A-Level Notes for Pearson Edexcel

Michael Tang

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1A.1 Chemistry of Life

Ionic Bonding (离子键)

- **Definition:** Atoms transfer electrons to achieve a stable electron configuration, resulting in positively charged cations and negatively charged anions.
- **Key Properties:**
  - High melting and boiling points.
  - Solubility in polar solvents like water.
- **Example:** Sodium (Na 钠) and chlorine (Cl 氯) form sodium chloride (NaCl 氯). Sodium donates an electron to chlorine, forming a strong ionic bond.

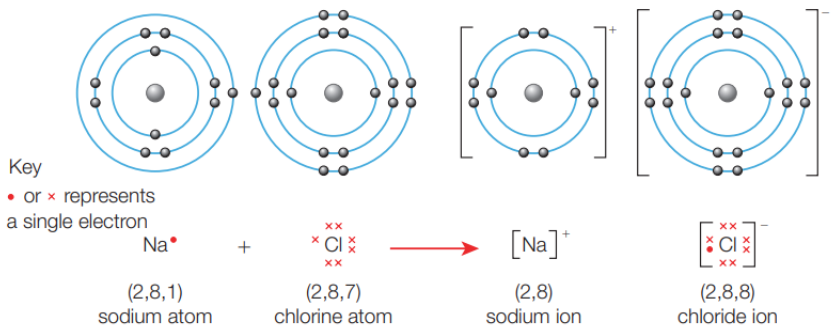

Figure 2.1: The formation of sodium chloride.

Covalent Bonding (共价键)

- **Definition:** Atoms shere electrons to achieve stability.
- **Polarity (极性):** Unequal sharing of electrons leads to polar molecules (极性分子 e.g., water).
- **Dipoles (偶极子):** Partial charges within the molecule, represented as δ^+ (positive) and δ^- (negative).

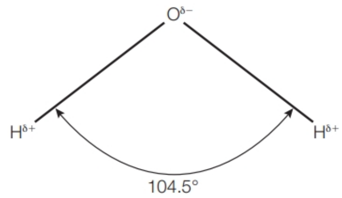

Figure 2.2: A model of a water molecule showing dipoles.

- **Examples:** Formation of <u>hydrogen</u> (H_2 氢气) molecules and the formation of <u>water</u> (H_2O 水).

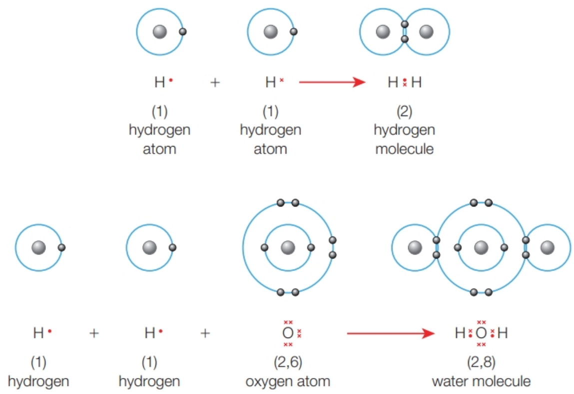

Figure 2.3: The formation of hydrogen molecules and water molecules are examples of covalent bonding.

Chemistry of Water

- **Molecular Structure**
  - **Polar Molecule:** Water (H_2O) has a bent structure with a partial charges (see figure 2.2) - oxygen is δ^-, and hydrogen is δ^+.
  - **<u>Hydrogen Bonding</u> (氢键):** Weak attractions between water molecules, providing <u>cohesion</u> (凝聚力) and a relatively high boiling point.

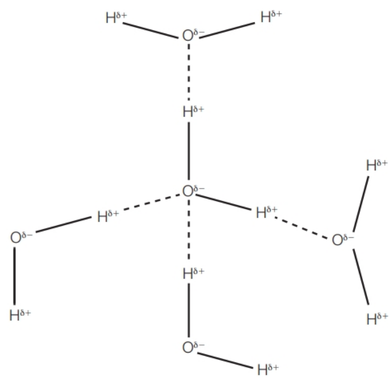

Figure 2.4: Hydrogen bonding in water molecules, based on attraction between positive and negative dipoles.

- **Unique Properties**

- **Solvent (溶剂) Properties**
  * Excellent solvent for ionic and polar substances (物质).

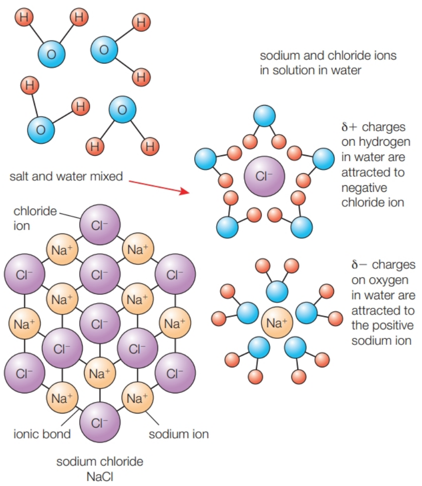

Figure 2.5: A model of sodium chloride dissolving in water as a result of the interactions between the charges on sodium and chloride ions and the dipoles of the water molecules.

  * Facilitates (促进) biochemical (生化) reactions in aqueous solutions (水溶液).
- **Thermal (热) Stability**
  * High specific heat capacity [1] (比热容) moderates temperature changes.
  * Ice floats due to lower density (密度) compared to liquid water, insulating (隔热) the aquatic (水生) life.
- **Cohesion (凝聚力) and Adhesion (粘附力)**
  * Enables water transport in plants.
  * High surface tension due to hydrogen bonding.

Importance of Water

- **Biological Reactions:** All cellular reactions occur in an aqueous environment.
- **Transport Medium:** Dissolves and carries nutrients (营养物质), gases, and waste products (废物).
- **Habitat:** Provides a stable environment for diverse (多样的) life forms.
- **Temperature Regulation:**
  - Evaporation (蒸发) cools organisms.
  - High specific heat stability ecosystems.
- **Structural Support:** Turgor pressure [2] (胀压) in plants depends on water.

[1] **Heat capacity:** Heat capacity refers to the amount of heat energy required to raise the temperature of a substance by one degree Celsius. It reflects the substance's ability to store thermal energy (热能). c is the symbol of heat capacity. The general formula of heat capacity is $c = \frac{Q}{m(t-t_0)} = \frac{Q}{m\Delta t}$. $\mathrm{J\,kg^{-1}\,K^{-1}}$ is the SI unit of heat capacity and $\frac{J}{(kg\cdot{}^\circ C)}$ is the common unit.

[2] **Turgor pressure:** Turgor pressure is the pressure exerted by the water-filled vacuole (液泡)

Importance of Inorganic (无机) Ions

- **Nitrate Ions (NO_3^- 硝酸根离子):** Vital for DNA [3] and protein synthesis (蛋白质合成) in plants.
- **Phosphate Ions (PO_4^{3-} 磷酸根离子):** Essential for ATP [4], DNA [3], and RNA [5].
- **Chloride Ions (Cl^- 氯离子):** Needed in all living organisms to make ATP and ADP as well as DNA and RNA.
- **Hydrogencarbonate Ions (HCO_3^- 碳酸氢根离子):** Needed in nerve impulses, sweating, and many secretory systems (分泌系统) in animals.

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against the cell wall in plant cells. It results from water entering the cell by osmosis (渗透) and helps maintain the cell's rigidity (刚性), supporting the plant's structure and preventing wilting (枯萎).

[3] **DNA (Deoxyribonucleic Acid 脱氧核糖核酸):** DNA is a molecule that carries the genetic instructions (遗传信息) used in the growth, development, functioning, and reproduction of all living organisms. It consists of two strands forming a double helix (螺旋), with each strand (股) made up of nucleotide bases (核苷酸碱基) (adenine 腺嘌呤, thymine 胸腺嘧啶, cytosine 胞嘧啶, and guanine 鸟嘌呤). These bases pair (碱基对) specifically (A-T, C-G) and encode the instructions for synthesizing (合成) proteins, which determine an organism's traits (特征).

[4] **ATP (Adenosine Triphosphate 腺嘌呤核苷三磷酸):** ATP is a molecule that acts as the primary energy carrier in cells. It consists of an adenosine molecule (腺苷分子) bonded to three phosphate (磷酸盐) groups. When ATP is broken down into ADP (adenosine diphosphate 二磷酸腺苷/核苷酸) and a phosphate group, energy is released to fuel cellular processes such as muscle contraction, active transport, and chemical synthesis.

[5] **RNA (Ribonucleic Acid 核糖核酸):** RNA is a single-stranded nucleic acid (单链核酸) that plays a crucial role in protein synthesis and gene expression. It is composed of ribose sugar (核糖/单糖), phosphate groups, and four nitrogenous bases (含氮碱基): adenine (A 腺嘌呤), uracil (U 尿嘧啶), cytosine (C 胞嘧啶), and guanine (G 鸟嘌呤). Unlike DNA, RNA contains uracil instead of thymine. Types of RNA include: mRNA [6] (messager RNA 信使核糖核酸), tRNA [7] (transfer RNA 转运核糖核酸), and rRNA [8] (ribosomal RNA 核糖体).

[6] **mRNA:** mRNA is a type of RNA that carries the genetic information from DNA in the cell nucleus to the ribosome (核糖体), where it is used as a template for protein synthesis. It is transcribed from DNA and contains codons [9] (密码子) that specify the amino acids (氨基酸) to be incorporated into the protein.

[7] **tRNA:** tRNA is a type of RNA that helps decode the genetic instructions in mRNA during protein synthesis. It carries specific amino acids to the ribosome, where it pairs its anticodon [10] (反密码子) with the complementary codon on the mRNA sequence. This ensures that amino acids are added in the correct sequence to form a protein.

[8] **rRNA:** rRNA is a type of RNA that is a key structural and functional component of ribosomes, the molecular machines [11] (分子机器) that synthesize proteins. rRNA helps align mRNA and tRNA during protein synthesis and catalyzes the formation of peptide bonds (肽键) between amino acids, facilitating the assembly of proteins.

[9] **Codon:** A codon is a sequence of three nucleotide bases in mRNA that corresponds to a specific amino acid or a stop signal during protein synthesis. For example, the codon AUG [12] (起始密码子) codes for the amino acid methionine (蛋氨酸) and also serves as the start signal for translation.

[10] **Anticodon:** An anticodon is a sequence of three nucleotide bases on a tRNA molecule that is complementary to a codon on the mRNA strand. During protein synthesis, the anticodon pairs with its corresponding codon, ensuring that the correct amino acid is added to the growing polypeptide chain.

[11] **Molecular machines:** Molecular machines are complex biomolecules or assemblies of molecules that perform specific tasks within a cell, often converting energy into mechanical work. Examples include ribosomes for protein synthesis, ATP synthase for energy production, and motor proteins [13] (马达蛋白) like kinesin (驱动蛋白) for intracellular transport (细胞内运输).

[12] **Codon AUG:** The codon AUG serves two critical roles in protein synthesis: start codon, it signals the beginning of translation, indicating where the ribosome should start assembling the protein; and amino acid, AUG codes for the amino acid methionine (Met), which is often the first amino acid in newly synthesized proteins. This dual function makes AUG essential in the initiation of protein synthesis.

[13] **Motor proteins:** Motor proteins are specialized molecular machines that convert chemical energy from ATP into mechanical work to perform cellular movements. They play key roles in intracellular transport, cell division, and structural support. Examples include: kinesin (驱动蛋白), dynein (动力蛋白), and myosin (肌球蛋白).

- **Sodium Ions (Na^+ 钠离子):** Critical in nerve impulses and secretory functions.
- **Magnesium Ions (Mg^{2+} 镁离子):** Needed for production of chorophyll (叶绿素) in plants.
- **Hydrogen Ions (H^+ 氢离子):** Needed in cellular respiration (呼吸) and photosynthesis (光合作用), and in numerous pumps and systems as well as pH balance.
- **Calcium Ions (Ca^{2+} 钙离子):** Needed for the formation of calcium pectate (果胶酸钙) for middle lamella (中膜) between two cell walls in plants, and for bone formation and muscle contraction in animals.

1A.2 Carbohydrates: Monosaccharides and Disaccharides

What are Organic Compounds?

- **Definition:** Organic compounds are molecules containing carbon atoms bonded to hydrogen and other elements, such as oxygen, nitrogen, and phosphorus. In some carbon compounds small molecules (monomers 单体) bond with many other similar units to make a very large molecule called a polymer (聚合物). The ability of carbon to combine and make macromolecules (大分子) is the basis of all biological molecules and provides the great variety and complexity found in living things.

