A-Level Notes for Pearson Edexcel

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Contents

Chapter 1

Pure Mathamatics

1.1 Algebraic Expressions

1.1.1 Index Laws

Index laws are used to simplify expressions involving powers (indices) of the same base.

- Multiplying Powers of the Same Base:

$$a^m \times a^n = a^{m+n} \tag{1.1}$$

- Dividing Powers of the Same Base:

$$\frac{a^m}{a^n} = a^{m-n} \tag{1.2}$$

- Power of a Power:

$$(a^m)^n = a^{m \times n} \tag{1.3}$$

- Multiplying Powers of Different Bases:

$$(ab)^n = a^n \times b^n \tag{1.4}$$

1.1.2 Expending Brackets

To expend a product of two expressions, multiply each term in one expression by each term in the other expression.

- Distributive Property:

Multiplying each of the 2 terms in the first expression by each of the 3 terms in the second expression gives 2 × 3 = 6 terms.

$x \times$

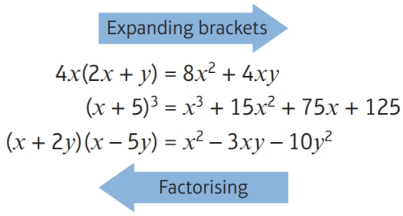
$$\begin{aligned}(x+5)(4x-2y+3) &= x(4x-2y+3)+5(4x-2y+3)\\ &= 4x^2-2xy+3x+20x-10y+15\\ &= 4x^2-2xy+23x-10y+15\end{aligned}$$

$5 \times$

Simplify your answer by **collecting like terms**.

1.1.3 Factorising

Factorising involves writing an expression as a product of its factors. The process is the reverse expanding brackets.



- Steps to Factorise:
  1. Identify the common factor in all terms of the expression and factor it out.
  2. For quadratic expressions (二次表达式) like ax^2+bx+c, find two numbers that multiply to give ac and add to give b.
  3. Factorise the quadratic expression by breaking it into two binomials (二项式).
- Factorising Formulae
  - **Common Factor**: To factor an expression by taking out the common factor:
  $$ax + ay = a\left(x + y\right) \tag{1.5}$$
  - **Quadratic Factorisation:** For a quadratic expression ax^2+bx+c, find two numbers that:
    * Multiply to ac (the product of a and c).
    * Add up to b (the coefficient of the middle term).

    The rewrite the middle term using these two numbers and factor by grouping. Formula:
  $$ax^2 + bx + c = a\left(x + p\right)\left(x + q\right) \tag{1.6}$$
    where p and q are the factors of ac that add up to b.
  - **Difference of Squares:** The difference of squares formula is used when you have an expression like $a^2 - b^2$. It can be factored as:
  $$a^2 - b^2 = \left(a + b\right)\left(a - b\right) \tag{1.7}$$
  - **Perfect Square Trinomial:** For expressions of the form $a^2 \pm 2ab + b^2$, it factors into a perfect square:
  $$a^2 \pm 2ab + b^2 = \left(a \pm b\right)^2 \tag{1.8}$$
  - **Factorising by Grouping:** When you have four terms, factor by grouping:
  $$ax + bx + ay + by = \left(a + b\right)\left(x + y\right) \tag{1.9}$$
  - **Factorising Quadratics by Completing the Square (for advanced problems):** For a quadratic expression of the form $ax^2 + bx + c$, it can sometimes be completed into a perfect square for easy factorisation.
  $$ax^2 + bx + c = a\left(x^2 + \frac{b}{a}x + \left(\frac{b}{2a}\right)^2\right) - a\left(\frac{b}{2a}\right)^2 + c \tag{1.10}$$

1.1.4 Negative and Fractional Indices

- **Negative Indices Formula:** When the exponent (指数) is negative, move the base to the denominator (or denominator to numerator) and make the exponent positive:

$$a^{-n} = \frac{1}{a^n} \tag{1.11}$$

- **Fractional Indices Formula:** Fractional exponents can be expressed as roots. If $a^{\frac{m}{n}}$, it represents the nth root of a^m, or the mth power of the nth root of a:

$$a^{\frac{m}{n}} = \sqrt[n]{a^m} = (\sqrt[n]{a})^m \tag{1.12}$$

Additional Notes on Simplification

- **Negative exponent rule:** Flip the base to the denominator or numerator depending on whether the exponent is negative.

- **Fractional exponent rule:** Convert fractional exponents into radical form (square roots, cube roots, etc.) or express them as fractional powers.

1.1.5 Surds

- A surd (根式) is an irrational number that cannot be written as a simple fraction. It is the square root of a number that is not a perfect square (e.g., $\sqrt{2}$, $\sqrt{3}$, $\sqrt{5}$, etc.).

- **Irrational numbers:** Cannot be written in the form $\frac{a}{b}$, where a and b are integers (e.g., π).

- **Manipulating surds**

$$\sqrt{a} \times \sqrt{b} = \sqrt{ab} \tag{1.13}$$

$$\frac{\sqrt{a}}{\sqrt{b}} = \sqrt{\frac{a}{b}} \tag{1.14}$$

1.1.6 Rationalising Denominators

- Rationalising the denominator is a technique used to remove surds from the denominator of a fraction.

- **Rules to rationalise denominators**

  1. For fractions of the form $\frac{1}{\sqrt{a}}$, multiply both the numerator and denominator by $\sqrt{a}$.

$$\frac{1}{\sqrt{a}} = \frac{1}{\sqrt{a}} \times \frac{\sqrt{a}}{\sqrt{a}} = \frac{\sqrt{a}}{a} \tag{1.15}$$

  2. For fractions of the form $\frac{1}{a+\sqrt{b}}$, multiply both the numerator and denom-

inator by the conjugate [1] (共轭) of the denominator by $a-\sqrt{b}$.

$$\frac{1}{a+\sqrt{b}}=\frac{1}{a+\sqrt{b}}\times\frac{a-\sqrt{b}}{a-\sqrt{b}}=\frac{a-\sqrt{b}}{a^2-b} \tag{1.16}$$

3. For fractions of the form $\frac{1}{a-\sqrt{b}}$, multiply both the numerator and denominator by $a+\sqrt{b}$.

$$\frac{1}{a-\sqrt{b}}=\frac{1}{a-\sqrt{b}}\times\frac{a+\sqrt{b}}{a+\sqrt{b}}=\frac{a+\sqrt{b}}{a^2-b} \tag{1.17}$$

1.2 Quadratics

1.2.1 Solving Quadratic Equations

Quadratic equation is in the form:

$$ax^2+bx+c=0 \tag{1.18}$$

where a, b, and c are constants, and $a\neq 0$.

Methods for Solving Quadratics

1. **Factoring**

   – Rearrange the equation into the form $ax^2+bx+c=0$.

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[1] In mathematics, conjugate refers to a pair of expressions or numbers that are related in a specific way. For example:

* In complex numbers, the conjugate of a complex number $a+bi$ is $a-bi$, where a and b are real numbers and i is the imaginary unit [2](虚数单位). The conjugates of complex numbers have useful properties, especially when simplifying expressions or dividing complex numbers. For instance, multiplying a complex number by its conjugate results in a real number, as the imaginary parts cancel out.
* In algebra, when dealing with binomials, the conjugate of a binomial like $(a+b)$ is $(a-b)$. Conjugates are often used to simplify expressions, particularly when rationalizing denominators or working with square roots.

The conjugate has many applications in solving equations and simplifying expressions in algebra, calculus, and complex number theory.

[2] The imaginary unit, denoted as i, is a mathematical concept used to define complex numbers. It is defined as the square root of -1:

$$i=\sqrt{-1}$$

This definition is fundamental because no real number has a square root that results in a negative value. Therefore, the imaginary unit allows for the extension of real numbers to complex numbers.

A complex number is a number that has both a real part and an imaginary part, and is generally written in the form:

$$a+bi$$

where a and b are real numbers, and i is the imaginary unit.

Some important properties of the imaginary unit include:

- $i^2=-1$
- $i^3=-i$
- $i^4=1$
- $i^5=i$
- $i^6=-1$

These properties repeat in a cycle, which is crucial in many algebraic manipulations, especially when working with powers of complex numbers. The imaginary unit is central to complex analysis, engineering, and physics.

- Factor the left-hand side of the equation.
- Set each factor equal to zero and solve for x.

2. **Using the Quadratic Formula** [3] The solution are given by the formula:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \tag{1.19}$$

where a, b, and c are the coefficients from the quadratic equation $ax^2+bx+c = 0$.

1.2.2 Completing the Square

A quadratic expression $ax^2 + bx + c$ can be rewritten by completing the square:

$$x^2 + bx = \left(x + \frac{b}{2}\right)^2 - \left(\frac{b}{2}\right)^2 \tag{1.20}$$

This method is useful to express quadratic equations in the form [4]:

$$a(x - h)^2 + k \tag{1.21}$$

From here, we can easily solve for x by taking the square root of both sides.

[3] Step by step transformation from the standard quadratic equation $ax^2 + bx + c = 0$ to the quadratic formula:

$$\begin{aligned} ax^2 + bx + c &= 0 \\ x^2 + \frac{b}{a}x + \frac{c}{a} &= 0 \\ x^2 + \frac{b}{a}x &= -\frac{c}{a} \\ x^2 + \frac{b}{a}x + \left(\frac{b}{2a}\right)^2 &= -\frac{c}{a} + \left(\frac{b}{2a}\right)^2 \\ \left(x + \frac{b}{2a}\right)^2 &= \frac{b^2 - 4ac}{4a^2} \\ x + \frac{b}{2a} &= \pm\sqrt{\frac{b^2 - 4ac}{4a^2}} \\ x &= \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \end{aligned}$$

[4] Step by step transformation of $ax^2 + bx + c$ to $a(x - h)^2 + k$:

$$\begin{aligned} ax^2 + bx + c &= a\left(x^2 + \frac{b}{a}x\right) + c \\ &= a\left(x^2 + \frac{b}{a}x + \frac{b^2}{4a^2}\right) - \frac{b^2}{4a} + c \\ &= a\left(x + \frac{b}{2a}\right)^2 - \frac{b^2 - 4ac}{4a} \\ &= a(x - h)^2 + k \end{aligned}$$

where:

- $h = -\frac{b}{2a}$
- $k = c - \frac{b^2}{4a}$

This transformation is crucial for converting a general quadratic equation to its vertex form, which reveals the vertex (h, k) of the parabola (抛物线). This from is especially useful for graphing quadratic functions and solving quadratic equations when factoring is not easy.

1.2.3 Functions

- **Domain and Range of a Function**
  - **Domain (定义域):** The set of all possible inputs for a function.
  - **Range (值域):** The set of all possible outputs for a function.

  A function $f(x)$ maps each value of x from the domain to a value in the range. The inputs are real numbers (denoted as $x \in \mathbb{R}$) and the outputs are real numbers as well.

- **Roots of a Function**
  - **Roots (根):** The values of x where $f(x) = 0$.
  - To find roots, set the function equal to zero and solve for x.

1.2.4 Quadratic Graphs

- **Key Features of Quadratic Graphs**
  - The graph of $f(x) = ax^2 + bx + c$ is a parabola (抛物线).
  - **Shape of the graph**
    * If $a > 0$, the parabola opens upwards (minimum point).
    * If $a < 0$, the parabola opens downwards (maximum point).
  - **Vertex (顶点):** The vertex of the parabola is the turning point of the graph. This can be found by completing the square or using the formula:

$$x_{\text{vertex}} = -\frac{b}{2a} \tag{1.22}$$

    For the function $f(x) = ax^2 + bx + c$, the x-coordinate of the vertex is $-\frac{b}{2a}$.

- **Roots of the Graph**
  - The roots (or solutions) of the quadratic equation are where the graph intersects the x-axis, i.e., $f(x) = 0$.
  - The number of real roots is determined by the discriminant (判别式) $\Delta = b^2 - 4ac$:
    * If $\Delta > 0$, the graph has two distinct real roots.
    * If $\Delta = 0$, the graph has one repeated real root.
    * If $\Delta < 0$, the graph has no real roots (the graph does not intersect the x-axis).

1.3 Equations and Inequalities

1.3.1 Linear Simultaneous Equations

- **Definition:** Linear simultaneous equations are two or more equations that must be satisfied at the same time. Each equation is a straight line, and their solution is the point where the lines intersect.

- **Methods for Solving Linear Simultaneous Equations**
  1. **Elimination Method:**

    * Multiply one or both equations to align one variable so that when you add or subtract the equations, one variable cancels out.
    * Solve for the remaining variable, and substitute back to find the other.

2. **Substitution Method:**
    * Solve one equation for one variable in terms of the other.
    * Substitute this into the second equation to find the value of the other variable.
    * Substitute the value of the first variable back into the original equation to find the second variable.

1.3.2 Quadratic Simultaneous Equations

- **Definition:** Quadratic simultaneous equations involve one linear equation and one quadratic equation. These equations intersect at specific points that provide the solutions.
- **Method for Solving Quadratic Simultaneous Equations**
    - **Substitution Method:**
        * Rearrange the linear equation to express one variable in terms of the other.
        * Substitute this expression into the quadratic equation.
        * Solve the resulting quadratic equation for the variable and find the corresponding (相应的) value of the other variable.
    - **Example Formulae:**
        * **Linear Equation:**
        $$y = mx + c \tag{1.23}$$
        * **Quadratic Equation:**
        $$ax^2 + bxy + cy^2 = d \tag{1.24}$$

1.3.3 Simultaneous Equations on Graphs

- **Key Concepts**
    - The solutions to simultaneous equations represent the points where the graphs of the equations intersect.
    - We can graph linear equations, quadratic equations, or a combination of both to find the points of intersection, which correspond to the solutions of the system of equations.
- **Types of Intersections**
    1. **Linear vs Linear:** The graphs of two linear equations intersect at one point unless they are parallel (no solution).
    2. **Linear vs Quadratic:** A linear equation and a quadratic equation can intersect at one or two points. The intersection points are the solutions to the system.
    3. **Quadratic vs Quadratic:** A quadratic equation and another quadratic equation may intersect at two points, one point, or not intersect at all.
- **Form of Equations**

- **Linear Equation:**
  - **General Formula**
    $$y = kx + b \tag{1.25}$$
  - Where k is the slope (gradient) and b is the y-intercept.
- **Quadratic Equation:**
  - **General Formula**
    $$y = ax^2 + bx + c \tag{1.26}$$
  - Where a is the coefficient (系数) that affects the curvature (曲率) of the graph, b is the coefficient of x, and c is the y-intercept.

- **Graphing Simultaneous Equations**
  - **Intersection of two lines:** Solve algebraically by substitution or elimination.
  - **Intersection of a line and a curve:** Use substitution to substitute the linear equation into the quadratic one, and solve for the variable(s).
  - **Intersection of two curves:** Set up both equations and solve the resulting system algebraically.
- **Discriminant and Number of Solutions** The number of intersection points between two equations, particularly when involving quadratics, can be analyzed by examining the discriminant:
  $$\Delta = b^2 - 4ac \tag{1.27}$$
  - If $\Delta > 0$, there are two real solution (two points of intersection).
  - If $\Delta = 0$, there is exactly one solution (one point of intersection).
  - If $\Delta < 0$, there are no real solutions (no intersection).

Graph Interpretation and Problem Solving

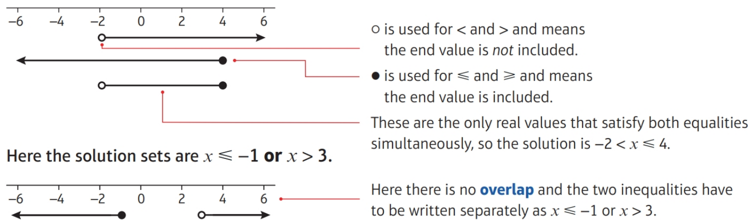
- **Graphing Linear Equations:** Plot lines carefully, check their slope and intercept, and identify intersection points by solving algebraically.
- **Graphing Quadratic Equations:** Understand the shape of the parabola (upward or downward) and its vertex.
- **Intersecting Curves:** When a linear equation intersects a quadratic, the point(s) of intersection provide the solution(s) to the system.

