Water

Water Cycle

Physical States of Water

Water is found in solid, liquid, and gaseous states in the environment. In the solid state, it is found in the form of ice, and as a liquid, it exists as water. It is present as water vapour in the gaseous state.

Physical Properties of Water

- Water is a colourless, tasteless, and transparent liquid. It also has no smell.
- Boiling point of pure water is 100°C at 760 mm of Hg pressure. However, boiling point of water increases due to increase in pressure and presence of dissolved impurities.
- Pure water freezes at 0°C at 760 mm of Hg pressure. However, freezing point of water decreases due to increase in pressure and presence of dissolved impurities.
- The state of water changes on heating or cooling. On heating, the state of water changes from liquid state to gaseous state (vapour). Similarly, on cooling, the state of water changes from liquid state to solid state (ice).
- Pure water is a bad conductor of heat and electricity.
- Water absorbs a fixed amount of heat. It has been found that 1 g of water always absorbs 4.2 J (=1 Calorie) of heat energy when heated through 1°C. This fixed amount of heat energy is called specific heat capacity. Specific heat capacity is the fixed amount of heat energy required to raise the temperature of 1 g of water by 1°C.

Water undergoes different processes in the environment and is found in different states during these processes. This cyclic process through which water circulates in the environment is called the **water cycle**.

Let us first describe the process of water cycle for you.

By now, you know the steps involved in a water cycle. Now, let us look at each step.

Evaporation

Have you observed that when the floor is wiped with water, the water dries up in some time? The roads and buildings that become wet after rainfall, dry up soon after. You may have also observed that the water level in a container reduces when it is kept in it for a long time.

Where is all this water disappearing?

The process whereby water disappears into air is called **evaporation**. During evaporation, liquid water is converted into gaseous water vapour.

How does evaporation occur? What are the factors that affect evaporation? Let us understand.

Wet two handkerchiefs and squeeze out the water. Dry one of it outside in the sun and the other inside a room. Observe the time taken for both of them to dry. Do they take the same amount of time?

The handkerchief that was put out to dry in the sun dries up faster than the one inside the room. This is because the heat from the sun speeds up the time taken for evaporation. Thus, ***heat is essential for evaporation.***

Then how did the handkerchief inside the room dry?

This is because the heat from the sun also heated the air inside the room, although indirectly. This warm air converted the water on the handkerchief into vapor. Since direct sunlight did not reach the room, the handkerchief took longer to dry.

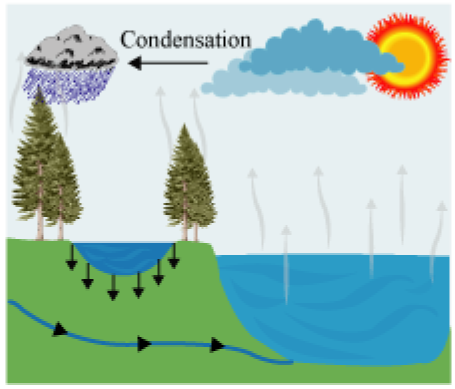
When water is poured over plants kept in pots, it is absorbed by the plant roots. Water is essential for plant growth. The plant utilizes the required quantities of water and the excess water is lost by the surface of the leaves as vapor through the process of ***transpiration.***

Thus, we can say that evaporation and transpiration are the processes by which water is converted into water vapor.

Since sunlight falls on all the water bodies such as oceans, seas, lakes, ponds, and rivers, water is being continuously converted to water vapor. Where does all this water vapor go? Does it disappear forever?

Condensation

As water vapor moves higher up, it cools down and forms water droplets through the process of **condensation**. Many water droplets join together to form clouds.



Precipitation

The water vapour that condenses as clouds falls down as rainfall, snow, or hail by the process of precipitation.

When clouds are large and laden with water, the water begins to fall as **rainfall.**

This rain enters the rivers, ponds, lakes, and other water bodies.

Some of the rainwater that falls on the ground enters the soil and adds to the **groundwater.** The returning of rain water into large water bodies and groundwater is known as **run off**.

This groundwater can be a source of water for the lakes. It can be drawn out using hand pumps and tube wells and utilized. The overuse of groundwater, however, can reduce its availability, thereby increasing water scarcity. When the land surface is covered with concrete, the amount of rainwater that can enter the soil drastically reduces, leading to a further decrease in the availability of ground water.

Thus, we now understand that water enters the atmosphere as water vapor by the processes of evaporation and transpiration. Water vapor condenses to form clouds and falls as rain. Rain water again runs off to large water bodies such as rivers, lakes, oceans, or groundwater.

Rajat wanted to observe the various processes that cause a change in the state of water in the environment. Let us try and mimic the processes.

Did you know that when rainwater flows on the ground, it washes away the valuable top soil? When this top soil is lost, plants cannot grow. This process is called soil erosion.

Water is found in many different states and these states keep changing depending on the temperature and other environmental conditions.

More to perform, observe, and learn

We can observe the processes that occur in the environment in our everyday lives. Do you notice that when water is placed in ice trays and kept in a freezer, it changes into solid ice cubes? Further, when water is heated in a pan, it changes into gaseous vapors.

You may also have observed that on heating water in a container that is covered with a lid, the water vapour cools down after some time to form droplets of water under the lid! When a glass filled with icy cold water is kept on the table, in normal temperatures, small droplets of water are formed over the external surface of the glass.

Physical Properties of Water

A molecule of water is made by the combination of two hydrogen atoms and one oxygen atom.

Do you know that on an average, an individual consumes about 2.9 litres of water everyday?

Water is required not only for drinking but also for many other purposes in our day-to-day lives.

Irrigation in agriculture, industrial processes, domestic purposes such as cooking and cleaning are some of the major uses of water.

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What happens when some crystals of copper sulphate are heated?

The crystals turn white. **Do you know why?**

This because crystals of copper sulphate contain water and this water is removed on heating. As a result, the salt turns white. This water is called **water of crystallisation**.

Do you know what water of crystallisation is?

Water of crystallisation is the fixed number of water molecules present in one formula unit of copper sulphate.

Hydrated copper sulphate has the chemical formula $CuSO_4.5H_2O$. That is, one formula unit of copper sulphate contains five water molecules. Therefore, water of crystallisation of copper sulphate is 5. Similarly, the water of crystallisation of calcium sulphate ($CaSO_4.2H_2O$) is 2.

