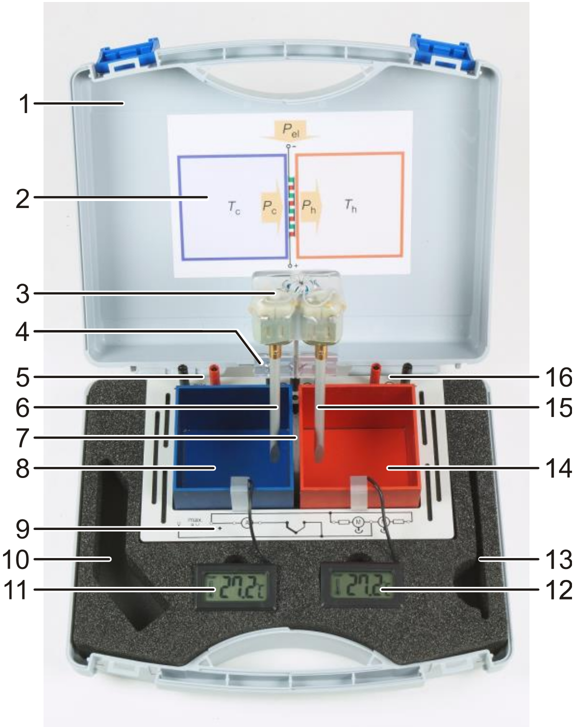
3B SCIENTIFIC® PHYSICS

...going one step further

Peltier Heat Pump 102076

Instruction manual

05/17 TL/JS



1 Transport case
2 Schematic view
3 Stirrer unit
4 Connector for stirrer unit
5 Connector for power supply
6 Stirring rod “cold side”
7 Peltier element
8 Reservoir for “cold side”
9 Wiring diagram sketch
10 Recess for stirrer unit
11 Digital thermometer for “cold side”
12 Digital thermometer for “hot side”
13 Recess for stirring rods
14 Reservoir for “hot side”
15 Stirring rod for “hot side”
16 Connector for measuring current
(operating current provided by Peltier element)

1. Safety instructions

Operation of the Peltier heat pump is guaranteed to be safe as long as it is used in accordance with the instructions. Safety cannot be guaranteed, however, if the equipment is used incorrectly or carelessly.

- Operate the heat pump solely with DC voltages of between 5 and 8 V.
- Do not run the heat pump dry or if filled with insufficient water.
- Allow the heat pump to dry after use.

2. Description

The Peltier heat pump is a functioning model with two aluminium water reservoirs, which are both thermally coupled to the surfaces of a Peltier element. If electric current flows through the Peltier element, then heat is transported between the reservoirs, causing one to cool down and the one on the other side to heat up. Electrically operated stirrers ensure an even distribution of temperature in both reservoirs. Two digital thermometers display the temperatures in both reservoirs. Since the specific heat capacity of the system as a whole is known, it is possible to determine the power involved in the heating and that involved in cooling, which can then both be compared with the electrical power supplied.

3. Technical data

Peltier element:

Supply voltage:	5 … 8 V
Current consumption(8 V):	2.5 … 3.5 A
Surface area:	40 x 40 mm²
Thickness:	3.7 mm
Seebeck coefficient *S*:	0.04 V/K approx.
Resistance *R*:	2.4 Ω approx.
Thermal conduction coefficient κ:	0.2 W/K approx.

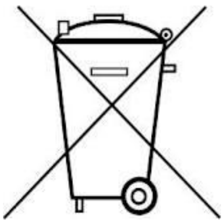
Water reservoirs:

Mass of empty reservoir:	105 g
Specific heat capacity of empty reservoir:	0.094 J/K
Water capacity:	200 ml
Specific heat capacity of water:	0.836 J/K
Specific heat capacity of filled reservoir:	0.930 J/K
Heat transfer coefficient α:	0.7 … 0.8 W/K

Overall dimensions:	244 x 160 x 70 mm³
Overall weight:	920 g

4. Storage, cleaning, disposal

- Keep the equipment in a clean, dry and dust-free place.
- Disconnect the equipment from its power supply before cleaning.
- Do not use aggressive cleaning agents or solvents.
- Use a soft, moist cloth for cleaning.
- Packaging should be disposed of at local recycling facilities.
- If the equipment itself is to be scrapped, it should not be disposed of in ordinary domestic waste. If it is used in private residences, it should be disposed of by legally authorised disposal agents.
- Observe applicable regulations for disposal of electrical equipment.