1.3.4 Linear Inequalities

- **Key Concept:** A linear inequality is similar to a linear equation, but instead of an equal sign, we have an inequality sign ($<$, $\leq$, $>$, $\geq$). The solution is the set of real numbers that satisfy the inequality.
- **Methods for Solving Linear Inequalities**
  - Rearrange the inequality to isolate the variable on one side.
  - Solve as would for an equation.
  - Check the direction of the inequality when multiplying or dividing by a negative number, as this reverses the inequality sign.
- **Set Notation (集合计数法) for Solutions**

  - For inequalities like $x \geq 2.75$, write in set notation as $\{x : x \geq 2.75\}$.
  - For compound inequalities (e.g., $x > -1$ and $x \leq 4$), write as $\{x : -1 < x \leq 4\}$.

- **Graphical Representation**



1.3.5 Quadratic Inequalities

- **Key Concept:** A quadratic inequality involves a quadratic expression (e.g., $ax^2 + bx + c$) and a comparison to zero. The solution set is determined by finding where the quadratic expression is positive or negative.

- **Steps to Solve Quadratic Inequalities**

  - Rearrange the inequality so that the quadratic expression is on one side and zero is on the other.
  - Solve the corresponding quadratic equation to find the critical values (i.e., where the quadratic expression equals zero).
  - Sketch the graph of the quadratic function and use the graph to determine the solution intervals.

- **Set Notation for Quadratic Inequalities**

  - If the quadratic expression is greater than zero (i.e., the curve is above the x-axis), the solution is the range of x-values where the curve lies above the x-axis. Example: $x < -3$ or $x > \frac{1}{2}$, written as $\{x : x < -3 \quad \text{or} \quad x > \frac{1}{2}\}$.
  - If the quadratic expression is less than zero (i.e., the curve is below the x-axis), the solution is the range of x-values where the curve lies below the x-axis. Example: $-3 < x < \frac{1}{2}$, written as $\{x : -3 < x < \frac{1}{2}\}$.

- **General Tips for Quadratic Inequalities**

  - **Critical Values:** These are the x-values where the quadratic expression equals zero. They are found by solving the corresponding quadratic equation.
  - **Sketching the Graph:** Determine the direction of the parabola (upward or downward) based on the leading coefficient a.
  - **Sign Analysis:** Use the sign of the quadratic expression in each interval defined by the critical values to determine where the inequality holds.

1.3.6 Inequalities on Graphs

- **Key Concept:** Inequalities on graphs can be interpreted by comparing the graphs of two functions. The inequality depends on which function lies above or below the other function.

- **Graph Interpretation for Inequalities**

1. For $y > f(x)$ or $y < f(x)$:
   * The region where $y > f(x)$ represents the area above the graph of $y = f(x)$.
   * The region where $y < f(x)$ represents the area below the graph of $y = f(x)$.
   * When the inequality involves $>$ or $<$, the graph of $y = f(x)$ is not included in the region, and the line is represented as a dotted line.
2. For $y \geq f(x)$ or $y \leq f(x)$: When the inequality involves $\geq$ or $\leq$, the graph of $y = f(x)$ is included in the region, and the line is represented as a solid line.

1.3.7 Regions

- **Key Concept:** Regions on a graph can be represent the solution to inequalities. We can identify regions where the solution to an inequality holds by testing specific points and shading the appropriate region on the graph.
- **Shading Region for Inequalities**
  1. Shading for $y > f(x)$:
     * The region where y is greater than $f(x)$ is above the graph of $f(x)$.
     * **Test Points:** Pick points in the region and check if they satisfy the inequality.
  2. Shading for $y < f(x)$:
     * The region where y is less than $f(x)$ is below the graph of $f(x)$.
- **Graphical Representation**
  - For linear inequalities, typically work with straight lines.
  - For quadratic inequalities, use curves, and the shaded region represents the area where the inequality holds true.

1.4 Graphs and Transformations

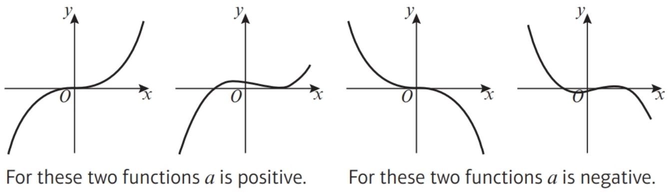
1.4.1 Cubic Graphs

- **Cubic Function General Form**

$$f(x) = ax^3 + bx^2 + cx + d \tag{1.28}$$

  Where:
  - a, b, c, and d are real numbers.
  - $a \neq 0$
- **Key Characteristics of Cubic Graphs**
  - **Shape of the Graph**
    * The shape of a cubic graph depends on the value of the coefficient a.
    * If $a > 0$, the graph tends to rise on the right and fall on the left (it has an ”S” shape).

    * If $a < 0$, the graph tends to fall on the right and rise on the left (it has an "N" shape).



  - **Root of the Cubic Function**
    * The points where the graph crosses the x-axis are the roots of the cubic function.
    * A cubic function can have:
      · **One real root**, where the graph crosses the x-axis once.
      · **Two real roots**, where the graph crosses the x-axis at two points.
      · **Three real roots**, where the graph crosses the x-axis at three points.
    * The multiplicity of a root indicates how many times it occurs:
      · **Single root:** The graph crosses the x-axis (i.e., $(x - p)$).
      · **Double root:** The graph touches the x-axis but does not cross it (i.e., $(x - p)^2$).
      · **Triple root:** The graph touches the x-axis and changes direction (i.e., $(x - p)^3$).

- **General Procedure for Sketching Cubic Graphs**

  1. **Find the roots:** Set $f(x) = 0$ and solve for x.
  2. **Determine the multiplicity of roots:** This tells you how the graph behaves at each root (cross or touch).
  3. **Find the y-intercept:** Set $x = 0$ and solve for y.
  4. **Check the end behavior:** Look at the sign of the leading coefficient a to determine whether the graph rises of falls at the end.
  5. **Sketch the graph:** Use the roots, y-intercept, and end behavior to sketch the cubic curve.

Chapter 2

Biology

2.1 Molecules, Transport, Health

2.1.1 Chemistry for Biologists

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.

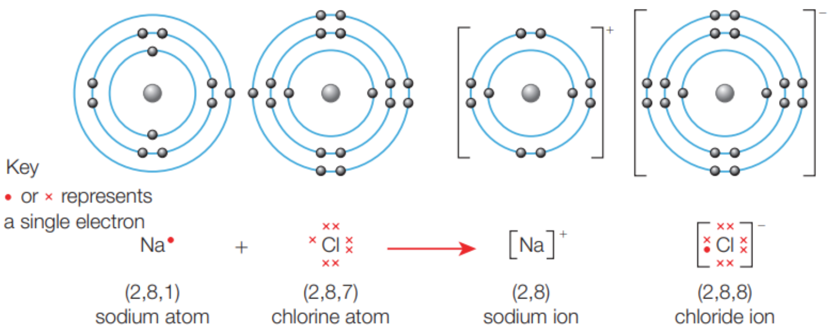


Figure 2.1: The formation of sodium chloride.

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).

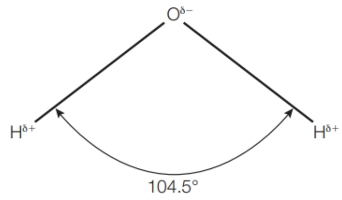


Figure 2.2: A model of a water molecule showing dipoles.

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

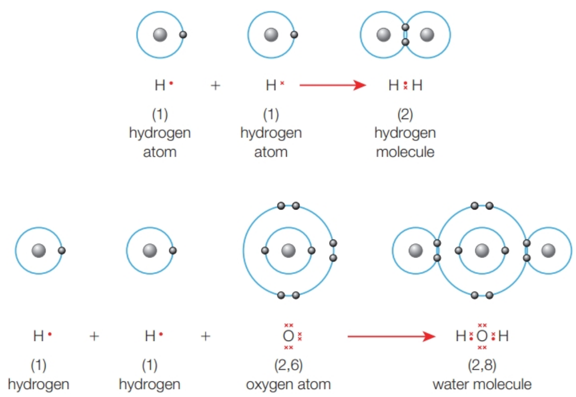


Figure 2.3: The formation of hydrogen molecules and water molecules are examples of covalent bonding.

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.

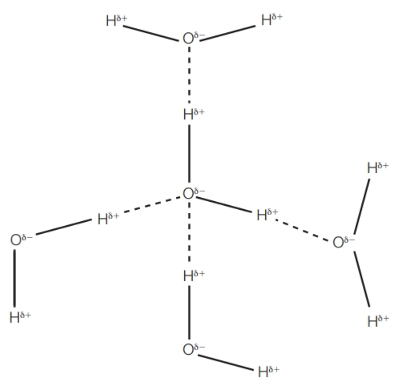


Figure 2.4: Hydrogen bonding in water molecules, based on attraction between positive and negative dipoles.

- **Unique Properties**

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

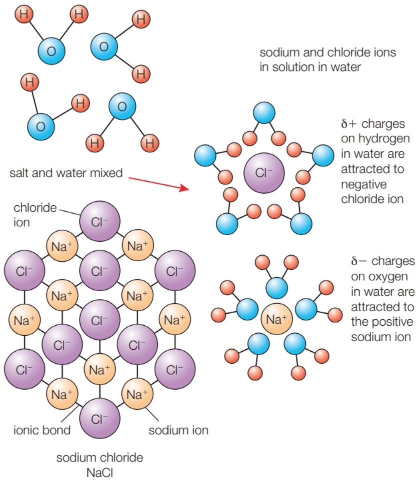


Figure 2.5: A model of sodium chloride dissolving in water as a result of the interactions between the charges on sodium and chloride ions and the dipoles of the water molecules.

  - 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.

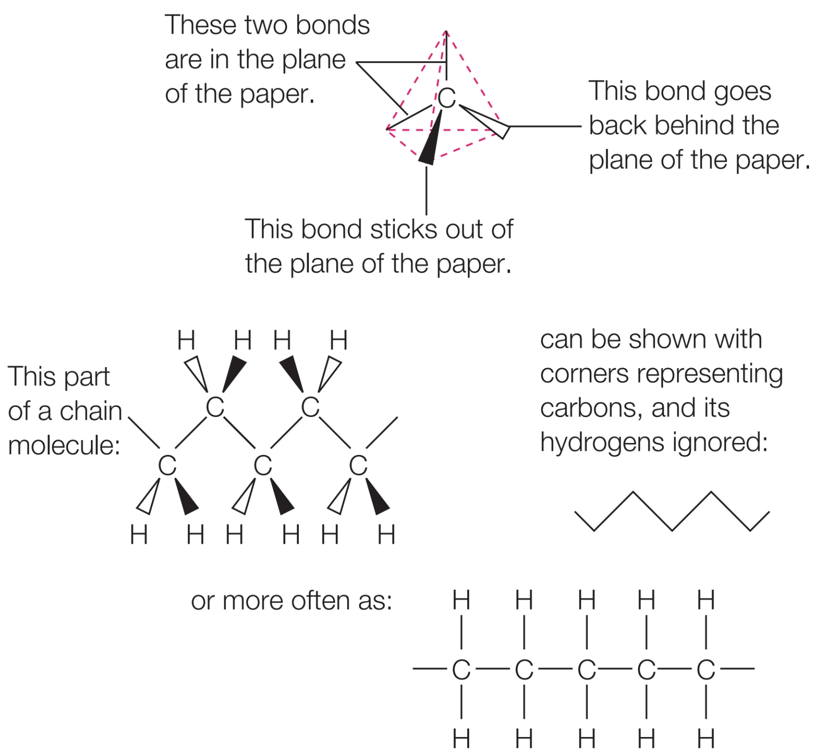

Figure 2.6: The bonds in a carbon atom have a complicated 3D shape. This is difficult to represent, so in most molecular diagrams we use one of several different ways to draw them.

- **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).

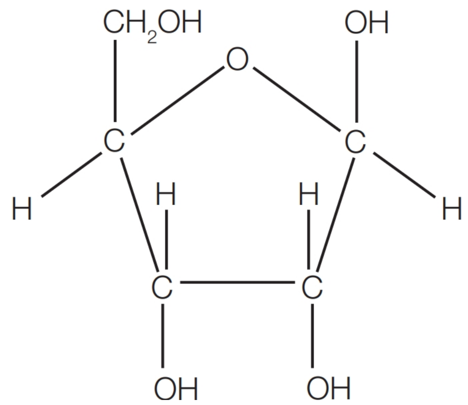

Figure 2.7: Pentose sugars such as ribose have 5 carbon atoms.

    * **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.

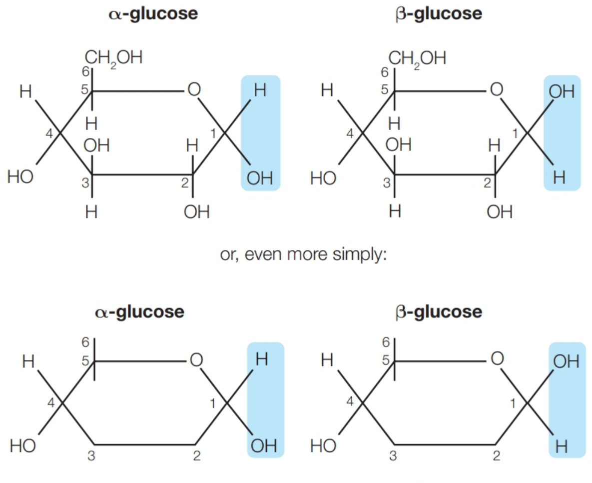

Figure 2.8: Hexose sugars have a ring structure. The arrangement of the atoms on the side chains can make a significant difference to the way in which the molecule can be used by the body. The carbon atoms are numbered in order to identify the different arrangements.

<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).

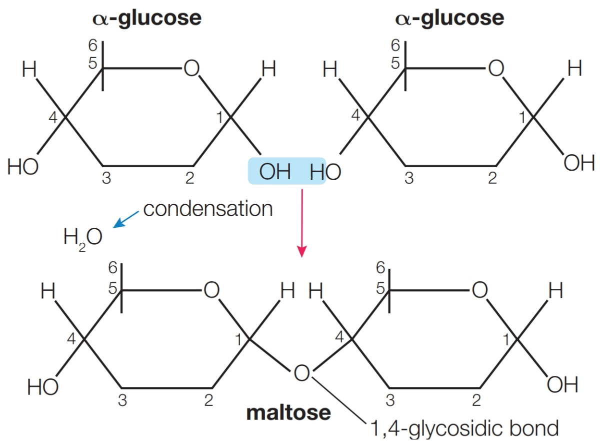

Figure 2.9: The formation of a glycosidic bond. The condensation reaction between two monosaccharides results in a disaccharide and a molecule of water.

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

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[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:

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

     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.

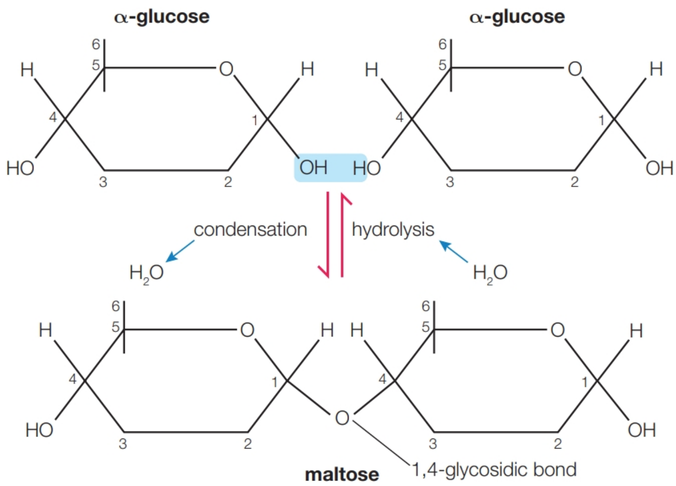


Figure 2.11: Glycosidic bonds are made by condensation reactions and broken down by hydrolysis.

