5. Heat

- Latent heat
- Anomalous behaviour of water
- Specific heat capacity
- Regelation
- Dew point and humidity

Can you recall?

1. What is the difference between heat and temperature?
2. What are the different ways of heat transfer?

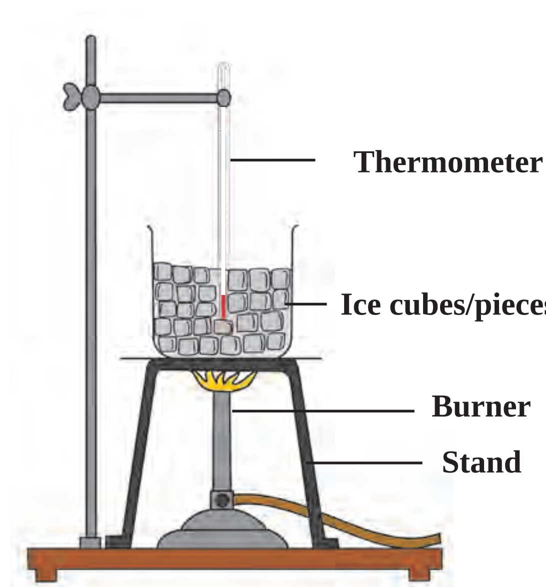
In the previous standard, we have learnt about heat and different types of heat transfer. We have also performed few experiments related to expansion and contraction of solids, liquids and gases. We have learnt about the difference between heat and temperature. We have also seen how temperature is measured using a thermometer.

Concepts like latent heat of phase transformation, anomalous behaviour of water, dew point, humidity, specific heat capacity etc. are related to certain phenomena experienced by us in our day-to-day life. Let us learn more about these concepts.

Latent heat

Try this

1. Take a few pieces of ice in a glass beaker. As shown in figure 5.1.
2. Insert the bulb of a thermometer in ice and measure its temperature.
3. Put the beaker on a stand and heat the ice using a burner.
4. Record the temperature using the thermometer after every minute.
5. As the ice is heated, it starts melting. Stir the mixture of ice and water.
6. Continue the heating even after ice starts melting.
7. Draw a graph of temperature versus time.



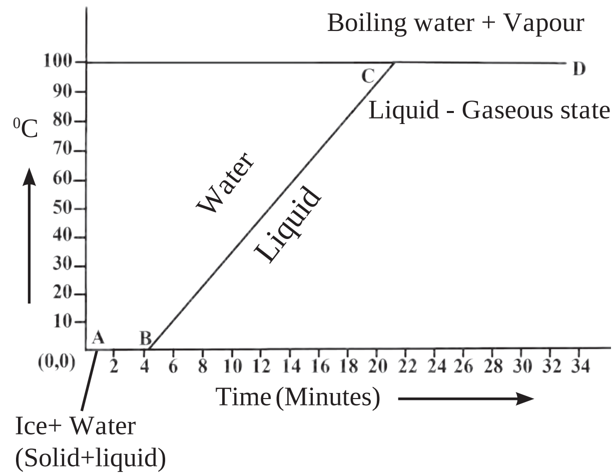
5.1 Latent heat

You will observe that the temperature of the mixture remains 0 ^{0}C till the ice melts completely. If we continue heating, even after conversion of all the ice into water, the temperature of water starts rising and reaches 100 ^{0}C. At this temperature water starts converting into steam. The temperature of water remains constant at 100 ^{0}C till all water converts into steam. The graph of temperature versus time is shown in figure 5.2.

In this graph, line AB represents conversion of ice into water at constant temperature. When ice is heated it melts at 0 ^{0}C and converts into water at this constant temperature. The ice absorbs heat energy during this transition and the absorption of energy continues till all the ice converts into water.

The temperature remains constant during this transition. This constant temperature, at which the ice converts into water is called the melting point of ice.

Thus, during transition of solid phase to liquid, the object absorbs heat energy, but its temperature does not increase. This heat energy is utilised for weakening the bonds between the atoms or molecules in the solid and transform it into liquid phase. The heat energy absorbed at constant temperature during transformation of solid into liquid is called the latent heat of fusion.



