Swiss Physics Olympiad 2024, Aarau, March 9, 2024

Experimental task
Thermoelectric effcts

Duration 180 minutes
Maximal number of points: 48

Allowed aids	**Calculator without formulae memory** **writing and drawing material**

Contents

PHYSICS OLYMPIAD is supported by

Supported by :

Staatssekretariat für Bildung, Forschung und Innovation
Deutschschweizerische Physikkommission VSMP / DPK
EMPA - Materials Science & Technology
Ecole Polytechnique Fédérale de Lausanne
ETH Zurich Department of Physics
Fondation Claude & Giuliana
Ernst Göhner Stiftung, Zug
Hasler Stiftung, Bern
Metrohm Stiftung, Herisau
Neue Kantonsschule Aarau
Novartis
Swiss Academy of Engineering Sciences SATW
Swiss Academy of Sciences
Swiss Physical Society
Università della Svizzera italiana
Universität Bern FB Physik/Astronomie
Universität Zürich FB Physik Mathematik

1. List of materials (Fig ...)

The following material is available for the experiments

- Board with measuring setup, temperature display and wire resistor
- VOLTCRAFT or PeakTec power supply unit (see APPENDIX A1 or A2)
- 10 V power supply unit for temperature measurement and fan (plug-in power supply unit)
- 2 cables with banana plugs (red/blue) with clamp
- 2 cables with banana plugs (red/blue) with terminal
- 2 cables with banana plugs on both sides
- 1 crocodile clip
- Multimeter
- Cardboard box as a cover for the LED
- Paper for graphical analyses

Safety instructions

The cables with the banana plugs may only be plugged into the power supply unit, the experimental unit and the multimeter. They must never be used at the mains socket**: Danger of death!**

2. Thermoelectric effects

Two thermoelectric phenomena will be investigated in the following experiments. These are the Seebeck effect and the Peltier effect. The Seebeck effect is used to determine the efficiency of an LED.

Peltier effect

An electric current I flows through a series connection of two different metals or semiconductors, as shown in Fig. 1. The electric current is associated with the transport of heat by the electrons. This heat transport depends on the properties of the metal (or semiconductor). We assume that the heat flow in metal 2 is greater than in metal 1 (indicated by the arrows). As a result, less heat flows in at contact point A than flows out, and the opposite is true at contact point B. Accordingly, contact point A cools down and B heats up. Net heat is transported from contact point A to contact point B. The heat flows are in good approximation proportional to the electric current. This effect is called the Peltier effect. The direction of the heat flows also changes when the direction of the current is reversed.

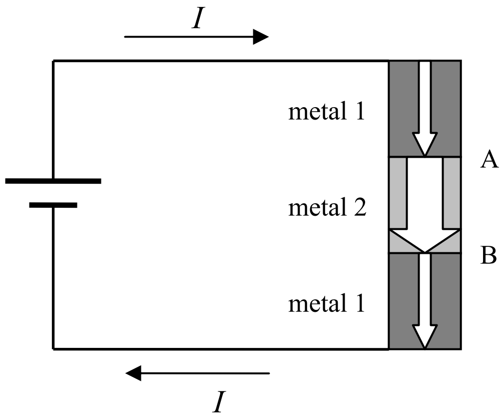


Fig. 1

Peltier devices are used, for example, to cool detectors or electronic circuits. Their efficiency is too low for refrigerators or heat pumps.

Seebeck effect

The arrangement of the metals is as in Fig. 2. If the contact points A and B are not at the same temperature, an electrical voltage U is generated across the connections on the metals. This effect is called the **Seebeck** effect.

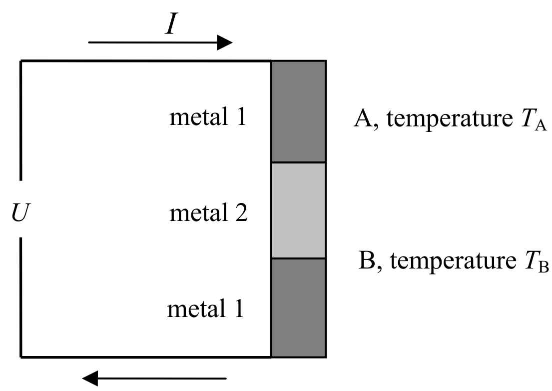


Fig. 2

3. Quantitative description of the Peltier effect

Different heat flows occur in a current-carrying Peltier device. The cold (respectively hot) side is labelled C (respectively H). The heat flows are powers and have the unit [P] = J/s = W.

A simplified model is used for the following considerations, but it captures the most important phenomena.

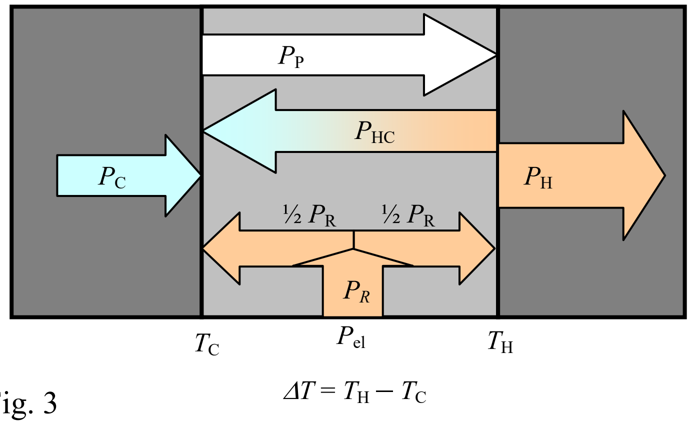


Fig. 3

We look at the individual heat flows (see Fig. 3):

1. Heat flow due to the Peltier effect $P_P = \Pi \cdot I$ (Π : Peltier coefficient)
2. Heat flow due to thermal conduction of the Peltier device $P_{HC} = \Lambda \cdot \Delta T$
3. Heat flow generated by the Joule effect of the electric current in the resistance R of the Peltier device: $P_R = R \cdot I^2$.
   This heat flows away in equal parts to the hot (H) and cold (C) sides.
4. Heat load on the cold side (utilisation effect) P_C (this flow could, for example, come from an electronic device to be cooled).

The heat flowing towards (respectively away) from the cold interface (C) is counted as positive (respectively negative), the balance must be = 0.

