Fundamentals of Chemistry and Matter 2

Chapter 15: Periodic Tables and Families of Elements

The periodic table is one of the most powerful tools in chemistry, organizing all known elements in a way that reveals trends in their properties and helps predict their behavior.

15.1 Periodic Table - Electronic Configuration of Atoms as the Basis

- **Basis of the Periodic Table:** The modern periodic table is based on the **atomic number** (number of protons) of elements, not atomic mass.
- **Electronic Configuration:** The arrangement of electrons in the energy shells (or orbitals) around an atom's nucleus is fundamental to its chemical properties.
    - Elements with similar outer electronic configurations (valence electrons) exhibit similar chemical properties.
    - The periodic table is arranged so that elements with similar electron configurations fall into the same vertical columns (groups).

15.2 Groups and Periods

- **Periods (Rows):** Horizontal rows in the periodic table.
    - Elements in the same period have the same number of electron shells.
    - As you move from left to right across a period, the atomic number increases by one, and electrons are added to the same valence shell.
    - Properties change gradually across a period, from metallic to non-metallic.
- **Groups (Columns):** Vertical columns in the periodic table.
    - Elements in the same group have the same number of valence electrons (outermost shell electrons).
    - Having the same number of valence electrons means they exhibit similar chemical properties.
    - The group number often corresponds to the number of valence electrons (for main group elements).

15.3 Metals, Metalloids, and Non-metals

Elements are broadly classified based on their characteristic properties:

- **Metals:**
  - Located on the left and center of the periodic table.
  - Typically solids at room temperature (except mercury).
  - Good conductors of heat and electricity.
  - Malleable (can be hammered into sheets) and ductile (can be drawn into wires).
  - Lustrous (shiny).
  - Tend to lose electrons and form positive ions (cations).
  - Have low ionization energies and low electronegativities.
  - Form basic oxides.
- **Non-metals:**
  - Located on the right side of the periodic table.
  - Can be solids, liquids, or gases at room temperature.
  - Poor conductors of heat and electricity (except graphite).
  - Brittle (if solid).
  - Lack of luster.
  - Tend to gain electrons and form negative ions (anions) or share electrons.
  - Have high ionization energies and high electronegativities.
  - Form acidic or neutral oxides.
- **Metalloids (Semimetals):**
  - Located along the "staircase" line between metals and non-metals (e.g., Boron, Silicon, Germanium, Arsenic, Antimony, Tellurium).
  - Exhibit properties intermediate between metals and non-metals.
  - Often semiconductors (conduct electricity under specific conditions).

15.4 Periodic Table and Atomic Properties

- **Atomic Size (Atomic Radius):**
  - **Across a Period (left to right):** Atomic size generally **decreases**. This is because the nuclear charge increases, pulling the valence electrons closer to the nucleus, even though electrons are added to the same shell.
  - **Down a Group (top to bottom):** Atomic size generally **increases**. This is because new electron shells are added, increasing the distance of valence electrons from the nucleus, despite the increased nuclear charge.
- **Ionic Sizes:**
  - **Cations (positive ions):** Always **smaller** than their parent neutral atoms because they have lost outer electrons, and the remaining electrons are pulled closer by the same nuclear charge.
  - **Anions (negative ions):** Always **larger** than their parent neutral atoms because they have gained electrons, increasing electron-electron repulsion and expanding the electron cloud.

15.5 Periodicity of Some Properties

- **Ionization Energy:** The minimum energy required to remove one electron from a gaseous atom in its ground state.
  - **Across a Period (left to right):** Generally **increases**. As nuclear charge increases and atomic size decreases, it becomes harder to remove an electron.

    - **Down a Group (top to bottom):** Generally **decreases**. As atomic size increases and shielding effects increase, the outermost electron is further from the nucleus and easier to remove.
- **Electron Affinity:** The energy change that occurs when an electron is added to a gaseous atom to form a negative ion.
    - Generally, more negative (more energy released, greater affinity) across a period (except noble gases).
    - Generally, less negative down a group.
- **Electronegativity:** A measure of the ability of an atom in a chemical compound to attract electrons towards itself.
    - **Across a Period (left to right):** Generally **increases**. Non-metals are more electronegative.
    - **Down a Group (top to bottom):** Generally **decreases**. Metals are less electronegative.
    - Fluorine is the most electronegative element.

