Water

Chemical Composition of Water

- The **molecular formula** of water is H_2O.
- **Mass ratio** of elements
  H_2O H:O, 2 × 1:16 × 1 = 1:8
  (Atomic mass of H = 1; atomic mass of O = 16)
- **Molecular formula** of the water molecule is H_2O.
- **Chemical name** of water is dihydrogen oxide.
- **Molecular mass** of water = 2 (atomic mass of H) + 1 (atomic mass of O)
  = 2 × (1) + 1 (16)
  = 2 + 16
  = 18 amu
- Hydrogen to oxygen to hydrogen **bond angle** in the water molecule is **104.5°**.

Physical Properties of Water

Nature	Pure water is a colourless, transparent, clear liquid at room temperature. It is odourless and tasteless.
Boiling point	Pure water boils at 100°C at normal pressure.
Freezing point	Pure water freezes at 0°C at normal pressure (1 atm).
Effect of pressure	• If the pressure is increased, then the boiling point increases. • If the pressure is decreased, then the boiling point decreases.
Density	Maximum 1 g/cm^3 or 1000 kg/m^3 at 4°C.
Anomalous expansion of water	When water is cooled, it first contracts in volume just like other liquids up to 4°C. On further cooling, it expands instead of contracting. This expansion takes place up to 0°C. Thus, at 0°C, water has maximum volume and minimum density. At 0°C, it becomes ice and has a density of 0.92 g/cm^3 and floats on water.
Conductivity	• Pure water is a non-conductor of electricity because it does not form ions. • Water can be decomposed by the passing of electric current. This process is called electrolysis. $2H_2O \xrightarrow{\text{Electrolysis}} 2H_2 + O_2$
Solvent properties	• Water is a **universal solvent** and can dissolve many substances as compared to other solvents because of its polar covalent nature. • Water has a **high dielectric constant** of 80.10 at 20°C. Because of this large value of the dielectric constant, water can dissolve a large number of ionic compounds.
Latent heat of fusion of ice	• The amount of heat energy required by ice to change into water is called the latent heat of fusion of ice. • The latent heat of fusion of ice is 336 J/g or 80 cal/g. • In the reverse process, 336 joules of heat is released when 1 g of water solidifies to form 1 g of ice at 0°C.
Latent heat of vaporisation of water	• The energy required to change water into its vapour at its boiling point without any change in temperature is called the latent heat of vaporisation of water. • The latent heat of vaporisation of water is 2260 J/g or 540 cal/g. • In the reverse process, 2260 joules of heat is released when 1 g of steam condenses to form 1 g of water at 100°C.

Specific heat capacity	• The specific heat or specific heat capacity of a substance is the amount of heat required to raise the temperature of a unit mass of that substance through 1°C. • The specific heat of water is 4.2 joules or 1 calorie.