5.2 Temperature vs Time Graph

The amount of heat energy absorbed at constant temperature by unit mass of a solid to convert into liquid phase is called the specific latent heat of fusion.

Once all the ice is transformed into water, the temperature of water starts rising. It increases up to 100 ^{0}C. Line BC in the graph represents rise in temperature of water from 0 ^{0}C to 100 ^{0}C. Thereafter, even though heat energy is supplied to water, its temperature does not rise. The heat energy is absorbed by water at this temperature and used to break the bonds between molecules of the liquid and convert the liquid into gaseous state. Thus, during transformation from liquid phase to gas phase, heat energy is absorbed by the liquid, but its temperature does not change. The constant temperature at which the liquid transforms into gaseous state is called the boiling point of the liquid. The heat energy absorbed at constant temperature during transformation of liquid into gas is called the latent heat of vapourization.

The amount of heat energy absorbed at constant temperature by unit mass of a liquid to convert into gaseous phase is called the specific latent heat of vapourization.

Different substances have different melting points and boiling points. The values of melting point, boiling point and latent heat depend on atmospheric pressure.

Substance	Melting point ^{0}C	Boiling point ^{0}C	Specific latent heat of fusion		Specific latent heat of vaporization	
			kJ/kg	cal/g	kJ/kg	cal/g
Water/ Ice	0	100	333	80	2256	540
Copper	1083	2562	134	49	5060	1212
Ethyl alcohol	-117	78	104	26	8540	200
Gold	1063	2700	144	15.3	1580	392
Silver	962	2162	88.2	25	2330	564
Lead	327.5	1749	26.2	5.9	859	207

Use your brain power !

1. Is the concept of latent heat applicable during transformation of gaseous phase to liquid phase and from liquid phase to solid phase?
2. Where does the latent heat go during these transformations?

Regelation

You may have seen the preparation of an ice-ball. First, an ice slab is shredded and then the shredded ice is pressurised around the tip of a stick to prepare the ice-ball. How does the shredded ice convert into solid ice ball? If two small pieces of ice are taken and pressed against each other for a while, they stick to each other. Why does this happen?

Try this Take a small slab of ice, a thin wire, two identical weights.

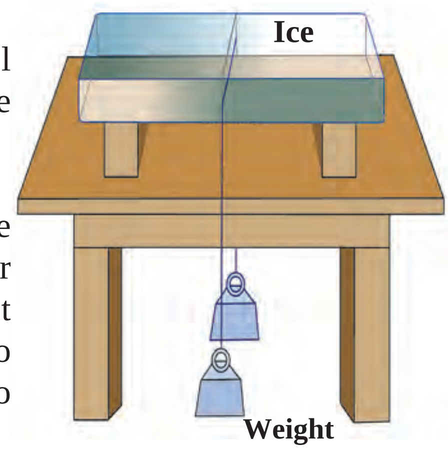
Activity:

1. Put a slab of ice on a stand as shown in Figure 5.3.
2. Hang two equal weights to the two ends of a metal wire and put the wire on the slab as shown in the figure.

   What do you observe?

   It is observed that the wire gradually penetrates the ice slab. After some time, the wire comes out of the lower surface of the ice slab. However, the ice slab does not break. The phenomenon in which the ice converts to liquid due to applied pressure and then re-converts to ice once the pressure is removed is called regelation.

   The melting point of ice becomes lower than 0 ^{0}C due to pressure. This means that at 0 ^{0}C, the ice gets converted into water. As soon as the pressure is removed, the melting point is restored to 0 ^{0}C and water gets converted into ice again.



5.3 Regelation

Use your brain power !

1. In the above experiment, the wire moves through the ice slab. However, the ice slab does not break. Why?
2. Is there any relationship of latent heat with the regelation?
3. You know that as we go higher than the sea level, the boiling point of water decreases What would be effect on the melting point of solid?

Can you tell? We feel that some objects are cold, and some are hot. Is this feeling related in some way to our body temperature?

