Water Supply Engineering

Chapter 4

Quality of Water

Lecture 5 (Week 5)

Impurities in water, their classification and effects, Hardness and alkalinity, Numerical on hardness and alkalinity, Living organisms in water

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Learning Objectives

By the end of this lesson, students will be able to:

- Identify and classify impurities in water (suspended, colloidal, and dissolved) and explain their effects on water quality.
- Understand the concepts of hardness and alkalinity, their types, and the relationship between them.
- Solve numerical problems related to water hardness and alkalinity.
- Recognize common living organisms in water.

4. Quality of Water

Water, often referred to as the **universal solvent**, is **never completely pure in nature**. Even in the most remote and apparently untouched environments, water contains various substances dissolved from the atmosphere, soil, and underlying rock layers. These substances may include **gases, minerals, and other chemicals**.

Sources of Impurities in Water:

- **Natural Sources:**
- Water can dissolve minerals and gases from air and earth materials. This natural process gives water its **distinct taste**—in contrast to laboratory-grade pure water, which is **flat and tasteless**.

Examples of naturally occurring impurities include:

    - **Calcium and magnesium** – cause **hardness**
    - **Iron** – gives water a **distinct color**
    - **Arsenic** – a **toxic contaminant**

    - **Radon or radium** – contribute to **radioactivity**
- **Human Activities:**
- Contaminants may also enter water through:
    - Improper use of **fertilizers and pesticides**
    - Disposal of **household or industrial waste**

These activities can cause harmful substances to **dissolve** into water, reducing its safety and quality.

Units of Measurement for Impurities:

Impurities in water are typically found in **very low concentrations** and measured in:

- **Parts per million (ppm)** or **milligrams per liter (mg/L)**

Groundwater vs. Surface Water Quality:

- **Groundwater** moves slowly through soil and rock, which naturally filters it.
- As a result, it typically contains more **dissolved minerals** (making it harder) and may have higher levels of **iron and manganese** than surface water.
- Groundwater from **deep aquifers** is more **stable in quality** and less prone to rapid changes.
- Unlike surface water, it's **less exposed to pollution** from the air or surface runoff—especially if the **well is properly sealed and constructed**.

Water Quality Changes:

Water is dynamic and undergoes **physical and chemical transformations**. However, these changes occur **more slowly in groundwater** due to its isolation from environmental fluctuations and pollutants.

Conclusion:

Even though water may look clean, it contains **dissolved substances** that affect its **taste, hardness, and safety**. Understanding these impurities, their sources, and how they affect water quality is essential for managing both **public health** and **infrastructure design**.

Characteristics of water for domestic use

- It Should be wholesome. And should be Colorless,Odourless but Tasteful
- It should be cool and sparkling clear
- It should free from biological germs that affect for health and should not corrode the pipe.
- It should have dissolved oxygen and free from carbolic acid so that it may remain fresh.
- It should be free from all objectionable matter.
- It should be free from poisonous and toxic substances
- It should not contaminate and doesn't cause water borne diseases.

4.1 Impurities in water, their classification and effects

Classification of Impurities According to its Characteristics

1. **Physical Impurities:**

- Which affect the physical characteristics of water such as color, odour, taste, and turbidity
- **Color, odour, and taste** is caused due to the presence of algae, organic matter, industrial waste, sewage, minerals, microorganisms, etc.
- **Turbidity** :caused by the suspended and colloidal matters such as sand, silt, clay, etc.

2. Chemical Impurities:

- Which affect the chemical characteristics of water such as suspended and dissolved solids, pH, hardness, mineral content, chloride, nitrogen, salts, etc.

3. Bacteriological Impurities:

- Which affect the bacteriological characteristics of water such as pathogenic and non-pathogenic microorganisms
- Presence of **pathogenic organisms** in water causes diseases in human beings making it unfit for consumption

Classification of impurities according to its occurrence/presence/state:

i. Suspended impurities   ii. Colloidal impurities   iii. Dissolved impurities

i) **Suspended Impurities**

- They are the dispersion of solid particles that are large enough to be removed by filtration or settling.
- Suspended impurities include clay, algae, fungi, organic and inorganic matters, mineral matter, bacteria, etc.

