IIW6

Modul Thermodynamics

Peltier heat pump

In the current experiment, the thermoelectricity based on a Peltier heat pump will be examined. Under thermoelectricity, the reversible interactions between the physical size of temperature and electricity will be understood. This will be described by the Seebeck effect (also called thermoelectric effect), Peltier effect, and Thomson effect. In the current experiment, the heating and cooling capacity, and the efficiency of a Peltier heat pump under different operating conditions will be determined.

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1.1 Preliminary Questions

- What is the cause of thermoelectricity?
- From what does the size of the thermal power depend on?
- How does a thermal generator function?
- What is the Seebeck effect and what does it describe?
- What is the Peltier effect and what does it describe?
- What is the Thomson effect and what does it describe?
- What is the unit of the Seebeck, Peltier, and Thomson coefficients?
- What is the difference between the performance by Thomson and Joule?

1.2 Theory

1.2.1 Thermoelectricity

If two different metals are brought into contact with each other, the temperature-dependent contact voltage is developed as a thermal diffusion of conduction electrons. A temperature difference between the two contact points generates an electrical current (SEEBECK EFFECT). Also, the flow leads to an electrical current, along the flow direction of different solders against each other metals, to the fact that the one contact, depending on the flow direction of the current, cools and the other is heated (PELTIER EFFECT). Even in a homogeneous conductor, the flow of current generates heat if the temeperature gradient of the conductor is maintained (THOMSON EFFECT). The decisive factor is that, depending on the metal, the presence of such a temperature gradient between two points or more or less can be heated, as solely by the thermal conductivity, ie without current flow.

1.2.2 Contact potential

Between the available metal electrons and positive ions are attractive forces. To solve the freely moving conduction electrons of the metal, the so-called *work function* W_a against these forces of attraction is achieved. This work function corresponds to the depth of the highest occupied electron states and therefore, is dependently different from the kind of solid and generally for the different metals. If a contact between two different metals $a1$ and $a2$ with work function W_{a1} and W_{a2} (where $|W_{a1}| < |W_{a2}|$) is produced, so the electrons from the metal $a1$ move around to the metal $a2$. The metal $a1$ is therefore positive and the metal $a2$ is negative. The resulting space-charge produces an opposing electrical field, which is directed opposite to the flow and the electron drifts back again. Once the currents are equal in both directions, the system is in equilibrium. The potential ϕ of the two metals is shifted by the space charges, so that a *contact voltage* $U = \phi_2 - \phi_1$ arises (see Figure 1.1).
This contact voltage is equal and opposite to the difference of the two Fermi levels. In this state, equilibrium occurs, and therefore, the same number of electrons diffuse from 1 to 2, such that from 2 to 1 is a result of the resulting electric field. The fact that the contact stress depends on the temperature of the contact, it may be explained, that the particle concentrations n_1 and n_2 are considered. In thermal equilibrium, their two electron gases approximately describe

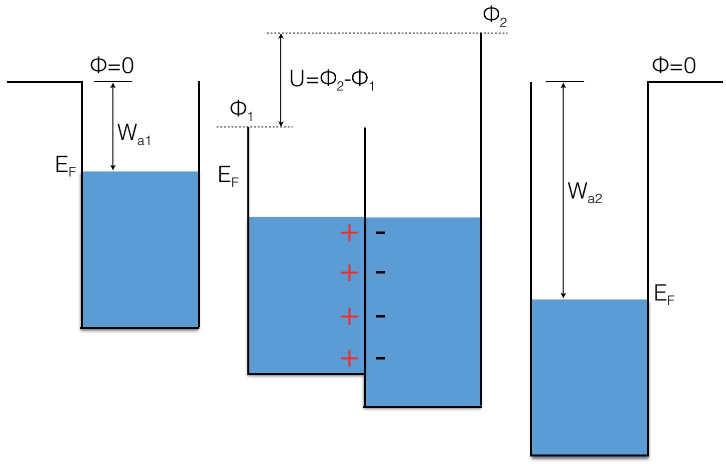

Figure 1.1: Schematic representation of the contact voltage $U = \phi_2 - \phi_1$ of two metals 1 and 2 with work functions W_{a1} and W_{a2}