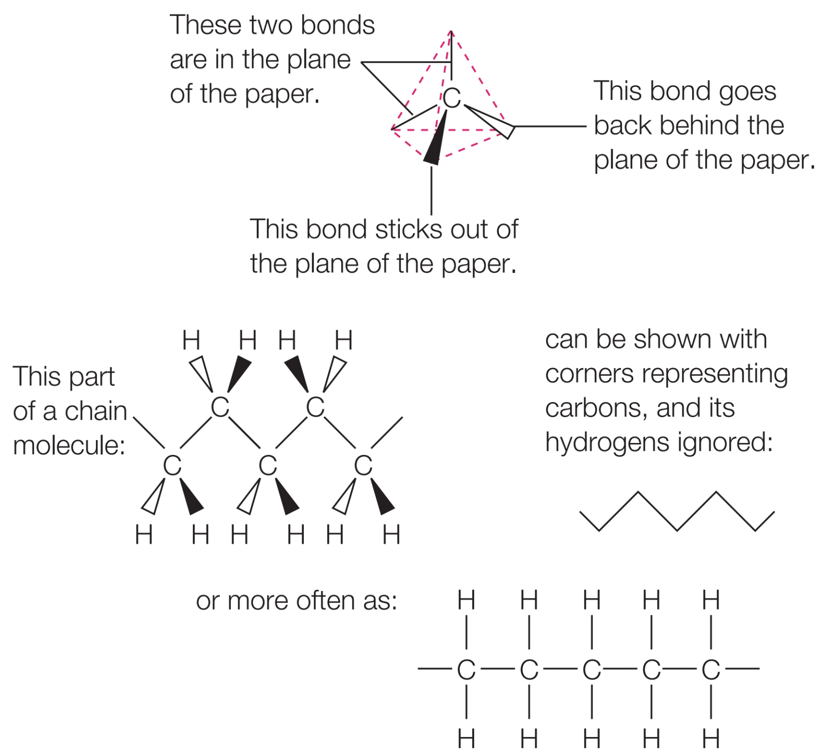


Figure 2.6: The bonds in a carbon atom have a complicated 3D shape. This is difficult to represent, so in most molecular diagrams we use one of several different ways to draw them.

- **Key Features:**

- Carbon atoms form stable covalent bonds, allowing complex structures.
- Organic compounds include carbohydrates (碳水化合物), lipids (脂质), proteins (蛋白质), and nucleic acids (核酸).

Carbohydrates Carbohydrates are essential organic molecules, primarily serving as energy sources and structural components. They are composed of carbon (C 碳), hydrogen (H 氢), and oxygen (O 氧), typically in a 1:2:1 ratio - $(CH_2O)_n$.

Monosaccharides (单糖): The Simplest Sugars

- **Key Characteristics:**
  - Simplest form of carbohydrates.
  - General formula: $(CH_2O)_n$, where n is the number of carbon. Although n can be any number, but it is usually low (3-7).
  - Examples:
    * **Triose (3-Carbon 三糖, $n = 3$):** $C_3H_6O_3$. E.g., glyceraldehyde (甘油醛), involved in glycolysis (糖酵解).
    * **Pentose (5-Carbon 五糖, $n = 5$):** $C_5H_{10}O_5$. E.g., ribose (核糖) and deoxyribose (脱氧核糖).

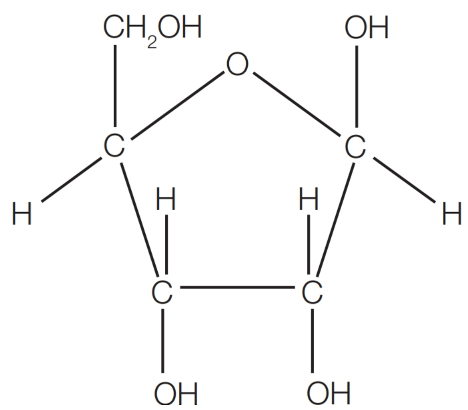


Figure 2.7: Pentose sugars such as ribose have 5 carbon atoms.

    * **Hexose (6-Carbon 六糖, $n = 6$):** $C_6H_{12}O_6$. E.g., glucose (energy source 葡萄糖), fructose (fruit sugar 果糖), galactose (milk sugar 半乳糖).
  - Structure of Glucose
    * Gulcose has two isomers (different forms 同分异构体): α-glucose and β-glucose. The two isomers have different arrangements of the atoms on the side chains of the molecule.
    * **Alpha(α) glucose:** Hydroxyl ($-$OH 羟基) group on carbon 1 is below the plane.
    * **Beta(β) glucose:** Hydroxyl group on carbon 1 is above the plane.

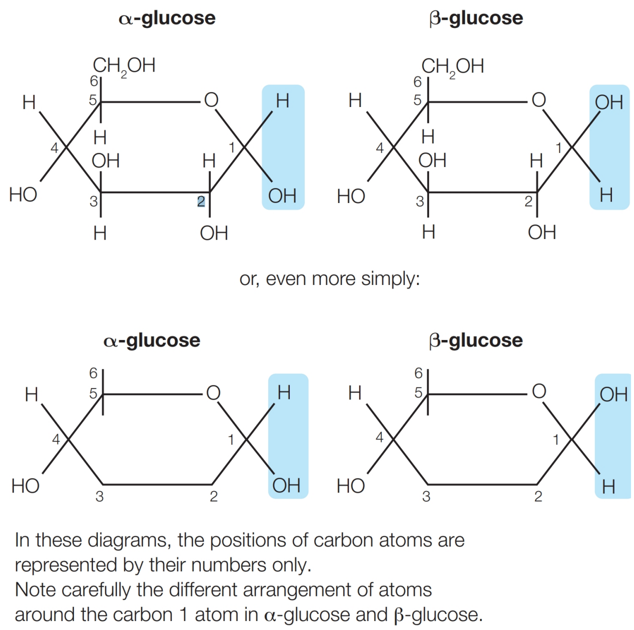


Figure 2.8: Hexose sugars have a ring structure. The arrangement of the atoms on the side chains can make a significant difference to the way in which the molecule can be used by the body. The carbon atoms are numbered in order to identify the different arrangements.

<u>Disaccharides</u> (二糖): The Double Sugars

- **Formation:**
  - **<u>Condensation Reaction</u> (缩合反应):** Two monosaccharides join, forming a <u>glycosidic bond</u> (糖苷键) and releasing a water molecule (H_2O).

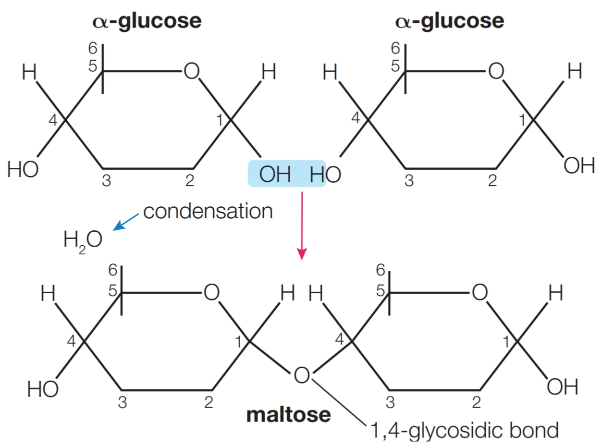


Figure 2.9: The formation of a glycosidic bond. The condensation reaction between two monosaccharides results in a disaccharide and a molecule of water.

  - **Examples:**
    * **<u>Sucrose</u> (蔗糖):** Glucose + Fructose. Stored in plants such as <u>sugar cane</u> (甘蔗).

  * **Lactose (乳糖):** Glucose + Galactose. Milk sugar - this is the main carbohydrate found in milk.
  * **Maltose (麦芽糖):** Glucose + Glucose. Malt (麦芽) sugar - found in germinating (发芽) seed such as barley (大麦).

- **Breakdown - Hydrolysis Reaction (水解反应):** Glycosidic bonds are broken with the addition (添加) of water, yielding (产生) two monosaccharides.

Testing for Sugars - Benedict's Test (本尼迪克特试验)

- **Principle:** Benedict's test is a qualitative test [6] (定性实验) used to detect the presence of reducing sugars (还原糖). These sugars can reduce copper (II) ions (Cu^{2+}) to copper (I) ions (Cu^{+}) due to the presence of a free aldehyde (R−CHO [7] 醛) or ketone (R−CO−R′ [8] 酮) group.

[6] **Qualitative Test:** A qualitative test determines the presence (存在) or absence (不存在) of a specific substance in a sample, without providing precise (精确的) numerical data about its concentration (浓度) or quantity (数量)

- **Key Features:**
  * **Purpose:** Identify whether a substance is present.
  * **Outcome:** Results are typically descriptive (描述性的 - e.g., color change, precipitation 沉淀, or effervescence 泡沫) rather than quantitative (定量性的).
  * **Examples in Biology and Chemistry:** Benedict's test for reducing sugars (color change from blue to brick-red), iodine test for starch (color change from yellow-brown to blue-black), and biuret test (缩二脲试验) for proteins (color change from blue to purple).
- **Limitations:**
  * Does not measure the exact amount of a substance.
  * Subjective interpretation (主观解释) of results (e.g., intensity of color change 颜色变化的程度).

[7] In organic chemistry R is a shorthand symbol (缩写符号) used to represent a generic alkyl group (烷基) or side chain (侧链) attached to a functional group [9] (官能团). It is a placeholder (占位符) for any group of carbon and hydrogen atoms (and sometimes other atoms) in a molecule.

- **Explanation of R in R−CHO:**
  * R: Represents a hydrocarbon (烃/碳氢化合物) chain or group, such as:
    · Methyl group (甲基): $CH_3{}^-$
    · Ethyl group (乙基): $CH_3CH_2{}^-$
    · Cycloalkyl group (环烷基): C_6H_{11}
    · Longer or branched alkyl chains: C_nH_{2n+1}
  * CHO: Represents the aldehyde functional group (醛官能团), where a carbon atom is double-bonded (双键) to an oxygen atom (C=O) and single-bonded (单键) to a hydrogen atom (−H).
- **Purpose of R:**
  1. **Generic Representation:** It simplifies chemical structures when the specific nature of the alkyl group is not important for the discussion.
  2. **Flexibility:** Allows focus on the functional group (CHO) rather than the details of the alkyl chain.
- **Examples:** Methanal (Formaldehyde 甲醛): H−CHO, where R=H.

[8] R−CO−R′ can also write as >C=O. In organic chemistry, the symbol >C=O is used to describe the structure of a carbonyl group (羰基), emphasizing that the carbon atom in the carbonyl group is bonded not only to an oxygen atom but also to two other groups (基团). The > symbol indicates that the carbonyl carbon is an internal carbon (内部碳), connected to two other groups or chains (rather than being a terminal carbon).

[9] **Functional group:** A functional group is a specific group of atoms within a molecule that determines the chemical properties and reactions of that molecule. It is the reactive part of the molecule, often defining its behavior in biological or chemical processes. Functional groups are crucial in organic chemistry because they dictate how molecules interact and bond with others.

- **Reducing sugars:** Reducing sugars include monosaccharides like glucose, fructose, and galactose, and disaccharides except sucrose. They have the ability to donate electrons to other molecules due to their reactive carbonyl group.

- **Reagents in Benedict's Test:** Benedict's Solution contains:
  - **Copper (II) Sulfate ($CuSO_4$):** Source of (Cu^{2+}) ions.
  - **Sodium Citrate ($C_6H_5Na_3O_7$):** Stablizes the copper (II) ions in the solution.
  - **Sodium Carbonate (Na_2CO_3):** Provides an alkaline environment.

- **Chemical Reaction:**
  1. In an alkaline medium, the carbonyl group of the reducing sugar reacts with the copper (II) ions.
  2. Reduction Process:
     * Cu^{2+} (blue) is reduced to Cu^{+} (red/orange precipitate of copper (I) oxide, Cu_2O).
     * Reaction:

$$R{-}CHO + 2\,Cu^{2+} + 5\,OH^{-} \longrightarrow R{-}COOH + Cu_2O + 2\,H_2O \quad (2.1)$$

       Where $R{-}CHO$ represents the reducing sugar.

- **Procedure:**
  1. Mix the sample with Benedict's solution.
  2. Heat the mixture in a boiling water bath for about 2-5 minutes.
  3. Observe the color change and precipitate formation.

- **Observation and Results:**

Color Change	Reducing Sugar Concentration
Blue (no change)	No reducing sugar present
Green	Low concentration
Yellow	Moderate concentration
Brick-red precipitate	High concentration

Table 2.1: Color changes observed in Benedict's test for reducing sugars.

Figure 2.10: Benedict's test for reducing sugars.

- **Limitations:** Non-reducing sugars like sucrose do not react directly unless hydrolyzed.

1A.3 Carbohydrates: Polysaccharides (多糖)

Carbohydrates and Energy Carbohydrates are a primary source of energy in biological systems, particularly glucose, which is a key monosaccharide used in cellular respiration.

- **Key Points**
  - **Energy Production:** Glucose ($C_6H_{12}O_6$) is broken down through cellular respiration to produce ATP (adenosine triphosphate), which powers cellular activities.
  - **End Products:** The breakdown of glucose result in:
    * Carbon dioxide (CO_2)
    * Water (H_2O)
    * Large amounts of ATP
  - **Glucose Utilization:**
    * **Monosaccharides** such as glucose are rapidly absorbed and used for immediate energy needs.
    * **Disaccharides** like sucrose and lactose are broken into monosaccharides for energy production.
    * **Polysaccharides** are complex carbohydrates made up of many monosaccharide units joined by glycosidic bonds. Note that molecules with between 3 and 10 sugar units are known as **oligosaccharides** (低聚糖), while molecules containing 11 or more monosaccharides are known as true polysaccharides.

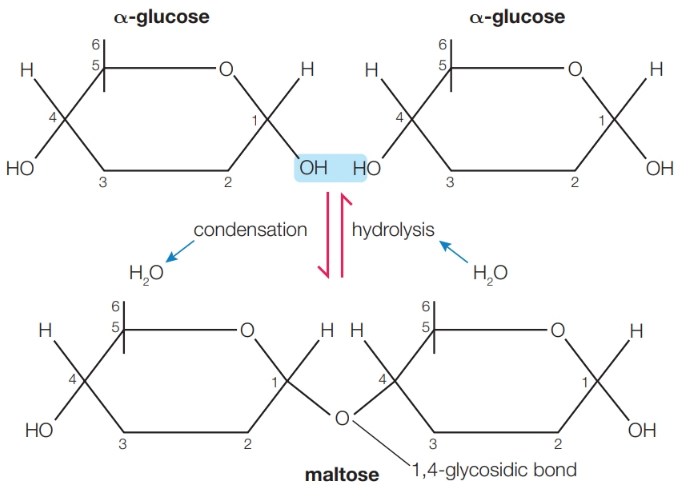


Figure 2.11: Glycosidic bonds are made by condensation reactions and broken down by hydrolysis.

