CHAPTER 03

Water Quality : Definition, Characteristics and Perspective

INTRODUCTION

The availability of a water supply adequately in terms of both quantity and quality is essential to human existence. Early people recognized the importance of water from a quantity viewpoint. Recognition of the importance of water quality developed more slowly. Early human could judge water quality only through the physical sense of sight, taste and smell.

Advance, in the Germ theory of disease was made by Pasteur and others in the late nineteenth century, and by 1990 the concept of water borne disease was all accepted. The development of the science of water chemistry roughly paralleled water microbiology. Many of the chemicals used in industrial processes and agriculture have been identified in water. It is likely that new analytical techniques will be developed that will identify compounds not yet known to exist in water, and it is conceivable that these materials will also be linked to human wealth. Thus, the science of water quality will remain a challenge for engineers and scientists for years to come.

The purpose of this chapter is to introduce the reader to the modern concept of water quality. The means by which the nature and extent of contaminants in water are measured and expressed are presented along with the sources of various contaminants that find their way into water.

Table: 3.1

Location	Volume, 10^{12} m^3	% of total
Land areas		
Freshwater lakes	125	0.009
Saline lakes and inland seas	104	0.008
Rivers (average instantaneous volume)	1.25	0.0001
Soil moisture	67	0.005
Groundwater (above depth of 4000 m)	8350	0.61
Ice caps and glaciers	29200	2.14
Total land area (rounded)	37800	2.8
Atmosphere (water vapour)	13	0.001
Oceans	1320000	97.3
Total all locations (rounded)	1360000	100

3.1 The Hydrologic Cycle and Water Quality

Water is one of the most abundant compounds found in nature, covering approximately three-fourths of the earth. Inspite of this apparent abundance, several factors serve to limit the amount of water available for human use.

- As shown in table, over 97% of the total water supply is contained in the oceans and other saline bodies of water and is not readily usable for most purposes.
- Of the remaining 3%, a little over 2% is tied up in ice caps and glaciers and, along with atmospheric and soil moisture, is inaccessible.
- Thus for general livelihood and the support of their varied technical and agricultural activities, humans must depend upon the remaining 0.62% found on fresh water lakes, rivers and ground water supplies.

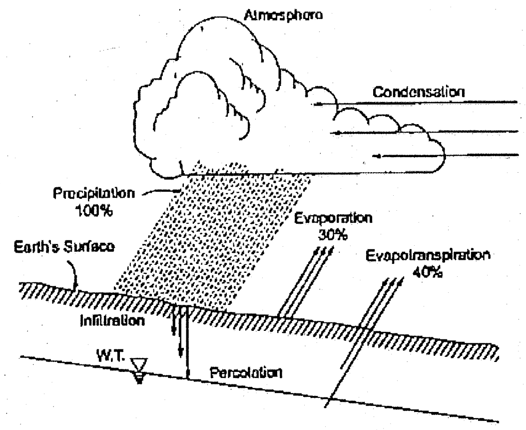


Fig. 3.1 Hydrologic Cycle

- Water is in a constant state of motion depicted in the hydrologic cycle shown in figure.
- Atmospheric water condenses and falls to the earth as rain, snow or some other form of precipitation.
- On the earth's surface, water flow into streams like lakes and eventually the oceans or percolates through the soil and into aquifers than eventually the oceans, discharge into surface waters. Water in nature is most nearly pure in its evaporation state.
- The impurities accumulated by water throughout the hydrologic cycle and as a result of human activities may be in both suspended and dissolved form.
- Dissolved material consists of molecules or ions that are held by the molecular structure of water.
- Colloids are very small particles that technically are suspended.
- Size range of dissolved, colloidal and suspended substances are shown in figure.

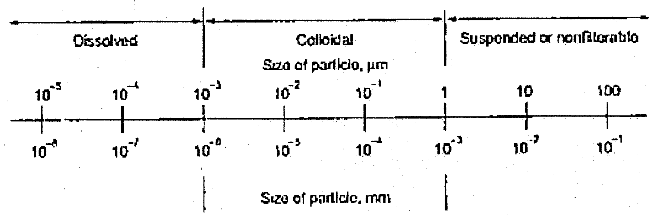


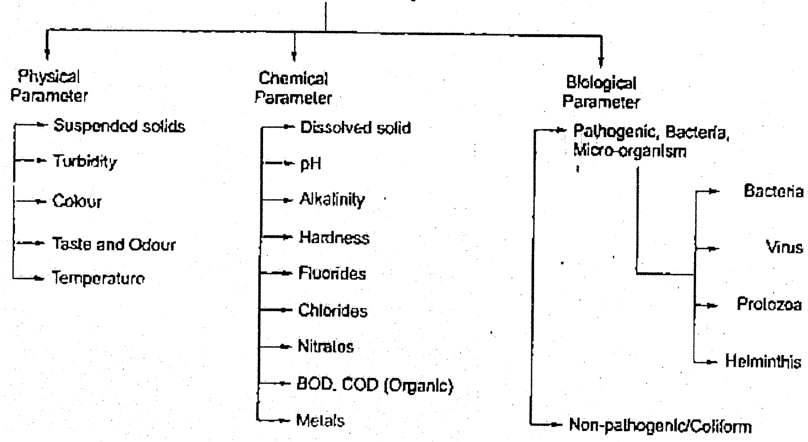
Fig. 3.2 Size classification of solids in water.

3.2 Water Impurity

Water impurities are classified as follows:

1. Physical impurities, 2. Chemical impurities, 3. Biological impurities

Classification of Water Quality Parameters



3.2.1 Physical Water Quality Parameter

Physical characteristics include several parameters which are obvious to a nonspecialist and other, which are not so obvious, at least by inspection.

Important physical characteristics include:

1. Suspended solids 2. Turbidity 3. Colour
4. Taste and Odour 5. Temperature 6. Conductivity

1. Suspended Solids

Total solids may be present in the form of

(i) Suspended solids – 10^{-1} to 10^{-3} mm size
(ii) Colloidal solids – 10^{-3} to 10^{-6} mm size
(iii) Dissolved solids – < 10^{-6} mm size

NOTE: Suspended and colloidal solids are combinedly called dispersed solids.

- Solids suspended in water may consist of inorganic or organic particles.
- Inorganic solids such as clay and immiscible liquid like oil and greases and other soil constituents are common in surface water.
- Organic material such as plant fibres and biological solids (algal cells, bacteria etc.) are also common constituents of surface waters.

Remember: Suspended material is seldom a constituent of ground water because of the filtering capacity of the soil.

Do you know? Inorganic solids are non-biodegradable solids.

Objection: These are objectionable and undesirable because:

(*i*) These make water aesthetically displeasing.
(*ii*) They are biologically active and may form disease causing organisms as well as organisms such as toxin producing strains of algae.
(*iii*) It provides adsorptions site for chemical and biological agents.

Measurement: Measurement is done by gravimetric test involving mass of residual measurement i.e. suspended solid (SS) are calculated by weighing them.

- Total solids i.e. all solids (suspended or dissolved) are calculated by evaporating the sample and measuring the residue. Heating temperature is 104°C.
- Total solids can be determined by evaporating and if dried mass is heated at 600°C then organic matter will be oxidized and only inorganic matter will be left.

NOTE: Organic matter $\xrightarrow[600^\circ C]{\text{Heat}} CO_2\uparrow + H_2O\uparrow$ + Other gases + Vapour.

- Mass of suspended solid is obtained by filtration and heating the residue on filter at 104°C.
  Dissolved solid (*DS*) = Total solid (*TS*) – Suspended solids (*SS*)

Do You Know? Filtration in real terms does not exactly divides the solids into suspended and dissolved fractions because some colloids may pass through the filter and can get measured along with dissolved fraction. Hence, classification is done as filterable and non-filterable solids. Hence, suspended solids are corresponding to non-filterable solids and dissolved solids are corresponding to filterable solids.

The permissible limit: EPA has set a maximum suspended solid standard of 30 mg/*l* for treated waste water discharge.

Example 3.1 **A filterable residue analysis is run on a sample of water as follows. Prior to filtering, the crucible and filter pad are kept overnight in the drying oven, cooled, and the dry mass (tare mass) of the pair determined to be 54.352 g. Two hundred and fifty millilitres of the sample is drawn through a filter pad contained in the porous-bottom crucible. The crucible and filter pad are then placed in a drying oven at 104°C and dried until a constant mass of 54.389 g is reached. Determine the suspended solids concentration of the sample.**

Solution:

1. Determination the mass of solids removed

Dry mass + solids = 54.389 g
– Dry mass = 54.352 g
Mass of solids = 0.037 g = 37 mg

2. Determination the concentration of the solids

$$\frac{\text{mg solids} \times 1000\ ml/l}{ml \text{ of sample}} = \text{conc in mg}/l\,; \quad \frac{37 \times 1000}{250} = 148 \text{ mg}/l$$

2. Turbidity

Large amount of fine suspended matters make the water to appear cloudy or turbid in appearance.

Turbidity depends upon the fineness and concentration of particles present in water.

Source: Turbidity is the measure of extent to which light is either absorbed or scattered by suspended material in water. It is not a direct quantitative measure of suspended solids.

- It depends on shape, size and refractive indices of the suspended particles as well.
- Mostly turbidity is due to colloidal materials like clay, silt, rock fragment, metal oxides, vegetation fibres and microorganisms.

Objection: Disinfection of turbid water is difficult because the suspended solids partially shield the organisms form disinfectant.

In natural body, turbidity interferes with light penetration and hence the photosynthetic reaction (which gives oxygen to the water).

Measurement of Turbidity: It is measured photochromatically by determining the % of the light of a given intensity i.e. either absorbed or scattered.

Measuring Device: Based on absorption principle:

1. Turbidity rod   2. Jackson's turbidity meter

Based on scattering principle:

1. Baylis turbidometer   2. Modern Nephelometer

1. Turbidity Rod

- Turbidity rod with platinum needle is inserted inside the water and the depth at which platinum needle just becomes invisible gives turbidity in ppm.
- As depth of insertion increases, reading will decrease.
- Turbidity of one milligram of finely divided silica produced in one litre of distilled water is taken as one unit.
- It is a field method.

Permissible Limit: The permissible limit is 5-10 ppm.

Remember: GOI manual gives turbidity in NTU i.e. nephalometric turbidity unit. Acceptable limit is 1 NTU and cause for rejection is 10 NTU.

2. Jackson's Turbidity meter

- The turbidity is expressed in standard unit called JTU (Jackson's turbidity unit) which is based on absorption principle.
- The level of water is increased till the image of flame cease to be seen.
- The turbidity is measured from graduated glass tube and it is used when turbidity is greater than 25 ppm.
- It is a laboratory method.
- This method is not used for drinking water.
- One JTU is equivalent to turbidity produced by 1 mg of fine silica (SiO_2) dissolved in one litre of distilled water.

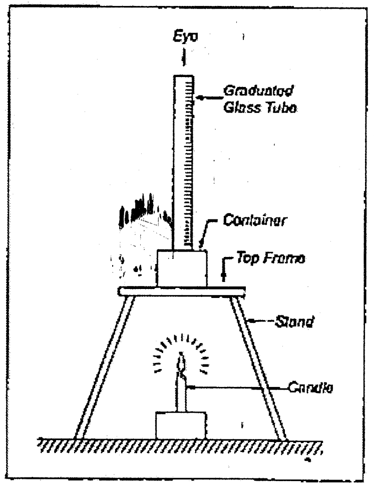


Fig.3.3 JacksonTurbidimeter

Baylis Turbidometer and Nephelometer:

- These turbidometer are based on colour matching techniques.
- In this method, even a small turbidity of one unit or less can be measured, so these are most widely used for domestic water supplies.
- In Baylis turbidity meter, light intensity is measured in the direction of incident light only whereas in nephelometer light intensity is measured at right angles to the incident ray.
- Hence, nephelometer is based on scattering principle.
- Here formazine, a chemical is used as base in place of SiO_2, the turbidity unit is also sometimes called FTU.

3. Colour

Pure water is colourless, but water in nature is often coloured by foreign substances.

- Water whose colour is partly due to suspended matter is said to have apparent colour.
- Colour contributed by dissolved solid, that remain after removal of suspended matter is known as true colour.

Source: Colour is caused by suspended and dissolved matter in water.

- After suspended matter causing colour is removed by centrifugation, the colour obtained is called true colour.
- Humic acid gives yellowish brown colour, Iron oxide gives reddish colour, manganese oxide gives brown or brackish colour.
- Water containing oxidised iron and manganese impart characteristic reddish or black colour. Heavy growth of algae may also impart colour to the water.

Objection: Coloured water is not aesthetically acceptable to the general public.

- Highly coloured water is unsuitable for laundering, dyeing, papermaking, beverage manufacturing, dairy production and other food processing and textile and plastic production.
- Thus, the colour of water affects its marketability for both domestic and industrial use.
- Phenolic compound with chlorine produces taste and odour. Organic compounds causing colour may exert chlorine demand and hence reduces the effectiveness of disinfection by chlorine.

NOTE: Some colour causing organic compounds with chlorine becomes carcinogenic which causes cancer.

Measurement: Measurement of colour is done by a colour matching technique, also called as Tintometer method.