Anomalous expansion of water

Water shows abnormal behaviour when heated or cooled between 4°C and 0°C. If water is cooled below 4°C, then it expands instead of contracting. This abnormal behaviour of water is called **anomalous expansion of water**.

Water as a solvent

Water is said to be a **universal solvent**. It can dissolve almost all kinds of substances (solid, liquid, or gas) in it to different extent.

The substances which dissolve rapidly in water are called soluble substances. Examples include sugar, common salt, etc.

On the other hand, the substances which do not dissolve or dissolve to very little extent are called insoluble substances. Examples include stones, plastic, glass, etc.

The respiration and survival of aquatic lives are possible only because of presence of dissolved oxygen in water. Moreover, carbon dioxide gas dissolved in water helps water plants in producing food.

Do you know that the water in the Dead Sea contains 23% to 25% salt. The salt is mainly potassium chloride, magnesium chloride, calcium chloride and calcium bromide. No aquatic life can survive in that much saline water.

Solutions

Whenever we talk about solutions, we instantly think of liquids. **But is it necessary that all solutions are liquids?**

No. A solution is simply a homogeneous mixture of two or more substances. We can also have solid solutions and gaseous solutions. Alloy is an example of a solid solution while air is a gaseous solution.

The only condition that has to be fulfilled for a mixture to be called a solution is that it should have homogeneity at particle level. For example, when sugar is dissolved in water, a solution is obtained because sugar particles are evenly present throughout the solution. As a result, all parts of a sugar solution taste the same.

A solution has two components, namely, the solvent and the solute.

- **Solvent** is that part of the solution in which the other component is dissolved. In other words, solvent is that component of a mixture that is present in large amounts.
- **Solute** is that part of the solution that is dissolved in the solution. This is present in a lesser quantity as compared to the solvent. Also, more than one solute can be present in a solution.

Some common examples of solutions are:

- **Solution of salt in water:** Salt is the solute and water is the solvent.
- **Solution of iodine in alcohol:** Iodine is the solute and alcohol is the solvent. It is also called ‘tincture of iodine’.
- **Vinegar:** Acetic acid is the solute and water is the solvent.
- **Soda water:** CO_2 is the solute and water is the solvent.
- **Air:** N_2 is the solvent and the other gases are the solutes.

Properties of a solution:

- It is a homogeneous mixture of solutes and solvents.
- The solute particles in a solution are extremely small in size. They are less than 1 nm (10^{-9} m) in diameter.
- Solute particles are not visible to the naked eye.
- As a result of the small size of the solute particles, a solution does not scatter light.
- Solute particles being small in size get dissolved in the solvent. Hence, the solute cannot be separated from the solution by filtration.
- Solute particles do not settle down when left undisturbed.

Solubility

The amount of a solute present in its saturated solution at a given temperature is called the solubility of the solute at that temperature.

For example, if 30 g of a substance dissolves in 100 g of water at 25°C, then the solubility of the substance is 30 g/ 100 g of water at 25°C.

Mathematically, solubility of a substance is given by,

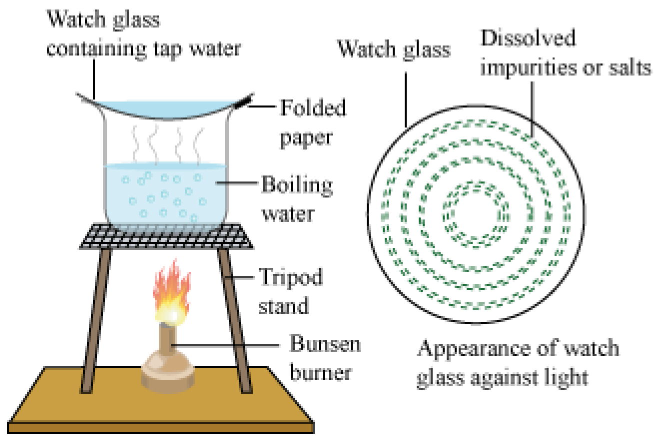
$$\text{Solubility of solute} = \frac{\text{Weight of solute (in g)}}{\text{Weight of solvent (water) (in g)}} \times 100$$

With an increase in the temperature of a solution, the solubility increases. This can be easily demonstrated as shown in the following animation.

Chemical Properties of Water

Experiment to show the presence of dissolved solids in tap water

Take some tap water in a 100 mL beaker and heat it. Place a large watch glass over the beaker and raise the edge of the watch glass from one side by placing a folded paper (as shown in the figure). Then pour about 10 mL of tap water into the watch glass.



What have you observed?

You will observe that the steam produced from the boiling water in the beaker starts evaporating the water in the watch glass slowly.

Let the water in the watch glass evaporate completely. Then, remove the watch glass from the beaker and look through it against light.

Can you see some concentric rings of fine solid materials sticking to the watch glass?

The tap water contains some dissolved solids. As the water evaporates slowly, the dissolved solids deposit and as a result, the concentric rings of the solid materials are formed.

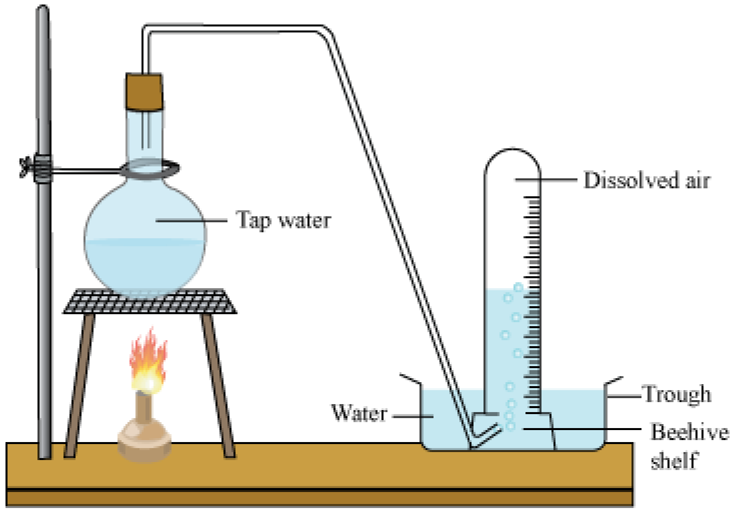
Why are the dissolved salts in water important?

The dissolved salts in water are important because of the following reasons:

- They provide taste to water.
- They are required by our body as they provide nutrients for growth, repair, and development of cells.
- Their deficiency may cause a number of diseases.

