UNIT 7

HEAT

Learning Objectives

After completing this lesson, students will be able to:

- understand the nature and the effects of heat.
- differentiate the conducting powers of various substances.
- list out good and bad conductors of heat and their uses.
- explain conduction using kinetic theory.
- describe the experiments to show convection in fluids.
- understand the concept of radiation.
- define specific heat capacity and thermal capacity.
- describe the concept of change of state.
- define specific latent heat of fusion and specific latent heat of vaporisation.

Introduction

All substances in our surrounding are made up of molecules. These molecules are generally at motion and posses kinetic energy. At the same time each molecule exerts a force of attraction on other molecules and so they posses potential energy. The sum of the kinetic and potential energy is called the internal energy of the molecules. This internal energy, when flows out, is called heat energy. This energy is more in hot substances and less in cold substances and flows from hot substances to cold substances. In this lesson you will study about how this heat transfer takes place. Also you will study about the effect of heat, heat capacity, change of state and latent heat.

7.1 Effects of Heat

When a substance is heated, the following things can happen.

Expansion: When heat is added to a substance, the molecules gain energy and vibrate and force other molecules apart. As a result, expansion takes place. You would have seen some space being left in railway tracks. It is because, during summer time, more heat causes expansion in tracks. Expansion is greater for liquids than solids and it is maximum in gases.

Figure 7.1 Gap in railway track

Change in State: When you heat ice cubes, they become water and water on further heating changes into vapour. So, solid becomes liquid and liquid becomes gas, when heat is added. The reverse takes place when heat is removed.

Change in Temperature: When heat energy is added to a substance, the kinetic energy of its particles increases and so the particles move at higher speed. This causes rise in temperature. When a substance is cooled, that is, when heat is removed, the molecules lose heat and its temperature falls.

Chemical changes: Since heat is a form of energy it plays a major role in chemical changes. In some cases, chemical reactions need heat to begin and also heat determines the speed at which reactions occur. When we cook food, we light the wood and it catches fire and the food particles become soft because of the heat energy. These are all the chemical changes taking place due to heat.

7.2 Transfer of Heat

Activity 1

Take a glass of water and put some ice cubes into it. Observe it for some time. What happens? The ice cubes melt and disappear. Why did it happen? It is because heat energy in the water is transferred to the ice.

Heat does not stay where we put it. Hot things get colder and cold things get hotter. Heat is transferred from one place to another till their temperatures become equal. Heat transfer takes place when heat energy flows from an object with higher temperature to an object with lower temperature (Fig. 7.2).

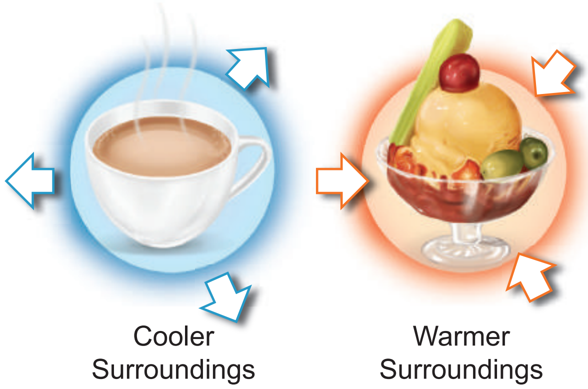


Figure 7.2 Hot and cold surroundings

DO YOU KNOW?

When a dog keeps out its tongue and breathes hard, the moisture on the tongue turns into water and it evaporates. Since, heat energy is needed to turn a liquid into a gas, heat is removed from dog's tongue. This helps to cool the body of the dog.

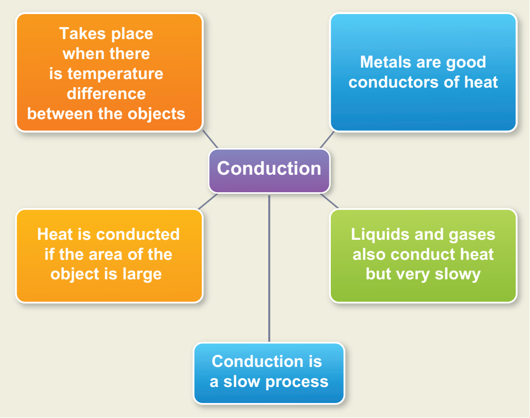
Heat transfer takes place in three ways:

i. Conduction, ii. Convection, iii. Radiation

7.2.1 Conduction

In solids, molecules are closely arranged so that they cannot move freely. When one end of the solid is heated, molecules at that end absorb heat energy and vibrate fast at their own positions. These molecules in turn collide with the neighboring molecules and make them vibrate faster and so energy is transferred. This process continues till all the molecules receive the heat energy.