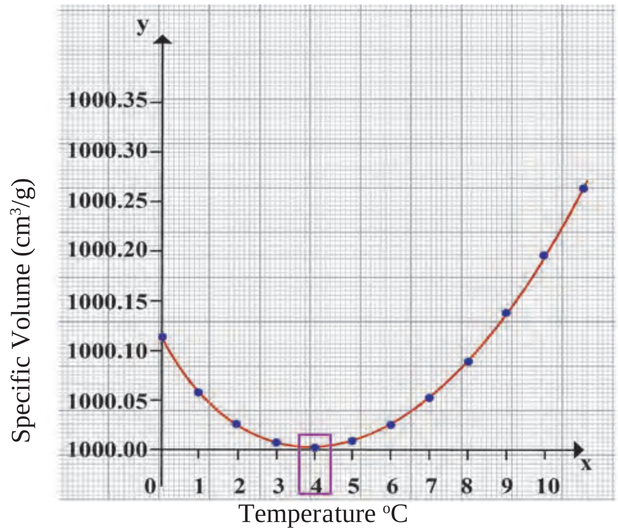
Anomalous behaviour of water

In general, when a liquid is heated up to a certain temperature, it expands, and when cooled it contracts. Water, however, shows a special and exceptional behaviour. If we heat water from 0 ^{0}C up to 4 ^{0}C, it contracts instead of expanding. At 4 ^{0}C its volume is minimum (due to contraction). If the water is heated further, it expands and its volume increases. The behaviour of water between its temperature from 0 ^{0}C to 4 ^{0}C is called anomalous behaviour of water.

If 1 kg of water is heated from 0 ^{0}C and its volume is plotted as a function of temperature, we get the graph, shown in fig 5.4. At 4 ^{0}C, the volume of water is minimum. It means that the density of water is maximum at 4 ^{0}C.

Study of anomalous behaviour of water using Hope's apparatus.

The anomalous behaviour of water can be studied with Hope's apparatus. In Hope's apparatus, a flat bowl is attached to a cylindrical container as shown in figure 5.5. There is provision to attach thermometers above (to measure temperature T_2) and below (to measure temperature T_1) the flat bowl on the cylindrical container. Water is filled in the cylindrical container and a mixture of ice and salt (freezing mixture) is put in the flat bowl.



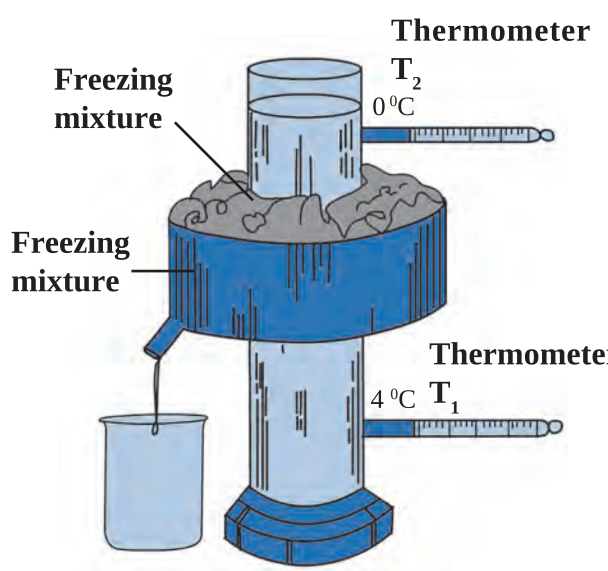
5.4 Graph between the volume and temperature of water

During the study of anomalous behaviour of water using Hope's apparatus, temperature T_1 and T_2 are recorded after every 30 seconds.

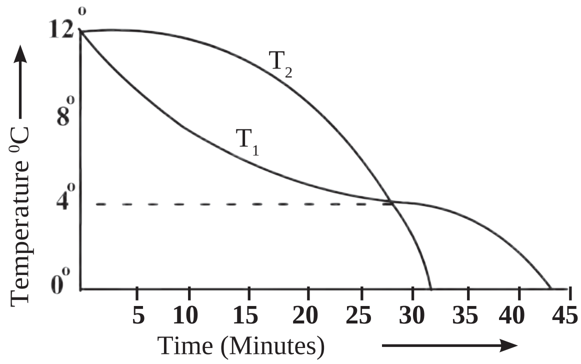
The temperatures are plotted on the Y-axis and the time in minutes on the X-axis. The graph is shown in figure 5.6. The graph shows that initially, both the temperatures T_1 and T_2 are identical. However, as time passes, temperature T_1 of water in the lower part of the cylinder decreases fast, while, temperature T_2 of water in the upper part of the cylinder decreases comparatively slowly.

