# Hard water

Hard water: is water which does not form lather easily with soap. This is due to formation of insoluble precipitate when soap molecules react with calcium or magnesium ions in water. The insoluble precipitates are called scum.

How does water become hard?
Rain dissolve carbon dioxide as it falls and form very dilute carbonic acid

$H_2O_{(l)} + CO_{2(g)} \leftrightarrow H_2CO_{3(aq)}$

If this water passes through rocks containing calcium carbonate or magnesium carbonate, the carbonates dissolves to form hydrogen carbonate forming temporary hard water.

$CaCO_{3(s)} + H_2CO_{3(aq)} \rightarrow Ca(HCO_3)_{2(aq)}$

$MgCO_{3(s)} + H_2CO_{3(aq)} \leftrightarrow Mg(HCO_3)_{2(aq)}$

If rain water passes through the rocks containing calcium or magnesium sulphate, the sulphates dissolves in water forming permanently hard water.

NB; calcium sulphate-2-water naturally occurs as gypsum '$CaSO_4.7H_20$'

**Types of water hardness**

**Temporally hardness**: this is caused by presence of calcium hydrogen carbonate or magnesium hydrogen carbonate

**Removal of temporally hardness.**

1) **Boiling:** decomposes the soluble calcium hydrogen carbonate to insoluble calcium carbonate

   $Ca(HCO_3)_{2(aq)} \rightarrow CaCO_{3(s)} + H_2O_{(l)} + CO_{2(g)}$

   After boiling, water is filtered to remove the insoluble carbonate.

   N.B: boiling removes only temporally hardness.

2) **Addition of lime water**: calculated amount calcium hydroxide solution precipitates all the calcium and magnesium ions as calcium or magnesium carbonates.

   $Ca(OH)_{2(aq)} + Ca(HCO_3)_{2(aq)} \rightarrow CaCO_{3(s)} + H_2O_{(l)}$

   $Mg(OH)_{2(aq)} + Mg(HCO_3)_{2(aq)} \rightarrow MgCO_{3(s)} + H_2O_{(l)}$

3) Addition of sodium carbonate (washing soda): sodium carbonate precipitates all the calcium ions / magnesium ions as calcium carbonate or magnesium carbonate, which can be filtered

$Ca(HCO_3)_{2(aq)} + Na_2CO_{3\,(aq)} \rightarrow CaCO_{3(s)} + 2NaHCO_{3\,(aq)}$

$Mg(HCO_3)_{2(aq)} + Na_2CO_{3\,(aq)} \rightarrow MgCO_{3(s)} + 2NaHCO_{3\,(aq)}$

Permanent hardness: this is caused by the presence of calcium sulphate or magnesium sulphate.

Removal of permanent hardness

i. Addition of sodium carbonate (washing soda): sodium carbonate precipitates all the calcium ions as calcium carbonate, which can be filtered.

$CaSO_{4\,(aq)} + Na_2CO_{3(aq)} \rightarrow CaCO_{3(s)} + Na_2SO_{4\,(aq)}$

ii. Distillation: this process removes all the types of hardness; it is expensive to distil large amount of water.

iii. Ion exchange: this method is used for softening water on a large scale. In this method the hard water containing calcium and magnesium ions is passed through Permutt (sodium aluminium silicate) NaY. As it does so, ion exchange occurs, that is, calcium ions are exchanged with sodium ions.

$CaSO_{4\,(aq)} + Na_2Y_{\,(aq)} \rightarrow CaY_{(s)} + Na_2SO_{4\,(aq)}$

## Soap

Soap is soluble sodium or potassium stearate.

**To prepare soap**

- Mix sodium hydroxide (about $10cm^3$ of is 5M) with castor oil (about $2cm^3$).
- Warm to boiling, and stir with a glass rod while it is boiling gently for 5-10 minutes.
- The soap remains in solution.
- Add saturated sodium chloride solution, boil gently and stir for further 2min and allow to cool. Soap is insoluble in sodium chloride. Filter off the solid soap.