The process of transfer of heat in solids from a region of higher temperature to a region of lower temperature without the actual movement of molecules is called conduction.



Conduction in daily life

i. Metals are good conductors of heat. So, aluminium is used for making utensils to cook food quickly.

ii. Mercury is used in thermometers because, it is a good conductor of heat.

iii. We wear woolen clothes is winter to keep ourselves warm. Air, which is a bad conductor, does not allow our body heat to escape.

Activity 2

Take metal rods of copper, aluminium, brass and iron. Fix a match stick to one end of each rod using a little melted wax. When the temperature of the far ends reach the melting point of wax, the matches drop off. It is observed that the match stick on the copper rod would fall first, showing copper as the best conductor followed by aluminum, brass and iron.

7.2.2 Convection

Activity 3

Drop a few crystals of potassium permanganate down to the bottom of a beaker containing water. When the beaker is heated just below the crystals, by a small flame, purple streaks of water rise upwards and fan outwards.

In this activity, water molecules at the bottom of the beaker receive heat energy and move upward and replace the molecules at the top. Same thing happens in air also. When air is heated, the air molecules gain heat energy allowing them to move further apart. Warm air being less dense than cold air will rise. Cooler air moves down to replace the air that has risen. It heats up, rises and is again replaced by cooler air, creating a circular flow.

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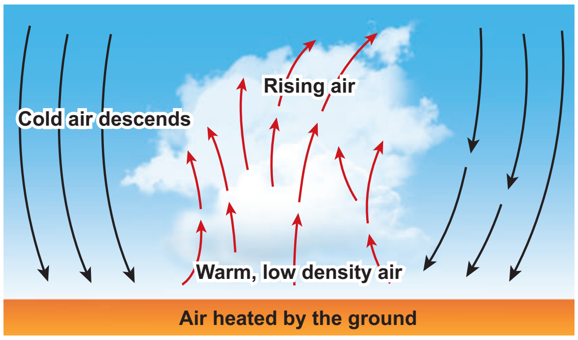

Figure 7.3 Convection in air

Convection is the flow of heat through a fluid from places of higher temperature to places of lower temperature by movement of the fluid itself.

Convection in daily life

Hot air balloons: Air molecules at the bottom of the balloon get heated by a heat source and rise. As the warm air rises, cold air is pushed downward and it is also heated. When the hot air is trapped inside the balloon, it rises.

Figure 7.4 Hot air balloon

Breezes: During day time, the air in contact with the land becomes hot and rises. Now the cool air over the surface of the sea replaces it. It is called sea breeze. During night time, air above the sea is warmer. As the warmer air over the surface of the sea rises, cooler air above the land moves towards the sea. It is called land breeze.

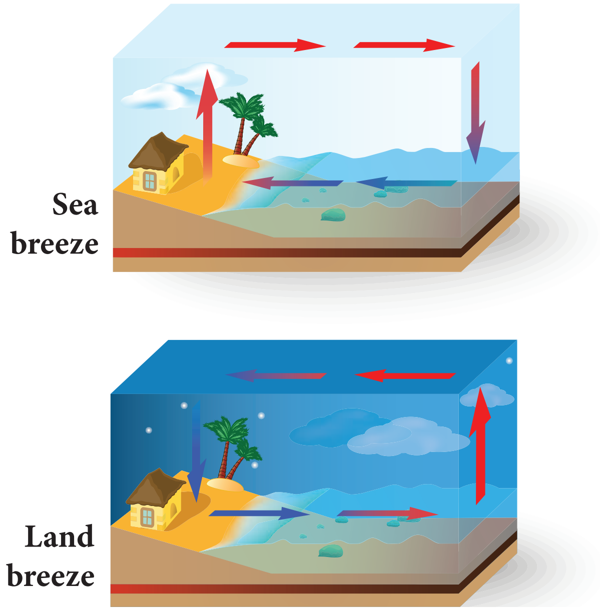

Figure 7.5 Land breeze and sea breeze

Winds: Air flows from area of high pressure to area of low pressure. The warm air molecules over hot surface rise and create low pressure. So, cooler air with high pressure flows towards low pressure area. This causes wind flow.

