Cleaning Capacity of Soap in Hard and Soft Water

Introduction

> Water is used for washing along with the soap. The effectiveness and cleansing action of soap depends on the type of water.

> **Soft water:** The type of water which produces lather with the soap is called soft water. Washing of clothes is very effective and easy in soft water.

> **Hard water:** The type of water which does not produce lather with the soap is called hard water. It contains dissolved salts in it. The soap forms scum with hard water and not fit for laundry purpose.

Types of Hard Water

> Temporary hard water contains dissolved hydrogen carbonate ions, HCO_3^-, of calcium and magnesium.

> **Removal of temporary hardness:** When water is heated, these ions decompose (break down) to form carbonate ions, CO_3^{2-}. The carbonate ions in the boiled water react with dissolved calcium and magnesium ions to form calcium carbonate and magnesium carbonate which is insoluble in water and can be removed by filtration. The residue is the insoluble calcium or magnesium carbonate and the filtrate is the soft water.

> **Equations:**

$$\underset{\text{Calcium bicarbonate}}{Ca(HCO_3)_2(aq)} \xrightarrow{\text{Boil}} \underset{\text{Calcium carbonate}}{CaCO_3(s)} + \underset{\text{Carbon dioxide}}{CO_2(g)} + \underset{\text{Water}}{H_2O(l)}$$

$$\underset{\text{Magnesium bicarbonate}}{Mg(HCO_3)_2(aq)} \xrightarrow{\text{Boil}} \underset{\text{Magnesium cabonate}}{MgCO_3(s)} + \underset{\text{Carbon dioxide}}{CO_2(g)} + \underset{\text{Water}}{H_2O(l)}$$

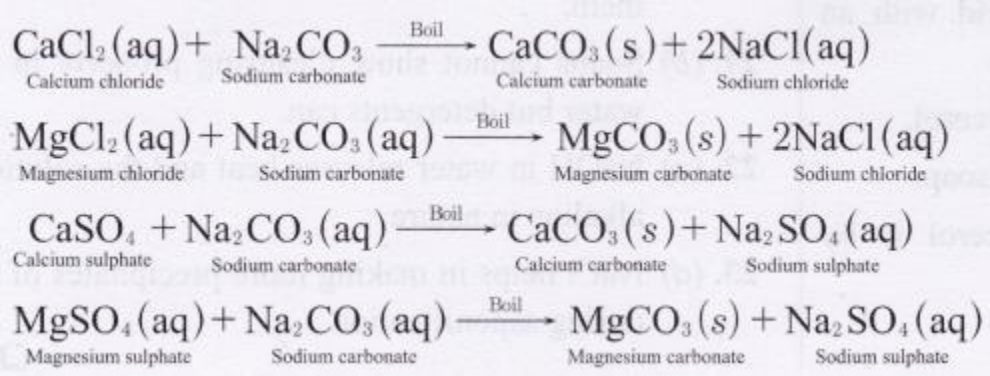
> Permanent hard water contains dissolved sulphate ions, (SO_4^{2-}) and chloride ions (Cl^-) of calcium and magnesium. These do not decompose when heated. The ions remain dissolved and do not react with calcium and magnesium ions so the water stays hard even when boiled.

> Soaps do not produce any lather with hard water.

> Removal of permanent hardness of water: The permanent hardness can be removed by boiling it with washing soda, i.e., sodium carbonate (Na_2CO_3)

> When the hard water is heated with sodium carbonate the double displacement reaction takes place. The insoluble calcium and magnesium carbonates are formed and can be removed by filtration.