5. Set-up

Additionally required:

1 DC power supply 20 V, 5 A @230V	1003312
or	
1 DC power supply 20 V, 5 A @115V	1003311
1 Digital multimeter	1018832
2 Pairs of safety experiment leads	1017718

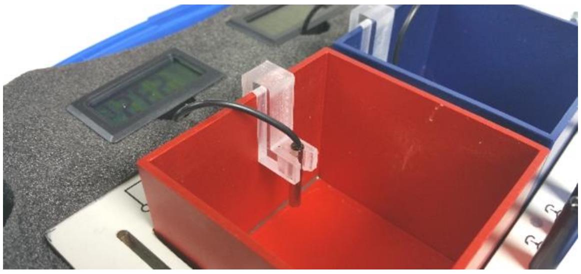


Fig.1 Alignment of temperature probes

- To start using the digital thermometer, it may be necessary to insert batteries.
- Line up the temperature probes for the two water reservoirs as shown in Fig. 1.

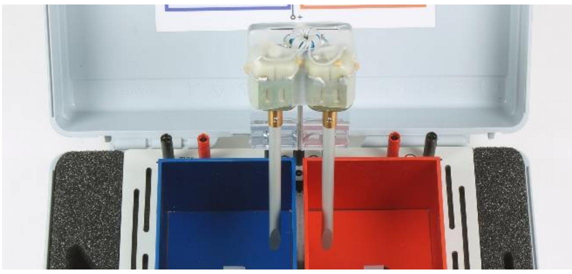


Fig. 2 Attachment of stirrer unit with stirring rods inserted

- Take the stirring rods and stirrer unit from their pockets in the carry case.
- Insert the stirring rods onto the motor shafts using the requisite coupling.
- Connect up the stirrer unit by means of the central trio of sockets.

Note: The stirrer unit starts running as soon as the left hand pair of sockets is supplied with power. The Peltier element, though, is only activated when the right-hand pair of sockets is connected together or when an ammeter is connected.

- Pour 200 ml of water into both reservoirs.
- Connect the power supply to start the stirrers and ensure even distribution of temperature.