    * **Exam Hint:** Avoid stating that energy is "created". Instead, describe how chemical energy from glucose is transferred to ATP molecules.

- **Properties of Polysaccharides**
  1. **Compact Structure:**
     * Takes up little space within cells.
     * Ideal for storage purposes.

2. **Insolubility:**
   * Reduces osmotic effects [9] (渗透效应) in cells.
   * Does not affect water potential.
3. **Chemical Inactivity:** Does not interfere with cellular reactions.

- **Starch (Plant Energy Store)**
  - Composed of α-glucose units.
  - Two main components:
    * **Amylose (直链淀粉):** Long, unbranched chains of α-glucose units. Forms a compact spiral sturcture due to 1,4-glycosidic bonds.
    * **Amylopectin (支链淀粉):** Branched chains of α-glucose units. Contains 1,4- and 1,6- glycosidic bonds, allowing rapid glucose release.

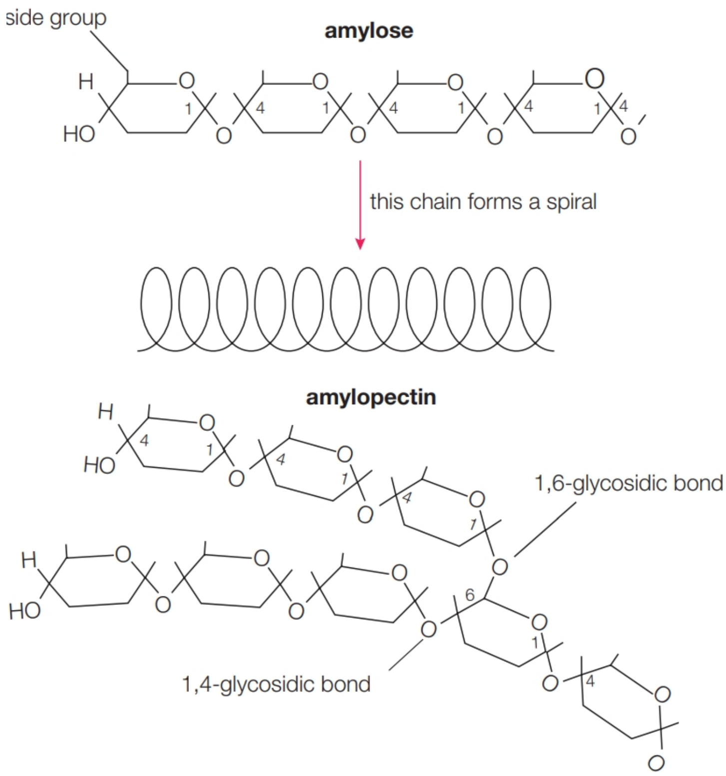


Figure 2.12: Amylose and amylopectin —a small difference in the position of the glycosidic bonds in the molecule makes a big difference to the properties of the compounds.

  - **Function:**
    * Efficient energy storage in plants.

[9]**Osmotic effects:** Osmotic effects refer to the movement of water across a semipermeable membrane [10] (半透膜) due to differences in solute concentration.

[10]**Semipermeable membrane:** It is a membrane that allows certain molecules to pass through while blocking others. It permits solvent molecules (such as water) to pass but prevents solute molecules from doing so. This property makes semipermeable membranes highly useful in various applications, such as desalination (海水淡化), where water and salt in seawater are separated using a semipermeable membrane.

    * Rapid glucose availability during high metabolic demands.

  - **Testing for Starch** If you add a few drops of reddish-brown iodine solution to a sample containing starch (whether it is a solid sample or a sample in solution), the iodine solution will turn blue-black.

Figure 2.13: The iodine test for starch.

- **Glycogen (Animal Energy Store)**

  - Similar to amylopectin but more extensively branched.
  - **Structure:**
    * Contains many 1,6-glycosidic bonds, leading to multiple branches.
    * Compact and can be rapidly hydrolyzed for energy.

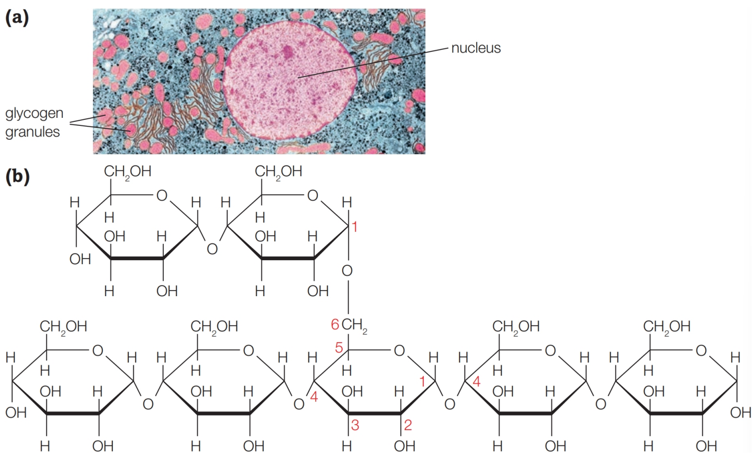


Figure 2.14: In **(a)** you can see liver cells full of small glycogen granules (微粒), stained (染色) pink in this micrograph (显微照片). If your blood glucose levels are low, this glycogen store in your liver can be broken down to provide the glucose you need for cellular respiration. In **(b)** you can see the structure of glycogen with 1,4 and 1,6-glycosidic bonds.

  - **Function:**
    * Found in the liver and muscle cells.
    * Acts as a quick energy source for animal during high activity.

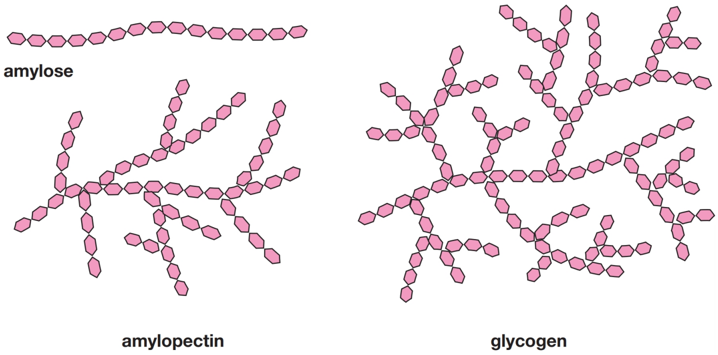


Figure 2.15: You can clearly see the many side branches which allow glycogen to be broken down so quickly when you compare amylose, amylopectin and glycogen.

1A.4 Lipids (脂类)

Fats and Oils Fats and oils are essential lipids with significant biological roles.

- **Definition:** Lipids include fats and oil. Fats are solid at room temperature, while oils are liquid at room temperature.
- **Composition:**
  - Made of glycerol ($C_3H_8O_3$ 甘油) and fatty acids ($C_nH_{2n+1}COOH$ 脂肪酸).

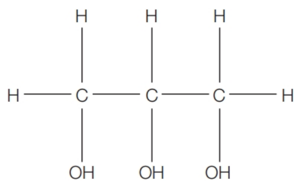


Figure 2.16: Displayed formula of glycerol (propane-1,2,3-triol).

  - Contain carbon (C), hydrogen (H), and small amount of oxygen (O) atoms.
- **Sources:**
  - **Fats:** Predominantly (大多数情况下) from animal sources (e.g., butter, lard 猪油).
  - **Oils:** Predominantly from plant sourcrs (e.g., olive oil, sunflower oil).
- **Energy Content:**
  - Store about three times as much energy as the same mass of carbohydrates.
  - Act as long-term energy storage, especially in seeds and adipose tissue (皮下脂肪组织).

Fatty Acids Fatty acids are hydrocarbon chains with a carboxyl group ($-COOH$ 羧基) at one end.

- **Types:**

1. **Saturated Fatty Acids (饱和脂肪酸):** Only single bonds between carbon atoms (e.g., stearic acid 硬脂酸).

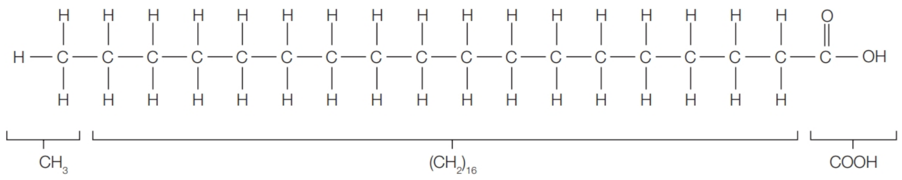


Figure 2.17: Displayed formula of stearic acid, a saturated fatty acid found in both plant and animal fats.

2. **Unsaturated Fatty Acids (不饱和脂肪酸):**
   * **Monounsaturated Fatty Acids (单不饱和脂肪酸):** One double bond between carbon atoms.
   * **Polyunsaturated Fatty Acids (多不饱和脂肪酸):** Multiple carbon-carbon double bonds (e.g., linoleic acid 亚油酸).

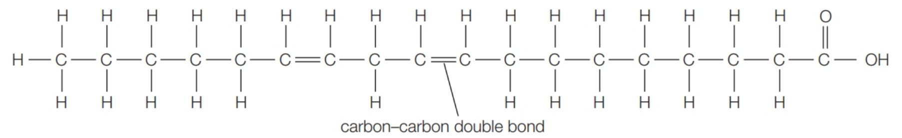


Figure 2.18: Displayed formula of linoleic acid, a polyunsaturated fatty acid.

- **Properties:**
  - Saturated fats are more likely to be solid at room temperature.
  - Unsaturated fats are usually liquid and healthier in the diet.

Forming Ester Bonds Ester bonds are formed in the synthesis of triglycerides [10] (甘油三酯) through a condensation reaction.

- **Process:**
  1. **Reactants:**
     * Glycerol provides hydroxyl groups ($-$OH).
     * Fatty acids provide carboxyl groups ($-$COOH).
  2. **Reaction:** A molecule of water (H_2O) is removed for each ester bond [11] (酯键) formed.
  3. **Product:** One molecule of glycerol reacts with three fatty acids to form a triglyceride.

- **Chemical Representation:**

$$\text{Glycerol} + 3\,\text{Fatty Acids} \longrightarrow \text{Triglyceride} + 3\,H_2O \tag{2.2}$$

[10] Note that a word with a prefix mono- usually means one, di- means two, tri- means three, and poly- means many.

[11] An ester bond is a covalent bond formed between the hydroxyl group ($-$OH) of glycerol and the carboxyl group ($-$COOH) of a fatty acid. This bond is a key structural feature of lipids, particularly triglycerides.

- **Hydrolysis:** Ester bonds in triglycerides can be broken down by adding water, releasing glycerol and fatty acids.

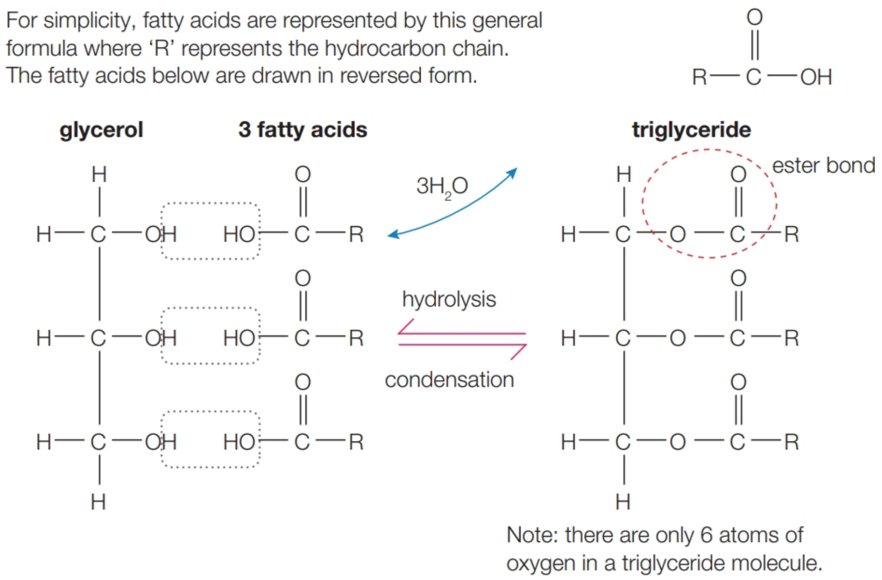


Figure 2.19: The formation of ester bonds.

1A.5 Proteins (蛋白质)

Introduction to Proteins Proteins are macromolecules essential to numerous biological processes. They are composed of long chains of amino acids linked by peptide bonds (肽键). Functions of proteins include:

- Providing structural support (e.g., hair, skin, and nails).
- Acting as enzymes (酶) for metabolism (新陈代谢) and digestion (消化).
- Regulating hormones (激素).
- Transporting oxygen (e.g., hemoglobin 血红蛋白).
- Supporting immune defense (免疫防御).

Proteins are made of carbon, hydrogen, oxygen, and nitrogen, with some containing sulfur. They are synthesized by linking amino acids through condensation reactions. There are about 20 different naturally occurring amino acids that can combine in different ways to produce a wide range of different proteins.

Amino Acids: The Building Blocks of Proteins All amino acids share the same basic structure:

- An amino group ($-NH_2$ 氨基).
- A carboxyl group ($-COOH$ 羧基).
- A variable R group (side chain) unique to each amino acid.