- True colour is measured on Burgess scale by Nessler's tubes.
- Result is expressed in TCU or Hazn unit (True colour unit) where 1 TCU is equal to colour produced by 1 mg per litre of platinum in the form of chloroplatinate.
- For colour other than yellowish brown i.e. from industrial effluent, spectrophotometric technique is used.

Remember: The colour testing must be done within 72 hours of collection of sample otherwise biological activity may alter the colour.

Permissible Limit: The permissible limit for drinking water is 5 ppm and in no case greater than 25 ppm

4. Taste and Odour

Many substances with which water comes into contact in nature or during human use may impart perceptible taste and odour.

- These include minerals, metals, salts from the soil, end products from biological reactions and constituents of waste water.
- Taste and odour are caused by dissolved gases like H_2S, mercaptan, methane, organic matter derived from certain dead or living microorganism, decomposed organic matter, industrial liquid, water containing phenols, cresols, ammonia, agricultural chemicals, high residual chlorine and chloro-phenols.

Source:

- Sulphur produced rotten egg like taste and odour.
- Algae secretes oily substances that may result in bad taste and colour.
- Alkaline material imparts a bitter taste to water, while metallic salts may give a salty or bitter taste.

Objection: The taste and odour causing compounds may be carcinogenic i.e. causing cancer.

Measurement of Taste and Odour: Taste and odour measurement, which is produced by organics, can be done using gas or liquid chromatography, however, this method is costly and not done in routine.

- An instrument known as sonoscope, is generally used for measurement of odour.
- It represents the dilution ratio at which odour is hardly detectable.
- Intensity of taste and odour is measured by "Threshold odour number (TON)".
- TON allowed is between 1 to 3.
- TON testing is done in cold water because increase in temperature may change the taste and odour.
- Odour and taste are expressed by threshold odour number as it represents dilution ratio at which odour can not be detected.

$$\text{T.O.N.} = \frac{A+B}{A} = \frac{\text{Volume of diluted sample}}{\text{Volume of undiluted sample}}$$

where, A = Volume of water sample undiluted

B = Volume of distilled water required to be added to remove the odour

Permissible Limit: The permissible limit for drinking water is 1 TON.

Remember: In any case, TON cannot be more than three (cause for rejection).

NOTE Odour can be removed by mechanical aeration, oxidation by chemical like chlorine or its compounds or ozone or permaganate and adsorption of odour by agents such as activated carbon.

5. Temperature

Temperature affects chemical and biological activities. If temperature increases by 10°, biological activities are doubled.

Hence, for water supply, the temperature should be between 10° – 25°C and greater than 25°C is objectional.

NOTE By increasing temperature, solubility of dissolved gases decreases. At 20°C DO (dissolved oxygen) in water is nearly 9.2 mg/l. If DO falls below 4 mg/l, then water species may die such as fishes, crabs and lobsters.

Thermal Shock: If hot water effluent from power plants and auto mobile industry is discharged in natural streams then due to rise of temperature, DO level may fall below 4 ppm which may lead to death of water species. Such type of situation is called thermal shock.

6. Specific Conductivity of Water

The total amount of dissolved salt, present in water can be easily estimated by measuring the specific conductivity of water. The specific conductivity of water is determined by means of a portable dionic water tester and is expressed in micro-mhos per cm at 25°C.

- Mho is the unit of conductivity and equals 1 ampere/1 volt.
- The specific conductivity of water in micromhos per cm at 25°C is multiplied by a coefficient (generally 0.65) so as to directly obtain the dissolved salt content in milligrams per litre or ppm.
- The exact value of this coefficient depends upon the type of salts present in water.

3.2.2 Chemical Water Quality Parameters

There are following chemical properties:

1. Total dissolved solids (TDS)	2. Alkalinity	3. pH
4. Hardness	5. Chloride content	6. Nitrogen content
7. Phosphorous	8. Fluorides	9. Metals

1. Total Dissolved Solids (TDS)

The total amount of solids (suspended as well as dissolved solids) present in water can be determined by evaporating a sample of water and weighing the dry residue left.

- The material remaining in the water after filtration is considered to be dissolved.
- A direct measurement of TDS can be made by evaporasing to dryness a sample of water which has been filtered. The residue is weighed and represent the TDS in the water.
- Generally, the analysis of TDS is often made by determining the electrical conductivity of water. (Electrical conductivity in µMho/cm at 25°C) × 0.65 = Dissolved solid content in mg/l.
- Electrical conductivity is measured by di-ionic water tester. Ions usually account for vast majority of TDS.
- The ability of water to conduct electricity is known as specific conductance which is known as ionic strength of water which can be measured by stone bridge method.

Source: There are two type of sources:

1. Major source of TDS : Na^+, Ca^{2+}, Mg^{2+}, HCO_3^-, SO_4^{-2}, Cl^-
2. Minor source of TDS : Fe, K, CO_3^{2-}, NO_3^-, Fluoride, Boron, Silica

- Major list characterizes the dissolved solid content of water and they are called common ions.

Permissible Limit: According to GOI manual, acceptable limit of TDS (mg/l) is 500 and cause for rejection is 2000.

Do You Know?

The ability of a water to conduct electricity, known as the specific conductance. Unfortunately, specific conductance and concentration of TDS are not related on a one-to-one basis. Only ionized substances of water contribute to specific conductance. Organics molecules and compound that dissolved without ionizing are not measured.

Example 3.2: Electrical conductivity (EC) of water and total dissolved solids (TDS) are interrelated. The value of EC will

(a) decrease with increase in TDS
(b) increase with increase in TDS
(c) decrease initially and then increase with increase in TDS
(d) increase initially and then decrease with increase in TDS

Ans. (b)

2. Alkalinity

It is defined as the quantity of ions in water that will react to hydrogen ion.

- It means, alkalinity is the ability of water to neutralize acids.

Source: Major compounds causing alkalinity are:

CO_3^{2-}	HCO_3^-	OH^-
↓cause	↓cause	↓cause
Carbonate alkalinity	Bicarbonate alkalinity	Caustic alkalinity

Minor compounds are: $HSiO_3^-$, $H_2BO_3^-$, HPO_4^{2-}, $H_2PO_4^-$ and HS^-

For purpose of computation alkalinity caused by minor compound is neglected. The alkalinity in water comes due to minerals or due to atmospheric CO_2 mixed in water or due to microbial decomposition of organic matter. The reaction as follows:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \text{ (Dissolved } CO_2 \text{ carbonic acid)} \quad \text{(i)}$$

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \text{ (Bicarbonate)} \quad \text{(ii)}$$

$$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-} \text{ (Carbonate)} \quad \text{(iii)}$$

$$CO_3^{2-} + H_2O \rightleftharpoons HCO_3^- + OH^- \text{ (Hydroxides)} \quad \text{(iv)}$$

The last reaction (iv) is a weak reaction but utilization of HCO_3^- by algae in water drives the reaction to the right and hence sufficient accumulation of OH^- occurs i.e. if algae is present in water, the water becomes alkaline (pH = 9 to 10). The above reactions are due to microbial decomposition of organic matter. In addition to this alkalinity may be of mineral origin.

- If pH is found less than 9 then usually OH^- may not present.
- The cation (Ca^{2+}) may combine alkalinity of water and may form solid precipitate of $CaCO_3$ which may get deposited on pipe surface and may cause incrustation in pipe.
- In large quantities, alkalinity imparts a bitter taste to water.

Remember: If water is acidic then corrosive action may result.

Measurement of Alkalinity

- Alkalinity measurements are done by titrating the water with an acid and determining the hydrogen equivalent of alkalinity and it is expressed in terms of mg/l as $CaCO_3$.
- If 0.02 N H_2SO_4 is used in titration then 1 ml of acid will neutralize 1 mg of alkalinity as $CaCO_3$ · 0.02 N H_2SO_4 means 0.02g equivalent H_2SO_4/litre.

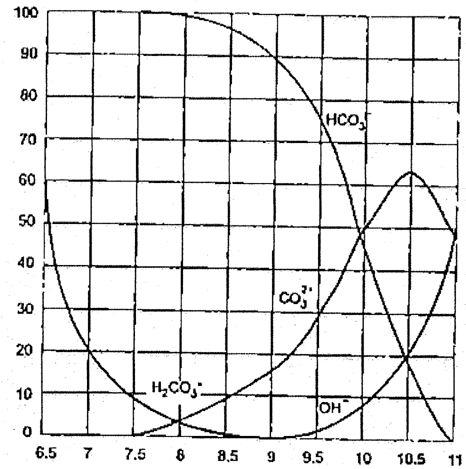


Fig. 3.4 Alkalinity species vs pH. Values are calculated for water at 25°C containing a total alkalinity of 100 mg/L as $CaCO_3$.

Example 3.3 Two samples of water A and B have pH values of 4.4 and 6.4 respectively. How many times is sample A more acidic than sample B is

(a) 0
(b) 50
(c) 100
(d) 200

Ans. (c)

$$pH = \log_{10}[H^+]$$

$$-\log_{10}(H^+) = p(H)_A$$

$$\Rightarrow \quad [H^+]_A = 10^{-4.4}$$

$$\therefore \quad [H^+]_B = 10^{-6.4}$$

$$\therefore \quad \frac{[H^+]_A}{[H^+]_B} = \frac{10^{-4.4}}{10^{-6.4}} = 100$$

Sample *A* is 100 times more acidic than sample *B*.

Example 3.4 How many grams of calcium will be required to combine with 90 g of carbonate to form calcium carbonate?

Solution:

1. Carbonate (CO_3^{2-}) is a radical composed of carbon and oxygen. In this particular combination, carbon has an atomic mass of 12 and a valence of +4, while oxygen has an atomic mass of 16 and

a valence of −2. Therefore, the radical has a total valence of −2 and an equivalence of 2. One equivalent of carbonate is

$$\frac{12+3(16)}{2} = 30 \text{ g/equiv}$$

2. The calcium ion has an atomic mass of 40 and a valence of +2; therefore, one equivalent of calcium is

$$\frac{40}{2} = 20 \text{ g/equiv}$$

3. The number of equivalents of calcium must equal the number of equivalents of carbonate, therefore

$$\frac{90 \text{ g}}{30 \text{ g/equiv}} = 3 \text{ equiv of carbonate}$$

Therefore, 3 equiv × 20 g/equiv = 60 g of calcium, and that amount will be required to react with 90 g of carbonate.

Equivalents are very important in water chemistry. In addition to being useful in calculating chemical quantities for desired reactions in water and waste water treatment, equivalents also provide a means of expressing various constituents of equal to an equivalent of any other substance. Therefore, the concentration of substance A can be expressed as an equivalent concentration of substrate B by the following method.

$$\frac{(g/L)A}{(g/equiv)A} \times (g/equiv)B = (g/L)A \quad \text{expressed as B}$$

Historically, constituents of dissolved solids have been reported in terms of equivalent calcium carbonate concentrations. The following example illustrates this technique.

Example 3.5 What is the equivalent calcium carbonate concentration of (a) 117 mg/L of NaCl and (b) 2×10^{-3} mol of NaCl?

Solution:

(a) 1. One equivalent of calcium carbonate is

$$\frac{40+12+3(16)}{2} = 50 \text{ g/equiv} = 50000 \text{ mg/equiv} = 50 \text{ mg/mequiv}$$

2. One equivalent of sodium chloride is

$$\frac{23+35.5}{1} = 58.5 \text{ g/equiv} = 58.5 \text{ mg/mequiv}$$

3. By equation (2-2)

$$\frac{117 \text{ mg/L}}{58.5 \text{ mg/mequiv}} \times 50 \text{ mg/mequiv} = 100 \text{ mg/L of NaCl as } CaCO_3$$

(b) 1. One mole of a substance divided by its valence is one equivalent

$$\frac{2 \times 10^{-3} \text{ mol/L}}{1 \text{ mol/equiv}} = 2 \times 10^{-3} \text{ equiv/L}$$

2. Thus, 2×10^{-3} equiv/L × 50,000 mg/equiv = 100 mg/L

Example 3.6 **The solubility product for the dissociation of $Mg(OH)_2$ is 9×10^{-12}. Determine the concentration of Mg^{2+} and OH^- at equilibrium, expressed as milligrams per litres of $CaCO_3$.**

Solution:

1. Write the equation for the reaction $\quad Mg(OH)_2 \rightleftharpoons Mg^{2+} + 2OH^-$
2. The solubility product equation becomes

$$[Mg^{2+}][OH^-]^2 = 9 \times 10^{-12}$$

If x is the number of moles of Mg^{2+} resulting from the dissociation, then OH^- is equal to $2x$. Therefore,

$$[x][2x]^2 = 9 \times 10^{-12}$$
$$4x^3 = 9 \times 10^{-12}$$
$$x = 1.3 \times 10^{-4} \text{ mol/L} = Mg^{2+}$$
$$2x = 2.6 \times 10^{-4} \text{ mol/L} = OH^-$$

3. $\dfrac{1.3 \times 10^{-4} \text{ mol/L}}{0.5 \text{ mol/equiv}} \times 50000 \text{ mg/equiv} = 13.0 \text{ mg/L of Mg as } CaCO_3$

4. $\dfrac{2.6 \times 10^{-4} \text{ mol/L}}{1 \text{ mol/equiv}} \times 50000 \text{ mg/equiv} = 13.0 \text{ mg/L of OH as } CaCO_3$

NOTE: Relative quantity of alkalinity species are pH dependent.