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Boltzmann statistics.[1] The contact voltage is then given by the ratio of the particle number densities:

$$\begin{aligned} \frac{n_2}{n_1} &= \exp\left(-\frac{\Delta E}{k_B T}\right) = \exp\left(-\frac{(E_2 - E_1)}{k_B T}\right) \\ &= \exp\left(-\frac{e(\phi_2 - \phi_1)}{k_B T}\right) = \exp\left(-\frac{eU}{k_B T}\right) \end{aligned} \tag{1.1}$$

and is given by:

$$U = \frac{k_B T}{e} \ln\left(\frac{n_1}{n_2}\right) \tag{1.2}$$

1.2.3 Seebeck effect

We now form both connected metals to a ring. Leave the ring open, so that it forms an electric field between the two open ends, connect the two ends, so that they are from the same contact stress. The current does not flow because the two voltages are mutually connected. First through the heating of one contact point are both contact stresses (despite an identical ratio n_2/n_1) are different so that a *thermal current* flows. The necessary energy comes from doing the Heat source.
This property is used in so-called *thermocouples*. Turn it into a closed ring made of two different metals in the metal, using a voltage measurement device, one can measure the *thermal voltage*. This depends on the previous considerations, in addition to the characteristic properties of the two metals only to the temperature from between the two contact points. Bring to a contact point on a constant temperature and allow the circuit to be a very sensitive thermometer with large heat capacity and very low inertia.
According to the previous considerations, this thermal stress can be thus calculated using the

[1]Due to the high density of the electron gas in the metal, the electrons follows a Fermi distribution. The limit $\Delta E \gg k_B T$ still applies to them, but is approximately Eq. (1.1).

formula (1.2) expressed:

$$\begin{aligned} U_{th} &= \Delta U = U_2 - U_1 \\ &= \frac{k_B}{e} \ln\left(\frac{n_1}{n_2}\right) \Delta T \end{aligned} \tag{1.3}$$

The material-dependent properties are also the so-called *Seebeck coefficients* S_A, S_B ($[S_i] = V/K$) merged according to:

$$U_{th} = (S_A - S_B)(T_1 - T_2) \tag{1.4}$$

The Seebeck coefficients are temperature dependent and strongly depend in semiconductors on the doping impurity

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Depending on the combination of metals, Eq. (1.3) is in a small or wider range of ΔT. More generally, obtained by using the Fermi distribution, the following is also valid for higher powers of the ΔT expression:

$$U_{th} = a \cdot \Delta T + b \cdot \Delta T^2 \tag{1.5}$$

The sensitivity of such a thermocouple is expressed by the *thermal power*, which is given by the change in thermal stress with temperature:

$$F_{th} = \frac{dU_{th}}{dT} = a + 2B\Delta T \tag{1.6}$$

Under the direct conversion of heat energy into electrical energy, which offers *thermal generators* the clear advantage that with them, there is no detour going between the mechanical energy.

1.2.4 The Thermal generator

The thermal generator consists of two materials 1 and 2, the heat is throughout a large-area bridge contact on its upper side. The bottom of both materials is maintained at the same temperature T_0. Now, one may (through resistance R) be connected, and receive the electric power from the thermovoltage. Unlike other heat engines, the efficiency for thermodynamic reasons, is much smaller than $(T - T_0)/T$. The efficiencies of $p-$ and $n-$ type semiconductors are between 8 and 10%, respectively.
In the current experiment is such a thermal generator. The generator block is located between two nickel-plated copper plates of 142 semiconductor thermocouples. By means of heat transfer, 10mm thick copper plates, each with a 7mm- bore for receiving a thermometer, are provided. Electrically, the thermocouples are in series and switched to increase the output voltage.

1.2.5 Peltier effect

The so-called Peltier effect is the reverse of the generation of a thermal stream. If a contact between two materials A and B is in the order ABA and can pass a flowing stream, then the one contact point cools the other heat themselves. This temperature change would be much stronger than we achieved by *Joule heat*. Reversing the current leads as well to reversing the

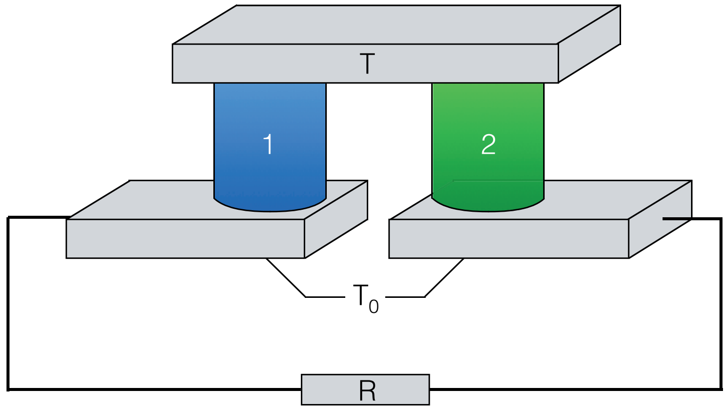

Figure 1.2: Schematic diagram of a thermal generator.