However, once the temperature T_1 of the lower part reaches 4 ^{0}C, it remains almost stable at that temperature. T_2 decreases slowly to 4 ^{0}C. Thereafter, since T_2 starts changing rapidly, it records 0 ^{0}C first and after that the lower thermometer T_1 records 0 ^{0}C temperature. The point of intersection of the two curves shows the temperature of maximum density.

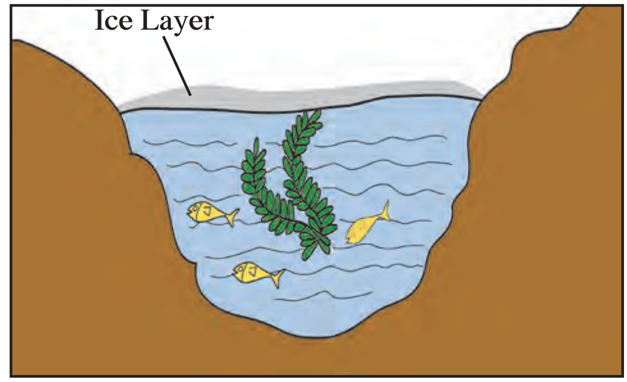
How can we explain these observations? Initially, the temperature of water in the middle of cylinder lowers due to freezing mixture in the outer bowl. Since the temperature of water there decreases, its volume decreases, and its density increases. The water with higher density moves downwards. Therefore, the lower thermometer T_1 shows rapid fall in temperature and this continues till the temperature of water becomes equal to 4 ^{0}C. When the temperature of water starts decreasing below 4 ^{0}C, its volume increases, and density decreases. It, therefore, moves in the upward direction. The temperature of water in upper part (T_2), therefore, decreases rapidly to 0 ^{0}C. The temperature of water in the lower part (T_1), however, remains at 4 ^{0}C for some time and then decreases slowly to 0 ^{0}C.



5.5 Hope's Apparatus



5.6 Time - Temperature Graph



5.7 Aquatic animals in cold regions

Use your brain power ! **How will you explain following statements with the help of the anomalous behaviour of water?**

1. In regions with cold climate, the aquatic plants and animals can survive even when the atmospheric temperature goes below 0 ^{0}C (See figure 5.7).
2. In cold regions in winter the pipes for water supply break and even rocks crack.

Dew point and Humidity

About 71% surface of the Earth is covered with water. Due to constant evaporation of water, water vapour is always present in the atmosphere. The amount of water vapour in the atmosphere helps us to understand the state of daily weather. The presence of water vapour in the air makes it moist. The moisture in the atmosphere is called humidity.

For a given volume of air, at a specific temperature, there is a limit on how much water vapour the air can contain. If the amount exceeds this limit, the excess vapour converts into water droplets. When the air contains maximum possible water vapour, it is said to be saturated with vapour at that temperature. The amount of vapour needed to saturate the air depends on temperature of the air. If air temperature is low, it will need less vapour to saturate the air. For example, if temperature of air is 40 ^{0}C, it can contain 49 grams of water vapour per kilogram of dry air without condensation. If the amount of vapour exceeds this limit, the additional vapour will condense. However, if the temperature of air is 20 ^{0}C, it can contain only 14.7 grams of water vapour per kilogram of dry air without condensing. If the vapour contained in air is less that the maximum limit, then the air is said to be unsaturated.

Suppose unsaturated air at a certain temperature is taken and its temperature is decreased, a temperature is reached at which the air becomes saturated with vapour. This temperature is called the dew point temperature.

The vapour content in the air is measured using a physical quantity called absolute humidity. The mass of vapour present in a unit volume of air is called absolute humidity. Generally absolute humidity is measured in kg/m^3.

The feeling of humid or dry nature of air not only depends on the amount of vapour in the air, but it also depends on how close that amount is for making the air saturated with vapour. It means that it depends on temperature of the air also.