- Most of the suspended impurities are macroscopic and cause turbidity in the water.
- The concentration of suspended matter in water is measured by turbidity.
- Suspended impurities also develop color, odor and taste in water. Some bacteria cause diseases.

ii) Colloidal impurities

- They are very finely divided dispersion of particles in water which are so small that these cannot be removed by ordinary filters and are not visible to the naked eye.
- Colloidal particles remain in motion and do not settle.
- Most of the color of the water is due to colloidal impurities. The size of colloidal particle is 1 micron to 1 milli micron.

Removed by:

i) chemical coagulation

ii) sedimentation

iii) filtration

iii) Dissolved Impurities

- A dissolved substance is one in solution in simple atoms or complex molecular compounds.
- Physical methods such as filtration, sedimentation, or centrifugation cannot remove dissolved substances from water.
- The removal of the dissolved substances requires a phase change from liquid such as distillation, precipitation, adsorption or extraction.

Constituent	Chemical Formula	Issues Caused	Treatment Method
Turbidity	Not specified in chemical terms	• Makes water appear dirty or cloudy • Can clog pipelines and damage industrial equipment • Reduces suitability for most applications	Coagulation, sedimentation, and filtration
Hardness	Mainly calcium and magnesium salts, expressed as $CaCO_3$	• Causes scale buildup in heat exchangers, boilers, and pipelines • Reduces soap effectiveness • Disrupts processes in industries like textile and dyeing	Water softening techniques like ion exchange and lime-soda treatment

Alkalinity	Bicarbonates (HCO_3^-), Carbonates (CO_3^{2-}), and Hydroxides (OH^-), as $CaCO_3$	• Leads to foaming in boilers • Can weaken boiler metals • Contributes CO_2 in steam, causing corrosion in condensate pipelines	Lime softening, acid dosing, ion exchange, hydrogen zeolite softening, and dealkalization
Carbon Dioxide	CO_2	• Causes corrosion in metallic water pipelines and especially affects steam lines and condensate systems	Removal via aeration and neutralization with alkaline substances
Sulfates	SO_4^{2-}	• Increase the salt content in water • May combine with calcium forming hard deposits such as calcium sulfate	Treatment by ion exchange, membrane methods (reverse osmosis,

			electrodialysis), and evaporation
Chlorides	Cl^-	• Increase the saltiness of water • Lead to corrosion, especially in the presence of high temperatures or oxygen	Demineralization, reverse osmosis, electrochemical methods, and evaporation
Nitrate	**NO3 -**	• Adds to solids content, but is not usually significant industrially: • high concentrations cause methemoglobinemia in infants; • useful for control of boiler metal embrittlement	demineralization, reverse osmosis, electrodialysis, evaporation
Sodium	**Na+**	• Adds to solids content of water:	demineralization, reverse osmosis,

		• when combined with OH- , causes corrosion in boilers under certain conditions	electrodialysis, evaporation
Silica	**SiO2**	• Scale in boilers and cooling water systems; •Insoluble turbine blade deposits due to silica vaporization	hot and warm process removal by magnesium salts; adsorption by highly basic anion exchange resins, in conjunction with demineralization, reverse osmosis, evaporation
Ammonia	NH_3	Corrosion of copper and zinc alloys by formation of complex soluble ion	cation exchange with hydrogen zeolite; chlorination; deaeration

Dissolved Solids	None	• High concentrations are objectionable because of process interference and as a cause of foaming in boilers	lime softening and cation exchange by hydrogen zeolite; demineralization, reverse osmosis, electrodialysis, evaporation
Suspended Solids	None	• Deposits in heat exchange equipment, boilers, water lines, etc	subsidence; filtration, usually preceded by coagulation and settling

(Dr. B.C Punmia, 2013)

