Thermodynamics

Heat Transfer

PHYSICS EXPERIMENT

Leslie Cube

MEASURE THE HEAT RADIATED BY A LESLIE CUBE.

- Detect radiation from a Leslie cube with a Moll thermopile.
- Measure intensity of heat radiated by four different surfaces in relation to one another as a function of temperature *T*.
- Confirm that the radiation intensities are proportional to T^4

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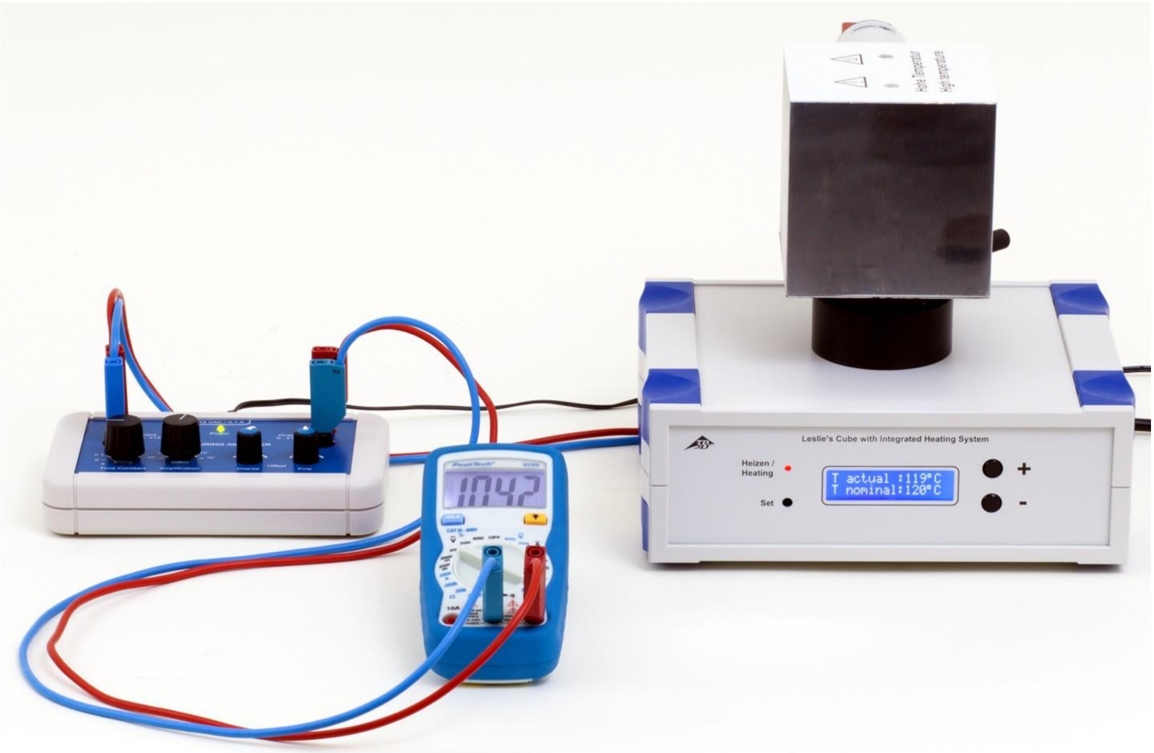

Fig. 1: Experiment set-up for measuring heat radiated by a Leslie cube

BASIC PRINCIPLES

Heat is exchanged between a body and its surroundings by the emission and absorption of heat radiation. The radiation depends on the body's temperature and the nature of its surface, as can be demonstrated by means of a Leslie cube.

The emitted intensity is described by the body's emissivity *E*. The absorptivity *A* is the ratio between absorbed and incident radiation intensity. It turns out that absorptivity increases with emissivity. More specifically, according to Kirchhoff's law, the ratio between emissivity and absorptivity is identical for all bodies at a given temperature, and corresponds to emissivity of a black body E_{SB} at this temperature:

(1) $$\frac{E(T)}{A} = E_{SB}(T) = \sigma \cdot T^4$$

σ: Stefan-Boltzmann constant
T: Temperature in Kelvin

The degree to which absorptivity depends on temperature is generally negligible. Therefore the emissivity of a body can be described as follows:

(2) $$E(T) = A \cdot \sigma \cdot T^4 .$$

If the body has the same temperature T_0 as its surroundings, the intensity of the heat radiated by the body into the surroundings is equal to that of the heat it absorbs from them:

(3) $$E(T_0) = A \cdot \sigma \cdot T_0^4$$

If the body's temperature is higher, the intensity of the radiation absorbed from the surroundings does not change as long as the ambient temperature remains constant. Therefore, the energy radiated by a body per unit of surface and time and measurable by means of a radiation detector is as follows:

(4) $$\Delta E(T) = A \cdot \sigma \cdot \left(T^4 - T_0^4\right).$$

In this experiment, a Leslie cube equipped with one white, one black, one matt and one shiny surface is heated to a temperature of 120 °C. The radiated intensity is then ascertained by means of a relative measurement using a Moll thermopile. The measured values for the four different surfaces are monitored during the entire process of cooling to room temperature.