5. Experiments

5.1 Symmetrical operation as heat pump

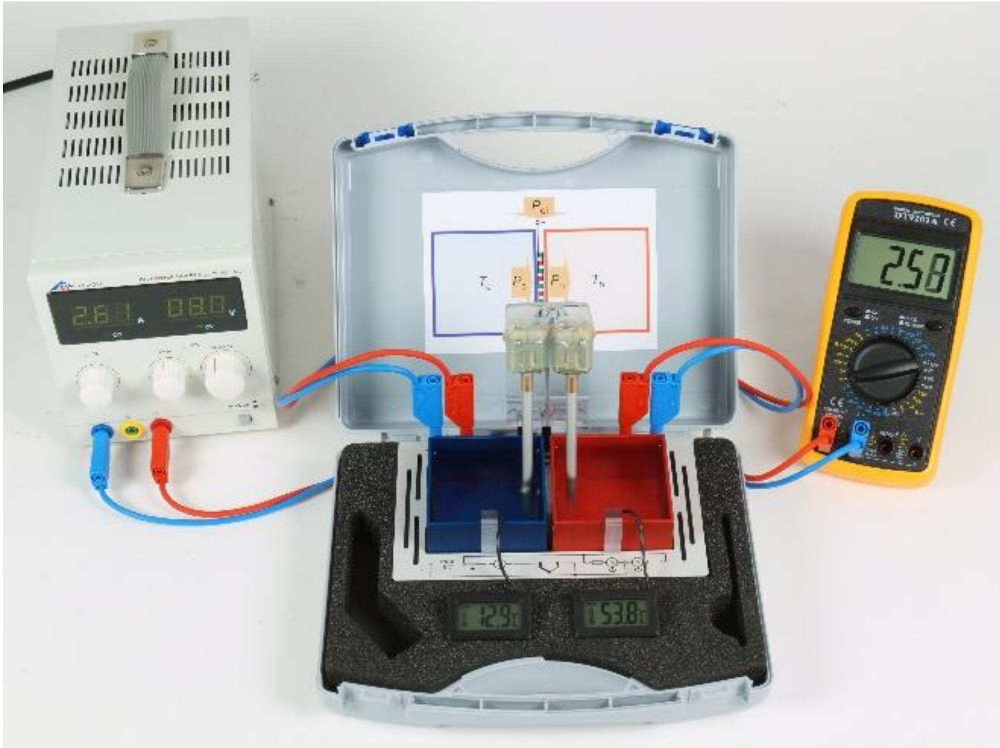


Fig. 3 Experiment set-up

- Make a note of the initial temperature in both reservoirs.
- Turn off the power supply and connect up the digital multimeter for use as an ammeter (measuring range up to 10 A).
- Turn on the power supply and set up a constant voltage supply of between 6 and 8 V.
- Start the stop watch.
- Write down the temperatures T_c and T_h in the two reservoirs and the current I every 30 s.

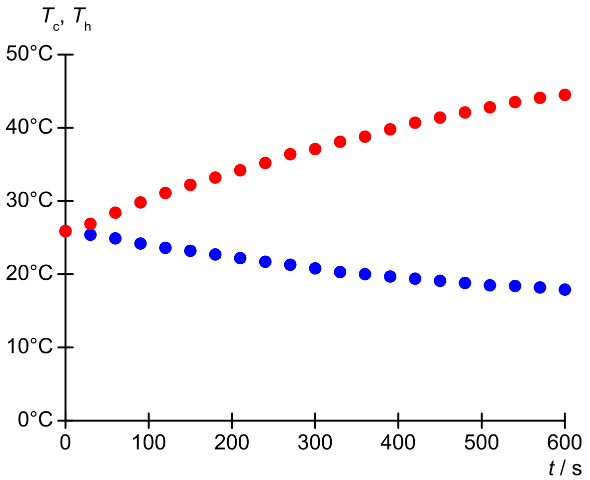


Fig. 4 Change in the temperatures in the two reservoirs over time when operation is symmetrical

Possible results:

Determination of heating power, cooling power and electrical power

Determination of coefficients of performance

Determine how current depends on the temperature difference when the power supply voltage is constant.

Determine ohmic resistance and Seebeck coefficients.

Trace the change in temperature over time.

Calculate how much the Peltier effect, Joule losses and reflux of heat each affect the temperature traces.

5.2 Measurement of how temperature changes over time and the thermal voltage after the heat pump is turned off

Fig. 5 Experiment set-up

- Remove the multimeter you have been using as an ammeter so that the flow of current through the Peltier element is cut off, then use it as a voltmeter to measure the thermal voltage.
- Keep the stirrers operating by leaving the power supply switched on.
- Write down the temperatures T_c and T_h in the two reservoirs and the voltage U every 30 s.

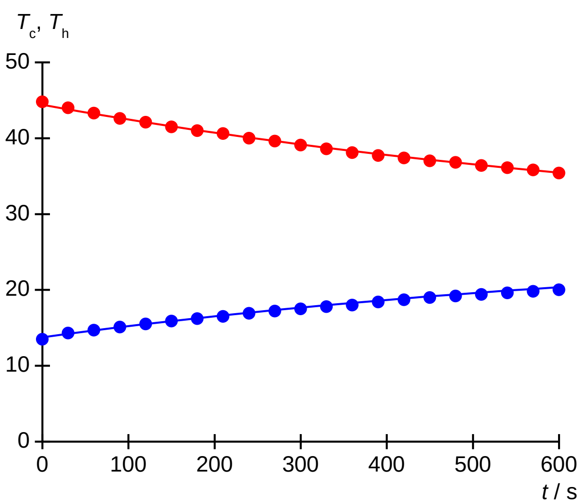


Fig. 6 Change in the temperatures in the two reservoirs over time after the heat pump is switched off

Possible results:

Plot the thermal voltage as a function of the temperature difference

Determine the Seebeck coefficients.

Plot the average of T_c and T_h as a function of time and determine the heat transfer coefficients α.

Plot the temperature difference as a function of time and determine the thermal conduction coefficients κ.

Note: To determine the thermal conduction coefficients and heat transfer coefficients, it is essential to continue the measurements as far as possible until the ambient temperature has been reached.

5.3 Asymmetric operation

Asymmetric operation involves filling the reservoir on the "hot side" with icy water in order to keep its temperature constant. The water in the cold reservoir should then be cooled from its initial temperature.

