Converting electrical energy into heat energy – measuring with the joule and wattmeter

Objects of the experiment

- Determination of the electrical energy and thermal energy.
- Confirming the equivalence of the energy quantities 1 Ws and 1 J.

Principles

Energy is a measure of stored work. It occurs in different forms, which can be converted one into the other. In a closed system, the total energy is conserved in conversion processes. therefore the energy is one of the fundamental quantities of physics.

In this experiment, the equivalence of electrical energy E_{el} and thermal energy E_{th} is established experimentally. The supplied electrical energy E_{el} is converted into heat E_{th} in the heating coil. This leads to a temperature rise in the calorimeter.

The supplied electrical energy is determined by:

$$E_{el} = U \cdot I \cdot t \qquad \text{(I)}$$

U: voltage

I: current

t: time

According equation (I) the electrical energy E_{el} can be determined by measuring the voltage U, the current I and the time t. In this experiment, however, the electrical energy is directly measured by using the Joule and Wattmeter. This device measures the effective voltage U, the effective current I and the nonreactive power P for voltages and currents of any shape, from which the electrical work is determined by:

$$E_{el} = \int P(t)\, dt \qquad \text{(II)}$$

P(t): electrical power

The thermal energy E_{th} is determined by:

$$E_{th} = c \cdot (\vartheta_2 - \vartheta_1) \qquad \text{(III)}$$

ϑ_1: temperature at start

ϑ_2: temperature at end

c: total heat capacity

where total heat capacity depends on the heat capacity of the calorimeter and the water equivalent of 1 g water in the bore of the Dewar vessel:

$$c = c_{cal} + c_w \qquad \text{(IV)}$$

c_{cal}: heat capacity of the calorimeter

c_w: heat capacity of water equivalent

Calorimeter	**Heat capacity C/(J/K)**
Copper (388 02)	264 + 4.2 (for 1 g water in the bore)
Aluminium (388 03)	188 + 4.2 (for 1 g water in the bore)
Aluminium, large (388 04)	384 + 4.2 (for 1 g water in the bore)

According to equation (III) measuring the temperature ϑ_1 at the beginning of the and ϑ_2 at the end of the experiment allows to determine the thermal energy E_{th}.

The two energy forms can be determined quantitatively in units of wattsecond (Ws) and Joule so that their numerical equivalence can be demonstrated experimentally: $E_{el} = E_{th}$.

Bi 1005

LD Didactic GmbH · Leyboldstrasse 1 · D-50354 Huerth / Germany · Phone: (02233) 604-0 · Fax: (02233) 604-222 · e-mail: info@ld-didactic.de

Apparatus

1 Copper-block calorimeter 388 02
1 Aluminium-block calorimeter 388 03
1 Large aluminium-block calorimeter.................... 388 04
1 Pair of connecting cables 388 06

1 Joule and Wattmeter 531 831
1 Variable extra-low voltage transformer S........... 521 35
1 Pair cables 50 cm, red/blue 501 45

Option (a)

1 Thermometer for calorimeters 388 05

Option (b)

1 Digital thermometer with one input 666 190
1 Temperature Sensor, NiCr-Ni 666 193

Option (c)