    * **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.

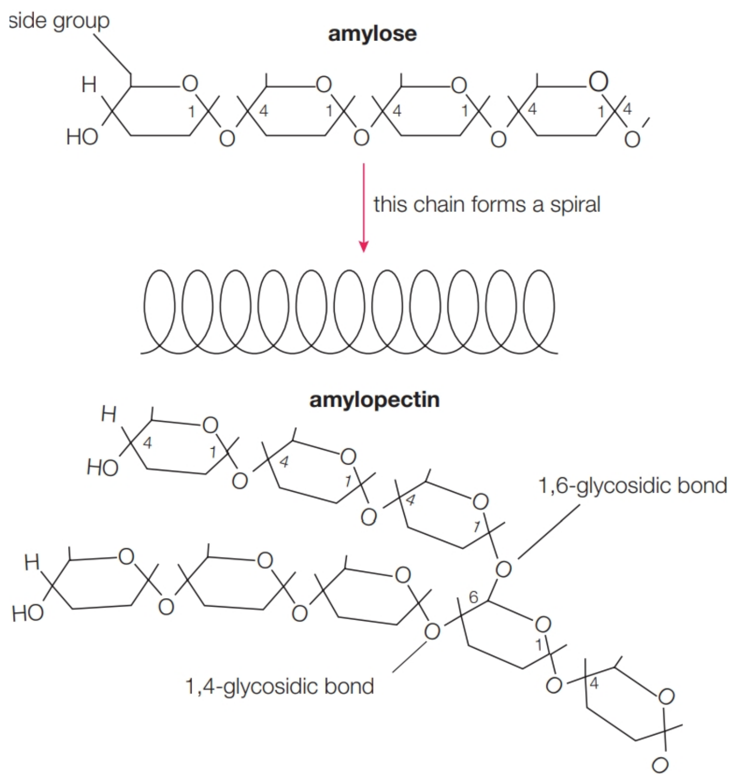


Figure 2.12: Amylose and amylopectin —a small difference in the position of the glycosidic bonds in the molecule makes a big difference to the properties of the compounds.

  - **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.

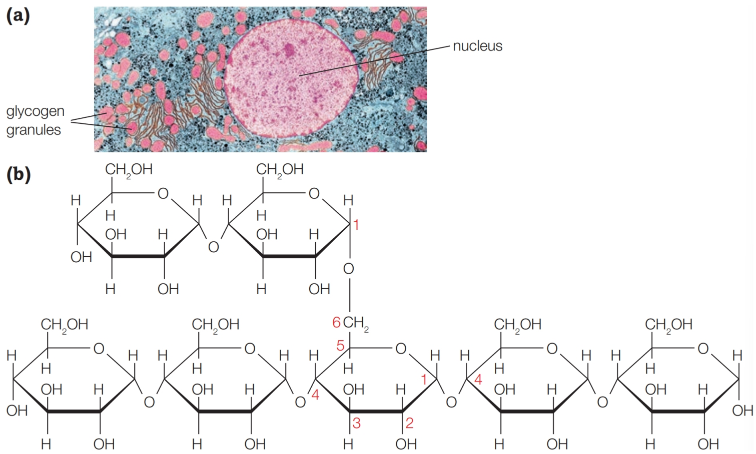


Figure 2.14: In **(a)** you can see liver cells full of small glycogen granules (微粒), stained (染色) pink in this micrograph (显微照片). If your blood glucose levels are low, this glycogen store in your liver can be broken down to provide the glucose you need for cellular respiration. In **(b)** you can see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

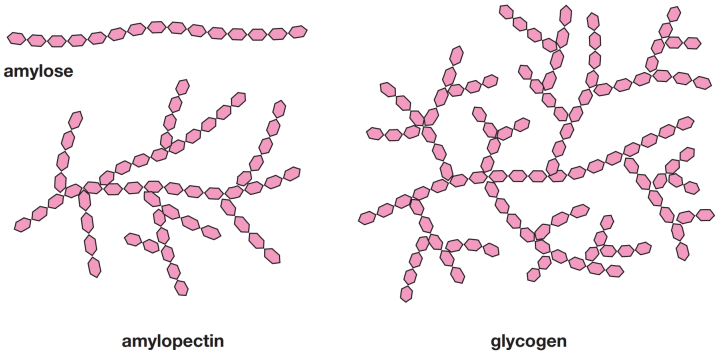


Figure 2.15: You can clearly see the many side branches which allow glycogen to be broken down so quickly when you compare amylose, amylopectin and glycogen.

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).

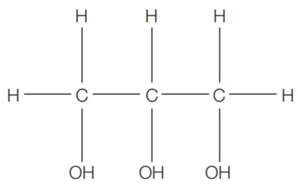


Figure 2.16: Displayed formula of glycerol (propane-1,2,3-triol).

  - 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).

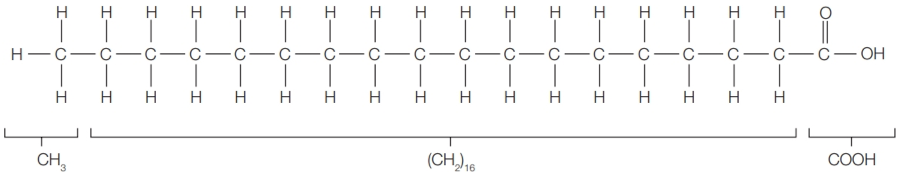


Figure 2.17: Displayed formula of stearic acid, a saturated fatty acid found in both plant and animal fats.

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).

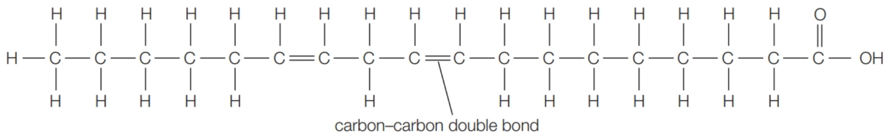


Figure 2.18: Displayed formula of linoleic acid, a polyunsaturated fatty acid.

- **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 ($-\mathrm{OH}$).
     * Fatty acids provide carboxyl groups ($-\mathrm{COOH}$).
  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:**

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

[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 ($-\mathrm{OH}$) of glycerol and the carboxyl group ($-\mathrm{COOH}$) 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.

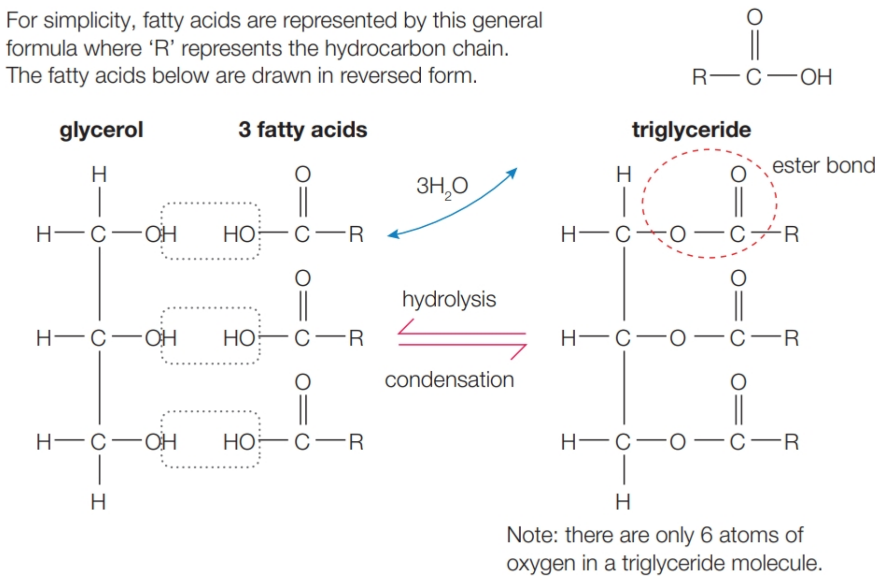


Figure 2.19: The formation of ester bonds.

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.

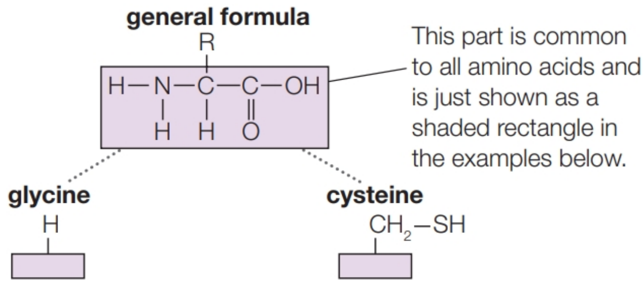


Figure 2.20: Some different amino acids. In the simplest amino acid, glycine (甘氨酸), R is a single hydrogen atom. In a larger amino acid such as cysteine (半胱氨酸), R is much more complex.

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.

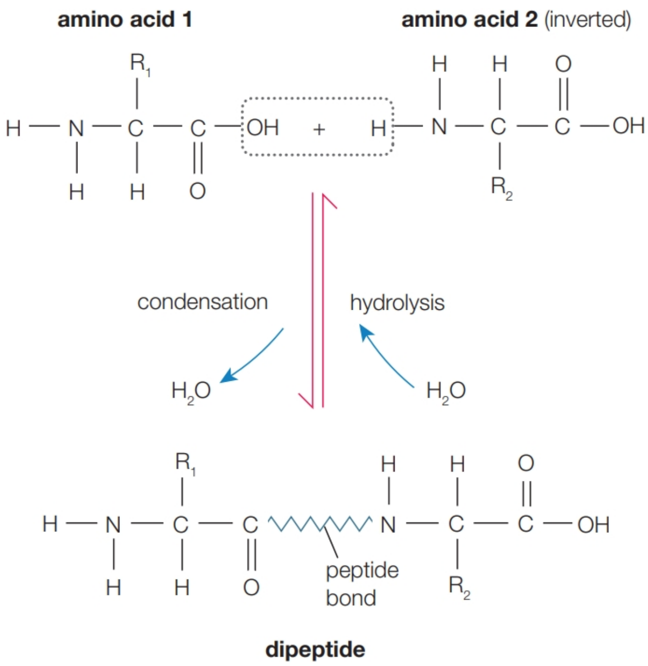


Figure 2.21: Amino acids are the building blocks of proteins, joined together by peptide bonds.

- 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.

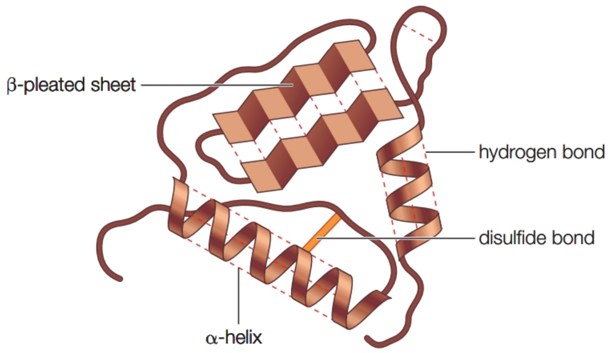


Figure 2.22: Hydrogen bonds and disulfide bonds maintain the shape of protein molecules and this determines their function.

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

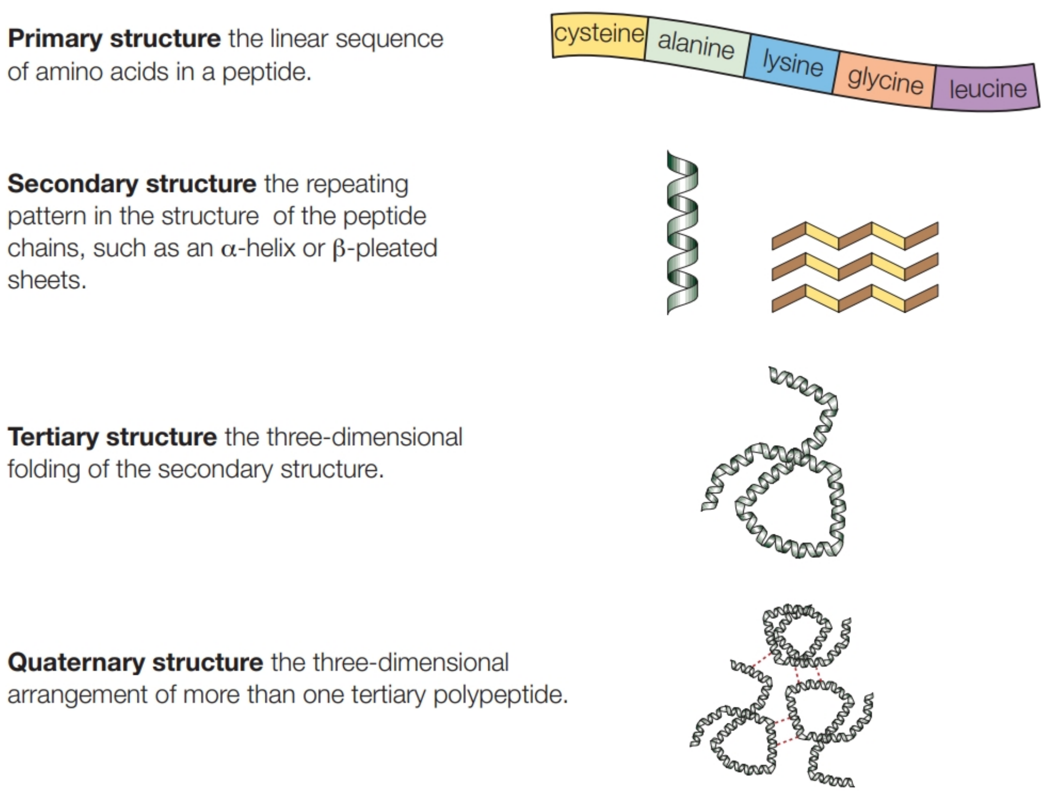


Figure 2.23: The 3D structure of proteins.

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.

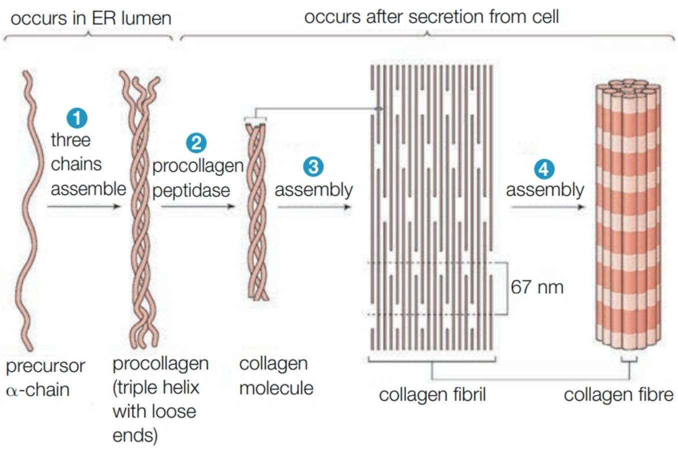


Figure 2.24: Collagen is a fibrous protein with an unusual triple helix structure and immense strength.