Fat + alkali → soap + glycerine

i.e. glycerol stearate + sodium hydroxide → sodium stearate + glycerine

**Manufacture of soap on large scale:**

Oil and fats (coconut oil, palm oil, mutton fat, fats made by hydrogenation of oil, etc.) are heated by steam with sodium or potassium hydroxide. Sodium chloride is added to separate the soap as an upper layer (the 'salting out' of soap). Potassium hydroxide forms soft soap. The glycerine or glycerol is obtained by distillation.

NB: the process of manufacturing of soap is called **saponification.**

**Action of soap with hard water**

When soap is added to hard water containing calcium or magnesium salts. It first precipitates calcium or magnesium stearate as **scum**. (***SCUM:*** *is the milky substance formed when soap reacts with hard water*) and no lather is formed until the entire calcium ion or magnesium ions are removed.

$2Nast_{(aq)} + CaSO_{4\,(aq)} \rightarrow Na_2SO_{4\,(aq)} + Cast_{(s)}$

(Scum)

**Detergents:** is any substance that facilitates the emulsification and removal of grease. Soap is a detergent, but the name is usually used for synthetic substituent of soap.

**Advantages of detergents:**

- Synthetic detergents are more soluble in water than soap.
- Synthetic detergents do not form scum with hard water unlike soap.

**Disadvantages of detergents.**

- Detergents are non-biodegradable i.e. cannot be decomposed /acted on by bacteria. (Soap is bio gradable). Therefore, synthetic detergents can pollute rivers, lakes or seas more than soap.
- Detergents are expensive.

**Disadvantages of hard water.**

Wastes soap: hard water needs much soap to form leather.

- With hard water, soap form scum, this makes / leaves dirt marks on clothes.
- Hard water form boiler scale inside the boiler tube and fur in kettles which is band conductor of heat and therefore wastes fuel.

**Advantages of hard water.**

- Hard water contains calcium used in formation of animal shells, teeth and bones.

*Water pipe; lead pipes cannot be used with soft water because soft water dissolves some lead, which is poison. Hard water forms a coating of lead carbonate and sulphate which prevents it from reacting.*

## Pollution

This is the addition of a substances or energy which is potentially harmful to life, to the environment at a rate higher than the environment can accommodate.

**Types of pollution.**

- Air pollution: is produced mainly by:
  i. Power and generating plants: fuel and coal used in power generating plants contain sulphur and when burnt, sulphur is oxidised to sulphur dioxide and sulphur trioxide.

$S_{(s)} + O_{2\,(g)} \rightarrow SO_{2\,(g)}$

$2SO_{2\,(g)} + O_{2\,(g)} \rightarrow 2SO_{2\,(g)}$

ii. Motor vehicles: fumes from the car exhaust contains; carbon dioxide carbon monoxide, water vapour, soot, nitrogen oxides, lead compounds and un burnt carbon

iii. Industrial processes: they emit into the air various pollutants e.g. paper making process use sulphides and emit hydrogen sulphide.

- Water pollution

Streams, rivers and lakes may be polluted by sewage, fertilizers, oil and hot water.

- Sewage: is the product formed when waste matter enters water. Sewage originates mainly from domestic and industrial sources. Untreated sewage may contain organisms which cause diseases such as cholera and typhoid.

- Treatment of sewage:

Sewage is first passed through screens to remove large solid particles such as wood, plastics and rugs. Then sewage is passed through a chamber where inorganic or mineral matter such as sand and gravel are made to settle. This is called **primary treatment.** An effluent from Primary treatment is passed to **secondary treatment** process. Here the effluent is brought into contact with oxygen and aerobic microorganisms. The metabolic activities of these organisms break down organic matter to harmless substances such as carbon dioxide and water. The product from secondary treatment is chlorinated to reduce the content of bacteria, the effluent is released into a river. The solid left after sewage treatment is called **sludge** and can be used as **organic manure and fuel.**

- Oil pollution: comes from ships, engine oil from motor vehicle. It prevents oxygen from entering the water. This leads to death of Fish and other aquatic organisms that use oxygen.