6. Results

6.1 Determination of heating power, cooling power and electrical energy

Table 1: Sample measurement

t	T_c	T_h	I	U
0	25.6°C	25.6°C	3.2 A	7.62 V
120	23.0°C	31.2°C	3.2 A	8.06 V

Heating power:

$$P_h = C \cdot \frac{dT_h}{dt} = 930\ \frac{J}{K} \cdot \frac{31.2 - 25.6}{120}\ \frac{K}{s} = 43.4\ W$$

Cooling power:

$$P_c = C \cdot \frac{dT_c}{dt} = 930\ \frac{J}{K} \cdot \frac{23.0 - 25.6}{120}\ \frac{K}{s} = -20.2\ W$$

Electric power:

$$P_{el} = U \cdot I = 3.2\ A \cdot \frac{7.62 + 8.06}{2}\ V = 25.1\ W$$

Coefficients of performance (power):

$$COP_h = \frac{P_h}{P_{el}} = \cdot \frac{43.4}{25.2}\ \frac{W}{W} = 1.73$$

$$COP_c = \frac{P_c}{P_{el}} = \cdot \frac{-20.2}{25.2}\ \frac{W}{W} = -0.80$$

$$COP_h + COP_c = 0.93$$

Note: Coefficients of performance depend on current I and on the temperature difference ΔT.

6.2 Thermal voltage as a function of temperature difference

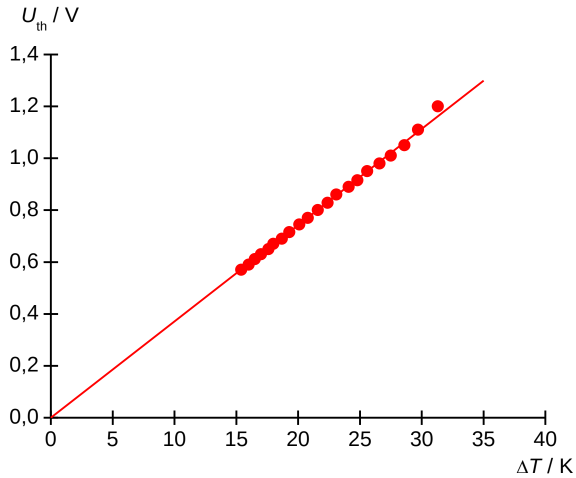


Fig. 7 In Thermal voltage measured as a function of temperature difference in the settling phase

The thermal voltage U_{th} between the two contacts to the Peltier element depends linearly on the temperature difference. It can be measured when no current I is flowing:

$$U_{th} = S \cdot (T_h - T_c) = S \cdot \Delta T$$

S: Seebeck coefficient of Peltier element

6.3 Operating voltage as a function of temperature difference

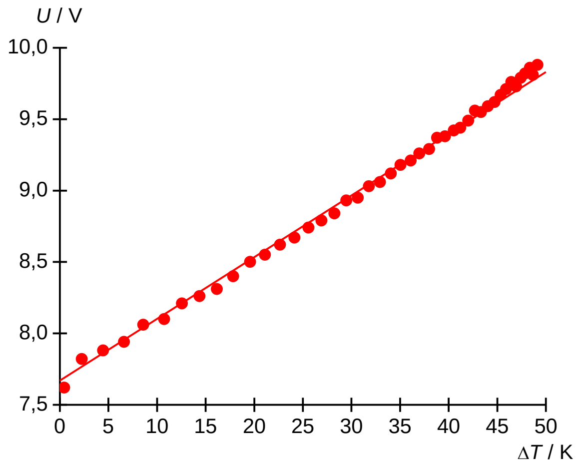


Fig. 8 Operating voltage measured as a function of temperature difference in the pumping phase at constant current

To generate current I, the following voltage needs to be applied across the Peltier element

$$U_0 = R \cdot I + S \cdot \Delta T$$

R: Resistance of Peltier element

Alternatively, the following electrical power is required:

$$P_{el} = U_0 \cdot I = R \cdot I^2 + S \cdot \Delta T \cdot I$$

Therefore, it is of importance whether the power is supplied with constant current or constant voltage.

6.4 Description of changes in temperature during pumping and settling phases

If an electric current I flows through the Peltier element, its cold side absorbs heat Q_c from the reservoir connected to that side and the hot side transfers heat Q_h to the reservoir on that side.

