St. Lawrence High School
A Jesuit Christian Minority Institution
Study Material – 4
Term : 1st

Class – X | Subject – Physical Science
Chapter – Thermal Phenomena | Date – 09.05.20
Topic – Conduction of Heat

❖ Conduction of Heat:

Conduction of heat means the flow of heat from a hot region to a relatively cold region through a conducting material by the molecular vibration of the material. Remember, heat will always flow from a region of higher temperature to a lower temperature region. It does not depend on the amount of heat present in those regions. That means, a body with less amount of heat in it can release heat to a body of relatively higher amount of heat when kept in contact with each other. But always the body that release heat, will be a hot body i.e. of higher temperature.

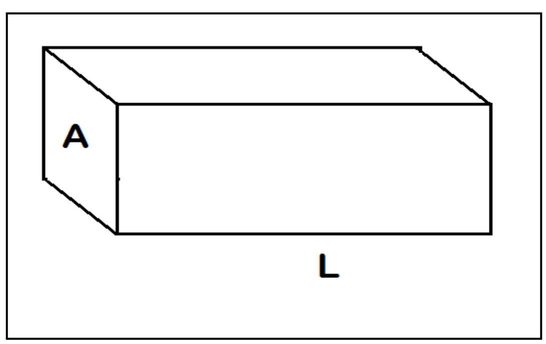
So, consider we have one conducting slab of length ‘L’ and area of cross section ‘A’ as shown in the figure. If the temperature of the left end of the slab is θ_2°C and that of the right end is θ_1°C, and if $\theta_2 > \theta_1$, then from the above discussion, we can understand that - heat will flow from left end to right end through the slab. Now, practically it is seen that the amount of heat flows (‘Q’) through the slab during ‘t’ time, depends on the following factors - **i) The length of the slab ‘L’**

ii) Area of cross section ‘A’

iii) The temperature difference of its two ends $(\boldsymbol{\theta_2 - \theta_1})$

iv) Time duration of flow ‘t’

- More is the length of the slab, less amount of heat will flow through it, hence Q and L are inversely proportional. Hence, $Q \propto \frac{1}{L}$……….(1)
- Experimentally it is seen that, more is the area of cross section, more amount of heat flows through the slab. So, Q and A are directly proportional. Hence, $Q \propto A$……….(2)
- More is the temperature difference between two ends, more amount of heat will flow through the slab. Hence, Q and $(\theta_2 - \theta_1)$ are directly proportional. So, $Q \propto (\theta_2 - \theta_1)$……….(3)
- If we allow the slab to conduct for a long time, then it is obvious that – the slab will conduct more amount of heat. So, more is the time duration of flow, more amount of heat will flow. Hence, Q and t are directly proportional. Hence, $Q \propto t$……….(4)



Therefore, combining the four equations together, we get,

$$Q \propto \frac{1}{L}$$
$$Q \propto A$$
$$Q \propto (\theta_2 - \theta_1)$$
$$Q \propto t$$

Hence combining, we get $Q \propto \frac{1}{L} . A . (\theta_2 - \theta_1) . t$

Or, $Q = K . \frac{1}{L} . A . (\theta_2 - \theta_1) . t$

Or, $\boldsymbol{Q = \frac{K\,A\,(\theta_2 - \theta_1)\,t}{L}}$ ……………………….(5)

The proportionality constant 'K' depends only on the nature of the conducting slab. Value of K gives a measure of how good a material conduct heat or not. Therefore K is then named as the conductivity of a material.

- Units of K

  ⇒ SI unit : $J/m - K - s$ or $J.m^{-1}.K^{-1}.s^{-1}$
  As, J/s is watt hence, the SI unit of K can also be written as $W/m - K$ or, $W.m^{-1}.K^{-1}$

  ⇒ C.G.S unit : $Cal/cm - ℃ - s$ or $Cal.cm^{-1}.℃^{-1}.s^{-1}$

➢ Thermal Resistivity: it is the reciprocal of thermal conductivity K.

$i.e.$ $\rho = \frac{1}{K}.$

Thermal resistivity is usually denoted by $\boldsymbol{\rho}$.

- Units of $\boldsymbol{\rho}$:

  ⇒ SI unit : $m - K - s/J$ or $m.K.s.J^{-1}$
  As, J/s is watt hence, the SI unit of K can also be written as $m - K/W$ or, $m.K.W^{-1}$

  ⇒ C.G.S unit : $cm - ℃ - s/cal$ or $cm.℃.s.cal^{-1}$

➢ **Comparison between conduction of current and conduction of heat**

- Heat flows because of the temperature difference. Actually, temperature difference causes thermodynamic potential difference between two ends of the slab and then heat energy flows from higher energy region to lower.
  Similarly, electric current flows from higher potential region to the lower potential region.
- The role played by the voltage difference in electrical conduction is played by the temperature difference in thermal conduction.
  Hence the voltage difference $(V_2 - V_1)$ and temperature difference $(\theta_2 - \theta_1)$ are analogical.

