

Engineering Chemistry CHY 1701

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Textbooks

- [O. G. Palanna](#), **Engineering Chemistry**, Tata McGraw-Hill Education, Edition 2E.
- [P. C. Jain & Monika Jain](#), **Engineering Chemistry**, Dhanpatrai publishers, 2005

Modules 1 Water Technology

Module 1

Characteristics of hard water - hardness, DO, TDS in water and their determination – numerical problems in hardness determination by EDTA; Modern techniques of water analysis for industrial use - Disadvantages of hard water in industries.

Introduction

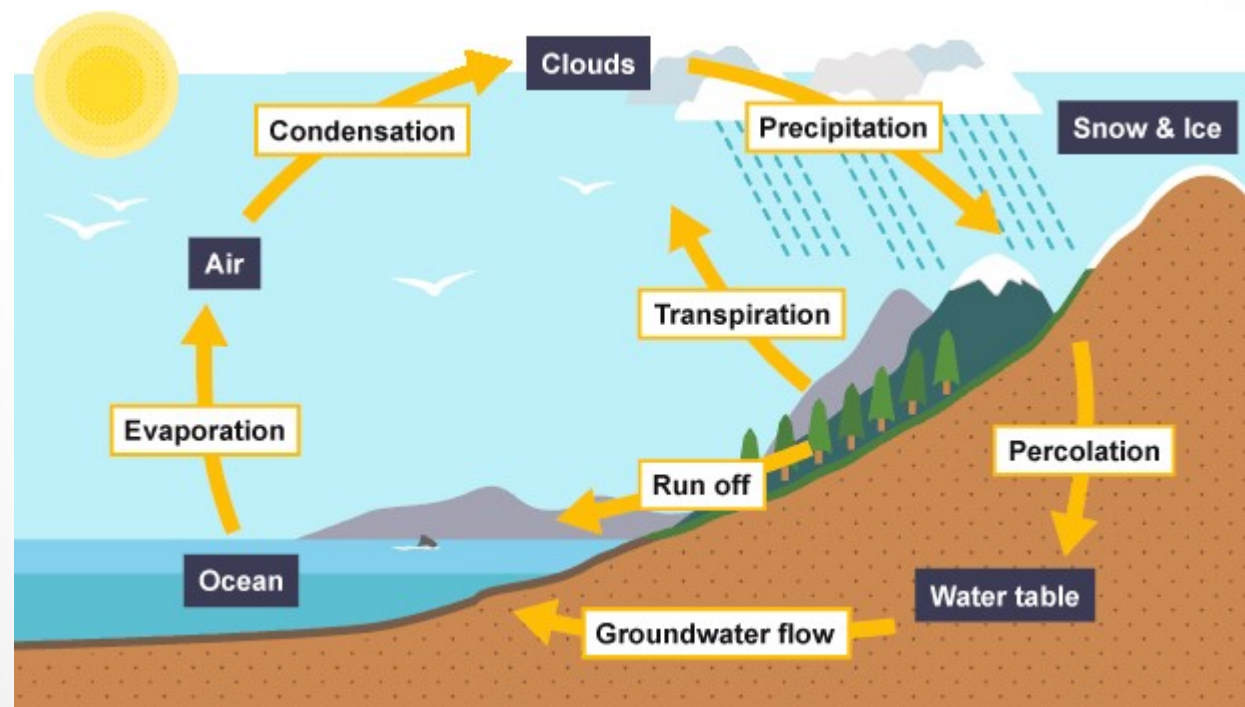
- Most essential & basic component of life
- Incredibly fine-tuned properties to sustain life
- Water covers 71% of Earth's surface
- Yet 97% of all water is saline (ocean)
- Fresh water (3%) – 2% locked in ice caps & glaciers
- Ground water – 0.61%
- Freshwater lakes - 0.01%
- Essential in living systems, industrial processes, agriculture & domestic use

Life without water is unimaginable!!

Properties	
Chemical formula	H ₂ O
Molar mass	18.01528(33) g/mol
Appearance	White solid or almost colorless, transparent, with a slight hint of blue, crystalline solid or liquid ^[2]
Odor	None
Density	Liquid: 999.9720 kg/m ³ ≈ 1 tonne/m ³ = 1 kg/l = 1 g/cm ³ ≈ 62.4 lb/ft ³ (maximum, at ~4 °C) Solid: 917 kg/m ³ = 0.917 tonne/m ³ = 0.917 kg/l = 0.917 g/cm ³ ≈ 57.2 lb/ft ³
Melting point	0.00 °C (32.00 °F; 273.15 K) ^[a]
Boiling point	100.02 °C; 212.04 °F; 373.17 K ^{[3][a]}
Solubility	Poorly soluble in haloalkanes, aliphatic and aromatic hydrocarbons, ethers. ^[4] Improved solubility in carboxylates, alcohols, ketones, amines. Miscible with methanol, ethanol, isopropanol, acetone, glycerol.
Vapor pressure	At 25 °C, 3.1690 kilopascals or 0.031276 atm ^[5]
Acidity (pK _a)	13.995 (at 25 °C) ^{[6][b]}
Basicity (pK _b)	13.995 (at 25 °C)
Thermal conductivity	0.6065 W/m·K ^[2]
Refractive index (n _D)	1.3325
Viscosity	0.890 cP (25 °C) ^[3]

Sources of water

- Surface water – Rivers, lakes, ponds, oceans
 - Rain is most essential to replenish surface water
 - Dissolves gases like CO_2 , SO_2 , NO_2 etc
- Underground water – springs, wells
- Glaciers, snow



Surface Water

■ River water

- Sources of river water, rain and spring
- Has considerable amount of dissolved and suspended impurities
- Eg. Cl^- , SO_4^{2-} , HCO_3^- of Na^+ , Ca^{2+} , Mg^{2+} , Fe^{n+} , mineral acids, K^+ , Mn^{2+} , NO_3^- , F^- , SiO_2 , organic matter, sand, rocks etc.

