
CHAPTER

15

Water

Animation 15.1: Reuse of water
Source & Credit : hongkongirport

Students Learning Outcomes

Students will be able to:

- Describe the occurrence of water and its importance in the environment including industry. (Analyzing);
- Review our dependence on water and its importance of maintaining its quality. (Analyzing);
- Describe the composition and properties of water. (Understanding);
- Differentiate among soft, temporary and permanent hard water. (Analyzing);
- Describe methods for eliminating temporary and permanent hardness of water. (Applying);
- Identify water pollutants.(Analyzing);
- Describe industrial wastes and household wastes as water pollutants. (Understanding);
- Describe the effects of these pollutants on life. (Understanding) and
- Describe various types of waterborne diseases. (Understanding)

Introduction

Throughout history, importance and significance of water has been recognized by mankind. Its importance is because of two reasons. First, it is an essential and major component of each and every living cell. For example, human body consists of about 70% water. Secondly, it provides an environment for animals and plants that live in water. So, all living organisms owe their life to water.

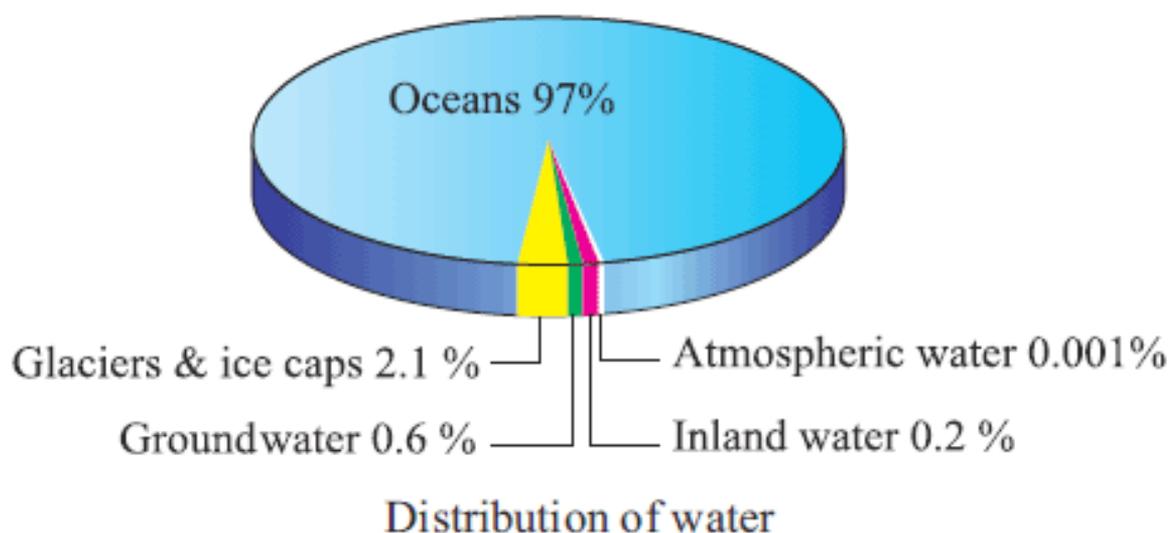
We use water in daily life for drinking, cooking and washing purposes. Quality of drinking water has remained a major factor in determining human health and welfare since ages. Since World War II, there has been a rapid production and use of synthetic chemicals. Many of these chemicals (fertilizers and pesticides run off from agriculture lands and industrial discharge from industrial units) have polluted water supplies. Besides this, there is also a threat to groundwater from waste chemical dumps and landfills.

Currently, waterborne toxic chemicals pose the greatest threat to the supplies of water especially in urban areas. Use of this water is causing waterborne diseases. So use of polluted water is a concern of every citizen. Therefore, understanding the sources and effects of water pollution is essential for controlling this alarming threat.

Occurrence of Water

The oceans contain about 97% of world's water. The rest of the water is in the form of glaciers, ice caps, groundwater and inland water (rivers, lakes, streams). It is also present in atmosphere in the form of water vapours. Sea water is unfit for drinking and agricultural purposes due to high percentage of dissolved salts.

Only 0.2% of the total water on the Earth is potable, i.e. fit for drinking purposes.



15.1 PROPERTIES OF WATER

Water is composed of two elements: oxygen and hydrogen. One atom of oxygen combines with two atoms of hydrogen to form one molecule of water. Pure water is a clear, colourless, odourless and tasteless liquid with following properties:

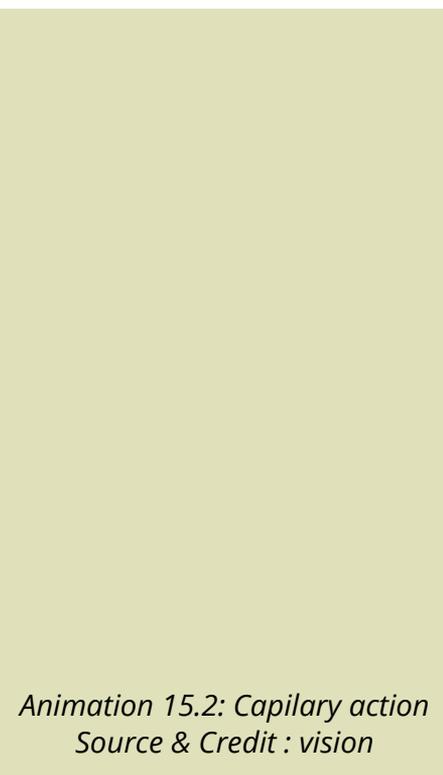
1. It is neutral to litmus.
2. Its freezing point is 0°C and boiling point is 100°C at sea level.
3. Its maximum density is 1 gcm^{-3} at 4°C .
4. It is excellent solvent for ionic as well as molecular compounds.
5. It has unusually high heat capacity about $4.2\text{ Jg}^{-1}\text{K}^{-1}$, which is about six times greater than that of rocks. This specific property of water is responsible for keeping the Earth's temperature within limits. Otherwise, day time temperature would have been too high to bear and night time temperature would have been too low to freeze everything.
6. It has high surface tension. This unique property of water is responsible for its high capillary

action. *Capillary action is the process by which water rises up from the roots of plants to leaves.* This process is vital for the survival of the land plants.