4.2 Hardness and alkalinity

Hardness

- It is the characteristics of water that prevents formation of sufficient lather foam with soap.
- It is caused by the presence of bicarbonates, sulphates, chlorides and nitrates of calcium, magnesium and strontium.
- Hardwater forms precipitate due to formation of insoluble soaps (calcium sterate, magnesium sterate)

$$C_{17}H_{35}COONa + Ca^{+2} \longrightarrow (C_{17}H_{35}COO)_2Ca + Na^{+}$$

$$C_{17}H_{35}COONa + Mg+2 \longrightarrow (C_{17}H_{35}COO)_2Mg + Na+$$

Alkalinity

- Alkalinity of water is its capacity to neutralize a standard solution of acid.
- It is caused due to presence of bicarbonate, carbonate and hydroxide.

Effects Of Hardness

- It consumes more soap.
- It forms scale in boilers.
- It modifies colour in the dyeing industries.
- It causes corrosion and incrustation of pipes.
- It makes food tasteless.

(Kansakar, 2015)

4.2.1 Types of hardness

1. **Carbonate or temporary hardness:**

- Hardness caused by the presence of bicarbonates of calcium, magnesium, and strontium is known as carbonate hardness
- Since it can be removed by the addition of lime or boiling it is also called as temporary hardness

2. **Non-carbonate or permanent hardness:**

- Hardness caused by the presence of sulphates, chlorides, and nitrates of calcium, magnesium, and strontium
- Cannot be removed by simple boiling so called as permanent hardness; can be removed by lime soda and zeolite methods

3. **Total hardness:**

- Sum of carbonate and non-carbonate hardness
- **TH= CH+NCH**

- Unit is mg/l or ppm or °clark, 1 °clark = 14.14 mg/l

Temporary Hardness	**Permanent hardness**
-caused by the presence of bicarbonates of calcium, magnesium and strontium.	-caused by presence of sulphates, chlorides and nitrates of calcium, magnesium and strontium.
-can be removed by boiling the water Or, by adding lime in water	-can be removed by lime soda and zeolite methods
-It is also known as carbonate hardness (CH)	-It is also known as non-carbonate hardness (NCH)

Total Hardness= CH + NCH

4.2.2 Types of alkalinity

The major form of alkalinity is the bicarbonate alkalinity. The carbonate alkalinity and bicarbonate alkalinity or carbonate alkalinity and hydroxide alkalinity can exist together. But bicarbonate alkalinity and hydroxide alkalinity do not exist together.

Determination of alkalinity:

- The alkalinity of water is expressed in ppm or mg/l as $CaCO_3$
- Carbonate alkalinity in mg/l as CaCO3

  $$=\text{ion concentration in mg/l} \times \frac{Equivalent\ weight\ of\ CaCO3}{Equivalent\ weight\ of\ ion}$$

- Total alkalinity = Carbonate alkalinity + Bicarbonate alkalinity
- Total alkalinity= Carbonate alkalinity + Hydroxide alkalinity

4.2.3 Relation between hardness and alkalinity

1. If TH > TA, CH= TA and NCH= TH-CH = TH-TA
2. If TH ≤ TA, CH= TH and NCH= 0

4.2.4 Numerical on hardness and alkalinity

Q. The analysis of water from a well showed the following result in mg/L. Find the total hardness, carbonate hardness and non-carbonate hardness.

Ca^{++} = 65, Mg^{++} = 51, Na^{+} = 101.5, K = 21.5,

HCO_3^{-} = 248, SO_4^{--} = 221.8, Cl^{-} = 79.2

Solution:

We have, Hardness (in mg/L) as $CaCO_3$ = ion concentration (in mg/L) * [(Equivalent weight of $CaCO_3$/ (Equivalent weight of ion)]

Total hardness = Hardness due to Ca^{++} ions and Mg^{++} ions.