Experiment to Show the Presence of Dissolved Gases in Tap Water

Take some tap water in a round bottomed flask and fill it completely. Fix a cork fitted with a delivery tube in mouth of the flask. The lower end of the delivery tube should be in line with under-surface of the cork. Its other end should be in the beehive shelf, placed in a trough of water. Set up the apparatus as shown in the figure.



Heat the water in the round bottomed flask. After some time, some tiny bubbles of gas coming out of the water are observed. If the heating is continued, then water starts boiling and the gas bubbles start coming out of the beehive shelf. Lower the flame to keep the water just near the boiling point. Then invert a graduated tube completely filled with tap water over the beehive shelf. The boiled off air starts collecting in the tube by replacing water.

Collect the tube filled with boiled off air and introduce a glowing splinter in it.

What have you observed?

The glowing splinter will burst into flames. This is possible only when the boiled off air contains more oxygen than atmosphere. Now, it can be concluded that oxygen is dissolved in water. Similarly, gases such as nitrogen, carbon dioxide are also dissolved in water.

Importance of dissolved gases in water

Similar to dissolved solids, dissolved gases (especially oxygen and carbon dioxide) in water are also important.

Dissolved oxygen in water is important because of the following reasons:

- It is required by animals living in water during their respiration, without which they cannot survive.

$$\underset{\text{Glucose}}{C_6H_{12}O_{6(s)}} + 6O_{2(g)} \longrightarrow 6CO_{2(g)} + 6H_2O_{(l)} + \text{Heat}$$

- It helps to keep water purified by killing germs and bacteria.

Dissolved carbon dioxide in water is important because of the following reasons:

- It is required by water plants during photosynthesis.

$$6CO_{2(g)} + 6H_2O_{(l)} \xrightarrow{\text{Sunlight}} \underset{\text{Glucose}}{C_6H_{12}O_{6(s)}} + 6O_{2(g)}$$

- Dissolved carbon dioxide reacts with limestone to form soluble calcium carbonate, which is used by animals living in water to form hard shells for the protection of their soft bodies.

$$\underset{\text{Limestone}}{CaCO_{3(s)}} + H_2O_{(l)} + CO_{2(g)} \longrightarrow \underset{\text{Calcium carbonate}}{Ca(HCO_3)_{2(aq)}}$$

Do you know how metals react with water?

Let us see.

Reaction with Sodium and Potassium

Sodium and potassium react violently even with cold water. When a small piece of sodium or potassium is dropped into a trough of cold water, it reacts with water and burns with a bright flame.

During this reaction, respective metal hydroxides are formed with the evolution of hydrogen gas.

$$Na_{(s)} + 2H_2O_{(l)} \longrightarrow 2NaOH_{(aq)} + H_{2(g)}$$
$$2K_{(s)} + 2H_2O_{(l)} \longrightarrow 2KOH_{(aq)} + H_{2(g)}$$

Reaction with Calcium

Calcium reacts very quickly with cold water forming calcium hydroxide with the evolution of hydrogen gas.

$$Ca_{(s)} + 2H_2O_{(l)} \longrightarrow Ca(OH)_{2(aq)} + H_{2(g)}$$

Reaction with Magnesium

Magnesium does not react with cold water. However, it reacts slowly with hot water. Also, it burns by reacting with steam for a few moments and then the reaction stops.

$$Mg + H_2O \rightarrow MgO + H_2 \uparrow$$

Reaction with Iron

Iron does not react with either cold water or hot water. It reacts with steam reversibly when heated (above 800 °C) to form ferrosoferric oxide and hydrogen.

$$\underset{\text{(Red hot)}}{3Fe_{(s)}} + 4H_2O_{(g)} \xrightarrow[\text{Above } 800^\circ C]{\Delta} Fe_3O_{4(s)} + 4H_{2(g)}$$

Reactivity Series

Metals can be arranged in an order of decreasing reactivity after observing their rate of reactions with water, resulting in the reactivity series. **Reactivity series is a series in which metals are arranged in decreasing order of their chemical reactivities as shown below.**

Potassium	K	Most reactive metal
Sodium	Na	
Calcium	Ca	
Magnesium	Mg	
Aluminium	Al	
Zinc	Zn	Reactivity decreases
Iron	Fe	
Lead	Pb	
Hydrogen	H	
Copper	Cu	
Mercury	Hg	
Silver	Ag	
Gold	Au	Less reactive metal

Distillation of water

Tap water and borewell water has a taste due to the presence of dissolved salts in it. Water can be made pure by the process of "**Distillation".** In this process, water is heated till it evaporates and water vapour is then collected in the receiver tube.

Water vapour then condensed by cooling water, salts and minerals which do not vapourise remain in the flask. Thus water free from any salts and minerals is known as distilled water. Distilled water is pure water.

Know this: Although distilled water is pure water, yet it should not use in drinking purposes. This is because distilled water do not contain any salts and mineral which are required by our body and therefore not suitable for drinking purpose.

Hygroscopic nature of water: Hygroscopic nature if the ability of a substance to hold the water molecules from its surroundings either by absorbing or by adsorbing.

When some salts dissolved in water, they tend to absorb water molecules, this property is termed as **Deliquescence**.

Deliquescent substances are those materials which have a great tendency to absorb moisture in a large amount.

For example: Zinc chloride, calcium chloride, potassium hydroxide etc.

Efflorescence: It is the loss of water of crystallization from a hydrated salt to the atmosphere.

For example: Gypsum ($CaSO_4.5H_2O$) is a hydrated salt and in dry environment it loses all its water molecules and form anhydrous salt $CaSO_4$.

Concentration of a Solution

We come across many solutions in daily life, for example, saltwater, lime juice, squashes, coconut water, etc. How do we rate these solutions? We do so by classifying them as sweet, salty, etc., on the basis of our senses.

In chemistry, however, such classification of solutions is not very informative or beneficial. So, chemists usually use words such as ‘saturated’, ‘unsaturated’, ‘supersaturated’, ‘dilute’ and ‘concentrated’ to define the concentration of a given solution.

Uses of Concentration in Real Life

- Maintenance of the ionic balance in our body
- Preparation of dyes
- Preparation of juices
- Labelling of alcoholic drinks
- Addition of antifreeze to vehicles

Let us learn more about concentration in this lesson.

Know More

Antifreeze

Antifreeze solutions are added to a liquid in a cooling system (such as the water in an automobile engine) to lower its freezing point and prevent ice build-up in the system at very low temperatures.