Chimneys: Tall chimneys are kept in kitchen and industrial furnaces. As the hot gases and smoke are lighter, they rise up in the atmosphere.

7.2.3 Radiation

Radiation is a method of heat transfer that does not require particles to carry the heat energy. In this method, heat is transferred in the form of waves from hot objects in all direction. Radiation can occur even in vacuum whereas conduction and convection need matter to be present. Radiation consists of electromagnetic waves travelling at the speed of light. Thus, radiation is the flow of heat from one place to another by means of electromagnetic waves.

Transfer of heat energy from the sun reaches us in the form of radiation. Radiation is emitted by all bodies above 0 K. Some objects absorb radiation and some other objects reflect them.

DO YOU KNOW?

While firing wood, we can observe all the three ways of heat transfer. Heat in one end of the wood will be transfered to other end due to conduction. The air near the wood will become warm and replace the air above. This is convection. Our hands will be warm because heat reaches us in the form of radiation.

Radiation in daily life

i. White or light colored cloths are good reflectors of heat. They keep us cool during summer.
ii. Base of cooking utensils is blackened because black surface absorbs more heat from the surrounding.
iii. Surface of airplane is highly polished because it helps to reflect most of the heat radiation from the sun.

7.3 Concept of Temperature

Temperature is the degree of hotness or coolness of a body. Hotter the body, higher is its temperature.

7.3.1 Unit of Temperature

The SI unit of temperature is ***kelvin*** (K). For day to day applications, ***Celsius*** (°C) is used. Temperature is measured with a thermometer.

7.3.2 Temperature scales

There are three scales of temperature.

i. Fahrenheit scale
ii. Celsius or Centigrade scale
iii. Kelvin or Absolute scale

Fahrenheit scale

In Fahrenheit scale, 32 °F and 212 °F are the freezing point and boiling point respectively. Interval has been divided into 180 parts.

Celsius temperature scale

In Celsius scale, also called centigrade scale, 0°C and 100 °C are the freezing point and boiling point respectively. Interval has been divided into 100 parts. The formula to convert a Celsius scale to Fahrenheit scale is:

$$F = \frac{9}{5} C + 32$$

The formula for converting a Fahrenheit scale to Celsius scale is:

$$C = \frac{5}{9} (F - 32)$$

Kelvin scale (Absolute scale)

Kelvin scale is known as the absolute scale. On the Kelvin scale 0 K represents absolute zero, the temperature at which the molecules of a substance have their lowest possible energy. The solid, liquid, gaseous phases of water can coexist in equilibrium at 273.16 K. *Kelvin is defined as 1/273.16 of the triple point temperature.* The formula for converting a Celsius scale to Kelvin scale is: K = C + 273.15

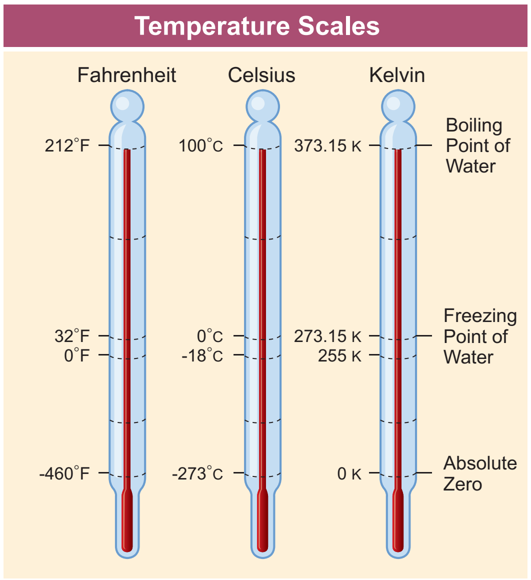

Figure 7.6 Types of temperature scales

Absolute zero

The temperature at which the pressure and volume of a gas theoretically reaches zero is called absolute zero. This is shown in Figure 7.7.