- Hydrogen ions in the acid react with the alkalinity according to the following equations:

$OH^- + H^+ \rightleftharpoons H_2O$ ...(v)

$CO_3^{2-} + H^+ \rightleftharpoons HCO_3^-$ (vi)

$HCO_3^- + H^+ \rightleftharpoons H_2CO_3$ ...(vii)

If acid is added slowly to water and the pH is recorded for each addition. A titration curve similar to that shown in figure is obtained.

During titration measurement of pH is done at every stage and a titration curve is plotted.

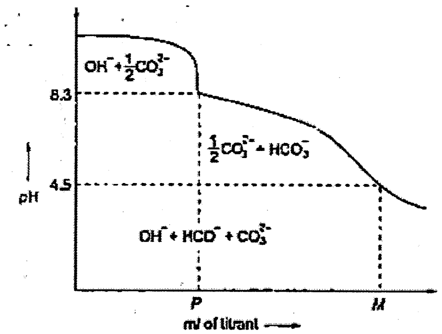


Fig.3.5

- Conversion of CO_3^{2-} to HCO_3^- is essentially complete at pH = 8.3, but resultant HCO_3^- also requires acid. Hence, half of CO_3^{2-} is thought to have neutralized upto pH = 8.3.
- Neutralization of OH^- is complete upto pH = 8.3. Hence $\left(OH^- + \frac{1}{2}CO_3^{2-}\right)$ alkalinity is completely neutralized upto pH = 8.3.
- The acid required to lower the pH from 8.3 to 4.5 must measure the other one-half of the carbonate plus all of the original bicarbonate.
- At pH = 4.5 all the bicarbonate will have been converted to carbonic acid H_2CO_3 (neutralized). Hence, the amount of acid required to titrate sample of water to pH = 4.5 is equivalent to total alkalinity of water.

- If $P = M$, all alkalinity is OH^- i.e, caustic alkalinity.
  If $P = M/2$, all alkalinity is CO_3^{2-} i.e., carbonate alkalinity.
  If $P = 0$ (i.e. initial pH is below 8.3), all alkalinity is HCO_3^-
  If $P < \frac{M}{2}$, predominant species are CO_3^{2-} and HCO_3^-.
  If $P > \frac{M}{2}$, predominant are OH^- and CO_3^{2-}.

Example 3.7 Water contains 210 gm of CO_3^{2-}, 122 gm of HCO_3^-, and 68 gm of OH^- what is the total alkalinity of water expressed as $CaCO_3^-$.

Solution:

$$210 \text{ gm } CO_3^{2-} \text{ will have } = \frac{210}{60/2} = \frac{210}{30} = 7 \text{ gm equivalent}$$

Here, 7 gm equivalent of CO_3^{2-} = 7 gm equivalent of $CaCO_3$

$$122 \text{ gm of } HCO_3^- \text{ will have } = \frac{122}{61/1} = 2 \text{ gm equivalent of } HCO_3^-$$

2 g equivalent of HCO_3^- = 2 gm equivalent of $CaCO_3$

$$68 \text{ gm of } OH^- \text{ will have } = \frac{68}{17/1} = 4 \text{ gm equivalent of } CaCO_3$$

∴ 4 gm equivalent of OH = 4 gm equivalent of $CaCO_3$

Now, Total alkalinity of water = 7 + 2 + 4 = 13 gm equivalent of $CaCO_3$

$$\therefore \quad \text{Weight in gm of } CaCO_3 = \frac{100}{2} \times 13 = 650 \text{ gm of } CaCO_3$$

∴ Total alkalinity of water = 650 gm expressed as $CaCO_3$

Example 3.8 A 200 ml of sample of water has initial pH of 10. 30 ml of 0.02 N H_2SO_4 is required to titrate the sample to pH = 4.5. What is the total alkalinity of water in mg/l as $CaCO_3$?

Solution:

30 ml of 0.02 N H_2SO_4 is required to reduce the pH upto 4.5.

∴ Total alkalinity of 200 ml of water sample = 30 mg as $CaCO_3$

$$\text{So, Total alkalinity of water in mg/l} = 30 \times \frac{1000}{200} = 150 \text{ mg/L as } CaCO_3$$

Example 3.9 In the previous question determine the concentration of species OH^-, HCO_3^-, and CO_3^{2-}. If pH = 8.3 is reached at 11 ml of acid.

Solution: Given that,

∴ Initial pH = 10

and we know that, pH + pOH = 14

⇒ pOH = 14 − 10 = 4

⇒ $-\log_{10}[OH] = 4$

⇒ $[OH^-] = 10^{-4}$ mol/litre

$$10^{-4}\frac{\text{mole}}{\text{litre}} = 10^{-4} \times 17 \text{ gm/litre} = 10^{-4} \times \frac{17}{17} \text{ gm equivalent/litre}$$

$= 10^{-4}$ (gm-equivalent/litre) of OH^- = $10^{-4} \times 50$ mg/litre of $CaCO_3$

= 5 mg/litre as $CaCO_3$

upto pH = 8.3 acid consumed = 11 ml of 0.02 N H_2SO_4 = 11 mg of $CaCO_3$

$$200 \text{ ml of sample will contain} = 5 \times \frac{200}{1000} \text{ mg of } OH^- \text{ as } CaCO_3 = 1 \text{ mg of alkalinity as } CaCO_3$$

$\frac{1}{2}CO_3^{2-}$ alkalinity in the sample = 11 − 1 = 10 mg as $CaCO_3$

⇒ CO_3^{2-} alkalinity in the sample = 10 × 2 = 20 mg as $CaCO_3$

$$\Rightarrow \left[CO_3^{2-}\right] \text{ in mg/litre as } CaCO_3 = 20 \times \frac{1000}{200} = 100 \text{ mg/litre}$$

So, Total alkalinity (upto pH = 4.5) = 30 ml of 0.02 H_2SO_4

= 30 mg of $CaCO_3$ in 200 ml of sample = 150 mg/l as $CaCO_3$

$\left[HCO_3^-\right]$ = 150 − (100 + 5) = 45 mg/litre as $CaCO_3$

NOTE: Table 3.2 shows the results of analysis of a natural water sample expressed in mg/l, meq/l and mg/l as $CaCO_3$.

Table 3.2

Component	mg/l	Equivalent Weight	meq/l	mg/l as $CaCO_3$
Calcium (Ca^{++})	72.0	20.0	3.6	180
Magnesium (Mg^{+})	48.8	12.2	4.6	200
Sodium (N^{+})	9.2	23.0	0.4	20
Bicarbonate (HCO^{-3})	305.0	61.0	5.0	250
Sulphate (SO_4^{--})	134.0	48.0	2.8	140
Chloride (Cl^-)	7.1	35.5	0.2	10

3. pH

It represents the presence of H^+ ion concentration pH is given as:

- $pH = -\log_{10}[H^+]$, where $[H^+]$ is in moles/litre.
- pH is measured by potentiometer in which potential exerted by H^+ is measured.
- It can also can be measured by colour indicator. Colour formed is compared with standard colour.
- Indicators used are methyl orange. Its original colour is red and colour produced is yellow. pH range of methyl orange is 2.8 – 4.4.
- Methyl orange is an acidic indicator.
- Phenolphthalein has pH range of 8.6 – 10.3. Original colour is colourless and final colour is pink.
- Phenolphthalein is a basic indicator.
- Acidic water cause corrosion and alkaline water cause incrustation of pipe.
- Alkaline water causes difficulty in chlorination.

Remember: Methyl orange is an acidic indicator and phenolphthalein is a basic indicator.

Permissible Limit: For drinking water, permissible limit of pH is 7 to 8.5, but it should not be less than 6.5 and not greater than 9.2.

Example 3.10 A sample of ground water at a pH of 7.0 contains 122 mg/l of bicarbonates. What is the alkalinity of this water (in terms of $CaCO_3$)?

(a) 120 mg/l (b) 60 mg/l
(c) 100 mg/l (d) 200 mg/l

Ans. (c)

Alkalinity expressed in equivalents $= HCO_3^- + OH^- - H^+$

Milliequivalent mass of $[HCO_3^-] = \frac{122}{61} = 2$ meq/l

Milliequivalent mass of $[OH^-] = \frac{10^{-7} \times 10^3 \times 17}{17}$ meq/l

Milliequivalent mass of $[H^+] = \frac{10^{-7} \times 10^3 \times 1}{1}$ meq/l

The milliequivalent of $[OH^-]$ and $[H^+]$ are negligible. So Alkalinity as $CaCO_3$

$= 2 \times 50 = 100$ mg/l

Example 3.11 The concentration of OH^- ion in a water sample is measured as 17 mg/l at 25°C. What is the pH of the water sample?

(a) 10 (b) 11
(c) 12 (d) 13

Ans. (b)

$$pOH = -\log[OH^-]$$

where $[OH^-]$ is concentration of OH^- ions in moles per litre

$$\text{Moles} = \frac{\text{Weight in gm}}{\text{Molecular mass}} = \frac{17 \times 10^{-3}}{17}$$

$\therefore$ Moles of $OH^- = 10^{-3}$

$\therefore$ $pOH = -\log[10^{-3}]$

$\Rightarrow$ $pOH = 3$

But $pH + pOH = 14$

$\Rightarrow$ $pH = 14 - 3$

$\Rightarrow$ $pH = 11$

Example 3.12 In a water treatment plant, the pH values of incoming and outgoing waters are 7.2 and 8.4 respectively. Assuming a linear variation of pH with time, determine the average pH value of water

Solution:

By definition of pH value, we have

$$pH = log\left[\frac{1}{H^+}\right]$$

Using suffix 1 for incoming water and 2 for outgoing water, we have

$$(pH)_1 = 7.2 = log_{10}\frac{1}{H_1^+}$$

$$(pH)_2 = 8.4 = log_{10}\frac{1}{H_2^+}$$

Now $log_{10}\frac{1}{H_1^+} = 7.2$

or $(-) log_{10} H_1^+ = 7.2$

or $H_1^+ = 10^{-7.2}$

Similarly $H_2^+ = 10^{-8.4}$

$$\text{Average value of } H^+ = \frac{H_1^+ + H_2^+}{2} = \frac{10^{-7.2} + 10^{-8.4}}{2} = 10^{-8.4}\left[\frac{(10)^{1.2} + 1}{2}\right] = 10^{-8.4}\left[\frac{15.8 + 1}{2}\right]$$

$$= 10^{-8.4} \times 8.4 = 8.4 \times 10^{-8.4}.$$

$\therefore$ Average value of pH

$$= log_{10}\left(\frac{1}{8.4 \times 10^{-8.4}}\right) = \log_{10}\left(\frac{10^{8.4}}{8.4}\right)$$

$$= log_{10}\left(10^7 \times \frac{10^{1.4}}{8.4}\right) = \log_{10} 10^7\left(\frac{25.2}{8.4}\right)$$

$$= \log_{10} 10^7 \times 3 = \log_{10} 30000000 = 7.477$$

4. Hardness

Hardness is defined as the concentration of multivalent metallic cations in solution.

Classification

- **Carbonate Hardness (CH)** or **Temporary Hardness** → Carbonate and Bicarbonate (CO_3^{2-}) (HCO_3^-) of Ca^{2+} and Mg^{2+} (if other multivalent cation are neglect)
- **Non-Carbonate Hardness (NCH)** or **Permanent Hardness** → Cl^-, SO_4^{2-} and NO_3^- of Ca^{2+} and Mg^{2+} (If other multivalent cation are neglected)

- At supersaturated conditions, the hardness cations will react with anions in the water to from a solid precipitate.
- Multivalent metallic ions most abundant in natural water are calcium and magnesium.
- Other ions which leads to hardness are Fe^{2+}, Mn^{2+}, Strontium (Sr^{2+}) and Aluminium (Al^{3+}).
- But Fe^{2+}, Mn^{2+}, Sr^{2+} Al^{3+} are found in such smaller quantity and hence for all practical purpose hardness may be represented by the sum of Ca^{2+} and Mg^{2+} ions.
- Hardness can be divided in two parts i.e. carbonate hardness and non-carbonate hardness.
- HCO_3^- and CO_3^{2-} of Ca and Mg cause carbonate hardness. It is also called **temporary hardness** because this hardness can be removed by simple boiling of water or by adding lime to water in which calcium carbonate ($CaCO_3$) precipitates.

Remember ∵ Magnesium carbonate ($MgCO_3$) is soluble in water, hence it does not precipitate.

1. Sulphate, chloride and nitrate of calcium and magnesium gives permanent hardness, this type of hardness is also called non-carbonate hardness.
2. Permanent hardness cannot be removed by simple boiling. It requires softening techniques.

Do you know? Magnesium hardness with sulphate ion (> 50 mg/*l*) have laxative effect which may cause loose motion. However, calcium carbonate does not give any health related problem.

