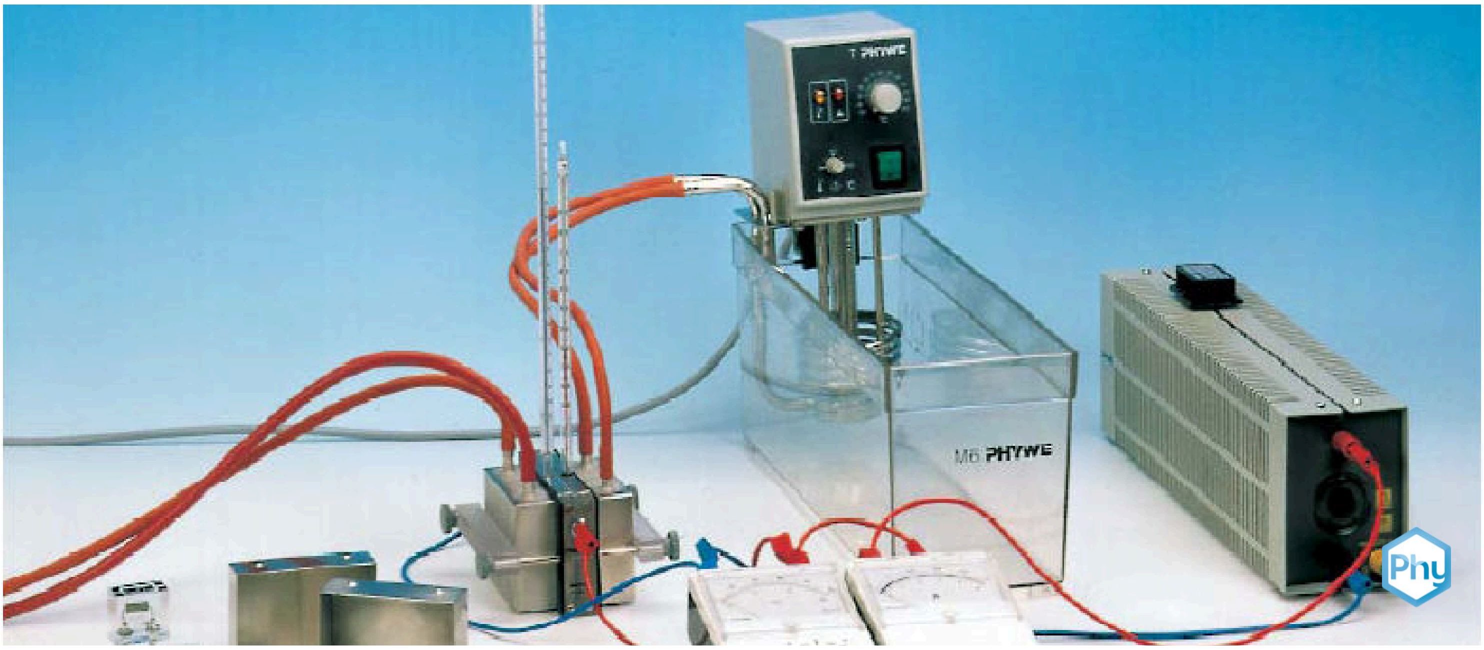
Semiconductor thermogenerator



Physics	Thermodynamics	Heat energy, thermal capacity	
Physics	Electricity & Magnetism	Electric current & its effects	
Applied Science	Engineering	Electrical Engineering	Properties of Electrical Devices
Applied Science	Engineering	Renewable Energy	Heat

Difficulty level	Group size	Preparation time	Execution time
hard	2	45+ minutes	45+ minutes

This content can also be found online at:

http://localhost:1337/c/6006d33793e22500031f5aef

General information

Application

Fig. 1: Experimental set-up for measuring no-load voltage and short-circuit current as a function of temperature difference.

Semi-conductors are widely used as detectors. As such they have industrial applications in cameras.