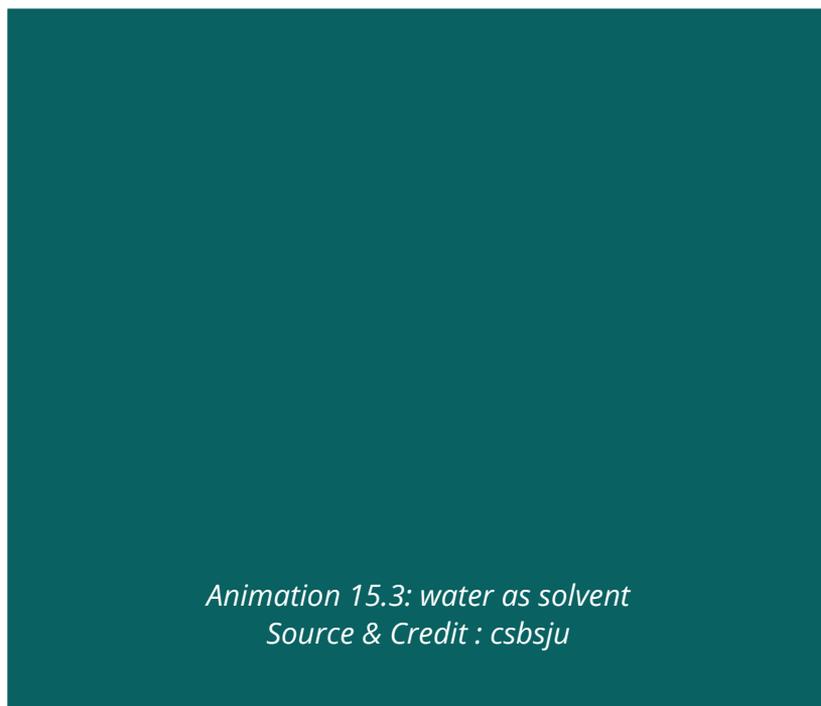
15.2 WATER AS SOLVENT

Water is the universal solvent because it can dissolve almost all the minerals. Its ability to dissolve substances is because of two unique properties of water:

- (i) Polarity of water molecule;
- (ii) Exceptional hydrogen bonding ability.



*Animation 15.2: Capillary action
Source & Credit : vision*



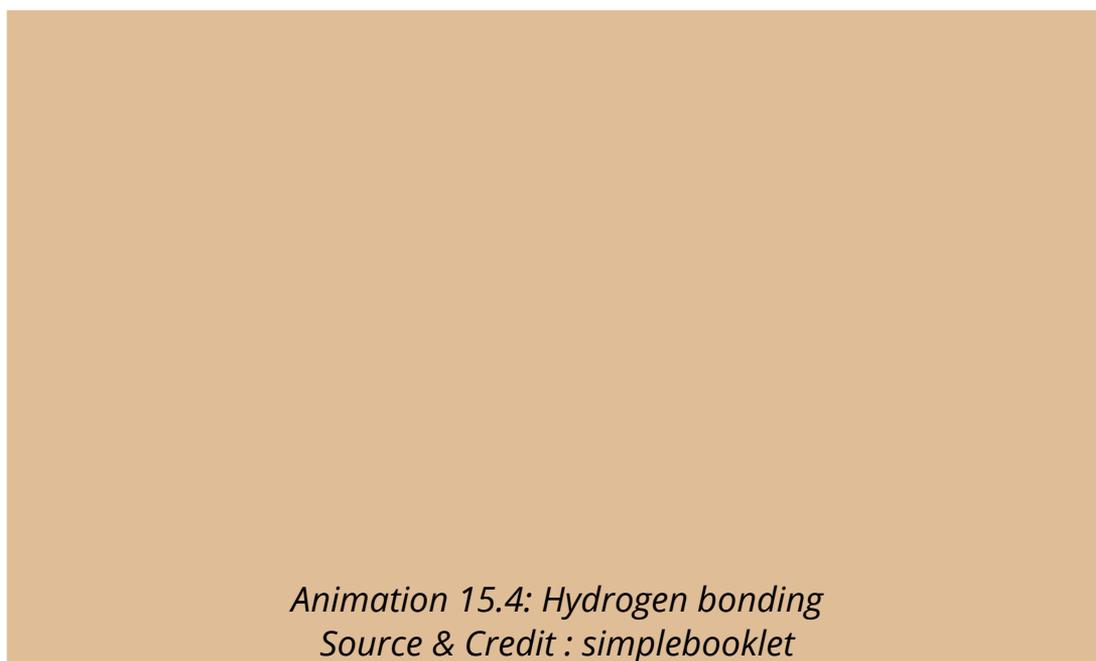
*Animation 15.3: water as solvent
Source & Credit : csbsju*

Polar nature of water

Water molecule has polar structure, i.e. one end of the molecule is partially positive while the other end is partially negative because of electronegativity difference between oxygen and hydrogen atoms.

All other polar substances are soluble in water,

because the positive end of the substance is attracted by the negative end ($O^{\delta-}$) of the water and negative end of the substance is attracted by the positive end ($H^{\delta+}$) of the water. The electrostatic attractions among the ions are overcome by the ion-dipole forces of attraction between ion and water molecules.



*Animation 15.4: Hydrogen bonding
Source & Credit : simplebooklet*

In this way, positive and negative ions of the compounds are pulled apart as shown in figure 15.1. Ultimately, these oppositely charged ions are surrounded by water molecules, thus separated and kept in solution. For example, most of the salts like NaCl, KCl, Na_2SO_4 , etc. are soluble in water. On the other hand, many covalent substances like benzene, ether, octane, etc., which do not have polar ends or bonds are not attracted by water molecules. Therefore, non-polar compounds do not dissolve in water.