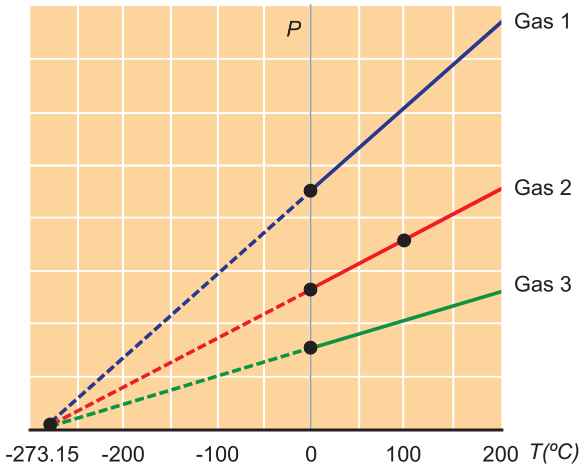

Figure 7.7 Variation of pressure (P) with temperature (T).

For all gases, the pressure extrapolates to zero at the temperature –273.15 °C. It is known as absolute zero or 0 K. Some base line temperatures in the three temperature scales are shown in Table 7.1.

Table. 7.1 Baseline temperatures in three scales.

Temperature	Kelvins (K)	Degrees Celcius (°C)	Degrees Fahrenheit (°F)
Boiling point of water	373.15	100	212
Melting point of ice	273.15	0	32
Absolute zero	0	–273	–460

Problem 1

Convert the following

i. 25 °C to Kelvin   ii. 200 K to °C

Solution:

i. $T_K = T_{°C} + 273.15$

$T_K = 25 + 273.15 = 298.15$ K

ii. $T_{°C} = T_K - 273.15$

$T_{°C} = 200 - 273.15 = -73.15$ °C

Problem 2

Convert the following

i. 35° C to Fahrenheit (°F)   ii. 14 °F to °C

Solution:

i. $T_{°F} = T_{°C} \times 1.8 + 32$

$T_{°F} = 25° \text{ C} \times 1.8 + 32 = 77$ °F

ii. $T_{°C} = (T_{°F} - 32)/ 1.8$

$T_{°C} = (14°\text{F} - 32)/ 1.8 = -10$ °C

7.4 Specific Heat Capacity

You might have felt that the land is cool in the morning and hot during day time. But, water in a lake will be almost at a particular temperature both in the morning as well as in the afternoon. Both are subjected to same amount of heat energy from the Sun, but they react differently. It is because both of them have different properties. In general, the amount of heat energy absorbed or lost by a body is determined by three factors.

1. Mass of the body
2. Change in temperature of the body
3. Nature of the material of the body

We can understand this from the following observations.

Observation:1

Quantity of heat required to raise the temperature of 1 litre of water will be more than the heat required to raise the temperature of 500 ml of water. If Q is the quantity of heat absorbed and m is the mass of the body, then

$Q \propto m$ (7.1)

Observation: 2

Quantity of heat energy (Q) required to raise the temperature of 250 ml of water to 100°C is more than the heat energy required to raise the temperature to 50°C. Here, $Q \propto \Delta T$, where ΔT is the change in temperature of the body.

Thus, heat lost or gained by a substance when its temperature changes by ΔT is,

$$Q \propto m\Delta T$$

$$Q = mC\Delta T \quad (7.2)$$

From the above equations, the absolute temperature and energy of a system are proportional to each other. The proportionality constant is the specific heat capacity (C) of the substance.

$$\therefore C = Q/m\Delta T$$

Thus, specific heat capacity of a substance is defined as the amount of heat required to raise the temperature of 1 kg of the substance by 1^0C or 1 K. The SI unit of specific heat capacity is $Jkg^{-1}\ K^{-1}$. The most commonly used units of specific heat capacity are J/kg°C and J/g°C.

Among all the substances, water has the highest specific heat capacity and its value is 4200 J/kg°K. So, water absorbs a large amount of heat for unit rise in temperature. Thus, water is used as a coolant in car radiators and factories to keep engines and other machinery parts cool. It is because of this same reason, temperature of water in the lake does not change much during day time.

