THERMAL CONDUCTIVITY OF A BAD CONDUCTOR
(LEE'S DISC METHOD)

===

Aim: To determine the coefficient of thermal conductivity of a bad conductor by Lee's method

Apparatus: Lee's apparatus, Steam generator, Given bad conductor (card board or glass or ebonite), Steam generator, Two thermometers (0-110^{0}C), Screw gauge, Vernier calipers, Rough balance, Stop-clock etc.,

Description of the Apparatus:

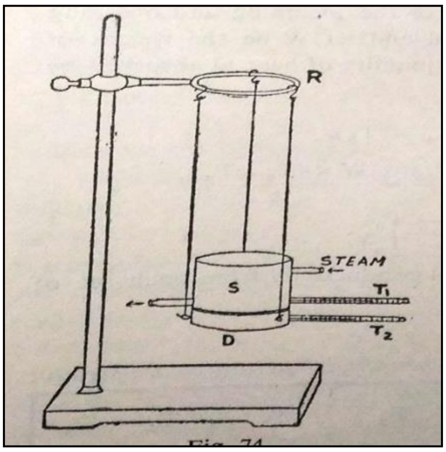


Fig: Lee's apparatus

The Lee's disc consists of a heavy circular metallic disc (D) about 10 cm in diameter and 1 cm thick suspended by three strong strings from a ring (R) and a hollow cylindrical steam chamber (S), 10 cm in diameter and 5 cm high, which rests on the disc.

The disc has a hole in it for introducing a thermometer(T_2). The steam chamber has an inlet and outlet for letting in and letting out steam. There is another hole in it for introducing a thermometer (T_1). The disc and the steam chamber are nickel or chromium plated and so, have brightly polished surfaces.

Procedure: The metallic disc is hung horizontally from the ring. The card-board, cut to the size of the disc is placed on it. The steam chamber is placed over the card-board, so that the latter is sand-witched between the disc and the steam chamber. The two thermometers are placed in position, one in the disc and the other in the steam chamber.

The steam boiler is set up and connected to the steam chamber by a long rubber tube. Steam is passed into the chamber. A long rubber tube connected to the outlet tube leads the escaping steam away from the disc.

The thermometers indicate rise in temperature. T_1 gives the temperature of the chamber, T_2 gives the temperature of the disc. The disc rises in temperature due to the heat conducted across the card-board. When the two temperatures are steady for fairly long time, say 15 to 25 minutes, note them and cut off the steam supply.

Gently remove the card-board between the disc and the steam chamber. Place the chamber directly in contact with the disc. Again, pass steam into the chamber. The disc gets heated more rapidly now. When its temperature is about 7 or 8^{0}C above the temperature T_2, reached by it formerly, cut off the steam and carefully remove the steam chamber.

Allow the disc to cool. When its temperature falls exactly to 5^0C above T_2 (its former temperature), start a stop-clock. Note the temperature every half minute till it falls by 5^0C below T_2 , its former temperature.

Measure the mean thickness and diameter of the disc with a vernier calipers. Find it mass using a rough balance. Measure the mean thickness of the card-board with a screw gauge. Take readings at not less than 6 different places on it.

Theory - Principle: At the steady state, heat conducted through the bad conductor is equal to heat radiated from the Lees disc i.e., the rate of conduction of heat across the bad conductor is equal to the rate of loss of heat from the exposed surface of the disc.

Let T_1 and T_2 be the steady temperatures of the steam chamber and the disc respectively when steam is passed through the chamber.

Let x be the thickness of the bad conductor (card-board) and let A= πr^2 be the area of surface (where r is the radius of the card-board as well as the disc also)

(1) The rate of heat conduction through the bad conductor is given by :

$$\left(\frac{Q}{t}\right) = \mathrm{R} = \frac{K.A.(T_1 - T_2)}{\mathrm{x}}$$

$$\mathrm{R} = \frac{K(\pi r^2)(T_1 - T_2)}{\mathrm{x}} \quad \text{---} \quad \text{--- (1)}$$

where K is the coefficient of thermal conductivity of the bad conductor.