> **Equations:**

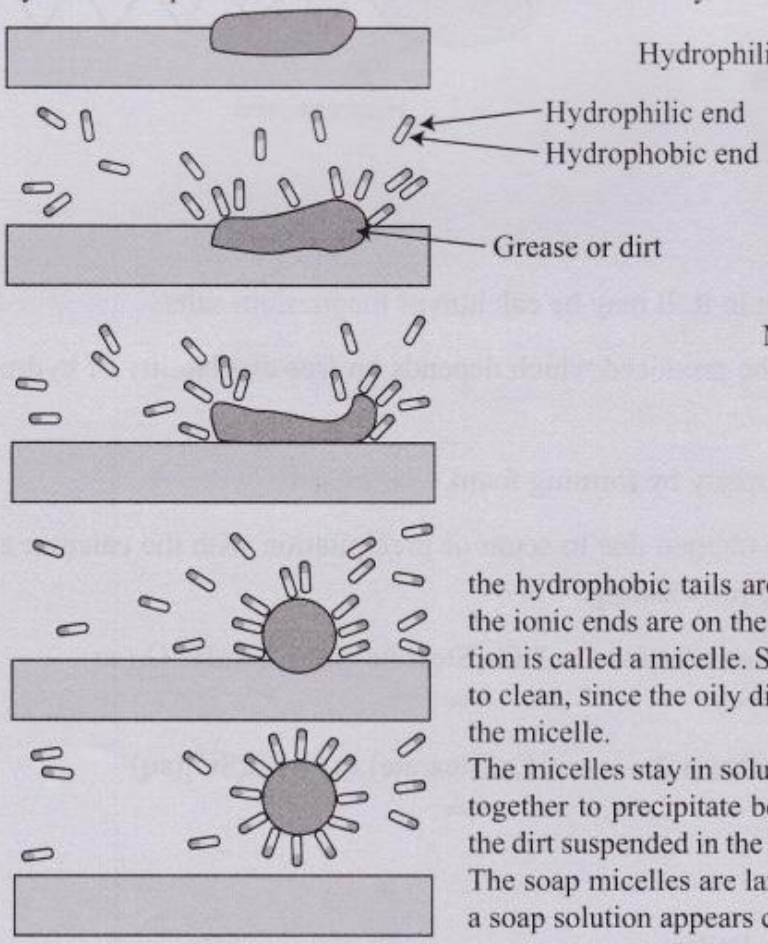


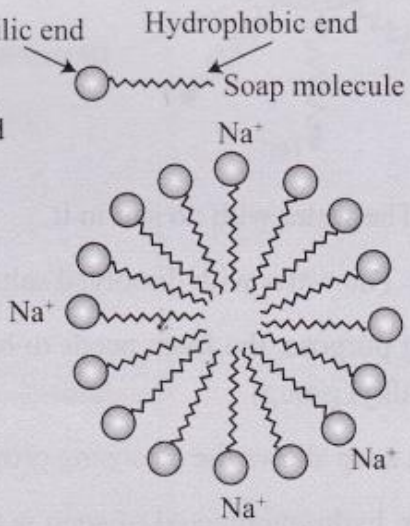
> Traditional soaps are ionic compounds which dissolve in water forming a long singly charged hydrocarbon negative ion (anion), which is balanced by a singly charged metal positive ion e.g. Na^+.
> Soap molecules have a hydrophilic 'head' ('water liking') and a hydrophobic 'tail' ('water hating').
> When you shake soap with an oily/greasy material (washing clothes or scrubbing a surface), the oil/grease breaks up into tiny droplets or globules and removed from the surface to which they were attached.
> The long 'hydrocarbon' hydrophobic tail of the soap dissolves in the oil or grease globule and the negative head is on the surface of the globules/droplets but in contact with water.
> The long 'hydrocarbon' hydrophobic tail can only interact at the molecular level with oil/grease. It is attracted to oil and grease.
> The 'ionic' hydrophilic head can only interact with water and forms weak bonds with water.
> Two negative hydrophilic heads cannot interact with each other and tend to repel each other, but strongly interact with water.
> The hydrophobic end takes the oil/grease with it and the hydrophilic end gets washed

away with the water carrying its tail which is hydrophobic along with the oil/grease.

Micelles

Soaps are molecules in which the two ends have differing properties, one is hydrophilic that is, it dissolves in water, while the other end is hydrophobic, that is, it dissolves in hydrocarbons. When soap is at the surface of water, the hydrophobic 'tail' of soap will not be soluble in water and the soap will align along the surface of water with the ionic end in water and the hydrocarbon 'tail' protruding out of water. Inside water, these molecules have a unique orientation that keeps the hydrocarbon portion out of the water. This is achieved by forming clusters of molecules in which





the hydrophobic tails are in the interior of the cluster and the ionic ends are on the surface of the cluster. This formation is called a micelle. Soap in the form of a micelle is able to clean, since the oily dirt will be collected in the centre of the micelle.