■ Lake water

- Constant chemical composition
- Contains less amount of dissolved minerals
- Contains more amount of organic matter

■ Sea water

- Most impure of all forms of natural water
- 3.5% dissolved salts, 2,6% is NaCl

Impurities in water

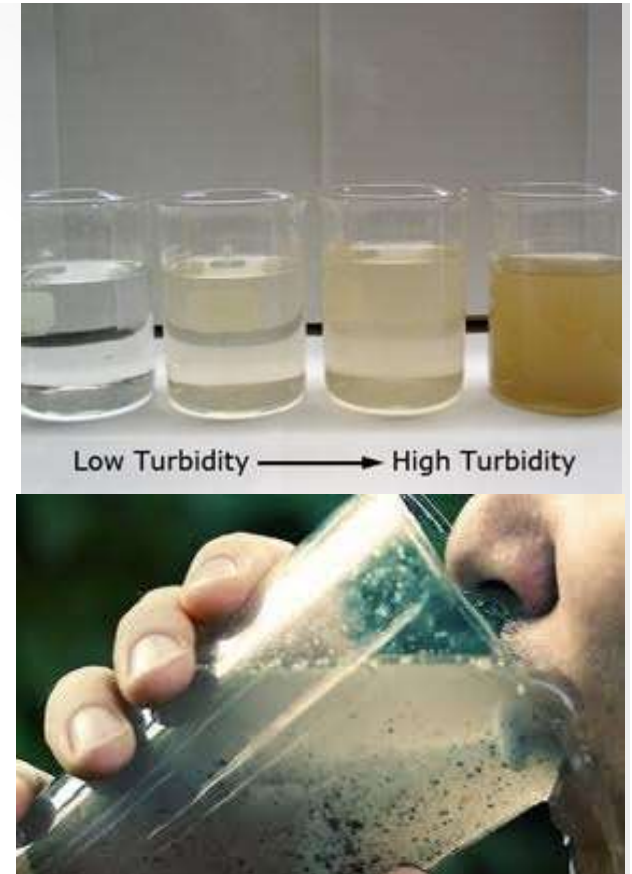
Naturally available water is characterised by measurable quantities such as

- | | |
|---|------------------------------|
| <ul style="list-style-type: none">• Turbidity• suspended solids, total solids | Physical impurities |
| <ul style="list-style-type: none">• Colour• Odour• Taste• pH• conductivity• hardness | Chemical impurities |
| <ul style="list-style-type: none">• Bacteria and micro-organisms | Biological impurities |

Impurities in water

Turbidity

- Suspended solids and colloids make water turbid
- Clay, silt, finely divided matter, planktons
- Sedimentation, coagulation and filtration can remove turbidity
- Adsorption on activated carbon



Impurities in water

Colour

- Due to dissolved salts of iron, manganese etc, humus materials, tannins, peat, industrial effluents
- Yellow colouration often due to Cr and organic impurities
- Yellowish red may be due to iron
- Red-brown colour may indicate peaty matter

Impurities in water

Odour and taste

- Organic and inorganic compounds contribute to both odour and taste
- Dissolved minerals of Fe, Al, Mn, lime, salts, dissolved CO₂

Odour maybe due to

- Living organisms
- Decaying vegetation
- Presence of compounds of N, S and P
- Putrefying proteins and other organic matter in sewage
- Industrial effluents containing alcohol, aldehydes, phenols, esters, ketones etc

Chemical impurities

- Chemical impurities from industries such as dye, paint, varnish, drug, insecticide, pesticide, detergent, pulp, textile, tannery
- Acidity (pH) - number of free hydrogen ion
 - Pure water pH = 7 (neutral) - suitable for plant and animal life
 - Acid rain - caused by presence of CO_2 , SO_x , NO_x , $\text{HCl}_{(g)}$.
 - Ground and surface water becomes acidic by industrial wastes.
- Dissolved gases
 - CO_2 and O_2 most commonly found dissolved in water – concentration depends on temperature, pressure and salt content in water.
 - Dissolved CO_2 has no significance but dissolved O_2 induces corrosion.
 - Dissolved NH_3 arises from decomposition of nitrogenous organic matter.

Chemical impurities

- Minerals from rocks and industrial effluents
- Minerals acids, Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Fe^{2+} , CO_3^{2-} , Mn^{2+} , HCO_3^- , Cl^- , SO_4^{2-} , NO_3^-

Biological impurities

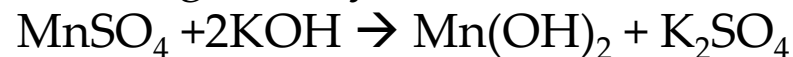
- Algae, pathogenic bacteria, fungi, viruses, parasites and worms
- High counts in surface waters, but deep well waters have low counts
- Algae, fungi and bacteria are the most common
- They form **slime** which can cause corrosion and fouling
- **Slime** also clogs spray nozzles in AC circulating pumps
- Chlorination disinfects water

Dissolved Oxygen (DO)

- DO is measure of health of the water. Natural water bodies has 5-8 mg/l.
- Oxygen in water – important for survival of aquatic animals and plants.
- O_2 transferred from atmosphere into surface waters, photosynthesis of aquatic plants.
- DO level measured in ppm (i.e) No. of O_2 molecule per million total molecules
- Factors affecting DO: Temp., aquatic plant population, stream flow, altitude, human activities, organic waste etc.
- Cold, fresh water holds more water than warm or salty water.
- DO in a water can be determined by Winkler's method.

Winkler's Method

1. To a water sample, Manganous sulphate and alkali-iodide (mixture of potassium iodide and potassium hydroxide solution) are added, which produces white flocculent precipitate of manganous hydroxide



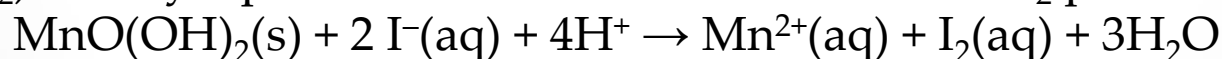
2. DO then reacts with MnSO_4 forming a brownish manganic oxide precipitate



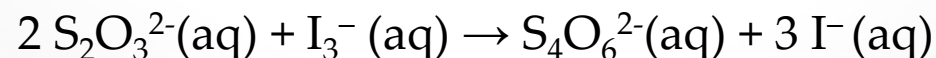
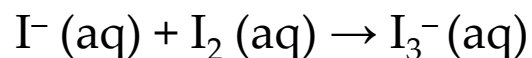
3. When the samples are ready to be titrated, H_2SO_4 is added to redissolve the brownish ppt. Now Manganic hydroxide is converted to manganic sulphate



4. This manganic sulphate immediately reacts with KI, liberating the number of moles of iodine (I_2) exactly equivalent to the number of moles of O_2 present in the sample



5. This liberated iodine is titrated against standard thiosulphate solution, with starch as an indicator



Total dissolved solids (TDS)

- Amount of particles dissolved in water
- Sources are leaves, silt, industrial waste and sewage, runoff from urban areas, road salts, fertilizers and pesticides
- Rain water contains less than 10mg/L of TDS
- Drinking water should contain TDS levels of 25-50 mg/L

Method to determine TDS in water sample

Gravimetric method

The material residue left in a vessel after evaporation of the sample and its subsequent drying @ 103 – 105 °C is known as TDS

Principle: 50mL of well-mixed sample is evaporated in a pre-weighed dish and dried to constant weight in an oven at 103-105 °C. the increase in weight over that of the empty dish gives the total solids

Total solids (mg/L) = $(W1 - W2) \times 1000 / \text{Sample volume (mL)}$

Where W1 = Weight of dried residue+dish

W2 = Weight of empty dish

This method is very accurate but is time consuming

Conductivity method

Principle: Electrical conductivity of water is directly related to the concentration of dissolved ionized solids in the water.