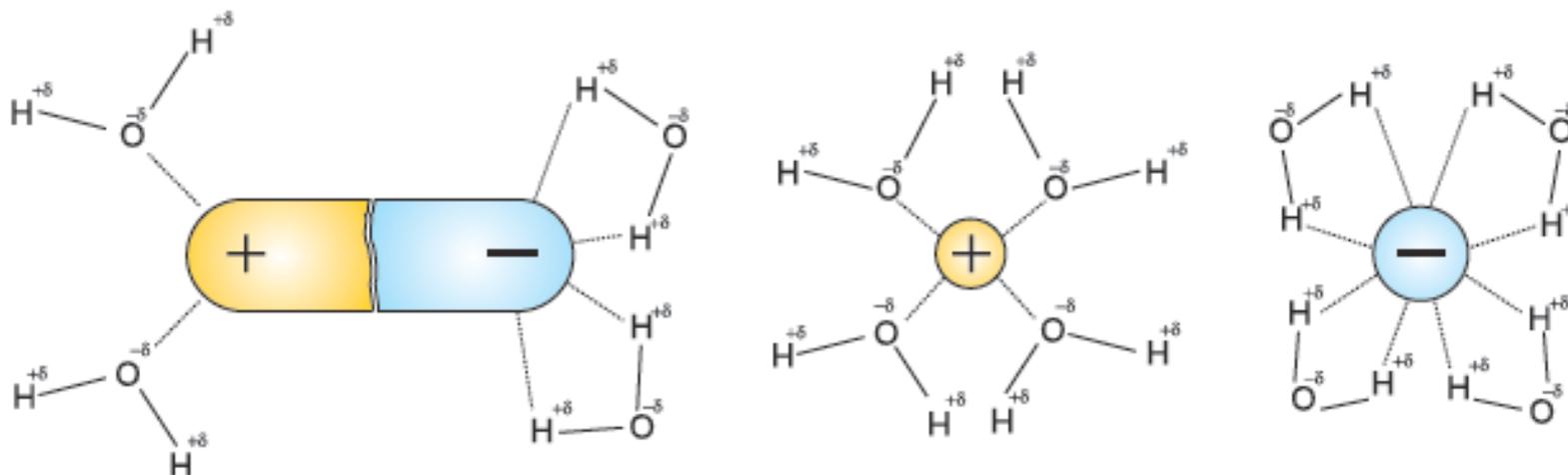


Fig. 15.1 Dissolving process of a polar substance in water.

Extensive hydrogen bonding ability

Water molecule is composed of oxygen and hydrogen atoms. Because of two O—H bonds and two lone pairs, one H_2O molecule can form hydrogen bonding with four other H_2O molecules, which are arranged tetrahedrally around the H_2O molecule as shown in Figure 15.2.

This unique behaviour of water enables it to dissolve many polar non-ionic compounds having hydroxyl group (-OH), like alcohols, organic acids, glucose, sugar, etc. by forming hydrogen bonds with them.

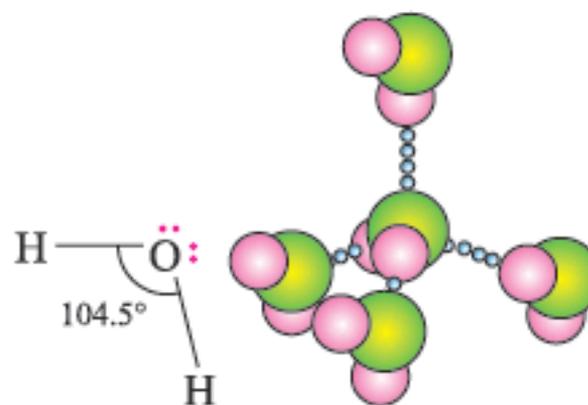


Fig. 15.2 Hydrogen bonding of water molecule.

Interesting Information



If you add a lump of caesium to water in a glass trough, the reaction is so vigorous that the trough will shatter into small pieces.

Animation 15.5: Hydrogen bonding of water molecule.

Source & Credit : elmhurst



Test yourself
15.1

Test Yourself 15.1

- i. What is capillary action ?
- ii. Point out two properties of water that make it an excellent solvent.
- iii. Why is the water molecule polar?
- iv. Explain why nonionic polar compounds are soluble in water?

15.3 SOFT AND HARD WATER

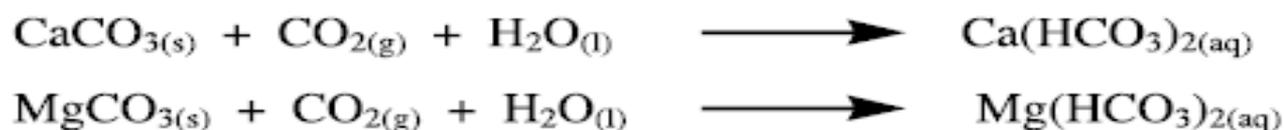
Soft water

Soft water is that water which produces good lather with soap.

Hard water

Hard water is that water which does not produce lather with soap. **Causes of hardness in water.**

The rain water while coming down absorbs carbon dioxide from the atmosphere. The water mixed with carbon dioxide, when passes through the beds of the soil, converts insoluble carbonates of calcium and magnesium into soluble bicarbonates. It may also dissolve chlorides and sulphates of calcium and magnesium. These salts make the water hard.

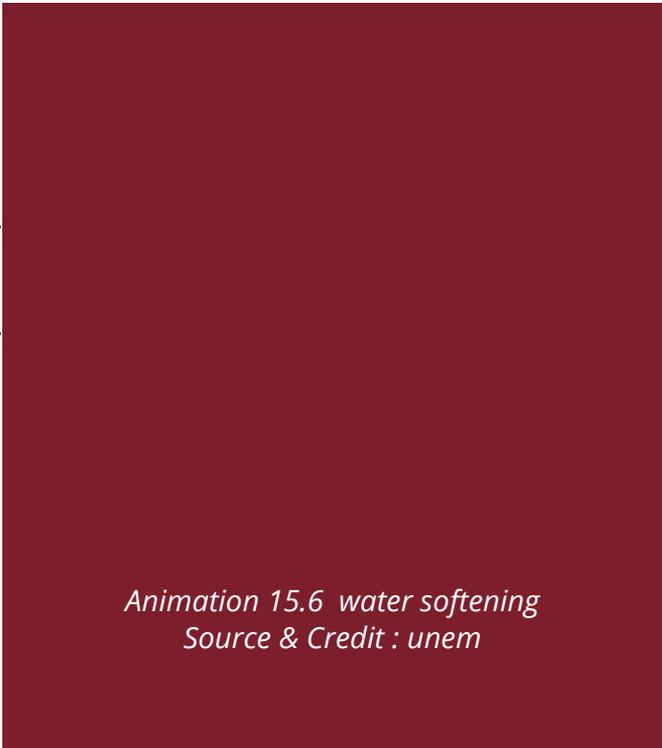


Thus, rain water dissolves many salts of divalent cations like Mg^{2+} , Ca^{2+} , and anions like Cl^- , SO_4^{2-} , HCO_3^- and CO_3^{2-} for example, gypsum ($CaSO_4 \cdot 2H_2O$) and limestone ($CaCO_3$). These salts make the water hard. Gypsum is sparingly soluble in water, while limestone is insoluble in water. However, in the presence of carbon dioxide small quantity of limestone is soluble in water according to the above chemical reaction.