The micelles stay in solution as a colloid and will not come together to precipitate because of ion-ion repulsion. Thus, the dirt suspended in the micelles is also easily rinsed away. The soap micelles are large enough to scatter light. Hence, a soap solution appears cloudy.

Effect of soap in cleaning

Science Lab Manual Experiment – 7

Aim

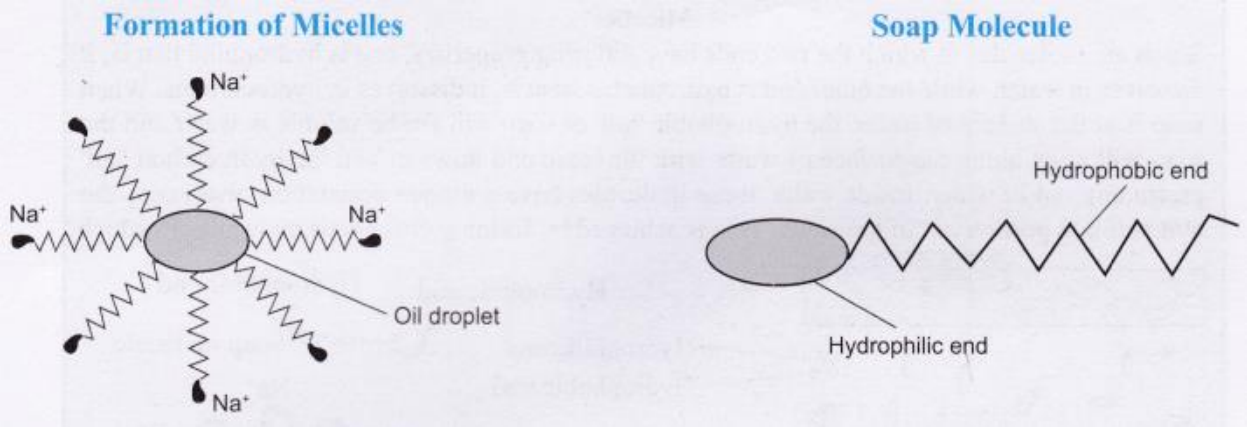
To study the comparative cleaning capacity of a sample of soap in soft and hard water.

Theory

> **Soap:** It is the sodium or potassium salt of long-chained carboxylic acids.

Cleansing Property of Soap

> Soaps when mixed in water its ionic end dissolves in water but the long chain of carboxylic acid does not dissolve in water but dissolves in oil.
> The soap molecules form structures called 'micelles'.
> The ionic end is towards the water and the non-ionic end faces towards the oil.
> This forms emulsion in water.



> The soap micelles thus helps.in dissolving the dirt in water and we can wash clothes clean.
> **Soft water:** The water with no salt in it.
> **Hard water:** The water with dissolved salt in it. It may be calcium or magnesium salts.
> For cleansing purpose, the foam needs to be produced which depends on free availability of hydrophobic portion of soaps (or alkyl group).
> In soft water, soap shows the cleansing property by forming foam.
> In hard water, hydrophobic end of soap is trapped due to scum or precipitation with the calcium and magnesium salts. This makes the hard water unsuitable for washing.

$$Ca(HCO_3)_2(aq) + 2Na^+ \text{ Stearate}(aq) \longrightarrow Ca(\text{Stearate})_2(s) + 2NaHCO_3(aq)$$

Sodium stearate (soap) — Scum

$$CaSO_4(aq) + 2Na^+ \text{ Stearate}(aq) \longrightarrow Ca(\text{Stearate})_2(s) + Na_2SO_4(aq)$$

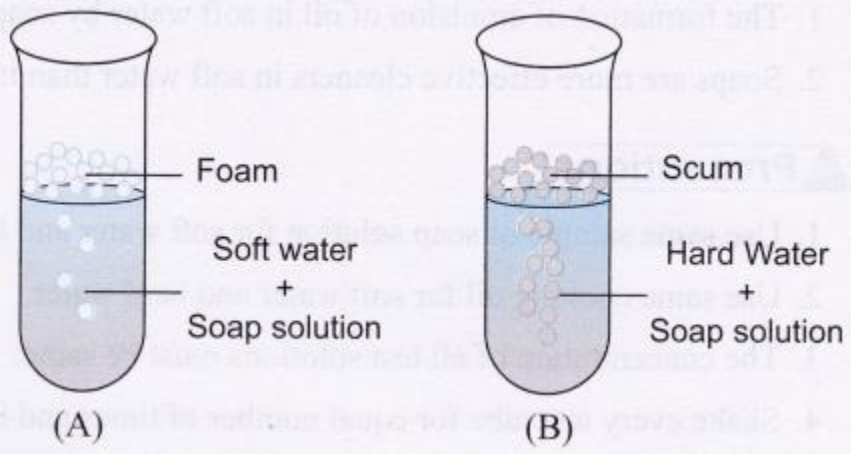
Scum

Materials Required

Two test tubes, test tube stand and measuring cylinder.