Chemical Properties of Water

Nature	Water in its pure form is neutral to litmus. There is no change in the colour of blue or red litmus solution.
Stability	Water is a stable compound, i.e. it does not decompose on heating. However, at very high temperature, between 2000°C and 3500°C, it decomposes slightly to form hydrogen gas and oxygen gas. $2H_2O \xrightarrow{2000-3500°C} 2H_2\uparrow + O_2\uparrow$
Catalytic activity	Water acts as a catalyst in the synthesis of hydrogen chloride in the presence of moisture. $\underset{\text{Hydrogen}}{H_2} + \underset{\text{Chlorine}}{Cl_2} \xrightarrow{\text{moisture}} \underset{\text{Hydrogen chloride}}{2HCl}$
	Combustion of white phosphorus to phosphorus pentoxide takes place in the presence of moisture. $\underset{\text{Phosphorous}}{4P} + \underset{\text{Oxygen}}{5O_2} \xrightarrow{\text{moisture}} \underset{\text{Phosphorous pentoxide}}{2P_2O_5}$
Reaction with non-metals	**Reaction with carbon** When steam is passed over red hot coke, water gas is formed. Water gas is an important industrial fuel. $\underset{\text{Carbon (Coke)}}{C} + \underset{\text{Water (Steam)}}{H_2O} \longrightarrow \underbrace{\underset{\text{Carbon monoxide}}{CO} + \underset{\text{Hydrogen}}{H_2}}_{\text{Water gas}}$
	Reaction with chlorine When chlorine gas is bubbled through water in the presence of diffused sunlight, hydrochloric acid and hypochlorous acid are formed. $\underset{\text{Chlorine}}{Cl_2} + \underset{\text{Water}}{H_2O} \longrightarrow \underset{\text{Hydrochloric acid}}{HCl} + \underset{\text{Hypochlorous acid}}{HClO}$
Reaction with metallic oxides	Metallic oxides dissolve in water to form corresponding alkalis. **Reaction with sodium oxide** $\underset{\text{Sodium oxide}}{Na_2O} + \underset{\text{Water}}{H_2O} \rightarrow \underset{\text{Sodium hydroxide (alkali)}}{2NaOH}$
	Reaction with potassium oxide $\underset{\text{Potassium oxide}}{K_2O} + \underset{\text{Water}}{H_2O} \rightarrow \underset{\text{Potassium hydroxide (alkali)}}{2KOH}$
	Reaction with calcium oxide $\underset{\text{Calcium oxide}}{CaO} + \underset{\text{Water}}{H_2O} \rightarrow \underset{\text{Calcium hydroxide (alkali)}}{Ca(OH)_2}$

Reaction with non-metallic oxides	Non-metallic oxides dissolve in water to form corresponding acidic solutions. **Reaction with carbon dioxide** CO_2 (Carbon dioxide) $+ H_2O$ (Water) $\rightarrow H_2CO_3$ (Carbonic acid)
	Reaction with sulphur dioxide SO_2 (Sulphur dioxide) $+ H_2O$ (Water) $\rightarrow H_2SO_3$ (Sulphurous acid)
	Reaction with sulphur trioxide SO_3 (Sulphur trioxide) $+ H_2O$ (Water) $\rightarrow H_2SO_4$ (Sulphuric acid)
	Reaction with nitrogen dioxide $2NO_2$ (Nitrogen dioxide) $+ H_2O$ (Water) $\rightarrow HNO_2$ (Nitrous acid) $+ HNO_3$ (Nitric acid)
Reaction with carbides	**Reaction with aluminium carbide** Al_4C_3 (Aluminium carbide) $+ 12H_2O$ (Water) $\rightarrow 4Al(OH)_3$ (Aluminium hydroxide) $+ 3CH_4$ (Methane)
	Reaction with calcium carbide CaC_2 (Calcium carbide) $+ 2H_2O$ (Water) $\rightarrow Ca(OH)_2$ (Calcium hydroxide) $+ C_2H_2$ (Acetylene)
Reaction with metal nitrides	Boiling water reacts with metal nitrides to form their respective hydroxides and ammonia gas. **Reaction with calcium nitride** Ca_3N (Calcium nitride) $+ 6H_2O$ (Water) $\rightarrow 3Ca(OH)_2$ (Calcium hydroxide) $+ 2NH_3$ (Ammonia)
	Reaction with magnesium nitride Mg_3N (Magnesium nitride) $+ 6H_2O$ (Water) $\rightarrow 3Mg(OH)_2$ (Magnesium hydroxide) $+ 2\,NH_3$ (Ammonia)
	Reaction with aluminium nitride AlN (Aluminium nitride) $+ 3H_2O$ (Water) $\rightarrow Al(OH)_3$ (Aluminium hydroxide) $+ NH_3$ (Ammonia)
Noble metals	Noble metals, such as silver, gold and platinum, are virtually inactive to water.

Activity Series of Metals

- The series of metals arranged in the decreasing order of their reactivity is called an activity or reactivity series.
- Hydrogen is a non-metal. It has been included in this series because it can form a positive ion. It would occupy the position based on its formation of a positive ion.
- Metals above hydrogen may displace hydrogen from water and dilute acids, but the metals below hydrogen cannot displace hydrogen.