15.6 Families of Elements

- **Group 1: Alkali Metals (Li, Na, K, Rb, Cs, Fr):**
    - Highly reactive metals, soft, silvery, low melting points.
    - Have 1 valence electron, readily lose it to form +1 ions.
    - React vigorously with water to produce hydrogen gas and hydroxides.
- **Group 2: Alkaline Earth Metals (Be, Mg, Ca, Sr, Ba, Ra):**
    - Reactive metals (less reactive than alkali metals), harder, higher melting points.
    - Have 2 valence electrons, readily lose them to form +2 ions.
- **Group 3-12: Transition Elements (Transition Metals):**
    - Located in the d-block of the periodic table.
    - Hard, high melting points, high densities.
    - Exhibit variable oxidation states.
    - Form colored compounds and often act as catalysts.
- **Group 13: Boron Group (B, Al, Ga, In, Tl):**
    - Contain a metalloid (Boron) and metals.
- **Group 14: Carbon Group (C, Si, Ge, Sn, Pb):**
    - Progression from non-metal (C), to metalloids (Si, Ge), to metals (Sn, Pb).
- **Group 15: Nitrogen Group (N, P, As, Sb, Bi):**
    - Progression from non-metals (N, P), to metalloids (As, Sb), to metal (Bi).
- **Group 16: Chalcogens (O, S, Se, Te, Po):**
    - Contain non-metals and metalloids.
    - Oxygen and Sulfur are very common.
- **Group 17: Halogens (F, Cl, Br, I, At):**
    - Highly reactive non-metals exist as diatomic molecules (F2, Cl2, etc.).
    - Have 7 valence electrons, readily gain 1 electron to form -1 ions.
    - Strong oxidizing agents.
    - Reactivity decreases down the group.
- **Group 0 (or 18): Noble Gases (He, Ne, Ar, Kr, Xe, Rn):**
    - Inert (unreactive) gases.
    - Have a full outer electron shell (duplet for He, octet for others), making them very stable and exist as monatomic gases.

- **Lanthanides (Rare-earth elements):**
    - Elements from Lanthanum (La) to Lutetium (Lu), typically placed below the main body of the periodic table.
    - Similar chemical properties, often found together in nature.
- **Actinides and the Artificial Elements:**
    - Elements from Actinium (Ac) to Lawrencium (Lr), also placed below the main table.
    - All are radioactive.
    - Many are artificial (man-made) and short-lived.

Chapter 16: Air and Air Pollution

Air is a vital mixture of gases that surrounds the Earth, essential for life. However, human activities can introduce harmful substances, leading to air pollution.

16.1 Composition of Air

Dry air is primarily composed of:
- Nitrogen (N2): Approximately 78%
- Oxygen (O2): Approximately 21%
- Argon (Ar): Approximately 0.9%
- Carbon Dioxide (CO2): Approximately 0.04% (variable)
- Trace amounts of other noble gases (Neon, Helium, Krypton, Xenon), Methane, Nitrous Oxide, etc.
- **Water Vapour:** The amount varies greatly depending on location and weather (humidity).
- **Dust Particles:** Also present in varying amounts.

16.2 Atmospheric Oxygen

Oxygen is the most crucial component of air for life processes.
- **Combustion of Substances in Air:** Oxygen supports combustion. Most substances burn in oxygen to form oxides, releasing heat and light.
    - Example: C(s) + O2(g) ➡️ CO2(g)
- **Flames:** A visible, gaseous part of a fire. The type of flame (luminous or non-luminous) depends on the completeness of combustion and the presence of unburnt carbon particles.
- **Corrosion of Metals:** As discussed in Chapter 10, oxygen is a key reactant in the corrosion (e.g., rusting) of metals.
- **Respiration in Living Organisms:** All aerobic organisms use oxygen to break down food (glucose) to release energy.
    - {Glucose} + O2 ➡️ CO2 + H2O + {Energy}
- **Photosynthesis in Plants:** Green plants use carbon dioxide and water in the presence of sunlight to produce glucose and oxygen. This process replenishes atmospheric oxygen.
    - CO2 + H2O ➡️ {{light}} {Glucose} + O2

16.3 Atmospheric Nitrogen

- **Inert Nature:** Nitrogen gas (N2) is relatively unreactive due to the strong triple bond between its atoms.