- Ions from the dissolved solids in water create the ability for that water to conduct an electric current, which can be measured using a conventional conductivity meter or TDS meter.
- When correlated with laboratory TDS measurements, conductivity provides an approximate value for the TDS concentration, usually to within 10% accuracy.
- The relationship of TDS and specific conductance of groundwater can be approximated by the following equation:

$$\text{TDS} = k_e \cdot \text{EC}$$

where TDS is expressed in mg/L and EC is the electrical conductivity in microsiemens per centimeter at 25 °C. The correlation factor k_e varies between 0.55 and 0.8

BOD

- BOD is a measure of the amount of oxygen needed (mg/L or ppm) by bacteria and other microorganisms, to oxidise the organic matter present in a water sample over a period of 5 days
- Drinking water should have BOD < 1 ppm. Raw sewage BOD = 500-800 ppm
- Amount of DO that bacteria may consume to oxidise organic matter in water
- High BOD implies low DO
- DO of a sample is measured before and after incubation for 5 days. The difference in DO levels is the measure of BOD in the sample

COD

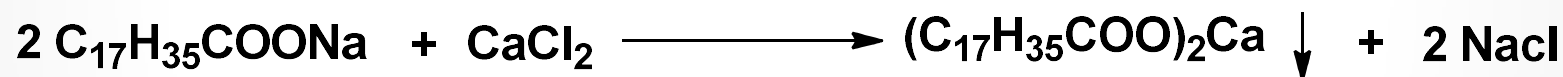
- It is an indirect measure of chemical compound present in given water. COD reflects the water quality

Less COD = good water

- It indicates mass of O_2 required per liter of solution (mg/l or ppm) to decompose chemical impurities.
- COD – No. of milligram of O_2 required to oxidize all oxidisable chemical impurities present in 1000 ml of waste water by strong oxidizing agents ($K_2Cr_2O_7$).
- COD > BOD

Hardness of water

- Hard water prevents soap from lathering. Instead it forms a white precipitate known as soap scum
- Hardness of water is due to the presence of certain salts of Ca^{2+} , Mg^{2+} and other heavy metals
- Soap is a sodium or potassium salt of long chain fatty acid e.g sodium palmitate, sodium stearate etc.
- With hard water, soaps form a white precipitate which is a calcium or magnesium salt of the fatty acid



sodium stearate

calcium sterate

soluble in water

insoluble! in water
white scum

Soft water does not contain calcium and magnesium salts in it!

Hard water

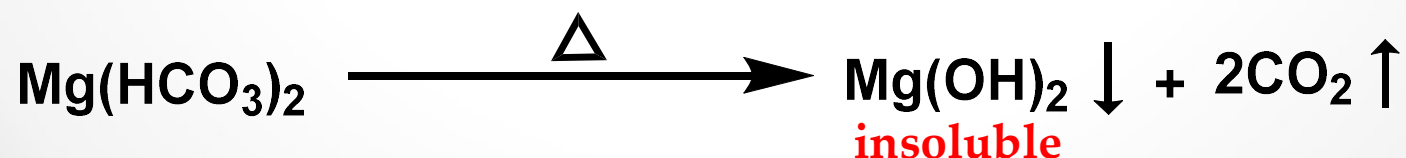
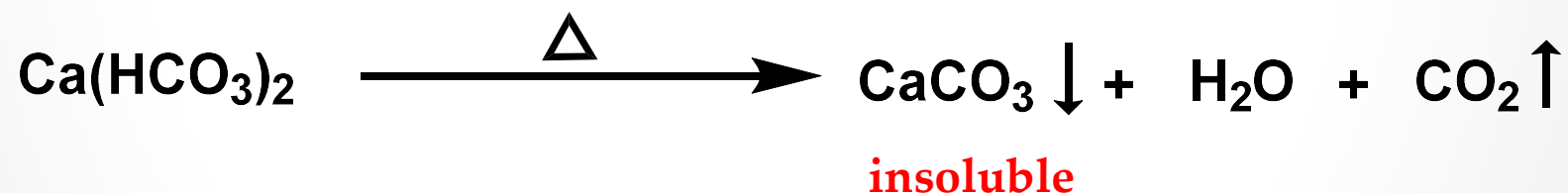
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graph LR; A[Hard water] --> B[Temporary hardness]; A --> C[Permanent Hardness]
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Temporary hardness

Permanent Hardness

Temporary or carbonate hardness

- Due to presence of dissolved bicarbonates (HCO_3^-) of calcium, magnesium and the carbonates of iron (CO_3^{2-})
- temporary hardness is destroyed by boiling such water.
- The bicarbonates get decomposed to carbonates yielding insoluble carbonates or hydroxides, which deposit as crust in the bottom of the vessel
- Thus boiling softens temporary hard water



Permanent or non-carbonate hardness

- Due to presence of dissolved sulphates, chlorides and nitrates of Mg and Ca
- Not removed by boiling

Substances which do not contribute to hardness

Eg. NaCl, KCl, SiO₂, Na₂SO₄, Fe₂O₃, K₂SO₄ etc.

- Total hardness of water measures the concentration of multivalent cations.
- From the concentration of the anions, one can estimate the permanent and temporary hardness

Expressing hardness in Equivalents of CaCO_3

- Hardness causing salts ($\text{Ca}(\text{HCO}_3)_2$, $\text{Mg}(\text{HCO}_3)_2$, CaCl_2 , MgCl_2 , CaSO_4 , MgSO_4) and non-hardness salts (NaCl , KCl , Na_2SO_4 etc) can be conveniently expressed in terms of CaCO_3 equivalents

$$\text{Equivalents of } \text{CaCO}_3 = \frac{\text{[Mass of hardness producing substances]}}{\text{[Chemical equivalent of } \text{CaCO}_3\text{]}} \times \frac{\text{[Chemical equivalent of } \text{CaCO}_3\text{]}}{\text{Chemical equivalence of hardness producing substances}}$$

Mass usually expressed in *mg* and hardness expressed as *mg/L* or *ppm*

Why CaCO_3 is chosen to express hardness as it equivalents?

