Black Body Radiation: Determination of Stefan's Constant

Aim:

Determination of Stefan- Boltzmann constant σ .

Apparatus:

Heater, temperature-indicators, box containing metallic hemisphere with provision for water-flow through its annulus, a suitable black body which can be connected at the bottom of this metallic hemisphere.

Principle:

A black body is an ideal body which absorbs or emits all types of electromagnetic radiation. The term 'black body' was first coined by the German physicist Kirchhoff during 1860's. Black body radiation is the type of electromagnetic radiation emitted by a black body at constant temperature. The spectrum of this radiation is specific and its intensity depends only on the temperature of the black body. It was the study of this phenomenon which led to a new branch of physics called Quantum mechanics.

According to Stefan's Boltzmann law (formulated by the Austrian physicists, Stefan and Boltzmann), energy radiated per unit area per unit time by a body is given by,

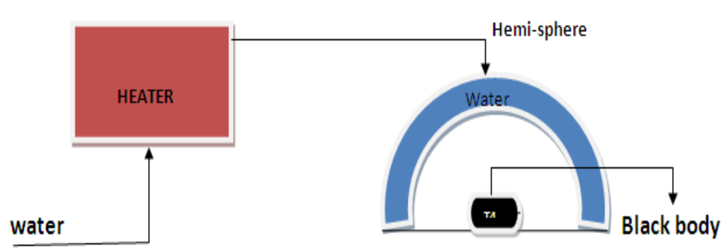
$$R = \epsilon \sigma T^4 \text{..........}(1)$$

Where R = energy radiated per area per time, Є = emissivity of the material of the body, σ = Stefan's constant = 5.67x10-8 $Wm^{-2}K^{-4}$, and T is the temperature in Kelvin scale.

For an ideal black body, emissivity Є=1, and equation (1) becomes,

$$R = \sigma T^4 \text{..........}(2)$$

The block diagram of experimental set up to study the blackbody radiation is given below.



This setup uses a copper disc as an approximation to the black body disc which absorbs radiation from the metallic hemisphere as shown in fig (1). Let T_d and T_h is the steady state temperatures of copper disc and metallic hemisphere respectively. Now according to the equation (2), the net heat transfer to the copper disc per second is,

$$\frac{\Delta Q}{\Delta t} = \sigma A\left(T_h^{\,4} - T_d^{\,4}\right) \text{..........}(3)$$

Where A is the area of the copper disc and $\Delta Q = (Q_h - Q_d)$.

Now, we have another equation from thermodynamics for heat transfer as,

$$\frac{\Delta Q}{\Delta t} = mC_p \frac{dT}{dt} \text{..........}(4)$$

Where 'm' mass of the disc, 'C_p'' specific heat of the copper, dT/dt is the change in temperature per unit time.

Equating equations (3) and (4),

$$\sigma A\left(T_h^{\,4} - T_d^{\,4}\right) = mC_p \frac{dT}{dt} \text{..........}(5)$$

Hence,

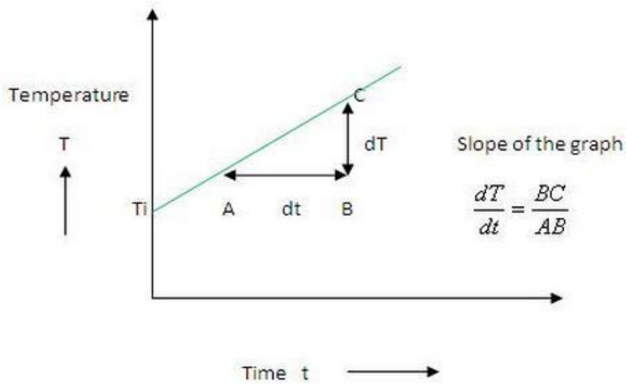
$$\sigma = \frac{mC_p}{A\left(T_h^{\,4} - T_d^{\,4}\right)} \frac{dT}{dt} \text{..........}(6)$$

Applications:

1. Determination of temperature of Sun from its energy flux density.
2. Temperature of stars other than Sun, and also their radius relative to the Sun, can be approximated by similar means.
3. We can find the temperature of Earth, by equating the energy received from the Sun and the energy transmitted by the Earth under black body approximation.

Procedure for performing real lab:

1. Remove the disc from the bottom of the hemisphere and switch on the heater and allow the water to flow through it.
2. Allow the hemisphere to reach the steady state and note down the temperature T_1, T_2, T_3.
3. Fit the disc (black body) at the bottom of the hemisphere and note down its rise in temperature with respect to time till steady state is reached.
4. A graph is plotted with temperature of disc along Y-axis and time along X-axis as shown.
5. Find out the slope dT/dt from the graph.



Observation table:

Trial No.	Temperature of hemisphere			Average Temperature $T_h = (T_1+T_2+T_3)/3$	Temperature of the disc in Kelvin, T_4	Time T (seconds)	Steady temperature of disc in kelvin
	T_1	T_2	T_3				
1							
2							
3							

Calculations:

Mass of the copper disc = ... kg

Specific heat of copper = 390 J kg^{-1} K^{-1}

Radius of the disc = ... m
Area of the disc = ...m^2

Slope of the graph $\frac{dT}{dt}$ = ……Ks^{-1}

Substituting the values in the given expression,

$$\sigma = \frac{mC_p \frac{dT}{dt}}{A\left(T_h{}^4 - T_d{}^4\right)}$$

= …………………………… Wm^{-2}K^{-4}

Result:

Stefan-Boltzmann's constant σ =……………. Wm^{-2}K^{-4}