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

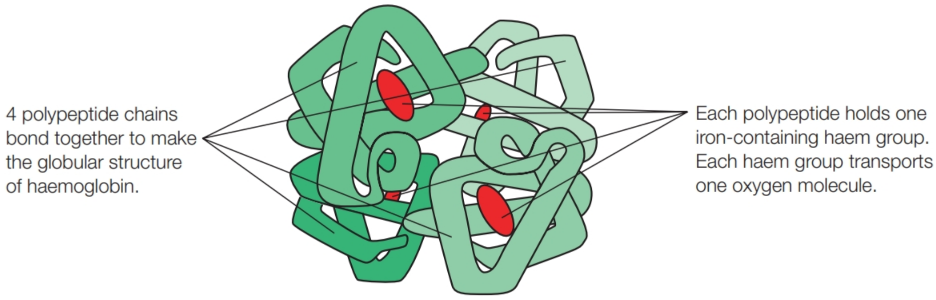


Figure 2.25: The complex quaternary structure of haemoglobin produces a globular protein containing four haem (血红素) groups which can carry oxygen to the tissues of the body.

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, mollusks (软体动物), and some invertebrates (无脊椎动物). Blood flows freely in the body cavity (hemocoel 血腔) and directly.
2. **Closed Circulatory System:** Found in vertebrates (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.

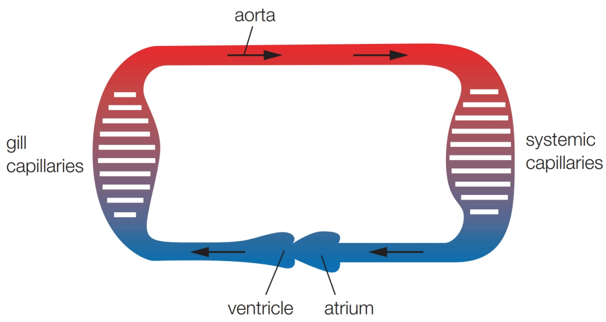


Figure 2.26: The single circulation of a fish.

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

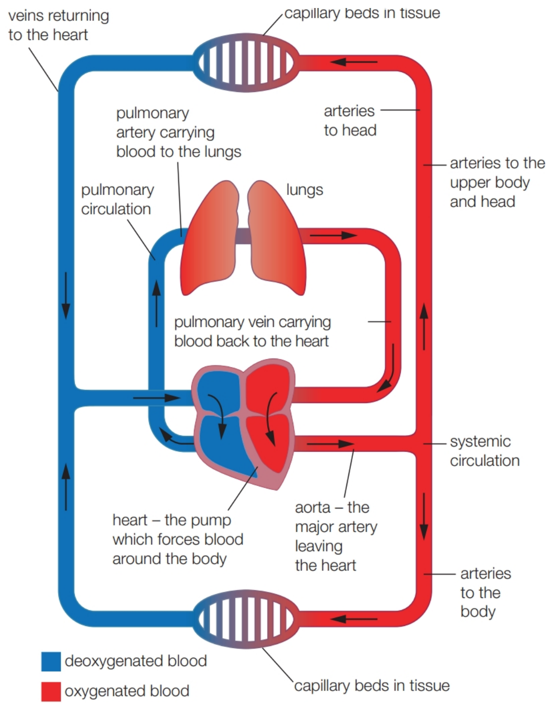


Figure 2.27: A double circulation sends blood at high pressure, carrying lots of oxygen, to the active cells of the body. Take note: this is a schematic diagram. In a real double circulation, all of the blood vessels enter and leave from the top of the heart.

- 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.

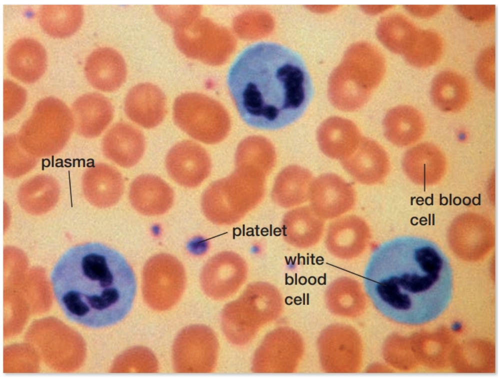


Figure 2.28: This light micrograph shows red blood cells, white blood cells and platelets.

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 $\sim$ 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.

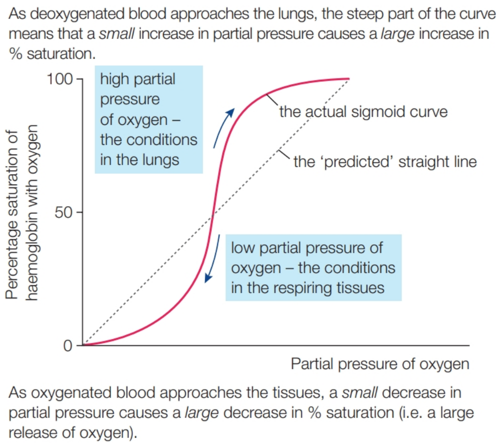


Figure 2.29: Oxygen dissociation curve for human haemoglobin.

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.

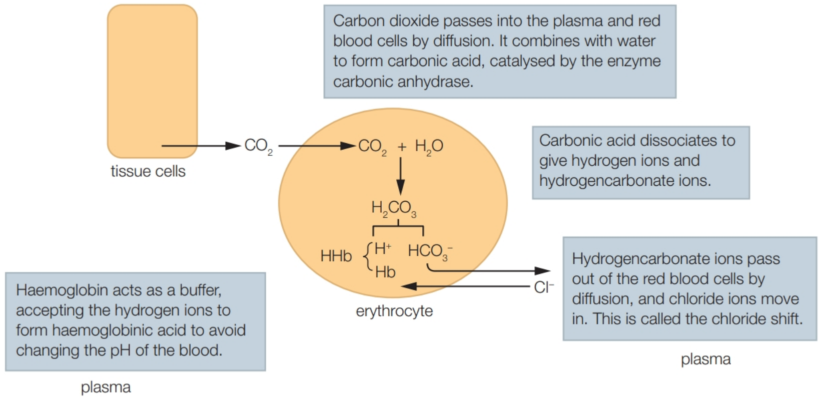


Figure 2.30: The transport of carbon dioxide from the tissues to the lungs depends on the reaction of carbon dioxide with water, controlled by an enzyme in the red blood cells.

<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.

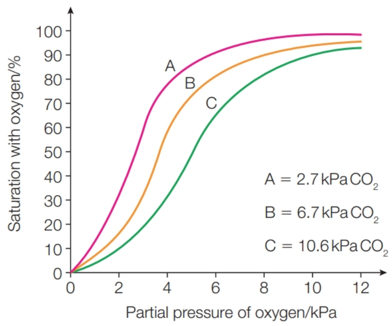


Figure 2.31: As the proportion of carbon dioxide in the environment rises, the haemoglobin curve moves down and to the right, so it gives up oxygen more easily. This is known as the Bohr effect.

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.

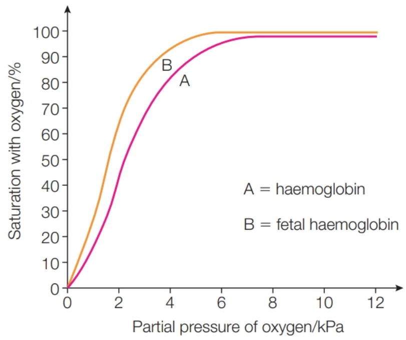
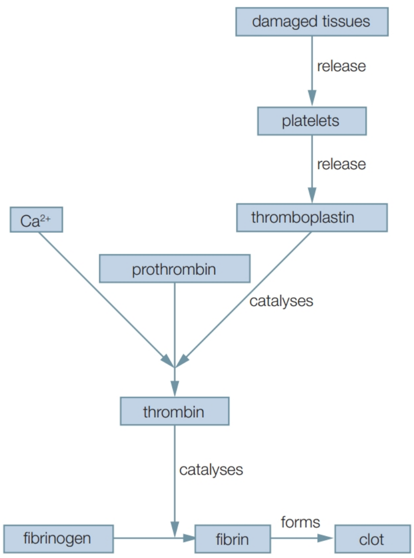


Figure 2.32: Fetal haemoglobin has a higher affi nity for oxygen than the adult haemoglobin of the mother, so it can take oxygen from the mother's blood and deliver it to the cells of the growing fetus.

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.



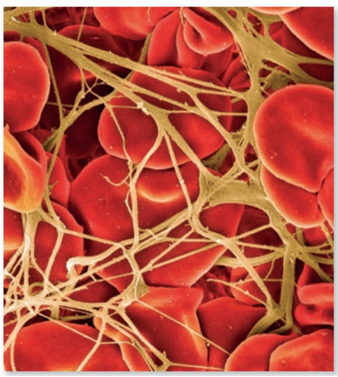


Figure 2.33: The cascade (大量) of events that results in a life-saving or life-threatening clot. When you cut yourself, this is the process which seals the blood vessels and protects the delicate new tissues that form underneath.

1B.3 Circulation in the Blood Vessels

Types of Blood Vessels

1. **Arteries (动脉)**

   - **Function:** Carry blood away from the heart (usually oxygenated (充满氧气的), except for pulmonary (肺部) and umbilical (脐带) arteries).
   - **Structure:**
     * Thick walls with elastic fibres (弹性纤维), smooth muscle (平滑肌), and collagen (胶原蛋白) to withstand (承受) high pressure.
     * Narrow lumen (管腔) to maintain high pressure.

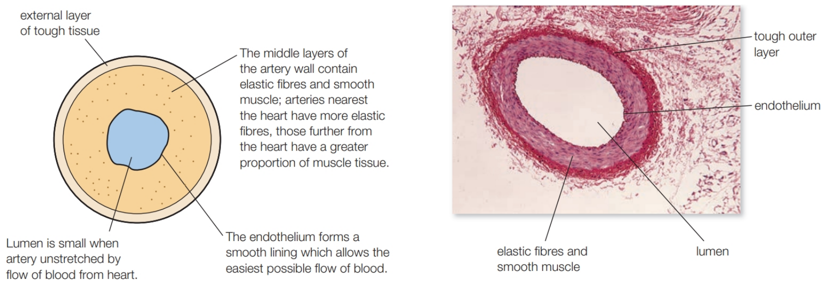


Figure 2.34: The structure of an artery means it is adapted to cope (处理) with the surging (涌动) of the blood as the heart pumps.

   - **Adaptations:**
     * Elastic recoil (弹性回缩) helps maintain blood flow during diastole (舒张期).
     * Arterioles (小动脉) regulate blood flow to tissues by adjusting (调整) lumen size.

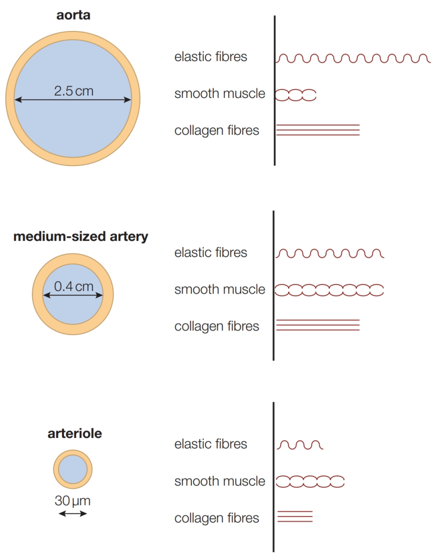


Figure 2.35: The relative proportions of different tissues in different arteries.Collagen gives general strength and flexibility to both arteries and veins.

2. **Capillaries** (毛细血管)

   - **Function:** Facilitate exchange of substances between blood and tissues.
   - **Structure:**
     * Very thin walls (one cell thick) for efficient diffusion (扩散).
     * Small lumen allows red blood cells to pass through single cell, increasing contact with the capillary walls (毛细血管壁).
   - **Adaptations:**
     * Large surface area for exchange.
     * Slow blood flow ensures more time for diffusion.

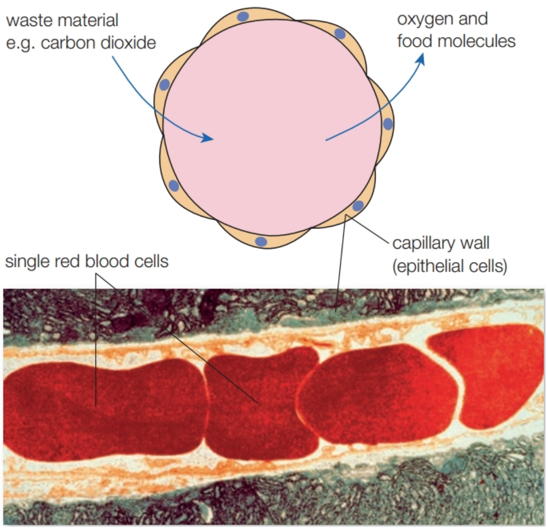


Figure 2.36: The relative proportions of different tissues in different arteries.Collagen gives general strength and flexibility to both arteries and veins.

3. **Veins** (静脉)

   - **Function:** Carry blood back to the heart (usually deoxygenated (缺氧的), except for pulmonary and umbilical veins).
   - **Structure:**
     * Thin walls with less elastic (弹性) and muscle tissue due to lower pressure.
     * Wide lumen to accommodate (容纳) large volume of blood.

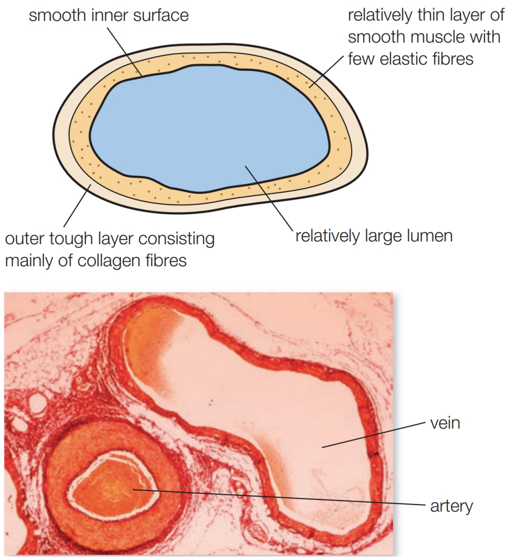


Figure 2.37: The arrangement of tissues in a vein reflects the pressure of blood in the vessel.

Key Adaptations of Blood Vessels

- **Arteries:**
  - High elasticity (弹性) for pressure surges (涌动) from the heart.
  - Smooth endothelium (内皮) reduces friction (摩擦) for efficient blood flow.

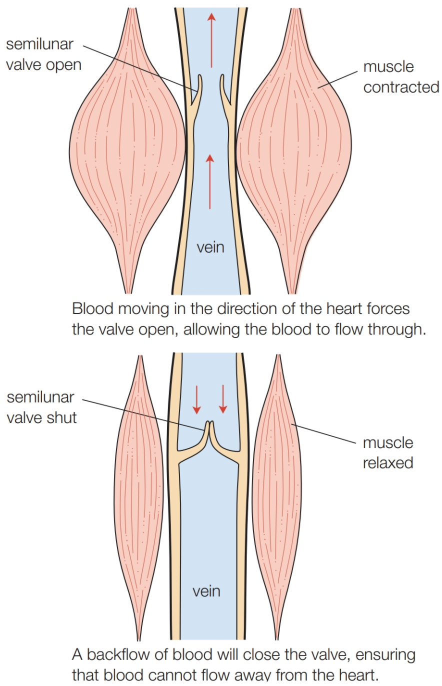


Figure 2.38: Valves in the veins make sure blood only flows in one direction - towards the heart. The contraction of large muscles encourages blood flow through the veins.

- **Capillaries:** Short diffusion distance for gas exchange.
- **Veins:**
  - Valves prevent backflow.
  - Act as a reservoir (储备) for blood (contain over 50% of body's blood).

Blood Flow Dynamics

- **Blood Pressure:** Highest in arteries, decreases in capillaries, and lowest in veins.
- **Velocity:** High in arteries, slows down in capillaries, and increases slightly in veins.
- **Surface Area:** Maximum in capillaries due to extensive branching.