The following equations apply for the power relationships:

$$P_h = \frac{dQ_h}{dt} = S \cdot I \cdot T_h + \frac{1}{2} \cdot R \cdot I^2 - \kappa \cdot (T_h - T_c),$$

$$P_c = \frac{dQ_c}{dt} = -S \cdot I \cdot T_c + \frac{1}{2} \cdot R \cdot I^2 + \kappa \cdot (T_h - T_c)$$

S: Seebeck coefficient
R: Resistance
κ: Thermal conduction coefficient

The first term in each of these equations represents the Peltier effect, the second term represents resistive losses, which are equally distributed between the two reservoirs in the form of Joule heat loss, and the third term is the heat returned by passing through the Peltier element.

In practice, it is also necessary to take into account heat losses to the surroundings, which is given to good approximation by the following:

$$P_{h\to 0} = \frac{dQ_{h\to 0}}{dt} = \alpha \cdot (T_h - T_0),$$

$$P_{c\to 0} = \frac{dQ_{c\to 0}}{dt} = \alpha \cdot (T_c - T_0)$$

T_0: Ambient temperature,
α: Heat transfer coefficient

Emission and consumption of heat can both be detected as changes in temperature in the connected reservoirs. Overall, the following differential equations apply

$$C \cdot \frac{dT_h}{dt} =$$
$$S \cdot I \cdot T_h + \frac{1}{2} \cdot R \cdot I^2 - \kappa \cdot (T_h - T_c) - \alpha \cdot (T_h - T_0)$$

$$C \cdot \frac{dT_c}{dt} =$$
$$-S \cdot I \cdot T_c + \frac{1}{2} \cdot R \cdot I^2 + \kappa \cdot (T_h - T_c) - \alpha \cdot (T_c - T_0)$$

Initial phase:

If the system starts with both reservoirs at the ambient temperature, then thermal conduction and heat transfer do not play any role in the initial phase. Thus the following applies for that phase:

$$C \cdot \frac{dT_h}{dt} = S \cdot I \cdot T_h + \frac{1}{2} \cdot R \cdot I^2$$

$$C \cdot \frac{dT_c}{dt} = -S \cdot I \cdot T_c + \frac{1}{2} \cdot R \cdot I^2$$

If the polarity of the current is reversed, the roles of the two reservoirs are swapped over. The temperature of the right-hand reservoir then decreases while that of the left-hand one increases.

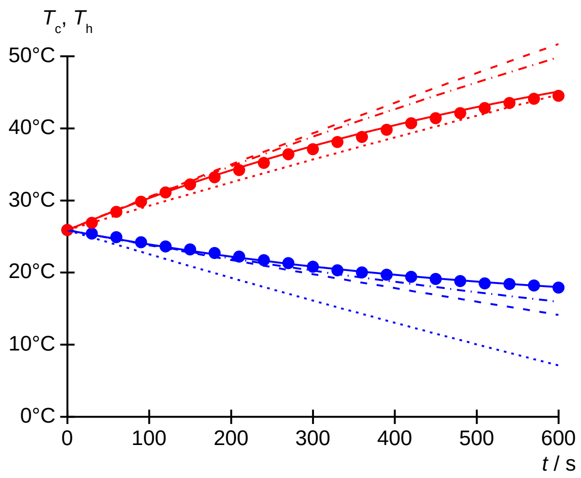


Fig. 9 Measured and calculated changes in temperature during pumping phase

- - - - -: Influence of Peltier effect
– – – –: Influence of Peltier effect & Joule heat
– · – · –: Effect of thermal conduction
———: Effect of thermal conduction and Transfer of heat to surroundings

Settling phase:

If the current is interrupted, turning off the pumping effect of the Peltier element, the temperatures in both reservoirs then settle back towards the ambient temperature.

Mathematically, the following is true

$$C \cdot \frac{dT_h}{dt} = -\kappa \cdot (T_h - T_c) - \alpha \cdot (T_h - T_0)$$

$$C \cdot \frac{dT_c}{dt} = +\kappa \cdot (T_h - T_c) - \alpha \cdot (T_c - T_0)$$

This can be rearranged as follows:

$$C \cdot \frac{d\Delta T}{dt} = -(2 \cdot \kappa + \alpha) \cdot \Delta T \text{ where } \Delta T = T_h - T_c$$

$$C \cdot \frac{dT_m}{dt} = -\alpha \cdot (T_m - T_0) \text{ where } T_m = \frac{T_h + T_c}{2}$$

To determine coefficients κ and α, it is therefore sensible to consider the temperature difference ΔT and mean (average) temperature T_m.