CaCO_3 ; M.wt = 100, ***Equiv. wt. = 50***

Most insoluble salt in water, thus it precipitates during water treatment.

Hardness producing substance	Molecular weight	Chemical equivalent	Multiplication factor
$\text{Ca}(\text{HCO}_3)_2$	162	81	100/162 or 50/81
$\text{Mg}(\text{HCO}_3)_2$	146	73	100/146 or 50/73
CaSO_4	136	68	100/136 or 50/68
CaCl_2	111	55.5	100/111 or 50/55.5
MgSO_4	120	60	100/120 or 50/60
MgCl_2	95	47.5	100/95 or 50/47.5
CaCO_3	100	50	100/100 or 50/50
MgCO_3	84	42	100/84 or 50/42
CO_2	44	22	100/44 or 50/22
HCO_3^-	61	61	100/61
OH^-	17	17	100/17
CO_3^{2-}	60	30	100/60 or 50/30

Express the concentration of the following in terms of CaCO_3 equivalents

81 mg of $\text{Ca}(\text{HCO}_3)_2$

146 mg of $\text{Mg}(\text{HCO}_3)_2$

34 mg of CaSO_4

222 mg of CaCl_2

15 mg of MgSO_4

$$\text{Equivalents of } \text{CaCO}_3 = \frac{[\text{Mass of hardness producing substances}]}{[\text{Chemical equivalent of } \text{CaCO}_3]} \times \frac{[\text{Chemical equivalent of } \text{CaCO}_3]}{\text{Chemical equivalence of hardness producing substances}}$$

Equivalents of CaCO_3 For 81 mg of $\text{Ca}(\text{HCO}_3)_2$

$$81 * 100/162 = 50 \text{ ppm } \text{CaCO}_3 \text{ equiv}$$

Express the concentration of the following in terms of CaCO_3 equivalents

81 mg of $\text{Ca}(\text{HCO}_3)_2$

50 mg of CaCO_3

146 mg of $\text{Mg}(\text{HCO}_3)_2$

100 mg of CaCO_3

34 mg of CaSO_4

≡

25 mg of CaCO_3

222 mg of CaCl_2

200 mg of CaCO_3

15 mg of MgSO_4

12.5 mg of CaCO_3

Water hardness expressed in CaCO_3 equivalents

Soft : 0 – 17 mg/L or ppm

Moderately hard : 60 – 120 mg/L or ppm

Hard : 120 – 180 mg/L or ppm

Very hard : 180 mg/L or ppm and above

Units of Hardness

- Parts per million (ppm)
1 ppm = 1 part of CaCO_3 eq. in 10^6 parts of water
- Milligrams per liter (mg/L)
1 mg/L = 1 mg of CaCO_3 eq. of 1 L of water
- Degree French
1° *Fr* = 1 part of CaCO_3 eq. per 10^5 parts of water
- Clarke's degree
1° *Cl* = 1 part of CaCO_3 eq. per 70,000 parts of water

Unit conversion

- $1 \text{ ppm} = 1 \text{ mg/L} = 0.1^\circ \text{ Fr} = 0.07^\circ \text{ Cl}$
- $1 \text{ mg/L} = 1 \text{ ppm} = 0.1^\circ \text{ Fr} = 0.07^\circ \text{ Cl}$
- $1^\circ \text{ Fr} = 0.7^\circ \text{ Cl} = 10 \text{ ppm} = 10 \text{ mg/L}$
- $1^\circ \text{ Cl} = 1.433^\circ \text{ Fr} = 14.3 \text{ ppm} = 14.3 \text{ mg/L}$

Numerical problem 1

Calculate the temporary and permanent hardness of a water sample in terms of CaCO_3 equivalent. It has the following salts.

		M.Wt
$\text{Mg}(\text{HCO}_3)_2 - 146 \text{ mg/L}$	$\text{Ca}(\text{HCO}_3)_2 =$	162
$\text{Ca}(\text{HCO}_3)_2 - 81 \text{ mg/L}$	$\text{Mg}(\text{HCO}_3)_2 =$	146
$\text{CaSO}_4 - 13.6 \text{ mg/L}$	$\text{CaSO}_4 =$	136
$\text{MgCl}_2 - 38 \text{ mg/L}$	$\text{MgCl}_2 =$	95
$\text{CaCl}_2 - 166.5 \text{ mg/L}$	$\text{CaCl}_2 =$	111
$\text{NaCl} - 200 \text{ mg/L}$	$\text{NaCl} =$	58.5

- Determine CaCO_3 equivalents of each component
- Categorise into ions contributing to temporary, permanent and no hardness
- Sum up the concentration for each category

$\text{Mg}(\text{HCO}_3)_2 - 100 \text{ mg/L equiv } \text{CaCO}_3$
 $\text{Ca}(\text{HCO}_3)_2 - 50 \text{ mg/L equiv } \text{CaCO}_3$
 $\text{CaSO}_4 - 10 \text{ mg/L equiv } \text{CaCO}_3$
 $\text{MgCl}_2 - 40 \text{ mg/L equiv } \text{CaCO}_3$
 $\text{CaCl}_2 - 150 \text{ mg/L equiv } \text{CaCO}_3$
 $\text{NaCl} - \text{Does not contribute to hardness}$

Temporary hardness = 150mg/L
Permanent hardness = 200 mg/L
Total hardness = 350 mg/L

Numerical problem 2

An analyzed sample of water containing only $\text{Ca}(\text{HCO}_3)_2$ is found to contain 150 ppm of hardness. Calculate the amount of $\text{Ca}(\text{HCO}_3)_2$ dissolved in that water sample.