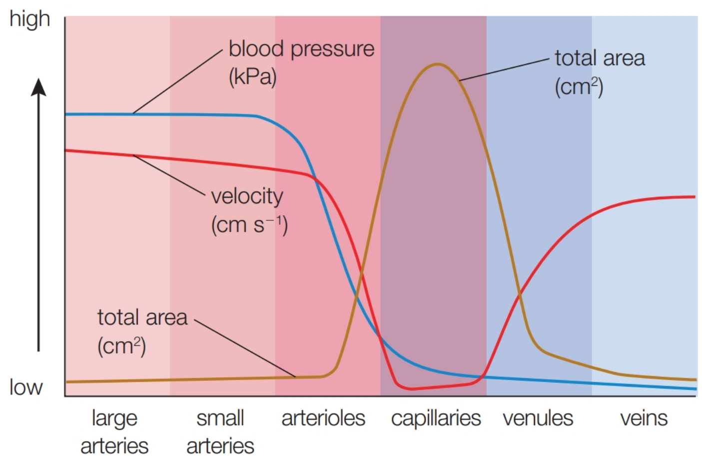


Figure 2.39: Graph to show the surface area of each major type of blood vessel in your body, along with the velocity and pressure of the blood travelling in them.

1B.4 The Mammalian Heart

Structure of the Heart

1. **General Description:**
   - The heart is a four-chambered organ (四腔器官) located in the thorax (胸腔).
   - Functions as a double pump to circulate oxygenated and deoxygenated blood.
   - Composed of cardiac muscle (心肌, specialized for continuous contraction without fatigue 疲倦).
2. **Chambers:**
   - **Right Atrium (右心房):** Recieves deoxygenated blood from the body via the vena cava (腔静脉).
   - **Right Ventricle (右心室):** Pumps deoxygenated blood to the lungs via the pulmonary artery (肺动脉).

- **Left Atrium** (**左心房**)**:** Recieves oxygenated blood from the lungs via the pulmonary vein (肺静脉).
- **Left Ventricle** (**左心室**)**:** Pumps oxygenated blood to the body via the aorta (主动脉). It has thicker walls than the right ventricle to withstand higher pressure.

3. **Key Structure:**
   - **Septum** (**隔膜**)**:** Thick muscular wall seperating the left and right sides of the heart.
   - **Valves** (**瓣膜**)**:** Prevent backflow of blood:
     * **Tricuspid Valve** (**三尖瓣**)**:** Between the right atrium and ventricle.
     * **Bicuspid (Mitral) Valve** (**二尖瓣**)**:** Between the left atrium and ventricle.
     * **Semilunar Valves** (**半月瓣**)**:** At the exit of the pulmonary artery and aorta.
   - **Tendineae Cords** (**腱索 Chordae Tendineae**)**:** Prevent valves from inverting under pressure.
4. **Coronary Circulation** (**冠状循环**)**:**
   - The heart muscle is supplied with oxygenand nutrients by the coronary arteries (冠状动脉).
   - Rich in myoglobin (肌红蛋白), a respiratory pigment (呼吸色素) with a higher oxygen affinity (亲和力) than hemoglobin.

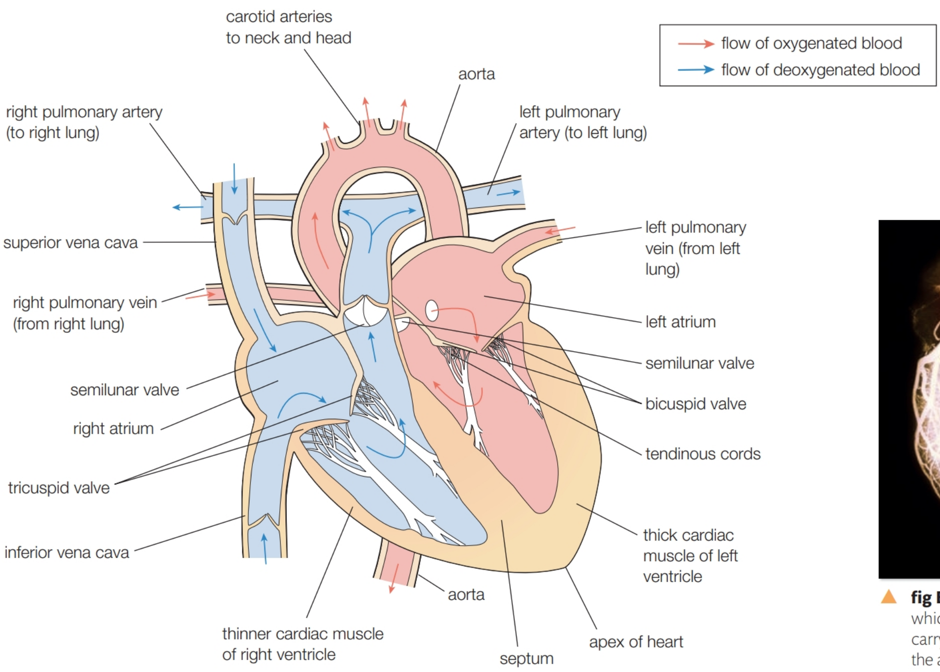


fig A The structure of the human heart

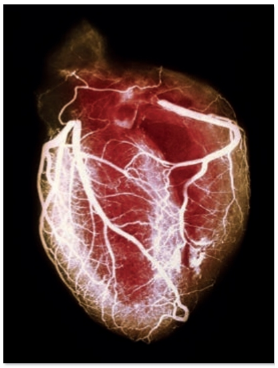


fig B The coronary arteries, which you can clearly see here, carry oxygenated blood from the aorta to the heart muscle, providing it with oxygen and digested food and removing carbon dioxide.

Action of the Heart

- **Blood Flow Sequence:**

1. **Deoxygenated Blood:**
   * Enters the right atrium via the vena cava (腔静脉).
   * Flows into the left ventricle through the tricuspid valve (三尖瓣).
   * Is pumped to the body through the aorta.
2. **Oxygenated Blood:**
   * Returns from the lungs to the left atrium via the pulmonary vein (肺静脉).
   * Flows into the left ventricle through the bicuspid valve (二尖瓣).
   * Is pumped to the body through the aorta.

- **Valve Function:**
  - Valves open and close due to pressure difference to ensure unidirectional flow (单向流动).
  - Semilunar valves prevent backflow from arteries to ventricles.
  - Atrioventricular valves (房室瓣) prevent backflow from ventricles to atria.
- **Pressure Adaptation:**
  - The left ventricle has a thicker muscular wall to pump blood at higher pressure to the systemic circuit (体循环).
  - The right ventricle pumps blood at lower pressure to the lungs to avoid damaging the delicate capillaries.

The Cardiac Cycle

- **Phases:**
  - **Atrial Systole (心房收缩):** Atria contract, forcing blood into the ventricles.
  - **Ventricular Systole (心室收缩):** Ventricles contract, pumping blood to the lungs and body.
  - **Diastole (舒张期):** Both atria and ventricles relax, allowing chambers to fill with blood.
- **Heartbeat Sounds:**
  - **'Lub' Sound (第一心音):** Closing of atrioventricular valves during ventricular systole.
  - **'Dub' Sound (第二心音):** Closing of semilunar valves during ventricular diastole.
- **Cycle Duration:** Each cardiac cycle lasts approximately 0.8 seconds in humans:
  - Atrial systole: 0.1 seconds.
  - Ventricular systole: 0.3 seconds.
  - Diastole: 0.4 seconds.

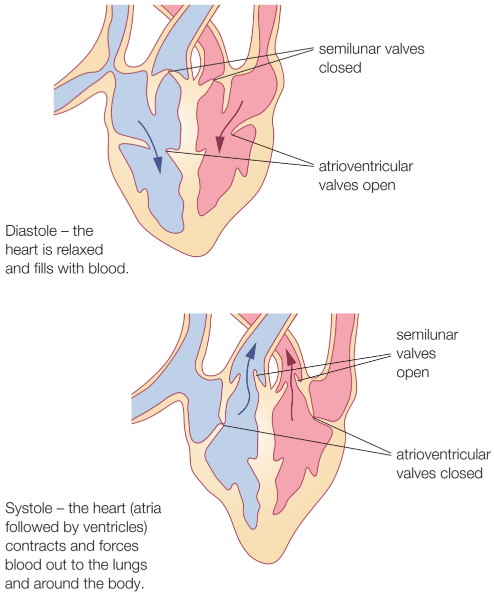


Figure 2.40: The cardiac cycle.

1B.5 Atherosclerosis

Overview

- Cardiovascular diseases (CVDs 心血管病) are the leading cause of death globally, responsible for 31% of all global deaths (according to WHO data, 2017).
- Many CVDs are associated with atherosclerosis (动脉粥样硬化), a condition where plaques (斑块) build up inside arteries.

Atherosclerosis

- **Definition:** A desease where plaques (fatty deposits) from in arteries, narrowing the lumen and reducing blood flow.
- **Development:**
  - **Step 1:** Damage to the endothelium (内皮 e.g., due to high blood pressure or smoking).
  - **Step 2:** Inflammatory response (炎症反应); white blood cells migrate to the area.
  - **Step 3:** Accumulation (积累) of cholesterol (胆固醇), forming a fatty deposit (atheroma 脂肪沉积).
  - **Step 4:** Calcium salts and fibrous tissue build up around the atheroma, forming a hardened plaque.
- **Effects:**
  - Narrowed arteries increase blood pressure.
  - Increased risk of blood clots (thrombosis 血栓形成) at the site of plaques.

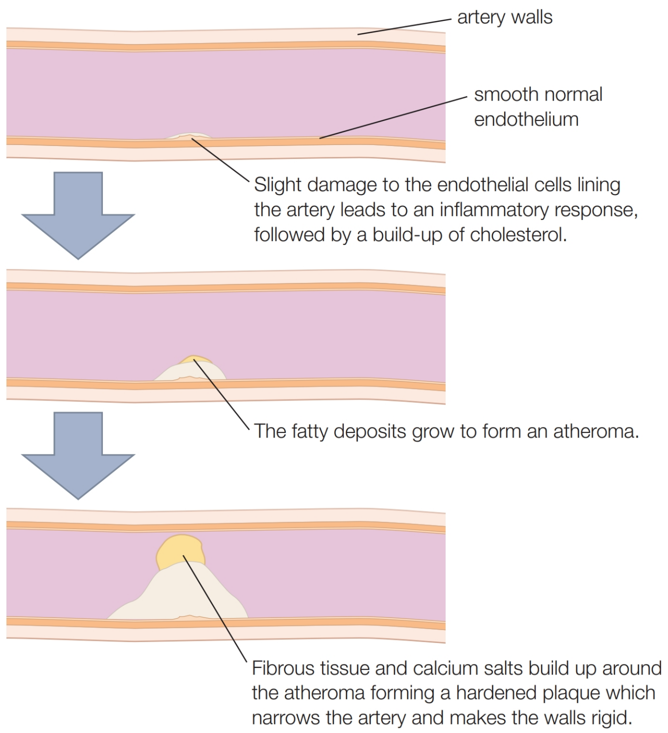


Figure 2.41: The development of atherosclerosis.

Health Impacts of Atherosclerosis

1. **Aneurysms (动脉瘤):**
   - Weakening of arterial walls due to plaque formation.
   - The artery may bulge (凸出) and rupture (破裂), causing internal bleeding.
   - Common in the aorta or brain arteries.
2. **Rised Blood Pressure (高血压):**
   - Narrowed arteries force the heart to pump harder.
   - High blood pressure damages organs like the kidneys (肾脏), eyes, and brain.
3. **Heart Diseases:**
   - **Angina (心绞痛):**
     * Reduced blood flow to the heart muscle due to narrowed coronary arteries (冠状动脉).
     * Symptoms include chest pain, especially during exercise.
   - **Myocardial Infarction (心肌梗死 Heart Attack):**
     * Complete blockage of a coronary artery.
     * Starves part of the heart muscle of oxygen, causing tissue death.
     * Severity depends on the location and extent (程度) of blockage.

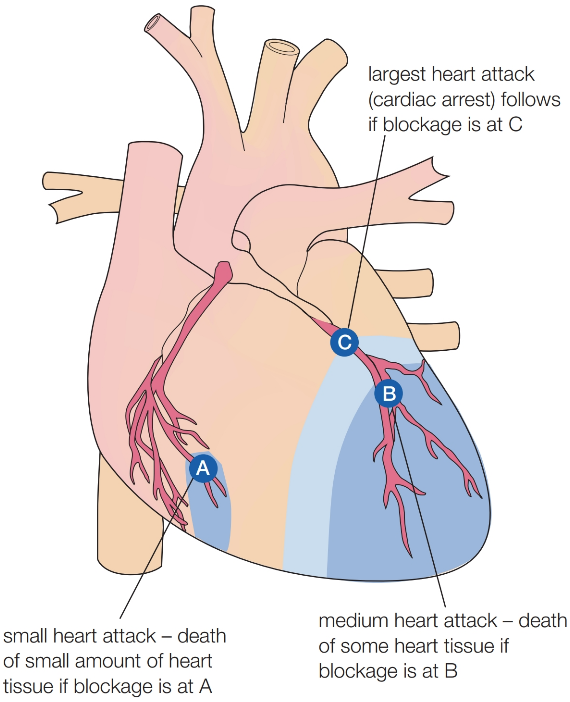


Figure 2.42: The size and severity of a heart attack is closely related to the position of the blockage in the coronary artery.

4. **Stroke** (中风):
   - Disruption of blood supply to the brain due to a clot or hemorrhage (出血).
   - Symptoms include dizziness (头晕), slurred speech (口齿不清), and paralysis (瘫痪).
   - Quick treatment with clot-busting drugs (溶栓药) increases survival chances.

Prevention and Treatment

- **Prevention:**
  - Regular exercise.
  - Healthy diet low in saturated fats.
  - Avoiding smoking and managing blood pressure.
- **Treatment:**
  - **Medication:** E.g., Statins (降脂药, lower cholesterol levels), antihypertensives (降压药).
  - **Surgery:** E.g., angioplasty (血管成形术) to widen arteries, bypass surgery (搭桥手术), stent insertion (支架植入).

2.1.3 Cardiovascular Health and Rick

1C.1 Risk, Correlation, and Cause

What is Risk?

- **Definition:**
  - Risk is the probability of an event occurring.
  - Example: The probability of picking a blue ball from a bag of six colored balls is 1 in 6, 0.1666, or 16.7%.
- **How Risk is Rerceived:**
  - Perception is influenced by:
    * Familiarity with the activity.
    * Enjoyment of the activity.
    * Approval or disapproval of the activity.
  - Actual mathematical risk may differ from personal perception.
  - Example: Risk of dying in a car accident is 1 in 5747, but many people fear flying more than driving.

Epidemiology (流行病学) and Risk Factors

- **Epidemiology:**
  - The study of disease patterns and their causes in populations.
  - Identifies risk factors that increase the likelihood of disease.
- **Risk Factors:**
  - Factors that increase the probability of developing a diesase (e.g., smoking, obesity, and lack of exercise).
  - Diseases like atherosclerosis are termed multifactorial disease as they result from multiple interacting factors.
- **Correlation vs. Causation:**
  - **Correlation (相关性):** Two sets of data change together but do not imply cause and effect.
  - **Causation (因果关系):** A direct cause-effect relationship is established.

Obesity and Cardiovascular Disease

- **Impact of Obesity:** Increased risk of diabetes and cardiovascular disease.
- **Why People Stay Obese:**
  - Overestimation of benefits or underestimation of risks of unhealthy behaviors.
  - Enjoyment of certain activities or foods.
  - Lack of motivation or understanding of the risks.

1C.2 Investigating the Causes of CVDs

Designing Studies

- **Purpose:**
  - Investigate one factor or variable while controlling others.
  - Larger sample sizes yield more statistically significant results.
- **Longitudinal Studies:** Follow the same group of individuals over many years to observe long-term patterns.
- **Meta-Analysis:** Combines results from multiple studies for more reliable data.

