STEFAN-BOLTZMANN LAW

EXPERIMENT PROCEDURE

- **Make a relative measurement of the intensity of radiation from an incandescent lamp with a tungsten filament as a function of temperature with the help of a Moll thermopile.**
- **Measure the resistance of the filament in order to determine the filament's temperature.**
- **Plot the measurements in a graph of ln (U_{th}) against ln (T) and determine the exponent from the slope of the resulting straight line.**

OBJECTIVE

Verify that intensity of radiation is proportional to the fourth power of the temperature, T^4.

SUMMARY

The way that intensity of radiation from a black body depends on temperature is described by the Stefan-Boltzmann law. Similar dependence on temperature is exhibited by the intensity of radiation from an incandescent lamp with a tungsten filament. In this experiment, a Moll thermopile is used to make a relative measurement which verifies the law. The temperature of the filament can be determined from the way its resistance depends on temperature, which can be determined very accurately using a four-wire method.

REQUIRED APPARATUS

Quantity	Description	Number
1	Stefan Boltzmann lamp	**1008523**
1	DC Power Supply 0 – 20 V, 0 – 5 A (230 V, 50/60 Hz)	**1003312 or**
	DC Power Supply 0 – 20 V, 0 – 5 A (115 V, 50/60 Hz)	**1003311**
1	Moll-Type Thermopile	**1000824**
3	Digital Multimeter P1035	**1002781**
2	Barrel Foot, 1000 g	**1002834**
1	Set of 15 Safety Experiment Leads, 75 cm	**1002843**

UE4050200

BASIC PRINCIPLES

Both the total intensity and the spectral distribution of the heat radiation from a body are dependent on the body's temperature and the nature of its surface. At a specific wavelength and temperature, the body emits more radiation if it is also better able to absorb it. A black body, a body with ideal surface characteristics, fully absorbs radiation of all wavelengths and can therefore emit the greatest amount of thermal radiation for a given temperature. Such a body is assumed when investigating how radiation of heat depends on temperature.

The way that intensity of radiation S from a black body depends on temperature is described by the Stefan-Boltzmann law.

(1) $$S_0 = \sigma \cdot T^4$$

T: absolute temperature

$$\sigma = 5{,}67 \cdot 10^{-8} \frac{\text{W}}{\text{m}^2\,\text{K}^4}$$: Stefan-Boltzmann constant

It is not possible to determine this intensity directly, since the body will also simultaneously be absorbing radiation from its surroundings. The intensity as measured is therefore

(2) $$S_1 = \sigma \cdot \left(T^4 - T_0^4\right)$$

T_0: absolute temperature of surroundings

Light emitted from an incandescent lamp also counts as heat radiation. In this case, the temperature of the filament is determined in such a way that a large amount of the heat is emitted in the spectrum of visible light. The way the total intensity of radiation depends on temperature is equivalent to that of a black body:

(3) $$S = \varepsilon \cdot \sigma \cdot \left(T^4 - T_0^4\right)$$

This is because the filament absorbs a proportion ε of radiation of all frequencies.

An incandescent lamp of this kind with a tungsten filament will be investigated in this experiment in order to determine how the intensity of radiation depends on the temperature. A Moll thermopile is used to measure relative radiation intensity. The temperature of the filament can be determined using the temperature-dependency of its resistance:

(4) $$R = R_0 \left(1 + \alpha \cdot \left(T - T_0\right)\right)$$

R_0: resistance at ambient temperature T_0

$$\alpha = 4{,}4 \cdot 10^{-3} \frac{1}{\text{K}}$$ for tungsten

R can be determined very accurately using a four-wire measurement.

EVALUATION

The following expression for temperature T is derived from equation (4)

$$T = \frac{R - R_0}{\alpha \cdot R_0} + T_0$$

However, equation (4) only applies as a good approximation. For more accurate results, it is possible to use a table provided in the operating instructions for the Stefan-Boltzmann lamp.

In this experiment, temperatures T are chosen to be so high that the ambient temperature T_0 can be ignored in equation (3). Instead of the absolute intensity S, the thermopile voltage U_{th} is read off as a measure of relative intensity. Equation (3) can then be rewritten as

$$U_{th} = a \cdot T^4 \quad \text{or} \quad \ln(U_{th}) = \ln(a) + 4 \cdot \ln(T)$$

This means that a graph of ln (U_{th}) against ln (T) will show all the measurement points along a straight line of gradient 4.

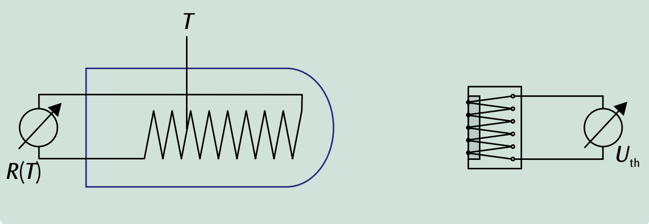

Fig. 1: Schematic of set-up

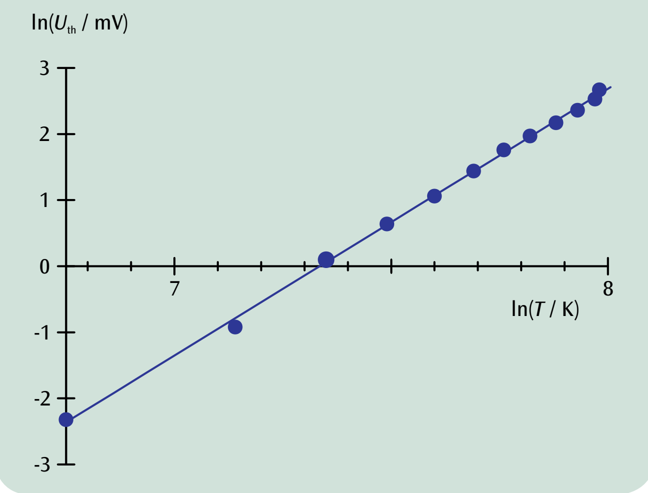

Fig. 2: Graph of ln (U_{th}) against ln (T)