- Fertilizer: fertilizer contains mainly nitrate and phosphorus which when leached into rivers and lakes cause **EUTROPHICATION** (over growth of algae). When the algae die the bacteria responsible for the decaying process use a lot of oxygen, hence depletes oxygen leading to death of fish.

- Hot water: hot water from power station raises the temperature of water reducing its ability to dissolve oxygen. It also causes high temperatures in aquatic organisms blocking their enzymes from functioning properly.

**Water treatment/purification**

Water treatment is any process that improves the quality of water to make it appropriate for a specific end-use.

The process of removing pollutants from water involves the following stages:

- Filtration: impure water is first passed through screens to filter out floating debris. It is then passed through courses of sand filter to remove large insoluble particles. The sand also contains microbes which remove some of the bacteria.

- Sedimentation: water obtained after filtration is not pure enough, it contains fine particles that must be removed. This is done by adding powdered potash alum (potassium aluminium sulphate) to water. The addition of alum coagulate/ precipitate

thin/fine particles and settle at the bottom of the container. This method is called sedimentation. These particles are removed by further filtration through fine sand.

- Chlorination: the clear liquid or water obtained after sedimentation may contain harmful bacteria. Adding recommended quantities of chlorine to the water kills these bacteria.

$H_2O$ (s) + $Cl_2$(g) → HOCl (aq) + HCl (aq)

- pH adjustment:

Addition of chlorine to water lowers its pH which is corrected by adding sodium carbonate (soda ash).

HOCl (aq) + $Na_2CO_3$ (aq) → NaCl (aq) + $CO_2$ (g)

HCl (aq) + $Na_2CO_3$ (aq) → NaCl (aq) + $CO_2$ (g)

EXERCISE

The table below shows results obtained when soap was added to $10cm^3$ of water samples P, Q and R in separate containers.

| | Before boiling | | | After boiling | | |
|---|---|---|---|---|---|---|
| Sample of water | P | Q | R | P | Q | R |
| Volume of soap required to form leather | 2 | 8 | 5 | 2 | 8 | 3 |

a. Identify which sample was temporary hard water (Give reasons for your answer)
b. Name one substance which can cause permanent hardness in water.
c. Name one disadvantage of using hardwater.
d. Name one substance that causes temporary hardness in water.
e. Write an equation to show that permutit ($Na_2Y$) removes permanent harness of water. State the principle on which it works.

**Exercise**

1. Which of the following method can be used to remove only temporary hardness of water?
   A. Boiling
   B. Distillation
   C. Ion exchange
   D. Addition of sodium carbonate
2. Potassium aluminium sulphate is used in the purification of water for
   A. Removing colouring matter
   B. Killing harmful bacteria
   C. Removing suspended matter
   D. Softening water
3. The compound which does not cause hardness of water is
   A. Calcium hydrogen carbonates
   B. Calcium sulphate
   C. Sodium carbonate
   D Magnesium sulphate

Question 5 consist of an assertion (statement) on the left hand side and a reason on the right hand side.

Select

A. If both assertion and reason are true statements and the reason is a correct explanation of the assertion.
B. If both assertion and reason are true statements and the reason is **not** a correct explanation of the assertion
C. If the assertion is true but the reason is not correct statement.
D. If the assertion is not correct but the reason is a correct statement.

Instruction summarized

| Assertion | |
|---|---|
| **A. True** | **True and a correct explanation** |
| **B. True** | **True but not a correct explanation** |
| **C. True** | **Incorrect** |
| **D. Incorrect** | **Correct** |

| | | | |
|---|---|---|---|
| 4. | Permutt is used for removing temporary and permanent hardness of water | Because | Ions in permanent and temporary hard water can be separated by ion-exchange method |