Designing and Evaluating Studies

- **Key Criteria:**
  - **Valid:** The study answers the questions it sets out to address.
  - **Precise:** Measurements are consistent and have little variation.
  - **Reliable:** Results can be reproduced by other scientists.
- **Factors Affecting Reliability:**
  - Who funded the study?
  - Were measurements biased or affected by external interests?
- **Importance:** Evaluation ensures practical applications in health and research are based on robust (坚固的) evidence.

Risk Factors for Cardiovascular Diseases (CVDs) Non-Modifiable Risk Factors:

- **Genetics:**
  - Inherited tendency (遗传趋势) for heart disease.
  - Example: Twin studies show a higher likelihood of heart disease in identical twins than fraternal (兄弟的) twins.
- **Age:** Older individuals have reduced elasticity (弹性) in arteries, leading to higher CVD risk.
- **Gender:**
  - Men are more likely to develop CVDs than pre-menopausal women (绝经前妇女).
  - Oestrogen (雌性激素) in women reduces plaque build-up, offering some protection before menopause (绝经期).

1C.3 Risk Factors for Cardiovascular Disease

Cardiovascular Disease Overview

- **Definition:** Diseases affecting the heart and blood vessels.
- **Global Impact:**
  - Account for 31% of global deaths (WHO data, 2017).
  - Significant causes include atherosclerosis.

Atherosclerosis

- **Process:**
  - Damage to endothelium (内皮细胞) due to high pressure or smoking.
  - Inflammatory (炎症性的) response → Cholesterol accumulates forming an atheroma.
  - Atheromas harden into plaques causing artery narrowing and reduced elasticity (弹性).
- **Effects:**
  - Increased blood pressure.
  - Risks of aneurysms (颅内动脉瘤), angina (心绞痛), myocardial infarction (心肌梗死), and stroke.

Heart Disease

- **Angina:**
  - Chest pain from restricted blood flow to the heart.
  - Triggered by anaerobic respiration [12] (无氧呼吸) in cardiac muscles (心肌).
- **Myocardial Infarction (Heart Attack):**
  - Complete blockage of coronary arteries (冠状动脉) → Heart muscle is oxygen-deprived (氧气供应不足).
  - Severe cases lead to cardiac arrest (心脏骤停) and death.

Stroke

- **Cause:** Interruption of blood supply to the brain (clot or rupture 破裂).
- **Symptoms:** Dizziness, speech issues, numbness (麻木) on one side.
- **Survival:** Quick medical intervention significantly increases recovery chances.

[12] **Anaerobic Respiration** Anaerobic respiration is the breakdown of glucose without oxygen to release energy. It occurs in the cytoplasm (细胞质) of cells and produces less ATP compared to aerobic respiration. **Process:**

* **In Animals:**
  · Glucose → Lactic Acid (乳酸) + Energy (ATP).
  · Reaction Formula:
  $$C_6H_{12}O_6 \longrightarrow 2\,C_3H_6O_3 + \text{ATP} \tag{2.5}$$
  · Key Point: Lactic acid builds up and can cause muscle fatigue (劳累) during strenuous (费力的) activities.
* **In Plants and Yeast (酵母):**
  · Glucose → Ethanol (乙醇) + Carbon Dioxide + Energy (ATP).
  · Reaction Formula:
  $$C_6H_{12}O_6 \longrightarrow 2\,C_2H_5OH + 2\,CO_2 + \text{ATP} \tag{2.6}$$
  · Key Point: Ethanol is produced and used in the production of alcoholic beverages.

Risk Factors

- **Non-Modifiable Risk Factors:**
  - **Age:** Increased risk as blood vessels lose elasticity.
  - **Gender:**
    * Males at higher risk.
    * Females post-menopause are at increased risk due to reduced oestrogen (雌性激素) levels.
  - **Genetics:** Family history of CVD or inheritable artery weakness.
- **Modifiable Risk Factors:**
  - **Smoking:**
    * Increases plaque formation.
    * Damages endothelium (内皮细胞) and narrows arteries.
  - **Inactivity:**
    * Increases risk of obesity, hypertension, and diabetes.
    * Exercise lowers lipoprotein (脂蛋白) levels, cholesterol, and stress.
  - **High Blood Pressure (Hypertension):**
    * Blood pressure consistently above 140/90 mmHg.
    * Leads to plaque build-up and artery narrowing.
  - **Diet:**
    * High saturated fats and sugar increase risk of atherosclerosis.
    * Balanced diet with fruits, vegetables, and exercise recommended.

Prevention of CVDs

- **Lifestyle Changes:**
  - Regular exercise and healthy diet.
  - Quit smoking.
- **Monitoring:**
  - Blood pressure monitoring.
  - Control diabetes and obesity.
- **Epidemiological (流行病学的) Evidence:** Studies demonstrate the impact of modifiable risk factors on reducing CVD.

1C.4 Diet and Cardiovascular Health

Weight Issues and CVD Risk

- **Obesity and CVDs:** Obesity, often caused by consuming more food than the body needs, increases the risk of cardiovascular diseases (CVDs) due to the accumulation (积累) of excess (过量的) fat.
- **BMI and Obesity:** The Body Mass Index (BMI) is commonly used to measure obesity. It is calculated as the following equation.

$$\text{BMI} = \frac{\text{Weight (kg)}}{\text{Height}^2(\text{m}^2)} \tag{2.7}$$

Measuring Healthy Weight

- **BMI Classification for Adults:**
  - Underweight: BMI $< 18.5\text{kg/m}^2$
  - Ideal weight: $18.5 \leq$ BMI $< 25\text{kg/m}^2$
  - Overweight: $25 \leq$ BMI $< 30\text{kg/m}^2$
  - Obese: BMI $\geq 30\text{kg/m}^2$
  - Severely obese: BMI $\geq 40\text{kg/m}^2$
- **Waist-to-Hip Ratio (WHR 腰臀比):**
  - **Waist size:** measured at the navel (肚脐) level.
  - **Hip size:** measured at the widest part of the hips.
  - **Indicator of Obesity:**
    * **Male:** WHR > 0.9 indicates obesity.
    * **Female:** WHR > 0.85 indicates obesity.
  - A high WHR indicates a higher risk of CVDs.

BMI Limitations in Predicting CVD Risk

- **Muscle vs. Fat:** BMI doesn't account for muscle mass. Athletes or muscular individuals might be classified as overweight or obese even if they are healthy.
- **Genetic Variation:** People metabolize fats differently, and some can maintain a healthy balance of LDLs (Low-Density Lipoproteins 低密度脂蛋白) and HDLs (High-Density Lipoproteins 高密度脂蛋白) despite higher body fat.

Cholesterol (胆固醇) and CVD Risk

- **LDL (Low-Density Lipoproteins):** Carry cholesterol from the liver to the cells. High LDL levels lead to plaque buildup in arteries, increasing the risk of CVD.
- **HDL (High-Density Lipoproteins):** Transport cholesterol from cells to the liver for disposal. Higher HDL levels reduce CVD risk.
- **Ideal LDL:HDL Ratio:** Around 3:1 (LDL:HDL).

Diet, Fat, and CVDs

- **Saturated Fats:** Linked to high cholesterol levels and increased risk of CVDs. Countries with high saturated fat intake (from animal fats) have higher heart disease rates.
- **Correlation between Fat Intake and CVDs:** Diets high in animal fats (mainly saturated fats) are associated with an increase in CVDs.

1C.5 Dietary Antioxidants and Cardiovascular Disease

Antioxidants (防老化) and Heart Health

- **Antioxidants:** Compounds found in fruits and vegetables that may reduce oxidative stress, which can contribute to CVDs.
- **Fruit and Vegetables:** Eating 5 or more portions of fruits and vegetables per day is linked to a lower risk of coronary heart disease (CVD), as seen in data from a longitudinal study.
- **Vitamin C:** An antioxidant known for its role in connective tissue and blood vessel health. It helps protect against damage in the arteries. A deficiency in vitamin C can lead to a higher risk of heart disease, as the body's blood vessels are more prone to damage.

Conflicting Evidence in Antioxidant Research

- Early studies suggested antioxidants like vitamin C could prevent heart disease.
- **Conflicting Evidence:** A major study in 2016 concluded that there was no clear relationship between vitamin C intake and heart health. It even showed that taking vitamin C supplements might damage heart health.

Testing for Vitamin C

- A simple laboratory test can be used to measure vitamin C in foods. The test uses a reagent called DCPIP (2,6-Dichlorophenolindophenol 二氯酚靛酚, $C_{12}H_7Cl_2NO_2$), which turns colorless when it reacts with vitamin C.
- The volume of DCPIP used indicates the concentration of vitamin C in the sample.
- **Application:** The test can be used to compare the vitamin C content in different foods

1C.6 Using the Evidence

Prevention is Better Than Cure

- CVDs cost individuals, families, and society a lot in terms of healthcare and lost productivity.
- Prevention is more cost-effective than treatment. Healthy habits can prevent the need for expensive medical interventions (干预).

Overweight or Underweight

- Being overweight or underweight both increase the risk of CVDs.
- Regular physical activity helps protect against CVDs by improving cardiovascular fitness. The more oxygen used during exercise, the lower the CVD risk.

Smoking and CVD Risk

- Smoking is one of the leading risk factors for CVD. Smokers are at a higher risk of developing heart disease. Research shows that people who quit smoking after 1 year see a significant reduction in their heart disease risk.
- **Global Smoking Statistics:** In the UAE, 21.9% of people are smokers, with higher rates among men (24.8%) than women (4.2%).

Obesity and CVDs

- Obesity is linked to a higher risk of developing CVDs due to increased fat storage, which can lead to health complications (并发症) like hypertension (高血压) and poor blood circulation (血液循环不良).
- **Diet and Exercise:** Eating a balanced diet and exercising regularly can help maintain a healthy weight and reduce the risk of obesity and related heart diseases.

Salt and CVDs In many developed countries, excessive salt intake is linked to high blood pressure and CVDs. Reducing salt intake globally could lower blood pressure and the incidence of CVDs.

Lifestyle Choices and Perception of Risk

- **Risk Perception:** People often miscalculate the risks of smoking, high-fat diets, and lack of exercise. Immediate rewards (e.g., pleasure from eating high-fat food) may be prioritized over long-term health risks.
- **Psychological Factors:** The habit of smoking or eating unhealthy food may be hard to break, even if people know the risks.

Global Public Health Efforts Governments and health organizations spend billions on campaigns to reduce smoking and promote healthy diets. However, some argue this spending might be a waste if individuals don't change their behavior.

1C.7 The Benefits and Risks of Treatment

Controlling Blood Pressure (Antihypertensives 降压药)

- Hypertension (high blood pressure) is a major risk factor for CVDs.
- Antihypertensive drugs help lower blood pressure and prevent complications.

Types of Antihypertensive Drugs

1. **Diuretics (利尿剂):** Increase urine output, removing excess fluids and salts, reducing blood volume and lowering blood pressure.
2. **Beta-blockers (β-受体阻滞剂):** Reduce the effects of adrenaline (肾上腺素), slowing the heart rate and making contractions less forceful.
3. **Symphathetic Nervous Inhibitors (交感神经系统抑制剂):** Prevent nerve signals that cause arteries to constrict (收缩), keeping arteries relaxed.
4. **ACE Inhibitors (ACE 抑制剂):** Block the production of angiotensin (a hormone that constricts blood vessels 血管紧张素), keeping blood pressure low.

Risks of Antihypertensive Drugs

- If not monitored properly, blood pressure may drop too low, causing falls, dizziness, and fainting (晕厥).
- **Side Effects (副作用):** Swelling (肿胀), tiredness, fatigue, constipation (便秘).
- **Compliance Issue (服从性问题):** Patients may stop taking medication due to side effects, ignoring the greater but invisible risk of CVDs.

Statins (Cholesterol-Lowering Drugs 他汀类药物 / 降胆固醇药物)

- Statins reduce blood cholesterol levels, particularly LDLs (bad cholesterol), while increasing HDLs (good cholesterol).
- **Function**
  - Block the enzyme in the liver responsible for cholesterol production.
  - Reduce inflammation (发炎) in the arteries, preventing plaque buildup.
- **Effectiveness**
  - Statins significantly reduce the risk of CVDs across different groups (e.g., smokers, diabetics, elderly).
  - Greatest effect seen in diabetics and smokers.
- **Risks**
  - Common side effects: Muscle/joint aches, nausea (恶心), constipation (便秘), and diarrhea (腹泻).
  - Rare but serious risks:
    * Muscle inflammation (can be fatal).
    * Liver damage (very rare but possible).
- **Long-Term Effects (UK Study)**
  - Over 5 years, statin users had a lower risk of heart attacks and death.
  - Protection lasted up to 10 years after stopping the drug.

Plant Stanols (植物甾烷醇 / 植物固醇) and Sterols

- Found in spreads and yoghurts, similar in structure to cholesterol.
- Reduce LDL absorption in the blood, lowering heart disease risk by 25%.
- Not as rigorously tested as statins, but still beneficial in a healthy diet.

Anticoagulants (抗凝血药) and Platelet Inhibitors (Preventing Blood Clots)

- Used after surgery or for people at risk of blood clots (thrombosis 血栓形成).
- Prevent blood clotting too easily, reducing heart attack and stroke risk.
- **Types**
  - Anticoagulants (抗凝血药, e.g., Warfarin (华法林))

    * Interferes with prothrombin (凝血酶原 / 凝血素) production, preventing clot formation.
    * **Risk:** If not monitored, internal bleeding can occur.
  - Platelet Inhibitory Drugs (血小板抑制剂, e.g., Aspirin (阿司匹林), Clopidogrel (氯吡格雷))
    * Prevent platelets from sticking together, reducing clot risk.
    * **Risk:** Can cause stomach irritation (刺激) and bleeding.

- **Balancing Risks and Benefits**
  - Combination of aspirin + clopidogrel can reduce CVD risk by 20-25%.
  - However, it increases the risk of serious bleeding.
    * **In high-risk patients:** 5 cardiovascular events avoided per 1000 treated, but 3 major bleeds occur.
    * **In low-risk patients:** 23 cardiovascular events avoided, but 10 major bleeds occur.

2.2 Membranes, Proteins, DNA, Gene Expression

2.2.1 Membranes and Transport

2A.1 Cell Membranes

Cell Membranes and Their Functions

- **Cell Membrane:** Forms the outer boundary of a cell, controlling what enters and exits.
- **Membranes in Cells:** Found around organelles [13] (细胞器) like the nucleus and mitochondria (线粒体).
- **Functions of Cell Membranes**
  - Act as barriers, maintaining different conditions inside and outside the cell.
  - Hold enzymes for reactions (e.g., respiration in mitochondria).
  - Allow vesicles (囊泡) to transport and secrete substances.

The Structure of Membranes

- Composed of phospholipids (磷脂) and proteins arranged in a specific way.
- **Phospholipid Bilayer (磷酸双分子层)**
  - **Phospholipid Molecule:**
    * **Hydrophilic head (亲水头):** Attracted to water, faces outwards.
    * **Hydrophobic tail (疏水尾):** Repelled by water, faces inwards.

[13] **Organelle:** An organelle is a specialized structure within a cell that performs a specific function. Examples include the nucleus (with contains genetic material), mitochondria (which produce energy), and the endoplasmic reticulum (内质网, which hepls in protein and lipid synthesis). Organelles are often surrounded by membranes to compartmentalize (划分) their functions within the cell.

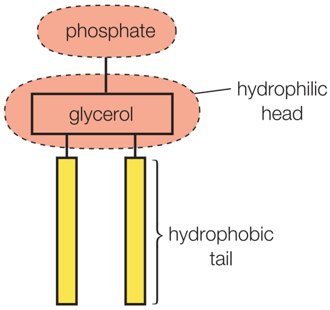


Figure 2.43: A phospholipid molecule.

- In water, phospholipids self-assemble:
  * **Monolayer (单分子层):** At air / water interface.
  * **Bilayer (双分子层):** Hydrophilic heads outward, hydrophobic tails inward.
  * **Micelle (胶束):** Spherical structure in water.