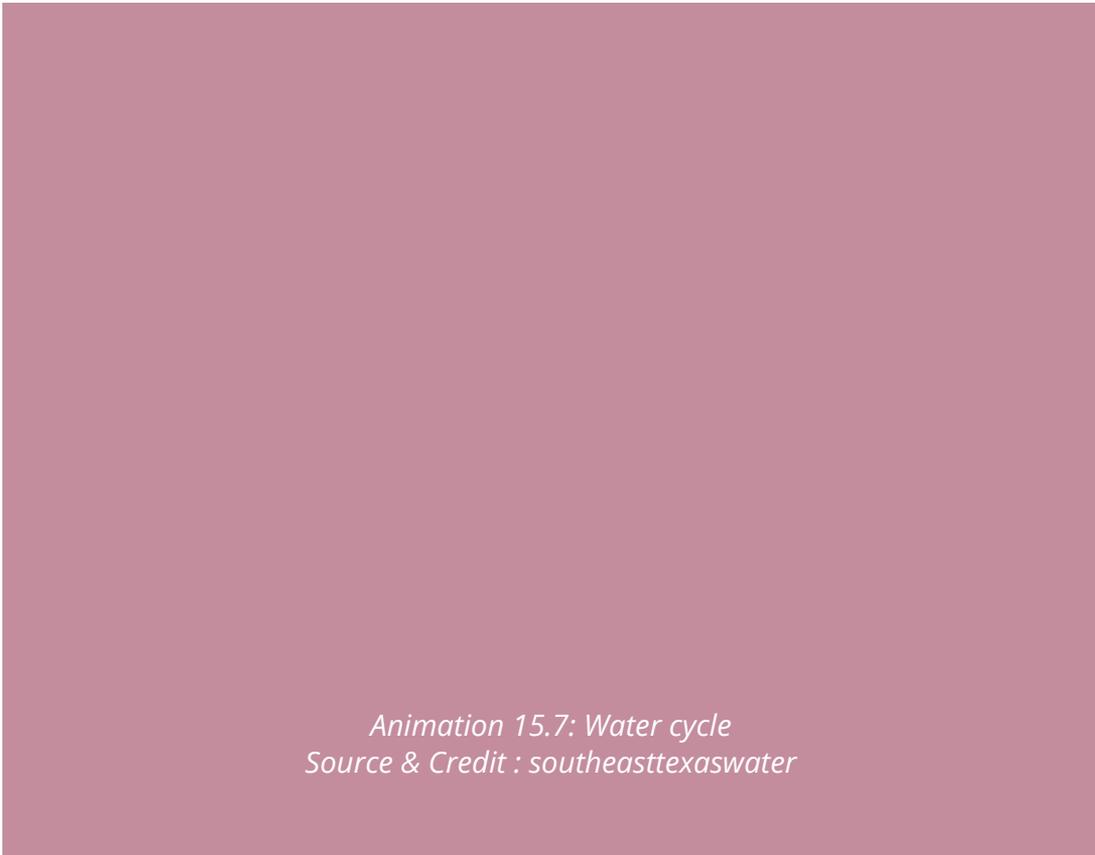
15.3.1 Types of Hardness of Water

Hardness is of two types:

- (i) *Temporary hardness is because of presence of bicarbonates of calcium and magnesium.*
- (ii) *Permanent hardness is because of presence of sulphates and chlorides of calcium and magnesium.*



*Animation 15.6 water softening
Source & Credit : unem*



*Animation 15.7: Water cycle
Source & Credit : southeasttexaswater*

15.3.2 Method of Removing Hardness

The removal of Mg^{2+} and Ca^{2+} ions which are responsible for the hardness is called water softening.

(i) Removal of temporary hardness

(a) By boiling

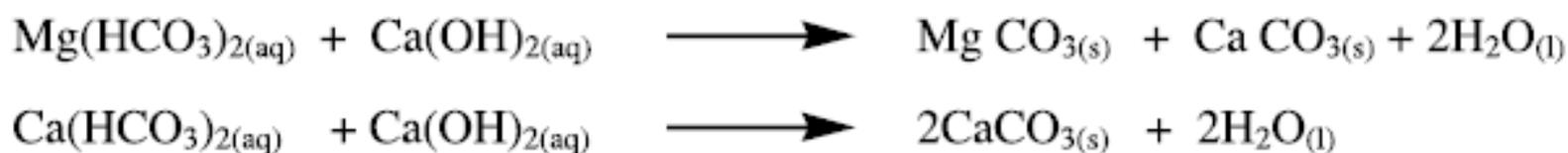
Temporary hardness of water is easily removed by boiling the water. On boiling, calcium bicarbonate $Ca(HCO_3)_2$ decomposes to produce insoluble calcium carbonate, which precipitates out of the solution.



(b) Clark's method

A chemical method to remove temporary hardness is by the addition of slaked lime $Ca(OH)_2$. A calculated amount of lime water is added to temporary hard water.

Thus, once the magnesium and calcium ions precipitate out water becomes soft.



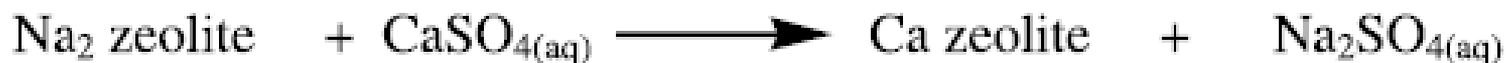
(ii) Removal of permanent hardness

Permanent hardness can only be removed by using chemicals. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) are removed as insoluble salts by adding washing soda (Na_2CO_3) or sodium zeolite.

(a) *By using washing soda:* The addition of washing soda removes the calcium and magnesium ions as the insoluble calcium and magnesium carbonates, respectively.



b) Using **Sodium Zeolite** (an ion Exchanger) Sodium zeolite is a naturally occurring resin of sodium aluminium silicate $\text{NaAl}(\text{SiO}_3)_2$, which can also be prepared artificially. It is used for softening of water at domestic as well as on industrial scale.