$$P_C + P_{HC} + ½ P_R - P_P = 0, \qquad (1)$$

expressed with the variables ΔT, R, Π, Λ and I

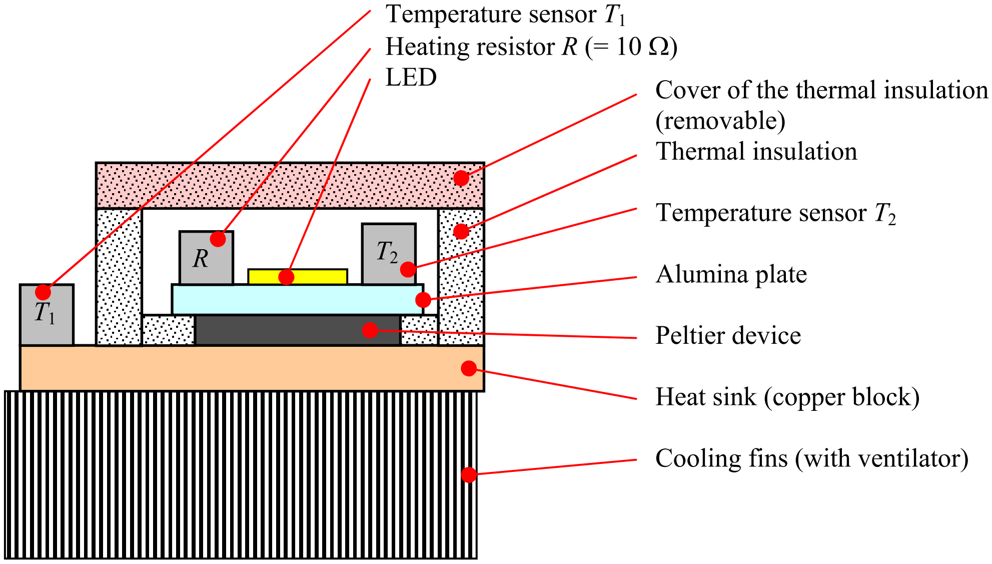
$$P_C + \Lambda \cdot \Delta T + ½ R \cdot I^2 - \Pi \cdot I = 0. \qquad (2)$$

This considers the fact that half of the heat from the Joule effect P_R flows to the hot side and half to the cold side.

4. Description of materials

4.1 Set-up of the measuring system (schematic)

The Peltier device is mounted on a heat sink to which it can transfer heat (the temperature of this side is measured with sensor T_1, the heat sink is cooled with a fan). An aluminium plate is mounted on the other side of the Peltier device. A heating resistor *R*, an LED, and a temperature sensor T_2 are mounted on it in thermal contact. Thermal insulation is fitted around the entire device to prevent heat inflow or outflow and condensation/icing. The cover of the thermal insulation must be removed for the experiment with the LED so that it can emit light freely (task 5).

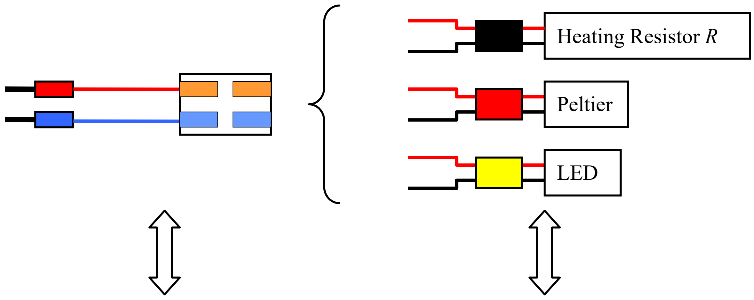


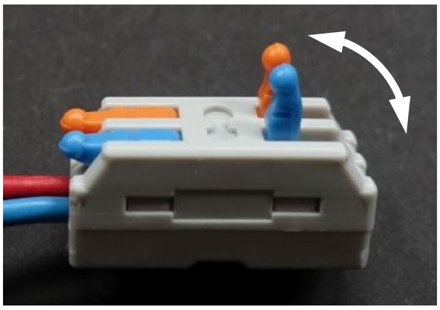
4.2 Cable with banana plug / Clamp / Cable for resistor / Peltier device / LED

The heating resistor, the Peltier element and the LED are connected to the two wires with banana plugs using a terminal.

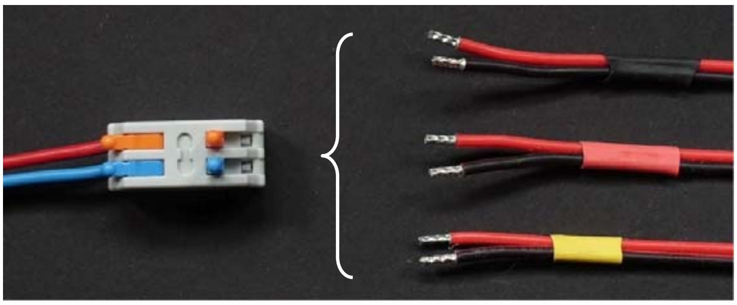
Please note: The polarity must be observed when connecting the Peltier element and the LED (see the individual tasks). The colour of the cables is important, the banana plugs may have different colours (e.g. white or black instead of red, or green instead of blue).

Labelling of the conductors: + (plus) red
– (minus) blue or black





The clamp can be closed or opened using the coloured levers. If the levers are pointing upwards as shown in the picture, the terminal is open. Open the terminal fully, insert the conductor fully, then close the terminal!



Depending on the application, one of the cables on the right-hand side is connected to the terminal. Note the colour coding (black, red, any yellow) of the cables.

4.3 Temperature display / fan

There are two versions of the temperature display

- With one display unit. The temperature sensor to be displayed can be selected using a switch:
  - Switch down T_1
  - Switch upwards T_2

- With two display units. The displays are as follows:
  - Left display T_1
  - Right display T_2

The fan runs when the display unit is connected to the mains using the small black mains adapter. If the fan is to be switched off, the black mains adapter must be unplugged from the socket.

Task 1	Mathematical relationships (Peltier effect)	8 points
In this task, the mathematical relationships are to be worked out with which the measurement results are later analysed.		

Task 1.1

Determine the units of the variables Π (Peltier coefficient) and Λ (heat conduction coefficient).

Task 1.2

a) Express the temperature difference ΔT in the other variables of equation (2).
b) How does ΔT behave as a function of I ?
c) Draw a sketch of the graph $\Delta T(I)$ for the case $P_C = 0$. Calculate the characteristic points of the graph and enter them in the sketch.
d) What influence does P_C have on the graph of $\Delta T(I)$?

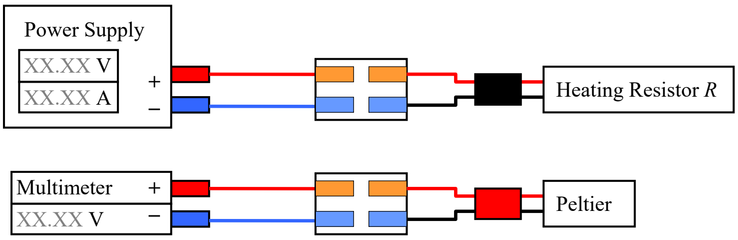
Task 2	Seebeck effect	10 points

If there is a temperature difference across a Peltier device, an electrical voltage is generated at the connections of the Peltier device; this effect is called the Seebeck effect. This effect will be investigated in this experiment.

Preparation:

Connect the heating element to the power supply (current and voltage at the beginning = 0). The polarity of the connection is not important here. The voltage at the Peltier device is measured with the multimeter. Switch on the displays/ventilator.

Electrical connections:



Task 2.1

Measure the voltage U_{Peltier} and the temperature difference ΔT across the Peltier device for at least 5 heating powers P_{Heater} in the range from 0 to ≤ 10 W. Note the measured values in a table.

Note:

The electrical power P_{Heater} of the measuring points should be evenly distributed in the range P_{Heater} from 0 to ≤ 10 W. Plan the measurement and document your considerations.

Task 2.2

Show graphically:

a) P_{Heater} as a function of U_{Peltier}

b) U_{Peltier} as a function of ΔT

Task 2.3

What is the relationship between the voltage U_{Peltier} and the temperature difference ΔT?

a) Express this relationship as $U_{\mathrm{Peltier}} = f(\Delta T)$

b) There is a constant in the function $U_{\mathrm{Peltier}} = f(\Delta T)$. Determine its value.