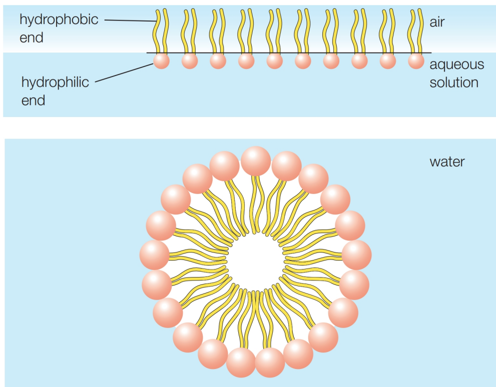


Figure 2.44: Phospholipids form a monolayer at an air / water junction and a micelle when water surrounds them.

- **Properties of the Bilayer**
  - Acts as a barrier to most molecules.
  - Allows fat-soluble molecules to pass but not ions.
  - More fluid with unsaturated fatty acids.
  - Cholestrol makes the membrane stronger and less permeable (渗透性).

The Fluid Mosaic Model (流动镶嵌模型)

- Proposed by S. J. Singer and G. Nicolson in 1972.
- Membrane is dynamic, not rigid.
- Proteins float inthe lipid bilayer.
  - Integral proteins (整合蛋白) span the membrane.
  - Peripheral proteins (外周蛋白) are attached to the surface.
  - Glycoproteins (糖蛋白) help in cell recognition.

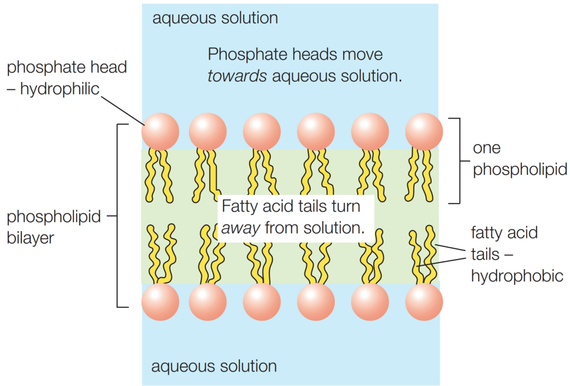


Figure 2.45: Phospholipids form a monolayer at an air / water junction and a micelle when water surrounds them.

- **Functions of Membrane Proteins**
  - **Transport:** Gated channels allow specific molecules through.
  - **Receptors (受体):** Detect hormones / signals.
  - **Enzymes:** Speed up reactions.
  - **Glycoproteins:** Involved in cell recognition.

Scientific Models of Membranes

- Early experiments showed membranes contained lipids.
- 1935: Davson-Danielli Model (达夫森-丹尼利模型) - Membrane had a lipid core with a protein layer.
- 1950s: Electron Microscopy (电子显微镜) confirmed a bilayer.
- 1972: Fluid Mosaic Model (流动镶嵌模型) replaced older models after further studies.

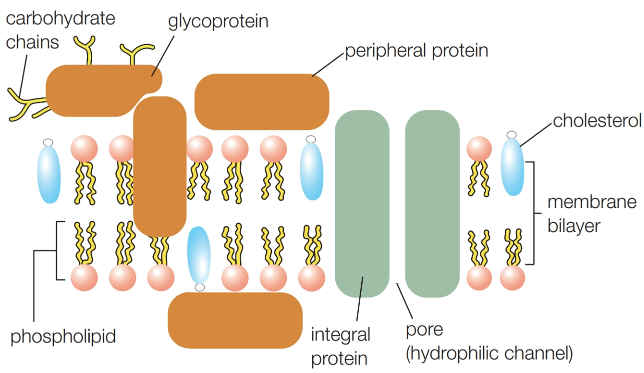


Figure 2.46: The fluid mosaic model of the cell membrane - a phospholipid sea with associated proteins, which may be floating or anchored within the membrane.

Investigating Membrane Properties

- Red beet experiments (红甜菜实验): More red dye (染料) in water = more permeable membrane.

- Alcohol dissolves lipids, increasing permeability.
- High temperature denatures (变性) proteins, making membranes leaky.

Exam Keys

- Phospholipid bilayer = barrier, but proteins control permeability.
- Membranes are flexible and fluid, not rigid.
- Cholesterol increases strength and reduces permeability.
- Use experimental data to explain membrane permeability changes.

2A.2 Cell Transport and Diffusion

Types of membrane transport Substance move across membranes via passive transport (no energy required / no ATP used) or active transport (energy required / ATP used).

- **Diffusion:** No energy required / no ATP used. Molecules move from high concentration to low concentration. Random movement of molecules.
- **Facilitated diffusion:** No energy required / no ATP used. Molecules move from high concentration to low concentration. Uses carrier or channel proteins (管道蛋白).
- **Osmosis:** No energy required / no ATP used. Movement of water molecules from high concentration to low concentration. Water moves through a selectively permeable membrane (渗透膜).
- **Active transport:** Energy required / ATP used. Molecules move from low concentration to high concentration. Uses carrier proteins.
- **Endocytosis (内吞作用):** Energy required / ATP used. Molecules move into the cell. Vesicle (囊泡) forms around the substance.
- **Exocytosis (胞吐作用):** Energy required / ATP used. Molecules move out of the cell. Vesicle fuses with the cell membrane.

Passive Diffusion No ATP required - molecules move down a concentration gradient.

- **Diffusion**
  - Movement of molecules from high concentration to low concentration due to kinetic energy (动能).
  - Example: Oxygen (O_2) and carbon dioxide (CO_2) diffuse freely across the cell membrane.

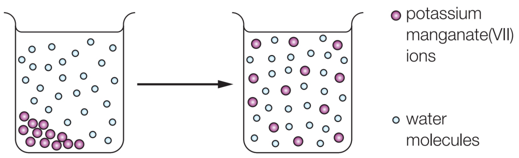


Figure 2.47: If the beaker is left to stand, diffusion takes place as the random movement of both the water and the potassium manganate (VII) ions (MnO_4^-) ensures that they become evenly mixed.

- **Facilitate Diffusion**
  - **Larger / polar molecules** (e.g., glucose, amino acids) need carrier or channel proteins.
  - **Channel proteins**
    * Specific to certain ions / molecules.
    * Can be gated (open / close in response to signals).

  Carrier proteins: Bind to a molecule and change shape to move it across the membrane.

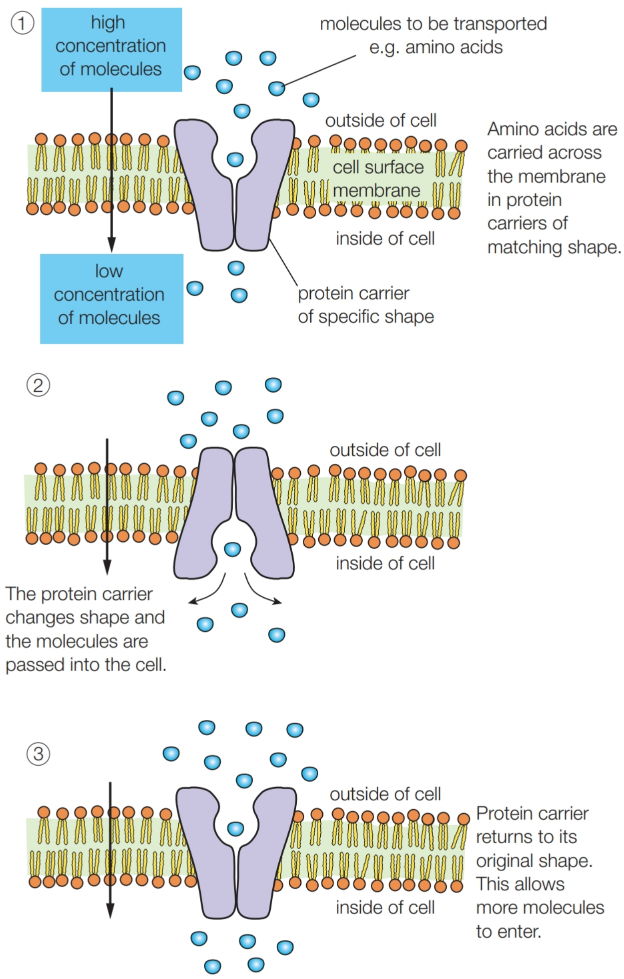


Figure 2.48: Facilitated diffusion acts as a ferry across the lipid membrane sea. It is not an active process, so it can only work when the concentration gradient is in the right direction.

- **Osmosis**
  - The movement of water molecules from a high water potential to a low water potential.
  - Occurs through a partially permeable membrane.

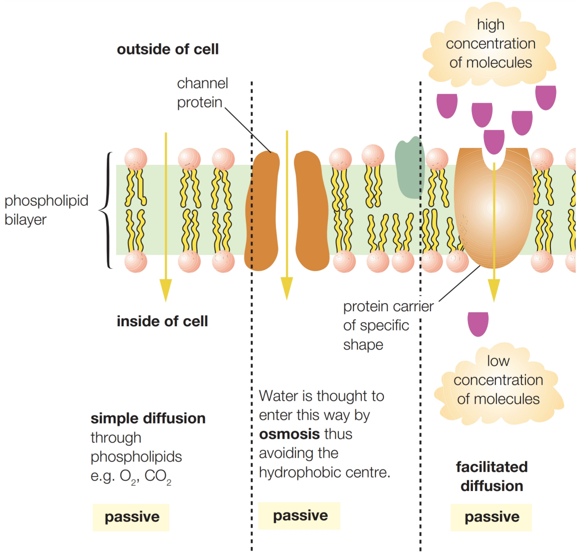


Figure 2.49: The main passive transport routes through a cell surface membrane.

Active Transport (ATP Required)

- Moves molecules against the concentration gradient.
  - Uses carrier proteins powered by ATP.
  - Example: Sodium-potassium pump [14] (钾钠泵) in nerve cells.
- **Endocytosis** (内吞作用) **and Exocytosis** (胞吐作用)
  - **Endocytosis:** Large molecules enter the cell by forming vesicles.
  - **Exocytosis:** Large molecules exit the cell by vesicle fusion [15] (囊泡融合) with the membrane.
  - Example: Secretion of enzymes, hormones, neurotransmitters [16] (神经递质).

[14] The sodium-potassium pump (Na^+ / K^+ pump) is a type of active transport that moves sodium (Na^+) out of the cell and potassium (K^+) into the cell, against their concentration gradients. This process requires ATP and helps maintain the resting membrane potential in nerve and muscle cells. The pump exchanges $3Na^+$ ions out for $2K^+$ ions in, making the inside of the cell more negative compared to the outside. This is essential for nerve impulse transmission, muscle contraction, and overall cell function.

[15] Vesicle fusion is the process by which a vesicle, a small membrane-bound sac (膜结合囊 / 膜包囊) containing substances, fuses with the cell membrane to release its contents into or out of the cell. This is a key mechanism in exocytosis (moving substances out of the cell) and endocytosis (bringing substances into the cell). During fusion, the vesicle membrane merges with the cell membrane, allowing the vesicle's contents, such as hormones or waste products, to be transported across the membrane. This process often requires energy in the form of ATP.

[16] Neurotransmitters are chemical messagers that transmit signals across a synapse (突触, the gap between two nerve cells). They are released from the axon terminal (轴突终末) of a neuron and bind to receptors (受体 / 感受器) on the dendrites (树突) of the next neuron triggering a response. Neurotransmitters play a key role in nerve signals transmission, influencing functions like mood, movement, and cognition (认知). Examples include dopamine (多巴胺, related to reward and movement), serotonin (血清素 / 五羟色胺, influences mood and sleep), and acetylcholine (乙酰胆碱, involved in muscle contraction). The proper balance of neurotransmitters is essential for normal brain function

Exam Keys

- Diffusion = kinetic energy only, no ATP.
- Facilitated diffusion uses proteins but still no ATP.
- Active transport uses ATP and carrier proteins to move substances against a gradient.
- Endocytosis and exocytosis uses vesicles for bulk transport.

2A.3 Osmosis: A Special Case of Diffusion

What is Osmosis?

- Osmosis is the movement of free water molecules through a partially permeable membrane from an area of high water potential to an area of low water potential.
- Water potential is a measure of the potential for water to move in or out of a solution due to osmosis. It depends on the concentration of free water molecules.
- Water always moves doen the water potential gradient, meaning form areas of high water potential (more free water molecules) to low water potential (less free water molecules).
- Water moves through membranes, but solute molecules cannot move in the same way.

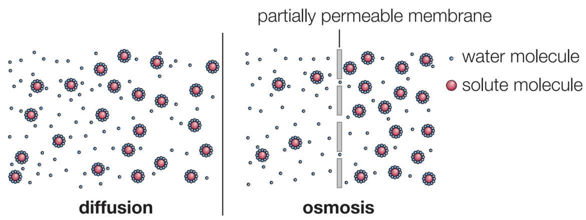


Figure 2.50: In diffusion, the random movement of particles results in an even distribution of both solute and solvent particles. In osmosis, a partially permeable membrane means only solvent molecules and very small solute particles can move freely.

Osmotic Concentrations

- Osmotic concentration refers to the amount of dissolved solutes in a solution. A solution with more solutes has lower water potential.
- Solutions are categorized as:
  - **Isotonic solution (等渗溶液):** The concentration of solutes is the same as inside the cell.
  - **Hypotonic solution (低渗溶液):** The concentration of solutes is lower than inside the cell, causing water to enter the cell.
  - **Hyperonic solution (高渗溶液):** The concentration of solutes is higher than inside the cell, causing water to leave the cell.

Osmosis in Animal Cells Animal cells must maintain a delicate balance of water to prevent cell bursting or shrinking.

- **Hypotonic solution:** Water enters the cell, causing it to swell and burst.
- **Hypertonc solution:** Water leaves the cell, causing it to shrink and shrivel.

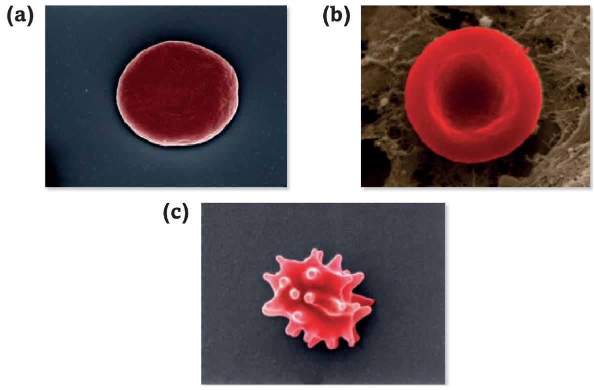


Figure 2.51: The effects of osmosis on red blood cells show why the systmes of the body that maintain solute concentrations and water balance are so important. **(a)** In hypotonic solution, water moves in and the cell swells and brusts; **(b)** in isotonic solution the red blood cell maintains its normal shape; **(c)** in hypertonic solution, water moves out and the cell shrinks.

Osmosis in Plant Cells Plant cells are more resistant to osmotic pressure due to their rigid cell walls.

- **Hypotonic solution:** Water enters the cell, causing it to swell and generate hydrostatic pressure (inward pressure that prevents further water influx). This is called turgor (膨压).
- **Hypertonic solution:** Water exits the cell, causing the protoplast (原生质, cell contents) to shrink from the cell wall in a process called plasmolysis (胞质裂解).

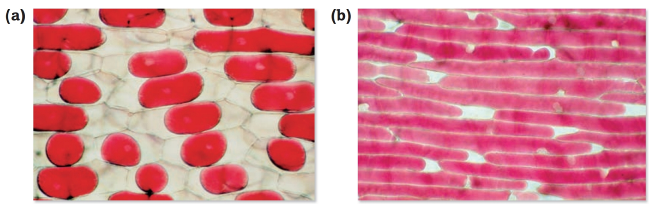


Figure 2.52: Plant cells from red beet showing **(a)** plasmolysis; and **(b)** turgor.

