PH160 Laboratory 6

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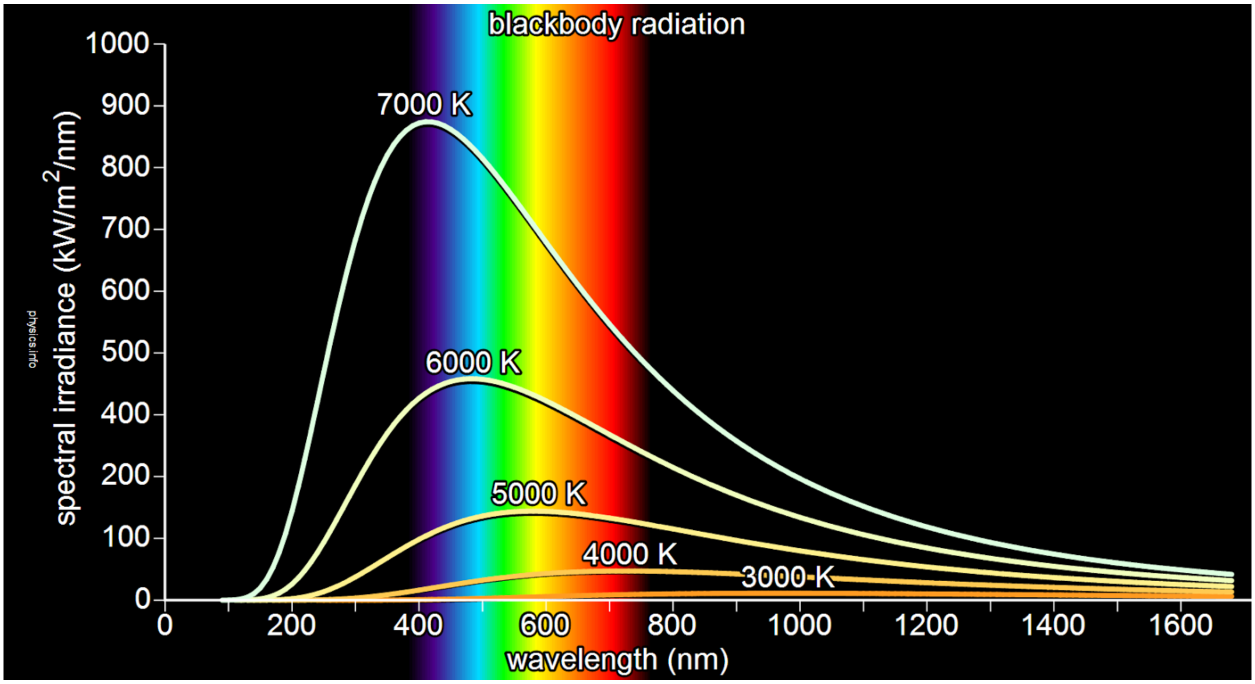
Aim : Determination of Stefan- Boltzmann constant σ

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.

Theory : 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.

Josef Stefan

Ludwig Boltzmann



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,

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

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 ΔQ= (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 the 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.

Observations :

Case 1 :

Conditions :

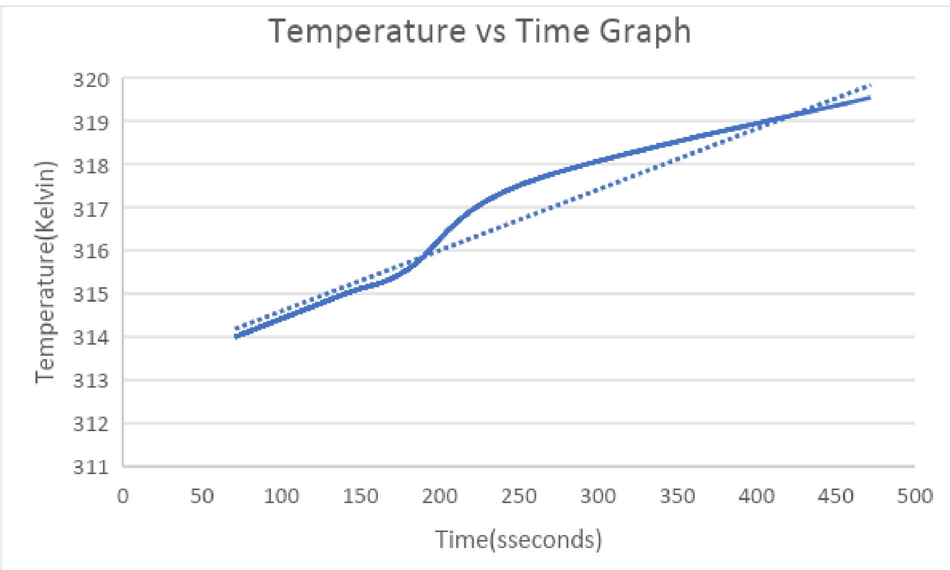
Mass of the copper disc = 0.0054 kg
Specific heat of copper = 385 $Jkg^{-1}K^{-1}$
Radius of the disc = 0.015 m