What is the relationship between the voltage U_{Peltier} and the heating power P_{Heater}?

a) Express this relationship as $P_{\mathrm{Heater}} = f(U_{\mathrm{Peltier}})$

b) There is a constant in the function. Determine its value.

Task 3	Peltier effect	13 Pt

As described in the introduction, if an electric current flows through a Peltier device, heat is transported through the device and a temperature difference is created. This relationship is investigated in this experiment.

Note that the temperature difference does not occur immediately.

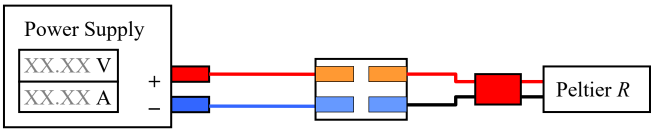
Preparation:

Connect the Peltier device to the power supply: Pay attention to the polarity here! The cables for the Peltier device are labelled red. Switch on the displays/ventilator.

- The red wire must be connected to the positive pole of the power supply unit and,
- The black one to the negative pole.

Start the measurement (task 3.1) with the lowest current.

Electrical connections:



Task 3.1

Measure the following values for at least 12 different currents up to a maximum Peltier current of I_P = 5 A (currents at approximately the same distance) and note them down:

- The temperatures T_1 und T_2
- The voltage U across the Peltier device

Caution!

- Large Peltier currents should only flow for as short a time as possible
- For a certain current, the temperatures do not set immediately

Task 3.2

a) Plot the measured data $\Delta T(I_P)$ from task 3.1.

b) Plot the voltage U_P across the Peltier device as a function of I.

Task 3.3

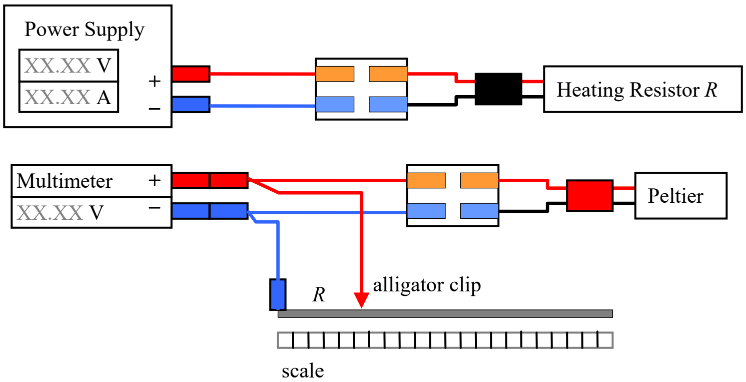
Determine the quantities Π, Λ, and R from the results of task 3.2 using the findings from task 1.2.

Task 4 Thermo-Electric Generator 12 Pt

This task involves using the Peltier device as a thermoelectric generator. A temperature difference across the Peltier device generates a voltage at its connections, which delivers an electrical power P_{Load} to a connected load resistor R. The load resistance for which the electrical power is a maximum is to be determined (power matching).

Load resistor:
A resistor wire mounted on a wooden board. A cable with a banana plug can be connected to a socket at one end. The wire can be tapped at any desired point using an alligator clip and a desired load resistor can be selected. The length of the resistor wire in use can be measured by a scale (in cm/mm).

Electrical connections:



Switch on the displays/ventilator.

Task 4.1 Characterisation of the load resistance

The resistance per unit length of the wire is unknown and should be determined. Do not use the multimeter's ohmmeter for this, as it is too inaccurate. Suggest a measurement method that works with the material available and carry it out.

Note:
The resistance wire can be loaded with a current of up to 1.0 A. Its resistance is practically constant for various temperatures.

Task 4.2 Determination of the load resistance for maximum power output

The same set-up is used as in task 2, with the following exception:

- In addition to the voltage measurement, a load resistor is connected across the Peltier device.

Set a heating power of $P_{Heater} \sim 7$ W, it should be constant in the experiment.

a) Determine the electrical power P_{Load} (R) delivered by the Peltier device for different load resistances R. The temperatures T_1 and T_2 must also be noted for each measuring points.
b) Plot P_{Load} (R) graphically and determine the load resistance P_{Load} with the maximum power output.

Task 4.3 Thermodynamic efficiency

The thermoelectric generator is a thermodynamic machine for which the 2nd law of thermodynamics applies. Determine the theoretical maximum possible efficiency at the maximum power output in the experiment (task 4.2) and compare it with the efficiency achieved from the data in task 4.2.

Task 5 Efficiency of an LED 5 Pt

The aim of this task is to determine the efficiency η_{LED} of an LED by means of a measurement.

The efficiency η_{LED} is defined by:

$$\eta_{\text{LED}} = \frac{\text{emitted light power}}{\text{electrical power}} = \frac{P_{\text{Light}}}{P_{\text{el}}} . \qquad (5.1)$$

To simplify matters, it is assumed that the electrical power is converted into the emitted light power P_{Light} and into heat power P_{Heat}:

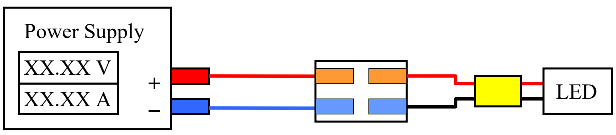
$$P_{\text{el}} = P_{\text{Light}} + P_{\text{Heat}} \qquad (5.2)$$

The heat output P_{Heat} is transferred from the LED to the heat sink via the Peltier device, in the same way as the heat output of the electrical resistor in task 2.

Preparation:

- The cover (red) of the thermal insulation must be removed for this measurement so that the LED can emit the light freely. The cover (red) is attached to the lower part (white) with small nails. Ask the supervisor for help to remove this cover.
- The LED can be very bright during operation. A cardboard box must be placed over the measuring device so that nobody is dazzled. **Never look into the LED when it is in operation, it can be very bright!** Only apply a voltage to the LED when it is covered with the box.
- Pay attention to the polarity of the LED: The cable has a yellow marking, the red wire of the cable is connected to the positive pole, the black wire to the negative pole of the power supply unit.
- Set a current limit of 0.9 A on the power supply unit.
- The voltage across the LED can be increased for the measurement from $I = 0$ until the current limit is reached (this is the case with a voltage U_{LED} of approx. 10 V). Work with this setting.
- With thermal measurements, temperatures are not set immediately, so a certain amount of patience is required.
- Switch on the displays/ventilator.

Electrical connections:



Task 5.1

Carry out the measurement and calculate the efficiency η_{LED} of the LED.

APPENDIX A1 Power Supply PeakTech

Current and voltage can be set on this power supply unit. Voltage and current limits can also be set. Depending on the connected load, the voltage or current limit comes into effect.

Setting the limit values (preparation)
The device has an 'Output' switch that can be used to switch the output of the power supply unit on or off. The status is indicated on the display by a red LED above the label 'output' (red display = output switched on).
If the output is switched off, the limit values can be set using the two 'VOLTAGE' and 'CURRENT' controls; the values are shown on the display.