Cation	Concentration (mg/L)	Equivalent weight (g/mole)
Ca^{2+}	65	20
Mg^{2+}	51	12.2

[65*(50/20)]+[51*(50/12.2)]

=162.5 + 209.02

Total Hardness = 371.52 mg/L as $CaCO_3$

For calculating non-carbonate hardness:

Since there is no carbonate and hydroxide alkalinity, (i.e no $CO3^{--}$ and OH^- ion)

TA = BCA

Total Alkalinity (in mg/L as CaCO3) = [$HCO3^-$ concentration (in mg/L) × 50] / (Eq. Wt. of $HCO3^-$)

Total Alkalinity (in mg/L as CaCO3) = 248 *50 / 61

Total Alkalinity (in mg/L as CaCO3) = 203.278 mg/L as CaCO3

Here, TH > TA

Therefore, CH = TA

CH = 203.278 mg/L as CaCO3

NCH = TH – CH = (371.52 - 203.278) mg/L as CaCO3

= 168.24 mg/L as CaCO3

Q. The total hardness value obtained from the analysis of a water sample is found to be 230 mg/l. The analysis further showed that the hardness has been caused by calcium and magnesium ions only and their concentrations are numerically same. If the value of carbonate hardness is 90 mg/l and alkalinity in water is caused by bicarbonate ions only, calculate the following:

i) the value of non- carbonate hardness;

ii) The concentrations of calcium and magnesium ions; and

iii) The concentration of bicarbonate ion in mg/l.

iv) Solution ;

v) we have ,Hardness in mg/l as $CaCO_3$. =ion concentration in mg/l * (Equivalent wt. of $CaCO_3$/ Equivalent wt. of ion)

i) Total hardness = 230 mg/l

Carbonate hardness = 90 mg/l

Therefore , Non carbonate hardness = 230 – 90 = 140 mg/l

ii) Let P be the concentration of calcium and Magnessium ions.

Total hardness = $\frac{P*50}{20} + \frac{P*50}{12.2} = 6.60$ P = 230

P=34.85 mg/l

iii) Since non- carbonate hardness >0

Total hardness > Total alkalinity

Total alkalinity = carbonate hardness = 90 mg/l

Bicarbonate alkalinity = total alkalinity = 90 mg/l

we have , bicarbonate alkalinity in mg/l as $CaCO_3$.=$\frac{HCO_3 \text{ concentration}}{1.22}$

HCO_3^- concentration = Bicarbonate alkalinity * 1.22

= 90*1.22 = 109.80 mg/l

(Kansakar, 2015)

4.3 Living organisms in water

- Living organisms either plant or animals exist in water.
- They may be unicellular or multi-cellular.
- They may be harmful or may not be harmful.
- They may be microscopic as well as macroscopic.
- Algae, Bacteria, Viruses, and Worms exist in the water as living organisms.

4.3.1 Algae

- Algae (one-celled, microscopic, and larger) aquatic plants, some microscopic, can be quite abundant in a surface water source, especially during the summer months and especially if the water contains nutrients that encourage their growth, such as phosphorus from domestic run-off or industrial pollution.
- They derive energy from inorganics substances as gases and salts dissolved in the presence of sunlight.
- They are self- nourishing.

- Algae may cause taste and odor problems, clog filters, and produce nuisance slime growths on intake pipes and equipment.
- Excessive growth of algae in water may be controlled by the application of copper sulphate or chlorine.

4.3.2 Bacteria

- Bacteria are microscopic one-celled organisms that multiple by simple division.
- Bacteria are universally distributed.
- Many of them are essential. For example, they aid in the decomposition of dead organic material. However, there are numerous disease-producing bacteria that the water industry needs to guard against. These may cause typhoid fever, dysentery, cholera, and gastroenteritis.
- Some bacteria, although not harmful, may cause taste and odor problems.
- Examples of such bacteria are sulfur bacteria, which may produce hydrogen sulfide, or crenothrix iron bacteria which can produce disagreeable taste, odors, and stains.