Ans = 243 ppm

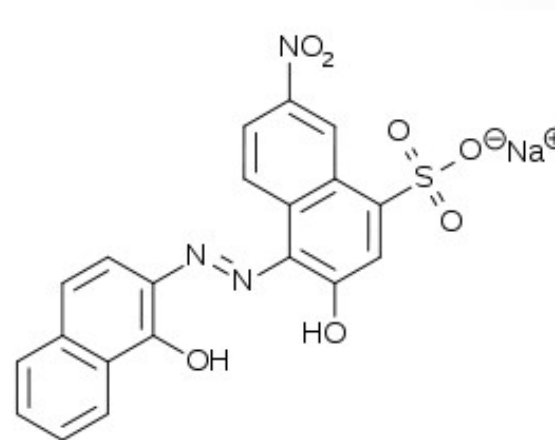
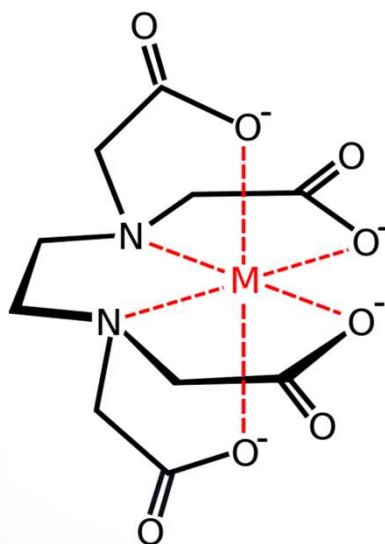
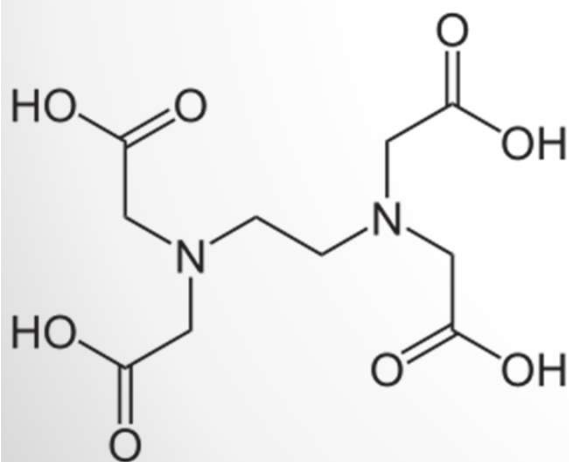
Numerical problem 3

A precipitate of 0.110 g of $\text{CaC}_2\text{O}_4 \cdot \text{H}_2\text{O}$ was obtained from 250 mL of water sample. Express the calcium content in the sample in ppm.

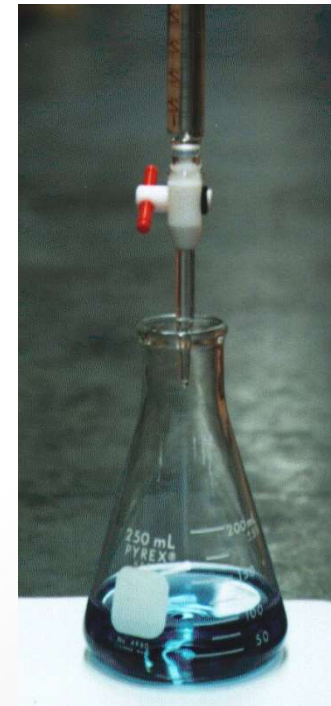
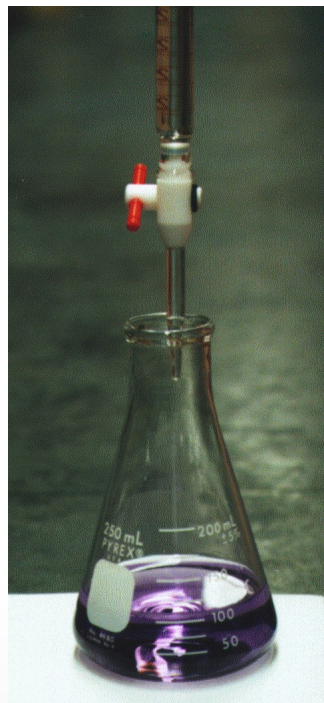
Estimation of hardness

EDTA method

- Complexometric titration
- EDTA is a hexadentate ligand, complexes many multivalent metal cations
- Eriochrome black T is the indicator (blue) which turns red in presence of Mg^{2+} or Ca^{2+}
- Ammonia buffer ($\text{NH}_4\text{Cl} + \text{NH}_4\text{OH}$) to be added to maintain alkaline pH



- EBT, when added in small quantity to hard water turns red due to a weak complex formation with Ca^{2+} and Mg^{2+}
- When EDTA is titrated into this solution, EDTA forms stronger complex with free Ca^{2+} and Mg^{2+} (uncomplexed with EBT).
- Once all Mg^{2+} and Ca^{2+} are complexed with EDTA, any more addition will remove the metal ion from Ca-EBT or Mg-EBT complex, releasing the free uncomplexed EBT.
- Thus the solution turns **red to blue** at the end point!



Estimation of hardness of water by EDTA method

Step 1 : Preparation of standard Hard water

1g of pure dry CaCO_3 is dissolved in 1L of distilled water.

1000 mg of CaCO_3 is present in 1000 mL of water

Or 1 mg of CaCO_3 is present in 1mL of standard hard water

Step 2: Standardization of EDTA solution

50mL of standard HW+ 10mL buffer + few drops of EBT indicator and let the volume of EDTA consumed = V_1 mL

Therefore, V_1 mL of EDTA consumed by = 50mL Std.HW

(1mL Std.HW contains = 1mg CaCO_3)

V_1 mL EDTA is consumed by = 50mg CaCO_3 eq

1mL EDTA will be consumed by = $50/V_1$ mg CaCO_3 eq

Step 3: Estimation of Total Hardness using Standardized EDTA solution

50mL of sample hard water + 10mL buffer + few drops of EBT indicator and let the volume of EDTA consumed = V_2 mL

Therefore, 50mL Sample. H W = V_2 mL of EDTA

We know that, 1mL EDTA = $50/V_1$ mg CaCO_3 eq

V_2 mL EDTA will contain = $(50/V_1) * V_2$ mg CaCO_3 eq

Therefore, 50 mL sample HW contains = $(50/V_1) * V_2$ mg CaCO_3 eq

And 1L sample HW contains = $\frac{50 * V_2}{V_1 * 50} * 1000$ mg/L CaCO_3

Total Hardness = $(V_2/V_1) * 1000$ ppm

Step 4: Estimation of Permanent Hardness

50mL of Boiled sample hard water + 10mL buffer + few drops of EBT indicator and let the volume of EDTA consumed = V_3 mL

Therefore, 50mL Boiled sample. H W = V_3 mL of EDTA

We know that, 1mL EDTA = $50/V_1$ mg CaCO_3 eq

V_2 mL EDTA will contain = $(50/V_1) * V_3$ mg CaCO_3 eq

Therefore, 50 mL sample HW contains = $(50/V_1) * V_3$ mg CaCO_3 eq

And 1L sample HW contains = $\frac{50 * V_3}{V_1 * 50} * 1000$ mg/L CaCO_3

$$\text{Permanent Hardness} = (V_3/V_1) * 1000 \text{ ppm}$$

$$\text{Temporary Hardness} = (\text{Total} - \text{Permanent})$$

- 50 mL of a standard hard water containing 1 mg of pure CaCO_3 per 1 mL, consumed 20 mL of EDTA. 50 mL of a water sample consumed 25 mL of EDTA solution using EBT indicator. Calculate total hardness of the water sample in 1L.