sign of the temperature $\Delta T_{1,2}$ at the two contact points. The generated heat at the contact point of the thermal input is proportional to the current I, in accordance with:

$$P = \frac{dW}{dt} = (\Pi_A - \Pi_B) \cdot I \tag{1.7}$$

where Π_A and Π_B are the Peltier coefficients of materials A and B, respectively. The sign of the thermal power P depends on the current direction. For $P > 0$, heat is generated, for $P < 0$, the contact point extracts heat, then cools. Between thermoelectric voltage U_{th} and the Peltier coefficient Π is the following relationship:

$$U_{th} = \frac{\Pi}{T} \cdot \Delta T \tag{1.8}$$

and between the thermopower F_{th} and the Peltier coefficient Π is the following relationship:

$$\Pi = F_{th} \cdot T \tag{1.9}$$

1.2.6 Thomson effect

The generation of heat when a current flows in a homogeneous conductor is also possible if a temperature gradient $\Delta T / l$ is maintained. The heat output in this case is:

$$P = -\sigma \cdot I \cdot \Delta T \tag{1.10}$$

where σ corresponds to the *Thomson coefficients*. In contrast to the thermal output according to Thomson, the *Joule power* is proportional to I^2. The Thomson coefficient is by *Thomson relations* closely related with the Peltier-coefficients, the Seeback coefficients, linked with thermopower:

$$\begin{aligned} \Pi &= S \cdot T \\ \sigma &= T \cdot \frac{dS}{dT} \end{aligned} \tag{1.11}$$

1.3 Experiment

1.3.1 Equipment

Components	Number
Thermal generator with 2 watertanks	1
Universal Power Supply	1
Slide resistance 33 Ohm, 3,1 A	1
Flow heat exchanger	1
Heatsink	1
Tripod	1
Digital multimeter	4
Hot/cold air blower	1
Distributor	1
Heating coil with sockets	1
Thermometer -10...+50 °C	2
Digital stopwatch	1
Support rod	1
Double socket	1
Thermal compound	1
Universal clamp, screw on movable side	1
Connector	2
Laborthermometer, -10...+100°C	1
Connecting line 32 A, 750 mm, blue	2
Connecting line 32 A, 750 mm, red	1
Connecting line 32 A, 500 mm, red	3
Connecting line 32 A, 500 mm, blue	2
Connecting line 32 A, 250 mm, red	3
Rubber hose, Inner-d = 6 mm	1

1.3.2 Experimental setup and execution

Note: This experiment is using with water AND electrical equipment. In dealing with the water, remove dust, empty the water tank only over the sink.

Determination of cooling capacity P_c of the pump as a function of the current and calculation of of the efficiency η_c at maximum power

- Attach the flow heat exchanger to a cold water bath flowing from the tap water on the warm side of the thermal generator. Make sure that the rubber seal is placed exactly and that the screws are firmly tightened, but not too tight.
- Ensure that the reflux tube extends into the sink.
- Buckle the heating coil, the thermal generator, and multimeter to the power unit according to Figure 1.3.
- Place the large two thermometers in the opening provided for the thermal generator. If necessary, use thermal grease to produce a better contact.
- Fill the water gently with tap water from the beaker.

- Turn the tap water on cautiously and until the flow heat exchanger is filled and the water flows out of the hose into the drain.
- Immerse the heating coil gently into the water.
- Unlock the power adapter.
- Choose an amperage and adjust the heating capacity with the sliding resistance such that the temperature difference between the cold and the warm side is negligible. The power then corresponds exactly to the cooling capacity. Measure 5 values: the heating current I_H, the heating voltage U_H, current I_p, voltage U_p, and two temperatures T_h and T_c.
- Turn both currents and voltages to zero and turn off the power supply.