Chemical required: Samples of hard and soft water, soap solution and cooking oil.

Procedure (Part A)



1. Take 10 mL of distilled water (soft water) in a test tube. Label it as ‘A’.
2. Take 10 mL of hard water (water from hand-pump, underground water) in another test tube. Label it as ‘B’.
3. In both the test tubes, add few drops of soap solution.
4. Shake the test tubes ‘A’ and ‘B’ vigorously for an equal period of time. Keep them in the test tube stand and record your observations.

Observations

1. In test tube A, soap formed lather or foam.
2. In test tube B, white precipitate was formed with no lather or foam.

Conclusion

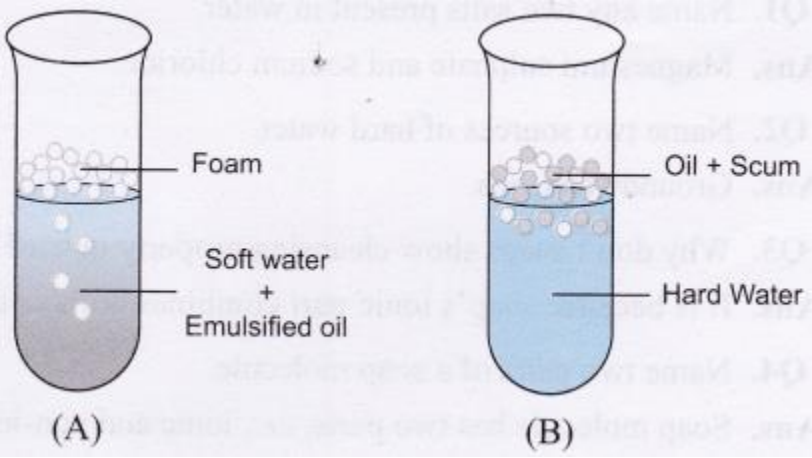
Soaps are effective cleaner only in soft water because the soap molecules form lather in soft water. But in case of hard water, the soap molecules do not remain as soap molecules but the ionic end of soap reacts with the salts present in hard water to form curdy white precipitate called scum.

Precautions

1. Use same sample of soap solution for soft water and hard water.
2. Same quantity of soap solution must be added to both the test tubes containing soft water and hard water.
3. The concentration of all test solutions must be same.
4. Shake every test tube for equal number of times and in a similar manner.

Note: If hard water is not available prepare some hard water by dissolving hydrogen carbonate/sulphates/chloride salt of calcium or magnesium in water.

Procedure (Part B)



1. Take 10 mL of distilled water/soft water and add a drop of cooking oil in it. Label this test tube as ‘A’.
2. Take 10 mL of hard water and add a drop of cooking oil in it. Label this test tube as ‘B’.
3. Now, add a few drops of soap solution in both the test tubes ‘A’ and ‘B’.
4. Shake both the test tubes vigorously for the same period of time.
5. Keep them on the test tube stand and record your observations.

Observations

1. The test tube ‘A’ with soft water showed the oil emulsified due to soap solution.
2. The test tube ‘B’ showed no emulsification due to soap solution.

Conclusion

1. The formation of emulsion of oil in soft water by soap shows the effect of soap in cleaning.
2. Soaps are more effective cleaners in soft water than in hard water.

Precautions

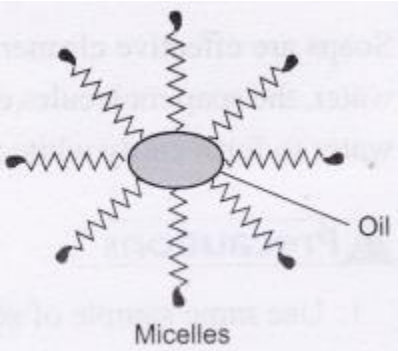
1. Use same sample of soap solution for soft water and hard water.
2. Use same cooking oil for soft water and hard water.
3. The concentration of all test solutions must be same.
4. Shake every test tube for equal number of times and in a similar manner.