Functions of antifreeze

- It contains chemicals that prevent corrosion and scale formation in the engine and radiator of a vehicle.
- It provides protection against boiling during summers. At 1 atmosphere pressure, water boils at 100°C; but a 50-50 blend of water−ethylene glycol boils at 106°C.
- A mixture of antifreeze and distilled water (in the ratio, one part antifreeze to one part water) provides freeze protection down to −36.67°C and boil-over protection up to 129.4°C.

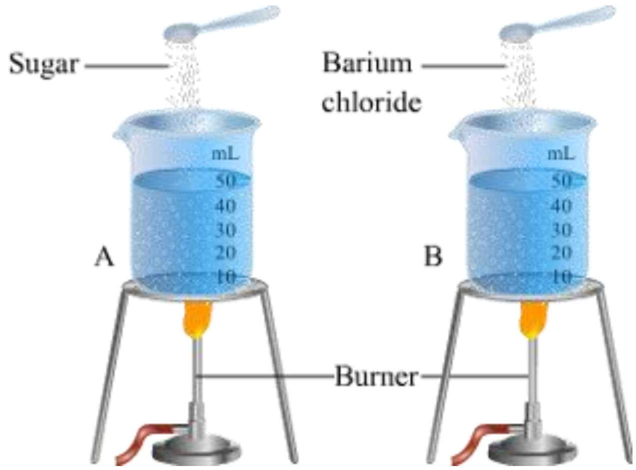
Precautions

- Avoid using concentrated antifreeze in a cooling system. At least 40% of the mixture should be water.
- Do not increase the concentration of antifreeze above 60% as it damages the freezing and overheating protection of the engine.
- Do not add too much water to the cooling system as it lowers the concentration of the corrosion inhibitor and antifreeze. This results in decreased protection against corrosion and freezing.

Did You Know?

The coke or colas (aerated drinks) available in the market are actually super saturated solution of CO_2 in water.

Experiment to Demonstrate Solubility



Procedure: Take two beakers and label them A and B. Fill each with 50 mL of water. Dissolve sugar in beaker A and barium chloride in beaker B. Keep dissolving the solutes in the respective beakers till the solutions become saturated and no more solute can be further dissolved. After this, heat the solutions and dissolve one more spatula of the solutes in the respective beakers. Slowly cool down the solutions after the solutes added further get completely dissolved.

Result:

- To saturate 50 mL of water, different amounts of sugar and barium chloride is added.
- Upon heating, the saturated sugar solution is able to dissolve more amount of sugar.
- When cooled, the sugar (dissolved after the saturated solution is heated) precipitates out from the solution.

Explanation: Upon heating, a saturated solution can accommodate more amount of solute. This is called a **super-saturated solution**. This solution is quite unstable as the molecules of the solute (dissolved after the saturated solution is heated) crystallise easily.

Conclusion: A particular amount of solute (here sugar or $BaCl_2$) can saturate a particular type of solvent (here water) at a particular temperature only. If temperature is changed, then the solubility of the solvent also changes. Solubility of a solute in a solvent is the maximum amount of solute that can be dissolved in 100 g of that solvent at a particular temperature. It is expressed in terms of concentration.

For example, a maximum of 36 g sodium chloride can be dissolved in 100 g water at 20°C. Therefore, the solubility of sodium chloride in water is 36 g at 20°C.

Concentration and Its Classification

A **solution** is a homogeneous mixture of two or more substances. The substance that is dissolved in a solution is called the **solute**, and the substance that dissolves the solute is called the **solvent**. The amount of solute in a solution may vary.

The amount of solute present in a given quantity of solution is called the concentration of that solution. The concentration of a solution helps us to determine the amount of solute present in the solution.

$$\text{Concentration of a solution} = \frac{\text{Amount of solute}}{\text{Amount of solution}}$$

OR

$$\text{Concentration of a solution} = \frac{\text{Amount of solute}}{\text{Amount of solvent}}$$

Depending on the amount of solute present, a solution can be classified as follows:

1.**Dilute solution**

2.**Concentrated solution**

3.**Saturated solution**

4.**Unsaturated solution**

5.**Supersaturated solution**

Concentration in terms of Molarity

It is defined as the number of moles of solute present in 1000 mL of the solution. Molarity is represented by M.

$$\text{Molarity } \left(M\right) = \frac{\text{Number of moles of solute}}{\text{Volume of solution in mL}} \times 1000$$

$$\text{or}$$

$$\text{M} = \frac{\text{Weight of solute}}{\text{Molar mass of solute} \times \text{Volume of solution in mL}} \times 1000$$

A 10 M solution indicates that 10 moles of solute are present in 1 L or 1000 mL of the solution. One mole of any amount is equal to the gram molecular mass to be taken. Consider the example of NaCl, the amount of 58.5g/mole(molecular weight) of NaCl is called one mole of NaCl. If the substance is in the elemental form, then its atomic mass will have to be considered for 1 mole amount.

Brush Up

Concentration
(Amount of Solute in Solvent/Solution)

Mass by mass percent

- $$\text{Mass by mass percent} = \frac{\text{Mass of solute}}{\text{Mass of solution}} \times 100$$
- Mass of solution = (Mass of solute + Mass of solvent)

Mass by volume percent

- $$\text{Mass by volume percent} = \frac{\text{Mass of solute}}{\text{Volume of solution}} \times 100$$
- Solute
  - **Solid** → Volume of solution = Volume of solvent
  - **Liquid** → Volume of solution = (Volume of solvent + Volume of solute)

Summary

The following chart shows the types of solutions that can be formed by varying the concentration.

Solubility

- Solubility of a substance is the maximum amount of the substance that can be dissolved in a specified amount of a solvent at a given temperature.

- Factors on which solubility depends:

- Nature of solute and solvent
- Temperature
- Pressure

Solubility of a Solid in a Liquid

When a solute is dissolved in a solvent, the following dynamic equilibrium is established.

Solute + Solvent $\longleftrightarrow$ Solution

This equilibrium follows Le Chatelier's Principle.

- Effect of temperature:

According to Le Chatelier's principle, in a nearly saturated solution, if the dissolution process is −

- Endothermic ($\Delta_{sol}H > 0$), then the solubility will increase with the increase in temperature

- Exothermic ($\Delta_{sol}H < 0$), then the solubility will decrease with the increase in temperature

- Effect of pressure:

- Pressure has no significant effect on the solubility of solids in liquids.

