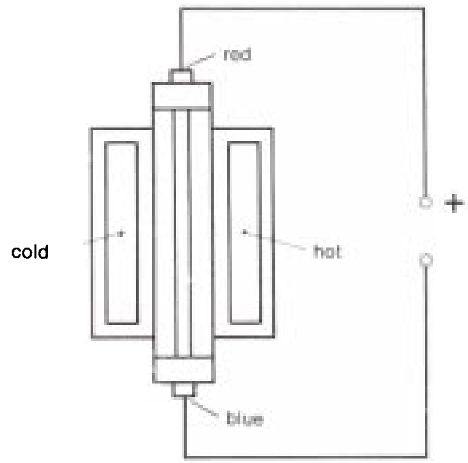

Fig. 6: Relation between electrical polarity and temperature

The thermogenerator must be operated with low-ripple direct current in order to attain full efficiency when used as a heat pump. The mains connection unit, universal (11704.93), is especially suitable for this purpose.

For continuous operation the maximum permissible temperature is 100 °C and should not be exceeded.

The maximum current is 6 A DC and should also not be exceeded.

The apparatus can be used either in an upright position or on its side. In general, it is recommended to carry out the operation on a heat-insulating base.

The generator block has two boreholes to accommodate thermometers. A small amount of heat-conducting paste (e.g. 03747.00) should be placed in the holes to improve the transfer of heat from the generator to the thermometer.

5. SUGGESTIONS FOR EXPERIMENTS

The thermogenerator enables a wide range of experiments on energy, energy transformation and direct transformation of energy to be performed. The following examples are given as suggestions.

5.1 Direct transformation of energy: Thermal energy → electrical energy

5.1.1 (Fig. 7)

Fig. 7: Thermal energy is transformed into electrical energy

Liquid containers are attached to the two sides of the generator block; one is filled with hot water, the other with cold water. The electrical energy can be demonstrated by using

— a moving-coil meter, e.g. 11100.00, with a 3 V DC measuring range (11104.33), or alternatively — for smaller temperature differencs — with a 1 V DC measuring range (11104.31)
— a 2 volt motor (11031.00) with disk (11031.01)
— or, in the case of higher temperature differences, with a 1.5 V bulb or a transistor radio (3 V operating voltage).

5.1.2 (Fig. 8)

Fig. 8: Experiment to demonstrate the symmetry of the Seebeck effect

The generator block is placed flat on a good heat-conducting base at room temperature (e.g. a metal table top or on the cooling body 04366.02 as shown in the photography) at ambient temperature. The 2 V motor with attached disk is connected, and a metal can (e.g. 05933.00) filled with hot water is placed on the generator block. After a short time, the motor begins to rotate. If the hot metal can is then replaced by one filled with ice-water, the motor will initially come to rest and then rotate in the opposite direction. The symmetry of the Seebeck effect has thus been demonstrated in the simplest possible manner. (With a little patience it is even possible to set the motor in motion simply by placing a warm hand on the generator block, it may be necessary to use the other hand from time to time.)

5.1.3 (Fig. 9)

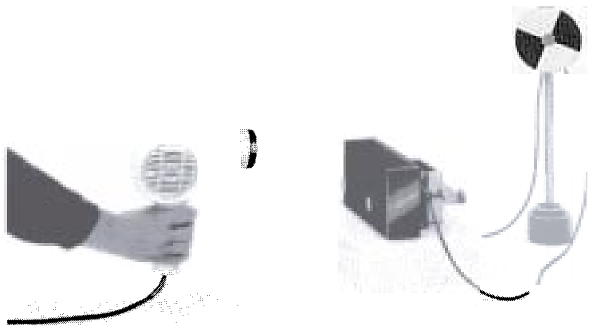

Fig. 9: Hot air as energy source

The cooling body is attached to one side of the generator and a liquid container filled with cold tap water is attached to the other side. The arrangement is assembled on a heat-insulating base. The 2 V motor is again connected. If the cooling body is now exposed to a stream of hot air (hair blow dryer), it will heat up. The thermogenerator will supply electrical energy until the water has attained the temperature of the hot air (equilization of temperature).

5.2 Energy transformation: Radiant energy → electrical energy

One side of the generator block is carefully blackened with a candle; a container filled with ice-water, or alternatively the cooling body 04366.02, is attached to the other side. The arrangement is placed on a heat-insulating base (Fig. 10). If the blackened side is exposed to radiant heat (sunlight or, if cloudy, the 150 W reflector lamp 06751.00), the radiant energy is transformed in the soot layer into heat, and the heat is then transformed by the thermogenerator into electrical energy. Demonstrate using the 2 V motor and disk.