Science Lab Manual Viva Voce

Question 1:
What is hard water?
Answer:
Water with salts in it is called hard water.

Question 2:
Name two sources of soft water.
Answer:
Rainwater, boiled water.

Question 3:
What is a micelle?
Answer:



When soap molecules are dissolved in water they form an arrangement as shown which is called micelle formation.
The ionic end is pointing outside towards water and non-ionic end is pointing towards the oil.

Question 4:
Name the cleansing agent that can be used in hard water.
Answer:
Detergents.

Question 5:
Would you be able to check if water is hard by using a detergent?
Answer:
No, we cannot test for water if it is hard on using a detergent.

Science Lab Manual Practical Based Questions

Question 1:
Name any two salts present in water.
Answer:
Magnesium sulphate and sodium chloride.

Question 2:
Name two sources of hard water.
Answer:
Groundwater, sea.

Question 3:
Why don't soaps show cleansing property in hard water?
Answer:
It is because soap's ionic part combines with salts present in hard water to form insoluble precipitate.

Question 4:
Name two parts of a soap molecule.
Answer:
Soap molecule has two parts, i.e., ionic and non-ionic. The ionic part of soap is hydrophilic and non-ionic part is hydrophobic.

Question 5:
Name few dissolved salts present in hard water.
Answer:
The salts that may be present in hard water are hydrogen carbonates, sulphates, chlorides of calcium or magnesium.

Question 6:
What happens when soap solution is mixed with hard water? Why?
Answer:
Soap forms curdy white precipitate when dissolved in hard water. This is because the ionic end of soap molecule on dissolving in water reacts with the salts of hard water to form the precipitate.

Question 7:
Why are soaps effective in soft water and not in hard water?
Answer:
In hard water it forms insoluble precipitate called scum whereas in soft water it does not form any such compound and hence shows its cleansing property.

Question 8:
How will you test in the laboratory, whether the given sample of water is hard or soft? Name two salts which make the water hard. **[Delhi 2011]**
Answer:
When few drops of soap solution are added in the given sample of water, if lather is formed with soap then water is soft water. If lather is not formed then water is hard. Calcium chloride and magnesium sulphate salts present in water make the water hard.

Question 9:
Can we test hard water by using detergent? Write one more method other than using soap to test the hardness of hard water. **[Delhi 2012]**
Answer:
We cannot use detergent for testing hard water. As detergents form lather in both hard

water and soft water.
Method to test the hardness of water: If on boiling the water, some insoluble salt's precipitates (white ppt.) are formed, these precipitates then settl e down and can be removed by filtering the water. The given sample of water is then hard water.

Question 10:
When boilers of water are used for a very long time, then white layers get deposited on inside of these boilers?
How can these white layers be removed? **[Outside Delhi 2012]**
Answer:
When hard water is used in these boilers, then white scum of salts present in the hard water gets deposited inside the boilers making a white layer. These white layers can be removed by washing the boilers with dil. HCl acid.

Question 11:
Name two salts each of calcium and magnesium which make the water hard. **[Outside Delhi 2013]**
Answer:
These salts are:
Calcium chloride — $CaCl_2$ Magnesium chloride — MgCl,
Calcium sulphate — $CaSO_4$ Magnesium sulphate — $MgSO_4$.

Science Lab Manual Questions

Question 1:
Do both hard water and soft water produces foam with soap?
Answer:
Only soft water produces foam with soap and hard water does not produce any foam.

Question 2:
Why is scum formed when hard water is treated with soap?
Answer:
Hard water contains calcium and magnesium ions in it which reacts with soap to form insoluble precipitate called scum.

Question 3:
What do you understand by temporary and permanent hardness of water?
Answer:
Temporary hardness of water is due to the presence of calcium and magnesium bicarbonate salt dissolved in water. These salts can be removed by a simple process of boiling the water or on addition of sodium carbonate to hard water.
Permanent hardness of water is due to the presence of chloride and sulphate salts of calcium and magnesium in water. These salts cannot be easily removed and needs ion exchange method for removal.