1 Mobile-CASSY 524 009
1 NiCr-Ni Adapter S... 524 0673
1 NiCr-Ni temperature sensor 1.5 mm.................. 529 676

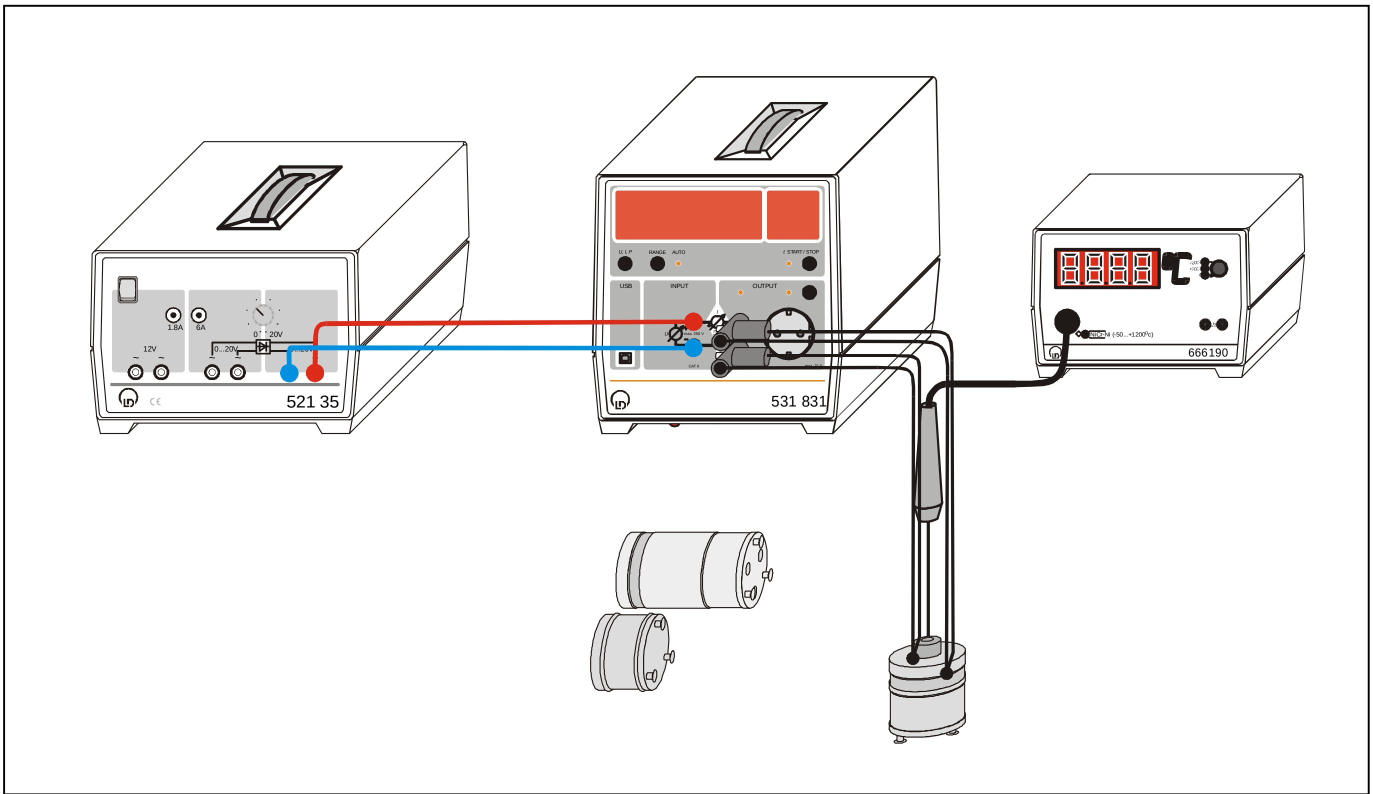
Setup

Note: There are 3 different options for measuring the temperature.

The experimental setup is shown in Fig. 1. In the following the setup option (b) is described, i.e. measuring the temperature with the Digital thermometer and the NiCr-Ni temperature sensor. For using the Mobile CASSY see Fig. 2.

- Set up the aluminium calorimeter so that the bore points upwards.
- Pour water into the opening.
- Insert the gasket in the bore and hold it with the locking screw.
- Insert the temperature sensor as deeply as possible in the opening of the calorimeter and tighten the locking screw of the calorimeter.
- Connect the variable extra-low voltage transformer S to the 4 mm input sockets of the Joule and Wattmeter as shown in Fig. 1.
- Connect the heating coil of the calorimeter to the 4 mm output sockets of the Joule and Wattmeter as shown in Fig. 1. Plug the large banana plugs together.
- For measuring the temperature at start and end of the experiment connect the NiCr-Ni temperature sensor to the Digital thermometer.

Fig. 1: Experimental setup for converting electrical heat into heat energy schematically.



Safety notes

Mind the safety notes of the instruction sheet for the calorimeters 388 00 and the Joule and Wattmeter.

- Do not exceed the maximum permissible current for the heating filament 0.8 A.

Carrying out the experiment

Important!

Before beginning the experiment, it is recommended to cool down the calorimeter to 5 °C below room temperature.

- Switch on the Digital thermometer (, Mobile CASSY or thermometer) to measure the temperature.
- Switch on the Joule and Wattmeter. The device automatically starts up with the status LED of the 4 mm sockets on. *(If required, press the pushbutton OUTPUT to switch the status LED of the 4 mm sockets on.)*
- If not selected use the pushbutton “*U*, *I*, *P*“ to select the unit “V”.

Note: You may choose appropriate measuring ranges for the energy (for further information see instruction sheet of the Joule and Wattmeter 531 831).

- Switch on the variable extra-low voltage transformer S and set the voltage to approx. 4 V.
- Select the unit “Ws” with the pushbutton “*U*, *I*, *P*“.
- Measure the electrical work by starting the integration with the pushbutton *t* START/STOP.
- When the desired measuring time *t* is over, stop the integration with the pushbutton *t* START/STOP.

Note: The temperature and the electrical work can also be read off as a function of time. Alternatively, the experiment can be repeated for different measurement times (see measuring example).