The R group determines the properties and function of the amino acid, influencing whether it is hydrophobic (疏水的), hydrophilic (亲水的), or changed.

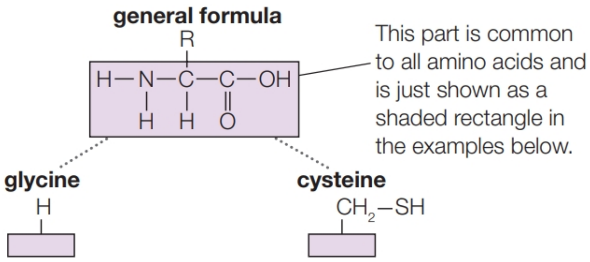


Figure 2.20: Some different amino acids. In the simplest amino acid, glycine (甘氨酸), R is a single hydrogen atom. In a larger amino acid such as cysteine (半胱氨酸), R is much more complex.

Formation of Proteins Proteins are formed by condensation reactions:

- **Peptide bonds** form between the carboxyl group of one amino acid and the amino group of another, releasing a molecule of water.

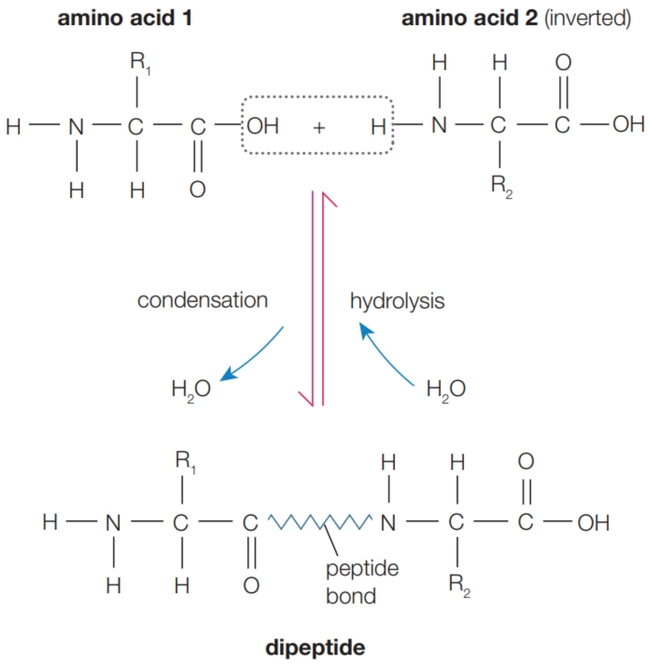


Figure 2.21: Amino acids are the building blocks of proteins, joined together by peptide bonds.

- Chains of amino acids linked by peptide bonds are called polypeptides (多肽). These fold to create functional proteins. The peptide bond between amino acids is a strong bond. Other bonds are also made between amino acids in a chain, to create the 3D structure of the protein. They depend on the atoms in the R group and include hydrogen bonds, disulfide bonds (二硫键), and ionic bonds.

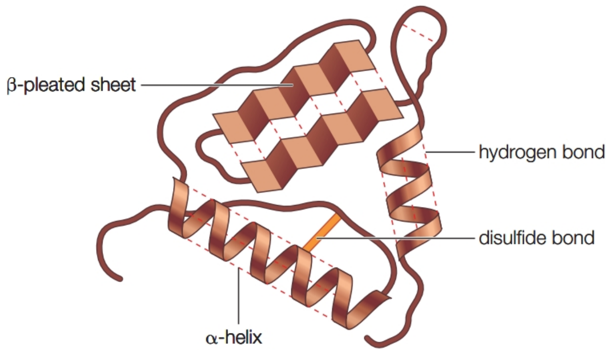


Figure 2.22: Hydrogen bonds and disulfide bonds maintain the shape of protein molecules and this determines their function.

Protein Structure Levels Proteins exhibit (表现) four levels of structure:

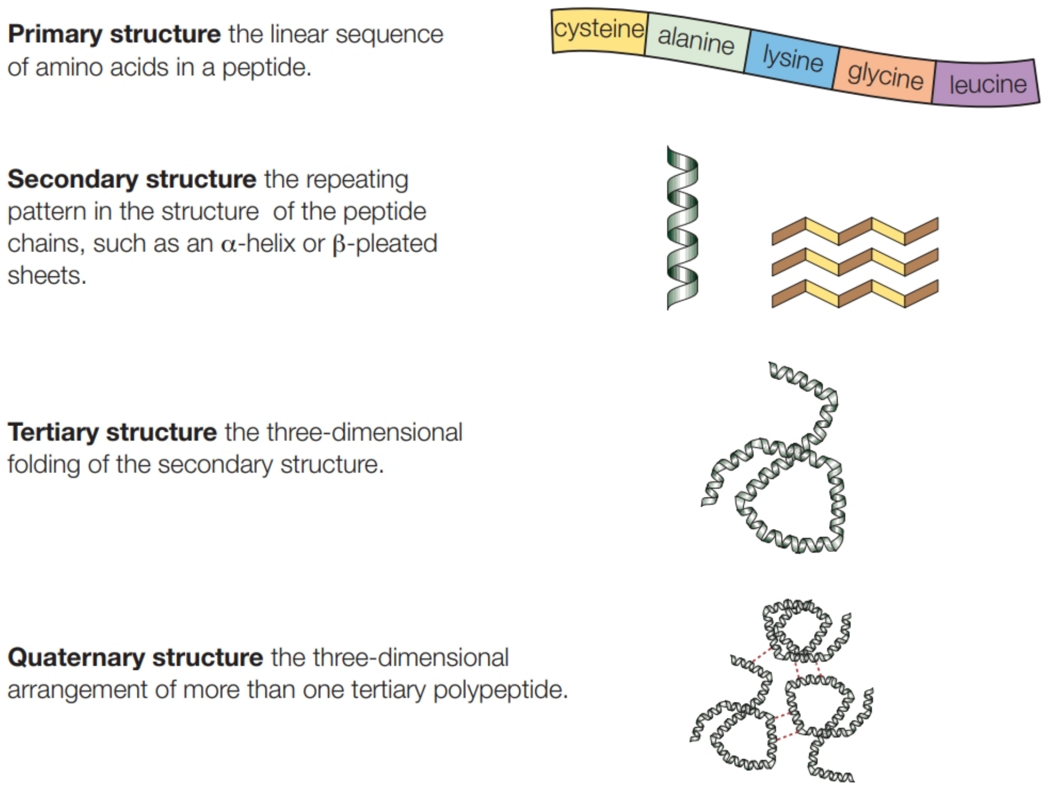


Figure 2.23: The 3D structure of proteins.

Types of Proteins

1. **Fibrous Proteins** (纤维蛋白质) are long, insoluble proteins that provide structural support. Examples include collagen (胶原蛋白) in skin and keratin (角蛋白) in hair.

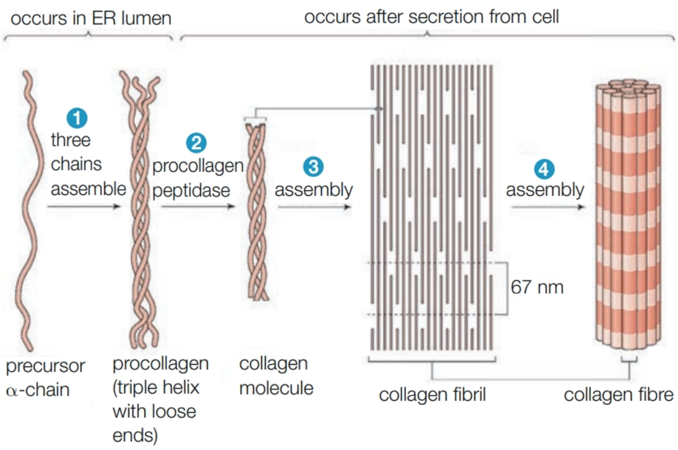


Figure 2.24: Collagen is a fibrous protein with an unusual triple helix structure and immense strength.

2. **Globular Proteins** (球蛋白质) are compact, spherical proteins with metabolic functions. Examples include enzymes and haemoglobin.

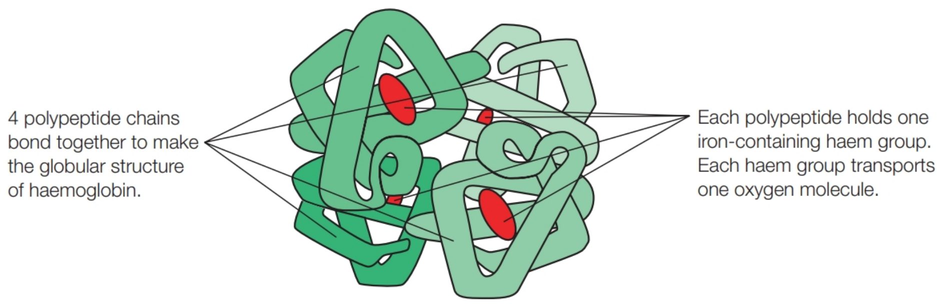


Figure 2.25: The complex quaternary structure of haemoglobin produces a globular protein containing four haem groups which can carry oxygen to the tissues of the body.

Denaturation (变性) of Proteins When proteins are exposed to extreme pH or temperature changes, they lose their 3D structure and functionality. This process is called denaturation.

Testing for Proteins Biuret Test (比约特试验) is used to test for the presence of proteins:

- Add Biuret reagent (sodium hydroxide and copper sulfate).
- A purple color indicates the presence of proteins.

2.1.2 Mammalian Transport Systems

1B.1 The Principles of Circulation

Need for Transport in Organisms

- **Diffusion (扩散):** The movement of substances from a region of high concentration to low concentration. Works efficiently only in small organisms where the surface area to volume ratio (sa:vol) is large.

- **Limitations of Diffusion:** As organisms grow larger, the sa:vol ratio decreases, and diffusion becomes insufficient to meet the metabolic demands of all cells.

Transport in Small Organisms

- Small organisms (e.g., amoeba 阿米巴原虫/变形虫, marine larvae 海洋幼虫) rely on diffusion for transport due to:
    1. Short diffusion distances.
    2. Large sa:vol ratio (e.g., jellyfish larvae 水母幼虫)
    3. Low metabolic demands.
- Surface area to volume ratio (sa:vol): Larger organisms have smaller sa:vol ratios, making diffusion less efficient.

Transport in Multicellular Organisms Larger organisms require specialized transport systems due to:

1. Increased metabolic demands (e.g., oxygen, nutrients, waste removal).
2. Removal of waste products (e.g., carbon dioxide, urea 尿素).
3. Greater distance between external environment and innermost cells.

Key Features of Mass Transport Systems

1. **Exchange surfaces:** Efficient transport of materials in and out (e.g., gases, nutrients, waste).
2. **Transport vessels:** Tubes to carry substances (e.g., blood vessels 血管, xylem 木质部).
3. **Mechanisms for movement:** Pumping (e.g., heart 心脏) or maintaining concentration gradients.
4. **Transport medium:** Fluid to carry substances (e.g., blood 血液, sap 树液).
5. **Adaptations:** To meet the specific needs of the organism (e.g., gills 鳃, lungs 肺).

Circulatory Systems

1. **Open Circulatory System:** Found in insects, <u>mollusks</u> 软体动物, and some <u>invertebrates</u> 无脊椎动物. Blood flows freely in the body cavity (hemocoel 血腔) and directly.
2. **Closed Circulatory System:** Found in <u>vertebrates</u> (脊椎动物) and some invertebrates. Blood is enclosed in blood vessels (e.g., arteries 动脉, veins 静脉, capillaries 毛细血管) and pumped by a heart.

Types of Circulatory Systems

1. **Single Circulation:**
   - Blood passes through the heart once per cycle.
   - Heart → Gills → Body → Heart.
   - Advantages: Simple and sufficient for lower metabolic demands.

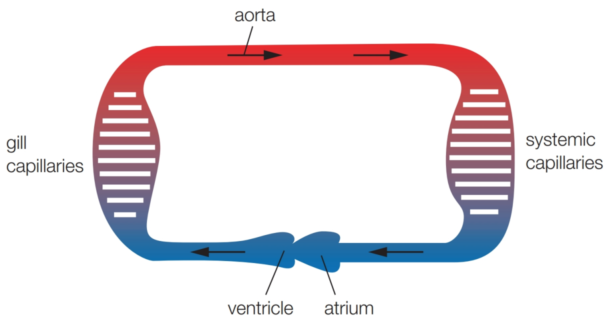


Figure 2.26: The single circulation of a fish.

2. **Double Circulation:**
   - Blood passes through the heart twice per cycle.
     a) **Pulmonary Circulation:** Heart → Lungs → Heart.
     b) **Systemic Circulation:** Heart → Body → Heart.

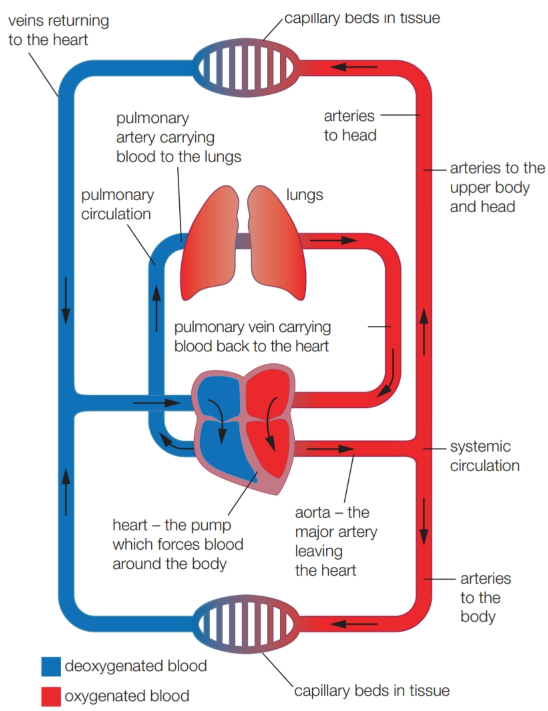


Figure 2.27: A double circulation sends blood at high pressure, carrying lots of oxygen, to the active cells of the body. Take note: this is a schematic diagram. In a real double circulation, all of the blood vessels enter and leave from the top of the heart.