Problem 3

Calculate the heat energy required to raise the temperature of 2 kg of water from 10°C to 50°C. Specific heat capacity of water is 4200 $JKg^{-1}\ K^{-1}$.

Solution:

Given m = 2 Kg, $\Delta T = (50 - 10) = 40^oC$ In terms of Kelvin, $\Delta T = (323.15 - 283.15) = 40K$, C = 4200 J $Kg^{-1}\ K^{-1}$

$\therefore$ Heat energy required, $Q = m \times C \times \Delta T$ $= 2 \times 4200 \times 40 = 3{,}36{,}000$ J

DO YOU KNOW?

Water in its various form, has different specific heat capacities.

Water (Liquid state)	= 4200 $JKg^{-1}\ K^{-1}$
Ice (Solid state)	= 2100 $JKg^{-1}\ K^{-1}$
Steam (Gaseous state)	= 460 $JKg^{-1}\ K^{-1}$

7.5 Heat capacity or Thermal capacity

Now, you are familiar with specific heat capacity. It is the heat required to raise the temperature of a unit mass of a body by 1°C. But, heat capacity is the heat required to raise the temperature of the entire mass of the body by 1°C. Thus, heat capacity or thermal capacity is defined as the amount of heat energy required to raise the temperature of a body by 1°C. It is denoted by C'.

$$\text{Heat Capacity} = \frac{\text{Quantity of heat required}}{\text{Raise in Temperature}}$$

$$C' = Q/T$$

SI unit of heat capacity is J/K. It is also expressed in cal/°C, kcal/°C or J/°C.

Problem 4

An iron ball requires 5000 J heat energy to raise its temperature by 20 K. Calculate the heat capacity of the iron ball.

Solution:

Given, Q = 5000 J, ΔT = 20 K

$$\text{Heat Capacity, C} = \frac{\text{Heat energy required, Q}}{\text{Rise in temperature, } \Delta T}$$

$$= \frac{5000}{20} = 250 \text{ JK}^{-1}$$

7.5 Change of state

The process of changing of a substance from one physical state to another at a definite temperature is known as change of state.

For example, water molecules are in liquid state at normal temperature. When water is heated to 100°C, it becomes steam which is a gaseous state of matter. On reducing the temperature of the steam it becomes water again. If we reduce the temperature further to 0°C, it becomes ice which is a solid state of water. Ice on heating, becomes water again. Thus, water changes its state when there is a change in temperature. There are different such processes in the change of state in matter. Figure 7.8 shows various processes of change of state.

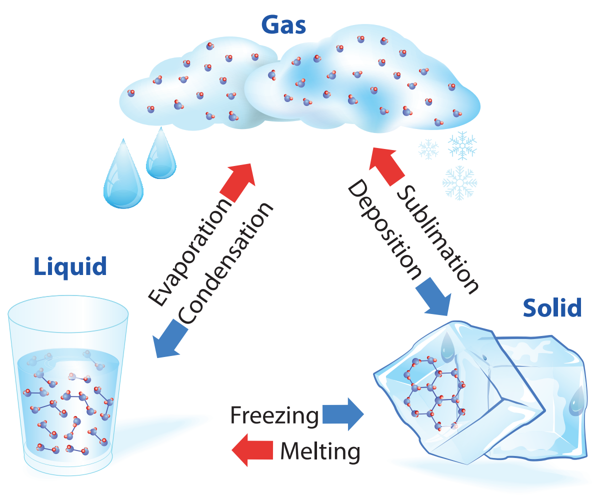

Figure 7.8 Change of state of matter

Melting – Freezing

The process in which a solid is converted to liquid by absorbing heat is called melting or fusion. The temperature at which a solid changes its state to liquid is called melting point. The reverse of melting is freezing. The process in which a liquid is converted to solid by releasing heat is called freezing. The temperature at which a liquid changes its state to solid is called freezing point. In the case of water, melting and boiling occur at 0°C.