The ratio of actual mass of vapour content in the air for a given volume and temperature to that required to make the air saturated with vapour at that temperature is called the relative humidity.

$$\% \text{ Relative humidity} = \frac{\text{actual mass of water vapour content in the air in a given volume}}{\text{mass of vapour needed to make the air saturated in that volume}} \times 100$$

The relative humidity at the dew point is 100%. If the relative humidity is more than 60% we feel that the air is humid. If the relative humidity is less than 60%, we feel that the air is dry.

During winter season, you may have observed a white trail at the back of a flying plane in a clear sky. As the plane flies, the vapour released by the aeroplane engine condenses and forms clouds. If the surrounding air is having more relative humidity, it takes a long time for the white trail, formed by condensation of the vapour, to disappear. If relative humidity of the surrounding air is less, either the size of the white trail may be small or it may not even get formed.

Try this.

1. Take a bottle of cold water out of a refrigerator and keep it outside for a while. Observe the outer surface of the bottle.
2. Drops of water can be observed on the outer surface of bottle. In the same way, if we observe the leaves of plants/grass or window-glass of a vehicle in the early morning we see water droplets collected on the surface.

Through these two observations, we sense the presence of water vapour in the atmosphere. When air cools, due to decrease in temperature it becomes saturated with water vapour. As a result, the excess water vapour gets converted into tiny droplets. The dew-point temperature is decided by the amount of vapour in the air.

Unit of heat

The units of heat are Joule (J) in SI units, cal (calorie) in cgs units.

The amount of heat necessary to raise temperature of 1 g of water by 1 ^{0}C from 14.5 ^{0}C to 15.5 ^{0}C is called one cal heat.

Similarly, the amount of heat necessary to raise the temperature of 1 kg of water by 1 ^{0}C from 14.5 ^{0}C to 15.5 ^{0}C is called one kcal heat.

It is clear that (1 kcal= 1000 cal).

Always remember

If we heat 1 kg of water by 1^{0}C in different temperature range than 14.5 ^{0}C to 15.5 ^{0}C, the amount of heat required will be slightly different. It is, therefore, essential to define a specific temperature range while defining the unit of heat. Calorie and Joule are related by following relation: 1 cal = 4.18 Joule

Introduction to Scientist

James Prescott Joule (1818-1889) : He was the first person to show that the kinetic energy of tiny particles of matter appears as heat energy and also that energy can be converted from one form to another. Conversion of heat energy to work gives the first law of thermodynamics. The unit of heat is called Joule (J) after him.

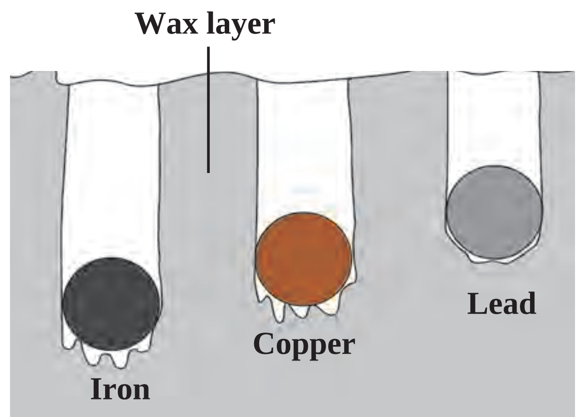
Specific Heat Capacity

Try this.

Material : A tray with thick layer of wax, solid spheres of iron, lead and copper of equal mass, burner or spirit lamp, large beaker.

Procedure :

1. Take three spheres of iron, copper and lead of equal mass (Fig. 5.8)
2. Put all the three spheres in boiling water in the beaker for some time.
3. Take the three spheres out of the water. All the spheres will be at temperature 100 ^{0}C. Put them immediately on the thick slab of wax.
4. Note, the depth that each of the sphere goes into the wax.



5.8 Specific heat capacity of metals

The sphere which absorbs more heat from the water will give more heat to wax. More wax will thus melt and the sphere will go deeper in the wax. It can be observed that the iron sphere goes deepest into the wax. Lead sphere goes the least and copper sphere goes to intermediate depth. This shows that for equal rise in temperature, the three spheres have absorbed different amounts of heat. This means that the property which determines the amount of heat absorbed by a sphere is different for the three spheres. This property is called the specific heat capacity.