Reactivity Series Of Metals	
K	Vigorous reaction – with cold water
Na	Less vigorous reaction – with cold water
Ca	Mild reaction – with cold water
Mg	Heated metal–with boiling water or steam
Al	Heated metal – with steam
Zn	Red hot metal – with steam
Fe	Red hot metal–with steam [slow reaction]
Pb	Metal below hydrogen
[H]	[Including lead] –
Cu	Have no reaction – with water
Hg	
Ag	
Pt	
Au	

Activity Series of Metals

Solutions

- **Solution:** A homogeneous mixture of two or more substances, the components of which cannot be seen separately.
- **Solute:** A substance which dissolves in a solvent to form a solution.
- **Solvent:** A medium in which the solute dissolves.

Solution = Solute + Solvent

- **True solution:** A homogeneous mixture of two or more substances, the composition of which is not fixed and may be varied within certain limits.
- **Dilute solution:** A solution in which the amount of solute is relatively small as compared to the amount of solvent.
- **Concentrated solution:** A solution in which the amount of solute is relatively large as compared to the amount of solvent.
- **Saturated solution:** A solution which cannot dissolve any more quantity of solute in a given amount of solvent at a given temperature.
- **Unsaturated solution:** A solution which can dissolve more of the solute in a given amount of solvent at a given temperature.
- **Supersaturated solution:** A solution which contains more of the solute than what is present in its saturated solution at a particular temperature.

- **Aqueous solution:** A solution in which water has been used as a solvent.
  Example: Solution of common salt or sugar in water
- **Non-aqueous solution:** A solution in which the solvent used is other than water.
  Example: Sulphur dissolved in carbon disulphide
  Non-aqueous solvents are alcohol, benzene, ether and acetone.

Common Solvents

Solvents	Solutes dissolved
Turpentine	Paint, paraffin wax
Carbon disulphide	Sulphur and phosphorus
Acetone	Nail polish
Alcohol	Iodine, naphthalene
Methylated spirit	Chlorophyll
Petrol	Grease
Oxalic acid	Rust
Benzene	Rubber

Concentration of a Solution

Concentration of a solution is the amount of solute dissolved in a given quantity of solution.

Mass Percent: The mass of a solid solute in gram present in 100 gram of solution.

$$\text{Concentration of solution (in terms of mass \%)} = \frac{\text{Mass of solute}}{\text{Mass of solution (Solute + Solvent)}} \times 100$$

Volume Percent: The volume of a solute in millilitre present in 100 millilitre solution.

$$\text{Concentration of solution (in terms of volume \%)} = \frac{\text{Volume of solute}}{\text{Volume of solute + Volume of solvent}} \times 100$$

Solubility

Solubility of a solute in a particular solvent at a particular temperature is the maximum amount of a solute in gram which can be dissolved in 100 gram of a solvent at that temperature.

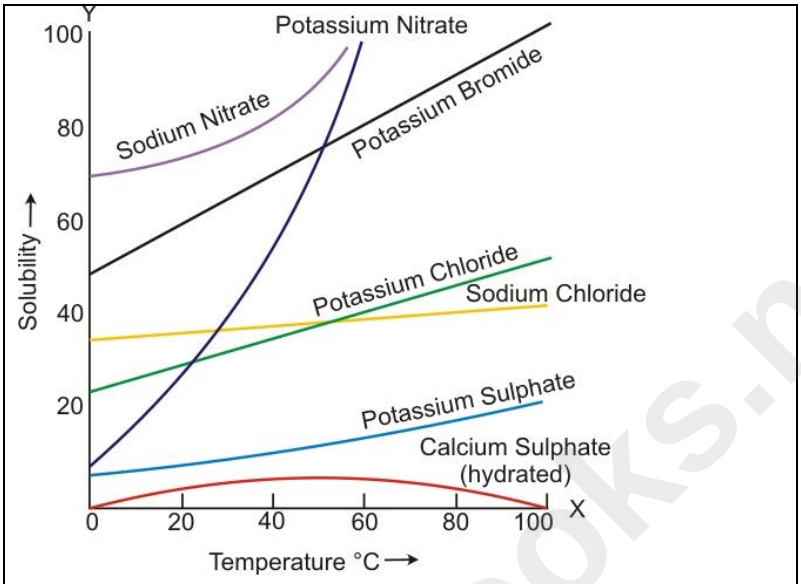
Determination of the solubility of a solute at a particular temperature can be calculated by

$$\text{Solubility} = \frac{\text{Mass of solute}}{\text{Mass of solvent}} \times 100$$

$$= \frac{M_2 - M}{(M_1 - M) - (M_2 - M)} \times 100$$

Solubility Curve

- A solubility curve is a line graph which shows changes in the solubility of a solute in a given solvent with a change in temperature.