When water is passed through resin, sodium ions of the resin are exchanged with the unwanted

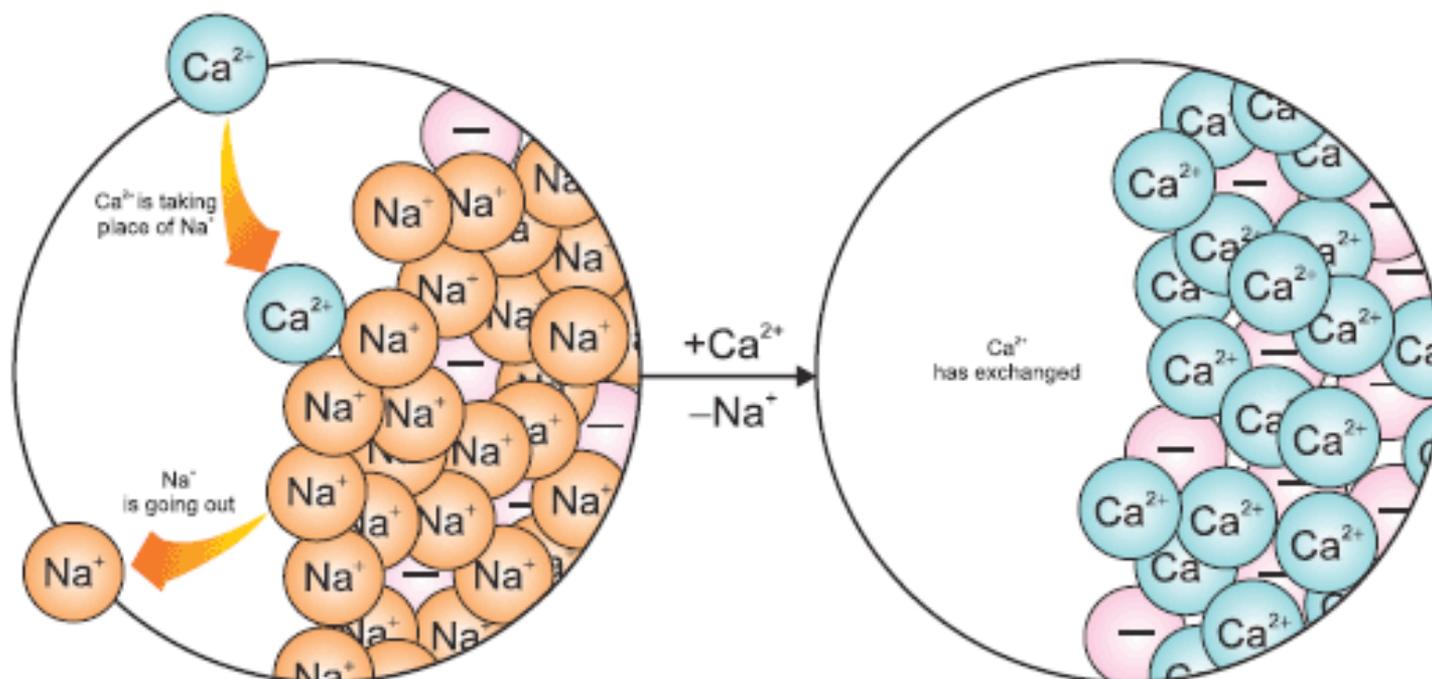


Fig. 15.3 Ion exchange for removal of hard water ions

calcium and magnesium ions of the hard water as shown in figure 15.3.



When resin is fully used up it can be regenerated by flushing it with concentrated solution of NaCl . The reverse process takes place because of high concentration of sodium ions.

Disadvantages of Hard Water

- (i) Hard water consumes large amount of soap in washing purposes.
- (ii) Drinking hard water causes stomach disorders.
- (iii) Hard water is unfit for use in steam engines, boilers and turbines because insoluble calcium and magnesium salts deposit inside. They are called scales. They are bad conductors of heat and hence more fuel is used. Insoluble calcium and magnesium sulphates not only reduce the efficiency of the engine but also cause the boiler to burst.



Test yourself
15.2

Test Yourself 15.2

- i. Which salts are responsible for hardness of water?
- ii. Explain the chemistry of removing the temporary hardness by boiling water.
- iii. What is the principle of removing permanent hardness of water?
- iv. How does addition of Na_2CO_3 remove permanent hardness of water?
- v. How does sodium zeolite soften water?
- vi. What do you mean by boiler scales? How are they removed?



Hard water hampers the cleaning action of soap.

Soap is the sodium salt of a long chain carboxylic acid (fatty acid). Hard water contains salts of magnesium and calcium. These ions react with the soap molecule to form an insoluble precipitate of calcium and magnesium salts of fatty acids called scum. As a result, a large amount of soap is wasted in scum formation. Thus, it reduces the efficiency of soap.

15.4 WATER POLLUTION

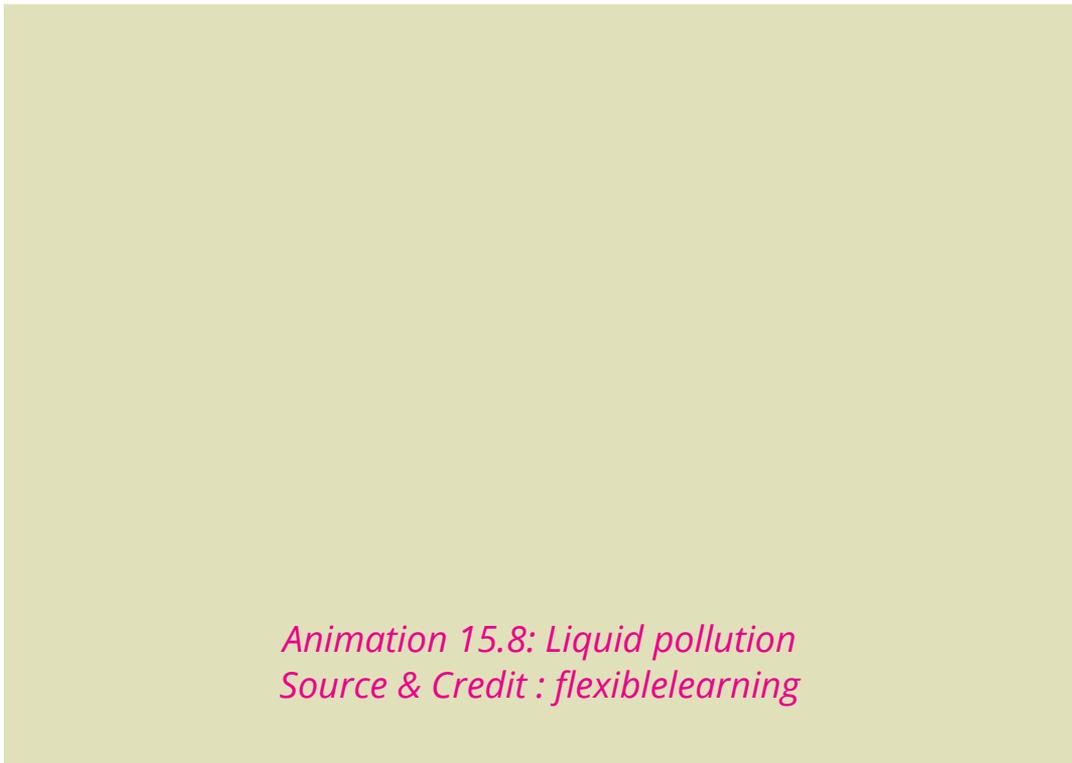
Water pollution is a contamination of water bodies (e.g. lakes, rivers, oceans and ground water). Water pollution occurs when pollutants are discharged directly or indirectly into water bodies without adequate treatment to remove harmful compounds.