(2) Let ***m*** be the mass of the lower disc and ***s*** be the specific heat of the material of the lower disc and $\boldsymbol{\alpha} = \frac{d\theta}{dt}$ is the rate of loss of heat radiation by the disc.

$$\mathrm{R} = m\, s \left(\frac{d\theta}{dt}\right) = m\, s\, \alpha \quad \text{---} \quad \text{--- (2)}$$

Taking into consideration the effective area of the surface of the disc which is radiating, the above equation gets modified as

$$\mathrm{R} = m\, s\, \alpha \left[\frac{r+2d}{2(r+d)}\right] \quad \text{---} \quad \text{--- (3)}$$

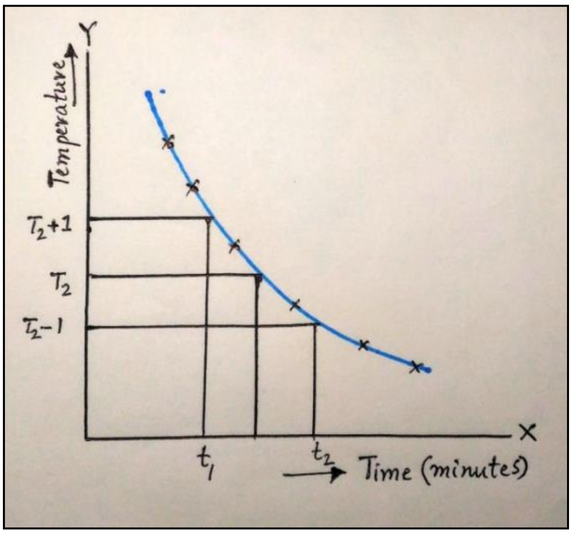
From Eq.(1) and (3), we have

$$\frac{K(\pi r^2)(T_1 - T_2)}{\mathrm{x}} = m\, s\, \alpha \left[\frac{r+2d}{2(r+d)}\right]$$

This is because, at the steady state, the rate of conduction of heat across the bad conductor is equal to the rate of loss of heat from the exposed surface of the disc.

$$K = \frac{m\, s\, \alpha\, (r+2d)\, x}{2(\pi r^2)(r+d)(T_1-T_2)}$$

Here the value of α can be calculated from the graph.



A cooling curve is drawn with time along the X-axis and the corresponding temperatures along the Y-axis. From the graph, the rate of cooling α can be calculated as follows:

$$\alpha = \left(\frac{d\theta}{dt}\right) = \left[\frac{(T_2+1)-(T_2-1)}{t_2-t_1}\right] \textit{(Time t in minutes)}$$

$$\alpha = \left(\frac{d\theta}{dt}\right) = \left[\frac{2}{60(t_2-t_1)}\right] \textit{(Time t in seconds)}$$

$$\therefore\ \alpha = \left[\frac{1}{30(t)}\right]$$

Graph: Time-temperature graph

Obsrvations:

(i) To determine the thickness of the card-board (x) using screw gauge:

Least count = 0.01 mm ; Zero-error = …… div ; Zero correction = …… div

S. No.	Pitch Scale Reading (a) (mm)	Head Scale coincidence		Fraction b = n x LC (mm)	Total Reading **X = a + b** (mm)
		Observed	Corrected (n)		
∴ Average thickness of the card-board (**x**) **= ……** mm = …… cm					

(ii) To determine the thickness of the lower disc (d) using screw gauge:

Least count = 0.01 mm ; Zero-error = …… div ; Zero correction = …… div

S. No.	Pitch Scale Reading (a) (mm)	Head Scale coincidence		Fraction b = n x LC (mm)	Total Reading **d = a + b** (mm)
		Observed	Corrected (n)		
∴ Average thickness of the lower disc (**d**) **= ……** mm = …… cm					

(iii) To determine the radius of the lower disc (r) using vernier calipers:

Least count = 0.01 cm

S. No.	Main Scale Reading (a) (cm)	Vernier coincidence (n)	Fraction b = n x LC (cm)	Total reading **r = a + b** (cm)
∴ Average thickness of the lower disc (**r**) **= ……** mm = …… cm				

(iv) Time-temperature readings:

Time (minutes)	**Temperature (^{0}C)**
0	
½	
1	
1½	
2	
2½	
3	
3½	
..	
..	