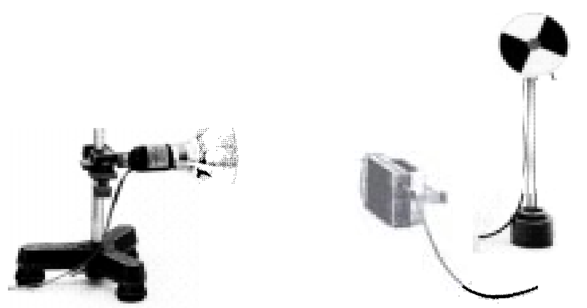

Fig. 10: Transformation of radiant energy

5.3 Operation as heat pump

The generator block is connected to a mains unit (e.g. mains unit, universal, Order No. 11704.93) and a current of 5 to 6 A DC is set. After just a short time an obvious temperature difference between the two sides can be detected either by testing with the finger or by using a thermometer.

If the direction of the current is reversed, then the hot and the cold side will interchange. In this way the symmetry of the Peltier effect can be demonstrated.

5.4 Operation as cooling machine

The experiment is assembled as shown in Fig. 11; the thermogenerator is placed on a heat-insulating base.

Fig. 11: Heat pump operation for producing low temperatures

In order to attain especially low temperatures it is necessary to cool the hot side with the flow-type heat-exchanger 04366.01. One piece of tubing is connected to the water tap, the other is led into the sink. By this means the hot side is maintained at approximately 10—18 °C. If a container filled with alcohol is attached to the cold side, it is possible to attain temperatures of the order of —15 °C after approximately 40 minutes (operation with mains connection unit, universal, current 5 A DC).

5.5 Thermal energy accumulator

A liquid container filled with water is attached to each side of the generator block. If a current is now passed through the circuit according to Fig. 12, a temperature difference will be set up between the two containers (charging of the accumulator). If a consuming device (e.g. 2 V motor) is then connected in place of the mains unit, the accumulator will discharge and thereby reduce the temperature difference.

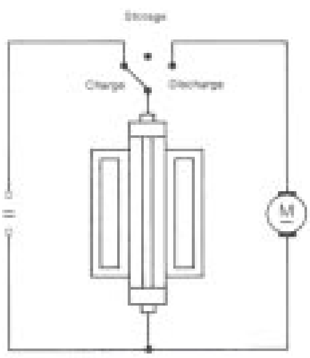

Fig. 12: Basic circuit diagram for the thermal accumulator

5.6 Further applications

5.6.1 Determination of freezing point

The set-up described in 5.4 (Fig. 11) can be used to undertake — amongst others — freezing point determinations. The substance under investigation is placed in a test tube immersed in the alcohol bath, and both the solidification temperature and the liquefaction temperature are measured during the cooling and reheating operations respectively. The mean value — optionally derived from several measurements — is the freezing point.

5.6.2 Determination of the air humidity (Dew-point hygrometer)

A container filled with water is placed on the hot side of the generator block which in turn is connected to the mains unit. The cold side is left free, but should be carefully degreased with alcohol. If the mains connection unit is now switched on (4—5 A DC), condensation will be observed at a temperature T_1 during the cooling process. After switching off, the temperature T_2 at which the condensation disappears is noted. The mean of the two values is the dew-point temperature, from which the air humidity can be determined. (cf. "University Laboratory Experiments, Physics", volume 2, Experiment 531.758 "Air Density and Air Humidity").

6. LITERATURE

PHYWE series of publications "University Laboratory Experiments, Physics", volume 2

7. TECHNICAL DATA

General

Generator block (24 mm x 80 mm x 126 mm) consisting of 142 silicon semiconductor elements fixed water-tight between two nickel-plated copper plates.

Thermal capacity of each copper plate: 255 J/K
Internal resistance of the generator: 2.8 Ω
Continuous operating temperature: max. 100 °C
Liquid containers (brass): 28 mm x 70 mm x 94 mm

Operation as thermogenerator

Seebeck coefficient of one element: 4 x 10^{-4} V/K
Efficiency (at ΔT = 40 °C): 1 %

Operation as heat pump

Max. continuous current: 6 A
Cooling operation
  max. pumping capacity (at I = 6 A): P_c = 52 W
  performance figure: η_c = 0.7
Heating operation
  max. power: P_h = 160 W
  performance figure: η_h = 1.5

8. LIST OF EQUIPMENT

8.1 Supply schedule of the thermogenerator 04366.00

two clamping jaws
four knurled screws
two liquid containers
two rubber gaskets

8.2 Accessories

Order No.	Equipment
04366.01	Flow-through heat exchanger
04366.02	Air cooler

8.3 Equipment recommended for the thermogenerator

Order No.	Equipment
11704.93	Power supply, universal
11031.00	Motor, 2 V DC
11031.01	Disk for 11031.00
03747.00	Heat-conductive paste, 50 g

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