- Ans = 1250 ppm

Disadvantages of hard water

■ Domestic

- **Washing** - doesn't produce lather cause wastage of soap, white scum formed adheres to fabric giving spots and streaks.
- **Bathing** - cleansing quality of soap is depressed.
- **Cooking** - boiling point of water increased so fuel and time wasted. Tea or coffee unpleasant taste. Salt deposition in heating utensils.
- **Drinking** – affect digestive track, form stones in urinary track.

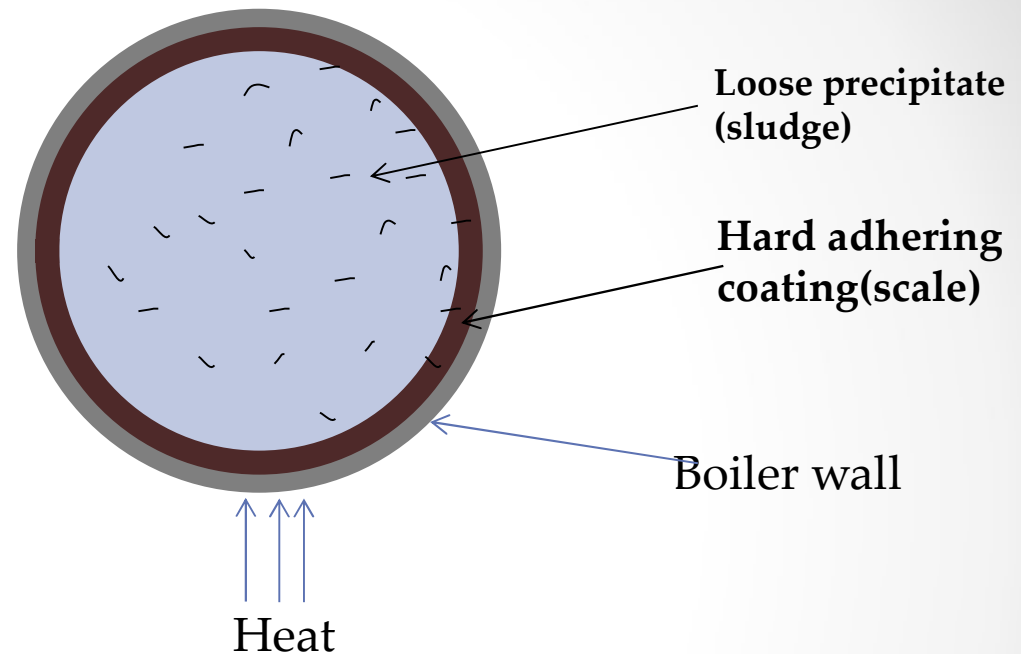
Disadvantages of hard water

■ Industry

- **Textile** – during dyeing dissolved salts cause poor quality shades and give spots.
- **Sugar** – crystallization becomes difficult, sugar so-produced is deliquescent.
- **Paper** – affects smoothness and glossiness of paper.
- **Concrete making** - affects hydration of cement and strength of concrete.
- **Steam generation and boilers** – scale and sludge formation, wastage of fuel, priming and foaming, corrosion and caustic embrittlement.

Scale and sludge formation in boilers

- Continuous water evaporation causes concentration of dissolved salts
- At saturation point, the salts precipitate out
- **Sludge** is the loose and slimy precipitate
- **Scale** is the hard adhering crust/coating on the inner wall of boilers



- **Sludge** is a soft, loose and slimy precipitate formed within the boiler. It can be easily scrapped off with a wire brush.
- It is formed at comparatively colder portions of the boiler and collects in areas of the system, where the flow rate is slow or at bends.
- It is formed by substances which have greater solubility's in hot water than in cold water, e.g. MgCO_3 , MgCl_2 , CaCl_2 , MgSO_4 etc.,

Scales in boilers

- Hard deposits, difficult to remove even with hammer and chisel
- Deposits of calcium carbonate, calcium sulphate, calcium phosphate and insoluble silicates
- Influence of scale on the temperature drop across a boiler tube is

$$\Delta T = QL/K$$

Q is the heat transferred in W cm^{-2}

L is the thickness of the scale in cm

K is the thermal conductivity in $\text{Wcm}^{-1} \text{K}^{-1}$

DT is the temperature drop across the pipe in K or $^{\circ}\text{C}$

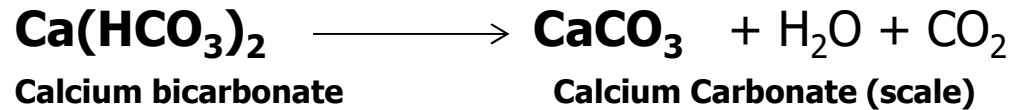
K values for:

CaCO_3	$= 0.03 \text{ Wcm}^{-1} \text{K}^{-1}$
CaSO_4	$= 0.003 \text{ Wcm}^{-1} \text{K}^{-1}$
silicate scale	$= 0.0008 \text{ Wcm}^{-1} \text{K}^{-1}$

A scale of just 0.15mm thick calcium carbonate can cause temperature gradient of ~200K and raise the temperature on the outside to unsafe levels

Formation of Scales in boilers

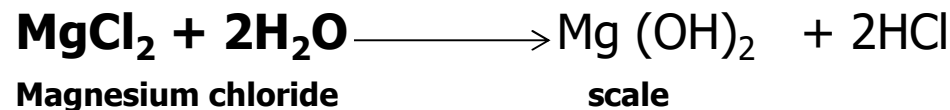
- **Decomposition of calcium bicarbonate** – in low pressure boilers



- In high pressure boilers, CaCO_3 decomposes to Ca(OH)_2 which is soluble

- **Deposition of calcium sulphate**– solubility of CaSO_4 drops from 3200 ppm at 15°C to 27 ppm at 320°C
- Gets deposited as very hard scale on heated portions of boilers

- **Hydrolysis of magnesium salts**– Mg salts hydrolyse to Mg(OH)_2 which forms a soft type of scale



Presence of silica – SiO_2 , even in small amounts, can deposit as very firmly sticking CaSiO_3 or MgSiO_3