Formula:

Coefficient of Thermal conductivity of card-board (K)

$$\mathbf{K} = \frac{m\, s\, \alpha\, (r+2d)\, x}{2(\pi r^2)(r+d)(T_1-T_2)}$$

Here m = mass of the lower disc = ….. g

r = Radius of the lower disc = …. cm

d = Thickness of the lower disc = …. cm

x = Thickness of the card-board = …. cm

T_2 = Steady temperature of the lower disc = …. ^{0}C

T_1 = Steady temperature of the steam chamber = …. ^{0}C

$\alpha = \left(\frac{d\theta}{dt}\right)$ = Rate of cooling = ….. (From the Graph)

s = Specific heat of material (brass)of the lower disc = 0.09 cal/gram-^{0}C

Result: The coefficient of thermal conductivity of the given bad conductor (card-board) is found to be **K= ………..cal/sec/cm^2/unit temperature gradient**

SPECIFIC HEAT OF A LIQUID BY APPLYING NEWTON'S LAW OF COOLING CORRECTION

==

Aim: To determine the specific heat of a liquid by applying Newton's law of cooling correction.

Apparatus: A calorimeter coated with lamp black on the outside, given liquid whose Specific heat is to be determined, a sensitive thermometer, a stop clock, a sensitive physical balance or electronic balance.

Formula: The specific heat of given liquid (x) can be calculated as below

$$\frac{W_1 s+(W_2-W_1)}{t_W} = \frac{W_1 s+(W_3-W_1)\, x}{t_L};\ \text{where}$$

W_1 = weight of empty calorimeter along with stirrer
W_2 = weight of calorimeter + water along with stirrer
W_3 = weight of calorimeter + liquid along with stirrer
t_W = time taken by hot water to cool from θ_1 to θ_2 °C (from the Graph)
t_L = time taken by hot liquid to cool from θ_1 to θ_2 °C (from the Graph)
s = Specific heat of material of calorimeter(Copper) = cal/gram-°C
x = Specific heat of given liquid =….. cal/gram-°C

Procedure: (i) First of all, the mass $\mathbf{W_1}$ of empty calorimeter along with stirrer (without the lid) is determined with physical balance. Next the calorimeter and stirrer are placed on non conducting stand. A suitable amount of water is taken in a vessel and is heated up to 90°C.

(ii) A mark is placed on the inner side of calorimeter at a height equal to nearly 2/3rd of height of the calorimeter. The hot water is gently poured into the calorimeter up to this mark. The lid is closed on the calorimeter and the stirrer and thermometer are inserted. When the temperature falls to 80°C, the stop clock is started and the temperatures are noted down at regular intervals of the time say, for every ½ minute. The time-temperature readings are continued until the temperature of water in the calorimeter falls to 50°C. The calorimeter and contents are allowed to cool up to the room temperature. Then the mass $\mathbf{W_2}$ of the calorimeter along with stirrer and water is determined. Readings are tabulated.

(iii) The calorimeter is cleaned and dried. The liquid, whose specific heat is to be determined, is taken in a beaker and heated up to 90^0C. The hot liquid is now poured into the calorimeter and is allowed to cool down to 80^0C. Afterwards, the time-temperature readings are taken at regular intervals of the time say, for every ½ minute till the temperature of the liquid cools to 50^0C.The mass of calorimeter and liquid at the room temperature $\mathbf{W_3}$ is determined after cooling it to room temperature. Readings are tabulated.

Observations:

Mass of the empty calorimeter along with stirrer = **W_1 = …..g**

Mass of the calorimeter + water along with stirrer = **W_2 = ….g**

Mass of the calorimeter + liquid along with stirrer = **W_3 = ….g**

The Masses W_1, W_2 and W_3 are determined using the physical balance or electronic balance.