- Hardness is commonly defined as the calcium carbonate equivalent of calcium and magnesium ions present in water and is expressed in mg/*l*.
- The hardness in mg/*l* can be determined by determination of amounts of calcium and magnesium ions present in water by filtration.
- Amount of CO^{2+} and Mg^{2+} in water is determined by titration with versanate solution (EDTA method).
- In EDTA method, water is titrated with ethylene diamine tetra-acetic acid using Eriochrome Black T (EBT) as an indicator.

Table: 3.3 Comparison of Hardness

Range (mg/*l*)	Hardness level
0 – 50	Soft
50 – 100	Moderately soft
100 – 150	Slightly hard
150 – 300	Hard
Over 300	Very hard

- EBT forms wine red colour and titration changes the colour to blue.
- If 0.01 M EDTA is used, 1 m*l* of the titrant is equivalent to 1 mg of hardness as $CaCO_3$.
- If $[Ca^{2+}]$ and $[Mg^{2+}]$ is known in mg/litre, total hardness would be equal to

Total hardness (mg/*l* as $CaCO_3$)

$$= \left\{Ca^{2+} \text{ in mg/}l \times \frac{\text{Combining weight of } CaCO_3}{\text{Combining weight of } Ca^{2+}}\right\} + \left\{Mg^{2+} \text{ in mg/}l \times \frac{\text{Combining weight of } CaCO_3}{\text{Combining weight of } Mg^{2+}}\right\}$$

$$= \frac{[Ca^{2+}]\text{mg/}l}{\text{equivalent weight of } Ca^{2+}} \times \text{equivalent weigth of } CaCO_3$$

$$+ \frac{[Mg^{2+}]\text{mg/}l}{\text{equivalent weight of } Mg^{2+}} \times \text{equivalent weight of } CaCO_3$$

∴ The combining weight of Ca^{2+}, Mg^{2+} and $CaCO_3$ are 20, 12 and 50, respectively.

$$\therefore \text{ Total hardness} = [Ca^{2+}] \text{ mg/}l \times \frac{50}{20} + [Mg^{2+}] \text{ mg/}l \times \frac{50}{12}$$

Sometimes, the hardness is expressed in degree of hardness. Each British degree of hardness is equal to 14.25 mg/*l* and America degree of hardness is equal to 17.12 mg/*l*. Comparison of hardness level expressed in mg/*l* as $CaCO_3$ is given in Table 3.3.

Example 3.13 Total hardness (mg/L as $CaCO_3$) present in the water sample 6 mg/*l* of Mg^{2+} and 100 mg/*l* of Ca^{2+} is

(a) 205 (b) 250
(c) 275 (d) 308

Ans. (c)

$$\text{Total hardness} = [Mg^{2+}] \times \frac{\text{eq. wt. of } CaCO_3}{\text{eq. wt. of } Mg^{2+}} + [Ca^{2+}] \times \frac{\text{eq. wt. of } CaCO_3}{\text{eq. wt. of } Ca^{2+}}$$

$$= 6 \times \frac{50}{12} + 100 \times \frac{50}{20} = 275 \text{ mg/L}$$

Do You Know? If the hardness is less than 150 mg/*l*, it is not economical to soften the water. The problems caused by excessive hardness gives rise to formation of scale in boilers and hot water system. Temporary hardness to some extent is preferable. Because water softer than 30 – 50 mg/*l* tend to be corrosive and is likely to corrode pipes into the water supply.

Alkalinity and Hardness: Bicarbonate and carbonate ions in water are usually given by calcium, magnesium and sodium.

- If $NaHCO_3$ and Na_2CO_3 are not present i.e. sodium alkalinity is absent, then carbonate hardness will be equal to alkalinity.
- It will be only possible i.e. sodium alkalinity will be absent only when SO_4^{2-} and Cl^- of calcium and magnesium are present i.e. Non-carbonate hardness is present (because sodium alkalinity will be converted to calcium and magnesium alkalinity).
- This implies that, if non-carbonate hardness is present:

  Carbonate hardness = Alkalinity

- If Non-carbonate hardness is absent, then

  Alkalinity > Carbonate hardness

  So, Total hardness = Carbonate hardness

  Hence, carbonate hardness is equal to total hardness or alkalinity whichever is less.
- Non-carbonate hardness is equal to total hardness in excess of alkalinity.

Permissible Limit: Acceptable limit of total hardness = 300 mg/*l* and cause for rejection = 600 mg/*l*

Example 3.14 Zero hardness of water is achieved by

(a) using lime soda process (b) excess lime treatment
(c) ion exchange method (d) using excess alum dosage

Ans. (c)

Ion exchange process is used for zero hardness water.

A variety of dissolved solids can be removed by ion exchange. For hardness removal zeolite (a naturally occurring sodium alumino-silicate material sometime called green sand) and synthetic resins are used. The removal process is based on high adsorption capacity of calcium and magnesium ions compared to sodium ions. In this process exchange sites are utilized to remove hardness. When all the exchange sites are utilized, hardness begins to appear in the effluent. This is called break through and it necessitates the regeneration of the medium by contacting it with a strong sodium-chloride solution.

Example 3.15 If the methyl orange alkalinity of water equals or exceeds total hardness, all of the hardness is

(a) Non-carbonate hardness (b) Carbonate hardness
(c) Pseudo hardness (d) Negative non-carbonate hardness

Ans. (b)

NOTE: If sodium cation present in water, it imparts pseudo-hardness to the water.

5. Nitrogen Content

The presence of nitrogen in water may be found to occur in one or more of the following forms.

Table 3.4

Type	Indication
1. Free ammonia	Indicates recent pollution
2. Organic ammonia (Alubiminoid)	Indicates quantity of nitrogen before decomposition has started
3. Nitrite	Indicate partly decomposed condition
4. Nitrate	Indicate old pollution (fully oxidised)

- Presence of nitrogen in water indicates presence of organic matter.
- Presence of free ammonia in water indicates its recent pollution. Free ammonia should not be more than 0.15 mg/*l* and it can be measured by simply boiling the water and measuring the liberated ammonia by distillation process.
- The presence of organic ammonia indicates decomposition has just started and limiting value in potable water is 0.3 mg/*l* and it is measured by boiling a sample of already boiled water plus strong alkaline like $KMnO_4$ and measuring the ammonia so liberated.
- Among all form of nitrogen, nitrite is highly dangerous, hence its permissible limit is zero and it is measured by colour matching technique. The colour for nitrite is developed bysulphuric acid + Napthamine
- Nitrate is not harmful because it is fully oxidised. But too much of nitrate affects infants. The reason behind this is it causes blue baby disease or mathemoglobinemia. Nitrate concentration should not be more than 45 mg/*l*.
- Nitrate concentration is measured by colour matching technique. Colour is formed by phenol-di-sulphonic + Potassium hydroxide.
- Free Ammonia + Organic Ammonia = Kjeldahl Ammonia

Do You Know?

- If in the cold water only $KMnO_4$ is added and sample heated then we get both free ammonia as well as organic ammonia.
- In children, nitrate is converted into nitrite in the intestinal which results sucks O_2 from blood and finally baby get turn blue.

6. Chloride Content

Chloride, which is a compound of chlorine with other elements, are present mostly in natural water, agricultural or irrigation discharge and range of concentration are very wide.

- The concentration due to chloride is mostly with sodium i.e. NaC*l* (the common salt) and to some extent with calcium and magnesium. They are the most stable components in water.
- Most of the river and lakes have chloride concentration of chloride less than 50 mg/*l*.
- The presence of chloride in high quantity indicates pollution of water due to sewage or industrial water.
- Chlorides are measured by Mohr's method in which raw water is titrated with standard $AgNO_3$ solution using K_2CrO_4 (Potassium chromate) as indicator.
- Another method to detect the chloride content is argenometric method.

Permissible Limit: Chloride are not detrimental to health but the salt intake (i.e. common salt or NaC*l*) for people suffering from heart or kidney ailment has to be restricted.

Acceptable limit is 200 mg/*l* and cause for rejection is 1000 mg/*l*.

7. Phosphorus

- Phosphorus is non-toxic and do not cause direct health threat.
- But indirectly, phosphorus has threat to water quality because:
  (a) It facilitates fast growth of aquatic plants.
  (b) It interferes with treatment of water like chemical coagulation.
- The very low concentration 0.2 mg/*l* of phosphorus may interfere with the water treatment process.

8. Fluorides

Fluorides occur sometimes naturally in water. If not, it should be added in controlled quantity during treatment process.

- Fluoridation of water supplies to a level of a 1 mg/*l* is safe and effective in reducing dental cavities.
- The greatest advantage against teeth decay is when water is drunk in childhood during the period of tooth formation.
- However, optimum concentration of fluoride has to be controlled because excessive amount leads to fluorosis, which causes decolouration or mottling of teeth and sometime bone damage both in children and adults.
- Greater than 5 mg/*l* cause deformation of bones called bone fluorosis and other skeleton abnormalities.

Permissible Limit: Acceptable limit is upto 1 mg/*l* and greater than 1.5 mg/*l* is cause for rejection.

Example 3.16 The temporary hardness of water is caused by

(a) dissolved carbon dioxide
(b) bicarbonates and carbonates of calcium and magnesium
(c) bicarbonates of sodium and potassium
(d) carbonates of calcium and magnesium

Ans. (b)

Example 3.17 Match List-I (Type of Impurity) with List-II (Harm caused) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Excess of nitrates	1. Brackish water
B. Excess of fluorides	2. Goitre
C. Lack of iodides	3. Fragile bones
D. Excess of chlorides	4. Blue babies

Codes:

	A	B	C	D
(a)	4	2	3	1
(b)	1	2	3	4
(c)	4	3	2	1
(d)	1	3	2	4

Ans. (c)

9. Pesticides

Pesticides cover a wide range of compounds they include inorganic compounds such as copper sulphate, chlorinated hydrocarbon such as DDT, aldrin and lindane.

- Discharge of pesticides in the water course has to be controlled because accidental discharge of pesticides in bulk becomes more serious causing fish death.
- Removal of pesticides are done by oxidative treatment using ozone, chlorine dioxide or potassium permanganate.

NOTE: Removal of pesticides through absorption by activated carbon is most effective.

10. Phenols

Phenol compound in surface water are mainly found due to pollution from industries.

- Effluents from petrochemicals, washing from termac roads, gas liquory are exerted on surface are the main source of phenols.
- Phenols are also found in water from decaying algae - a vegetation.
- Presence of phenols makes water objectionable in taste and odours. Highest desirable of phenol that has been recommended is 0.001 mg/*l*.
- Removal of phenols is done by super chlorinating process, oxidation with ozone or by absorption by activated carbon.

11. Metals

They are classified in two ways:

1. Toxic type 2. Non-toxic type

1. **Toxic type metals:** Example of toxic metals are Arsenic, Barium, Cadmium, Chromium, Cyanide, Lead and Mercury.
2. **Non-toxic type metals:** Example of non-toxic metals are Ca, K, Na, Zn, Mn and Fe.

Sodium: Harmful to some persons with cardiac problem. Excess of Na may be destructive to soils. It is also corrosive to metal surface in large concentration. It is toxic for plants.

Measurement: Measurement is done by atomic absorption spectrophotometry.

Iron and Manganese: Iron and manganese in concentration greater than 0.3 ppm and 0.05 ppm respectively are undesirable as they may cause colouration of clothes washed in such waters.

- They may cause incrustation in water mains due to deposition of ferric hydroxides ($Fe(OH)_3$) and manganese oxide.
- Some bacteria use iron and manganese compounds for an energy source and results in lime formation which may produce taste and odour.

$$Fe(HCO_3)_2 \xrightarrow{\text{Oxidation}} Fe(OH)_3 \downarrow$$

$$FeCl_3 \xrightarrow{\text{Oxidation}} Fe(OH)_3 \downarrow$$

$$FeSO_4 \xrightarrow{\text{Oxidation}} Fe(CH)_3 \downarrow$$

- In similar fashion, manganese also precipitates.
- Iron and manganese posses problems in ground water and bottom layer of lakes but not in surface water. Because surface water has sufficient O_2 and hence precipitate of $Fe(OH)_3$ and MnO_2 will occur.

Permissible Limit: Acceptable limit for Fe is 0.1 – 1.0 mg/*l* and Mn 0.05 – 0.5 mg/*l*.

Copper:

- Essential to humans in small daily amounts (2 mg).
- Its large quantity affects respiratory organs system and lungs.
- Laxative effect has occurred when $CuSO_4$ is greater than 250 mg/*l*.
- Its limit is 0.05 – 1.5 mg/*l*.

Calcium:

- Calcium is very essential for bones and teeth formation.
- The acceptable limit is 75 mg/*l* and cause for rejection is 200 mg/*l*.

Sulphate:

- The main source of sulphate is dissolution of gypsum and other mineral deposits containing sulphates and from industrial effluents.
- Acceptable limit is 200 mg/*l* and cause for rejection is 400 mg/*l*.

Zinc (Zn):

- Zn is very essential nutrient for life.
- At high concentration, zinc is acutely and chronically toxic to aquatic organisms.
- Acceptable limit is 5 mg/*l* and cause for rejection is 15 mg/*l*.

Arsenic:

- Acute or chronic toxicity to humans.
- By product of smelting ores and used in other industries.
- Acceptable limit is 0.01 mg/*l* and cause for rejection is 0.05 mg/*l*.