LIST OF EQUIPMENT

1	Leslie Cube with Heater @230V	1017730	(U8498299-230)
or			
1	Leslie Cube with Heater @115V	1017729	(U8498299-115)
1	Moll-Type Thermopile	1000824	(U8441301)
1	Measurement Amplifier U @230V	1020742	(U8557560-230)
or			
1	Measurement Amplifier U @115V	1020744	(U8557560-115)
1	Digital Multimeter P3340	1002785	(U118091)
2	Pair of Safety Experiment - Leads, 75 cm, red/blue	1017718	(U13816)

SAFETY INSTRUCTIONS

Risk of burns: In this experiment, the Leslie cube is heated to temperatures up to 120°C.

- Do not touch the Leslie cube during the experiments, e.g. when rotating the cube.

SET UP

Note:

In order to avoid any drifting of the output voltage, the metal casing of the thermopile should be at the ambient temperature. It is also possible for body heat and other external factors to cause errors in the experiment results.

- *Wait a few minutes after setting up the experiment before making any measurements.*
- *Do not touch the thermopile while making measurements.*
- *Avoid setting up in direct sunlight or close to a radiator.*
- *Avoid draughts and variations in room temperature during the measurement.*

- Align the Moll-type thermopile in the Leslie cube holder such that it is aimed at the centre of the cube. Secure it in place and connect it to the measurement amplifier.
- Switch on measurement amplifier U, setting it up with a gain of 10^3 and a time constant of 0.1 s.
- Connect the digital multimeter to the output of measurement amplifier U to measure voltage and turn it on.
- Set a measuring range of 20 V DC.
- Calibrate the output voltage *U* from the thermopile to zero using the offset knob on the measurement amplifier.
- Check the result for all four surfaces of the cube.

PROCEDURE

- Switch on the heating for the Leslie cube and read off the first temperature displayed to use as room temperature ϑ_0.
- Set the desired temperature for the Leslie cube to ϑ = 40°C and wait till the actual temperature has reached that setting.
- One by one, turn all the faces of the Leslie cube to face the thermopile, wait till the output value of the pile *U* has stabilised and then make a note of the value.
- Raise the pre-set temperature for the Leslie cube in 10° steps from 40°C to 120°C and measure the output voltage *U* of the pile for all four sides each time.

SAMPLE MEASUREMENT AND EVALUATION

- Using the temperatures as measured for ϑ in °C, calculate the absolute temperatures $T = \vartheta + 273.15$ K, then calculate the term $T^4 - T_0^4$ from these and enter the results into Table 1.
- Plot the voltages measured for all four surfaces against $T^4 - T_0^4$ on a graph.
- Fit a straight line through the origin to each set of points (see Fig. 2) and enter the relevant values obtained from these into Table 2.

The various gradients of the lines correspond to the differing absorption properties of the Leslie cube surfaces. Surprisingly, the ability of the white surface to absorb the infra-red wavelengths used in this experiment is greater than that of the black surface.

Table 1: Measurements of intensity of radiated heat emitted by the four differing sides of the Leslie cube as a function of the cube's temperature

ϑ	U / mV	U / mV	U / mV	U / mV	$\frac{T^4 - T_0^4}{10^8 \cdot K^4}$
	Matt	Shiny	White	Black	
27 °C	0.00	0.00	0.00	0.00	0.0
40 °C	0.09	0.01	1.03	0.98	15.0
50 °C	0.20	0.05	1.97	1.83	27.9
60 °C	0.35	0.09	3.14	2.94	42.0
70 °C	0.52	0.13	4.15	3.88	57.5
80 °C	0.70	0.18	5.56	5.21	74.4
90 °C	0.87	0.25	6.79	6.39	92.8
100 °C	1.10	0.32	8.26	7.76	112.7
110 °C	1.25	0.38	9.61	9.07	134.4
120 °C	1.44	0.39	11.12	10.48	157.7

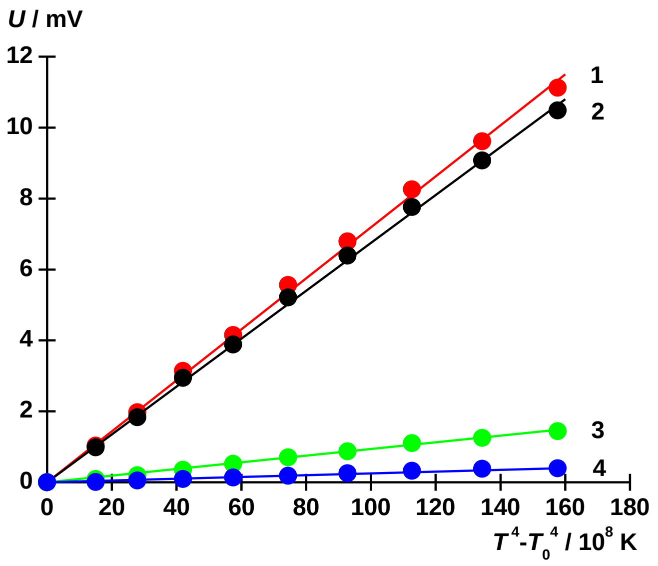

Fig. 2 Radiated intensity from a Leslie cube as a function of $x = T^4 - T_0^4$

1: White surface. 2: Black surface,
3: Matt surface. 4: Shiny surface

Table 2: Gradients *a* of straight lines through the origin and relative values

Gradient	Matt	Shiny	White	Black
$\frac{\alpha}{\text{mV} / 10^8 \cdot K^4}$	0.009	0.003	0.072	0.068
α_{rel}	12.9%	3.6%	100.0%	94.1%