- Reason − Solids and liquids are negligibly affected by pressure as they are highly incompressible.

Solubility of a Gas in a Liquid

- The solubility of gases in liquids increases with the increase in pressure.

- Henry's law − The solubility of a gas in a liquid is directly proportional to the pressure of the gas.

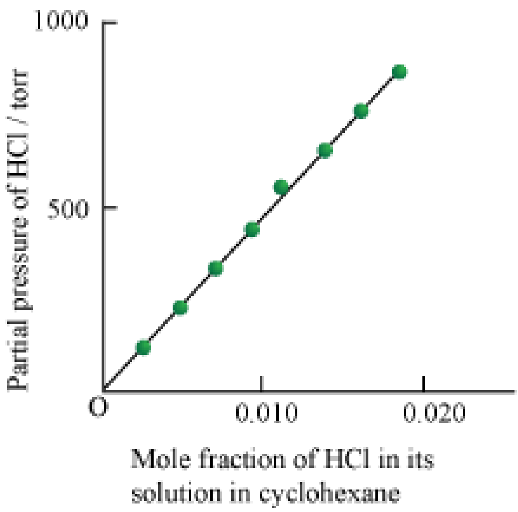
Or

The partial pressure of a gas in vapour phase (p) is directly proportional to the mole fraction of the gas (x) in the solution, i.e.,

$p = K_H x$

Where, K_H = Henry's law constant

The plot of the partial pressure of HCl vs. its mole fraction in a solution of cyclohexane is given below.



- Some important applications of Henry's law

  (i) Bottles are sealed under high pressure to increase the solubility of CO_2 in soft drinks and soda water.

  (ii) Henry's law states that the solubility of gas increases with an increase in pressure. Therefore, when a scuba diver dives into the sea, the increased sea pressure causes the nitrogen present in air to dissolve in his blood in great amounts. As a result, when he comes back to the surface, the solubility of nitrogen again decreases and the dissolved gas is released, leading to the formation of nitrogen bubbles in the blood.

  This results in the blockage of capillaries and leads to a medical condition known as 'bends', which are painful and dangerous to life. Hence, the oxygen tanks used by scuba divers are filled with air and diluted with helium to avoid bends.

  (iii) The concentration of oxygen is low in the blood and tissues of climbers or people living at high altitudes. This is because at high altitudes, the partial pressure of oxygen is less than that at ground level. Low blood oxygen causes climbers to become weak and prevents them from thinking clearly. These are symptoms of 'anoxia'.

- Effect of temperature

Solubility of gases in liquids decreases with the increase in temperature.

Water of Crystallization

We know that washing soda is produced by mixing water and sodium carbonate. The molecular formula of washing soda is $Na_2CO_3.10H_2O$.

Sodium carbonate is obtained by heating sodium hydrogencarbonate.

$$\underset{\text{(Sodium Hydrogen carbonate)}}{2NaHCO_3} \rightarrow \underset{\text{(Sodium carbonate)}}{Na_2CO_3} + H_2O + CO_2$$

The re-crystallization of sodium carbonate then produces washing soda.

$$Na_2CO_3 + 10H_2O \rightarrow Na_2CO_3 \cdot 10H_2O$$

Ten water molecules are present in the formula of washing soda. These water molecules are called **water of crystallization.**

Water of crystallization refers to a fixed number of water molecules present in one formula unit of salt.

The following experiment will help in understanding the concept of water of crystallization.

Aim: To prepare crystals of copper sulphate ($CuSO_4$)

Material required: Beaker, distilled water, copper sulphate ($CuSO_4$) crystals, glass rod, thread, watch glass

Theory: Water of crystallization imparts the characteristic blue colour to copper sulphate ($CuSO_4$) crystals. These crystals are obtained by the process of *seeding*. In this process crystallization is induced with the help of small crystal of pure hydrated copper sulphate ($CuSO_4.5H_2O$) which is added in the saturated copper sulphate solution.

Procedure:

1. Take a beaker and prepare a saturated solution of copper sulphate ($CuSO_4$) at 80^o C and filter the solution to remove any undissolved impurity.
2. Cover the filtrate with watch glass.
3. Cool down the filtrate and leave it undisturbed for 24 hours.

4. Some crystals of copper sulphate ($CuSO_4.5H_2O$) will be formed at the bottom of the beaker. Collect a few of them.
5. Suspend one of the well formed small crystal in the saturated solution by tying to a glass rod using a thread.
6. Again cover the beaker with watch glass to avoid dust entering the solution.
7. Leave it undisturbed.

Observation: The suspended crystal grows in size with each passing day.

Water of crystallization is the fixed number of water molecules present in one formula unit of salt.

It is in chemical combination with a crystal
It is necessary for the maintenance of crystalline properties of the crystal
It can be removed by sufficient heat

The following experiment shows the effect of heat on solids that do not contain water of crystallisation.

Aim: To show effect of heat on solids that do not contain water of crystallisation.

Material required: Test tube, burner, potassium nitrate (KNO_3)

Theory: Not all crystalline solids contain water of crystallisation. These solids when heated decompose to form new compounds.

Procedure:

1. Take some potassium nitrate crystals in a test tube.
2. Heat the tube gently.

Observation: The crystals form a colourless solution giving off a gas, that bursts the glowing splinter. It signifies that oxygen is being involved. In the end, a pale yellow residue is left in the test tube.

$$\underset{\text{Potassium nitrate}}{2\ KNO_3} \xrightarrow{\Delta} \underset{\text{Potassium nitrite}}{2\ KNO_2} + O_2$$

Hydrated Substances

Those substances which contain water of crystallization like hydrated copper sulphate

($CuSO_4.5H_2O$), are called hydrated substances. The water of crystallisation gives their crystals shape and in some cases colour.

Gypsum is another salt that possesses the water of crystallization. It has a chemical formula of $CaSO_4.2H_2O$. It is also known as hydrated calcium sulphate.

When hydrated calcium sulphate ($CaSO_4.2H_2O$) or gypsum is heated at 373K, it loses its water molecules and forms calcium sulphate hemihydrate ($CaSO_4.\frac{1}{2}H_2O$). **This hemihydrate form of calcium sulphate is known as Plaster of Paris.** It is in the form of a white powder.