Time-temperature readings:

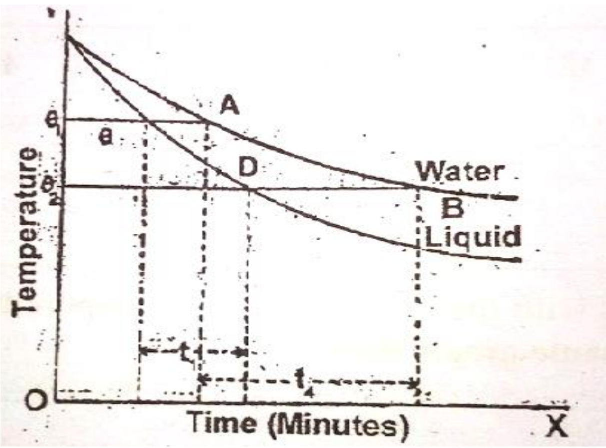
For water:

Time (minutes)	Temperature(^{0}C)
0	80^{0}C
½	---
1 ½	---
2	---
2 ½	---
3	---
3 ½	---
:	---
:	---

For liquid:

Time (minutes)	Temperature(^{0}C)
0	80^{0}C
½	---
1 ½	---
2	---
2 ½	---
3	---
3 ½	---
:	---
:	---

Graphs: Taking time along X-axis and temperature along Y-axis, two graphs are drawn one for water and the other for liquid. They are shown in Figure.



From these graphs, the times t_W and t_L to cool from θ_1 to θ_2 °C are determined:

Time taken by hot water in the calorimeter to cool from $\theta_1{}^0$ **C** to $\theta_2{}^0$ **C** (in seconds)= **t_W = … sec**

Time taken by hot liquid in the calorimeter to cool from $\theta_1{}^0$ **C** to $\theta_2{}^0$ **C** (in seconds)= **t_L = … sec**

Precautions:

1. The water and the liquid are to be taken exactly to same fixed mark.
2. The temperature difference between the calorimeter contents and surroundings should not be large. Preferably 50°C

Result: The specific heat of given liquid (x) is found to be …… cal/gram-°C

***

THERMAL CONDUCTIVITY OF RUBBER
(RADIAL FLOW METHOD)

==

Aim: To determine the coefficient of thermal conductivity of rubber by radial flow method.

Apparatus: Steam generator, rubber tube of diameter about one cm, calorimeter, thermometer (0-110^0 C), stop-clock, vernier microscope, physical balance, weights ect.

Theory : The thermal conductivity of rubber is given by

$$\mathbf{K} = \frac{\{w_1 s_1 + (w_2 - w_1)\}\,(\theta_2 + \delta\theta - \theta_1)\,\log_e\left(\frac{r_2}{r_1}\right)}{2\,\pi\,l\,t\left\{\theta - \left(\frac{\theta_1 + \theta_2}{2}\right)\right\}}$$

Where,

w_1 = Mass of the empty calorimeter along with stirrer

w_2 = Mass of the calorimeter + water along with stirrer

θ_1 = Initial temperature of the calorimeter

$\delta\theta$ = Radiation correction to temperature (from Barton graph)

t = time for rise of temperature

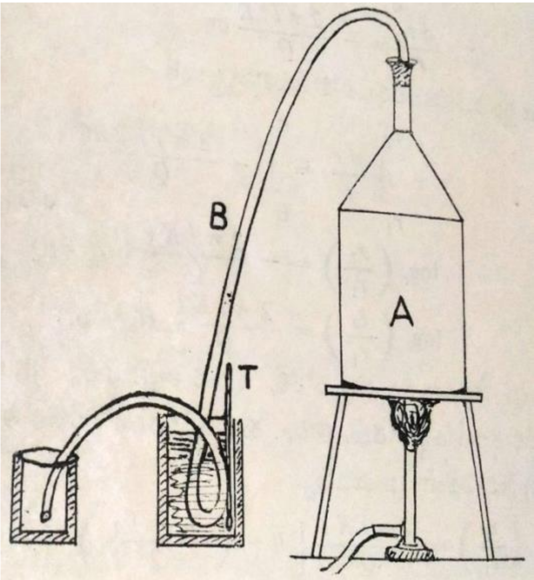
θ = temperature of steam

r_1 = inner radius of rubber tube

r_2 = outer radius of rubber tube

l = length of rubber tube immersed in water in calorimeter

Description :



Water is heated in a steam generator A to produce steam . Steam comes out through a rubber tube B.