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Other information (1/2)

Prior knowledge

The prior knowledge for this experiment is found in the Theory section.

Main principle

In a semi-conductor thermogenerator, the no-load voltage and the short-circuit current are measured as a function of the temperature difference. The internal resistance, the Seebeck coefficient and the efficiency are determined.

Other information (2/2)

Learning objective

The goal of this experiment is to investigate the Seebeck effect.

Tasks

1. To measure no-load voltage U_o and short-circuit current I_s at different temperature differences and to determine the Seebeck coefficient.
2. To measure current and voltage at a constant temperature difference but with different load resistors, and to determine the internal resistance R_i from the measured values.
3. To determine the efficiency of energy conversion, from the quantity of heat consumed and the electrical energy produced per unit time.

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Theory

If a temperature drop is created along a current-free branch of a conductor made up of different materials, heat flows from the warmer region to the cooler one. The charge carriers which take part in this transfer of heat are unevenly distributed along the conductor. An internal field strength is set up, which can be shown to be the e.m.f. U_o at the open ends of the conductor (Seebeck effect).

The voltage level depends on the temperature difference and on the materials used. To a first approximation, the voltage may be written:

$$U_\mathrm{o} = \alpha_{1,2}(T_\mathrm{h} - T_\mathrm{c}) = \alpha_{1,2}\Delta T$$

where $a_{1,2}$ is the Seebeck coefficient of the combination of materials used, T_h is the temperature of the hot side and T_c the temperature of the cold side.

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Equipment

Position	Material	Item No.	Quantity
1	Thermogenerator with 2 water baths	04366-00	1
2	Flow-through heat exchanger	04366-01	2
3	Heat conductive paste, 60 g	03747-00	1
4	Connection box	06000-00	1
5	Rheostat, 33 Ohm , 3.1A	06112-02	1
6	Digital multimeter, 600V AC/DC, 10A AC/DC, 20 MΩ, 200 µF, 20 kHz, −20°C…760°C	07122-00	2
7	Digital stopwatch, 24 h, 1/100 s and 1 s	24025-00	1
8	Immersion thermostat Alpha A, 230 V	08493-93	1
9	External circulation set for thermostat Alpha A	08493-02	1
10	Bath for thermostat, makrolon	08487-02	1
11	Lab thermometer,-10..+110 °C	38056-00	1
12	Thermometer -10...+50 °C	38034-00	1
13	Resistor 2 Ohm 5%, 2W, G1	06055-20	1
14	Resistor 1 Ohm 2%, 2W, G1	06055-10	1
15	Resistor 5 Ohm 2%, 2W, G1	06055-50	1
16	Resistor 10 Ohm 2%, 2W, G1	06056-10	1
17	Rubber tubing, i.d. 6 mm	39282-00	4
18	Connecting cord, 32 A, 500 mm, red	07361-01	3
19	Connecting cord, 32 A, 500 mm, blue	07361-04	2
20	Tubing connector, ID 6-10mm	47516-01	2

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Setup and Procedure

Procedure

- Secure flow-type heat exchangers to each side of the thermogenerator. Fill the cold side with tap water and set the temperature of the hot side on the thermostat. The two temperatures are measured using the holes in the thermogenerator provided for the purpose. The short-circuit current and the noload voltage are measured directly, the internal resistance of the measuring equipment being disregarded

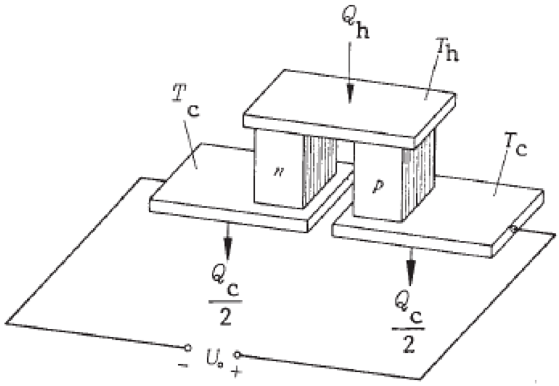

Fig. 2: Construction of a semiconductor Seebeck element. Several elements are generally connected electrically in series and thermally in parallel.