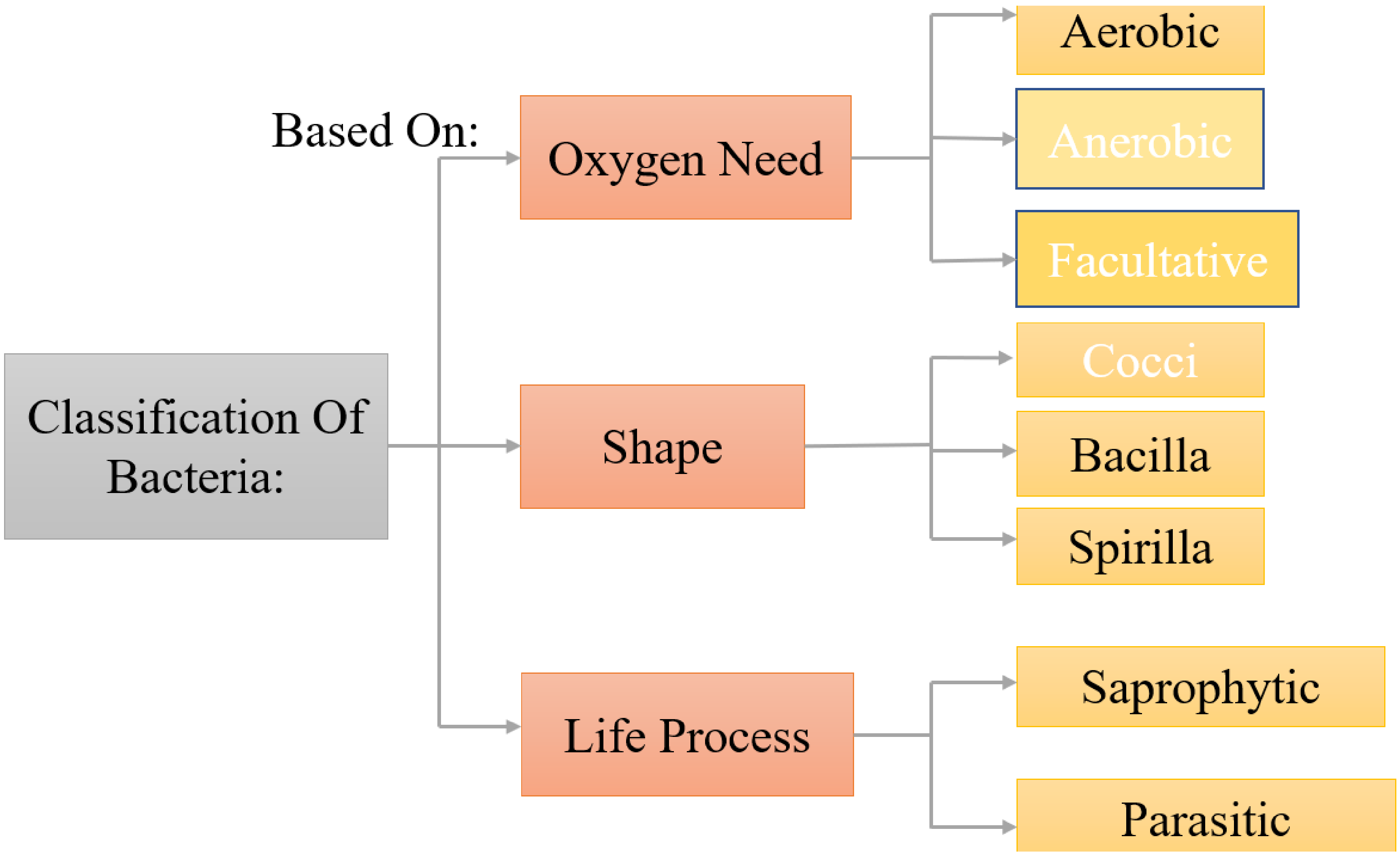

Figure 1: Classification of Bacteria

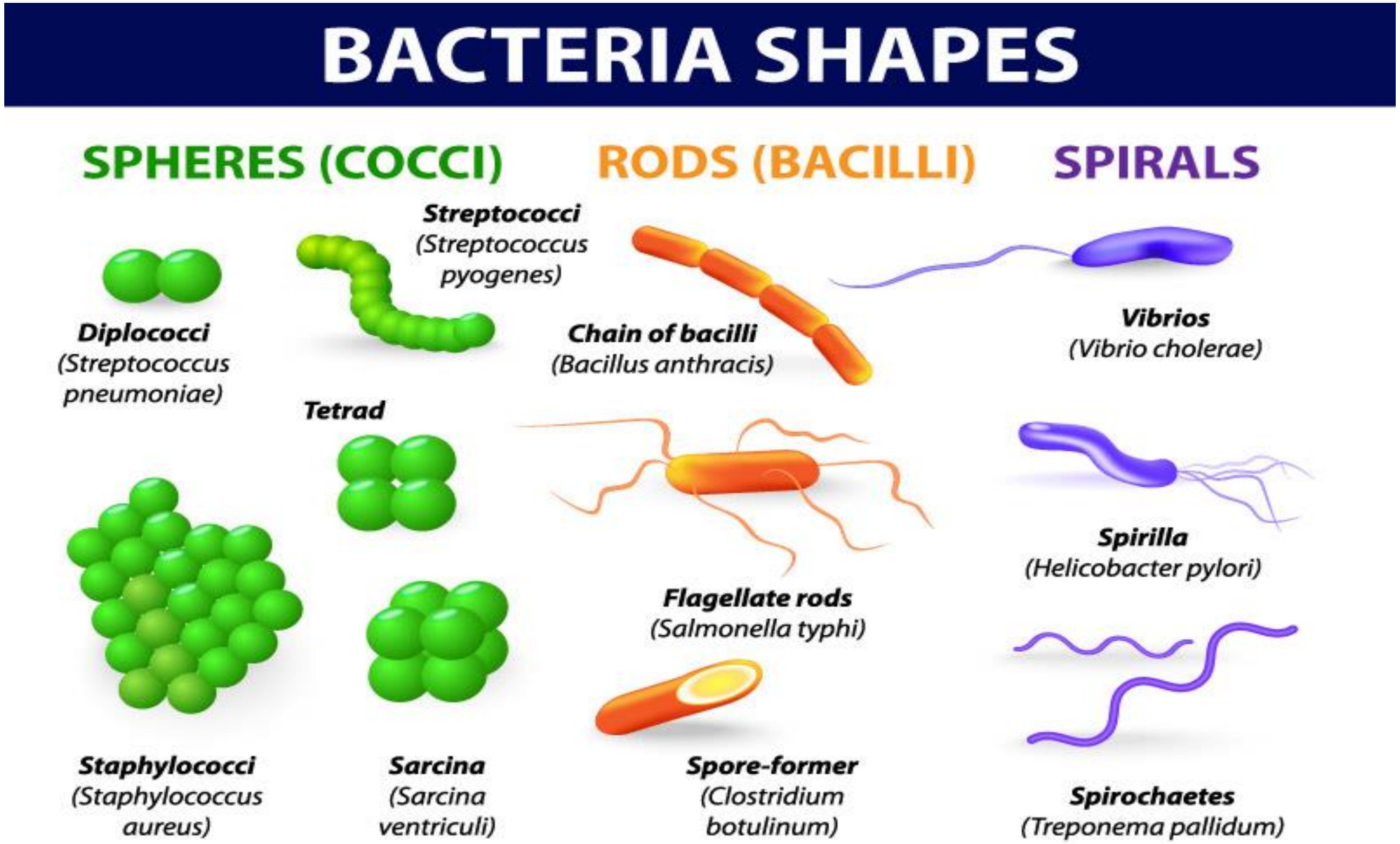

Figure 2: Shape of the Bacteria

Source: (www.medicalexamprep.co.uk, 2023)

4.3.3 Viruses

- Infectious agents of both plant and animal cell
- Lack biochemical system for metabolism so need host to multiply but can survive for several weeks in atmosphere specially with temperature less than 15°C
- Ultramicroscopic in size -10 to 500 milli microns
- Viruses that may be carried by water include the hepatitis and polio virus.
- They are very difficult to test for; usually large amounts of water have to be tested by using very sophisticated methods.
- Viruses can be inactivated by disinfection.
  - Polio virus : polio (paralysis of any part of body)
  - Hepatitis type A virus : hepatitis, jaundice