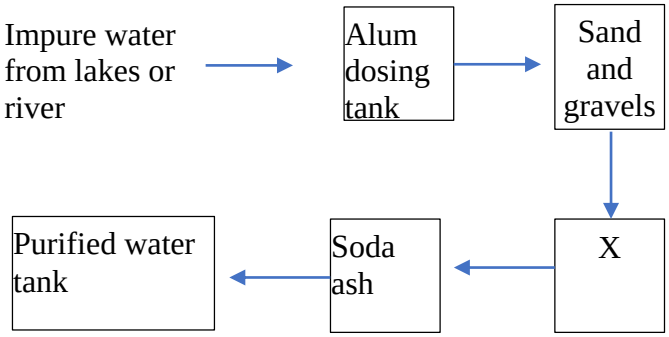
In each of the questions 6 to 9 one or more of the answers given may be correct. Read each questions carefully and then indicate the correct answer according to the following

A. If 1, 2, 3, only are correct
B. If 1 and 3 only are correct
C. If 2 and 4 only are correct
D. If 4 only is correct

5. Which of the following salts dissolved in water cause(s) hardness in water?
   1. Ammonium nitrate
   2. Calcium sulphate
   3. Potassium chloride
   4. Magnesium hydrogen carbonate
6. Which of the following substances can cause water pollution?
   1. Insecticide
   2. Fertilizers
   3. Detergents
   4. Carbon monoxide
7. Which of the following usually cause(s) water pollution?
   1. Calcium hydrogen carbonate
   2. Phosphate detergent
   3. Magnesium sulphate
   4. sewage
8. Which of the following gases is/are produced by sewage?
   1. Nitrogen
   2. Ammonia
   3. Ethene
   4 Methane

Section B
Answer correctly

| | | | | |
|---|---|---|---|---|
| 9 | (a) | | What is meant by the term water pollution? | (2marks) |
| | (b) | (i) | Name two substances that can cause water pollution | (1mark) |
| | | (ii) | Describe how each of the substances you named in (b)(i) above can cause water pollution | (3marks) |
| | (c) | | The flow diagram shows the general scheme used in water purification | |




| | | | | |
|---|---|---|---|---|
| | | (i) | State the purpose of the alum dosing and the sand and gravels | (2marks) |
| | | (ii) | Identify X and state its purpose | (2marks) |
| | | (iii) | State the role of soda ash | (2marks) |
| | | (iv) | Write equation to show the role of soda ash | (3marks) |
| 10 | (a) | | State the difference between fats and oils | |
| | (b) | | Fats and oils can be used to make soap | |
| | | (i) | Define the term soap | (2marks) |
| | | (ii) | Briefly describe how soap can be prepared | (3marks) |
| | (c) | (i) | Name two substances which when present in water can cause permanent hardness of water | (2marks) |
| | | (ii) | State one chemical method of removing permanent hardness of water | (1mark) |
| | | (iii) | Write equation for the reaction involved in (c)(i) above | (1 ½ mark) |

Answers

1. A 2. C 3. C 4. A 5. C 6. A 7. D 8. C

| | | | |
|---|---|---|---|
| 9. | (a) | | Water pollution is contamination of ware as a result of human activity |
| | (b) | (i) | - sewage<br>- detergents<br>- industrial effluent |
| | | (ii) | - Sewage introduces bacteria into the water<br>- Detergents adds nitrates and phosphates to water causing eutrophication<br>- Industrial effluents add toxic chemicals to water |
| | (c) | (i) | Alum remove suspended pesticide |
| | | (ii) | X is chlorine kills germs |
| | | (iii) | Soda ash adjusts pH |
| | | (iv) | $2H^+ (aq) + CO_3^{2-} (aq) \longrightarrow H_2O (l) + CO_2 (aq)$ |
| 10 | (a) | | Fats are solid at room temperature while oils are liquids |
| | (b) | (i) | Soap is sodium stearate |
| | | (ii) | Fat is boiled with concentrated sodium hydroxide. Concentrated sodium chloride solution is added to separate soap from the mixture. |
| | (c) | (i) | Calcium sulphate<br>Magnesium sulphate |
| | | (ii) | Soda ash |
| | | (iii) | $Ca^{2+} (aq) + CO_3^{2-} \longrightarrow CaCO_3 (s)$ |