- Advantages:
  * Maintain high blood pressure in systemic circulation.
  * Efficient oxygen delivery to active tissues.

1B.2 The Roles of the Blood

The Cardiovascular System (心血管系统)

- The cardiovascular system is a mass transport system in mammals, consisting of:
  1. **Heart:** Pumps blood.
  2. **Blood vessels:** Transport blood to tissues.
  3. **Blood:** The transport medium carrying nutrients, gases, hormones, and waste.
- Functions:
  - Delivers materials like oxygen and glucose to body cells.
  - Removes waste products (e.g., carbon dioxide, urea).
  - Distributes heat and maintains body temperature.

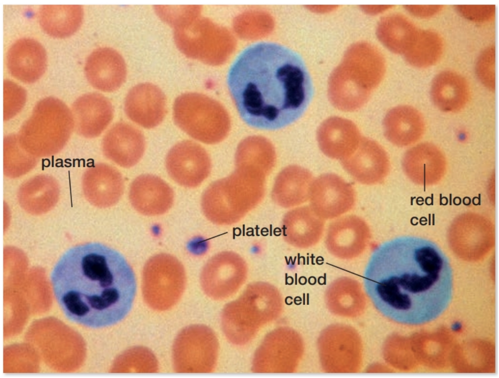


Figure 2.28: This light micrograph shows red blood cells, white blood cells and platelets.

Components of Blood

1. **Plasma (血浆):**
   - Liquid part of blood (55% of blood volume).
   - Transport:
     * Digested food (e.g., glucose, amino acids).
     * Excretory products (排泄物 e.g., urea, carbon dioxide).
     * Hormones.
   - Maintains a stable pH and regulates body temperature.
2. **Erythrocytes (红细胞 Red Blood Cells):**
   - Approximately 4-6 million cells per mm^3.

  - Contain haemoglobin to transport oxygen.
  - Adaptations:
    * Biconcave (双凹面) shape increases surface area.
    * No nucleus allows more haemoglobin storage.
    * Lifespan (寿命) of ~ 120 days.

3. **Leukocytes (白细胞 White Blood Cells):**
  - Approximately 4,000-11,000 cells per mm^3.
  - Role:
    * Defend against pathogens (病原体 e.g., bacteria, viruses).
    * Aid in inflammatory response (炎症反应).
  - Types:
    * Granulocytes (contain granules 粒细胞 e.g., neutrophils 嗜中性粒细胞, eosinophils 嗜酸性粒细胞).
    * Agranulocytes (no granules 无颗粒细胞 e.g., lymphocytes 淋巴细胞, monocytes 单核细胞).

4. **Platelets (血小板):**
  - Small cell fragments (片段) without a nucleus ($\sim 150,000 - 400,000$ per mm^3).
  - Involved in blood clotting (凝血).

Transport of Oxygen

- Haemoglobin binds oxygen in the lungs and forms oxyhaemoglobin (氧合血红蛋白):

$$\frac{\mathrm{Hb} + 4\,\mathrm{O_2} \rightleftharpoons \mathrm{Hb}\cdot 4\,\mathrm{O_2}}{\text{Haemoglobin} + \text{Oxygen} \rightleftharpoons \text{Oxyhaemoglobin}} \tag{2.3}$$

- Oxygen dissociation curve (氧解离曲线):
  - S-shaped curve showing haemoglobin saturation (血红蛋白饱和度) at different oxygen pressures.
  - In low oxygen environments, haemoglobin releases oxygen to tissues efficiently.

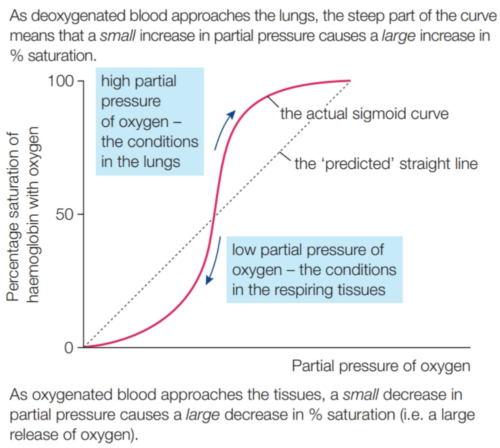


Figure 2.29: Oxygen dissociation curve for human haemoglobin.

Transport of Carbon Dioxide

- Carbon dioxide is transported in three forms:
  1. Dissolved in plasma (5%).
  2. Bound to haemoglobin as carbaminohaemoglobin ($10 - 20\%$).
  3. As <u>bicarbonate ions</u> (HCO_3^- 碳酸氢根离子) in plasma ($70 - 85\%$, majority).
- The reaction of the carbon dioxide with water is crucial. When carbon dioxide is dissolved in the blood it reacts slowly with the water to form carbonic acid (H_2CO_3). The carbonic acid separates to form hydrogen ions (H^+) and hydrogencarbonate ions (HCO_3^-):

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \tag{2.4}$$

- **<u>Chloride shift</u> (氯离子转移):** Exchange of bicarbonate ions for chloride ions in red blood cells maintains charge balance.

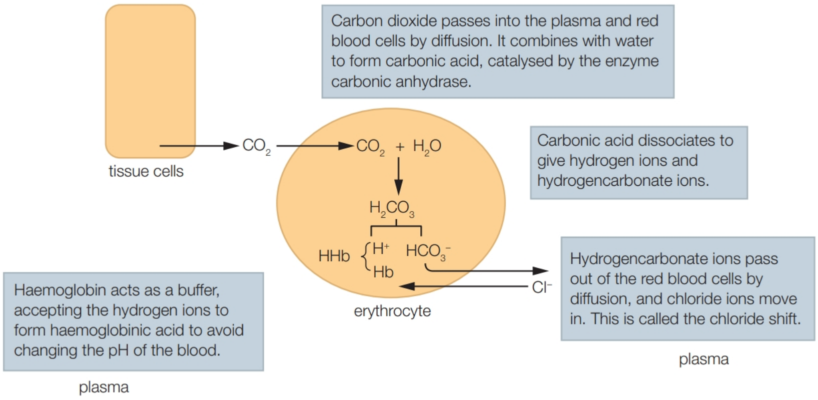


Figure 2.30: The transport of carbon dioxide from the tissues to the lungs depends on the reaction of carbon dioxide with water, controlled by an enzyme in the red blood cells.

<u>The Bohr Effect</u> (波尔效应) High carbon dioxide levels in active tissues lower haemoglobin's affinity for oxygen, allowing oxygen to be released more readily. The changes in the oxygen dissociation curve that result as the carbon dioxide level changes are known as the Bohr effect.

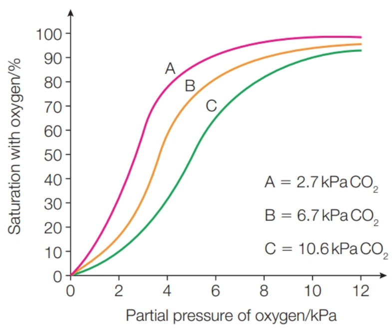


Figure 2.31: As the proportion of carbon dioxide in the environment rises, the haemoglobin curve moves down and to the right, so it gives up oxygen more easily. This is known as the Bohr effect.

Fetal Haemoglobin (胎儿血红蛋白) Fetal haemoglobin has a higher oxygen affinity than adult haemoglobin, enabling oxygen transfer from the mother's blood to the fetus.

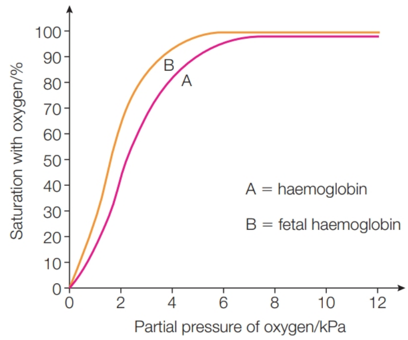


Figure 2.32: Fetal haemoglobin has a higher affi nity for oxygen than the adult haemoglobin of the mother, so it can take oxygen from the mother's blood and deliver it to the cells of the growing fetus.

Clotting (凝血) of Blood Blood clotting mechanism:

1. Platelets (血小板) release thromboplastin (凝血酶原) at the injury site.
2. Thromboplastin catalyzes (催化) the conversion of prothrombin (凝血酶原) to thrombin (凝血酶). This requires calcium ions.
3. Thrombin converts fibrinogen (纤维蛋白原) to fibrin (纤维蛋白) which is insoluble.
4. Fibrin forms a mesh that traps red blood cells and platelets, forming a clot.

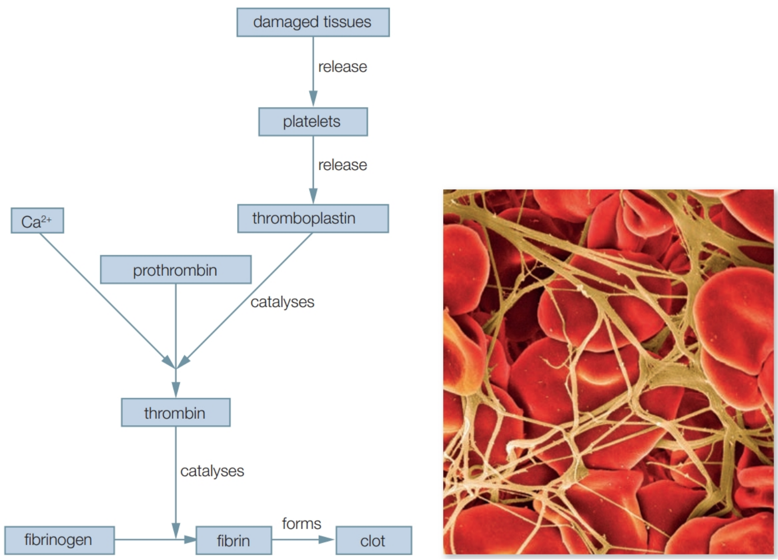


Figure 2.33: The cascade (大量) of events that results in a life-saving or life-threatening clot. When you cut yourself, this is the process which seals the blood vessels and protects the delicate new tissues that form underneath.

Chapter 3

Chemistry

3.1 Formulae, Equations and Atoms of Substances

3.1.1 Atoms, Elements and Molecules

1A Techniques for Measuring the Rate of Reaction

What is an Element?

- **Definition of an Element:** A pure substance that cannot be broken down into simpler substances through chemical reactions.
  - It consists of only one type of atom.
  - Represented on the Periodic Table (元素周期表) by a one or two-letter symbol. Example: H for hydrogen, Ne for neon.
- **Periodic Table**

PERIODIC TABLE OF ELEMENTS

1 H 1.008																	2 He 4.003
3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
11 Na 22.990	12 Mg 24.305											13 Al 26.981	14 Si 28.085	15 P 30.974	16 S 32.066	17 Cl 35.453	18 Ar 39.948
19 K 39.098	20 Ca 40.078	21 Sc 44.956	22 Ti 47.88	23 V 50.941	24 Cr 51.996	25 Mn 54.938	26 Fe 55.847	27 Co 58.933	28 Ni 58.69	29 Cu 63.546	30 Zn 65.39	31 Ga 69.72	32 Ge 72.61	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80
37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.905	46 Pd 106.42	47 Ag 107.868	48 Cd 112.41	49 In 114.82	50 Sn 118.710	51 Sb 121.757	52 Te 127.60	53 I 126.905	54 Xe 131.29
55 Cs 132.905	56 Ba 137.33	57 *La 138.905	72 Hf 178.49	73 Ta 180.948	74 W 183.85	75 Re 186.207	76 Os 190.2	77 Ir 192.22	78 Pt 195.08	79 Au 196.967	80 Hg 200.59	81 Tl 204.383	82 Pb 207.2	83 Bi 208.980	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra 226.025	89 †Ac 227.028	104 Rf (261)	105 Db (262)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (266)	110 Ds (271)	111 Rg (272)	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og

*LANTHANIDES	58 Ce 140.12	59 Pr 140.908	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.925	66 Dy 162.50	67 Ho 164.930	68 Er 167.26	69 Tm 168.934	70 Yb 173.04	71 Lu 174.967
†ACTINIDES	90 Th 232.038	91 Pa 231.036	92 U 238.029	93 Np 237.048	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)