- Enterovirus : vomiting, diarrhoea, fever
- Echovirus : meningitis, respiratory disease

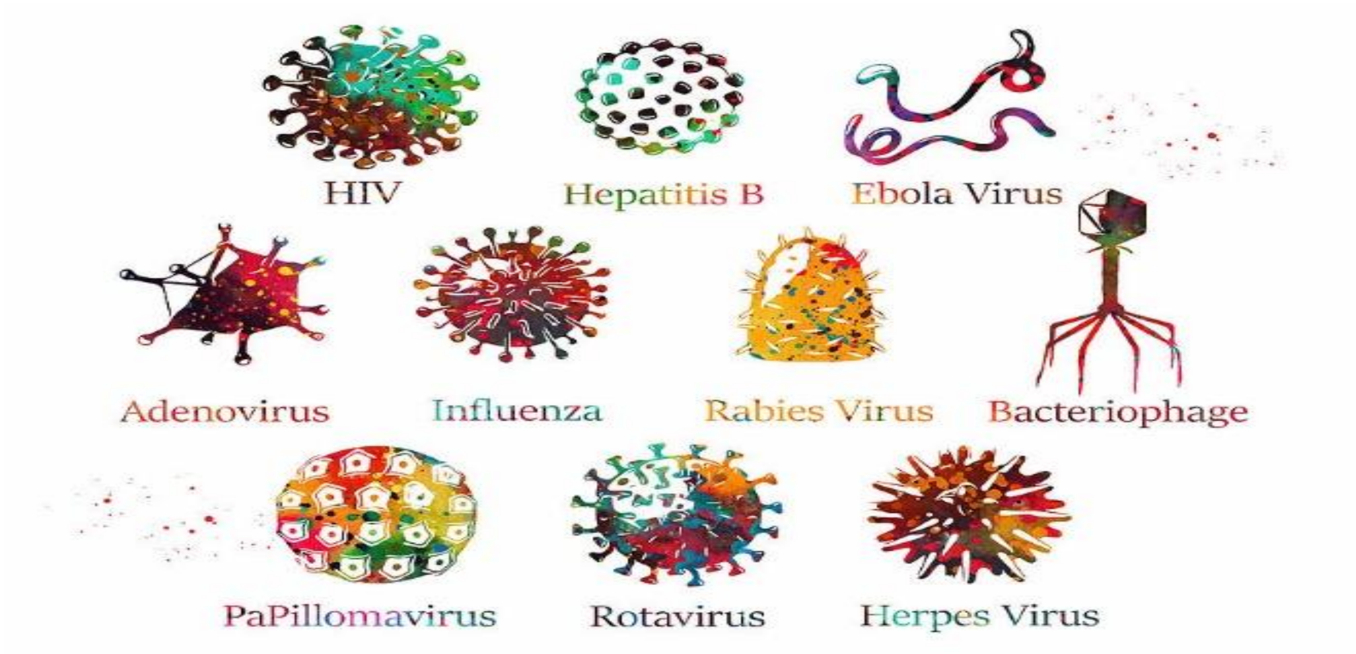

Figure 3: Different Types of Viruses

Source: (https://vajiramandravi.com/upsc-exam/virus/, 2025)

4.3.4 Worms

- Worms are also known as helminths.
- Worms are classified into roundworms (nematodes) and flatworms. Hook worms and ascarids are example of round worms.
- Flat worms are two groups: tapeworms or cestodes and flukes or trematodes.
- Ascaris and guinea worms are disease associated with nematode worm while schistosomiasis is caused by trematode flatworms.
- Infection is either through the ingestion of worms or penetration through the skin.
- The worms and eggs are transmitted via consumption of contaminated water or vegetables or body contact with polluted water.
- They can be removed by controlling turbidity through effective coagulation and filtration.