Cadmium (Cd):

- Cumulative, highly toxic in humans and livestock.
- Affects all life.
- Protects other metals against oxidation. Also used in other industries.
- Its concentration must not be greater than 0.01 mg/*l*.

Chromium (Cr):

- Toxic to human and plants.
- It should not be greater than 0.05 mg/*l*.

Cyanide (CN):

- Cyanides renders tissues incapable of oxygen exchange.
- It should not be greater than 0.05 mg/*l*.
- It is not cumulative and it is biodegradable in streams.

Lead (Pb):

- Cumulative in humans and livestock. Humans absorption of integrated lead is small.
- It is toxic to many organs and tissues including the heart, bones, kidney, intestine, reproductive and nervous systems.

Mercury (Hg):

- Toxic to all types/forms of life.
- Mercury is very slowly excreted from the human body.
- Methyl mercury is 50 times more toxic than inorganic mercury.
- Mercury poisoning cause depression, numbness, sensations, leaky gut syndrome, immune dysfunction etc.
- It should not be greater than 0.001 mg/*l*.

Table 3.5 Summary of Harmful Effects Caused by Various Toxic Elements and Compounds		
S.No.	Substance	Harmful effects
1.	Antimony, Sb	Accumulates in liver and is detrimental to the heart in humans. Can be accumulated by marine organisms.
2.	Arsenic, As	Acute or chronic toxicity to humans. Toxic to all life. By-product of smelting ores and used in other industries
3.	Barium, Ba	Ingested Ba salts are highly toxic to humans. Usually found in trace amounts in natural waters but surface water concentrations are sometimes as high as 0.34 mg/L. May be toxic to plants if present above trace amounts.
4.	Beryllium, Be	Extremely toxic to all life. Usually, naturally present in concentrations less than 0.0001 gm/L in surface waters. Oxides and hydroxides are insoluble within normal pH ranges.
5.	Boron, B	No evidence of accumulation in humans. Large amounts may produce digestive difficulties and nerve disorders.
6.	Bromine, Br	Free bromine (Br_2) is a strong oxidant not found naturally. Bromine salts are harmless.
7.	Cadmium, Cd	Cumulative, highly toxic in humans and livestock. Affects all life. Protects other metals against oxidation.
8.	Chlorine, Cl	Same as bromine
9.	Chromium, Cr	Natural Cr is rare. Cr(VI) is the toxic form to humans. Cr(III) is slowly oxidized to Cr(VI) in waters. Toxic to plants. Varying tolerance to Cr salts in aquatic life.
10.	Cobalt, Co	Low toxicity to humans; essential in trace amounts.
11.	Copper, Cu	Essential to humans in small daily amounts (2.0 mg). Upper limits not determined but water is very distaste-ful at 1-5 mg/L Cu. Essential to all life but is toxic at differing levels to plants and aquatic life.
12.	Cyanide, CN	Cyanide renders tissues incapable of oxygen exchange. It is not cumulative and it is biodegradable in streams. CN^- behaves like halides.
13.	Fluorine, F	Fluoride has been shown to reduce dental caries. Above concentration guidelines there is no further reduction in cavities but mottling increases. Natural F^- concentrations are generally low but wide fluctuations occur.
14.	Lead, Pb	Cumulative in humans and livestock. Human absorption of ingested lead is small; single large doses are not a problem.
15.	Lithium, Li	Higher concentrations cause phytotoxicity.
16.	Mercury, Hg	Toxic to all forms of life. Mercury is very slowly excreted from the human body. Methyl mercury is 50 times more toxic than inorganic mercury.
17.	Molybdenum, Mo	Essential micronutrient. Does not accumulate and humans can tolerate large quantities. Plants accumulate Mo in their foliage but at normal concentrations in water it is not harmful. Some grazing animals, e.g., cattle, sheep and swine exhibit sensitivity to this metal.
18.	Nickel, Ni	Low oral toxicity to humans. Toxic to plants and marine life.
19.	Nitrogen, N and ammonia, NH_3	Non toxic to humans at natural levels. Fish can not large quantities of ammonia.
20.	Nitrate, NO_3^-	Toxic to infants at high concentrations
21.	Nitrite, NO_2^-	Toxic
22.	Organic N	No health effects per se.
23.	Phenol	Taste and odour from these compounds are more sig-nificant than their toxicity. They exhibit direct toxicity to fish.
24.	Selenium, Se	Cumulative poison in humans and animals. Moderately toxic to plants.
25.	Silver, Ag	Cumulative in human tissue resulting in blue-gray discoloration of skin (argyria). Toxic to aquatic organisms.
26.	Sodium, Na	Harmful to some persons with cardiac problems. Destructive to soils
27.	Strontium	The stable isotope is a widespread minor component of igneous rocks. It is similar to calcium and of no health significance. Industrial sources of radioactive strontium are insignificant.
28.	Sulfide, S^{2-}	Undissociated hydrogen sulfide (H_2S) is the toxic entity. Also toxic to aquatic life.
29.	Thallium, Tl	Cumulative poison with sublethal effects such as hair loss and hypertension. Thallium has been shown to inhibit photosynthesis and acts as a neuropoison to fish and aquatic invertebrates.
30.	Tungsten, W	Highly insoluble in water and little information on health effects.
31.	Uranium, U	Uranium and its salts are quite toxic to humans and have also been reported to be toxic to aquatic organisms.
32.	Vanadium, V	Low concentrations are not toxic to humans. Toxicity has been demonstrated in plants.
33.	Zinc, Zn	Relatively non toxic to humans and animals. Essential nutrient for life. Only at high concentrations it has been found toxic to plants. However, zinc is acutely and chronically toxic to aquatic organisms.

12. Dissolved Gases

The various gases which may get dissolved in water due to its contact with the atmosphere or the ground surface may be nitrogen, methane, hydrogen sulphide, CO_2 and O_2.

1. **CH_4:** It is explosive in nature and causes green house effect.
2. **H_2S:** It is produces bad taste and smell to the water and therefore it should be removed.
3. **CO_2:** Its presence indicates biological activities. It imparts bad taste and make water more corrosive.
4. **Nitrogen:** The nitrogen gas is not very important.
5. **O_2:** O_2 is required for respiration of water species and in no case it should be less than 4 mg/*l*. O_2 level less than saturation level indicates oxygen deficiency.

To estimate the deficiency of water 10% solution of $KMnO_4$ is exposed to 27°C for 4 hours and the amount of oxygen absorbed is calculated.

NOTE: At particular temperature, the maximum capacity of water to absorb the O_2 is called saturation capacity.

Remember: Carbon, Nitrogen and Phosphorus are the chief nutrients which helps in growth of plants.

3.3 Presence of Organic

There are two types of organics:
(a) Biodegradable (b) Non-biodegradable

(a) Biodegradable: Biodegradable organics are utilized as food by microorganisms, example-starch, fats, protein, alcohol, acids, aldehydes and esters.

The utilization of dissolved organic is accompanied by:
1. Oxidation 2. Reduction

- Reaction in the presence of oxygen is called aerobic reaction and it is a oxidation reaction.
- Reaction in the absence of oxygen is called anaerobic reaction and it is a reduction reaction.
- Usually, aerobic reaction gives stable and acceptable end product and anaerobic reaction gives unstable and objectionable end product.
- The amount of oxygen consumed during microbial utilization of organics is called BOD (Biochemical oxygen demand).
- BOD will be dealt with detail in waste water engineering.

Do you know? BOD of drinking and treated water should be zero.

(b) Non-Biodegradable: Non-biodegradable organics are lignic acid, cellulose, tanic acid, phenols, detergent compound and industrial waste.

- The constituents of woody plants biodegrades so slowly that they are usually considered non-biodegradable.
- Molecules with exceptionally strong bonds (some of polysaccharides) and ringed structures (benzene) are essentially non-biodegradable like detergent compounds, organic pesticides, industrial chemicals.
- Hydrocarbon combined with chlorine are toxic to organisms hence considered non-biodegradable.
- Pesticides including insecticides and herbicides, have found wide-spread use in modern society in both urban and agricultural settings.
- Organic insecticides are usually chlorinated hydrocarbons (i.e. aldrin, dieldrin, endrin and lindane), while pesticides are usually chlorophenoxy (e.g. 2, 4-dichlorophenoxy acetic acid and 2, 4, 5-trichlorophenoxy-propionic acid).
- Many of the pesticides are cumulative toxins and cause severe problems at the higher end of food chain.
- An example is the near-extinction of the brown pelican that feeds on fish and other macroaquatic species by the insecticides DDT, the use of which is now banned in the United States.

- Measurement of non-biodegradable organics is usually by the chemical oxygen demand (COD).
- Non-biodegradable organics may also be estimated from a total organic carbon (TOC) analysis.
- COD measure the biodegradable fraction of the organics, so the BOD_u must be subtracted from the COD or TOC to quantify the non-biodegradable organics.
- Both COD also measures biodegradable organics. COD is determined by mixing the sample with very strong oxidizing agent like $K_2Cr_2O_7$ which oxides all organic matter.
- Non-biodegradable organics = COD − BOD_u.
- COD = Total biodegradable BOD + Total non-biodegradable BOD.

NOTE: COD is also sometimes called dichromate demand.
- Specific organic compounds can be identified and quantified through analysis by gas chromatography.

Type of Aquatic Plants

These are classified as:
1. Spermophyta → Waterweeds
2. Bryophyte → Mosses
3. Peteridophyta → Ferms and hortails
4. Thallophyta → Algae (Photosynthesis plants)

Type of Aquatic Animals

These are following types:
1. Vertebrata → Fish and Amphibian
2. Mollusca → Snails, sludge and lymplets
3. Orthopoda → Insets, spiders, slugs
4. Worms → Rotifera or thread worms
5. Metazoa → Polyzoa and Hydra
6. Protozoa → Entamoeba histolytica

3.4 Biological Water Quality Parameter

Those microorganism which are harmful for human and animal are called pathogens.

- These are capable of infecting and transmitting the diseases to human being.
- Example of pathogens are bacteria, virus, protozoa and helminths.

Bacteria: Among all living things, either in plant or animal kingdom, bacteria are the smallest visible forms.

- They belong to group of organisms known as "Fission fungi" (Schizomycetes) and reproduce by direct splitting of a parent cell into two daughter cells and not by any complicated reproductive process.
- All of them with a few exception, use organic carbon because they are devoid of chlorophyll and hence, are unable to obtain their carbon from carbon dioxide (CO_2) through energy obtained from sunlight as green plants do.

Bacteria are grouped under four categories based on their shapes as given below:
1. Rod or cylinder shaped – Bacilli (Singular-Bacillus)
2. Spherical shaped – Cocci (Singular-Coccus)
3. Spiral shaped – Spirilla (Singular-Spirillum)
4. Comma shaped – Vibrio (Singular-Vibrium)

- Testing and counting of pathogenic bacteria can be done but only with great difficulty. Hence, these tests are not performed generally in routine.

- The usual routine tests are generally conducted to detect and count the presence of coliforms, which themselves are harmless aerobic lacteal fermentery organisms but their presence or absence indicates the presence and absence of pathogenic bacteria.
- Coliforms also known as bacteria coli (B-coli) or Escherichia coli (E-coli) are important harmless aerobic microorganisms, which are found residing in the intestine of all warm blooded animals including human beings, therefore, are excreted with their faces.
- Since they are harmless organisms to coliform group live longer in water than the pathogenic bacteria. It is generally presumed that the water will be safe and free from pathogenic bacteria if no coliform bacteria are present in it.

The tests for coliforms are:

1. Membrance filter technique
2. MPN test (Most probable number)
3. Coliform Index

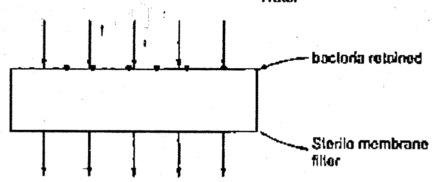


Fig. 3.6 Membrance filter Technieque

1. **Membrane Filter Technique:** The simplest and the most recent method adopted for detecting and measuring the presence of coliform bacteria is to filter the water sample through a sterile membrane of special design (i.e. porosity 80%, pore size), on which the bacteria will be retained if at all present.
   - Water sample is poured on the sterile membrane filter.
   - In this, membrane is than put in contact with nutrients (M-endo medium) that permits the growth of only coliform colony.
   - After incubation for 20 hrs number of visible colonies are counted. No visible colonies should be detectable in any 100 m*l* sample.
   - Coliform bacteria will produce characteristic colonies, which are pink to dark red with golden metallic sheen, often with greenish first. Non-coliform bacteria which grow in this medium will lack the characteristic sheen.