The values can be set to coarse and fine. Switching between coarse and fine is done by pressing the control for the corresponding quantity (VOLTAGE or CURRENT). After pressing, the selected digit flashes briefly on the display. The coarse and fine settings are as follows:

VOLTAGE: XX.XX or XX.XX (in 1 V or 0.01 V increments)
Current X.XX or X.XXX (in 0.1 A or 0.01 A steps)

Operation with load
After preparation, the output can be switched on by pressing 'OUTPUT'. The two digital displays (blue) now show the actual voltage and current. Depending on the load, one or the other limit is reached. The display 'C.V' (voltage) or 'C.C' (current) indicates which limit has been reached. Note: If the output is switched off, 'C.V' lights up, this is of no significance.

Tips
Depending on the experiment, you may want to set either the voltage or the current in certain steps. If you want to set a voltage series, for example, proceed as follows: With the output switched off, set the maximum current that you do not want to exceed. The limit for the voltage is set to 0 V at the beginning. If the output is switched on, the voltage at the output is 0 V and no current flows. The desired voltages can now be set with the 'VOLTAGE' control (they are shown on the voltage display), either in 1 V or 0.01 V increments). For a current series it is the other way round: With the output switched off, select the voltage limit and the current limit = 0 A at the beginning.

Mains switch on the back!

Voltage display (limit or current value)

Current display (limit or current value)

C.V Voltage limit reached

C.C Current limit reached

output (Output switched on)

VOLTAGE: Voltage setting

CURRENT: Current setting

OUTPUT: Switch for output

Sockets for connection (the green connection can be ignored)

APPENDIX A2 Power supply unit VOLTCRAFT LSP-1403

Current and voltage can be set on this power supply unit.

The output can be switched on or off (OUTPUT ON button). When the output is switched on, a green LED lights up. When the output is switched off, 0.00 V and 0.00 A are displayed for the voltage and the current.

The two rotary knobs VOLT (voltage) and CURR (current) set limits for current and voltage. The REVIEW button must be pressed continuously for the set limits to be displayed.

When the load is connected and the output is switched on, either the voltage or current limit is reached depending on the load. This is indicated by one of the two LEDs on the right of the display (C.V. green = voltage limit, C.C. red = current limit. During operation, the preselected limits are shown on the display by pressing the REVIEW button.

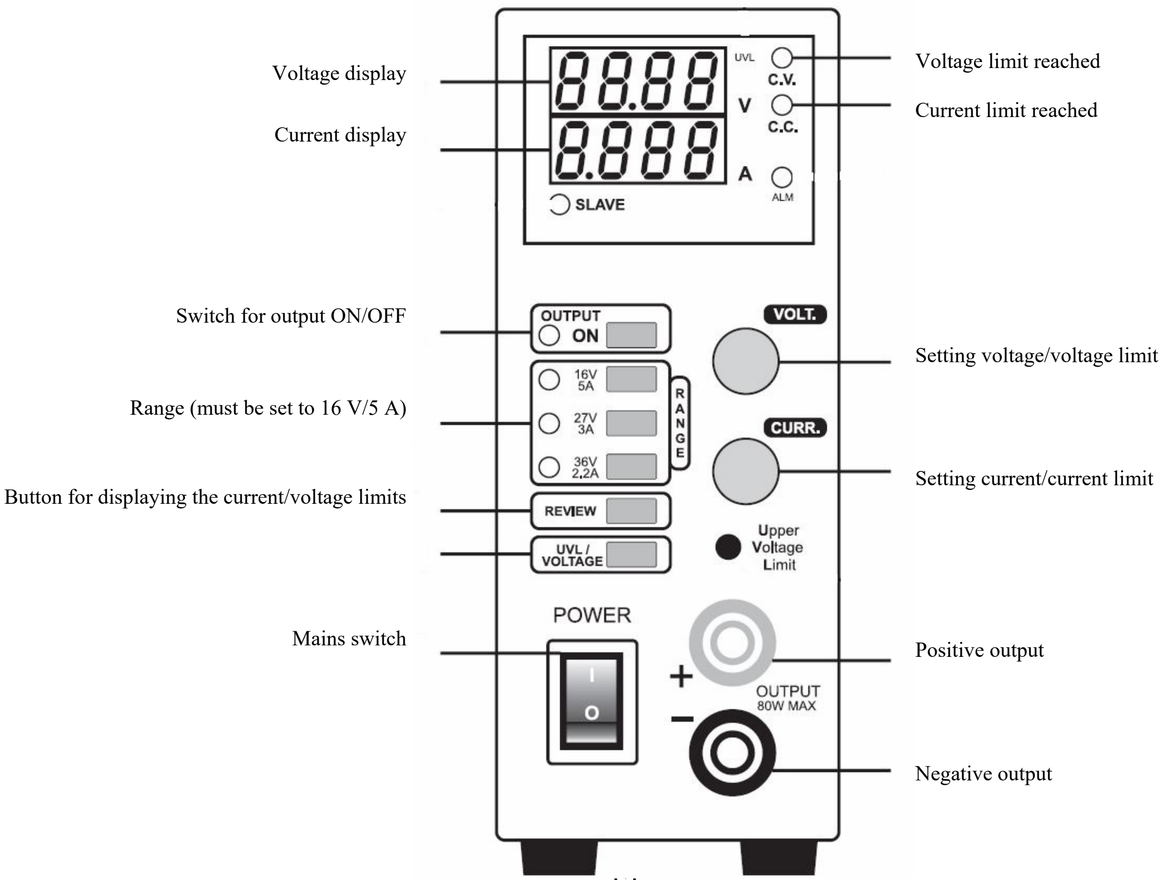
Of the other buttons, the following is also important: RANGE (three buttons). The range 16 V/5 A must be selected; this is automatically the case after switching on.

Tip:
Depending on the experiment, you may want to set either the voltage or the current in certain steps.

If you want to set a voltage series, for example, proceed as follows: with the output switched off, set a maximum current that you do not want to exceed (hold down REVIEW!). The limit for the voltage is set to 0 V. If you now switch on the output (with the load connected), the voltage at the output is 0 V and no current flows. The desired voltages can now be set with the VOLTAGE control (they are shown on the voltage display).

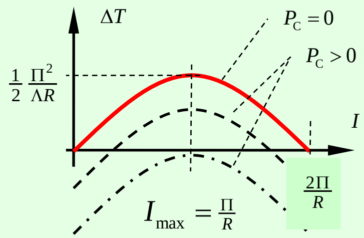
For a current series, it is the other way round: with the output switched off, select the voltage limit (hold down REVIEW!) and the current limit = 0 A. When the output is switched on, the current can then be gradually adjusted to the desired values.

Please note: Current and voltage cannot be set with a precision of 0.01 V and 0.001 A respectively. For example, if you want to set the voltage to 2.75 V, it may be that only the neighboring values 2.72 V and 2.84 V are possible. In this case, select 2.72 V (and use this as the measured value!).