- **Importance:** Although unreactive, it dilutes oxygen, making combustion less vigorous. It is also essential for life as a component of proteins and nucleic acids.
- **Nitrogen Fixation:** The process of converting atmospheric nitrogen into usable nitrogen compounds (e.g., ammonia, nitrates) by bacteria or lightning.

16.4 The Noble Gases

- These are the elements in Group 18 (or 0) of the periodic table (Helium, Neon, Argon, Krypton, Xenon, Radon).
- They are known for their extreme inertness (unreactivity) due to their full valence electron shells.
- **Uses:**
    - **Argon:** Used as an inert atmosphere in welding and in incandescent light bulbs.
    - **Neon:** Used in neon lights (produces a red-orange glow).
    - **Helium:** Used in balloons (less dense than air, non-flammable), and in diving mixtures.

16.5 Air Dissolved in Water

- Air, particularly oxygen, dissolves in water.
- **Importance:** Dissolved oxygen is essential for aquatic life (fish and other aquatic organisms use it for respiration).
- **Factors Affecting Solubility:** Solubility of gases in water decreases with increasing temperature.

16.6 Air Pollution

Air pollution is the presence of harmful substances in the atmosphere that can damage human health, the environment, and property.

- **Causes of Air Pollution:**
    - **Industrial Emissions:** Factories release gases like sulfur dioxide, nitrogen oxides, and particulate matter.
    - **Vehicle Exhaust:** Burning of fossil fuels in cars and trucks releases carbon monoxide, nitrogen oxides, unburnt hydrocarbons, and particulate matter.
    - **Burning of Fossil Fuels:** Power plants and domestic heating contribute to sulfur dioxide and carbon dioxide emissions.
    - **Agricultural Activities:** Ammonia from fertilizers, methane from livestock.
    - **Natural Sources:** Volcanic eruptions (ash, sulfur dioxide), wildfires (smoke, carbon monoxide, carbon dioxide).
- **Pollutants and Their Effects:**
    - **Carbon Monoxide (CO):** Produced by incomplete combustion. Highly toxic, binds to hemoglobin in blood, reducing oxygen transport.
    - **Sulfur Dioxide (SO2):** From burning fossil fuels containing sulfur. Causes acid rain, respiratory problems.
    - **Nitrogen Oxides (NOx):** From high-temperature combustion in engines and power plants. Contributes to acid rain, photochemical smog, respiratory issues.
    - **Particulate Matter (PM):** Tiny solid particles or liquid droplets (soot, dust). Causes respiratory and cardiovascular problems, reduces visibility.

    - **Lead Compounds:** From leaded gasoline (historically). Highly toxic, damages the nervous system.
    - **Chlorofluorocarbons (CFCs):** Used in refrigerants and aerosols. Deplete the ozone layer.
    - **Carbon Dioxide (CO2):** A major greenhouse gas, contributes to global warming.
- **Control of Air Pollution:**
    - **Catalytic Converters:** In vehicles, convert harmful gases (CO, NOx, unburnt hydrocarbons) into less harmful ones (CO2, N2, H2O).
    - **Desulfurization of Fuel/Flue Gases:** Removing sulfur from fuels or from exhaust gases of power plants to reduce SO2 emissions.
    - **Alternative Energy Sources:** Shifting from fossil fuels to renewable energy (solar, wind, hydroelectric).
    - **Improved Public Transportation and Fuel Efficiency:** Reducing vehicle emissions.
    - **Legislation and Regulations:** Setting emission standards for industries and vehicles.
    - **Afforestation:** Planting more trees to absorb CO2.

Chapter 17: Water, Solutions, and Solubility

Water is the most abundant compound on Earth and is essential for all known forms of life. Its unique properties make it an excellent solvent.