Disadvantages of scale formation

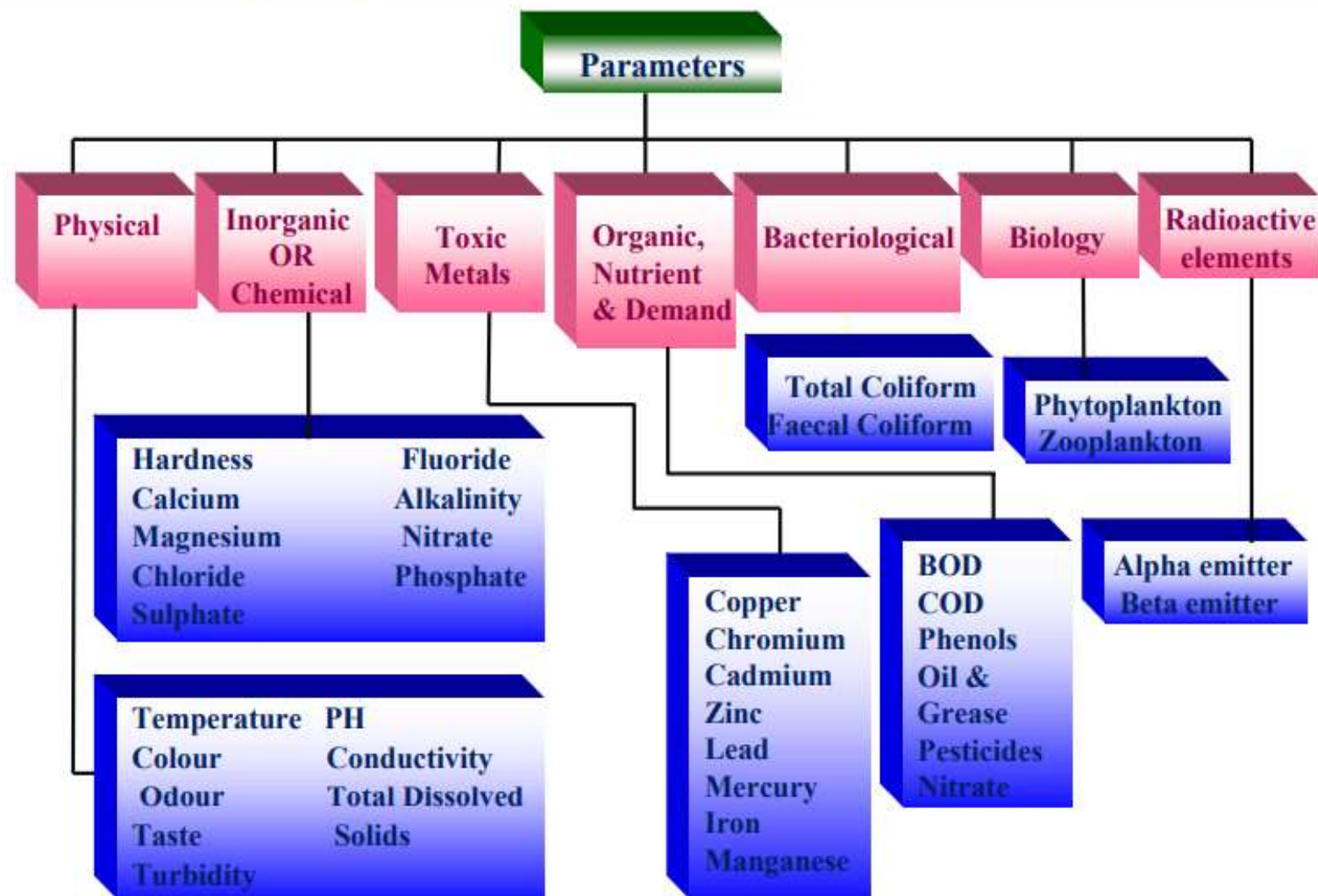
1. Fuel wastage – scales have low thermal conductivity
2. Degradation of boiler material and increases the risk of accident
3. Reduces the efficiency of the boiler and- deposit on the valves and condensers
4. The boiler may explode – if crack occurs in scale

Scale Removal

1. Using scrapper, wire brush
2. By thermal shock- heating and cooling suddenly with cold water
3. Using chemicals – 5-10% HCl and by adding EDTA , especially for CaSO_4 scales
4. Blow-down operation to remove loosely adhering scales – Very hard water is removed from a tap at the bottom and topped with softened “make up” water

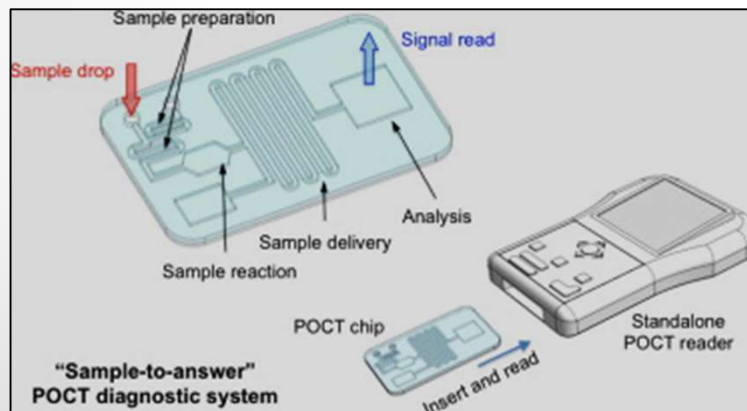
Modern techniques of water analysis

Water Quality Assessment : Potable & Industrial Uses



Lab-on-a-chip

- A lab-on-a-chip (LOC) is a device that integrates one or several laboratory functions on a single integrated circuit (commonly called a "chip") of only millimeters to a few square centimeters to achieve automation and high-throughput screening.
- LOCs can handle extremely small fluid volumes down to less than pico liters.
- Lab-on-a-chip devices are a subset of microelectromechanical systems (MEMS) devices and sometimes called "micro total analysis systems" (μ TAS).
- LOCs may use microfluidics, the physics, manipulation, and study of minute amounts of fluids.



Microfluidics deals with the behaviour, precise control and manipulation of fluids that are geometrically constrained to a small, typically sub-millimeter, scale at which capillary penetration governs mass transport.

Microfluidics and Lab-On-A-Chip for Water Analysis

- Microfluidics and lab-on-a-chip systems are advanced technologies that may replace the traditional methods of water analysis in the near future.
- Lab-on-a-chip technology employs microfluidics, which deals with very minute amounts of fluids in microchannels, to perform the analysis.
- The lab-on-a-chip device is a chip that **resembles electronic chips**, but with microchannels instead of electrical circuits.
- It **shrinks** the lab to the chip size and can perform complete analysis or even series of analysis.

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Using the lab-on-a-chip technology in water analysis **can reduce time and manpower** in the sampling process because this technology can offer immediate, onsite results.

- In addition, this technique **is much less expensive and offers higher accuracy**, because of the small volumes analyzed and the possibility of eliminating the sampling process, which reduces the human error.