Schweizerische Physikolympiade 2024 Lösung mit Punkteverteilung

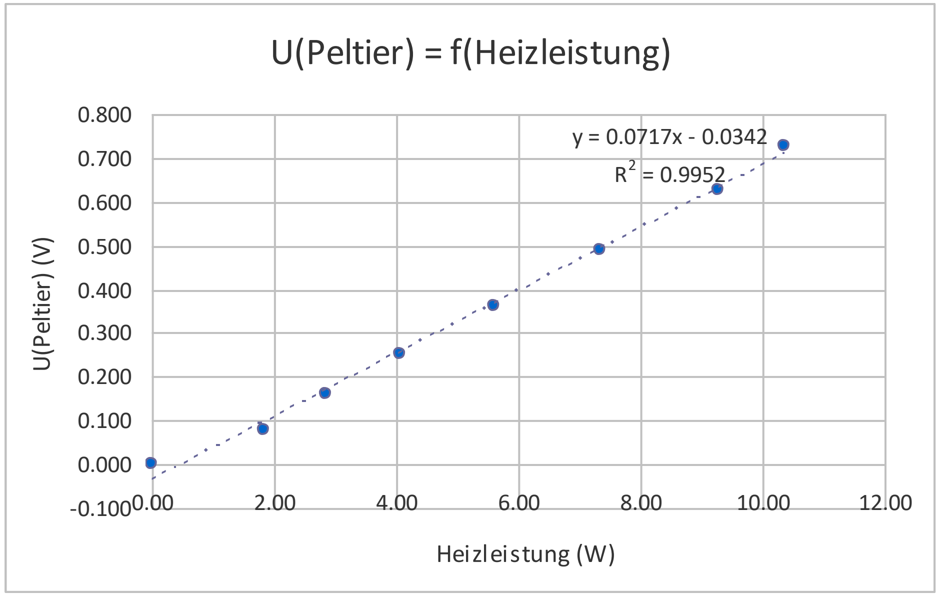
Experiment: Thermoelektrische Effekte

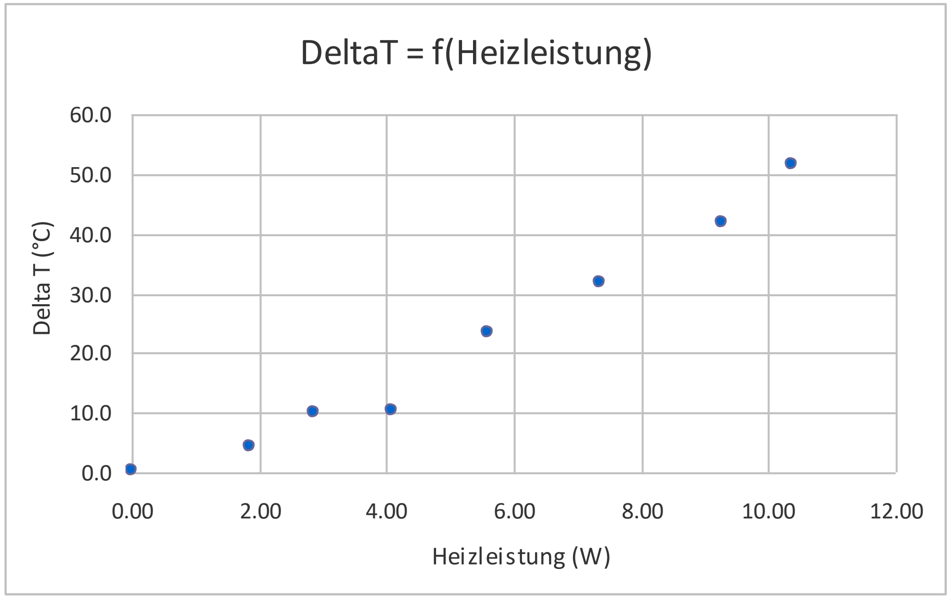
Aufgabe 1 Mathematische Zusammenhänge (Peltiereffekt)		**8 Pt**
L 1.1: $[\Pi]$ = W/A = V = kg m^2/(s^{3}A), , $[\Lambda]$ = W/K = kg m^2/(s^3 K)		**0.5 Pt** **0.5 Pt**
L 1.2: a) $\Delta T = \frac{\Pi \cdot I - \frac{1}{2} R I^2 - P_C}{\Lambda} = \frac{\Pi}{\Lambda} \cdot I - \frac{1}{2}\frac{R}{\Lambda} I^2 - \frac{P_C}{\Lambda}$	Umformung korrekt, sonst keine Pt.	**Delta T 2 Pt** **(alles oder nichts)**
b) ΔT ist eine quadratische Funktion in I, mit einer Parabel als Graphen, die drei **charakteristischen Grössen** **Scheitel** und **Nullstellen** sind beschriftet. Diese Grössen erhält man aus (3 Möglichkeiten)  *i)* $\frac{d(\Delta T)}{dI} = 0:$ $\frac{d(\Delta T)}{dI} = \frac{\Pi}{\Lambda} - \frac{R}{\Lambda} I = 0$, $I_{max} = \frac{\Pi}{R}$, $\Delta T_{max} = \frac{1}{2}\frac{\Pi^2}{\Lambda R}$, 2. Nullstelle $I = 2 I_{max} = 2\frac{\Pi}{R}$ *ii)* aus den bekannten Scheitelpunktsformeln, *iii)* elementar aus Symmetrieüberlegungen mit den Nullstellen der Funktion $\Delta T(I) = \frac{\Pi}{\Lambda} \cdot I - \frac{1}{2}\frac{R}{\Lambda} I^2 = \left(\frac{\Pi}{\Lambda} - \frac{1}{2}\frac{R}{\Lambda} I\right) I = 0$, eine NS ist trivial: $I_1 = 0$, die andere $I_2 = 2\frac{\Pi}{R}$, ΔT_{max} bei $I = \frac{1}{2} I_2 = \frac{\Pi}{R}$	Quadratische. Fkt. muss erkannt werden Parabel: nach unten offen, durch Ursprung Maximaler Wert von ΔT und dazugehöriger Strom müssen angegeben sein	**b) 4 Pt** **Draw or mention parabola: 0.5 Pt** **Each quantity (Vertex, x and y coordinate, x-coordinate of zero): 0.5 pt for value, 0.25 pt if drawn, total 3 Pt** **Label x and y axis: each 0.25 pt** **If wrong zero coordinates due to calculation error: -0.5 Pt**
c) Parabelschar wird für P_C↑ nach unten verschoben, siehe a) Für welches P_C ist $\Delta T = 0$?: $P_C = \frac{1}{2}\frac{\Pi^2}{R}$	Verschiebung der Parabel nach unten für $P_C > 0$	**1 Pt,** **0.5 Pt mentioning that it shifts, 0.5 Pt which direction**