Figure 3.1: Full set of Periodic Table

1. [Nonmetals] Hydrogen 氢 (H)
2. [Nonmetals] Helium 氦 (He)
3. [Metals] Lithum 锂 (Li)
4. [Metals] Beryllium 铍 (Be)
5. [Metalloids] Boron 硼 (B)
6. [Nonmetals] Carbon 碳 (C)
7. [Nonmetals] Nitrogen 氮 (N)
8. [Nonmetals] Oxygen 氧 (O)
9. [Nonmetals] Fluorine 氟 (F)
10. [Nonmetals] Neon 氖 (Ne)
11. [Metals] Sodium 钠 (Na)
12. [Metals] Magnesium 镁 (Mg)
13. [Metals] Aluminium 铝 (Al)
14. [Metalloids] Silicon 硅 (Si)
15. [Nonmetals] Phosphorus 磷 (P)
16. [Nonmetals] Sulfur 硫 (S)
17. [Nonmetals] Chlorine 氯 (Cl)
18. [Nonmetals] Argon 氩 (Ar)
19. [Metals] Potassium 钾 (K)
20. [Metals] Calcium 钙 (Ca)
21. [Transition Metals] Scandium 钪 (Sc)
22. [Transition Metals] Titanium 钛 (Ti)
23. [Transition Metals] Vanadium 钒 (V)
24. [Transition Metals] Chromium 铬 (Cr)
25. [Transition Metals] Manganese 锰 (Mn)
26. [Transition Metals] Iron 铁 (Fe)
27. [Transition Metals] Cobalt 钴 (Co)
28. [Transition Metals] Nickel 镍 (Ni)
29. [Transition Metals] Copper 铜 (Cu)
30. [Transition Metals] Zinc 锌 (Zn)
31. [Metals] Gallium 镓 (Ga)
32. [Metalloids] Germanium 锗 (Ge)
33. [Metalloids] Arsenic 砷 (As)
34. [Nonmetals] Selenium 硒 (Se)
35. [Nonmetals] Bromine 溴 (Br)
36. [Nonmetals] Krypton 氪 (Kr)
37. [Metals] Rubidium 铷 (Rb)
38. [Metals] Strontium 锶 (Sr)
39. [Transition Metals] Yttrium 钇 (Y)
40. [Transition Metals] Zirconium 锆 (Zr)
41. [Transition Metals] Niobium 铌 (Nb)

42. [Transition Metals] Molybdenum 钼 (Mo)
43. [Transition Metals] Technetium 锝 (Tc)
44. [Transition Metals] Ruthenium 钌 (Ru)
45. [Transition Metals] Rhodium 铑 (Rh)
46. [Transition Metals] Palladium 钯 (Pd)
47. [Transition Metals] Silver 银 (Ag)
48. [Transition Metals] Cadmium 镉 (Cd)
49. [Metals] Indium 铟 (In)
50. [Metals] Tin 锡 (Sn)
51. [Metalloids] Antimony 锑 (Sb)
52. [Metalloids] Tellurium 碲 (Te)
53. [Nonmetals] Iodine 碘 (I)
54. [Nonmetals] Xenon 氙 (Xe)
55. [Metals] Caesium 铯 (Cs)
56. [Metals] Barium 钡 (Ba)

57-71 [Not In Consideration]

72. [Transition Metals] Hafnium 铪 (Hf)
73. [Transition Metals] Tantalum 钽 (Ta)
74. [Transition Metals] Tungsten 钨 (W)
75. [Transition Metals] Rhenium 铼 (Re)
76. [Transition Metals] Osmium 锇 (Os)
77. [Transition Metals] Iridium 铱 (Ir)
78. [Transition Metals] Platinum 铂 (Pt)
79. [Transition Metals] Gold 金 (Au)
80. [Transition Metals] Mercury 汞 (Hg)
81. [Transition Metals] Thallium 铊 (Tl)
82. [Metals] Lead 铅 (Pb)
83. [Metals] Bismuth 铋 (Bi)
84. [Metals] Polonium 钋 (Po)
85. [Nonmetals] Astatine 砹 (At)
86. [Nonmetals] Radon 氡 (Rn)
87. [Metals] Francium 钫 (Fr)
88. [Metals] Radium 镭 (Ra)

88-103 [Not In Consideration]

104. [Transition Metals] Rutherfordium 鑪 (Rf)
105. [Transition Metals] Dubnium 𨧀 (Db)
106. [Transition Metals] Seaborgium 𨭎 (Sg)
107. [Transition Metals] Bohrium 𨨏 (Bh)
108. [Transition Metals] Hassium 𨭆 (Hs)

109-118 [Not In Consideration]

- **Perodic Table Representation**

  - Each box in the Periodic Table corresponds to an element. The symbol for an element is followed by the following rules:
    1. **First letter:** Always capitalized.
    2. **Second letter (if any):** Always lowercase.
  - The Periodic Table organizes elements based on their atomic number and properties. The table is divided into groups (族) and periods (周期). Every element in a group has similar properties, and every element in a period has the same number of outermost electron shells.

- **Examples from Everyday Life**
  - **Oxygen (O_2 氧气):** Essential for respiration (呼吸) and combustion (燃烧).
  - **Iron (Fe 铁):** Used in construction and manufacturing.

- **Chemical Simplicity:** Elements are chemically the simplest substances.
  - Example: Neon (Ne 氖) contains only neon atoms and cannot be further simplified chemically.
  - Water (H_2O 水) is not an element, as it can be broken down into hydrogen (H 氢) and oxygen (O 氧).

- **Isotopes (同位素) of Elements:** Some elements have isotopes, which are atoms of the same element with the same number of protons (质子) but a different number of neutrons (中子). For example, neon contains three stable isotopes, $^{20}_{10}Ne$, $^{21}_{10}Ne$, and $^{22}_{10}Ne$. Note that the number of protons and is always the same for isotopes of the same element, but the number of neutrons can vary (不同). The number of neutrons is usually write as a superscript (写在化学符号上脚的) to the left of the element symbol, and the number of protons is written as a subscript (写在化学符号下脚的) to the left of the element symbol.

What is an Atom?

- An atom is the smallest particle of an element that retains (保持) the properties of that element.
- Atoms are extremely small and cannot be seen with the naked eye (肉眼). For example, a grain (粒) of sand contains about 10,000,000,000,000,000,000 (billions of) atoms of silicon (Si) and oxygen (O).
- An atom is made up of subatomic particles (亚原子粒子), including protons (质子), neutrons (中子), and electrons (电子). The protons and neutrons are located in the nucleus (原子核) of the atom, while the electrons orbit the nucleus in shells (壳层).
- Aroms are fundamental units in chemistry and play a crucial role in understanding elements and their behavior.

What is a Molecule?

- A molecule is a group of two or more atoms chemically bonded (化学键合) together.
- Molecules an be of:

- **Elements (单质):** Molecules consisting of the same type of atom. Example: O_2 (oxygen gas) or H_2 (hydrogen gas).

Figure 3.2: Molecule formula of oxygen gas (on the left) and hydrogen gas (on the right).

- **Compounds (化合物):** Molecules made of different types of atoms bonded together. Example: H_2O (water) or CO_2 (carbon dioxide).

Figure 3.3: Molecule formula of water (on the left) and carbon dioxide (on the right).

- The formula of a molecule gives the number and type of atoms it contains, e.g., H_2O contains 2 hydrogen atoms and 1 oxygen atom.

What is a Compound?

- A compound is a substance formed when atoms of two or more diferent elements chemically combine in fixed proportions (比例).
- Compounds have unique properties distinct (独特) from the individual elements that from them.
- Example:
  - **Water (H_2O):** Contains hydrogen and oxygen atoms.

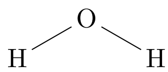


Figure 3.4: Molecule formula of water.

  - **Sodium chloride (NaCl):** Contains sodium and chlorine atoms.

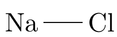


Figure 3.5: Molecule formula of sodium chloride.

- Compounds may consist of large numbers of bonded atoms, forming molecules or giant structures.
- Types:
  - **Molecular compounds:** Consist of distinct molecules (e.g., water H_2O, methane CH_4).
  - **Ionic compounds:** Consist of ions (charged particles) arranged in lattices (晶格) structures (e.g., sodium chloride NaCl, magnesium oxide MgO).

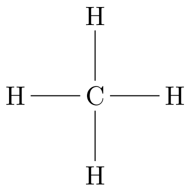


Figure 3.6: Molecule formula of methane.

What is and Ion?

- An ion is a species consisting of one or more atoms that have gained or lost electrons, resulting is a positive or negative charge.
- Types of Ions:
  - **Cations (阳离子):** An ion with a positive charge, formed by losing electrons (e.g., Na^+, Ca^{2+}).
  - **Anions (阴离子):** An ion with a negative charge, formed by gaining electrons (e.g., Cl^-, O^{2-}).
- Formation: Ions are formed when atoms or molecules lose or gain electrons to achieve a stable electron configuration (usually a full outer shell).
- Examples of Common Ions:
  - **Monatomic Ions (单原子离子):** Ions formed from a single atom (e.g., Na^+, Cl^-).
  - **Polyatomic Ions (多原子离子):** Ions formed from two or more atoms bonded together (e.g., $SO_4{}^{2-}$, $NH_4{}^+$).
- Illustration (图示)

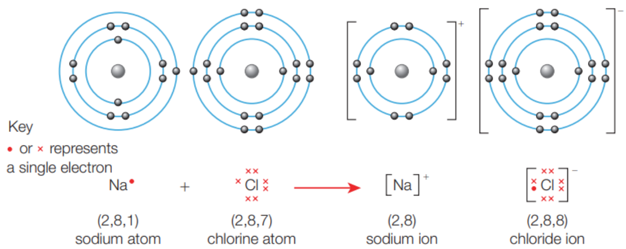


Figure 3.7: The formation of sodium chloride.

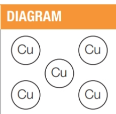
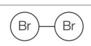
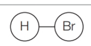
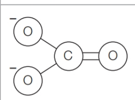
TERM	DIAGRAM	NAME	SYMBOL OR FORMULA	NOTE
element		copper	Cu	This is an element. All the atoms are the same.
atom		helium	He	This is an atom of an element.
molecule		bromine	Br_2	This is a molecule of an element. The atoms are the same.
compound		hydrogen bromide	HBr	This is a molecule of a compound. The atoms are different.
ion		carbonate	CO_3^{2-}	This is an ion. There are two negative charges shown.

Figure 3.8: Illustrations of terms used in this chapter.

Other Terms

1. Monatomic (单原子): Element consisting of single atoms are referred to as monatomic. Example: Helium (He), a gas used in weather balloons, is a monatomic element.

2. Diatomic (双原子): Elements and compounds made up of two atoms joined together are called diatomic. Common examples include diatomic gases in the atompshere, such as oxygen (O_2) and nitrogen (N_2).

3. Polyatomic (多原子): Elements and compounds made up of molecules containing several atoms joined together are described as polyatomic. Examples include sulfuric acid (H_2SO_4) and ammonia (NH_3).

4. Monatomic, Diatomic, and Polyatomic Ions: The same terms apply to ions. Examples include monatomic ion like sodium (Na^+), diatomic ion like hydroixde (OH^-), and polyatomic ions like sulfate (${SO_4}^{2-}$).

3.1.2 Equations and Reaction Types

1B.1 Writing Chemical Equations

Writing Formulae for Names

- Familiarize yourself with the formulae of common compounds, and deduce (推断) the formulae from given names. Examples:
  - **Oxygen:** O_2 not O
  - **Hydrogen:** H_2 not H
  - **Nitrogen:** N_2 not N
  - **Water:** H_2O
  - **Sodium Hydroxide:** NaOH
  - **Nitric Acid:** HNO_3
- Work out the formulae for:
  - **Iron(II) Sulfate:** $FeSO_4$
  - **Iron(III) Oxide:** Fe_2O_3
  - **Calcium Carbonate:** $CaCO_3$
- **Exam Hint:** Use the periodic table to deduce formulae for compounds within the same group (e.g., Magnesium sulfate $MgSO_4$ and strontium sulfate $SrSO_4$).

Balancing Equations

- Add coefficients (系数) to ensure the number of atoms for each element is equal on both sides.
- Example:

$$\begin{aligned} & \mathrm{H_2O_2} \longrightarrow \mathrm{H_2O} + \mathrm{O_2} \\ \text{Balanced Equation:}\quad & 2\,\mathrm{H_2O_2} \longrightarrow 2\,\mathrm{H_2O} + \mathrm{O_2} \end{aligned} \tag{3.1}$$

State Stmbols: Indicate the state of substances:

(s) = solid, (l) = liquid, (g) = gas, (aq) = aqueous (dissolved in water)

Ionic Equations

- **Simplifying Full Equations**
  - Ionic equations include only the ions that participate in the reaction.
  - Steps to simplify:
    1. Write the full balanced equation.
    2. Replace ionic compounds with their respective ions.
    3. Cancel out identical ions on both sides (spectator ions 旁观离子).
- **Worked Example 1:** Neutralization (中和) of sodium hydroxide and nitric acid:

  The full balanced equation is:

  $$NaOH(aq) + HNO_3(aq) \longrightarrow NaNO_3(aq) + H_2O(l) \tag{3.2}$$

  You should now consider which of these species are ionic and replace them with ions. In this example, the first three compounds are ionic:

  $$Na^+(aq) + OH^-(aq) + H^+(aq) + NO_3{}^-(aq) \longrightarrow Na^+(aq) + NO_3{}^-(aq) + H_2O(l) \tag{3.3}$$

  After deleting the identical ions, the equation becomes:

  $$OH^-(aq) + H^+(aq) \longrightarrow H_2O(l) \tag{3.4}$$

- **Worked Example 2:** Reaction between lead(II) nitrate and sodium sulfate:

  The full balanced equation is:

  $$Pb(NO_3)_2(aq) + Na_2SO_4(aq) \longrightarrow PbSO_4(s) + 2\,NaNO_3(aq) \tag{3.5}$$

  The ionic equation is:

  $$\begin{aligned} &Pb^{2+}(aq) + 2\,NO_3{}^-(aq) + 2\,Na^+(aq) + SO_4{}^{2-}(aq) \\ &\longrightarrow PbSO_4(s) + 2\,Na^+(aq) + 2\,NO_3{}^-(aq) \end{aligned} \tag{3.6}$$

  After deleting the identical ions, the equation becomes:

  $$Pb^{2+}(aq) + SO_4{}^{2-}(aq) \longrightarrow PbSO_4(s) \tag{3.7}$$

- **Worked Example 3:** Carbon dioxide reacts with calcium hydroxide:

  The full balanced equation is:

  $$CO_2(g) + Ca(OH)_2(aq) \longrightarrow CaCO_3(s) + H_2O(l) \tag{3.8}$$

  The ionic equation is:

  $$CO_2(g) + Ca^{2+}(aq) + 2\,OH^-(aq) \longrightarrow CaCO_3(s) + H_2O(l) \tag{3.9}$$

  After deleting the identical ions, the equation becomes:

  $$CO_2(g) + Ca^{2+}(aq) + 2\,OH^-(aq) \longrightarrow CaCO_3(s) + H_2O(l) \tag{3.10}$$

Ionic Half-Equations (半反应)

- Half-equations show the oxidation or reduction process of individual reactants.
- Example: Reduction during the electrolysis of sulfuric acid:

  $$\begin{aligned} 2\,H^+(aq) + 2\,e^- &\longrightarrow H_2(g) \\ 2\,H_2O(l) + 2\,e^- &\longrightarrow H_2(g) + 2\,OH^-(aq) \end{aligned} \tag{3.11}$$

1B.2 Typical Reactions of Acids

Introduction Acids are common reagents in chemistry, used to prepare salts. Examples of acid include hydrochloric acid (HCl 氯化氢/盐酸), nitric acid (HNO_3 硝酸), sulfuric acid (H_2SO_4 硫酸), and phosphoric acid (H_3PO_4 磷酸).