The amount of heat energy required to raise the temperature of a unit mass of an object by 1 ^{0}C is called the specific heat of that object.

The specific heat capacity is denoted by letter 'c'. The SI unit of specific heat is J/ ^{0}C kg, and the CGS unit is cal/g ^{0}C.

S. No.	Substance	Specific heat (cal/g ^{0}C)	S. No.	Substance	Specific heat (cal/g ^{0}C)
1.	Water	1.0	5.	Iron	0.110
2.	Paraffin	0.54	6.	Copper	0.095
3.	Kerosene	0.52	7.	Silver	0.056
4.	Aluminium	0.215	8.	Mercury	0.033

5.9 Specific heat capacity of some substances

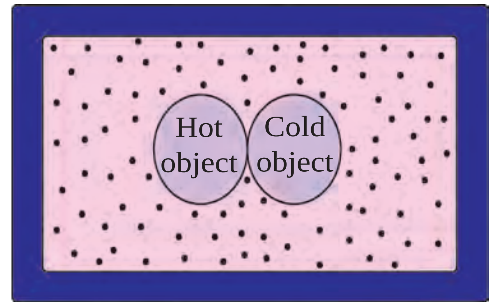
If specific heat of an object is 'c', the mass of the object is 'm' and if the temperature of the object is raised by ΔT ^{0}C, the heat energy absorbed by the object is given by,

$$m \times c \times \Delta T.$$

In the same way if specific heat of an object is 'c', the mass of the object is 'm' and if the temperature of the object is decreased by ΔT ^{0}C, then the heat energy lost by the object will be,

$$m \times c \times \Delta T.$$

Heat Exchange If heat is exchanged between a hot and cold object, the temperature of the cold object goes on increasing due to gain of energy and the temperature of the hot object goes on decreasing due to loss of energy. The change in temperature continues till the temperatures of both the objects attain the same value. In this process, the cold object gains heat energy and the hot object loses heat energy. If the system of both the objects is isolated from the environment by keeping it inside a heat resistant box (meaning that the energy exchange takes place between the two objects only), then no energy can flow from inside the box or come into the box (fig 5.10). In this situation, we get the following principle



5.10 Box of heat resistant material

Heat energy lost by the hot object = Heat energy gained by the cold object. This is called as 'Principle of heat exchange'

Measurement of specific heat: (mixing method) and calorimeter

The specific heat of an object can be measured using mixing method. For this calorimeter is used. You have learnt about calorimeter in the previous standard. If a hot solid object is put in the water in a calorimeter, heat exchange between the hot object and the water and calorimeter starts. This continues till the temperatures of the solid object, water and the calorimeter become equal. Therefore,

Heat lost by solid object = heat gained by water in calorimeter + heat gained by the calorimeter.

Here, heat lost by the solid object (Q) = mass of the solid object × its specific heat × decrease in its temperature.

Similarly,

Heat gained by the water (Q_1)= mass of the water × its specific heat × increase in its temperature
Heat gained by the calorimeter (Q_2)= mass of the calorimeter × its specific heat × increase in its temperature.

Heat lost by hot object = Heat gained by calorimeter + Heat gained by water.

$$Q = Q_2 + Q_1$$

Using these equations, if the specific heat of water and the calorimeter are known, the specific heat of the solid object can be calculated.

ICT :

Prepare a presentation using videos, pictures, audios, graphs etc. to explain various concepts in this chapter. Collect all such material from the Internet, using Information Technology. Under the guidance of your teachers, arrange a competition of such presentations in your class.

Solved Examples

Example 1: How much heat energy is necessary to raise the temperature of 5 kg of water from 20 ^{0}C to 100 ^{0}C.

Given: m= 5 kg, c = 1 kcal/kg ^{0}C and change in temperature ΔT = 100-20 = 80 ^{0}C

Energy to be supplied to water = energy gained by water

= mass of water × specific heat of water × change in temperature of water

= $m \times c \times \Delta T$

= 5 × 80 ^{0}C

= 400 kcal

Hence, the heat energy necessary to raise the temperature of water = 400 kcal.