Boiling-Condensation

The process in which a liquid is converted to vapor by absorbing heat is called boiling or vaporization. The temperature at which a liquid changes its state to gas is called boiling point. The process in which a vapor is converted to liquid by releasing heat is called condensation. The temperature at which vapour changes its state to liquid is called condensation point. Boiling point as well as condensation point of water is 100°C.

Sublimation

Some solids like dry ice, iodine, frozen carbon dioxide and naphthalene balls change directly from solid state to gaseous state without becoming liquid. The process in which a solid is converted to gaseous state is called sublimation.

Various stages of conversion of state of matter by heat with the corresponding change in temperature is shown in Figure 7.9

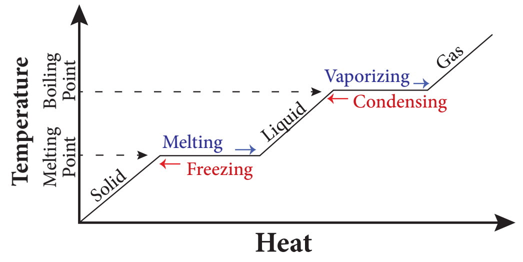

Figure 7.9 Various stages of conversion of state of matter

7.6 Latent heat

The word, 'latent' means hidden. So, latent heat means hidden heat or hidden energy. In order to understand latent heat, let us do the activity given below.

Activity 4

Take some crushed ice cubes in a beaker and note down the temperature using thermometer. It will be 0^0C. Now heat the ice in the beaker. You can observe that ice is melting to form water. Record the temperature at regular intervals and it will remain at 0^0C until whole ice is converted to liquid. Now heat the beaker again and record the temperature. You can notice that the temperature will rise up to 100^0C and it will retain the same even after continuous heating until the whole mass of water in the beaker is vaporized.

In the above activity, temperature is constant at 0°C until entire ice is converted into liquid and again constant at 100°C until all the ice is converted into vapor. Why? It is because, when a substance changes from one state to another, a considerable amount of heat energy is absorbed or liberated. This energy is called latent heat. Thus, latent heat is the amount of heat energy absorbed or released by a substance during a change in its physical states without any change in its temperature.

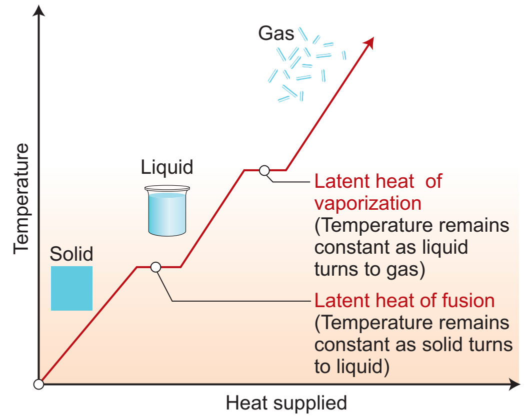

Figure 7.10 Latent heat

Heat energy is absorbed by the solid during melting and an equal amount of heat energy is liberated by the liquid during freezing, without any temperature change. It is called latent heat of fusion. In the same manner, heat energy is absorbed by a liquid during vaporization and an equal amount of heat energy is liberated by the vapor during condensation, without any temperature changes. This is called latent heat of vaporization.

Specific latent heat

Latent heat, when expressed per unit mass of a substance, is called specific latent heat. It is denoted by the symbol L. If Q is the amount of heat energy absorbed or liberated by 'm' mass of a substance during its change of phase at a constant temperature, then specific latent heat is given as L = Q/m.

Thus, specific latent heat is the amount of heat energy absorbed or liberated by unit mass of a substance during change of state without causing any change in temperature. The SI unit of specific latent heat is J/kg.

Problem 5

How much heat energy is required to melt 5 kg of ice? (Specific latent heat of ice = 336 Jg^{-1})

Solution:

Given, m = 5 Kg = 5000g, L = 336 Jg^{-1}

Heat energy required = m × L

= 5000 × 336

= 1680000J or 1.68×10^6 J

Problem 6

How much boiling water at 100°C is needed to melt 2 kg of ice so that the mixture which is all water is at 0°C?

[Specific heat capacity of water = 4.2 JKg^{-1} and Specific latent heat of ice = 336 Jg^{-1}].

Solution:

Given, mass of ice = 2 kg = 2000 g.