When the powder of Plaster of Paris is mixed with water, it becomes hard and solid gypsum. Plaster of Paris is generally used to support fractured bones in their correct positions.

$$\underset{\text{(Plaster of Paris)}}{CaSO_4.\frac{1}{2}H_2O} + 1\frac{1}{2}\ H_2O \rightarrow \underset{\text{(Gypsum)}}{CaSO_4.2H_2O}$$

In $CaSO_4.\frac{1}{2}H_2O$**,** only half a water molecule is shown as the water of crystallization because two formula unit of $CaSO_4$ share one molecule of water.

Plaster of Paris is used for making toys, materials for decoration, and for making smooth surfaces.

Determination of Water of Crystallization

Heat a known weight of a hydrated substance to a temperature above 100^o C. Weigh the residue. Repeat these two steps, till the weight of the residue becomes constant. Use the following formula to obtain the percentage of water of crystallization in a link:

Initial weight of the hydrated substance = *x* g
Final constant weight of the substance after heating = *y* g

$$\%\ \text{of water of crystallization} = \frac{x-y}{x} \times 100$$

Anhydrous Substances

Those substances which do not contain any water of crystallization or the substances from which the water of crystallization have been removed like sodium chloride (NaCl) are called anhydrous substances.

The water of crystallization can be removed by using any of the following methods:

- Direct heating of the hydrated substance
- Heating the hydrated substance in dry and hot air
- Heating the hydrated substance under vacuum
- Using dehydrating/desiccating agents

Drying Agents

The substances that absorb moisture from other substances without undergoing a chemical reaction with them are called drying agents or desiccants or desiccating agents. Examples of drying agents are anhydrous calcium chloride, anhydrous zinc chloride etc.

Most of the hygroscopic substances are desiccating agents like concentrated sulphuric acid, silica gel etc.

The following table illustrates the techniques used to dry certain substances.

Substance	Drying technique
Gases	By passing through concentrated sulphuric acid Used for drying acidic gases like HCl gas By passing through a drying tower or a U-tube containing anhydrous sodium sulphate By passing through a drying bulb containing anhydrous calcium chloride
Liquids	By keeping them over anhydrous sodium sulphate or calcium chloride for over a night After this, solid is removed by filtration.
Solids	By placing them in a desiccator (air-tight vessel with a drying agent like calcium chloride spread at the bottom)

Dehydrating Agents

The substances that can remove chemically bounded water from compounds are called dehydrating agents. Concentrated sulphuric acid is a strong dehydrating agent. It can remove water molecules from hydrated copper sulphate ($CuSO_4.5H_2O$).

$$\underset{\text{(blue)}}{CuSO_4.5H_2O} \xrightarrow{Conc.\ H_2SO_4} \underset{\text{(white)}}{CuSO_4} + 5H_2O$$

The following table explains the differences between drying agents and dehydrating agents.

Drying Agents	Dehydrating Agents
Removes moisture from other substances	Removes chemically bounded water molecules from substances
Performs a physical change in the substance	Performs a chemical change in the substance

Deliquescent and Efflorescent Substances

Deliquescence

• Certain substances, when kept open in atmosphere at room temperature, absorb water from the atmosphere and become moist. On further absorption of water they dissolve.

• Such substances which absorb water from the atmosphere are known as deliquescent substances and the phenomenon is known as deliquescence. Examples of such substances are sodium hydroxide, potassium hydroxide, calcium chloride, zinc chloride, ferric chloride, sugars etc.

• It is necessary to keep the deliquescent substances in a special type of closed container known as desiccators. They keep the deliquescent substance dry.

• Certain substances like concentrated sulphuric acid and calcium chloride, which keep the atmosphere dry, are known as desiccants or drying agents.

Efflorescence

• Certain hydrated compounds lose water when exposed to air with moderate humidity. Such substances, which lose their water of hydration to the surroundings, are known as efflorescent substances and the phenomenon is known as efflorescence. Sodium sulphate ($Na_2SO_4.10\ H_2O$) and washing soda ($Na_2CO_3.10\ H_2O$) are some examples of efflorescent substances.

Hygroscopy

- Certain substances tend to absorb moisture from the air upon exposure. Such substances are known as hygroscopic substances and the phenomenon is known as hygroscopy. Concentrated sulphuric acid (H_2SO_4), phosphorous pentoxide (P_2O_5), and quicklime (CaO) are some examples of hygroscopic substances.

Soft and Hard Water

Water is a very precious natural resource found only on earth. Pure water is colourless, tasteless and odourless. It gets colour, odour and taste due to the presence of salts like nitrates, sulphates, chlorides and bicarbonates. The presence of these salts further affects the property of soap. Water is thus classified into soft water and hard water on the basis of its interaction with soap.

• **Hard water:** Presence of Ca^{2+} and Mg^{2+} ions/salts in water causes formation of insoluble scum rather than foam with soap. This type of water which does not form lather with soap is known as ***hard water***.

• **Soft water:** Water which is free from salts of calcium and magnesium, and gives lather with soap easily is known as ***soft water***.

• When water is free from the presence of any ions/salts, it is known as ***distilled water***.

Note: Salts of metals like iron, manganese and those of other divalent metals can also cause hardness of water.

Reason for the formation of scum:

Soap is a sodium or potassium salt of higher fatty acids (fats). When it reacts with soft water, it easily dissociates into ions and forms lather. But when water contains Ca^{2+} and Mg^{2+} ions, soap reacts with these ions to form insoluble precipitates of calcium and magnesium salts of higher fatty acids and does not form lather.

$$\underset{\text{soap}}{2\,H_3C(CH_2)_nCOO^-\,Na^+} \xrightarrow{M^{2+}} \underset{\text{insoluble scum}}{(H_3C(CH_2)_nCOO^-)_2M} + 2\,Na^+ \qquad [M^{2+} = Ca^{2+}, Mg^{2+}\ \text{ion}]$$

Types of hardness of water:

Hardness of water can be divided into two categories:

• **Temporary hardness:** When water contains bicarbonates of calcium and magnesium [M(CO_3), M = Ca^{2+}, Mg^{2+} ion], they can be removed by simple methods like boiling. This type of hardness is known as temporary hardness.

• **Permanent hardness:** When chlorides and sulphates of calcium and magnesium [MCl_2 and MSO_4, M = Ca^{2+}, Mg^{2+} ion] are present in water, they cannot be removed by simple methods; they require special methods for their removal. This type of hardness is known as permanent hardness.