Acid with Metals

- **General Equation:**

$$\text{Metal} + \text{Acid} \longrightarrow \text{Salt} + \text{Hydrogen Gas} \tag{3.12}$$

- **Example:**

$$\begin{aligned} \mathrm{Mg} + 2\,\mathrm{HCl} &\longrightarrow \mathrm{MgCl_2} + \mathrm{H_2} \\ \mathrm{Mg(s)} + 2\,\mathrm{H^+(aq)} &\longrightarrow \mathrm{Mg^{2+}(aq)} + \mathrm{H_2(g)} \end{aligned} \tag{3.13}$$

- **Explanation:** Hydrogen ions (H^+) are reduced to hydrogen gas (H_2), so these are redox reactions (氧化还原反应), not neutralization reactions (中和反应).

Acids with Metal Oxides (金属氧化物) and Insoluble Metal Hydroxides (金属氢氧化物)

- **General Equation:**
  - Metal Oxide:

$$\text{Metal Oxide} + \text{Acid} \longrightarrow \text{Salt} + \text{Water} \tag{3.14}$$

  - Metal Hydroxide:

$$\text{Metal Hydroxide} + \text{Acid} \longrightarrow \text{Salt} + \text{Water} \tag{3.15}$$

- Typical equations for copper(II) oxide and zinc hydroxide reacting with sulfuric acid are:

$$\begin{aligned} \mathrm{CuO} + \mathrm{H_2SO_4} &\longrightarrow \mathrm{CuSO_4} + \mathrm{H_2O} \\ \mathrm{CuO(s)} + 2\,\mathrm{H^+(aq)} &\longrightarrow \mathrm{Cu^{2+}(aq)} + \mathrm{H_2O(l)} \\ \mathrm{Zn(OH)_2} + \mathrm{H_2SO_4} &\longrightarrow \mathrm{ZnSO_4} + 2\,\mathrm{H_2O} \\ \mathrm{Zn(OH)_2(s)} + 2\,\mathrm{H^+(aq)} &\longrightarrow \mathrm{Zn^{2+}(aq)} + 2\,\mathrm{H_2O(l)} \end{aligned} \tag{3.16}$$

- **Explanation:** These are neutralization reactions (中和反应) with no change in oxidation numbers [1] (氧化数).

[1] **Oxidation numbers:** An oxidation number is the charge that an atom would have if all bonds in a compound were ionic.

Rules for Assigning Oxidation Numbers

1. **Elements:** An atom in its elemental form (e.g., O_2, H_2, Na) has an oxidation number of 0.
2. **Simple Ions:** The oxidation number of a monatomic ion is equal to its charge (e.g., $Na^+ = +1$, $Cl^- = -1$).
3. **Compound:**
   * The sum of oxidation numbers in a neutral compound (中性化合物) is 0.
   * In polyatomic ions (多原子离子), the sum of oxidation numbers is equal to the ion's charge.

Acids with Alkalis (碱)

- **General Equation:**

$$\text{Acid} + \text{Alkali} \longrightarrow \text{Salt} + \text{Water} \tag{3.18}$$

- **Example:**

$$\begin{aligned} NaOH + H_3PO_4 &\longrightarrow NaH_2PO_4 + H_2O \\ 2\,NaOH + H_3PO_4 &\longrightarrow Na_2HPO_4 + 2\,H_2O \\ 3\,NaOH + H_3PO_4 &\longrightarrow Na_3PO_4 + 3\,H_2O \\ H^+(aq) + OH^-(aq) &\longrightarrow H_2O\,(l) \end{aligned} \tag{3.19}$$

- **Explanation:** These are neutralization reactions with no oxidation state changes.

Acids with Carbonates (碳酸盐)

- **General Equation:**

$$\text{Acid} + \text{Metal Carbonate} \longrightarrow \text{Salt} + \text{Water} + \text{Carbon Dioxide} \tag{3.20}$$

- **Example:**

$$\begin{aligned} Li_2CO_3 + 2\,HCl &\longrightarrow 2\,LiCl + H_2O + CO_2 \\ CO_{32-}(aq) + 2\,H^+(aq) &\longrightarrow H_2O\,(l) + CO_2(g) \end{aligned} \tag{3.21}$$

- **Explanation:** These are neutralization reactions with the release of carbon dioxide gas.

Acids with Hydrogencarbonates (碳酸氢盐)

- **General Equation:**

$$\text{Acid} + \text{Metal Hydrogencarbonate} \longrightarrow \text{Salt} + \text{Water} + \text{Carbon Dioxide} \tag{3.22}$$

- **Example:**

$$NaHCO_3 + HCl \longrightarrow NaCl + H_2O + CO_2 \tag{3.23}$$

- **Application:** Used in baking to release carbon dioxide gas, making baked goods light and fluffy.

- **Test for Carbonates and Hydrogencarbonates:** Add an acid and test the gas produced with limewater ($Ca(OH)_2$ 澄清石灰水).

---

4. **Common Elements:**
   * Group 1 elements (alkali metals 碱金属): Always +1.
   * Group 2 elements (alkaline earth metals 碱土金属): Always +2.
   * Hydrogen: +1 (except in peroxides −1, e.g., H_2O_2, or when bonded to fluorine +2).
   * Fluorine: Always −1.

Oxidation and Reduction

- **Oxidation:** Increase in oxidation number.
- **Reduction:** Decrease in oxidation number.
- Example:

$$2\,Mg + O_2 \longrightarrow 2\,MgO \tag{3.17}$$

- Magnesium (Mg) changes from 0 to +2 (oxidized).
- Oxygen (O_2) changes from 0 to −2 (reduced).

1B.3 Displacement Reactions (置换反应)

What is a Displacement Reaction? A displacement reaction occurs when a more reactive element replaces a less reactive element in a compound. These reactions are often redox reactions (氧化还原反应) where:

- The more reactive element is **oxidized** (氧化) and loses electrons.
- The less reactive element is **reduced** (还原) and gains electrons.

Displacement Reactions Involving Metals

1. General Characteristics:
   - A metal reacts with the compound of aother metal.
   - Produces a new metal and a new compound.
   - Involves electron transfer (redox).
2. Examples:
   - Reaction 1:

     $$Mg(s) + CuSO_4(aq) \longrightarrow MgSO_4(aq) + Cu(s) \tag{3.24}$$

     * Mg oxidized to Mg^{2+}.
     * Cu^{2+} reduced to Cu.
   - Reaction 2 (Thermite Reaction 铝热反应):

     $$Al(s) + Fe_2O_3(s) \longrightarrow Al_2O_3(s) + Fe(s) \tag{3.25}$$

     * Al oxidized to Al^{3+}.
     * Fe^{3+} reduced to Fe.
3. Differences Between Reactions:
   - Reaction 1: Occurs in aqueous solution.
   - Reaction 2: Requires high temperatures; used in industrial processes like railway welding.
4. Ionic Equations

   Example: Reaction 1

   $$Mg(s) + Cu^{2+}(aq) \longrightarrow Mg^{2+}(aq) + Cu(s) \tag{3.26}$$

Displacement Reactions Involving Halogens

- General Concept:
  - A more reactive halogens [2] (卤素) displaces a less reactive halogen from its compound.
  - Follows the order of reactivity: F > Cl > Br > I.
- Example:

[2] Halogens are Group 7 elements in the periodic table, including fluorine (F), chlorine (Cl), bromine (Br), iodine (I), and astatine (At).

- Reaction of chlorine with potassium bromine. The full, ionic and simplified ionic equations for this reaction are:

$$\begin{aligned} Cl_2(aq) + 2\,KBr(aq) &\longrightarrow 2\,KCl(aq) + Br_2(aq) \\ Cl_2(aq) + 2\,Br^-(aq) + 2\,K^+(aq) &\longrightarrow 2\,K^+(aq) + 2\,Cl^-(aq) + Br_2(aq) \\ Cl_2(aq) + 2\,Br^-(aq) &\longrightarrow 2\,Cl^-(aq) + Br_2(aq) \end{aligned} \tag{3.27}$$

- Key Points: Halogen displacement reactions are redox reactions. Note that the reactivity of halogens decreases down the group.

Applications of Displacement Reactions Industrial Welding:

- The thermite reaction is used to join railway tracks.
- The exothermic reaction produces molten iron (熔融铁), which fills the gap between tracks.

1B.4 Precipitation Reactions (沉淀反应)

Overview: Precipitation reactions involve the formation of an insoluble solid (precipitate 沉淀) when two solutions are mixed. They are used in chemical tests and for writing chemical equations.

Chemical Tests

1. Carbon Dioxide
   - **Test:** Bubble CO_2 gas through limewater ($Ca(OH)_2$ 澄清石灰水).
   - **Observation:** Limewater turns milky or cloudy due to the formation of calcium carbonate ($CaCO_3$ 碳酸钙).
   - **Equation:**

$$Ca(OH)_2(aq) + CO_2(g) \longrightarrow CaCO_3(s) + H_2O(l) \tag{3.28}$$

Figure 3.9: Limewater is a colourless solution. As more carbon dioxide is bubbled through it, the amount of white precipitate increases.

2. Sulfates
   - **Test:** Add barium chloride ($BaCl_2$ 氯化钡) or barium nitrate ($Ba(NO_3)_2$ 硝酸钡) solution to a solution containing sulfate ions (${SO_4}^{2-}$).

  - **Observation:** A white precipitate of barium sulfate ($BaSO_4$ 硫酸钡) forms.
  - **Equation:**

$$\begin{aligned} Na_2SO_4(aq) + BaCl_2(aq) &\longrightarrow BaSO_4(s) + 2\,NaCl(aq) \\ {SO_4}^{2-}(aq) + Ba^{2+}(aq) &\longrightarrow BaSO_4(s) \end{aligned} \tag{3.29}$$

3. Halides (卤化物)
  - **Test:** Add silver nitrate ($AgNO_3$ 硝酸银) to a solution containing Halide ions (Cl^-, Br^-, I^-).
  - **Observation:** A precipitate of silver halide forms: White (AgCl), Cream (AgBr), Yellow (AgI).
  - **Equation:**

$$\begin{aligned} NaCl(aq) + AgNO_3(aq) &\longrightarrow AgCl(s) + NaNO_3(aq) \\ Cl^-(aq) + Ag^+(aq) &\longrightarrow AgCl(s) \end{aligned} \tag{3.30}$$

Working Out Equations Example: Reaction Between Lead Nitrate and Potassium Iodide

- **Reaction:** Lead nitrate reacts with potassium iodide to form lead iodide (yellow precipitate) and potassium nitrate.
- **Word Equation:**

$$\text{Lead Nitrate} + \text{Potassium Iodide} \longrightarrow \text{Lead Iodide} + \text{Potassium Nitrate} \tag{3.31}$$

- **Balanced Equations:**

$$\begin{aligned} Pb(NO_3)_2(aq) + 2\,KI(aq) &\longrightarrow PbI_2(s) + 2\,KNO_3(aq) \\ Pb^{2+}(aq) + 2\,I^-(aq) &\longrightarrow PbI_2(s) \end{aligned} \tag{3.32}$$

- Experimental Procedure:
  1. Place the same volume of a potassium iodide solution in a series of test tubes.
  2. Add different volumes of a lead nitrate solution to the tubes.
  3. Place each tube in a centrifuge and spin the tubes for the same length of time.
  4. Measure the depth of precipitate in each tube.
- Figure 3.10 shows the results of one experiment. The concentration of both solutions is 1.0 mol dm^{-3}. The depth of each precipitate indicates the mass of precipitate formed.

TUBE	1	2	3	4	5	6	7
volume of potassium iodide solution / cm^3	5.0	5.0	5.0	5.0	5.0	5.0	5.0
volume of lead nitrate solution / cm^3	0.5	1.0	1.5	2.0	2.5	3.0	3.5
depth of precipitate / cm	2.5	3	4	5	6	6	6

Figure 3.10: Results of the reaction between aqueous solutions of lead nitrate and potassium iodide in one experiment.