Let 'm' be the mass of boiling water required.

Heat lost = Heat gained.

$m \times c \times \Delta t = m \times L$

$m \times 4.2 \times (100 - 0) = 2000 \times 336$

$$m = \frac{2000 \times 336}{4.2 \times 100}$$

= 1600 g or 1.6 kg.

Points to Remember

- Heat is transferred from hot region to cold region.
- Heat is transferred in three forms: conduction, convection and radiation.
- Conduction takes place in solids and convection takes place in liquids and gases.
- Radiation takes place in the form of electromagnetic waves.
- There are three scales of temperature: Fahrenheit scale, Celsius or Centigrade scale and Kelvin or Absolute scale.
- Amount of heat energy absorbed or lost by a body is determined by three factors: mass of the body, change in temperature of the body, nature of the material of the body.
- The SI unit of specific heat capacity is $Jkg^{-1} K^{-1}$.
- Among all the substances, water has the highest specific heat capacity.
- SI unit of heat capacity is J/K.
- Depending upon the temperature, pressure and transfer of heat, matter is converted from one state to another.

A-Z GLOSSARY

Conduction	Process of transfer of heat in solids from a region of higher temperature to a region of lower temperature without the actual movement of molecules.
Convection	Flow of heat through a fluid from places of higher temperature to places of lower temperature by movement of the fluid itself.
Radiation	Flow of heat from one place to another by means of electromagnetic waves.
Temperature	It is the degree of hotness or coolness of a body.
Specific heat capacity	The amount of heat required to raise the temperature of 1 kg of the substance by 1°C or 1 K.
Heat capacity	The amount of heat energy required to raise the temperature of a body by 1°C.
Melting or fusion	Process in which a solid is converted to liquid by absorbing heat.
Freezing	Process in which a liquid is converted to solid by releasing heat.
Vaporization	Process in which a liquid is converted to vapour by absorbing heat.
Condensation	Process in which a vapor is converted to liquid by releasing heat.
Latent heat	Amount of heat energy absorbed or released by a substance during a change in its physical state without any change in its temperature.
Specific latent heat	Amount of heat energy absorbed or liberated by unit mass of substance during change of state without causing any change in temperature.

TEXT BOOK EXERCISES

BL58LS

I. Choose the correct answer.

1. Calorie is the unit of

   a) heat b) work

   c) temperature d) food

2. SI unit of temperature is

   a) fahrenheit b) joule

   c) celsius d) kelvin

3. Two cylindrical rods of same length have the area of cross section in the ratio 2:1. If both the rods are made up of same material, which of them conduct heat faster?
   a) Both rods b) Rod-2
   c) Rod-1 d) None of them
4. In which mode of transfer of heat, molecules pass on heat energy to neighbouring molecules without actually moving from their positions?
   a) Radiation b) Conduction
   c) Convection d) Both B and C
5. A device in which the loss of heat due to conduction, convection and radiation is minimized is
   a) solar cell b) solar cooker
   c) thermometer d) thermos flask

II. Fill in the blanks.

1. The fastest mode of heat transfer is ______.
2. During day time, air blows from ________ to ________.
3. Liquids and gases are generally ________ conductors of heat.
4. The fixed temperature at which matter changes state from solid to liquid is called ________.

III. Assertion and reason type questions.

Mark the correct choice as:

a. If both assertion and reason are true and reason is the correct explanation of assertion.
b. If both assertion and reason are true but reason is not the correct explanation of assertion.
c. If assertion is true but reason is false.
d. If assertion is false but reason is true.

1. **Assertion:** Food can be cooked faster in vessels with copper bottom.

   Reason: Copper is the best conductor of heat.

2. **Assertion:** Maximum sunlight reaches earth's surface during the noon time.

   Reason: Heat from the sun reaches earth's surface by radiation.

3. **Assertion:** When water is heated up to 100°C, there is no raise in temperature until all water gets converted into water vapour.

   Reason: Boiling point of water is 10°C.

IV. Answer briefly.

1. Define conduction.
2. Ice is kept in a double-walled container. Why?
3. How does the water kept in an earthen pot remain cool?
4. Differentiate convection and radiation.
5. Why do people prefer wearing white clothes during summer?
6. What is specific heat capacity?
7. Define thermal capacity.
8. Define specific latent heat capacity.