Advantages of hard water:

- It tastes better because of the presence of salts and hence, is used in making beverages and wines.
- Salts of magnesium and calcium present in hard water are required for growth of bones and teeth.
- It checks the lead poisoning by lead pipes as it forms a layer inside the lead pipe and does not let lead mix up with passing water.

Disadvantages of using hard water:

• **Household use:** Water is used in a number of household activities, like washing, bathing, drinking, cooking, etc. If hard water is used in these activities, lather is not formed.

It also makes the skin dry and leaves stains on utensils and clothes. Food cannot be cooked properly. Using hard water causes accumulation of salts on the inner walls of containers and makes their cleaning difficult.

• **Industrial use:** Hard water used in various industries like paper, printing, dye and textile, etc. causes great difficulties. Boilers used in these industries get scales on their inner walls due to accumulation of insoluble carbonates formed from calcium and magnesium bicarbonates (temporary hardness).

Note: These days temporary hardness and permanent hardness are referred to as carbonated hardness and non-carbonated hardness respectively.

Methods of Softening Hard Water

Temporary hardness:

• **Boiling:** Since, temporary hardness is due to presence of soluble bicarbonate salts of calcium and magnesium, these upon boiling are converted into insoluble carbonate salts which can be removed by filteration.

$Ca(HCO_3)_2 \rightarrow CaCO_3 + H_2O + CO_2$ (g)

soluble insoluble

Also, $Mg(HCO_3)_2 \rightarrow MgCO_3 + H_2O + CO_2$ (g)

soluble insoluble

Although this method is quite simple, but for softening large quantities of water requires huge amount of energy and consumes too much time.

• **Clark's method:** This method is used at industrial scale to remove temporary hardness of water. In this method calculated amount of lime [$Ca(OH)_2$] is added to hard water, which converts soluble bicarbonates to insoluble carbonates.

$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2\ CaCO_3\downarrow + 2\ H_2O$

$Mg(HCO_3)_2 + Ca(OH)_2 \rightarrow MgCO_3\downarrow + CaCO_3 + H_2O$

Permanent hardness:

• **Distillation:** During distillation of water both temporary and permanent hardness are removed. In this method water is heated which converts it into its vapour. These vapours are condensed and collected in a separate container to obtain pure water. Hence water obtained after distillation is soft as well as pure.

• **Washing soda process:** In this method calculated amount of washing soda (Na_2CO_3) is added to hard water which removes both temporary and permanent hardness by converting chloride, sulphate and bicarbonate salts into insoluble carbonates which are easily removed by filtration.

$CaSO_4 + Na_2CO_3 \rightarrow CaCO_3 + Na_2SO_4$

$MgSO_4 + Na_2CO_3 \rightarrow MgCO_3 + Na_2SO_4$

$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaCl$

$MgCl_2 + Na_2CO_3 \rightarrow MgCO_3 + 2NaCl$

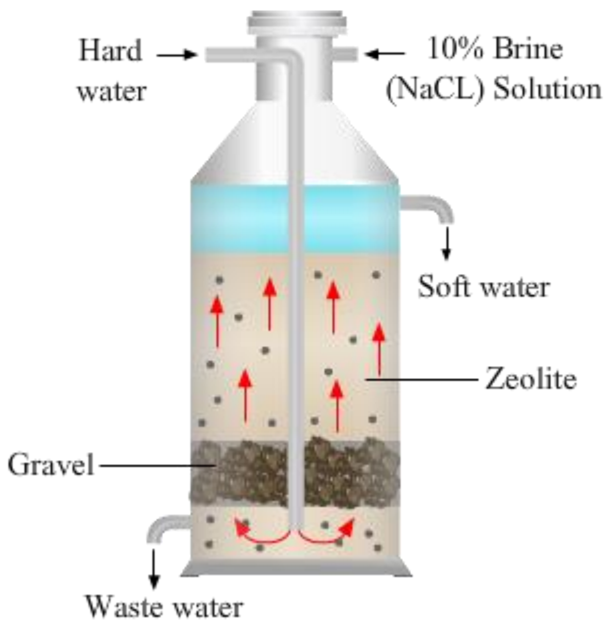
$Ca(HCO_3)_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaHCO_3$

$Mg(HCO_3)_2 + Na_2CO_3 \rightarrow MgCO_3 + 2NaHCO_3$

• **Permutit method:** This is a new method of softening hard water by using hydrated sodium aluminium silicate ($Na_2Al_2Si_2O_8.xH_2O$) alos known as **permutit**. Naturally occurring sodium aluminium silicate is known as **zeolite**.

(i) It is used in the form of a porous gel and is prepared by heating sodium silicate and sodium aluminate.

(ii) In this method soluble salts of calcium and magnesium are converted into insoluble calcium and magnesium permutits by exchanging the Ca^{2+} and Mg^{2+} ions with base ion Na^+ of sodium aluminium silicate (zeolite). This is done by passing hard water through the layers of zeolite or permutit as shown in the figure given below:



(iii) In the column given in the figure, sand, gravel and permutit are placed in alternate layers through which hard water flows down. As water passes, Ca^{2+} and Mg^{2+} ions are exchanged with Na^+ ions of the permutit. This forms calcium and magnesium permutit leaving behind only pure water.

Sodium permutit + $CaCl_2/Ca(HCO_3)/CaSO_4$ →

Calcium permutit + $NaCl/NaHCO_3/Na_2SO_4$

(iv) Calcium/magnesium permutit thus obtained is further converted into sodium permutit by reacting it with 10% NaCl solution and hence it can be recycled.

Calcium/magnesium permutit + NaCl → Permutit + $CaCl_2/MgCl_2$

(v) This process is widely used for removal of hardness water, but this method does not work if certain ions like lead, iron or manganese are present which does not exchange themselves with sodium ions. Thus water obtained by this method is soft water but not pure water.

Water Pollution

*The addition of harmful substances to water, as a result of which its physical, chemical, and biological properties get altered, is called **water pollution**. The substances that pollute water are called water pollutants.* Sewage, toxic chemicals, silt etc. are examples of water pollutants.

What effect does water pollution have on living organisms? Let us explore the effects of various water pollutants on living organisms.

Water pollutants:

There are three main categories of water pollutants:

Biological pollutants: Biological pollutants make the water unfit for consumption and are responsible for causing various kinds of diseases, for example, algae, bacteria, fungi, etc.

Inorganic pollutants: These include suspended particles like dust, sand, soil etc.

Organic pollutants: These include weedicides, pesticides, fertilizers, sewage etc.

