Increase of internal energy by mechanical work

VERIFYING THE FIRST LAW OF THERMODYNAMICS

- Measure the temperature of the aluminium body as a function of the number of rotations against the friction cord.
- Investigate the proportionality between the temperature change and the frictional work, and thereby verifying the First Law of Thermodynamics.
- Determine the specific heat capacity of aluminium.

UE203030

08/08 JS

BASIC PRINCIPLES

According to the First Law of Thermodynamics, the change of the internal energy of a system ΔE is equal to the sum of the work performed ΔW and the transferred heat ΔQ. It can be measured as the proportional change in the temperature of the system ΔT, provided that there is no change in the state of aggregation and that no chemical reaction occurs.

The experiment is conducted to investigate the increase in the internal energy of an aluminium body caused by mechanical work. The cylindrical body is rotated about its axis by means of a hand-operated crank. A cord running over the curved surface provides the friction to heat the body. The frictional force F corresponds to the weight of a mass that is suspended from the end of the friction cord. The suspended mass is balanced by the frictional force. Therefore, the work performed against friction during n revolutions of the body is

(1) $\Delta W_n = F \cdot \pi \cdot d \cdot n$

where d is the diameter of the cylindrical body.

During the n revolutions, the frictional work raises the temperature of the body from the initial value T_0 to the final value T_n. At the same time the internal energy is increased by

(2) $\Delta E_n = m \cdot c_{Al} \cdot (T_n - T_0)$

where m is the mass of the body

c_{Al} is the specific heat capacity of aluminium.

To avoid a net exchange of heat with the environment as far as possible, the body is cooled, before starting the measurement, to an initial temperature T_0 that is only slightly below room temperature. The measurement is concluded as soon as the body reaches a final temperature T_n that is slightly above room temperature. Note: The difference below and above room temperature prior to starting the measurements and at the point of concluding them should approximately be the same.

This ensures that the conversion of internal energy matches the work done. Thus, we have the following relation:

(3) $\Delta E_n = \Delta W_n$.

Fig. 1: Experiment set-up

LIST OF APPARATUS

1	Heat Equivalent Apparatus	U10365
1	Digital Multimeter P1035	U11806
1	Pair of Safety Experiment Leads, 75 cm	U13812

SET-UP

- Clamp the heat equivalent apparatus to the edge of a stable bench or table.
- Put the aluminium cylinder into a closed plastic bag and cool it down to 5°-10° below room temperature by placing it in a refrigerator.

EXPERIMENT PROCEDURE

- Take the aluminium cylinder out of the plastic bag and mount it on the apparatus.
- Lubricate the temperature sensor with a drop of oil and insert it into the aluminium cylinder.
- Switch the digital multimeter to its resistance-measuring function and connect it to the temperature sensor.
- Fill the bucket with water almost to the brim.
- Tie the friction cord to the handle of the bucket and, starting from the front, wind it about five times around the aluminium cylinder and allow the counterweight to hang down behind.
- Raise the bucket slightly, turn the hand-crank slowly, and check whether the bucket remains hanging in position as the crank is turned.
- If the bucket starts to descend, rewind the cord with one extra turn. If it rises, rewind with one fewer turn.
- Set the counter to zero and note the resistance R of the temperature sensor.
- Continue turning the crank, reading the resistance value after every 10 rotations, until the temperature is about 5°-10° above room temperature.
- Using Equation 1, calculate the frictional work ΔW_n from the number of rotations n.
- From the resistance readings R of the temperature sensor, calculate the temperatures T in °C using the formula $T = \frac{217}{R^{0.13}} - 151$.

SAMPLE MEASUREMENTS

Mass of filled bucket: 5 kg

Weight of filled bucket: 49.05 N

Effective diameter of aluminium cylinder: 46 mm

Table 1

n	ΔW_n / J	R / kΩ	T
0	0.0	7.90	14.87°C
10	70.9	7.76	15.26°C
20	141.8	7.64	15.59°C
30	212.7	7.50	15.99°C
40	283.5	7.38	16.34°C
50	354.4	7.26	16.70°C
60	425.3	7.14	17.07°C
70	496.2	7.03	17.41°C
80	567.1	6.92	17.75°C
90	638.0	6.81	18.10°C
100	708.8	6.70	18.46°C
110	779.7	6.61	18.76°C
120	850.6	6.51	19.10°C
130	921.5	6.40	19.47°C
140	992.4	6.31	19.79°C
150	1063.3	6.23	20.07°C
160	1134.1	6.14	20.39°C
170	1205.0	6.05	20.72°C
180	1275.9	5.96	21.06°C
190	1346.8	5.88	21.36°C
200	1417.7	5.80	21.67°C
210	1488.6	5.72	21.98°C
220	1559.4	5.64	22.30°C
230	1630.3	5.57	22.58°C
240	1701.2	5.49	22.91°C
250	1772.1	5.42	23.20°C
260	1843.0	5.35	23.49°C
270	1913.9	5.28	23.79°C
280	1984.7	5.21	24.09°C
290	2055.6	5.14	24.40°C
300	2126.5	5.08	24.67°C

EVALUATION

From Equations 2 and 3, we derive the relation

$$T_n = T_0 + \frac{1}{m \cdot c_{Al}} \cdot \Delta W_n .$$

It is therefore necessary to plot the measured final temperatures T_n as functions of the work performed ΔW_n on a graph (see Fig. 2). The values measured in the vicinity of room temperature lie on a straight line. It is possible to determine the specific heat capacity of aluminium from its gradient. In the region below room temperature, the measured temperatures rise faster than would correspond to the gradient of the straight line, as the aluminium body absorbs heat from the surroundings. Conversely, in the region above room temperature heat is lost to the surroundings.

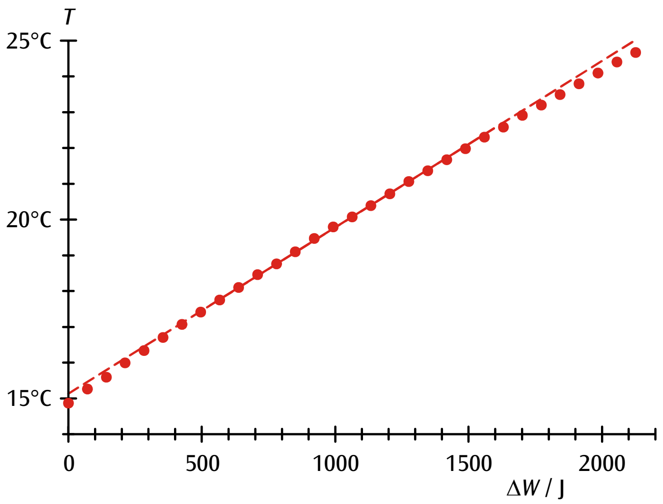

Fig. 2: The temperature of the aluminium body as a function of work performed against friction