Area of the disc = pi*r^2 = 7.068 x 10^{-4} m^2

T_1=T_2=T_3= 50°C = 323 K
Surrounding Temperature = 40 °C = 313K
T_h = (T_1+T_2+T_3)/3 = 50°C =323 K
T_d = 319.5 K

S no.	Time(in seconds)	Temperature(in Kelvin)
1	71	314
2	140	314.99
3	180	315.56
4	253	317.55
5	472	319.54

Graph of Temperature versus time:



Case 2 :

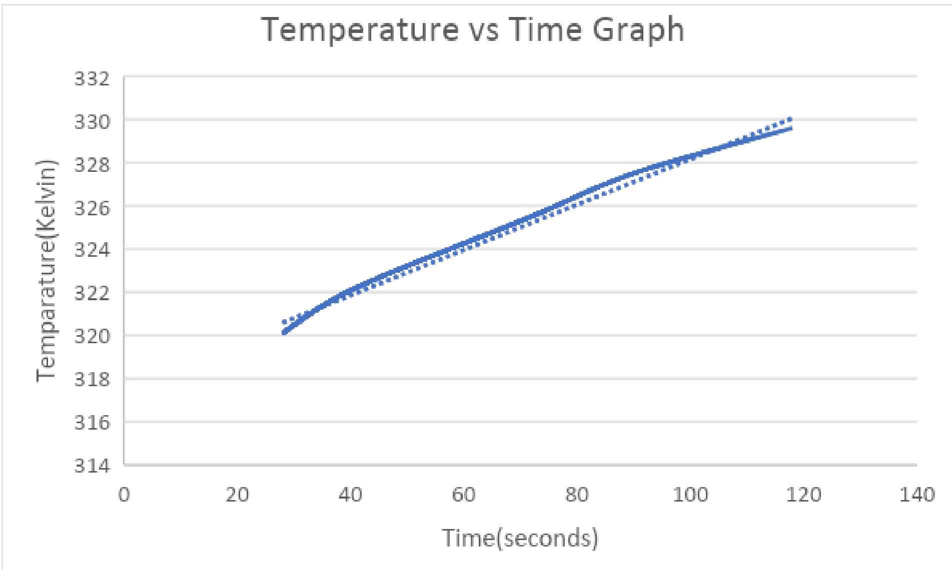
Conditions :

Mass of the copper disc = 0.007 kg
Specific heat of copper = 385 Jkg^{-1}K^{-1}
Radius of the disc = 0.03 m
Area of the disc = pi*r^2 = 2.83 x 10^{-3} m^2

T_1=T_2=T_3= 60°C = 333K
Surrounding Temperature = 45 °C = 318K
T_h = (T_1+T_2+T_3)/3 =60°C =333 K
T_d = 329.6K

S no.	Time(in seconds)	Temperature(in Kelvin)
1	28	320.1
2	41	322.2
3	71	325.4
4	90	327.5
5	118	329.6

Graph of Temperature versus time:



Case 3 :

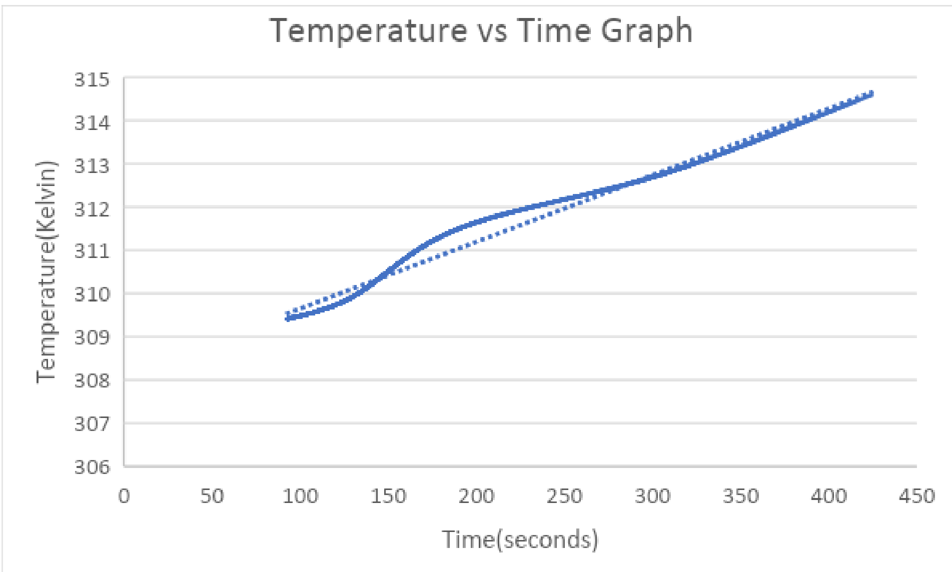
Conditions :