Do you know that water pollution can occur either through natural reasons or man made reasons?
Natural reasons of water pollution include the presence of aquatic weeds, decomposing matter, mud/sludge, algae or nematodes. Presence of these components in water bodies makes them unfit for human consumption.

Man made reasons of water pollution include industrial wastes, pesticides etc. Lets study them in detail.

Industrial waste

In the absence of proper treatment facilities for industrial wastes, most of these wastes are directly dumped into the rivers. The industrial wastes from oil refineries, chemical factories, sugar mills, and fertilizer plants carry toxic substances such as arsenic, lead, mercury, and fluoride. These substances cause toxicity in plants and animals.

They also pollute the soil by increasing its acidity, decreasing its fertility, and affecting the growth of worms which are beneficial for the soil.

Pesticides and fertilizers

We know that fertilizers and pesticides are the farmer’s friends as they help in killing the pests and weeds and increasing the fertility of the soil. **However, do you know that they also have a significant negative impact on the water bodies?**

The chemicals that are contained in these pesticides and fertilizers get dissolved in the water and eventually get washed away to the water bodies. They also seep into the ground and pollute the ground water.

On entering the water bodies, these pesticides and fertilizers increase the nutrient content of the soil as they contain various nutrients. This accelerates the growth of algae in the water bodies. You may have observed that some water bodies appear green in colour.

This is because of the excessive growth of algae in water. **Does this excessive algal growth have any effect on the living organisms present in the water body?** The answer is a yes.

When these algae die, they are decomposed by the action of micro-organisms that are present in water. Consequently, the number of these micro-organisms in water bodies increases.

Since they consume a large quantity of oxygen that is present in the water, it leads to a decrease in the levels of oxygen. The absence of oxygen eventually leads to the death of the living organisms.

Sewage

Sewage is waste water that contains faecal matter, urine, food wastes, detergents, and other solid substances. Sewage contains many disease-causing pathogens such as bacteria, fungi, viruses, and parasites. When drinking water gets contaminated with sewage water, these harmful organisms enter the bodies of the living organisms and cause several diseases.

Some of the diseases caused by the drinking of contaminated water and the names of the respective causal organisms are listed in the given table.

Name of the disease	Causal organism
Cholera	Bacteria
Typhoid	Bacteria
Diarrhoea	Bacteria
Hepatitis	Virus
Amoebic dysentery	Protozoan

Several bacteria are present in the faeces of mammals. If the water is contaminated with faeces, then these bacteria function as indicator organisms for the quality of water i.e., the number of these faecal bacteria indicates the extent to which the water is contaminated by faecal matter.

Release of Superheated Water

The release of superheated water from some industries and nuclear power plants causes thermal pollution of the water bodies.

It results in the increase in temperature of ambient water that reduces dissolved oxygen content of water bodies. The abrupt change in the temperature of water body can kill the fish and other organisms adapted to particular temperature range.

Release of Waste and Oil from Refineries

The wastes and oil released from the refineries mainly in the seas and oceans cause marine pollution. The released oil penetrates into the plumage of birds and fur of mammals. This reduces their insulating ability and makes them more vulnerable to temperature fluctuations.

Methods of preventing water pollution

- Industrial waste must be chemically treated to remove harmful substances before dumping into the water bodies
- Disposal of human and animal excreta into water should be avoided
- Sewage water must be treated before releasing into the rivers
- Dumping of dead bodies, carcasses and other wastes into the water must be stopped
- Aquatic animals like tortoise and some special types of fishes help in purifying water, therefore they are termed as natural purifier of water

Some Interesting Facts:

- According to the Central Pollution Control Board, about 3,684 million litres of sewage is produced in Delhi in a single day.

- *Escherichia coli* bacterium, which is present in the faeces of humans and other living organisms, is used as an indicator organism for water contaminated with faeces.

Conservation and Purification of Water

Water is a precious resource and we need to conserve it. **How can the conservation and purification of water be carried out?** Let us explore the various methods that can be adopted to save water.

Water can be conserved by following the simple principle of reduce, reuse, and recycle. This can be practiced easily at homes. Some examples are

- Reusing the waste water from the kitchen (water that has been used to wash vegetables etc.) to water the plants in the garden
- Turning the tap off while brushing or shaving
- Checking for leaky taps and fixing them up
- Rain water harvesting
- Using improved farming and irrigation techniques
- Preventing pollution of water
- Conserving and replenishing ground water
- Proper removal of silt from water bodies
- Preventing cutting of trees
- Recycling and reusing water

Thus, we can reduce the total amount of water consumed by us by recycling and reusing most of the waste water for other purposes.

What about the waste water that is released from industries? Can it be recycled and reused too? The waste water from industries first needs to be treated in sewage treatment plants. This water can then be used for growing plants and other industrial purposes.

Some Interesting Facts:

- Leaking taps can lead to the wastage of thousands of litres of water in a single day.
- Drip irrigation is a method of irrigation that helps in the maximum conservation and utilization of water.

Purification of water

Do you know what potable water is? *Potable water is the water that is safe for drinking.* Although the water may look clean on mere observation, it may contain disease-carrying micro-organisms. In order to prevent the occurrence of diseases, this water has to be cleaned and only then can it be used safely for drinking.

What are some of the methods that can be used to purify water? The methods for obtaining potable water can be divided into two groups: physical methods and chemical methods. Let us discuss them in detail.

Physical methods

- **Sedimentation**: It is a process in which suspended particles are allowed to settle down in water.

- **Filtration:** It is one of the common methods used for removing impurities from water. A simple filter paper can be used to obtain clean water. Candle type filter that is commonly used in households is also based on the principle of filtration.

- **Boiling:** Boiling the water helps in killing the germs present in water.

Chemical Methods

- **Chlorination:** Adding chlorine to water is one of the most commonly used methods of purifying water. Chlorine, when used in the prescribed amount, kills the germs present in water and makes it safe for consumption. You may have observed that tap water sometimes appears milky. **Do you know why?** This is because it contains chlorine.

- **Ozonisation**: It is a process of treatment of water with ozone. Due to great oxidation power, ozone acts as a powerful disinfectant.

- Adding bleaching powder also helps in purifying water.

Water Purifiers:

Water is purified at homes using a domestic water purifier. They have microporous filters and activated charcoal along with a source of UV radiations.

Insoluble impurities, such as sand, etc. are removed by the filters and microbes are killed by UV radiations. Organic impurities and undesirable odour are removed by activated charcoal.