17.1 Natural and Treated Water

- **Natural Water Sources:** Rainwater, river water, lake water, well water, seawater. These naturally contain dissolved minerals, gases, and sometimes suspended impurities.
- **Treated Water (Potable Water):** Water that has been treated to be safe for drinking.
    - **Stages of Water Treatment:**
        1. **Screening:** Removes large debris.
        2. **Coagulation/Flocculation:** Chemicals (e.g., aluminium sulfate) are added to clump small suspended particles together.
        3. **Sedimentation:** The heavy clumps settle at the bottom.
        4. **Filtration:** Water passes through sand and gravel filters to remove remaining suspended particles.
        5. **Chlorination/Disinfection:** Chlorine or other disinfectants are added to kill harmful microorganisms.
        6. **Fluoridation (Optional):** Fluoride may be added to prevent tooth decay.

17.2 Hardness of Water

- **Origin of Hard Water:** Hard water contains dissolved mineral ions, primarily calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions. These ions react with soap to form an insoluble scum, reducing the effectiveness of soap.
- **Types of Hard Water:**
    1. **Temporary Hardness:** Caused by the presence of dissolved calcium hydrogencarbonate ($Ca(HCO_3)_2$) and magnesium hydrogencarbonate ($Mg(HCO_3)_2$).

        - Can be removed by **boiling** (which decomposes the hydrogen carbonates to insoluble carbonates that precipitate out) or by adding slaked lime (Ca(OH)2).
    2. **Permanent Hardness:** Caused by the presence of dissolved calcium sulphate (CaSO4) and magnesium sulphate (MgSO4) or chlorides.
        - **Cannot be removed by boiling.**
        - Can be removed by:
            - **Adding Washing Soda (Na2CO3):** Precipitates out the calcium/magnesium carbonates.
            - **Ion-Exchange Resins:** Exchange Ca^{2+} and Mg^{2+} ions for Na^+ or H^+ ions.
            - **Distillation:** Boiling and condensing the water (removes all dissolved impurities).
- **Advantages of Hard Water:** Provides essential minerals (Ca^{2+}) for healthy bones and teeth, reduces lead poisoning from lead pipes (forms a protective layer).
- **Disadvantages of Hard Water:** Wastes soap (forms scum), causes scaling in pipes and kettles (reduces efficiency, leads to blockages), can make food tougher to cook.

17.3 Water Pollution

Water pollution is the contamination of water bodies (rivers, lakes, oceans, groundwater) by substances that are harmful to living organisms or render the water unsuitable for use.

- **Pollutants:**
    - **Sewage:** Contains organic matter, bacteria, and nutrients. Leads to oxygen depletion (eutrophication) and spread of diseases.
    - **Industrial Effluents:** Discharge of toxic chemicals (heavy metals, acids, alkalis, dyes) from factories.
    - **Agricultural Runoff:** Fertilizers (nitrates, phosphates) leading to eutrophication, and pesticides.
    - **Oil Spills:** From tankers or drilling, harms aquatic life and coastal ecosystems.
    - **Waste Heat:** From power plants, reduces dissolved oxygen.
    - **Solid Wastes:** Plastic, garbage dumped into water bodies.
- **Control of Water Pollution:**
    - **Wastewater Treatment:** Treating sewage and industrial effluents before discharge.
    - **Proper Waste Disposal:** Preventing direct dumping of waste into water bodies.
    - **Regulation of Agricultural Practices:** Controlled use of fertilizers and pesticides.
    - **International Cooperation:** For managing transboundary water pollution.

17.4 Composition of Water

- **Chemical Formula:** H2O
- **Atomic Composition:** Two hydrogen atoms covalently bonded to one oxygen atom.
- **Physical Properties:** Colorless, odorless, tasteless liquid at room temperature.
    - Melting point: 0 {°C}
    - Boiling point: 100 {°C} (at 1 atm pressure)
    - Maximum density at 4 {°C}.
- **Chemical Properties:**
    - **Amphoteric:** Can act as a weak acid or a weak base.
    - **Solvent:** Excellent solvent for many ionic and polar substances due to its polarity.

    - **Reactions with active metals:** Produces hydrogen gas and metal hydroxides (e.g., 2Na(s) + 2H2O(l) ➡️ 2NaOH(aq) + H2(g)).
    - **Reactions with some non-metal oxides:** Forms acids (e.g., CO2(g) + H2O(l) ↔ H_2CO3(aq)).
    - **Reactions with some metal oxides:** Forms bases (e.g., CaO(s) + H2O(l) \rightarrow Ca(OH)2(aq)).