Aufgabe 2 Seebeckeffekt		**10 Pt**
L 2.1 Berechnung der notwendigen Heizspannungen $P_i = \frac{P_{max}}{n} k, \quad U_i = \sqrt{P_i R} = \sqrt{\frac{P_{max}}{n} kR} = \sqrt{\frac{P_{max}}{n} R}\sqrt{k}$ n = Anzahl Messpunkte (>= 5) k = Laufindex Messpunkte (1 <= k <= n), P_{max} = maximale Leistung R: Widerstand des Heizelements, bestimmt aus einer Messung $R = U/I$ **Liste** mit mindestens 5 aequidistanen Spannungswerten Für R = 10 Ω, P_{max} = 10 W: U_i = 4.47/6.32/7.75/8.94/10.0 V **Tabelle** mit den Messresultaten U_{Heiz} I_{Heiz} (P_{Heiz} berechnet) T_1 T_2 ΔT (= $T_2 - T_1$)	Korrekte Herleitung der mind. 5 Spannungswerte (Stromwerte werden ebenfalls akzeptiert) Korrekte Berechnung der num. Werte Vollst. Tabelle mit Messwerten	**4 Pt** **Clear table: 0.5 Pt** **Correct units in table: 0.5 Pt** **Insert I_n od U_n: 0.5 Pt** **Insert T^1 and T^2: 0.5 Pt** **Formula U = sqrt(PR) or I = sqrt(P/R): 1 P** **Aequidistant distribution of values (2, 4, …10) or (1, 3, …9): 1 Pt**
L 2.2 Grafische Darstellung a) Grafik $U_{Peltier}$ als $f(\Delta T)$ b) Grafik P_{Heater} als $f(U_{Peltier})$	Korrekte graf. Darstellung	**a) 1 Pt** **b) 1 Pt** **subtract 0.5 Pt for:** - **False/no units** - **Up/W on the x-axis** - **No/unclear image**
L 2.3 Der Student muss selbst erkennen, dass $\Delta T = T_2 - T_1$ ist, Berechnung in der Tabelle Aufgabe 2.1 a) Aus den Grafiken erkennt man klar einen linearen Zusammenhang $U = S \cdot \Delta T$ b) die Konstante ist der Proportionalitätsfaktor S [S] = V/K mit der Steigung der besten Geraden aus L 2.2 a) für S Angabe der Werte mit korrekten Einheiten und sinnvollen SZ. c) Aus den Grafiken erkennt man klar einen linearen Zusammenhang $P_{Heater} = K \cdot U_{Peltier}$		**a) 1 Pt** **Correct formula y = mx 1Pt** **Subtract 0.5 Pt for y-intercept y= mx + q, q not 0** **b) 1 Pt** **Solution with derivation (no**

d) die Konstante ist der Proportionalitätsfaktor K $[K]$ = V/W mit der Steigung der besten Geraden aus L 2.2 b) für K Angabe der Werte mit korrekten Einheiten und sinnvollen SZ.		**matter whether slope or compare max difference). Subtract 0.5 Pt if no units and subtract 0.5 Pt if no derivation** **c) 1 Pt** **Correct formula y = mx 1Pt** **Subtract 0.5 Pt for y-intercept y= mx + q, q not 0** **d) 1 Pt** **Correct formula y = mx 1Pt** **Subtract 0.5 Pt for y-intercept y= mx + q, q not 0**

Heizung I (A)	Heizung U (V)	Peltier-Element U-Peltier (V)	Heizung P=U*I (W)	2.5 min warten, bis Ablesung Tc (°C)	Th (°C)	DeltaT (°C)
0.00	0.00	0.000	0.00	21.9	22.2	0.3
0.40	4.60	0.076	1.84	22.7	27.1	4.4
0.50	5.70	0.159	2.85	23.2	33.2	10.0
0.60	6.80	0.252	4.08	23.6	33.9	10.3
0.70	8.00	0.361	5.60	24.2	47.6	23.4
0.80	9.20	0.489	7.36	24.9	56.9	32.0
0.90	10.30	0.625	9.27	25.9	67.7	41.8
0.95	10.90	0.728	10.36	26.7	78.4	51.7



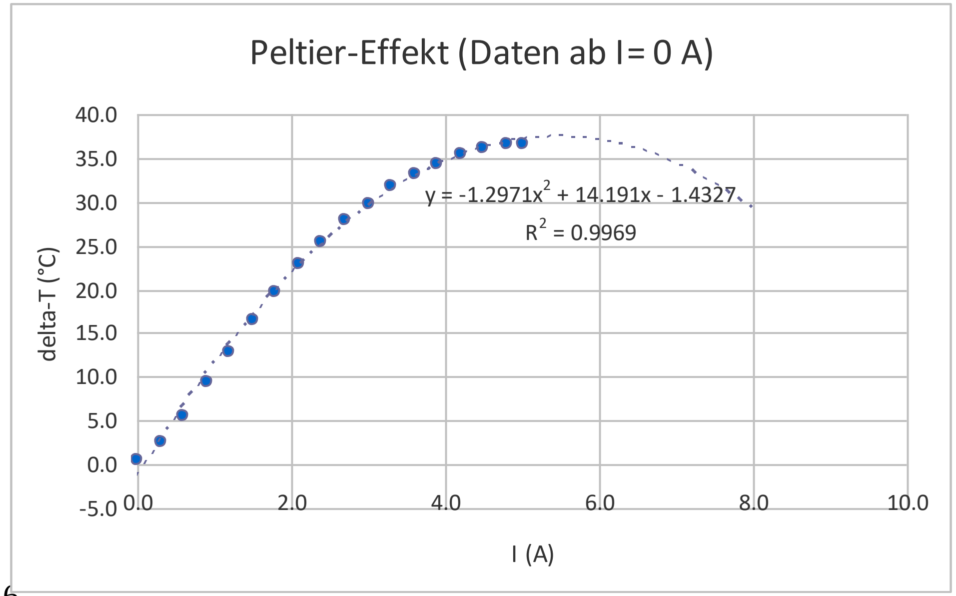


Aufgabe 3 Messung des Peltiereffekts		13 Pt
L 3.1 Tabelle mit Messresultaten, sauber dargestellt Mind. 12 Messwerte $\boldsymbol{I_{\mathrm{Peltier}}}$ $\boldsymbol{U_{\mathrm{Peltier}}}$ $\boldsymbol{T_1}$ $\boldsymbol{T_2}$ daraus $\boldsymbol{\Delta T = T_1 - T_2}$ Bemerkung das Vorzeichen von ΔT ist unwichtig		**4 Pt:** 0.2 pt per reasonable measurement, up to 2.4 0.6 table with correct labels and units 1 pt for measurements spread over a range of at least 4.5A
L 3.2 a) Grafische Darstellung $\Delta T = f(I_{\mathrm{Peltier}})$ b) Grafische Darstellung $U_{\mathrm{Peltier}} = f(I_{\mathrm{Peltier}})$ Achsen beschriftet, Einheiten, saubere Darstellung		**a) 1.5** **b) 1.5** For each: 0.3 data correctly plotted, 0.3 axes labels, 0.3 units, 0.3 size of plot, 0.3 axes drawn with ruler
L3.3 Es muss erkannt werden, dass man Messpunkte bis etwa zum Scheitel der Parabel hat. Mit den Erkenntnissen aus der Aufgabe 1.2 kann man aus der Grafik herauslesen: • **Strom $\boldsymbol{I_{\max}}$** für das Maximum von ΔT • **Maximum von $\boldsymbol{\Delta T}$** Aus diesen Werten kann man bestimmen • Den **Widerstand *R*** kann man aus der Steigung der Grafik Aufgabe 3.2/b) bestimmen • Π: Strom $I_{\max}$ für $\Delta T_{\max}$: $I_{\max} = \Pi/R$, $\Pi = R \cdot I_{\max}$ Λ: $\Delta T_{\max} = ½\, \Pi^2/(\Lambda R)$, $\Lambda = \frac{1}{2}\frac{\Pi^2}{\Delta T_{\max} R}$		**6 Pt** 1 pt value of R 2 pt idea to compute Π and Λ 0.5 pt correct eq for Π 0.5 pt correct eq for Λ 1 pt value of Π with units 1 pt value of Λ with units

