# 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

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| **Nature** | Pure water is a colourless, transparent, clear liquid at room temperature.<br>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.<br>• 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.<br>• Water can be decomposed by the passing of electric current. This process is called electrolysis.<br>$2H_2O \xrightarrow{\text{Electrolysis}} 2H_2 + O_2$ |
| **Solvent properties** | • Water is a **universal solvent** and can dissolve many substances as compared to other solvents because of its polar covalent nature.<br>• 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.<br>• The latent heat of fusion of ice is 336 J/g or 80 cal/g.<br>• 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.<br>• The latent heat of vaporisation of water is 2260 J/g or 540 cal/g.<br>• 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. |

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| **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.<br>• The specific heat of water is 4.2 joules or 1 calorie. |

## Chemical Properties of Water

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| **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.<br>$2H_2O \xrightarrow{2000-3500°C} 2H_2\uparrow + O_2\uparrow$ |
| **Catalytic activity** | Water acts as a catalyst in the synthesis of hydrogen chloride in the presence of moisture.<br>$H_2$ (Hydrogen) + $Cl_2$ (Chlorine) $\xrightarrow{\text{moisture}}$ $2HCl$ (Hydrogen chloride) |
| | Combustion of white phosphorus to phosphorus pentoxide takes place in the presence of moisture.<br>$4P$ (Phosphorous) + $5O_2$ (Oxygen) $\xrightarrow{\text{moisture}}$ $2P_2O_5$ (Phosphorous pentoxide) |
| **Reaction with non-metals** | **Reaction with carbon**<br>When steam is passed over red hot coke, water gas is formed. Water gas is an important industrial fuel.<br>$C$ (Carbon / Coke) + $H_2O$ (Water / Steam) $\longrightarrow$ $CO$ (Carbon monoxide) + $H_2$ (Hydrogen)<br>Water gas |
| | **Reaction with chlorine**<br>When chlorine gas is bubbled through water in the presence of diffused sunlight, hydrochloric acid and hypochlorous acid are formed.<br>$Cl_2$ (Chlorine) + $H_2O$ (Water) $\longrightarrow$ $HCl$ (Hydrochloric acid) + $HClO$ (Hypochlorous acid) |
| **Reaction with metallic oxides** | Metallic oxides dissolve in water to form corresponding alkalis.<br>**Reaction with sodium oxide**<br>$Na_2O$ (Sodium oxide) + $H_2O$ (Water) $\rightarrow$ $2NaOH$ (Sodium hydroxide (alkali)) |
| | **Reaction with potassium oxide**<br>$K_2O$ (Potassium oxide) + $H_2O$ (Water) $\rightarrow$ $2KOH$ (Potassium hydroxide (alkali)) |
| | **Reaction with calcium oxide**<br>$CaO$ (Calcium oxide) + $H_2O$ (Water) $\rightarrow$ $Ca(OH)_2$ (Calcium hydroxide (alkali)) |

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

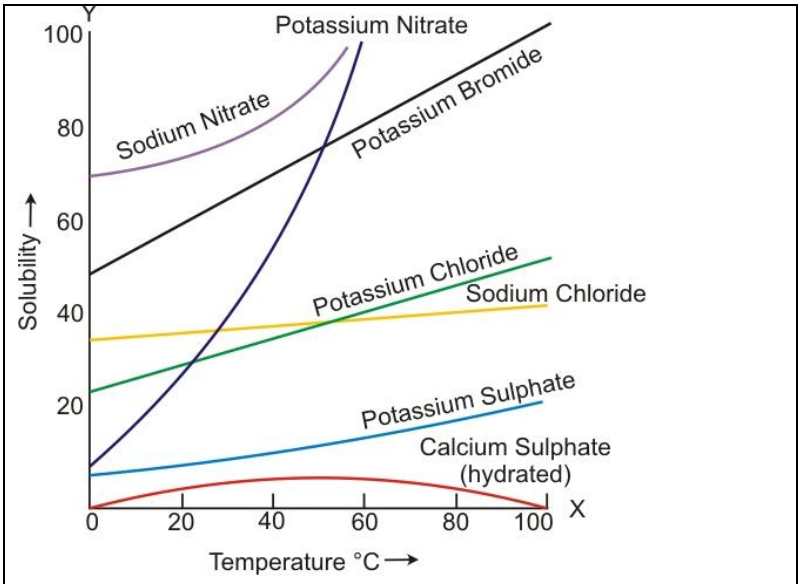
Determination of the solubility of a solute at a particular temperature can be calculated by

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

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

## 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

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- **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

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**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.