Industrial Effluents

Industrial units are installed to produce the desired substances (chemicals, cloth, leather goods, paper, plastic items, petrochemicals and rubber items) on commercial scale to meet the needs of the society. But unfortunately all the industrial units discharge their wastes (*chemicals and solid materials*) either to open ground or to water channels. *This is called **industrial effluent**. The industrial effluent may be highly toxic organic chemicals, inorganic salts, heavy metals, mineral acids, oil and greases, etc.* On the other hand, water used as cleaning agent in industries is directly discharged out. This water contains all kinds of toxic chemicals and detergents.

When these effluents and used water enter lakes, streams, rivers or oceans, they either get dissolved or float suspended in water. Even they get deposited on the bed. This results in the pollution of water, i.e.

1. They deteriorate the quality of water.
2. They reduce the quantity of dissolved oxygen which ultimately affects aquatic life and ecosystem



*Animation 15.8: Liquid pollution
Source & Credit : flexiblelearning*

3. They can also seep down and affect the groundwater deposits. They contaminate the water deposits. When this water is used by human beings, it causes serious diseases like cancer and gastro. This polluted water damages soil, crops, plants and animals.
4. Heavy metals like cadmium, lead and mercury are toxic and health hazards for human beings. Acute cadmium poisoning causes high blood pressure, kidney damage and destruction of red blood cells. Acute lead poisoning causes dysfunction of kidneys, liver, brain, central nervous system and reproductive system. Mercury poisoning causes neurological damage.

Domestic Effluents

Use of detergents is increasing day by day for cleaning purposes in houses and industries. It is because, detergents have strong cleaning action than that of soap even in hard water. They can work even in acidic solutions. But they have a major disadvantage over the soaps, as some of the detergents are non-biodegradable (cannot be decomposed by microorganisms like bacteria). When household water containing these detergents is discharged in streams, ponds, lakes and rivers, it causes water pollution.

The detergent remains in the water for a long time and makes the water unfit for aquatic life. The phosphate salts present in detergents cause rapid growth of algae in water bodies, which floats over the surface of water. These plants ultimately die and decay. Decaying plants being biodegradable consume oxygen gas present in water. Thus, depletion of oxygen gas results in death of aquatic life.

Domestic sewage contains a wide variety of dissolved and suspended impurities. They include food and vegetable waste, garbage, cans, bottles, chemical soaps, washing powder, etc. It also contains disease causing microbes. All these substances add to water pollution.

Agricultural Effluents

Water pollution due to agricultural waste is because of use of fertilizers and pesticides. Fertilizers are used to make up the deficiency of nitrogen, phosphorus, etc. of the soil because of intensive cultivation of crops in the recent years.

On the other hand, pesticides are used either directly to kill or control the growth of pests. Pests may be weeds, herbs, insects, fungi, viruses, etc. They all damage crops and transmit diseases both to human beings and animals.

Agricultural effluents have dual effects:

1. Intensive cultivation of crops causes these chemicals from fertilizers and pesticides to seep into the groundwater commonly called leaching process. The high nitrate contents in ground water is mainly because of irrigation run-off from agricultural fields.
2. Run-off from the agricultural land (where fertilizers and pesticides have been used) enters into ponds, streams or rivers. This water contains nitrate (NO_3^-) and phosphate (PO_4^{3-}) salts. These substances result in a rapid growth of algae, floating over the surface of water. They prevent the sunlight and air (oxygen) to reach upto aquatic life. When algae dies, bacteria consume oxygen of the water for decomposition of algae. As a result oxygen depletes in the water. Aquatic animals feel suffocation and ultimately die due to insufficient supply of oxygen.

Animation 15.9: water cycle
 Source & Credit : usgs

Effects of Water Pollution**Water pollution has the following effects:**

1. It is hazardous to human health. Drinking polluted water can cause cholera, typhoid and diarrhea.
2. The use of polluted water is not only devastating for people but also for animals and birds.
3. It causes rapid growth of algae. Death and decomposition of algae causes deficiency of oxygen in water that affects organism living in water.
4. It is damaging aquatic life, thus breaking a link in food chain.
5. It reduces the aesthetic quality of lakes and rivers.
6. It is unfit for cleaning or washing purposes.



Test yourself
15.3

- What is an industrial waste?*
- How does water use as a cleaning agent in industries causes pollution?*
- Why is the use of detergents increasing day by day?*
- How decaying plants consume oxygen?*
- What is the function of fertilizers?*
- How do the pesticides cause water pollution?*

15.5 WATERBORNE INFECTIOUS DISEASES

Diseases that spread because of drinking polluted water or eating food prepared with polluted water are called waterborne infectious diseases. Water pollution may be due to toxins or microorganisms. Toxins are arsenic, mercury, calcium, lead and many organic chemicals. Microorganisms are viruses, bacteria, protozoa and worms.

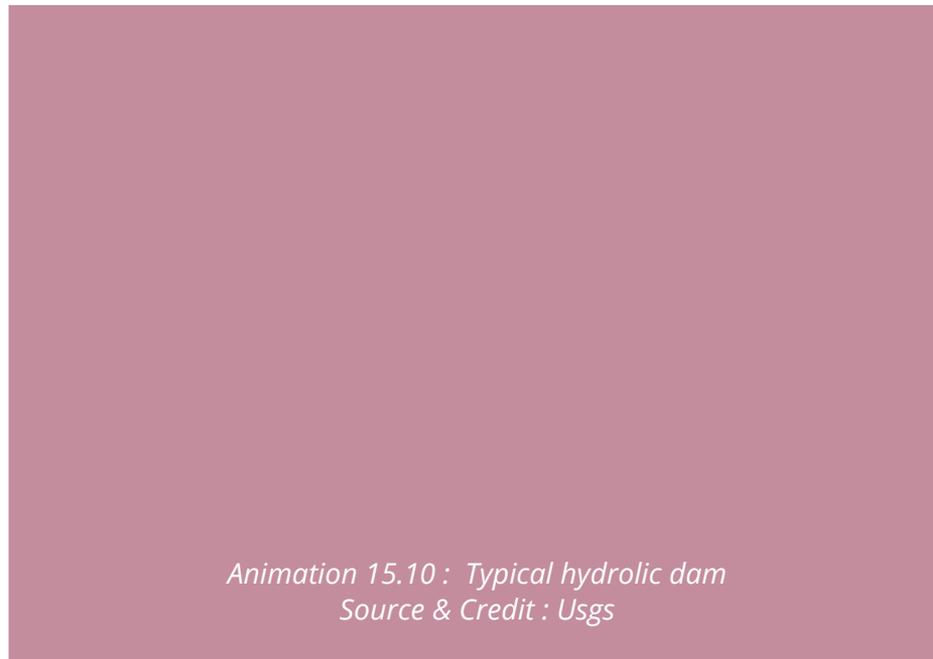
Lack of proper sanitation facilities is the main cause of rapidly spreading waterborne diseases. A few common diseases are mentioned here:

(i) Diarrheal diseases

Intestinal diseases, such as cholera, that may cause dangerous dehydration. Diarrhea may be caused by viruses, bacteria or parasites.

(ii) Dysentery

Dysentery is an intestinal disease which is typically caused by certain bacteria or parasites. It is characterized by severe diarrhea that may be accompanied by blood or mucous.



(iii) Cholera

Cholera is an acute infection caused by the bacteria *Vibrios cholerae*, which may be found in water contaminated by human feces. Cholera causes severe diarrhea and can be fatal.

(iv) Cryptosporidium

Waterborne microorganism (protozoa) that causes gastrointestinal illness (cryptosporidiosis) including diarrhea and vomiting. These tiny pathogens are found in surface water sources like reservoirs, lakes and rivers.

(v) Fluorosis

Fluorosis is a disease caused by the consumption of excess fluoride. Fluorosis can cause bones and teeth damage.

(vi) Hepatitis

It is liver inflammation commonly caused by one of five viruses called hepatitis A, B, C, D, and E. Hepatitis A and E can be transmitted by contaminated water.

(vii) Hookworm

Hookworm is a parasitic worm that infects the small intestine. Severe cases can result in anemia and stunted growth in children. Hookworm larvae enter the body through the skin, often via the feet. Spread by poor sanitary conditions, hookworms infect about one billion people worldwide per annum.

(viii) Jaundice

Jaundice is caused by an excess of bile pigments in the blood. Liver ceases to function and eyes turn yellow. Patient feels weakness and fatigue.

(ix) Typhoid

A dangerous bacterial disease often spread by contaminated water or by food prepared with contaminated water.

Prevention of waterborne diseases

Waterborne diseases can be prevented by taking the following measures:

- (i) *Provision of safe water:* Drinking water must be properly treated and purified.
- (ii) *Disposal of sewage:* There must be adequate sanitary disposal of sewage. Any type of waste must not be thrown or discharged directly in water supplies or reservoirs.

(iii) Control of toxic chemicals: Chemical contamination can cause acute illness, but often toxic contaminants are slow poisons and carcinogens. There must be a strict control over the use of pesticides and other chemicals.



- i. Define water borne diseases
- ii. What is dysentery?
- iii. Which bacteria causes the cholera?
- iv. What do you mean by fluorosis?
- v. What is hepatitis?

Chemistry of swimming pool cleanliness

Swimming pools are cleaned by chlorination process. It is the addition of chlorine solution in swimming pools. Chlorine kills bacteria and other microorganisms. Cl_2 itself does not kill rather it dissociates in water to form hypochlorous acid (HOCl) and hydrochloric acid



HOCl further ionizes to produce hypochlorite and proton



Both the products HOCl and OCl kill bacteria and microorganisms



Key Points

- Water is an excellent solvent, has high specific heat capacity, high surface tension and high capillary action.
- Water is universal solvent because of its polarity and hydrogen bonding ability.
- Soft water produces lather with soap.
- Hard water does not produce lather with soap.
- Hardness is of two types: temporary and permanent.
- Temporary hardness is because of bicarbonates of calcium and magnesium. This hardness can be removed by boiling or by addition of slaked lime ($Ca(OH)_2$) in water.
- Permanent hardness is because of presence of carbonates and sulphates of calcium and magnesium. This hardness can be removed by treating water with washing soda and sodium zeolite.
- Used water is called waste water or sewage.
- Water pollution is caused by affecting water quality by pollutants.
- Industrial effluents are one of the main causes of water pollution. It includes high toxic organic chemicals, inorganic salts, heavy metals, mineral acids, oil and greases, etc.

- Household water in the sewage from toilets, baths, kitchens, etc. consists of detergents used for cleaning purposes. Detergent being non-biodegradable causes rapid growth of aquatic plants. When these plants die and decay, they consume O_2 present in the water. Thus, aquatic life is badly affected because of scarcity of O_2 .
- Agricultural effluents consist of fertilizers and pesticides. These substances provide nitrate and phosphate ions for rapid growth of aquatic plants. When these plants die and decay, their decomposition process consumes O_2 of water. Thus, depletion of O_2 causes damage to the aquatic life.
- Waterborne diseases are those diseases that spread because of drinking polluted water. These diseases spread because of lack of proper sanitation arrangements. These diseases can be prevented by using safe water, properly disposing sewage and controlled use of toxic chemicals

SKILLS:

Quality of Water

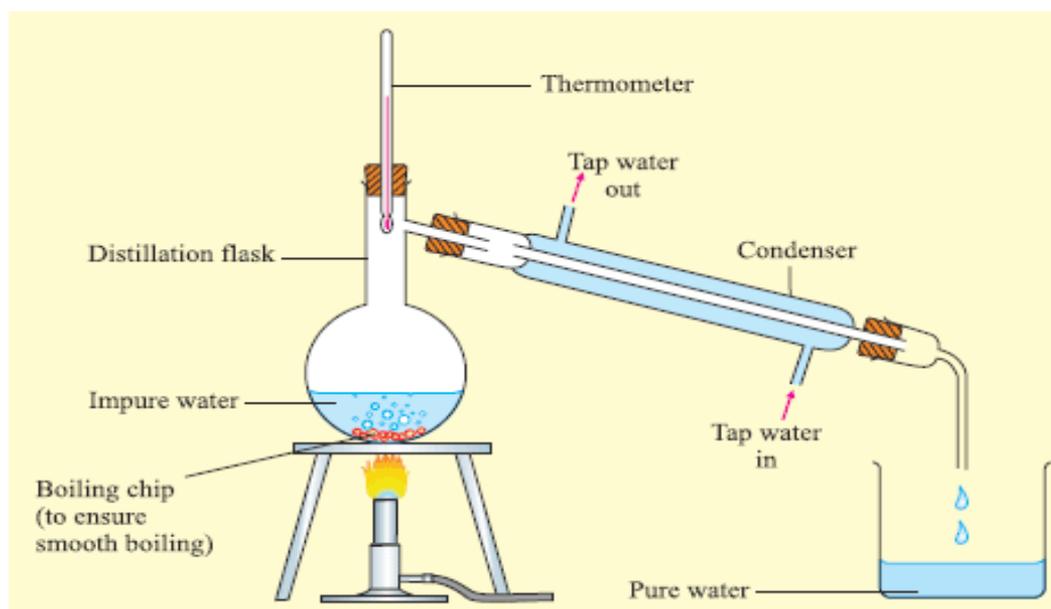
Good quality water is colourless, odourless and tasteless. Hardness of water can be checked by washing. Soft water produces lather with water. Pure water has least conductivity.