Components of Lab-On-A-Chip Systems

The main components of a lab-on-a-chip system for water analysis are; a liquid delivery system (injector and fluidic transporter), mixer, reactor, separator, and power supply.

- **The Injector** is used to deliver precise volumes into the chip. The most common types of the injectors are syringe pumps and robotic pipets.
- **Transporters** control all aspects of the flow. They can be active, which need an energy source, or passive, which are achieved by manipulating the geometries of the channels and do not require any energy source. The choice between the active and passive types is based on the application. There are multiple types of active transporters, but the most preferred is electrochemical pumping systems, such as microsyringe pumps, because they eliminate the design complexity.
- **Mixers** are used to mix different fluids into the channels. Similar to the transporters, the types of mixers are divided into passive, which are achieved by design manipulation, and active, which require power.
- **The Reactor** is where the reaction takes place. There are three types of reactors used in lab-on-a-chip systems: gas phase, liquid phase, and packed-bed reactors.
- **Controllers** are used for controlling all types of activities in the chip as well as data acquisition and signal processing.
- **Power supplies**, such as batteries, are essential to run the lab-on-a-chip systems. Many research studies focus on finding more advanced power supplies because some types of lab-on-a-chip systems require high voltage

Advantages of Lab-on-a-chip

- Low fluid volumes consumption (less waste, lower reagents costs, and fewer sample volumes)
- Faster analysis and response time due to short diffusion distance & high surface to volume ratio.
- Better process control because of a faster response of the system compactness of the systems due to the integration of much functionality and small volumes
- Lower fabrication costs, allowing cost-effective disposable chips, fabricated in mass production
- Safer platform for chemical, radioactive or biological studies because of integration of functionality, smaller fluid volumes, and stored energies

Current Applications in Water Analysis

- Though LOC technology for water analysis are still developing, some lab-on-a-chip applications in water analysis are already established, such as pH testing and detection of various chemicals (e.g., nitrates and nitrites, manganese, phosphates, and silicates).
- For example, the microfluidic pH analysis uses sulfonephthalein as the main indicator, which includes the absorption cell, a static mixer, as well as a syringe pump and four valves attached to the chip to regulate the flow.

Ion Selective Electrodes (ISE)

- Ion Selective Electrodes (ISE) are membrane electrodes that respond selectively to ions in the presence of others.
- These include probes that measure specific ions and gases in solution.
- The most commonly used ISE is the pH probe.
- Other ions that can be measured include fluoride, bromide, cadmium, and gases in solution such as ammonia, carbon dioxide, and nitrogen oxide.
- The use of Ion Selective Electrodes in environmental analysis offer several advantages over other methods of analysis. First, the cost of initial setup to make analysis is relatively low. The basic ISE setup includes a meter (capable of reading millivolts), a probe (selective for each analyte of interest), and various consumables used for pH or ionic strength adjustments.
- The expense is considerably less than other methods, such as Atomic Adsorption Spectrophotometry or Ion Chromatography.
- ISE determinations are not subject to interferences such as color in the sample. This makes them ideal for clinical use (blood gas analysis) where they are most popular
- A large number of indicator electrodes with good selectivity for specific ions are based on the measurement of the potential generated across a membrane

Electronic nose (e-nose)

- An electronic nose (e-nose) is a device that identifies the specific components of an odor and analyzes its chemical makeup to identify it.
- An electronic nose consists of a mechanism for chemical detection, such as an array of electronic sensors, and a mechanism for pattern recognition, such as a neural network.
- Current research is focused on making the devices smaller, less expensive, and more sensitive.
- The smallest version, a nose-on-a-chip is a single computer chip containing both the sensors and the processing components
- An odor is composed of molecules, each of which has a specific size and shape.
- Each of these molecules has a correspondingly sized and shaped receptor in the human nose.
- When a specific receptor receives a molecule, it sends a signal to the brain and the brain identifies the smell associated with that particular molecule.
- Electronic noses based on the biological model work in a similar manner, though substituting sensors for the receptors, and transmitting the signal to a program for processing, rather than to the brain.

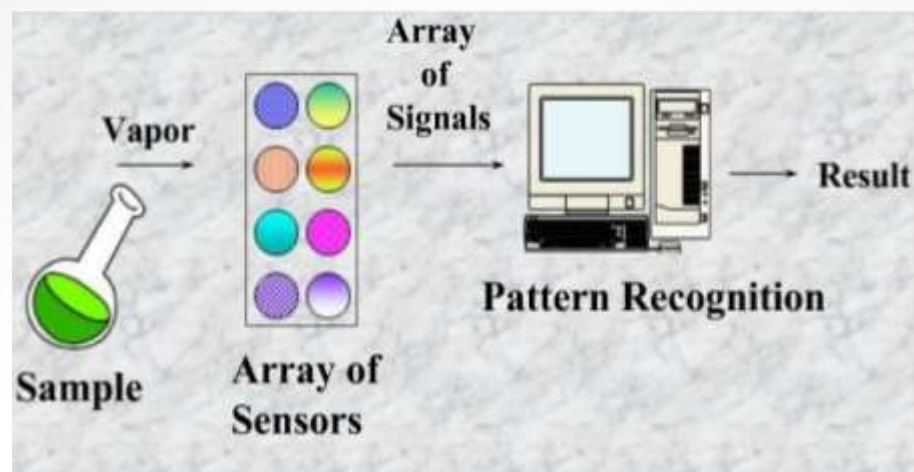


Table 2.1 Comparing electronic nose with human nose

Bio-nose	Electronic nose
It uses the lungs to bring the odor to epithelium layer	It employs a pump to smell the odor
It has mucus, membrane, and hair to act as filter	It has an inlet sampling system that provides filtration
The human nose contains the olfactory epithelium, which contains millions of sensing cells that interact with odorants in unique	Electronic nose has a variety of sensors that interact differently with a group of odorous molecules
The human receptors convert the chemical response to electronic nerve impulses whose unique patterns are propagated by neurons through a complex network before reaching the higher brain for interpretation	Similarly, the chemical sensors in the electronic nose react with the sample and produce electrical signals. A computer reads the unique pattern of signals and interprets them with some form of intelligent pattern classification algorithms

Electronic tongue (e-tongue)

Similar to E-nose, E-tongues are also analytical instruments that can detect specific substances in solution in water, consisting of sensor array, signal transduction system and involving signal processing and pattern recognition (resulting in detection)

Uses of e-nose and e-tongue

- Mixing of sewage in drinking water supply can be detected
- Presence of specific ions and their concentrations can be monitored
- Contamination by toxic metal ions can be detected
- Water treatment processes can be continuously monitored