A calorimeter is taken and filled with water up to certain level. A small rubber tube of length about 10 cm is taken in the form of a loop and it is immersed in water as shown in figure.

The other end of the rubber tube is kept in a beaker.

Procedure: (i) First of all, the mass $\mathbf{w_1}$ of empty calorimeter along with stirrer (without the lid) is determined with physical balance. About half of the calorimeter is filled with water and again the mass $\mathbf{w_2}$ of calorimeter along with water is determined. The initial temperature θ_1 of the calorimeter is recorded.

(ii) A rubber tube of length 10 cm is taken in the form of a loop and it is tied with a piece of string. The rubber loop is then completely immersed in water up to the knot.

(iv) The steam produced from the steam generator is allowed to pass through the rubber tube. The other end of the rubber tube is kept in a beaker.

(v) The stop clock is started simultaneously after the immediate passage of steam into the rubber tube.

(vi) Note the temperature of water every half a minute with the help of thermometer T till the temperature raises by 10^0C. The final temperature is θ_2 of the calorimeter is recorded.

(vii) Now the passage of steam through the rubber tube is stopped. The fall of temperature of calorimeter is noted every half a minute. After the temperature falls by about 1^0C, the radiation correction $\boldsymbol{\delta\theta}$ is found out from Barton's method.

(viii) The length of rubber tube immersed in water in calorimeter *l* is measured. A small portion of the rubber tube is cut and its inner and outer radii are measured with the help of a vernier microscope.

Precautions:

(1)

Result:

The coefficient of thermal conductivity (K) of rubber by radial flow method is found to be ….. cal/sec/cm^2/unit temperature gradient.

****

TEMPERATURE CHARACTERISTICS OF THERMISTER

==

Aim: To study the temperature characteristics of given thermister

Apparatus: Thermistor, Post-office Box, galvanometer, two tap keys, Dry cell battery cell 2V, Temperature bath, thermometer, connecting wires.

Theory: The variation of resistance R, of a thermistor with Temperature T is given by

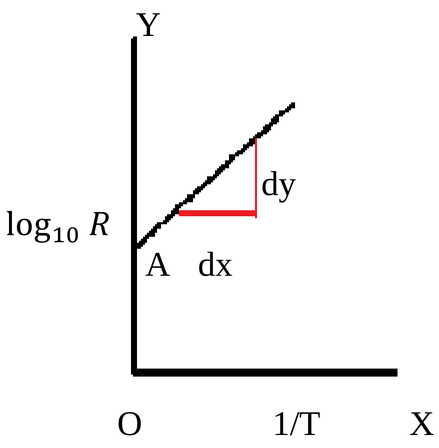
$$R = a\, e^{\frac{b}{T}}$$

$$\log_{10} R = \log_{10} a + 0.4343\, \frac{b}{T}$$

Slope of the graph 1/T versus $\log_{10} R$ is equal to β = 0.4343b

The Temperature Coefficient of Resistance α is given by

$$\alpha = \frac{1}{R}\frac{dR}{dT} = -\frac{b}{T^2} \quad \text{, α is negative}$$



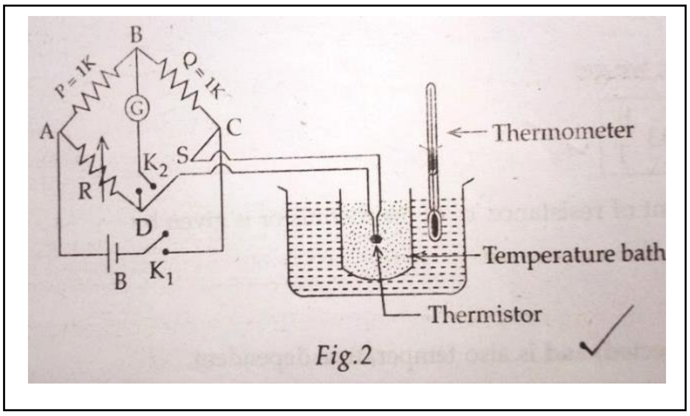


Fig.2

Procedure:

Thermistor has a negative temperature coefficient of resistance α of large value. It is connected in the fourth arm S of the Wheatstone bridge formed with P= 1 kΩ , Q = 1 kΩ , R= variable resistance. The galvanometer in series with tap key is connected across B and D and the storage cell is connected across A and C. The thermistor is placed in a thin walled glass tube and is immersed in the heat bath as shown in figure.