Question 4:
What is the reaction between soap molecules and ions present in hard water?
Answer:

$$Ca^{2+}(aq) + RCOONa \longrightarrow RCOOCa(s) + 2Na^{+}(aq)$$

Calcium ion (in hard water) — Soap — Scum — Sodium ion

$$Mg^{2+}(aq) + RCOONa \longrightarrow RCOOMg(s) + 2Na^{+}(aq)$$

Magnesium ion (in hard water) — Soap — Scum — Sodium ion

Questions based on Procedural and Manipulative Skills

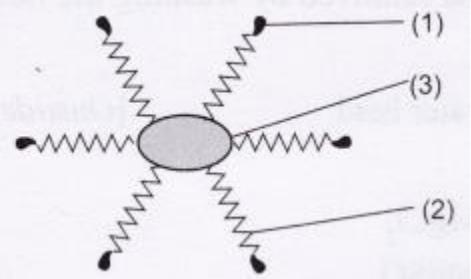
1. The correct formula for soap is
(a) $C_{17}H_{35}COO^{+}$-Na^{-}
(b) $C_{17}H_{35}COO^{-}Na^{+}$
(c) Both (a) and (b)
(d) None of these

2. A student wanted to make hard water in lab, the correct method of doing so is
(a) Water + Magnesium sulphate and sodium chloride
(b) Water + Magnesium chloride and sodium chloride
(c) Water + Magnesium bicarbonate and sodium bicarbonate
(d) All of the above

3. Hardness of water cannot be detected when we add:
(a) soap
(b) detergent
(c) both (a) and (b)
(d) none of these.

Questions based on Observational Skills

4. The micelle of soap is formed on adding soap to water. What is the correct labelling of this micelle?

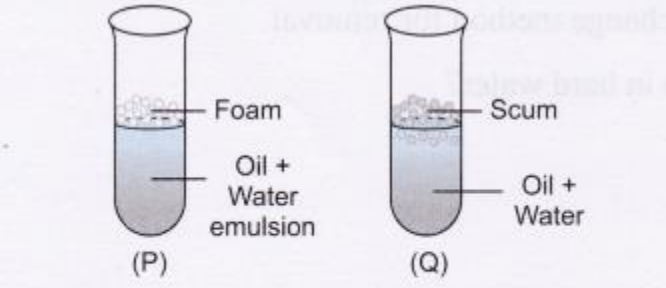


(a) (1) hydrophobic end (2) hydrophilic end (3) soap

(b) (1) oil (2) hydrophilic end (3) soap
(c) (1) hydrophilic end (2) hydrophobic end (3) oil
(d) (1) hydrophobic end (2) hydrophilic end (3) oil

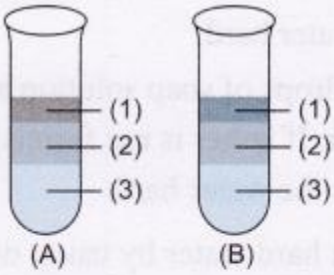
5. Soap does not show its cleansing property in
(a) distilled water
(b) mineral water
(c) soft water
(d) salty water

6. Two test tubes P and Q as shown in given figure were used to study the cleansing property of soap. In test tube P foam is formed and in test tube Q scum is formed. The best cleansing property of soap is seen in



(*a*) P (*b*) Q
(*c*) both P and Q (*d*) neither P nor Q

7. The correct labelling of test tube A and B when A contains soft water and B contains hard water is:



(a)	A → (1) foam	(2) oil	(3) water
	B → (1) foam	(2) oil + water	(3) scum
(b)	A → (1) oil	(2) foam	(3) water
	B → (1) foam	(2) oil + water	(3) scum
(c)	A → (1) foam	(2) oil	(3) water
	B → (1) scum	(2) oil	(3) water
(d)	A → (1) foam	(2) oil	(3) water
	B → (1) foam	(2) oil + water	(3) scum

8. Four test tubes marked as P, Q, R and S, contain solutions of sodium chloride, potassium chloride, calcium chloride and magnesium chloride. On adding soap in it the test tube that gives lather is:
(a) P only (h) Q only
(c) R only (d) both P and Q

9. In the above set-up (Q.8) the scum is formed in:
(a) P (b) R
(c) S (d) R and S

10. Soap solution is added to ethyl alcohol, the correct observation is:
(a) it forms lather.
(b) micelles are formed.
(c) soap dissolves in alcohol.
(d) soap forms scum.