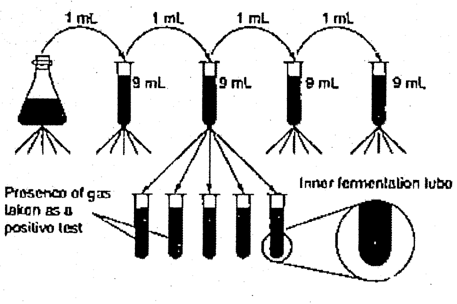


Fig. 3.7 Membrance Filter Technique

2. **Most Probable Number (By Multiple Tube Fermentation):**
   - Most Probable number is a number, which represents the bacterial density, which is most likely to be present in the water.
   - Different dilution of sample of water is mixed with lactose broth and incubated in test tubes for 48 hours at 37°C.
   - The presence of acid or carbon dioxide gas in the test tubes indicates the presence of coliform bacteria.
   - The coliform actually is gram-negative, non-spore forming, rod shaped bacteria that ferment lactose and the end products are acid and CO_2.
   - Then referring to standard table MPN of E-coli per 100 m*l* water is found out.
   - MPN represents bacterial density which is most likely to be present.
   - Say 10 m*l*, 1 m*l* and 0.1 m*l* dilution samples are taken and 5 number of test tubes with each dilution are tested. If positive test is seen in 4 number of 10 m*l* sample, 2 number of 1 m*l* and 2 number of 0.1 m*l* sample then from the standard table MPN/100 obtained from series 4-2-2.
   - If sample size is taken of 1 m*l*, 0.1 m*l* and 0.01 m*l* then MPN/100 obtained from table of (10 m*l*, 1 m*l*, 0.1 m*l*) is multiplied by 10 to get actual value.
   - If more than three dilution samples are available then the dilution chosen for MPN calculation should be three consecutive dilution which shows dilution of organisms to extinction (i.e. max +ve results to minimum results in three consecutive dilutions).
   - When tables are not available, then Thomas equation can be used to estimate the MPN

$$\text{MPN/100 m}l = \frac{\text{Number of positive tube} \times 100}{\sqrt{(\text{m}l \text{ of sample in negative tube}) \times (\text{m}l \text{ of sample in all tube})}}$$

- In applying the Thomas equation, the count of positive tubes should begin with the highest dilution in which at least one negative results has occurred.

Example 3.18 Determine the MPN using the Thomas equation

Size of Sample(m*l*)	Number of Positive	Number of Negative
1	4	1
0.1	3	2
0.01	2	3
0.001	0	5

Solution:

Number of the tube = 4 + 3 + 2 = 9

m*l* of sample in negative tube = 1 × 1 + 2 × 0.1 + 3 × 0.01 + 5 × 0.001 = 1.235

m*l* of sample in all tube = 5 × 1 + 5 × 0.1 + 0.01 × 5 + 0.001 × 5 = 5.555

$$\text{MPN/100 m}l = \frac{9 \times 100}{\sqrt{1.235 \times 5.555}} = 344$$

3. **Coliform Index:** It is defined as the reciprocal of smallest quantity of a sample which will give 1 positive B-coli test.

NOTE: MPN and B-coli index are now absolute. Now-a-days, we use membrane filter technique.

Diseases Disseminated by Water Supplies i.e. Water Borne Diseases

Water borne disease are those disease which spread primarily through contaminated waters and the important water borne disease are:

1. **Disease Caused by Bacteria Infections**

   (*i*) Typhoid fever and paratyphoid fever (caused by Salmonella typhi Bacteria)

(*ii*) Cholera (caused by vibrio-cholera bacteria)
(*iii*) Bacillary dysentery (caused by Shiga bacillus or flaner bacillus or sonne bacillus)

2. **Disease Caused by Viral Infections**
   (*i*) Infectious hepatitis or infectious Jaundice (caused by hepatitis virus)
   (*ii*) Poliomyelitis (caused by polio virus)

3. **Disease Caused by Protozoal Infections**
   (*i*) Amoebic dysentery (caused by entamoeba hystalica germ)
   (*ii*) Giardiasis (caused by Giardia Lamblia)

4. **Diseases Caused by Helminths (Parasitic Worms)**
   (*i*) Echinococcosis (hydatidosis, granulosuy dog tapeworms) – (caused by Echinoccoccus)
   (*ii*) Schistosomiasis or Billhorris (caused by Schistosoma)

Example 3.19 Match List-I with List-II and select the correct answer using the codes given below the lists.

List-I		List-II	
A.	Protozoa	1.	Methaemoglobinemia
B.	Bacteria	2.	Poliomyelitis
C.	Presence of nitrate > 45 mg/L	3.	Dysentry
D.	Virus	4.	Typhoid fever

	A	B	C	D
(a)	3	2	1	4
(b)	1	4	3	2
(c)	3	4	1	2
(d)	1	2	3	4

Ans. (c)

Example 3.20 Match List-I (Equipment) with List-II (Parameter) and select the correct answer using the codes given below the lists.

List-I		List-II	
A.	Tintometer	1.	Temperature
B.	Nephelometer	2.	Colour
C.	Imhoff cone	3.	Settleable solids
D.	Muffle furnace	4.	Volatile solids
		5.	Turbidity

	A	B	C	D
(a)	4	3	1	5
(b)	2	5	3	4
(c)	4	5	1	3
(d)	2	5	4	3

Ans. (b)

Nuissance Bacteria

(*i*) **Iron Bacteria:** It causes pitting and tuberculation in pipes and renders water unsuitable for industrial purposes.

(*ii*) **Sulphur Bacteria:** Acid produced during their metabolism is destructive to concrete and other structure.

Table 3.8 Indian Standards for Drinking Water

Parameters	Permissible Limit	Cause for rejection
Total suspended solids	500	2000
Turbidity (NTU)	1	10
Colour (TCU)	5	25
Taste & odour (TON)	1	3
Chemical		
Total dissolved solid (mg)	500	2000
Alkalinity (mg/l)	200	600
pH	7 – 8.5	< 6.5 & > 9.2
Hardness (mg/l)	200	600
Chloride content (mg/l)	250	1000
Free ammonia (mg/l)	0.15	0.15
Organic ammonia (mg/l)	0.3	0.3
Nitrate (mg/l)	45	45
Nitrite (mg/l)	0	0
Fluoride content (mg/l)	1	1.5
Iron as Fe (mg/l)	0.1	1.0
Manganese as Mn (mg/l)	0.05	0.5
Copper as Cu (mg/l)	0.05	1.5
Zinc as Zn (mg/l)	5.0	15.0
Phenolic compound as phenol (mg/l)	0.001	0.002
Mineral Oil (mg/l)	0.01	0.3
Arsenic (mg/l)	0.01	0.05
Sulphate (mg/l)	200	400
Calcium (mg/l)	75	200
Mercury (mg/l)	0.001	0.001

Illustrative Examples

Example 3.21 The chemical analysis of a water indicates the presence of cations as Na^+ = 20 mg/L; Mg^{++} = 60 mg/L; Ca^{++} = 45 mg/L. Compute the hardness (as equivalent of $CaCO_3$). The combining weights of Ca, Mg and $CaCO_3$ are 20, 12 and 50 respects.

Solution:

Hardness is due to multixalent cations.

Total hardness in mg/*l* as $CaCO_3$

$$= \left[Ca^{++} \text{ in mg/}l \times \frac{\text{Combining weight of } CaCO_3}{\text{Combining weight of } Ca^{++}}\right]$$

$$+ \left[Mg^{++} \text{ in mg/}l \times \frac{\text{Combining weight of } CaCO_3}{\text{Combining weight of } Mg^{+}}\right]$$

$$= \left[45 \times \frac{50}{20} + 60 \times \frac{50}{12}\right] = 112.5 + 250 = 362.5 \text{ mg/}l$$

Important Expressions

1. Threshold odour number (TON) = $\frac{A+B}{A}$ when, A = Volume of water sample undiluted
   B = Volume of distilled water required to be added to remove the odour
2. Equivalent weight = $\frac{\text{Moleculer weight}}{\text{Valencey}}$
3. Gram equivalent = $\frac{\text{Weight in gram}}{\text{Equivalent weight}}$
4. Total hardenss = $\frac{[Ca^{2+}]\text{mg/}l}{\text{Equi. wt. of Ca}} \times \text{Equi. wt. of } CaCO_3 + \frac{[Mg^{2+}]\text{ mg/}l}{\text{Equi. wt of Mg}} \times \text{Equi. wt. of } CaCO_3$
5. Total hardness = $[Ca^{2+}] \times \frac{50}{20} + [Mg^{2+}] \times \frac{50}{12}$
6. Thomas equation, MPN/100 m*l* = $\frac{\text{Number of positive tube} \times 100}{\sqrt{(\text{m}l \text{ of sample in negative tube}) \times (\text{m}l \text{ of sample in all tube})}}$
7. Photosynthesis reaction in green plants,
   CO_2 + Chlorophyll + Solar energy = Plant tissue + Oxygen

Summary

1. The maximum permissible and colour limit for public water supply is 20 on cobalt scale, it should be preferably less than 10.
2. Water having low pH value have tendency of corrosion and if it is very low, the taste will be acidic or sour and will be unacceptable.
3. Acidity in an unpolluted water is usually due to dissolved carbon dioxide, which produces weak carbonic acid.
4. Copper salts are used to control algal growth in reservoirs.
5. The radioactive substances in water may contain trace of isotope of potassium (40 K), sodium and uranium.
6. One hundred million live typhoid organisms may be present in a glass of drinking water without causing any noticeable turbidity and one millionth of that quantity of typhoid organisms may cause typhoid fever if taken in a glass of water.
7. Viruses differ from bacteria in the fact that they are much smaller and they multiply only when suitable host cells in which they produce changes, which give rise to a range of disease.
8. Leptospirosis: Diseases of this group which vary from mild fever to severe Jaundice are caused by numerous serogroups of the motile spiral organisms known as Leptospira. They commonly infect rats, dogs, pigs and other vertebrates and are shed in the urine of these animals.
9. Typhoid, Jaundice and Cholera are known as water borne disease because they are caused in epidemic form due to drinking of polluted water.
10. In virological, quality of drinking water should be free from viruses which causes diseases to the consumers. It is a costly test and is done for examination for plague forming unit (PFU) of virus.
11. Modified Winkler method: The dissolved oxygen in a water sample is generally estimated by modified Winkler method. The water sample is taken in a 300 m*l* BOD bottle and the dissolved oxygen is fixed by adding 1 m*l* of conc. of H_2SO_4 followed by addition of 1 m*l* of alkali-iodide-azide reagent and then the contents mixed thoroughly thereafter waiting for 5-10 minutes and then 1 m*l* of $MnSO_4$ reagent is added.

Objective Brain Teasers

Q.1 The pH of water admitted into a treatment plant was 6.0 in the morning. Consequent to inflow of raw water from a different source, it changed to 8.0 in the next 24 hours. Assuming linear variation in time of the hydrogen ion concentration, the time mean pH value of the water over this 24 hour period is.......

Q.2 Methemoglobinemia, the 'blue baby' syndrome is caused by consuming water containing excess of

(a) fluoride (b) phosphate

(c) nitrate (d) nitrite

Q.3 Hardness of water is caused by the presence of which of the following in water?

(a) Chlorides and Suplhates
(b) Calcium and Magnesium
(c) Nitrites and Nitrates
(d) Sodium and Potassium

Q.4 A rapid test to indicate the intensity of pollution in river water is
(a) Biochemical Oxygen Demand
(b) Dissolved Oxygen
(c) MPN
(d) Total Dissolved Solids

Q.5 Bacteriological examination of drinking water for Escherischia Coliforms (E.Coli) is performed because
(a) they are pathogenic causing intestinal diseases
(b) their presence indicates viral contamination of water
(c) they are used as indicator organisms for probable presence of pathogens
(d) they represent unique indicator organism for sewage pollution

Q.6 The most important water quality parameter for domestic use of water is
(a) carbonate hardness
(b) non-carbonate hardness
(c) coliform group of organisms
(d) chlorides

Q.7 Presence of fluoride in water greater than permissible level of 1.5 mg/L causes
(a) cardiovascular disease
(b) methemoglobinemia
(c) hepatitis
(d) dental fluorosis

Q.8 Alkalinity of water can be defined correctly in one of the following ways
(a) it is the measure of ability of water to neutralize oxygen
(b) it is the measure of ability of water to neutralize carbonates
(c) it is the presence of ions in water that will neutralize hydrogen ions
(d) it is the measure of ability of water to neutralize hydroxides

Q.9 MPN index is a measure of one of the following
(a) Coliform bacteria
(b) BOD_5
(c) Dissolved Oxygen content
(d) Hardness

Q.10 The microbial quality of treated piped water supplies is monitored by
(a) Microscopic examination
(b) Plate count of heterotrophic bacteria
(c) Coliform MPN test
(d) Identification of all pathogens

Q.11 Excessive fluoride in drinking water causes
(a) Alzheimer's disease
(b) Mottling of teeth and embrittlement of bones
(c) Methamoglobinemia
(d) Skin cancer

Q.12 Temporary hardness in water is caused by the presence of
(a) Bicarbonates of Ca and Mg
(b) Sulphates of Ca and Mg
(c) Chlorides of Ca and Mg
(d) Nitrates of Ca and Mg

Q.13 The Ca^{2+} concentration and Mg^{2+} concentration of a water sample are 160 mg/lit and 40 mg/lit as their ions respectively. The total hardness of the water sample in terms of $CaCO_3$ in mg/lit is approximately equal to
(a) 120 (b) 200
(c) 267 (d) 567

Q.14 In natural water, hardness is mainly caused by
(a) Ca^{++} and [illegible] (b) Ca^{++} and Fe^{++}
(c) Na^{+} and K^{+} (d) Ca^{++} and Mg^{++}

Q.15 The results of analysis of a raw water sample are given below:

Turbidity	:	5 mg/L
pH	:	7.4
Fluorides	:	2.5 mg/L
Total Hardness	:	300 mg/L
Iron	:	3.0 mg/L
MPN	:	50 per 100 mL

From the data given above, it can be inferred that water needs removal of
(a) turbidity followed by disinfection
(b) fluorides and hardness
(c) iron, followed by disinfection
(d) fluorides, hardness and iron followed by disinfection

Q.16 Results of a water sample analysis are as follows:

Cation	Concentration (mg/L)	Equivalent Weight
Na^{+}	40	23
Mg^{+2}	10	12.2
Ca^{+2}	55	20
K^{+}	52	39

(milliequivalent weight of $CaCO_3$ = 50 mg/meq). Hardness of the water sample in mg/L as $CaCO_3$ is
(a) 44.8 (b) 89.5
(c) 179 (d) 358

Q.17 Hardness of water is directly measured by titration with ethylene-di-amine-tetracetic acid (EDTA) using
(a) eriochrome black T indicator
(b) ferroin indicator
(c) methyl orange indicator
(d) phenolphthalein indicator

Q.18 The organism, which exhibits very nearly the characteristics of an ideal pathogenic indicator is
(a) Entamoeba histolytica
(b) Escherichia coli
(c) Salmonella typhi
(d) Vibrio comma

Q.19 A standard multiple-tube fermentation test was conducted on a sample of water from a surface stream. The results of the analysis for the confirmed test are given below.