17.5 Solutions, Colloids, Suspensions

These are different types of mixtures, distinguished by the size of the dispersed particles.

- **Solutions:**
    - **Definition:** Homogeneous mixtures where one substance (solute) is completely dissolved in another (solvent).
    - **Particle Size:** Very small (molecular or ionic level, <1 nm).
    - **Appearance:** Clear and transparent.
    - **Settling:** Particles do not settle on standing.
    - **Filtration:** Cannot be separated by filtration.
    - **Tyndall Effect:** Does not scatter light.
    - Example: Saltwater, sugar water.
- **Colloids (Colloidal Dispersions):**
    - **Definition:** Heterogeneous mixtures with dispersed particles larger than solutions but smaller than suspensions.
    - **Particle Size:** 1 nm to 1000 nm.
    - **Appearance:** Often translucent or cloudy.
    - **Settling:** Particles do not settle readily.
    - **Filtration:** Generally cannot be separated by ordinary filtration.
    - **Tyndall Effect:** Exhibits the Tyndall effect (scatters light, making the beam visible).
    - Example: Milk, fog, paint, jelly.
- **Suspensions:**
    - **Definition:** Heterogeneous mixtures where solid particles are dispersed in a liquid or gas and will eventually settle out.
    - **Particle Size:** Large (>1000 nm).
    - **Appearance:** Opaque or turbid.
    - **Settling:** Particles settle out on standing.
    - **Filtration:** Can be separated by filtration.
    - **Tyndall Effect:** May scatter light, but less distinctly than colloids, and often appears opaque.
    - Example: Muddy water, sand in water, flour in water.

17.6 Solubility

- **Definition:** The maximum amount of a solute that can dissolve in a given amount of solvent at a specific temperature to form a saturated solution.
    - Usually expressed in grams of solute per 100 g of solvent (g/100g water) or moles per liter (Molarity).
- **Saturated Solution:** A solution that contains the maximum amount of solute that can be dissolved at a given temperature. If more solute is added, it will not dissolve and will remain as a solid.

- **Factors Affecting Solubility:**
    1. **Temperature:**
        - For most **solids**, solubility **increases with increasing temperature**.
        - For most **gases**, solubility **decreases with increasing temperature**.
    2. **Nature of Solute and Solvent ("Like Dissolves Like"):**
        - Polar solutes (e.g., ionic compounds, sugar) dissolve well in polar solvents (e.g., water).
        - Non-polar solutes (e.g., oils, fats) dissolve well in non-polar solvents (e.g., benzene, carbon tetrachloride).
    3. **Pressure (for gases only):**
        - The solubility of a gas in a liquid **increases with increasing pressure** of the gas above the liquid (Henry's Law).

Glossary of Terms

- **Periodic Table:** Organized arrangement of elements based on atomic number and electron configuration.
- **Period:** Horizontal row in the periodic table.
- **Group:** Vertical column in the periodic table.
- **Metals:** Elements typically lustrous, malleable, ductile, good conductors, lose electrons.
- **Non-metals:** Elements typically brittle, poor conductors, gain or share electrons.
- **Metalloids:** Elements with properties intermediate between metals and non-metals.
- **Atomic Size:** Radius of an atom.
- **Ionization Energy:** Energy to remove an electron from an atom.
- **Electron Affinity:** Energy change when an electron is added to an atom.
- **Electronegativity:** Ability of an atom to attract electrons in a bond.
- **Alkali Metals:** Group 1 elements.
- **Halogens:** Group 17 elements.
- **Noble Gases:** Group 18 elements, unreactive.
- **Air Pollution:** Harmful substances in the atmosphere.
- **Hard Water:** Water containing dissolved Ca^{2+} and Mg^{2+} ions.
- **Soft Water:** Water free from hardness-causing ions.
- **Temporary Hardness:** Removed by boiling.
- **Permanent Hardness:** Not removed by boiling.
- **Solution:** Homogeneous mixture, very small particles.
- **Colloid:** Heterogeneous mixture, intermediate particle size, scatters light.
- **Suspension:** Heterogeneous mixture, large particles, settles out.
- **Solubility:** Maximum amount of solute that dissolves in a solvent at a given temperature.
- **Saturated Solution:** Solution holding the maximum amount of dissolved solute.