Initially at room temperature the bridge is balanced varying the variable resistance. As P=Q the balancing condition of Wheatstone bridge gives R=S (resistance of thermister). With the help of a heater the water bath is gradually heated and the variation of resistance with respect to temperature at different values found. Next the water bath is gradually cooled by removing the heater and again the resistances are found corresponding temperatures.

Resistance of the thermister at particular temperature $R = \frac{R_1+R_2}{2}$ is calculated and readings are tabulated in the table.

Temperature		1/T	Value of R_{Th}			$\log_{10} R$
t (° C)	T= (t+273) K		T increasing (R_1)	T decreasing (R_2)	Mean $(R_1+R_2)/2$	
Room temperature						
30						
40						
50						
60						
70						
80						

Calculation and Result: on the 1/T - $\log_{10} R$ graph, the straight line is obtained extended backwards to intersect y axis at A, then

OA = $\log_{10} a$

a = -------

Slope of the curve m= dy / dx = 0.4343 b = ----------------

Temperature coefficient of thermistor α = $-\frac{b}{T^2}$

Precautions:

1. Do not operate the thermistor above 90°C
2. Temperatures are to be determined accurately
3. Observations are taken corresponding to both increasing and decreasing temperatures.

Result:

The temperature characteristics of a thermister are studied.

Thermister constant (β) of the given thermister is found to be …..

***

HEATING EFFICIENCY OF AN ELECTRIC KETTLE

Aim: To determine the heating efficiency of the electric kettle at different voltages.

Apparatus: A Joule Calorimeter (in place of electronic kettle), D.C Voltmeter, D.C ammeter, a Battery eliminator, rheostat, plug-key, connecting wires, a physical balance and a stop clock.

Formula:

$$\eta = \frac{[W_1 S+(W_2 - W_1)] (\theta_2 - \theta_1) . J}{V i\, t} \quad X\ 100$$

where W_1= Mass of empty calorimeter

W_2= mass of calorimeter + water

S= Specific heat of the material of the calorimeter (S= 0.1cal/gm- °c)

θ_1= temperature of water in the calorimeter before passing current

θ_2= temperature of calorimeter after passing current

t = time of passage of current in Secs

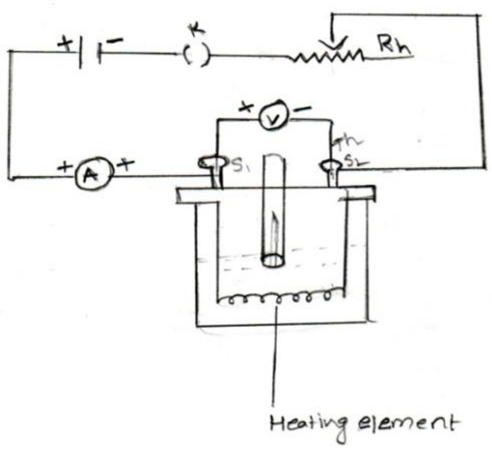
v = Voltmeter reading in volts.

i = Ammeter reading in Amperes

J = Mechanical equivalent of heat = 4.18 Joules/calorie.

η = heating efficiency of the heating element.

Description:



The joule calorimeter is an aluminium vessel with a stirrer. The calorimeter is kept inside a wooden box with a hole. A lid made of a bad conductor like ebonite is used to cover the hole. There are two screws S_1 and S_2 on the lid. The binding screws are connected to the upper ends of two thick copper rods the lower ends of the copper rods are connected by a nichrome wire; the nichrome wire is the heating element. The lid consists of two holes – one, to insert the thermometer, the other to insert the stirrer. The wooden box is packed with cotton wool, etc to prevent the loss of heat due to conduction.

The colorimeter is polished well to prevent the loss of heat due to radiation.

The heating element is connected to ammeter A_1, voltmeter V1, Battery B, and a Rheostat Rh as shown in figure.