Sample size (mL)	No. of positive results out of 5 tubes	No. of negative results out of 5 tubes
1.0	4	1
0.1	3	2
0.01	1	4

MPN index and 95% confidence limits for combination of positive results when five tubes used per dilutions (10 mL, 1.0 mL, 0.1 mL)

Combination of positive	MPN index per 100 mL	95% confidence limit	
		Lower	Upper
4-2-1	26	12	65
4-3-1	33	15	77

Using the above MPN index table, the Most Probable Number (MPN) of the sample is
(a) 26 (b) 33
(c) 260 (d) 330

Q.20 Total Kjeldahl nitrogen is a measure of
(a) total organic nitrogen
(b) total organic and ammonia nitrogen
(c) total ammonia nitrogen
(d) total inorganic and ammonia nitrogen

Q.21 1 TCU is equivalent to the colour produced by
(a) 1 mg/L of chloroplatinate ion
(b) 1 mg/L of platinum ion
(c) 1 mg/L platinum in form of chloroplatinate ion
(d) 1 mg/L of organo-chloroplatinate ion

Q.22 If tomato juice is having a pH of 4.1, the hydrogen ion concentration will be
(a) 10.94×10^{-5} mol/L (b) 9.94×10^{-5} mol/L
(c) 8.94×10^{-5} mol/L (d) 7.94×10^{-5} mol/L

Q.23 Match List-I with List-II and select the correct answer using the codes given below the lists:
List-I
A. Release valve
B. Check valve
C. Gate valve
D. Pilot valve

List-II

1. Reduce high inlet pressure to lower outlet pressure
2. Limit the flow of water to single direction
3. Remove air from the pipeline
4. Stopping the flow of water in the pipeline

Codes:

	A	B	C	D
(a)	3	2	4	1
(b)	4	2	1	3
(c)	3	4	2	1
(d)	1	2	4	3

Q.24 A synthetic sample of water is prepared by adding 100 mg Kaolinite (a clay mineral), 200 mg glucose, 168 mg NaCl, 120 mg $MgSO_4$, and 111 mg $CaCl_2$ to 1 liter of pure water. The concentrations of total solids (TS) and fixed dissolved solids (FDS) respectively in the solution in mg/L are equal to

(a) 699 and 599 (b) 599 and 399
(c) 699 and 199 (d) 699 and 399

Q.25 The presence of hardness in excess of permissible limit causes

(a) cardio-vascular problems
(b) skin discolouration
(c) calcium deficiency
(d) increased laundry expenses

Q.26 The alkalinity and the hardness of a water sample are 250 mg/L and 350 mg/L as $CaCO_3$, respectively. The water has

(a) 350 mg/L carbonate hardness and zero non-carbonate hardness
(b) 250 mg/L carbonate hardness and zero non-carbonate hardness
(c) 250 mg/L carbonate hardness and 350 mg/L non-carbonate hardness
(d) 250 mg/L carbonate hardness and 100 mg/L non-carbonate hardness

Q.27 A wastewater sample contains $10^{-5.6}$ mmol/L of OH^- ions at 25°C. The pH of this sample is

(a) 8.6 (b) 8.4
(c) 5.6 (d) 5.4

Q.28 Match List-I (Estimation method) with List-II (Corresponding indicator) and select the correct answer using the codes given below the lists:

List-I

A. Azide modified Winkler method for dissolved oxygen
B. Dichromate method for chemical oxygen demand
C. EDTA titrimetric method for hardness
D. Mohr or Argentometric method for chlorides

List-II

1. Eriochrome Black T
2. Ferroin
3. Potassium chromate
4. Starch

Codes:

	A	B	C	D
(a)	3	2	1	4
(b)	4	2	1	3
(c)	4	1	2	3
(d)	4	2	3	1

Q.29 In a water sample total hardness is 205 mg/l and alkalinity is 300 mg/l. Carbonate hardness (mg/L as $CaCO_3$) present in the above water sample is

(a) 205 (b) 250
(c) 275 (d) 289

Q.30 Anaerobically treated effluent has MPN of total coliform as 10^6/100 mL. After chlorination, the MPN value declines to 10^2/100 mL. The percent removal (%R) and log removal (log R) of total coliform MPN is

(a) %R = 99.90; log R = 4
(b) %R = 99.90; log R = 2
(c) % R = 99.99; log R = 4
(d) % R = 99.99; log R = 2

Q.31 Chlorine gas (8 mg/L as Cl_2) was added to a drinking water sample. If the free chlorine residual and pH was measured to be 2 mg/L (as Cl_2) and 7.5, respectively, what is the concentration of residual OCl^- ions in the water? Assume that the chlorine gas added to the water is completely converted to HOCl and OCl^-. Atomic Weight of Cl: 35.5

Given: $OCl^- + H^+ \overset{K}{\rightleftharpoons} HOCl$, K = $10^{7.5}$

(a) 1.408×10^{-5} moles/L
(b) 2.817×10^{-5} moles/L
(c) 5.634×10^{-5} moles/L
(d) 1.127×10^{-4} moles/L

Q.32 A water sample has a pH of 9.25. The concentration of hydroxyl ions in the water sample is

(a) $10^{-9.25}$ moles/L (b) $10^{-4.75}$ mmoles/L
(c) 0.302 mg/L (d) 3.020 mg/L

Q.33 If the total hardness and alkalinity of a sample of water are 300 mg/L and 100 mg/L ($CaCO_3$ scale) respectively, then its carbonate and non-carbonate hardness (in units of mg/L) will be respectively

(a) 100 and 200 (b) 400 and 300
(c) 100 and 400 (d) 400 and zero

Q.34 Which one of the following would contain water with the maximum amount of turbidity?

(a) Lakes (b) Oceans
(c) Rivers (d) Wells

Q.35 Eutrophication of water bodies is caused by the

(a) discharge of toxic substances
(b) excessive discharge of nutrients
(c) excessive discharge of suspended solids
(d) excessive discharge of chlorides

Q.36 Match List-I (Parameters) with List-II (Permissible concentration in drinking water) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Hardness	1. 0.1 mg/L
B. Nitrate concentration	2. 1.5 mg/L
C. Iron concentration	3. 200 mg/L
D. Fluoride concentration	4. 45 mg/L

Codes:

	A	B	C	D
(a)	3	4	2	1
(b)	3	4	1	2
(c)	4	3	2	1
(d)	4	3	1	2

Q.37 Which of the following determinations are NOT necessary for raw water from a lake for use as source of supply of water for boiler-feed?

1. Turbidity 2. Bacterial count
3. Iron 4. Hardness

Select the correct answer using the codes given below:

(a) 1, 2 and 3 (b) 1, 2 and 4
(c) 1, 3 and 4 (d) 2, 3 and 4

Q.38 Which of the following is/are the characteristic(s) of coliform organism?

1. Bacillus
2. Gram-negative
3. Ferments lactose
4. Spore-forming

Select the correct answer using the codes given below:

(a) 1 alone (b) 1, 2 and 4
(c) 1, 2 and 3 (d) 2, 3 and 4

Q.39 Consider the following statements:

Some amount of chlorides is allowed in drinking water because

1. it helps in killing bacteria
2. small quantity of chlorides adds to the taste
3. it is not injurious to human health
4. it is not economical to remove it completely

Which of these statements are correct?

(a) 1, 2 and 4 (b) 1, 2 and 3
(c) 2, 3 and 4 (d) 1, 3 and 4

Q.40 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I

A. Protozoa
B. Bacteria
C. Presence of nitrate>45 mg/L
D. Virus

List-II

1. Methaemoglobinemia
2. Poliomyelitis
3. Dysentry
4. Typhoid fever

Codes:

	A	B	C	D
(a)	3	2	1	4
(b)	1	4	3	2
(c)	3	4	1	2
(d)	1	2	3	4

Q.41 Which one of the following organisms is responsible for enteric fever?
(a) ECHO
(b) Salmonella typhi
(c) Entamoeba histolytica
(d) Echinococcus

Q.42 Match List-I (Type of impurity) with List-II (Effect) and select the correct answer using the codes given below the lists:

List-I
A. Carbonates and bicarbonates of calcium and magnesium
B. Carbonates and bicarbonates of sodium
C. Sulphates and chlorides of calcium and magnesium
D. Oxides of iron and manganese

List-II
1. Permanent hardness
2. Temporary hardness
3. Alkalinity and softness
4. Colour and taste

Codes:

	A	B	C	D
(a)	1	3	2	4
(b)	2	4	1	3
(c)	1	4	2	3
(d)	2	3	1	4

Q.43 Which of the following are associated with alum coagulation?
1. A decrease in alkalinity of treated water
2. Formation of hydroxide flocs of aluminium
3. A slight decrease in pH of treated water
4. An increase in permanent hardness

Select the correct answer using the codes given below:
(a) 1, 2 and 3 (b) 1, 3 and 4
(c) 1, 2, 3 and 4 (d) 2 and 4

Q.44 What is the equivalent calcium carbonate concentration of 110 mg/L of $CaCl_2$?
(a) 50 mg/L (b) 58.5 mg/L
(c) 100 mg/L (d) 117 mg/L

Q.45 Which of the following cations impart(s) pseudo-hardness to water?
(a) Calcium only
(b) Magnesium only
(c) Calcium and magnesium
(d) Sodium

Q.46 After which of the following treatment units, the turbidity is maximum?
(a) Chlorination
(b) Primary sedimentation
(c) Flocculation basin
(d) Secondary sedimentation

Q.47 What is the most common cause of acidity in water?
(a) Carbon monoxide
(b) Nitrogen
(c) Hydrogen
(d) Carbon dioxide

Q.48 If total hardness and alkalinity of a water sample are 200 mg/L as $CaCO_3$ and 260 mg/L as $CaCO_3$ respectively, what are the values of carbonate hardness and non-carbonate hardness?
(a) 200 mg/L and zero
(b) Zero and 60 mg/L
(c) Zero and 200 mg/L
(d) 60 mg/L and zero

Q.49 Match List-I (Process/Bacteria) with List-II (Energy/Material) and select the correct answer using the codes given below the lists:

List-I
A. Anabolism
B. Autotrophs
C. Catabolism
D. Heterotrophs

List-II
1. Providing energy for the synthesis of new cells and maintenance of other cell functions
2. Obtaining energy and material for growth from organic sources
3. Providing the material necessary for cell growth
4. Obtaining energy and material for growth from inorganic sources

Codes:

	A	B	C	D
(a)	1	4	3	2
(b)	3	2	1	4
(c)	1	2	3	4
(d)	3	4	1	2

Q.50 Hardness to water is caused by the presence of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions. Which are the least soluble forms of calcium and magnesium at normal water temperature?
(a) $CaCl_2$ and $MgCO_3$
(b) $Ca(HCO_3)_2$ and $MgCl_2$
(c) $Ca(OH)_2$ and $Mg(HCO_3)_2$
(d) $CaCO_3$ and $Mg(OH)_2$

Q.51 Match List-I (Pathogen) with List-II (Epidemic) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Bacteria	1. Gastroenteritis
B. Virus	2. Cholera
C. Protozoa	3. Worms
D. Helminth	4. Polio

Codes:

	A	B	C	D
(a)	2	4	1	3
(b)	3	1	4	2
(c)	2	1	4	3
(d)	3	4	1	2

Q.52 Match List-I (Parameters) with List-II (Units) and select the correct answer using the code given below the lists:

List-I	List-II
A. Turbidity	1. TON
B. Pathogen	2. TCU
C. Odour	3. JTU
D. Colour	4. MPN

Codes:

	A	B	C	D
(a)	2	1	4	3
(b)	3	1	4	2
(c)	2	4	1	3
(d)	3	4	1	2

Q.53 The maximum safe permissible limit of sulphates in domestic water supply is
(a) 100 mg/L (b) 200 mg/L
(c) 500 mg/L (d) 600 mg/L

Q.54 One Nephelometry Turbidity Unit (NTU) is equal to the turbidity produced by
(a) 1 mg SiO_2 dissolved in 1 *l* of distilled water with the test being run according to absorption principle.
(b) 1 mg SiO_2 dissolved in 1 *l* of distilled water with the test being run according to scattering principle.
(c) 1 mg Formazin dissolved in 1 *l* of distilled water with the test being run according to absorption principle.
(d) 1 mg Formazin dissolved in 1 *l* of distilled water with the test being run according to scattering principle.