Resultate Aufgabe 3

#	I (A)	U (V)	Tc (°C)	Th (°C)	DeltaT (°C)	R=U/I (Ohm)
1	0.0	0.00	22.1	22.6	0.5	#DIV/0!
2	0.3	0.26	20.1	22.7	2.6	0.87
3	0.6	0.51	17.1	22.7	5.6	0.85
4	0.9	0.81	13.4	22.7	9.3	0.90
5	1.2	1.05	9.7	22.6	12.9	0.88
6	1.5	1.34	5.9	22.4	16.5	0.89
7	1.8	1.60	2.7	22.4	19.7	0.89
8	2.1	1.86	-0.4	22.4	22.8	0.89
9	2.4	2.11	-2.8	22.6	25.4	0.88
10	2.7	2.35	-5.1	22.9	28.0	0.87
11	3.0	2.61	-6.9	22.9	29.8	0.87
12	3.3	2.85	-8.4	23.4	31.8	0.86
13	3.6	3.11	-9.6	23.6	33.2	0.86
14	3.9	3.36	-10.4	23.9	34.3	0.86
15	4.2	3.63	-10.6	24.9	35.5	0.86
16	4.5	3.90	-10.8	25.4	36.2	0.87
17	4.8	4.18	-10.6	25.9	36.5	0.87
18	5.0	4.38	-10.1	26.4	36.5	0.88

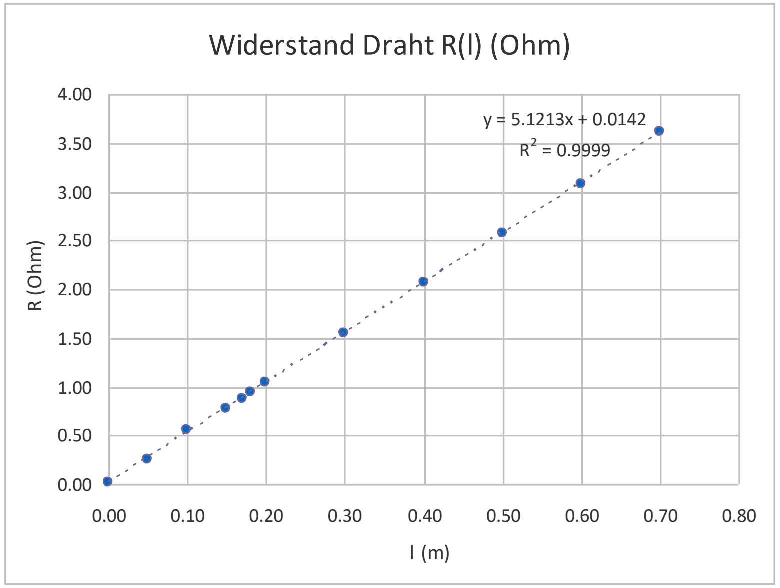
Peltier-Koeffizient:	4.18
I(max)*R	
(W/A = V)	
Wärmeleitungskoeffizient	0.27
(Imax*R/(2*DeltaTmax))	
(W/K)	

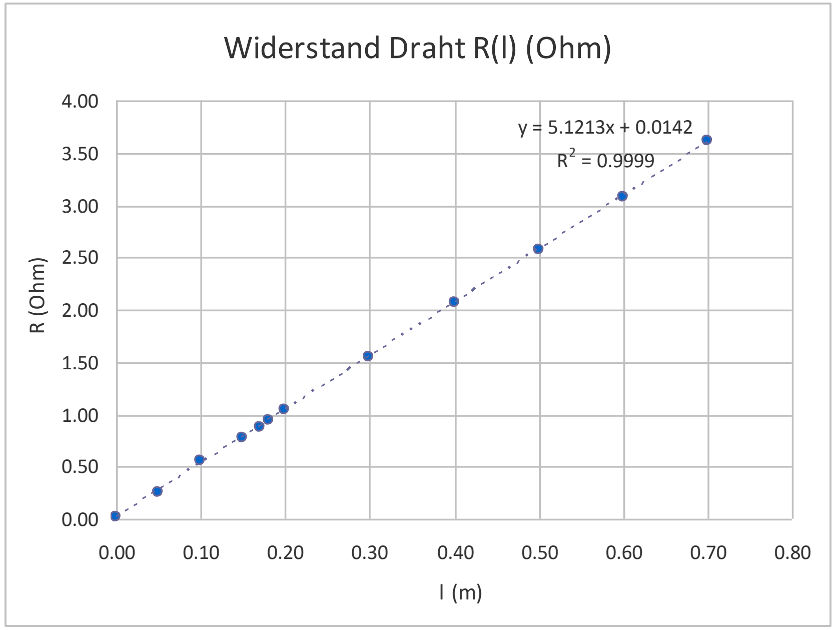


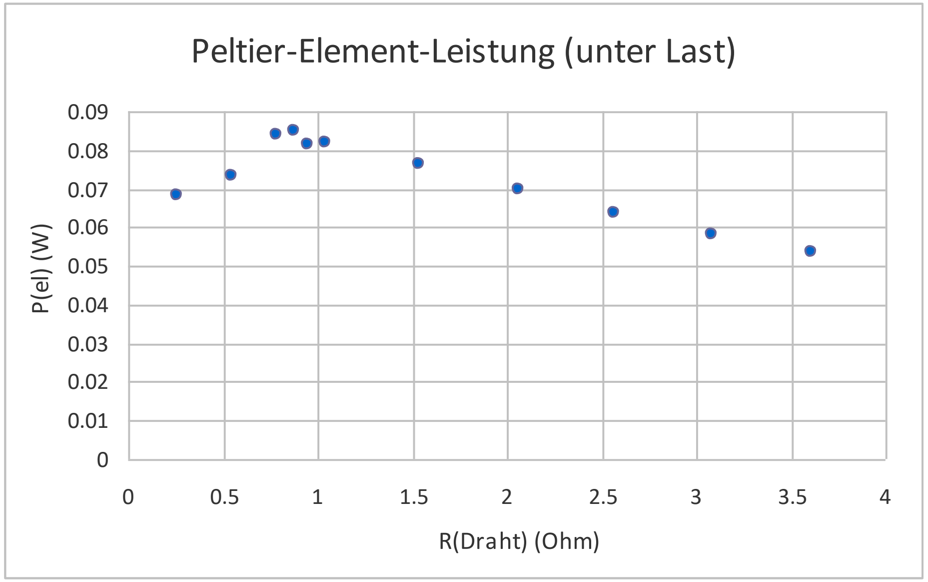
Aufgabe 4 Thermoelektrischer Generator		**12 Pt**
L 4.1 Ausmessung des Widerstandsdrahts: Der Widerstandsdraht wird an das Netzgerät angeschlossen: ein Anschluss an der Buchse, der 2. mit der Krokodilklemme möglichst weit von der Buchse entfernt (Abstand zur Banenanbuchse). Man notiert • Den Strom *I* gemessen mit dem Netzgerät (typ. 1 A) • Die Spannung *U* gemessen mit den Netzgerät • Die Länge *d* des Drahts zw. Buchse und Krokodilklemme. Daraus kann man den spez. Widerstand/Länge R^*= berechnen $R^* = \frac{U / I}{d}$ Der Wert ist typisch 7.5 Ω/m oder praktischer 0.075 Ω/cm. ***Etwas aufwendigere Methode:*** Wiederum mit einem Messstrom von *I* = typ. 1 A. Man bestimmt für eine Reiche von Distanzen *d* von der Buchse entfernt die Spannungen *U* über der Widerstandstrecke. Die grafische Darstellung ergibt eine gute Gerade. Aus der Steigung kann R^* bestimmt werden. Eine allfällige Abweichung von einer Ursprungsgeraden deute auf Widerstand deute auf kabel und Kontaktwiderstaände hin, diese sollten aber typ. nicht grösser als 0.05 Ω sein.		**2 Pt** - **Measurement (no matter how many): 0.5 Pt** - **Rho = U/(Id) (give points if obviously used but not explicitly stated): 0.5 Pt** - **Value between 7 and 8 ohm/m: 0.5 Pt** - **Get value with a method removing offset, usually linear regression (offset corresponds to resistance in banana cable): 0.5 Pt**
L 4.2 (a) Tabelle mit Messresultaten **Position X_{Klemme}**, daraus berechnet R_{Load}, $U_{Peltier}$, daraus berechnet $I_{Load} = U_{Load}/ R_{Load}$, $P_{Load} = U_{Peltier} \cdot I_{Load}$ (b) Grafik $P_{Load} = f(R_{Load})$ mit Achsenbeschriftung Bestimmung Maximum von P_{Load}		**a) 4.5 Pt** **- 0.5 Pt for entering each of the following quantities:** **- position** **- resistance** **- $U_{peltier}$ or U_{Load}** **- current (if directly used for power, give this point aswell)** **- P_{Load} (note, this is power drop over the peltier element, see definition aside)** **- T1** **- T2** **Number of data points: of less than 6: 0Pt, between 6 and 8 (incl 6 and 8): 0.5 Pt, more than 8: 1 Pt**