Theory: The work done in passing current i through the heating element at a voltage V during a time t, is given by

$$W = V\,i\,t \text{ joules} \qquad \ldots.\ (1)$$

Heat gained by calorimeter + water is given by

$$Q = [W_1 s + (W_2 - W_1)]\ (\theta_2 - \theta_1) \text{ calories}$$

$$= [W_1 S + (W_2 - W_1)]\ (\theta_2 - \theta_1) \cdot J \text{ joules} \ \ldots.\ (2)$$

Efficiency of the heating element,

$$\eta = \frac{Q}{W} = \frac{[W_1 S + (W_2 - W_1)]\ (\theta_2 - \theta_1) \cdot J}{V\,i\,t} \times 100$$

Procedure: The mass of the empty calorimeter with stirrer (W_1 gm) is determined using a sensitive balance. Sufficient water (above two-thirds) is taken in the calorimeter, so that the coil is completely immersed in it. Its mass (W_2 gm) is again determined. Then the calorimeter is kept inside the wooden box. And the lid is tightly closed. A thermometer is inserted into the water.

The calorimeter is connected in series with the battery, the key k, the Rheostat Rh and an Ammeter A. The voltmeter v is connected in parallel with the coil between the screws S_1 and S_2. The positive terminal of the Battery must be connected to positive of the Ammeter. The positive of the voltmeter must be connected to S_1.

The key is closed. The rheostat is adjusted so that the voltmeter should read 4 volts. The key is opened; the initial temperature of water (θ_1°C) is noted. The planning key is closed. A stop clock is started simultaneously. Current is passed through the coil until the temperature of water raises by 5°C. The stop clock is stopped time *t* seconds is noted.

The final temperature of water is noted (θ_2°C). The values are tabulated. The efficiency (η) of the heating coil is calculated.

The experiment is repeated by varying the voltmeter reading to 5v, 6v etc the efficiency (η) is calculated each time.

Observations:

Mass of the calorimeters W_1 = gm.

Mass of the calorimeter + water W_2 = gm.

Mechanical equivalent of heat J = 4.8 J/cal.

Specific heat of material of the calorimeter, S = 0.1 cal/gm -°C

S. No	θ_1 (°C)	θ_2 (°C)	*Voltmeter reading (volts)*	*Ammeter reading (Amperes)*	*Time of passage of current* (t) sec

Result: Percentage of efficiency of the heating coil η = ……%

***

MEASUREMENT OF STEFAN'S CONSTANT

Aim: To determine the Stefan's constant (σ) using a black body radiation chamber.

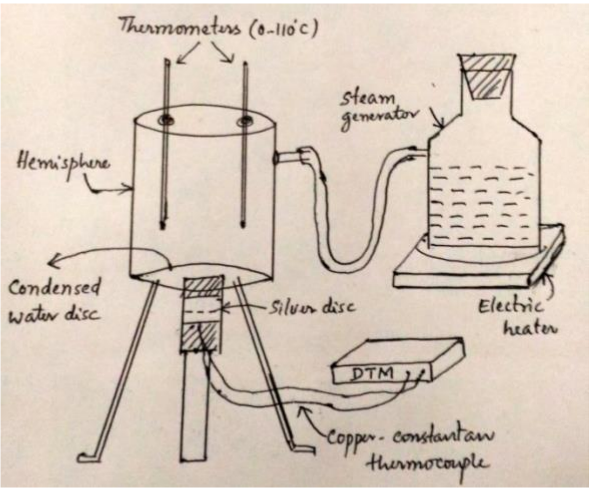
Apparatus: Black Body radiation chamber with a window/ hole (W), Thermocouple, Steam boiler, Vertical rod with silver/copper disc at the top, Digital thermometer(DTM), stop-watch, Two Thermometers (0-110^{0}C), electric heater

Description: The apparatus used for determining the Stefan's constant comprises a blackened hollow hemisphere of about 20 cm diameter fitted in a wooden board lined with blackened-tin There is a steam chamber just above the hemisphere to measure the mean uniform temperature by passing steam through it. The temperature inside it can be measures by two thermometers.