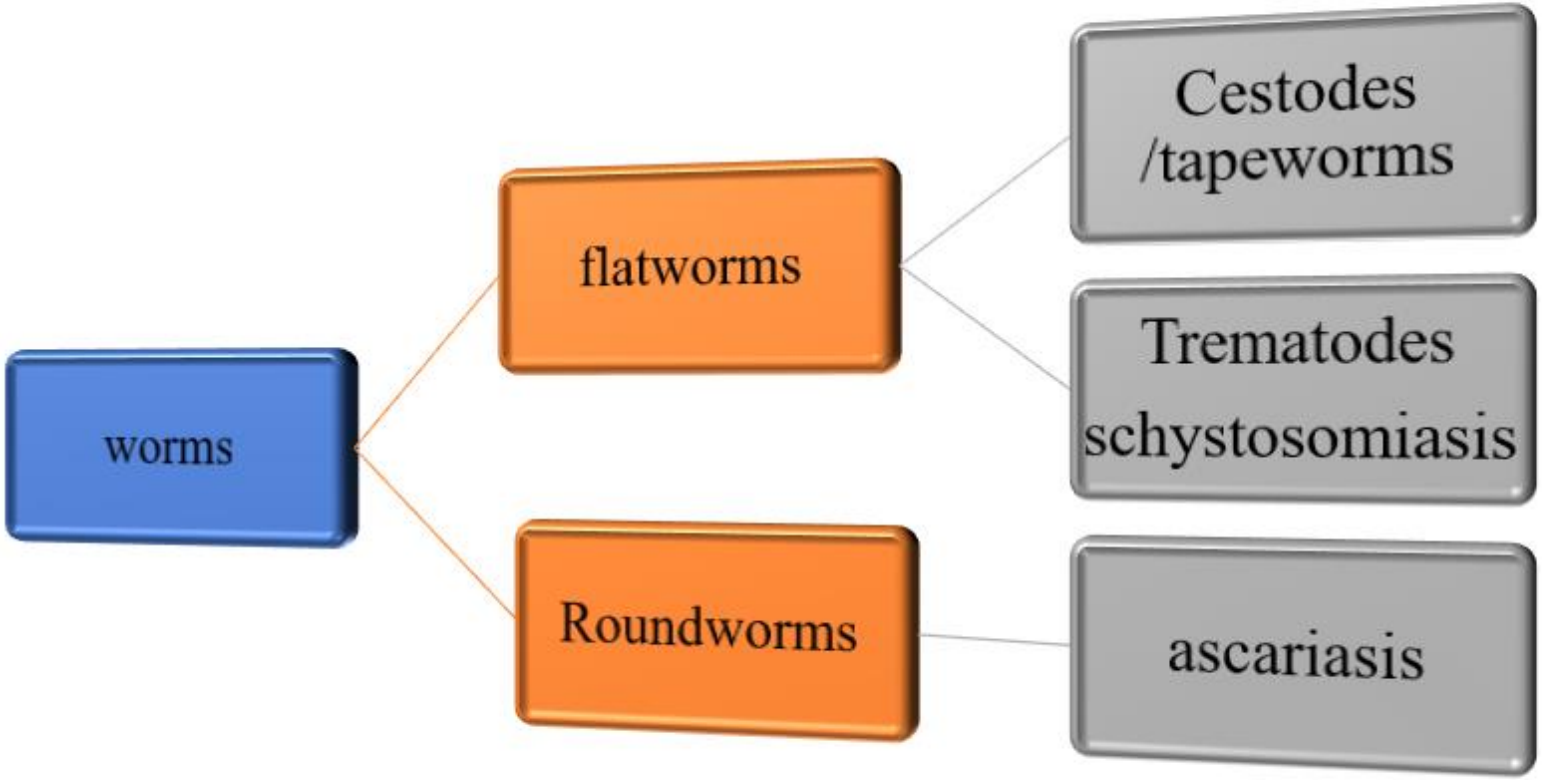

Figure 4: Classification of Worms

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Thank You!!!