V. Answer in detail.

1. Explain convection in daily life.
2. What are the changes of state in water? Explain.
3. How can you experimentally prove water is a bad conductor of heat? How is it possible to heat water easily while cooking?

VI. Numerical Problems.

1. What is the heat in joules required to raise the temperature of 25 grams of water from 0 °C to 100 °C? What is the heat in Calories? (Specific heat of water = 4.18 J/g °C) **(Ans. 10450 J)**
2. What could be the final temperature of a mixture of 100 g of water at 90 °C and 600g of water at 20°C. **(Ans. 30°C)**
3. How much heat energy is required to change 2 kg of ice at 0°C into water at 20°C? (Specific latent heat of fusion of water = 3,34,000 J/kg, Specific heat capacity of water = 4200 $JKg^{-1}K^{-1}$). **(Ans. 8,36,000 J)**

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1. Mike Crundell, Geoff Goodwin and Chris Mee (2016). Cambridge International. AS and A Level physics, Second edition. Hodder Education, London.
2. Tom Duncon and Heather Kenneth(2017). Cambridge IGCSE Physics, Third edition. Hodder education, London.
3. Goyal R.P., and Tripathi S.P (2016). Concise physics, Selena publishers, New Delhi.
4. Frank New Certificate Physics. Frank Bros & co, Chennai.

INTERNET RESOURCES

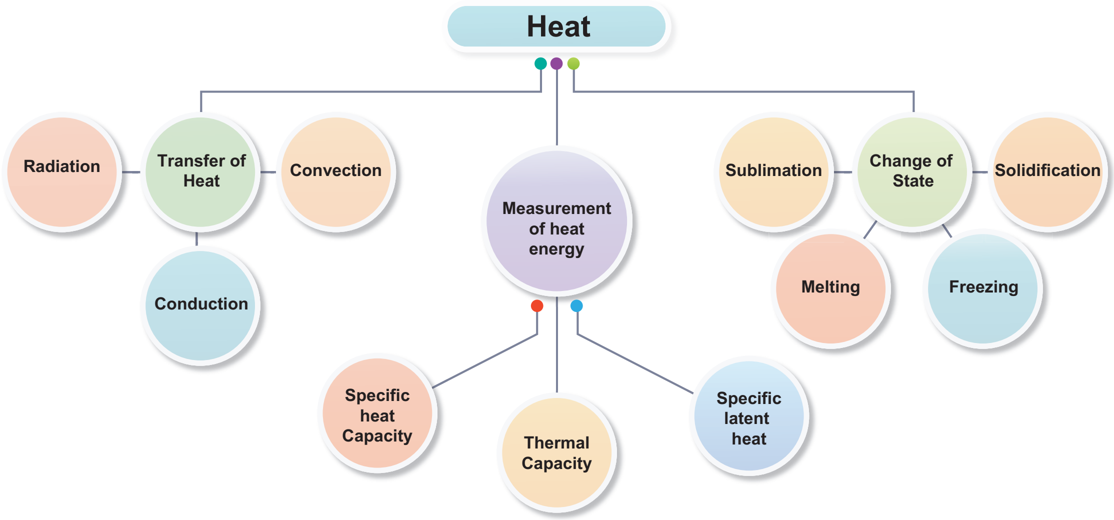
https://betterlession.com

http://www.britannica.com

http://study.com

http://www.sciencelearn.org

Concept Map



ICT CORNER

States of Matter - Effects of Heat changes

Steps

- Copy and paste the link given below or type the URL in the browser. Click the option States.
- You can find Atom & Molecules with four options – Neon, Argon, Oxygen and Water. You can also find Solid, Liquid and Gas options.
- Click any one of the Atoms & Molecules to stimulate by holding the Heat or Cool option under the simulation chamber.
- You can also try the simulation by changing the Solid, Liquid and Gas options too.
- The temperature option can be changed to Fahrenheit or Celsius.

Browse in the link:

URL: https://phet.colorado.edu/sims/html/states-of-matter/latest/states-of-matter_en.html

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*Pictures are indicative only