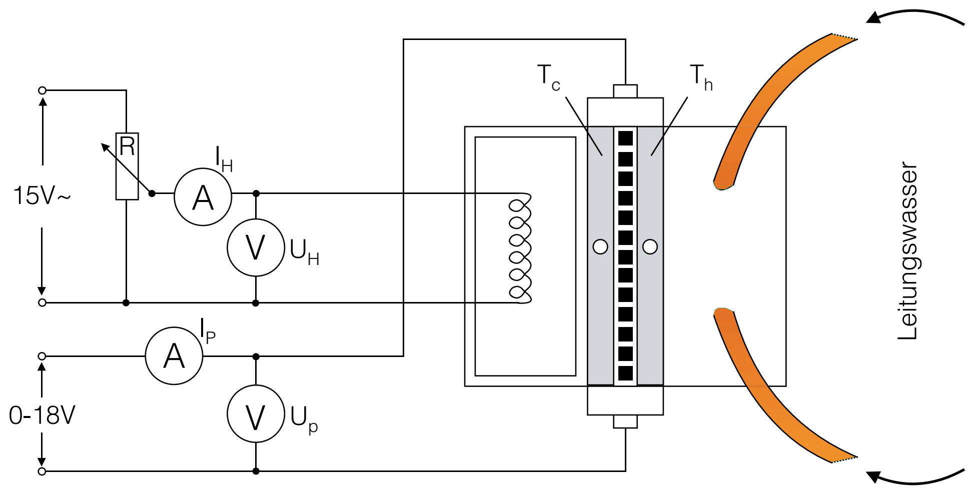

Figure 1.3: Setup for determining the cooling capacity.

Determine the heating power P_w of the pump and its efficiency η_c at a constant current and constant temperature on the cold side

- Carefully remove the heater coil.
- Wait about 10 minutes until the temperature has stabilized.
- Return the flow of current in a way that the water in the bath is now heated.
- Unlock the power adapter.
- Measure the temperature rise of the water T_w as a function of time at a constant current I_p during 20min. Measure also I_p, U_p und T_c.
- Turn both the amperage and voltage to zero and turn off the power supply.
- Weigh a copper block that the strip as the water.
- Turn off the tap.
- Remove the heat generator from the circuit and move it carefully without spilling water and pour it in the sink.

Determination of P_w, η_w and P_c, η_c from the relationship between temperature and time.

- Open the screws of the thermal generator in the sink and empty the two containers out. Dry them off with paper towels.
- Attach now on both sides of the thermal generator a water bath, then close the thermo-generator back to the circuit and fill both baths careful with tap water from the beaker.
- Wait about 10 minutes until the temperature has stabilized.
- Unlock the power adapter.
- Measure at constant current I_p, the temperatures T_h and T_c as a function the time and jot out the values âĂŃâĂŃof I_p and U_p during 20 min.
- Turn both the amperage and voltage to zero and turn off the power supply.
- Remove the heat generator from the circuit and move it carefully without spilling water and pour into the sink.

Investigation of the temperature behavior when the pump for cooling the air-cooled hot side is used

- Open the screws of the thermal generator in the sink and empty the two containers out. Dry them off with paper towels.
- Attach now to the cold side of the water bath and on the warm side of the cooling body and close the thermal generator back to the circuit. Fill the water bath with water from the beaker.
- Wait about 10 minutes until the temperature has stabilized.
- Unlock the power adapter.
- Measure the temperature on the cold side as a function of time, once in static atmospheric air and once additionally with cold air from the hair dryer during 20 min.
- Turn both the amperage and voltage to zero and turn off the power supply.
- Remove the heat generator from the circuit and move it carefully without spilling water and pour it into the sink.
- Open the screws on the thermal generator in the sink and empty the two containers out. Dry them off with paper towels.

1.3.3 Tasks for Evaluation

Determination of the cooling capacity P_c of the pump as a function of the current and calculation of efficiency η_c at maximum power

- Plot the cooling capacity P_H against the current I_p.
- Determine the efficiency η_c at maximum power.
- Discuss your observations.

Determination of the heating power P_w of the pump and its efficiency η_c at constant current and constant temperature on the cold side

- Calculate the heat capacity of the copper block, the metal bath, and the water and the total heat capacity.
- Plot the temperature T_w versus time.
- Determine the heating capacity P_w of the pump.
- Calculate the efficiency η_c.
- Discuss your observations.

Determination of P_w, η_w und P_c, η_c from the relationship between temperature and time on the hot and cold sides

- Plot the temperatures T_c and T_w versus time.
- Calculate the heating and cooling capacity.
- Compute both efficiencies η_c and η_w.
- Discuss your observations.

Determination of the temperature behavior when the pump is used to cool down the hot, air-cooled side.

- Plot for both series of measurements the temperature T_c as a function of time.
- Discuss your observations.

1.4 Literature

- D. Meschede, "*Gerthsen Physik*", Springer Verlag, Berlin Heidelberg
- W. Demtröder, "*Experimentalphysik 2*", Springer Verlag, Berlin Heidelberg