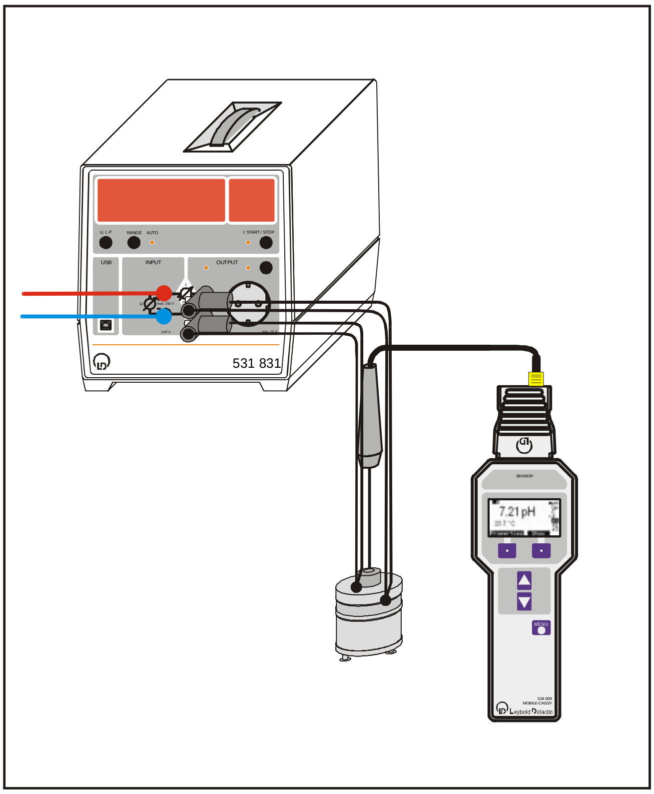


Fig. 2 Experimental setup for measuring the temperature with Mobile CASSY schematically (compare Fig. 1).

Measuring example

The electrical work is determined to

E_{el} = 1259 Ws

The temperatures at start and end:

ϑ_1 = 23.3 °C

ϑ_2 = 29.6 °C

Note: The experiment can also be repeated for different measurement times to confirm the equivalence of the thermal and electrical energy. The results of such a measurement series are listed in Table 1.

Table 1: Electrical energy and temperature increase as function of time. The thermal energy is calculated for the aluminium calorimeter using equation (III).

$\frac{t}{\text{min}}$	$\frac{E_{el}}{\text{Ws}}$	$\frac{\vartheta_2 - \vartheta_1}{\text{K}}$	$\frac{E_{th}}{\text{J}}$
2	313	1.6	327
3	488	2.5	483
4	635	3.3	639
5	771	4.0	795
6	927	4.8	950
7	1063	5.5	1105

Evaluation and results

With equation (IV) follows for the heat capacity:

$$c = 188\ \frac{J}{K} + 4.2\ \frac{J}{K} = 192\ \frac{J}{K}$$

The thermal energy can then be determined using equation (III):

E_{th} = 1210 J

The figure for electric energy measured in Ws (E_{el} = 1259 Ws) agrees with the figure for the thermal energy measured in J (E_{th} = 1210 J) within the accuracy of the experiment. Thus the equivalence

1 Ws = 1 J

is experimentally confirmed.

Note: When the experiment is performed for different measurement times (see Table 1 and Fig. 3) the equivalence between the thermal energy and the electrical energy can be verified as follows:

The equivalence of the electrical energy E_{el} and the thermal energy E_{th} can be confirmed by fitting a line through the origin in Fig. 3. Usually the slope of the straight line through the origin is somewhat smaller than 1 because of heat loss due to emission of heat radiation. This becomes particularly obvious in the case of long measuring times where the measuring data can deviate significantly from the straight line through the origin.

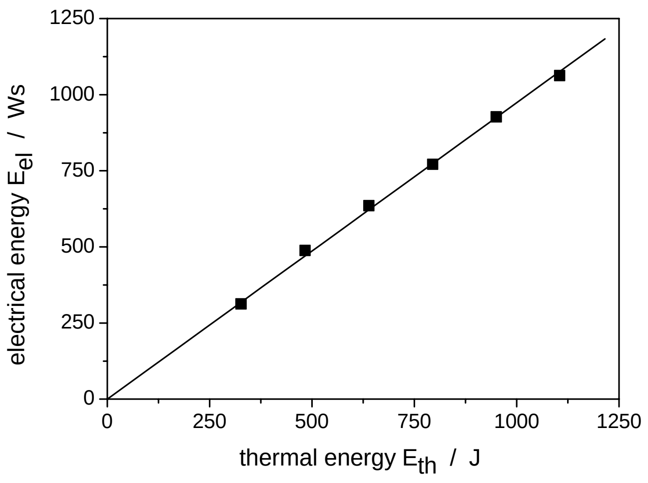


Fig. 3: Electrical energy as a function of the thermal energy. The solid line corresponds to a fit of straight line through the origin with a slope 0.97.

Supplementary information

The heat capacity as a function of mass and material can also be determined by using different calorimeters.