Boiling point of water

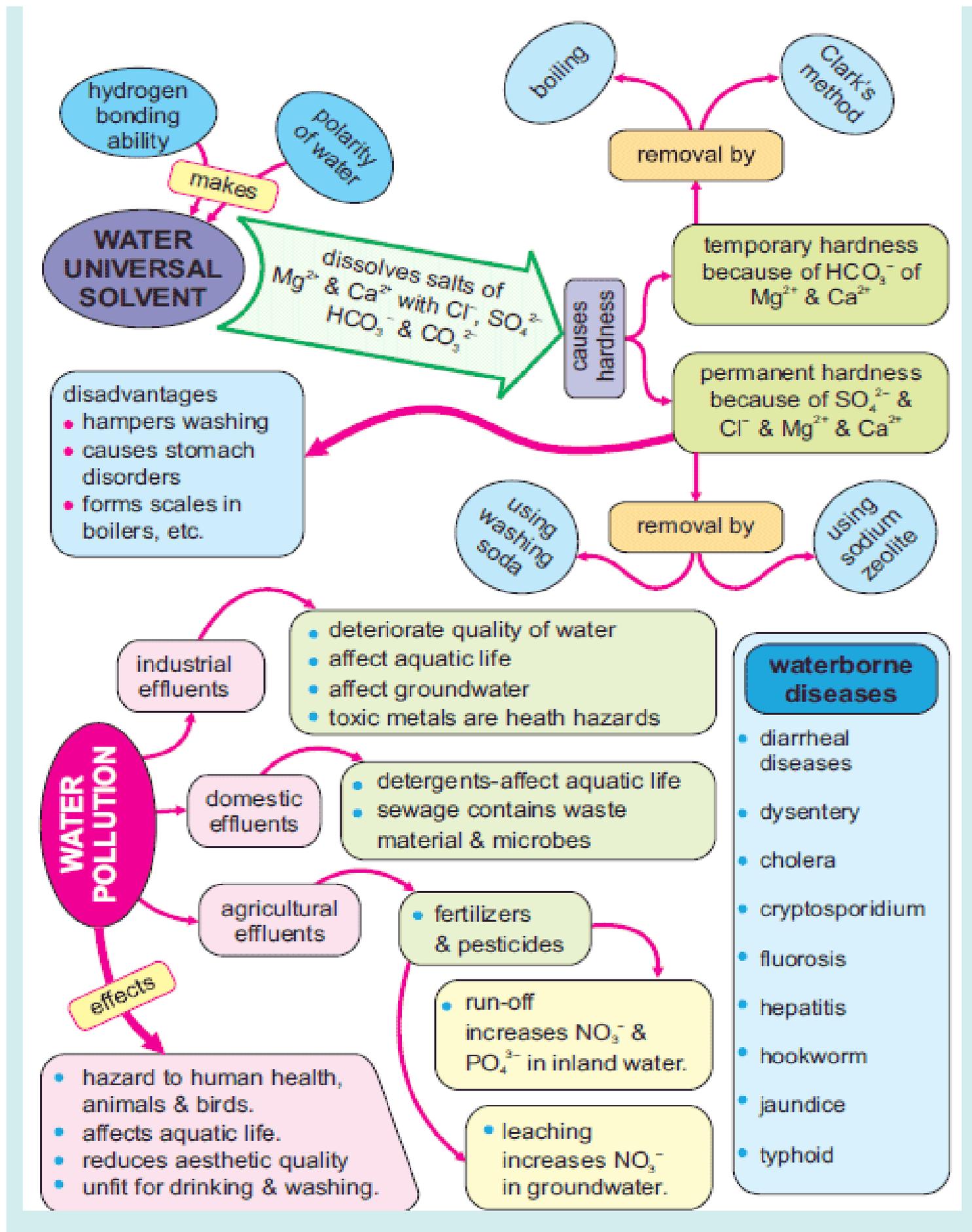
Water boils at 100°C .

Distillation of impure water

Impure water can be purified by simple distillation apparatus as shown in figure. Distillation process involves boiling of a liquid and then condensing the vapours.



Impure water is taken in a distillation flask. It is boiled. Water vapours rise and enter the condenser. The vapours condense while passing through condenser. Thus, they are changed back into pure water, which is called distillate (distilled water). The distillate is collected in a beaker. The impurities remain behind in the distillation flask.



Short Questions

1. How water rises in plants?
2. Which forces are responsible for dissolving polar substances in water?
3. Why are non-polar compounds insoluble in water?
4. How does water dissolve sugar and alcohol?
5. How does limestone dissolve in water?
6. Differentiate between soft and hard water.
7. What are the causes of hardness in water?
8. What are the effects of temporary hardness in water?
9. Mention the disadvantages of detergents.
10. What is the difference between biodegradable and non-biodegradable substances?
11. How detergents make the water unfit for aquatic life?
12. Why are pesticides used?
13. What are the reasons of waterborne diseases?
14. How waterborne diseases can be prevented?

Extensive Questions

1. How polarity of water molecule plays its role to dissolve the substances?
2. Explain the methods of removing permanent hardness.
3. Explain the water pollution because of industrial waste.
4. Justify the statement: household water is the reason of water pollution.
5. Explain that agricultural effluents are fatal for aquatic life.
6. Explain five important waterborne diseases. How can these be prevented?
7. Give some disadvantages of hard water.
8. What is water pollution? Describe the effects of using polluted water.
9. Explain the reasons, why water is considered a universal solvent.
10. Write a note on the treatment of sewage water.