A small silver disc, which is soldered at bottom to Copper-constantan thermocouple, is housed in an ebonite tube screwed on a rod adjustable for setting the silver disc at the center of hemisphere. Silver disc is sorrounded with cotton wool and cold reservoir is placed over it. The disc physical constants are engraved on the ebonite tube.

A small hole is provided in the wooden board of about 2 cm diameter permits silver disc with upper surface coated black at the center. A stopper is provided to check the out coming radiation when is out. One junction of a thermocouple is connected to the silver disc while the other junction is kept at room temperature.

Procedure:



Set up the apparatus and ensure proper working of each component. Draw the disc down by using the clamping screw and close the hole by stopper.

Heat the steam generator with the help of electric heater. Allow the steam from the steam generator in to the black body radiator through a rubber tube. The temperature of the enclosure rises and reaches a steady state in about 30 minutes.

Record the steady temperature of the chamber with the help of two thermometers and take the average of the two temperatures.

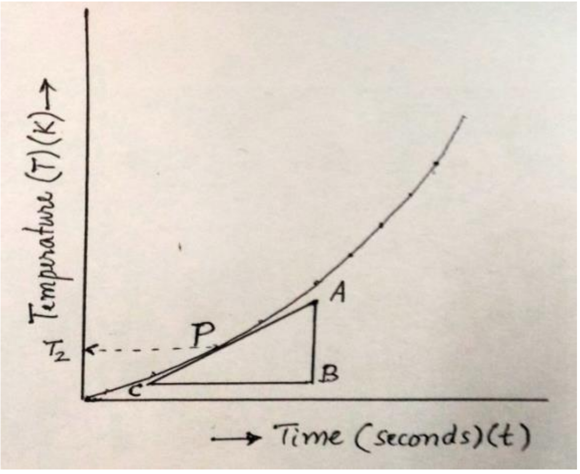
Now, keeping the stop-watch ready at hand, open the hole(window) of the hemisphere and insert the silver disc immediately through the hole into the chamber at its centre. Start the stop-clock and note the readings of temperatures on the digital panel meter (DPM) for every 10 seconds for 3 minutes. (The final temperature of the should be below the equilibrium (steady) temperature of the chamber).

Tabulate the results as shown below:

Time (seconds) (t)	Temperature(^{0}C) (T)
0	30^{0}C (say)
5	---

10	---
15	---
20	---
25	---
:	---
:	50^0C

Graph:



A graph is drawn between time (t) on X-axis and temperature (T) (in K) on Y-axis. We get a curve as shown in the figure.

(dT/dt) gives us the rate of rise of temperature of the silver disc. On the curve, a point P, not far from the origin is taken. A tangent to the curve is drawn at the point P . The value of (dT/dt) is calculated as follows:

$$\frac{dT}{dt} = \tan\beta = \frac{AB}{BC}.$$

The absolute temperature (T_2) of silver disc is the temperature corresponding to the point P (at the point of tangent) on the graph.

Calculation of Stefan's constant (σ) :

$$\sigma = \frac{J\, m\, s}{A\,[T_1^4 - T_2^4]}\left[\frac{dT}{dt}\right]$$

where, J = Mechanical equivalent of heat = 4.18 x 10^7 ergs

m = Mass of the silver disc = 0.43 g

s = Specific heat of silver = 0.091 cal/g-^{0}C

A= Area of the disc = $\pi\, r^2 = \pi\,(0.7)^2$ sq.cm (Diameter of the silver disc=1.4 cm)

T_1 = Steady temperature of the black body radiator = ….K

T_2 = Absolute temperature of the silver disc = ….K (from the graph)

The standard value of Stefan's constant is given by

σ = 5.67 x 10^{-5} ergs/cm^2 sec^2 K^4 (or) 5.67 x 10^{-8} watts/m^2 K^4

Precautions: (i) The silver disc should be introduced keeping ready the stop-watch at hand and the stop-watch is started simultaneously soon after the insertion of silver disc into the chamber.

(ii) The time-temperature readings should be recorded simultaneously with the help of DTM.

Result: The value of Stefan's constant (σ) is found to be …… ergs/cm^2 sec^2 K^4

***