Therefore, we should have a heat current analogical to the electric current as stated in **Ohm's Law.**

From equation (5) we get , $\boldsymbol{\frac{Q}{t} = \frac{K\,A\,(\theta_2 - \theta_1)}{L}}$

Now, $\boldsymbol{\frac{Q}{t}}$ is nothing but the rate of flow of heat, which can be considered as the **heat current**, similar to the rate of flow of electric charge, considered as the electric current.

So, heat current $I = \boldsymbol{\frac{Q}{t} = \frac{K\,A\,(\theta_2 - \theta_1)}{L}}$

If we rearrange this equation, we get,

$\boldsymbol{I = \frac{(\theta_2 - \theta_1)}{\left(\frac{L}{K\,A}\right)}}$ $\left\{\boldsymbol{Recall\ Ohm's\ Law\ to\ get\ electric\ current\ as\ I = \frac{(V_2 - V_1)}{R}}\right\}$ $\boldsymbol{where\ R = Electrical\ resistance}$

Therefore, $\left(\frac{L}{K\,A}\right)$ can be considered as the thermal resistance.

➢ Thermal resistance:
So, thermal resistance $R = \frac{L}{KA}$. But, $\rho = \frac{1}{K}$

So, $R = \rho\,\frac{L}{A}$

❖ Important Questions and Answers

➢ Very Sort Answer Questions (1mark each)

1. What is/are the factor/factors on which the thermal conductivity of a material depends? – WBBSE, 2017
   Ans: Thermal conductivity of a material depends only on the nature of the material.

2. What is the SI unit of conductivity? – WBBSE, 2017, 2018
   Ans: $J.m^{-1}.K^{-1}.s^{-1}$ or $W.m^{-1}.K^{-1}$

3. What is the CGS unit of conductivity?
   Ans: $Cal.cm^{-1}.℃^{-1}.s^{-1}$

4. What is the SI unit of thermal resistivity?
   Ans: $m.K.s.J^{-1}$ or $m.K.W^{-1}$

5. What is the CGS unit of thermal resistivity?
   Ans: $cm-℃-s/cal$ or $cm.℃.s.cal^{-1}$

6. If length of a conducting slab is increased, then the amount of heat flows through it also increases – Write true or False.
   Ans: False.

7. Mention a non-metal having high thermal conductivity. – WBBSE, 2017
   Ans: Diamond, conductivity is about 1000 $W.m^{-1}.K^{-1}$ which is five times that of copper.

8. The length and the cross section of a conductor remaining unchanged, what is the relation between the thermal resistance and thermal conductivity of that conductor? – WBBSE, 2019

   Ans: We know, thermal resistance $R = \rho \frac{L}{A} = \frac{1}{K}\frac{L}{A}$

   If L and A remains unchanged, then for a particular material, K is also constant. Hence in that case R will also be constant.

9. Name a non metal which is good conductor of heat. – WBBSE, 2019.

   Ans: Diamond.

10. Which one among Diamond, silver, copper and Aluminum, has highest thermal conductivity? – WBBSE, 2020

    Ans: Diamond.

11. The conductivity of a material is the reciprocal of its resistivity. – write True or False.
    Ans: True.

12. Heat through a body always flows from higher heat region to lower heat region. - write True or False.
    Ans: False.

13. Heat current is directly proportional to the time duration of flow of heat. - write True or False.
    Ans: False, it is independent of time duration of flow of heat.

Sort Answer Questions (each of 2 marks)

1. What is thermal conductivity? – WBBSE, 2017, 2018
   Ans: It is defined as the amount of heat flows through a unit cube during 1sec, when the temperature difference between two ends is 1℃.
2. Mention two similarities between heat conduction and electrical conduction. – WBBSE, 2017
   Ans: 1. Electric current always flows from higher potential region to lower potential region. Similarly, heat also flows from higher temperature region to lower temperature region.
   2. The amount of electric current is directly proportional to the potential (or voltage) difference. Similarly, the amount of heat flows (or the heat current) is directly proportional to the temperature difference.

3. What are the factors on which the amount of heat flows through a conductor depends? – WBBSE, 2020

   Ans: It depends on - i) The length of the slab 'L'
   ii) Area of cross section 'A'
   iii) The temperature difference of its two ends $(\theta_2 - \theta_1)$
   iv) Time duration of flow 't'

4. What are the factors on which the thermal resistance of a conductor depends?
   Ans: It depends on i) Resistivity of the material ii) Length of the material and iii) Area of cross section of the material.

5. What are the factors on which the thermal resistivity of a conductor depends?
   Ans: It only depends on the nature of the material i.e. on the thermal conductivity.

6. How does the heat current depend on the thermal resistance for constant temperature difference?
   Ans: Heat current is inversely proportional to the thermal resistance.

7. How does the heat current depend on cross sectional area and length of the conducting slab for a fixed temperature difference?
   Ans: We, know heat current is $I = \frac{\boldsymbol{K\,A\,(\theta_2 - \theta_1)}}{\boldsymbol{L}}$

   So, for constant temperature difference, $I \propto \frac{1}{L}$ and $I \propto A$.

8. For a particular conducting slab, if the temperature difference is decreased, then how will the heat current through the slab be affected?
   Ans: Heat current is directly proportional to the temperature difference. Therefore in this case heat current will decrease.

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