11. A student takes potassium chloride, magnesium sulphate, calcium chloride and calcium sulphate in test tubes A, B, C and D respectively. On adding soap solution to each test tube lather is formed in test tube:
(a) A (b) B
(c) C (d) D

12. If soap is added in hard water which of the .following will not happen?
(a) Scum is formed.
(b) Lather is not formed.
(c) Micelles are formed.
(d) No cleansing action of soap.

13. In hard water, detergent is added. Which of the following observation is true?
(a) Foam is formed.
(b) Cleansing action is seen.
(c) Micelles are formed
(d) All of the above.

14. A student takes about 6 mL of distilled water in four test tubes marked P, Q, R and S. He dissolves sodium sulphate in P, potassium sulphate in Q, calcium sulphate in R and magnesium sulphate in S. After that he adds equal amount of soap solution in each test tube. On shaking these test tubes, he would observe a good amount of lather in the test tubes marked
[All India Delhi 2013]
(a) P and Q (b) Q and R
(c) R and S (d) P and S

Questions based on Reporting and Interpretation Skills

15. The white precipitate that is formed when soap is mixed with hard water is due to
(a) ions in water (b) minerals in water
(c) salts in water (d) acid in water

16. Soap shows its cleansing property due to
(a) micelles formation
(b) lather formation
(c) both (a) and (b)
(d) none of these

17. Soap removes dirt from any surface due to
(a) its tadpole structure
(b) mixture formation
(c) lather formation
(d) hydrophobic and hydrophilic ends

18. Two students A and B were told to test for hard and soft water. They both were given test tubes with soft and hard water respectively and few drops of oil in them. Both the students added soap solution in it and recorded their observations. The correct record is

	Student	Observations	Conclusion
(a)	A	soap + oil + water → foam	hard water
	B	soap + oil + water → no foam	soft water
(b)	A	soap + oil + water → foam	soft water
	B	soap + oil + water → scum	hard water
(c)	A	soap + oil + water → scum	soft water
	B	soap + oil + water → foam	hard water
(d)	A	soap + oil + water → foam	soft water
	B	soap + oil + water → foam	hard water

19. The foaming capacity of soap depends on:
(a) hydrophilic part
(b) saponification
(c) ions present in water
(d) alkyl group.

20. The hardness of water is due to
(a) calcium and magnesium ions
(b) sodium and chloride ions
(c) carbonate and biocarbonate
(d) alkyl group.

21. To remove the temporary hardness of water, we can:
(a) add sodium carbonate to it
(b) add sodium hydroxide to it
(c) filter it
(d) boil it.

22. Hard water required for an experiment is not available in a school laboratory. However, following salts are available in the laboratory. Select the salts which may be dissolved in water to make it hard for the experiment. **[Delhi 2013]**
1. Calcium Sulphate
2. Sodium Sulphate
3. Calcium Chloride
4. Potassium Sulphate
5. Sodium Hydrogen Carbonate
6. Magnesium Chloride
(a) 1,2 and 4 (c) 3, 5 and 6 (b) 1,3 and 6 (d) 2, 4 and 5

23. In a locality, hard water, required for an experiment, is not available. However, the following salts are available in the school laboratory: **[Outside Delhi 2014]**
(1) Sodium sulphate
(2) Calcium sulphate
(3) Magnesium chloride
(4) Sodium chloride
(5) Calcium chloride
(6) Potassium sulphate
Which of the above salts may be dissolved in water to obtain hard water for the experiment?
(a) 2, 3 and 5 (b) 1,2 and 5
(c) 1,2, 4 and 6 (d) 3 and 5 only

ANSWERS

1. (*b*)	2. (*d*)	3. (*b*)	4. (*c*)	5. (*d*)
6. (*a*)	7. (*c*)	8. (*d*)	9. (*d*)	10. (*c*)
11. (*a*)	12. (*c*)	13. (*d*)	14. (*a*)	15. (*c*)
16. (*c*)	17. (*d*)	18. (*b*)	19. (*d*)	20. (*a*)
21. (*d*)	22. (*b*)	23. (*a*)		