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Procedure (part 2)

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- Connect rheostat R_{ext} to the thermogenerator at a constant average temperature difference. Measure the current and voltage at different settings and plot the results on a graph.
- Remove the heat exchanger which was connected to the thermostat and put a water bath brim-full of boiling water in its place. Measure the temperature of the hot side $T_h = f(t)$ and of the cold side $T_c = f(t)$ as a function of time. Measure the current and the voltage across an external resistance of approximately the same value as the internal resistance.

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Evaluation

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Task 1

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Applying the regression expression $U_\mathrm{o} = a + b\Delta T$

to the measured values in Fig. 3, we obtain $b = 0.0587\,\frac{\mathrm{V}}{\mathrm{K}}$

with the standard error $s_\mathrm{b} = 0.0006\,\frac{\mathrm{V}}{\mathrm{K}}$

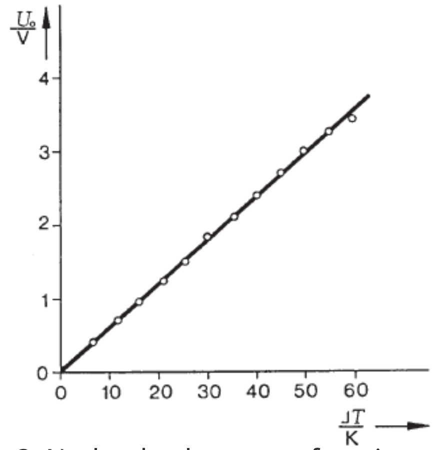

Fig. 3: No-load voltage as a function of the temperature difference.

Task 1 (part 2)

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The thermogenerator consists of 142 elements connected in series. The Seebeck coefficient of the semiconductor combination used is therefore

$\alpha_{1,2} = 4.13 \cdot 10^{-4}\,\frac{\mathrm{V}}{\mathrm{K}}$

with the standard error

$s_{\alpha 1,2} = 4.04 \cdot 10^{-4}\,\frac{\mathrm{V}}{\mathrm{K}}$

As the short-circuit also increases linearly with the temperature, the internal resistance of the thermogenerator is constant in the temperature range considered.

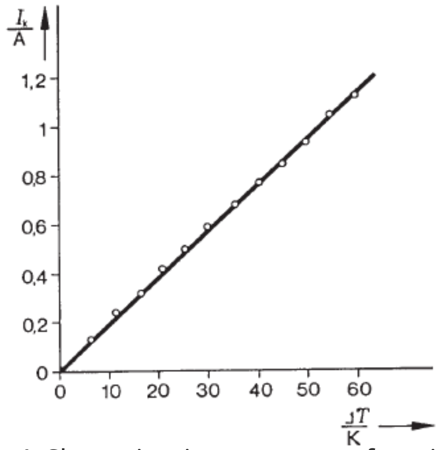

Fig. 4: Short-circuit current as a function of the temperature difference.

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Task 2

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Applying the regression expression $U = a + bI$ to the measured values from Fig. 5 we obtain

$a = U_\text{o} = 2.34\ \text{V}\ s_\text{a} = s_{\text{U}_\text{o}} = 0.01\ \text{V}$

and $|b| = R_i = 2.80\ \Omega\ s_\text{b} = s_{\text{R}_\text{i}} = 0.02\ \Omega$

and the short circuit current $I_\text{s} = \frac{U_\text{o}}{R_\text{i}} = 0.84\ \text{A}$ with $s_{\text{I}_\text{s}} = 0.01\ \text{A}$