Variation in the solubility of some solids with changing temperature

Inferences from Solubility Curves

- Decrease in solubility of substances with rise in temperature. Example: Calcium sulphate ($CaSO_4$)
- Increase in solubility of substances with rise in temperature. Examples: Sodium nitrate ($NaNO_3$), potassium nitrate (KNO_3), potassium bromide (KBr_3)
- Slight increase in solubility with increase in temperature. Example: Sodium chloride (NaCl)
- Anomalous solubility. Example: Sodium sulphate ($Na_2SO_4.10H_2O$)

Crystals and Crystallisation

- **Crystal:** A crystal is a homogeneous solid, arranged symmetrically, meeting at sharp edges at definite angles to one another and having a definite geometrical shape.
- **Crystallisation:** A process by which the crystals are obtained from a hot saturated solution by cooling.
- **Water of crystallisation:** The fixed amount of water which is associated with crystals and which form an integral part of the crystal is called water of crystallisation.
- **Decrepitation:** The heating of some crystals which produce a crackling sound is called decrepitation. Example: Sodium chloride crystals
- **Hydrated salt:** A salt which contains a fixed number of water molecules, as water of crystallisation, with loose chemical bond is called a hydrated salt.
- **Anhydrous salt:** A salt which does not contain any fixed number of water molecules, as water of crystallisation, with loose chemical bond is called an anhydrous salt.
- **Efflorescence:** Crystalline hydrated salts which on exposure to the atmosphere lose their moisture (water of crystallisation) partly or completely to the atmosphere and change into the amorphous state. Examples: Washing soda ($Na_2CO_3.10H_2O$), Glauber salt ($Na_2SO_4.10H_2O$)

- **Deliquescence:** Water-soluble salts absorb moisture from the atmosphere and dissolve in it to form a saturated solution. The substance is called a deliquescent substance and the phenomenon is called deliquescence.
  Examples: Caustic soda (NaOH), caustic potash (KOH), magnesium chloride ($MgCl_2$), zinc chloride ($ZnCl_2$), ferric chloride ($FeCl_2$)
- **Hygroscopy:** When a substance can absorb moisture from the air without changing its state (solid/liquid), the substance is called hygroscopic, and the phenomenon is known as hygroscopy.
  Examples: Copper oxide (CuO), calcium oxide (CaO), copper sulphate ($CuSO_4$), concentrated sulphuric acid (H_2SO_4)
- **Desiccants:** Substances which can readily absorb or remove moisture from other substances are called desiccants. Most of the hygroscopic substances are desiccants (drying agents).
  Examples: Fused calcium chloride ($CaCl_2$), fused phosphorus pentoxide (P_2O_5), anhydrous calcium chloride $CaCl_2$), quick lime (CaO), concentrated sulphuric acid (H_2SO_4)

Water Pollution

Pollution is an undesirable change in the natural environment brought about by physical, chemical and biological factors in the atmosphere, water or land.

Pollutants are physical, chemical and biological agents or foreign substances introduced into the environment in quantities which have an undesirable effect on human health and environment.

Water pollution is defined as an undesirable change in the physical, chemical and biological conditions of water due the presence of foreign substances in water.

Causes of Water Pollution

- Household detergents
- Industrial waste
- Domestic sewage
- Offshore oil drilling
- Agricultural wastes
- Thermal pollution

Treatment of Water Pollution

- Collection and disposal of domestic sewage, mainly sewage and municipal garbage.
- Treatment of industrial waste to yield safe effluents.