Q.55 The dissolved oxygen in a water sample is generally estimated by modified Winkler method. The water sample is taken in a 300 m*l* BOD bottle and the dissolved oxygen is fixed by adding
(a) 1 m*l* of conc. H_2SO_4 followed by addition of 1 m*l* of $MnSO_4$ reagent and contents mixed thoroughly, thereafter waiting for 5-10 minutes, and then 1 m*l* of alkali-iodide-azide reagent is added.
(b) 1 m*l* of alkali-iodide-azide reagent followed by addition of 1 m*l* of conc. H_2SO_4 and then the contents mixed thoroughly, thereafter waiting for 5-10 minutes, 1 m*l* of $MnSO_4$ regent is added.
(c) 1 m*l* of $MnSO_4$ followed by addition of 1 m*l* of alkali-iodide-azide reagents and then the contents mixed thoroughly, thereafter waiting for 5-10 minutes and then 1 m*l* of conc. H_2SO_4 is added.

(d) 1 ml of conc. of H_2SO_4 followed by addition of 1 ml of alkali-iodide-azide reagent and then the contents mixed thoroughly, thereafter waiting for 5-10 minutes and then 1 ml of $MnSO_4$ reagent is added.

Q.56 Consider the following statements:

1. Typhoid fever is caused by viral infection.
2. Infectious hepatitis is caused by bacterial infection.
3. Cholera is caused by bacteria.
4. Amoebic dysentery is caused by protozoal infection.

Which of these statements are correct?

(a) 1, 2, 3 and 4 (b) 1, 2 and 3 only
(c) 3 and 4 only (d) 2 and 3 only

Directions : Each of the next items consists of two statements, one labeled as the 'Statements (I)' and the other as 'Statement (II)'. You are to examine these two statements carefully and select the answers to these items using the codes given below :

Codes:

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

Q.57 Statement-I : Fluoride concentrations of approximately 1.0 mg/l in drinking water help to prevent dental cavities in children.
Statement-II : During formation of permanent teeth, fluoride combines chemically with tooth enamel resulting in softer and weaker teeth that are less resistant to decay.

Q.58 Statement-I : Virus is living organisms in a natural environment including soil.
Statement-II : Virus comes to life after entering the host tissue through contamination.
Virusus are the smallest biological structure, containing all information necessary for its reproduction. They are obligate parasites, and as such, require a host in which to live.

Q.59 Statement-I : The ability of water to conduct electricity, known and measured as the specific conductance, and concentration of total dissolved solids are not relatable on a one-to-one basis.
Statement-II : Many organic molecules and compounds dissolve in water without ionizing and hence are not taken into account while measuring specific conductance.

Q.60 Statement-I: Water with heavy algal growth often has pH values as high as 9 to 10.
Statement-II: Non-utilization of the bicarbonate ion as a carbon source by algae can result in substantial accumulation of OH^- ions.

Q.61 Statement-I: Alum is the most commonly used coagulant in water treatment.
Statement-II: Alum is very effective in killing pathogens present in water.

Q.62 Statement-I: Fluorides should always be present in drinking water upto a value 1.5 mg/l.
Statement-II: Such a water helps clean the teeth well.

Q.63 Statement (I): 'Environment' includes abiotic and biotic parameters.
Statement (II): Abiotic parameters include algae, bacteria, animals; and biotic parameters are air, water and soil.

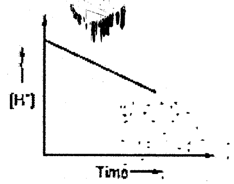
Answers

2. (c)	3. (b)	4. (b)	5. (c)	6. (c)
7. (d)	8. (c)	9. (a)	10. (c)	11. (b)
12. (a)	13. (d)	14. (d)	15. (d)	16. (c)
17. (a)	18. (b)	19. (d)	20. (b)	21. (c)
22. (d)	23. (a)	24. (d)	25. (d)	26. (d)
27. (d)	28. (b)	29. (a)	30. (c)	31. (a)
32. (c)	33. (a)	34. (c)	35. (b)	36. (b)
37. (a)	38. (c)	39. (c)	40. (c)	41. (b)
42. (d)	43. (c)	44. (c)	45. (d)	46. (c)
47. (d)	48. (a)	49. (d)	50. (d)	51. (a)
52. (d)	53. (b)	54. (d)	55. (c)	56. (c)
57. (c)	58. (d)	59. (a)	60. (c)	61. (b)
62. (c)	63. (c)			

Hints and Explanations:

Sol. 1

Given, initial pH value = 6.0
after 24 hour, pH = 8.0



$$[H^+]_{at\ t=0} = 10^{-6}$$
$$[H^+]_{t=24\,hr.} = 10^{-8}$$

$$\therefore \text{Mean of } [H^+] = \frac{10^{-6}+10^{-8}}{2} = \frac{10^{-6}(1+10^{-2})}{2} = \frac{1.01\times10^{-6}}{2} = 0.50\times10^{-6}$$

So, Mean of pH $= -\log_{10}(0.505\times10^{-6})$
$= -\log_{10}(0.505)+6$
$= 0.2967+6 = 6.2967$

Ans.13 (d)

Total hardness

$$= Ca^{++}mg/l\left(\frac{50}{20}\right)+Mg^{++}mg/l\times\left(\frac{50}{12}\right)$$

$$= 160\times\frac{50}{20}+40\times\frac{50}{12} = 566.67 \text{ mg/l}$$

Ans.19 (d)

The MPN for the combination 4-3-1 is 33 but the standard sample sizes are 10 mL, 1.0 mL and 0.1 mL. The specimen sample sizes are 1.0 mL, 0.1 mL and 0.01 mL i.e 10 times less than standard sample. Therefore MPN = 33 × 10 = 330.

Ans.20 (b)

The sum total of organic nitrogen and ammonia nitrogen is called Kjeldahl nitrogen.

Ans.24 (d)

Total solids = 100 + 200 + 168 + 120 + 111
= 699 mg
Fixed dissolved solids
= Total solids − 100 = 699 − 100 = 599 mg/L

Ans.26 (d)

Carbonate hardness is equal to the total hardness or alkalinity, whichever is lesser.
In this case alkalinity (250 mg/L) is less than total hardness (350 mg/L).
Carbonate hardness = 250 mg/L as $CaCO_3$
Non-carbonate hardness is the total hardness in excess of the alkalinity i.e.
Non-carbonate hardness
= Total hardness − alkalinity
= 350 − 250
= 100 mg/L as $CaCO_3$

Ans.30 (c)

$$\%R = \left(\frac{10^6-10^2}{10^6}\right)\times100$$
$$= 0.9999\times100 = 99.99\%$$
$$\log R = \log 10^6 - \log 10^2 = 6-2 = 4$$

Ans. 31 (a)

$$OCl^- + H^+ \xrightarrow{K} HOCl;\ K = 10^{7.5}$$

Now,

$$\frac{[HOCl]}{[OCl^-][H^+]} = K$$

pH = 7.5
$[H^+] = 10^{7.5}$

$$\left[\frac{HOCl}{OCl^-}\right] = 10^{7.5}\times10^{-7.5} = 1$$

$\therefore$ $[HOCl] = [OCl^-]$

$$\begin{bmatrix}\text{Free chlorine}\\ \text{residual}\end{bmatrix} = [HOCl]+[OCl^-]$$

Free chlorine residual = 2 mg/l

$$[\text{Free chlorine residual}] = \frac{2\times10^{-3}}{\text{Mol. wt of } Cl_2}$$

$$= \frac{2 \times 10^{-3}}{2 \times 35.5}$$

$= 2.817 \times 10^{-5}$ moles/l

$\therefore\ 2.817 \times 10^{-5} = [HOCl] + [OCl^-]$

$$\therefore\quad [OCl^-] = \frac{2.817 \times 10^{-5}}{2}$$

$\because\quad [OCl^-] = [HOCl]$

$= 1.4084 \times 10^{-5}$ moles/l

Ans.34 (c)

Rivers during monsoon season have high suspended solids concentration in suspension. This causes high turbidity.

Ans.35 (b)

Nutrients (phosphorous and nitrate nitrogen) cause eutrophication. It results in excessive algal growth.

Ans.36 (b)

Small concentrations (approximately 1.0 mg/L) of fluoride are helpful to prevent dental cavities in children. Iron concentrations of 0.3 mg/L may cause colour problem. The Indian standard have desirable limits of 0.3 mg/L for iron and 1.5 mg/L for fluoride. Nitrate concentrations above 45 mg/L may cause blue baby disease.

Ans.37 (a)

Turbidity, bacterial count and iron has no significant effect on efficiency of boiler. However, hardness causes scaling.

Ans.41 (b)

Salmonella typhi and Salmonella paratyphi (bacteria) cause enteric fever.

Enteric Cytopathogenic Human Orphan ECHO (virus) cause aseptic meningitis, epidemic exanthem, infantile diarrhoea.

Entamoeba histolytica (protozoa) cause dimebiasis (amebic dysentry, amebic enteritis, amebic colitis). Echinococcus (helminth) cause enchinococcosis (hydlatidosis, granulosis, dog tapeworm).

Ans.46 (c)

Flocculation basin is used for formation of flocs through coagulation. After this process turbidity is highest. Primary sedimentation causes settling of particles and turbidity reduces.

Ans.47 (d)

CO_2 reacts with water to form carbonic acid.

Ans.49 (d)

Metabolic processes are of two types:

(i) Catabolism provides energy for synthesis of new cells as well as for maintenance of other cell functions.

(ii) Anabolism provides the material necessary for cell growth. When an external food source is interrupted the organism will use stored food for maintenance energy in a process called endogenous catabolism. Enzymes play major role in biochemical reactions.

The chemical formula for bacterial cell is assumed to be $C_5H_7O_2N$. Organisms that derive energy and material from inorganic sources are called autotrophs, while bacteria that obtain both energy and material from organic compounds are called heterotrophs. Phototrophs, bacteria which utilize sunlight for an energy source and inorganic sub-stances for a material source, play important role in natural water purification processes.

Ans.50 (d)

Carbonates are less soluble than bicarbonates. Bicarbonates begin to convert to less soluble carbonates at pH values above 9.0. The least soluble forms are calcium carbonate and magnesium hydroxide. Chemical precipitation is accomplished by converting calcium hardness to calcium carbonate and magnesium hardness to magnesium hydroxide.

Ans.52 (d)

JTU: Jackson turbidity unit is a unit of measure turbidity on silica scale. Other turbidity units are NTU (Nephelometric turbidity unit) and FTU (Formazin Turbidity unit.

The extent of taste or odour present in a particular sample of water is measured by a term called odour intensity, which is related with the threshold odour. The threshold odour or threshold odour number, as it is generally called, represents the dilution ratio at which the odour is hardly detectable. MPN (Most Probable Number) is an index to measure the coliforms in the total water sample.

Ans.58 (d)

Virusus are the smallest biological structure, containing all information necessary for its reproduction. They are obligate parasites, and as such, require a host in which to live.

Ans.59 (a)

Specific conductance and concentration of TDS are not related on one-to-one basis, only ionized substances contribute to specific conductance. Organic molecules and compounds that dissolve without ionizing are not measured. Additionally, the magnitude of specific conductance is influenced by the valance of the ions in solution, there mobility and relative numbers.

Ans.60 (c)

The alkalinity present in water may be of mineral origin. It may be present due to atmospheric carbon dioxide mixed in water or due to microbial decomposition of organic matter.

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$
$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$
$$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}$$
$$CO_3^{2-} + H_2O \rightleftharpoons HCO_3^- + OH^-$$

Last reaction is a weak reaction but utilization of bicarbonate by algae drives the reaction to the right and hence sufficient accumulation of $[OH^-]$ takes place. Hence if algae is present in water, it becomes alkaline.

Ans.61 (b)

Alum is very effective coagulant for water treatment and is most commonly used. It is quite cheap, forms excellent stable floc and does not require any skilled supervision.

Destruction of bacteria by different treatment processes.

Process	Per cent removal
Coarse screens	0 – 5
Fine screens	10 – 25
Grit chambers	10 – 25
Plain sedimentation	25 – 27
Chemical coagulation	40 – 80
Trickling filters	90 – 95
Activated sludge	90 – 98
Chlorination	98 – 99.9

Ans.63 (c)

Algae, bacterial etc. fall under biotic category and air, water and soil fall under abiotic category.

■■■■