Example 2: A copper sphere of 100 g mass is heated to raise its temperature to 100 ^{0}C and is released in water of mass 195 g and temperature 20 ^{0}C in a copper calorimeter. If the mass of calorimeter is 50 g, what will be the maximum temperature of water?

Given: Specific heat of copper = 0.1 cal/g ^{0}C

And so specific heat of calorimeter= 0.1 cal/ g ^{0}C

Suppose the copper ball water and the calorimeter attain final temperature T.

Heat lost by solid object = heat gained by water in calorimeter + heat gained by the calorimeter.

Here, heat lost by the copper ball = mass of the copper ×specific heat of copper × decrease in temperature of the ball

$Q = 100 \times 0.1 \times (100 - T)$

Similarly,

Heat gained by the water = mass of the water X its specific heat X increase in its temperature

$Q_1 = 195 \times 1 \times (T - 20)$ and

Heat gained by the calorimeter = mass of the calorimeter × its specific heat × increase in its temperature

$Q_2 = 50 \times 0.1 \times (T - 20)$

$Q = Q_1 + Q_2$

$100 \times 0.1 \times (100 - T) = 195 \times 1 \times (T - 20) + 50 \times 0.1 \times (T - 20)$

$10\ (100 - T) = 195\ (T - 20) + 5\ (T - 20)$

$10\ (100 - T) = 200\ (T - 20)$

$210\ T = 5000$

$T = 23.8\ ^0C$

$\therefore$ The maximum temperature of water will be 23.8 ^{0}C.

Example 3: If 80 g steam of temperature 97 ^{0}C is released on an ice slab of temperature 0 ^{0}C, how much ice will melt? How much energy will be transferred to the ice when the steam will be transformed to water?

Given: Latent heat of melting the ice = L_{melt}= 80 cal/g

Latent heat of vaporization of water = $L_{vap.}$ = 540 cal/g

Solution: mass of steam = m_{steam} = 80 g

Temperature of steam = 97 ^{0}C

Temperature of ice = T_{ice} = 0 ^{0}C

Heat released during conversion of steam of temperature 97 ^{0}C into water of temperature 97 ^{0}C = $m_{steam} \times L_{vap.}$

= 80 X 540 ---------------------------- (1)

Heat released during conversion of water of 97 ^{0}C into water at 0 ^{0}C

$= m_{steam} \times \Delta T \times c$

$= 80 \times (97 - 0) \times 1 = 80 \times 97$ -------------- (2)

Total heat gained by the ice $80 \times 540 + 80 \times 97$ from equations (1) and (2)

$= 80\ (540 + 97)$

$= 80 \times 637 = 50960$ cal.

Some mass, of the ice, m_{ice} will melt due to this heat gained by the ice, then,

$$m_{ice} \text{ X } L_{melt} = 50960 \text{ cal}$$
$$m_{ice} \text{ X } 80 = 50960$$
$$m_{ice} = 637 \text{ g}$$

Thus, 637 g ice will melt and 50960 cal kcal will be given to the ice.

Books are My Friends : Read for more information

1. A Textbook of heat - J.B. Rajam
2. Heat - V.N Kelkar
3. A Treatise on Heat - Saha and Srivastava

Exercise

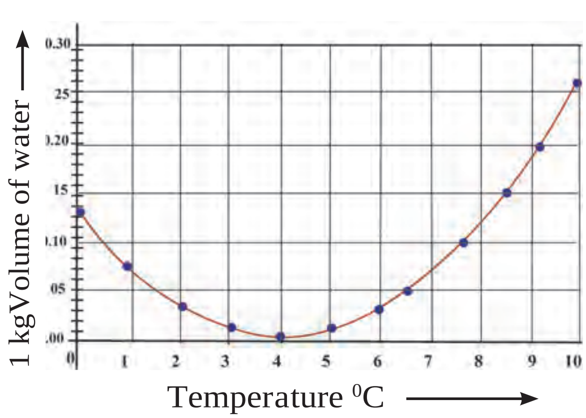
1. Fill in the blanks and rewrite the sentence.

a. The amount of water vapour in air is determined in terms of its …………

b. If objects of equal masses are given equal heat, their final temperature will be different. This is due to difference in their ……………...

c. During transformation of liquid phase to solid phase, the latent heat is ………….