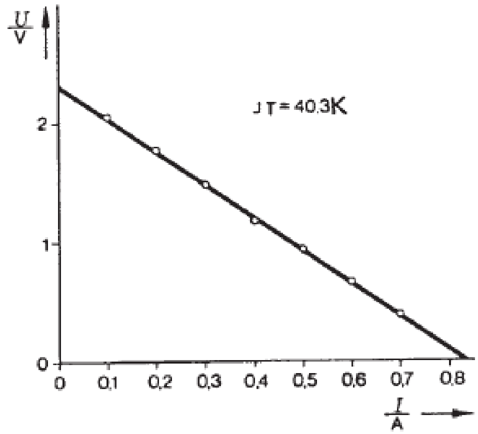

Fig. 5: Terminal voltage as a function of the current strength of a constant temperature difference.

Task 3

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From Fig. 6 we determine the slope of the (descending) curve at one point by drawing a tangent or by linear regression.

At a temperature difference ΔT of 40 K we obtain the following for the nearest measured values, using the regression expression $\Delta T = a + bt$:

$b = \frac{d\Delta T}{dt} = -0.0361 \frac{\text{K}}{\text{s}}$

We can thus work out the quantity of heat Q flowing through the generator in unit time in accordance with

$\frac{dQ}{dt} = P_\text{th.} = C \cdot (\frac{d\Delta T}{dt})$

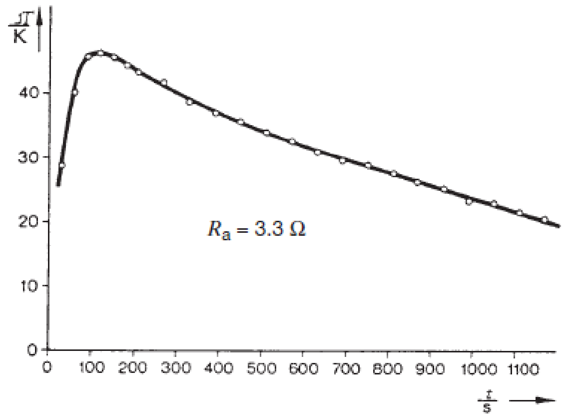

Fig. 6: Temperature difference as a function of time.

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Task 3 (part 2)

As the mass of water $m_w = 0.194\ \mathrm{kg}$ and the specific heat capacity if water

$c_\mathrm{w} = 4182\,\frac{\mathrm{J}}{\mathrm{K}}$ we optain $C = m_\mathrm{w} \cdot c_\mathrm{w} = 811\,\frac{\mathrm{J}}{\mathrm{kg\ K}}$

so that $P_\mathrm{th.} = 29.3\,\frac{\mathrm{J}}{\mathrm{s}}$

The electrical power, measured at constant load, P_{el}, can be obtained from Fig. 7. For a temperature difference $\Delta T = 40\ \mathrm{K}$ we obtain $P_\mathrm{el.} = 0.25\ \mathrm{W}$, so that the efficiency $\eta = \frac{P_\mathrm{el.}}{P_\mathrm{th.}} = 0.009 \text{ or } 0.9\%$

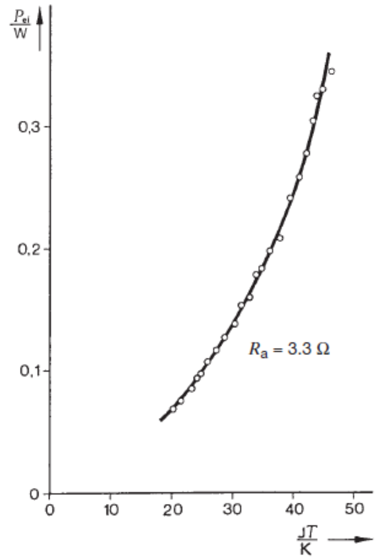

Fig. 7: Electrical power generated as a function of the temperature difference.

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