Mass of the copper disc = 0.006 kg
Specific heat of copper = 385 $Jkg^{-1}K^{-1}$
Radius of the disc = 0.02 m
Area of the disc = pi*r^2 = 1.26 x 10^{-3} m^2

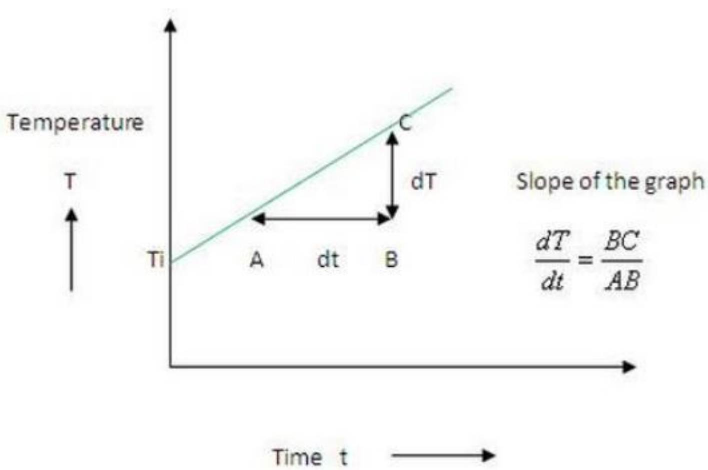
T_1=T_2=T_3= 45°C = 318K
Surrounding Temperature = 35 °C = 308K
T_h = (T_1+T_2+T_3)/3 = 45°C =318 K
T_d = 314.6 K

S no.	Time(in seconds)	Temperature(in Kelvin)
1	92	309.4
2	129	309.9
3	190	311.5
4	309	312.8
5	425	314.6

Graph of Temperature versus time:



Calculations :



Case 1 :

Slope of the graph dT/dt = 0.0141

Substituting the values in the given expression,

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

= (0.0054 x 385 x 14.1x 10^{-3})/ 7.068 x 10^{-4} x (323^4-319.5^4)

= 8.935x 10^{-8}

Therefore, calculated value of Stefan-Boltzmann's constant σ = 8.935x 10^{-8} $Wm^{-2}K^{-4}$

Case 2 :

Slope of the graph dT/dt =0.1051

Substituting the values in the given expression,

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

= (0.007 x 385 x 0.1051)/ 2.83 x 10^{-3} x (333^4-329.6^4)

=2.02 x 10^{-8}

Therefore, calculated value of Stefan-Boltzmann's constant σ = 8.935x 10^{-8} $Wm^{-2}K^{-4}$

Case 3 :

Slope of the graph dT/dt =0.0154 (from the graph)

Substituting the values in the given expression,

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

= (0.006 x 385 x0.0154)/ 1.26 x 10^{-3} x (318^4-314.6^4)

= 6.56 x 10^{-8}

Therefore, calculated value of Stefan-Boltzmann's constant σ = 6.56 x 10^{-}8 $Wm^{-2}K^{-4}$

Error Analysis :

There could have been error in recording time and temperature simultaneously.

Percentage Error in case 1:

= (8.935-5.67) x 10^{-8}/5.67 x 10^{-8}

= 0.0.5758

=57.58 % error (increase)

Percentage Error in case 2:

= (5.67-2.02) x 10^{-8}/5.67 x 10^{-8}

= 0.6437

=64.37 % error (decrease)

Percentage Error in case 3:

= (6.56-5.67) x 10^{-8}/5.67 x 10^{-8}

= 0.1569

=15.69 % error (increase)

Average Error

= (57.38-64.37+15.69)/3

= 2.99 % error

Result Analysis and Conclusion :

- As observed in the readings, the time taken for the temperature to be constant is directly proportional to the differences between the water and surrounding temperature.
- The graph Temp. vs time is a straight line.
- Stefan's constant is coming almost the same in different conditions but there is some error also due to the fast timer.
- The actual value of σ is in the range of 2 x 10^{-8} to 9 x10^{-8} $Wm^{-2}K^{-4}$

Thank You