		b) 1.5 Pt **each axis:** - **Labelling: 0.25 Pt** - **Units: 0.25 Pt** **Marking the maximum: 0.5 PT**
L 4.3 (prov. Werte), Rechnung mit absoluten Temperaturen Theoretisch möglicher WG $\frac{T_{\text{heiss}} - T_{\text{kalt}}}{T_{\text{heiss}}} = \frac{60-22}{60+273} = 0.11$ Im Experiment erreicht ca. 0.013 Das sind etwa 11 % des theoretisch möglichen WG **Bemerkung**: Bei zunehmender Belastung nimmt die Temperaturdifferenz über dem Peltierelement leicht ab, der thermoelektrische Generator arbeitet also nicht bei konstanter Temperaturdifferenz, dieser Effekt wird aber nicht berücksichtigt. Für die Berechnung des gemessenen Wirkungsgrades sollten aber die Temperaturwerte beim Leistungsmaximum verwendet werden. Die maximale Leistungsabgabe (Leistungsanpassung!) wird etwa erreicht, wenn der Lastwiderstand = dem Innenwiderstand des Peltierelementes ist.		**4 Pt:** - **$(T_h-T_l)/T_h$: 0.5 Pt** - **Using abolute Temperature: 0.5 Pt** - **Obtain a value (corresponding to measurement): 0.5 Pt** - **P_{Load}/P_{heat}: 1 Pt** - **Value: 0.5 Pt** - **Ratio of the measured and effective efficiency: 1 Pt**

sstab	Netzgerät	Voltmeter		
	I (A)	U (V)	R=U/I (Ohm)	R/l (Ohm/m)
0.00	1.50	0.02	0.01	#DIV/0!
0.05	1.50	0.39	0.26	5.20
0.10	1.50	0.82	0.55	5.47
0.15	1.50	1.17	0.78	5.20
0.17	1.50	1.32	0.88	5.18
0.18	1.50	1.42	0.95	5.26
0.20	1.50	1.56	1.04	5.20
0.30	1.50	2.31	1.54	5.13
0.40	1.50	3.09	2.06	5.15
0.50	1.50	3.85	2.57	5.13
0.60	1.50	4.62	3.08	5.13
0.70	1.50	5.42	3.61	5.16







4.3: Wirkungsgrad	(maximal)	
[Zeit: 5-10 min]	Experimentell:	Theoretisch: Th=62°C, Tc=24°C
	P(el)/P(Heiz)	(Carnot)
	0.0121	0.113

Aufgabe 5 Messung der Effizienz einer LED		**5 Pt**
(a) aus $P_{\text{elektrisch}} = P_{\text{Licht}} + P_{\text{Wärme}}$ erhält man $P_{\text{Licht}} = P_{\text{elektrisch}} - P_{\text{Wärme}}$ und damit $$\eta_{\text{LED}} = \frac{\text{abgestrahlte Lichtleistung}}{\text{elektrische Leistung}} = \frac{P_{\text{Light}}}{P_{\text{el}}} = \frac{P_{\text{el}} - P_{\text{Heat}}}{P_{\text{el}}}$$ $\boldsymbol{P_{\text{el}}}$ erhält man direkt aus $P_{\text{el}} = I_{\text{LED}}\, U_{\text{LED}}$ $\boldsymbol{P_{\text{Wärme}}}$ wird an das Peltierelement abgegeben und erzeugt einen Temperaturgradienten über dem Peltierelement, und damit eine Spannung U_{Seebeck} (siehe Aufgabe 2). In Aufgabe 2 wurde P_{therm} als Funktion der Spannung U_{Pelrtier} über dem Peltierelement dargestellt, damit kann man P_{therm} bestimmen mit der Beziehung $$\eta = \frac{P_{\text{el}} - P_{Heat}}{P_{\text{el}}}$$ kann die die Effizienz η berechnet werden.		1 pt: measurement of U,I over LED and U_pel or T_2-T_1 1pt $P_{\text{el}} = I_{\text{LED}}\, U_{\text{LED}}$ 1pt use part 2 to get P_th/U_pel or P_th/(T_2-T_1) 1pt compute P_th 1pt Compute efficiency

Messwerte

Seebeckeffekt $P = 9.87$ W, $U_{\text{Pel}} = 0.79$ V

Koeffizient $P/U_{\text{Pel}} = 12.5$ A

LED $U = 10.86$ V, $I = 0.898$, $P = 9.75$ W
$U_{\text{LED}} = 0.61$ V daraus folgt Wärmeleistung $P_{\text{th}} = 0.61\text{ V} \cdot 12.5\text{ A} = 7.6$ W
$P_{\text{Licht}} = P_{\text{el}} - P_{\text{th}} = 2.1$ W

Effizienz = P_{Licht} / P_{el} = 2.1 W/9.75 W = 0.219, also 21.9% (sinnvolle Angabe 2 SZ: 22 %)

Bemerkung:
Literaturwerte sind nicht einfach zu finden. Es werden eher höhere WG angegeben (25% bis 35%, oder gar mehr), meist aber ohne Angabe, ob die LED weiss oder farbig ist. Unsere Messung ist sicher nicht sehr genau. Dennoch liegt der berechnete Werte nicht grob daneben.