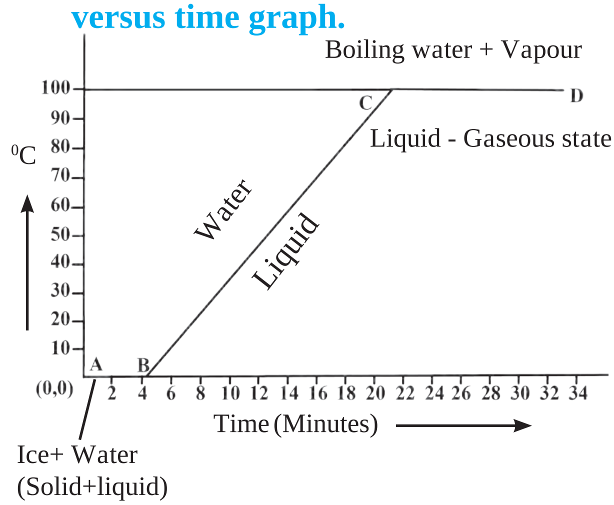
2. Observe the following graph. Considering the change in volume of water as its temperature is raised from 0 °C, discuss the difference in the behaviour of water and other substances. What is this behaviour of water called?



3. What is meant by specific heat capacity? How will you prove experimentally that different substances have different specific heat capacities?

4. While deciding the unit for heat, which temperatures interval is chosen? Why?

5. Explain the following temperature versus time graph.



6. Explain the following:

a. What is the role of anomalous behaviour of water in preserving aquatic life in regions of cold climate?

b. How can you relate the formation of water droplets on the outer surface of a bottle taken out of refrigerator with formation of dew?

c. In cold regions in winter, the rocks crack due to anomalous expansion of water.

7. **Answer the following:**

a. What is meant by latent heat? How will the state of matter transform if latent heat is given off?

b Which principle is used to measure the specific heat capacity of a substance?

c. Explain the role of latent heat in the change of state of a substances?

d. On what basis and how will you determine whether air is saturated with vapour or not?

8. **Read the following paragraph and answer the questions.**

If heat is exchanged between a hot and cold object, the temperature of the cold object goes on increasing due to gain of energy and the temperature of the hot object goes on decreasing due to loss of energy.

The change in temperature continues till the temperatures of both the objects attain the same value. In this process, the cold object gains heat energy and the hot object loses heat energy. If the system of both the objects is isolated from the environment by keeping it inside a heat resistant box (meaning that the energy exchange takes place between the two objects only), then no energy can flow from inside the box or come into the box.

i. Heat is transferred from where to where?

ii. Which principle do we learn about from this process?

iii. How will you state the principle briefly?

iv. Which property of the substance is measured using this principle?

9. **Solve the following problems:**

a. Equal heat is given to two objects A and B of mass 1 g. Temperature of A increases by 3 ^{0}C and B by 5 ^{0}C. Which object has more specific heat? And by what factor?

Answer : A, $\frac{5}{3}$

b. Liquid ammonia is used in ice factory for making ice from water. If water at 20 ^{0}C is to be converted into 2 kg ice at 0 ^{0}C, how many grams of ammonia are to be evaporated? (Given: The latent heat of vaporization of ammonia= 341 cal/g)

Answer : 586.4 g

c. A thermally insulated pot has 150 g ice at temperature 0 ^{0}C. How much steam of 100 ^{0}C has to be mixed to it, so that water of temperature 50 ^{0}C will be obtained?

(Given : latent heat of melting of ice = 80 cal/g,
latent heat of vaporization of water = 540 cal/g,
specific heat of water = 1 cal/g ^{0}C)

Answer : 33 g

d. A calorimeter has mass 100 g and specific heat 0.1 kcal/ kg ^{0}C. It contains 250 gm of liquid at 30 ^{0}C having specific heat of 0.4 kcal/kg ^{0}C. If we drop a piece of ice of mass 10 g at 0 ^{0}C, What will be the temperature of the mixture?

Answer : 20.8 ^{o}C

Project

Take help of your teachers to make a working model of Hope's apparatus and perform the experiment. Verify the results you obtain.

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