The diagram shows the tubes at the end of the experiment.

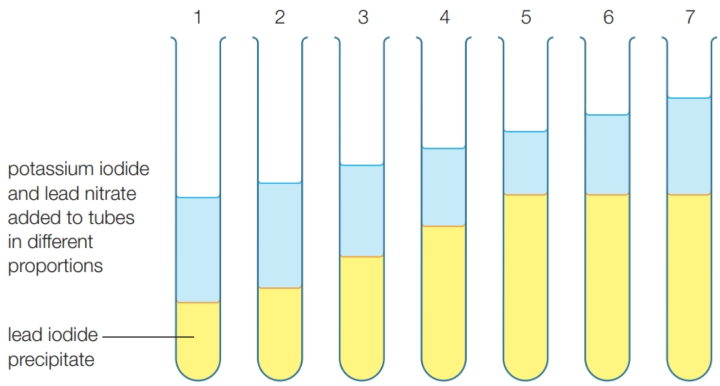


Figure 3.11: Results of the reaction between aqueous solutions of lead nitrate and potassium iodide in one experiment.

- **Results:** Tube 5 has complete reaction with a mole ratio of lead nitrate to potassium iodide as 1:2.
- **Calculaton for Tube 5:**

$$\begin{aligned} n(\text{potassium iodide}) &= 0.005 \times 1.0 = 0.005\text{mol} \\ n(\text{lead nitrate}) &= 0.0025 \times 1.0 = 0.0025\text{mol} \end{aligned} \tag{3.33}$$

3.1.3 Mole Calculations

1C.1 Comparing Masses of Substances

Relative Atomic Mass (A_r 相对原子质量)

- **Definition:** The weighted mean (average) mass of an atom of an elemet compared to $\frac{1}{12}$ of the mass of an atom of ^{12}C (carbon-12).

$$A_r = \frac{\text{Mean mass of an atom of the element}}{\frac{1}{12} \text{ of the mass of an atom of } ^{12}\text{C}} \tag{3.34}$$

- **Key Points:**
  - Based on isotopic masses.
  - Has no units.
  - Found in the preiodic table.

Relative Molecular Mass (M_r 相对分子质量)

- **Definition:** Sum of the relative atomic masses (A_r) of the atoms in a molecule.
- **Examples:**
  - CO_2:
  $$M_r = 12.0 + (2 \times 16.0) = 44.0 \tag{3.35}$$
  - H_2SO_4:
  $$M_r = (2 \times 1.0) + 32.1 + (4 \times 16.0) = 98.1 \tag{3.36}$$

Relative Formula Mass (M_r 相对式量/化学式质量)

- **Definition:** Silimar to M_r, but used for ionic compounds (e.g., NaCl, $CuSO_4 \cdot 5\,H_2O$).
- **Example:** $CuSO_4 \cdot 5\,H_2O$:

$$M_r = 63.5 + 32.1 + (4 \times 16.0) + (5 \times 18.0) = 249.6 \tag{3.37}$$

Molar Mass (M 摩尔质量)

- **Definition:** The mass of one mole of a substance; has units $\mathrm{g\,mol^{-1}}$.
- **Formula:**

$$\text{Amount in moles} = \frac{\text{Mass of substance (g)}}{\text{Molar mass (g mol}^{-1}\text{)}} \quad \text{or} \quad n = \frac{m}{M} \tag{3.38}$$

- **Examples:**
  - O_2: Molar mass = 32.0 $\mathrm{g\,mol^{-1}}$
  - H_2O: Molar mass = 18.0 $\mathrm{g\,mol^{-1}}$

The Avogadro Constant (N_A 阿伏伽德罗常数)

- **Definition:** The number of particles (atoms, molecules, or ions) in one mole of a substance.

$$N_A = 6.02 \times 10^{23}\mathrm{mol^{-1}} \tag{3.39}$$

- **Applications:**
  - Number of particles:

$$\text{Number of particles} = \text{Amount in moles} \times N_A \tag{3.40}$$

  - Example:

$$\begin{aligned} n &= \frac{1.25\text{g of } H_2O}{18.0\text{g mol}^{-1}} = 0.0694\text{mol} \\ \text{Number of molecules} &= 0.0694 \times 6.02 \times 10^{23} = 4.18 \times 10^{22} \end{aligned} \tag{3.41}$$

Worked Examples

1. Calculate M_r of H_2SO_4:

$$M_r = (2 \times 1.0) + 32.1 + (4 \times 16.0) = 98.1 \tag{3.42}$$

2. Number of Particles in 1.25 g of H_2O:

$$\begin{aligned} n &= \frac{1.25\text{g of } H_2O}{18.0\text{g mol}^{-1}} = 0.0694\text{mol} \\ \text{Number of molecules} &= 0.0694 \times 6.02 \times 10^{23} = 4.18 \times 10^{22} \end{aligned} \tag{3.43}$$

3. Mass of 100 Million Atoms of Gold:

$$\begin{aligned} n &= \frac{100 \times 10^6 \text{ atoms}}{6.02 \times 10^{23}\text{mol}^{-1}} = 1.66 \times 10^{-16}\text{mol} \\ m &= 1.66 \times 10^{-16} \times 197.0 = 3.27 \times 10^{-14}\text{g} \end{aligned} \tag{3.44}$$

1C.2 Calculations Involving Moles

Definition of Mole

- A mole is the amount of substance that contains the same number of particles (atoms, molecules, ions, or electrons) as there are in 12 g of carbon-12.
- The number is the Avogadro constant, $N_A = 6.022 \times 10^{23}\text{mol}^{-1}$.

Counting Atoms

- Atoms are extremely small, so we use relative atomic masses to compare the masses of atoms.
- Example: Oxygen is 16 times heavier than hydrogen (A_r of O = 16.0, A_r of H = 1.0).
- A mole of oxygen atoms (16.0 g) contains the same number of particles as a mole of hydrogen atoms (1.0 g).

Calculations Using Moles

- **Equations for Calculating Moles**

$$\text{Amount in moles}(n) = \frac{\text{Mass in grams}(m)}{\text{Molar mass}(M)} \tag{3.45}$$

  Rearrangements:

$$m = n \times M \quad \text{or} \quad M = \frac{m}{n} \tag{3.46}$$

- **Worked Examples**
  - **Substance in Moles:** What is the amount of soldium chloride in 6.15g ($M = 58.5$)?

$$n = \frac{m}{M} = \frac{6.51}{58.5} = 0.111\text{mol} \tag{3.47}$$

  - **Mass of a Substance:** What is the mass of 0.263 mol of hydrogen iodide ($M = 127.9$)?

$$m = n \times M = 0.263 \times 127.9 = 33.6\text{g} \tag{3.48}$$

  - **Molar Mass:** A sample has $n = 0.284$ mol and $m = 17.8$g. What is the molar mass?

$$M = \frac{m}{n} = \frac{17.8}{0.284} = 62.7\text{g} \cdot \text{mol}^{-1} \tag{3.49}$$

What to Remember When Using Moles

- Always specify the type of particle (e.g., atoms, molecules, ions).
- For compounds, specify the formula to avoid confusion.

1C.3 Calculations Using Reacting Masses

Introduction to Reacting Masses

- A balanced chemical equation provides the relationship between the amounts of reactants and products.
- Example:

$$N_2 + 3\,H_2 \longrightarrow 2\,NH_3 \tag{3.50}$$

  - 1 mole of N_2 reacts with 3 moles of H_2 to produce 2 moles of NH_3.
  - In terms of mass:

$$28.0 \text{ g of } N_2 + 6.0\text{g of } H_2 \longrightarrow 34.0\text{g of } NH_3 \tag{3.51}$$

Steps to Calculate Reacting Masses

1. Write a balanced chemical equation.
2. Calculate moles of the known substance using:

$$n = \frac{m}{M} \tag{3.52}$$

3. Use the mole ratio from the balanced equation to calculate moles of the unknown substance.
4. Calculate the mass of the other substance using:

$$m = n \times M \tag{3.53}$$

1C.4 The Yield of a Reaction

Theoretical Yield (理论产量), Actual Yield (实际产量), and Percentage Yield (产率)

Introduction

- In laboratory and industrial chemistry, it is essential to maximize product yield.
- Factors reducing yield:
  - The reaction may be reversible (可逆的) and not go to completion.
  - Side-reactions producing unwanted products.
  - Purification (提纯) steps leading to product loss.

Terminology Relating to Yield

1. **Theoretical Yield:**
   - The maximum possible amount of product calculated from the balanced chemical equation.
   - Assumes (假设) the reaction goes to completion with no losses.
2. **Actual Yield:**
   - The actual mass of product obtained (获得) from an experiment.

  - Measured by weighing the final product.

3. **Percentage Yield:**
   - A measure of the efficiency of the reaction:
   $$\text{Percentage Yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100\% \tag{3.54}$$
   - Indicates how much of the theoretical yield was obtained.
   - Higher yields indicate more efficient processes.

Applications in Industry

- Percentage yield is crucial for cost efficiency.
- High yields reduce waste and maximize resource utilization.

1C.5 Atom Economy

Background

- **Definition:** Atom economy measures the efficiency of a reaction in converting reactants into useful products.
- **Importance:**
  - A higher atom economy reduces waste and increases the sustainability (持续性) of industrial processes.
  - Factors influencing industrial suitability:
    * Availability and cost of raw materials.
    * Energy requirements.
    * Environmental impact of waste products.

How Atom Economy Works Example: Manufacture of phosphoric acid (H_3PO_4):

- Process 1
  $$Ca_3(PO_4)_2 + 3\,H_2SO_4 \longrightarrow 2\,H_3PO_4 + 3\,CaSO_4 \tag{3.55}$$
  Many atoms end up in the waste product, calcium sulfate ($CaSO_4$). The atom economy is lower.
- Process 2
  $$P_4O_{10} + 6\,H_2O \longrightarrow 4\,H_3PO_4 \tag{3.56}$$
  All atoms in reactants form the desired product. Higher atom economy.

Formula for Atom Economy

$$\text{Atom Economy} = \frac{\text{Molar Mass of Desired Product}}{\text{Sum of Molar Masses of All Products}} \times 100\% \tag{3.57}$$

Developed by Barry Trost to evaluate reaction efficiency in industrial processes.

- Worked Example for Process 1:
  - Desired product: $2\,H_3PO_4$.
    * Molar mass of $H_3PO_4 = 98.0$ g/mol.
    * Total mass of product $= (98.0 \times 2) + (136.2 \times 3) = 644.6$ g.
  - Atom economy:
  $$\frac{(98.0 \times 2)}{(98.0 \times 2) + (136.2 \times 3)} \times 100\% = 32.4\% \tag{3.58}$$

Reaction Types and Atom Economy

- Addition reactions have 100% atom economy.
- Elimination and substitution reactions have lower atom economies.
- Multistep reactions may have even lower atom economies.

3.1.4 Empirical and Molecular Formulae

1D.1 Empirical Formulae

The Definition of Empirical Formulae (实验式)

- An empirical formula represents the simplest whole-number ratio of atoms of each element in a compound.
- It is determined from experimental data such as masses or percentage compositions.

Steps to Calculate Empirical Formula

1. Divide the mass or percentage composition of each element by its relative atomic mass (A_r).
2. Calculate the ratio of the elements by dividing all results by the smallest number obtained.
3. If necessary, round to the nearest whole number or multiply to achieve whole numbers

Example Using Masses Determining the formula of copper oxide (CuO):

- Mass of copper: 3.43 g, mass of oxygen: 0.85 g
- Relative atomic masses: Cu = 63.5, O = 16.0.
- Steps:
  1. Divide masses by A_r:
  $$\frac{3.43}{63.5} = 0.0540, \quad \frac{0.85}{16.0} = 0.0531 \tag{3.59}$$
  2. Simplify ratio
  $$\frac{0.0540}{0.0531} \approx 1 : 1 \tag{3.60}$$
  3. Empirical formula: CuO.

Example Using Percentage Composition Compound with C = 38.4%, H = 4.8%, Cl = 56.8%:

- Relative atomic masses: C = 12.0, H = 1.0, Cl = 35.5.
- Steps:
  1. Divide percentages by A_r:
  $$\frac{38.4}{12.0} = 3.2, \quad \frac{4.8}{1.0} = 4.8, \quad \frac{56.8}{35.5} = 1.6 \tag{3.61}$$
  2. Simplify ratio:
  $$3.2 : 4.8 : 1.6 \approx 2 : 3 : 1 \tag{3.62}$$
  3. Empirical formula: C_2H_3Cl.

Handling Oxygen as a Missing Value Example: Na = 29.1%, S = 40.5%, oxygen not provided.

- Calculate oxygen by subtraction:

$$\text{Oxygen Percentage} = 100 - (29.1 + 40.5) = 30.4\% \tag{3.63}$$

- Determine ratio:

$$\frac{29.1}{23.0} = 1.27, \quad \frac{40.5}{32.1} = 1.26, \quad \frac{30.4}{16.0} = 1.90 \tag{3.64}$$

- Simplify ratio:

$$1.27 : 1.26 : 1.90 \approx 1 : 1 : 2 \tag{3.65}$$

- Empirical formula: $Na_2S_2O_3$.

Using <u>Combustion Analysis</u> (燃烧分析) Determine the mass of C, H, and O from the masses of CO_2 and H_2O produced.

$$\begin{aligned} C &= \frac{\text{Mass of } CO_2}{44.0} \times 12.0 \\ H &= \frac{\text{Mass of } H_2O}{18.0} \times 2.0 \\ O &= \text{Total mass} - (C + H) \end{aligned} \tag{3.66}$$

Chapter 4

Physics

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