Modelling Osmosis in Cells

- **Experimental model:** We can model osmosis using an artificial membrane to demonstrate (证明) the movement of water through a partially permeable membrane (半透膜).
- **Sucrose solution** can be used to illustrate (说明) osmotic movement (water moves to the area with higher solute concentration).

Exam Tips

- Use the term water potential to explain osmotic movement in and out of cells.
- **Remember the gradient:** Water always moves from high to low water potential.
- Osmosis requires **no ATP** - It is a passive process relying on kinetic energy of water molecules.

2A.4 Active Transport

What is Active Transport?

- Active transport moves substances against their concentration gradient (from low to high concentration), requiring ATP (energy).
- This process is crucial for maintaining concentration gradients of ions and molecules within and outside the cell.
- Carrier proteins are used to move substances across the membrane.

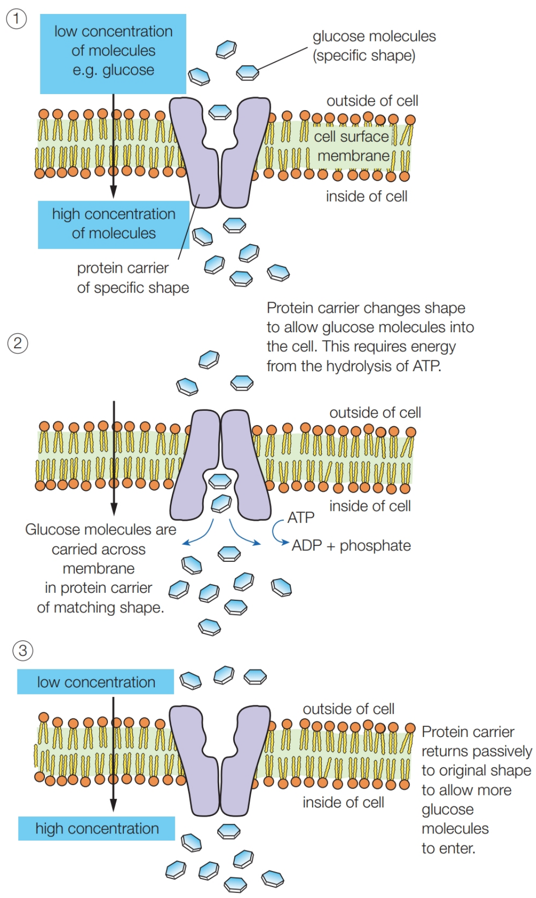


Figure 2.53: Using active transport, cells can move selected substances into or out of the cell, even when the concentration gradient is in the wrong direction.

How Active Transport Works

- Carrier proteins bind to the substance (e.g., glucose).
- ATP provides energy for the protein to change shape, allowing the molcule to be transported.
- Once the molecule is inside the cell, the carrier returns to its original shape.

Energy Source: ATP

- Active transport requires ATP to provide the energy needed for molecules to move against their concentration gradient.
- ATP hydrolysis (breaking down ATP into ADP + phosphate) releases the energy required to change the shape of the carrier protein.

Sodium-Potassium Pump A classic example of active transport is the sodium-potassium pump:

- **Sodium ions (Na^+)** are pumped out of the cell.
- **Potassium ions (K^+)** are pumped into the cell.
- This process helps maintain the resting membrane potential in cells, expecially in nerve and muscle cells.

Endocytosis and Exocytosis

- **Endocytosis:** The process of taking materials into the cell by forming vesicles. This can be used for large molecules like bacteria (phagocytosis 吞噬作用) or liquids (pinocytosis 胞饮作用).
  - **Phagocytosis:** The cell engulfs (吞没) large particles such as bacteria.

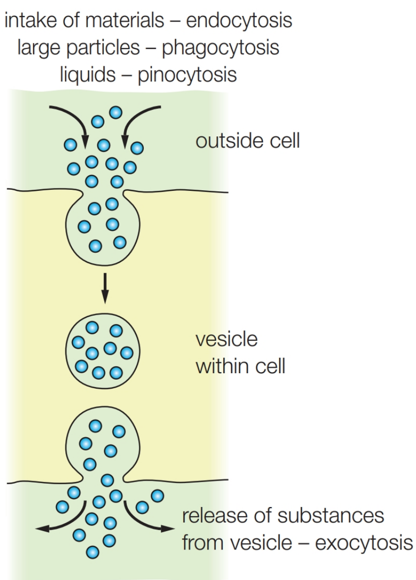


Figure 2.54: The properties of the cell membrane allow cells to take in large particles or release secretions.

- **Pinocytosis:** The cell takes in liquids and small solutes.

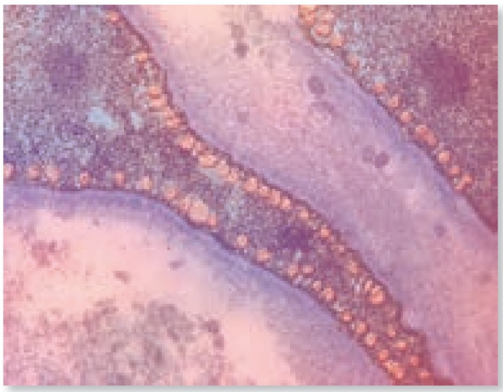


Figure 2.55: The mass of tiny vesicles along these cell membranes show pinocytosis.

The Fluid Mosaic Model of Membranes The processes of active transport, endocytosis, and exocytosis are facilitated by the fluid mosaic model of the cell membrane.

- Carrier proteins and vesicles (formed from the membrane) play a central role in these processes.
- The flexible nature of the membrane allows for vesicle formation and fusion.

Exam Tips

- Always highlight that acive transport requires energy (ATP) and is against the concentration gradient.
- For endocytosis and exocytosis, focus on the vesicle formation and its fusion with the membrane.
- Explain ATP's role clearly in processes that need energy for molecular movement (e.g., active transport, vesicle fusion).

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 钡 (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 鲥 (Rf)
105. [Transition Metals] Dubnium 镝 (Db)
106. [Transition Metals] Seaborgium 坦 (Sg)
107. [Transition Metals] Bohrium 波 (Bh)
108. [Transition Metals] Hassium 哈 (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.

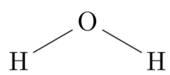


Figure 3.4: Molecule formula of water.

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

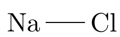


Figure 3.5: Molecule formula of sodium chloride.

- 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).

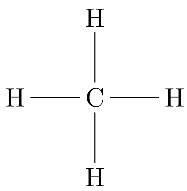


Figure 3.6: Molecule formula of methane.

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)

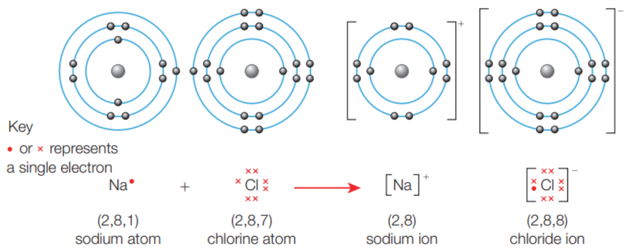


Figure 3.7: The formation of sodium chloride.

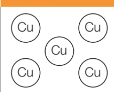
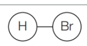
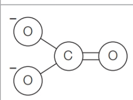
TERM	DIAGRAM	NAME	SYMBOL OR FORMULA	NOTE
element		copper	Cu	This is an element. All the atoms are the same.
atom		helium	He	This is an atom of an element.
molecule		bromine	Br_2	This is a molecule of an element. The atoms are the same.
compound		hydrogen bromide	HBr	This is a molecule of a compound. 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:

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

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:

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

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

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

  After deleting the identical ions, the equation becomes:

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

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

  The full balanced equation is:

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

  The ionic equation is:

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

  After deleting the identical ions, the equation becomes:

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

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

  The full balanced equation is:

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

  The ionic equation is:

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

  After deleting the identical ions, the equation becomes:

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

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:

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

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:**

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

- **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:

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

- **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.

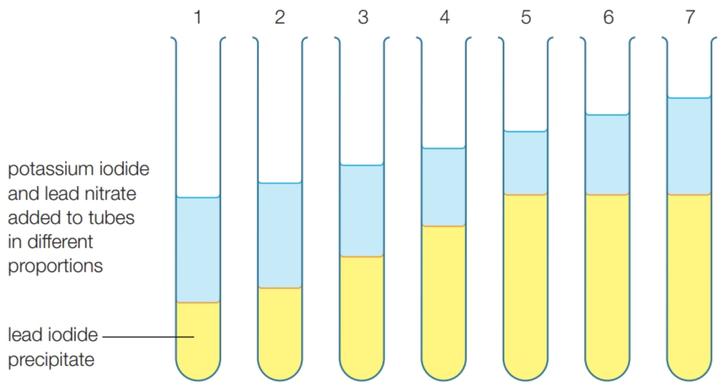


Figure 3.11: Results of the reaction between aqueous solutions of lead nitrate and potassium iodide in one experiment.

- **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:**

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

- **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:

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

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:

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

3. Mass of 100 Million Atoms of Gold:

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

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 Combustion Analysis (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

4.1 Mechanics

4.1.1 Motion

1A.1 Velocity and Acceleration

Rate of Movement

- **Speed**
  - Formula:

$$\begin{aligned} \text{Speed}(\mathrm{m\,s^{-1}}) &= \frac{\text{Distance(m)}}{\text{Time(s)}} \\ v &= \frac{d}{t} \end{aligned} \tag{4.1}$$

  - Scalar quantity (标量, magnitude only).

- **Velocity (速度)**
  - Formula:

$$\begin{aligned} \text{Velocity}(\mathrm{m\,s^{-1}}) &= \frac{\text{Displacement (位移量)(m)}}{\text{Time(s)}} \\ v &= \frac{\Delta s}{\Delta t} \end{aligned} \tag{4.2}$$

  - Vector quantity (矢量, include magnitude and direction).

- **Displacement (位移量)**
  - Defined as the shortest straight-line distance in a specific direction between the start and end points.
  - Example: The displacement of an athlete running 300 m around a track but ending 75 m north of the start point is 75 m due north.

Scalar (标量) and Vector (向量) Quantities

- **Scalar:** Magnitude only (e.g., speed, distance, mass).
- **Vector:** Magnitude and direction (e.g., velocity, displacement, acceleration 加速度).

Average and Intantaneous Speed (瞬时速度)

- **Average Speed:** Accounts for variations in speed over a period of time.

$$\text{Average Speed}(\mathrm{m\,s^{-1}}) = \frac{\text{Total Distance(m)}}{\text{Total Time(s)}} \tag{4.3}$$

- **Instantaneous Speed:** The speed of an object at a specific instant in time.

Acceleration (加速度)

- **Definition:** The rate of change of velocity.
- **Formula:**

$$\begin{aligned}\text{Acceleration}(\mathrm{m\,s^{-2}}) &= \frac{\text{Change in Velocity}(\mathrm{m\,s^{-1}})}{\text{Time(s)}} \\ a &= \frac{\Delta v}{\Delta t} \\ &= \frac{v-u}{t}\end{aligned} \tag{4.4}$$

where: a = acceleration, v = final velocity, u = initial velocity, t = time taken.

- **Key Notes:**
  - Positive acceleration: Speeding up.
  - Negative acceleration (deceleration): Slowing down.

1A.2 Motion Graphs

Displacement-Time Graphs

- **Definition:** Tracks the position of an object over time.
- **Key Features:**
  - **Gradient:** Represents the velocity of the object.

$$v = \frac{\Delta s}{\Delta t} \tag{4.5}$$

  - **Straight Line:** Constant velocity.
  - **Curved Line:** Changing velocity (acceleration or deceleration).
  - **Flat Line:** Object is stationary.

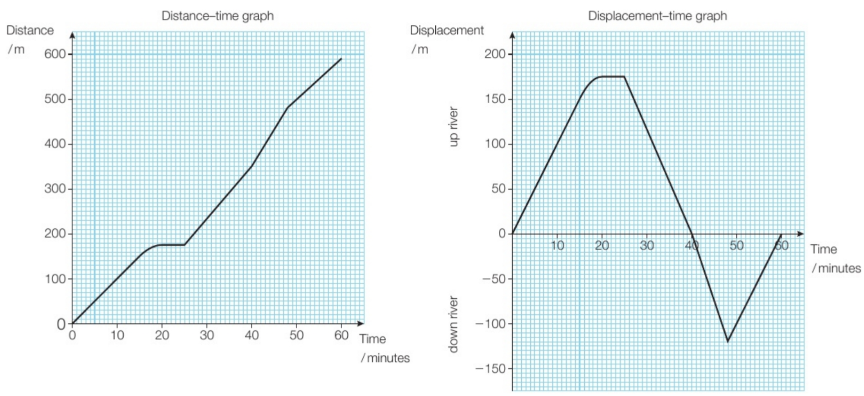


Figure 4.1: A comparsion of the displacement-time graph of the boat trip up and down the river with its corresponding distance-time graph.

- **Example:** According to the graph above, from 0-15 minutes, boat travels 150 m up to the river.

$$v = \frac{\Delta s}{\Delta t} = \frac{150}{(15-0)\times 60} = 0.167\text{m/s} \tag{4.6}$$

Velocity-Time Graphs

- **Definition:** Shows velocity of an object over time.
- **Key Features:**
  - **Gradient:** Represents the acceleration of the object.

$$a = \frac{\Delta v}{\Delta t} \tag{4.7}$$

  - **Area Under Graph:** Total distance traveled by the object.

$$d = v \times t \tag{4.8}$$

  - **Positive / Negative Gradient:** Direction of velocity (up / down motion).

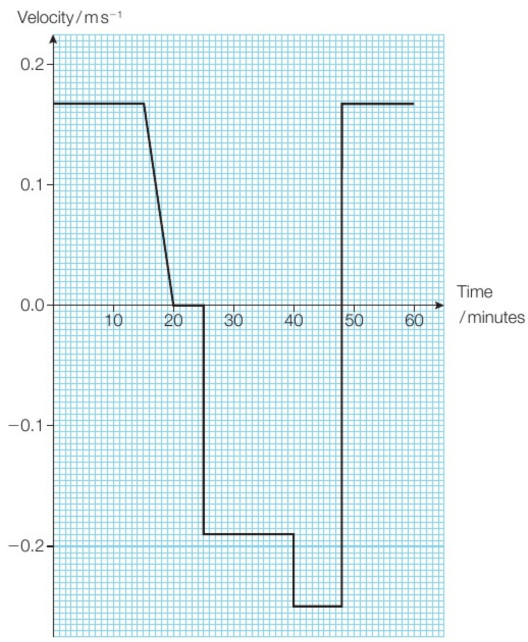


Figure 4.2: Velocity-time graph for the boat trip.

- **Example:** According to the graph above, acceleration is zero (flat line at 0.167 m/s). Calculate the acceleration between 15-20 minutes.

$$a = \frac{v-u}{t} = \frac{0-0.167}{(20-15)\times 60} = -0.0006\text{m/s}^2 \tag{4.9}$$

Acceleration-Time Graphs

- **Definition:** Represents acceleration over time.
- **Key Features:**
  - **Flat Line Above Zero:** Constant positive acceleration.
  - **Flat Line Below Zero:** Constant negative acceleration (deceleration).
  - **Area Under Graph:** Change in velocity.

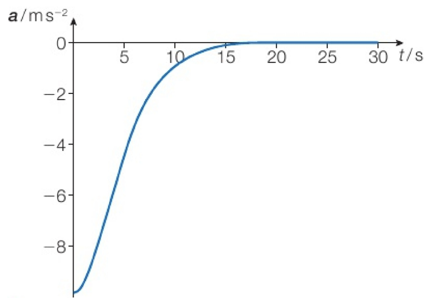


Figure 4.3: Acceleration-time graph for a skydriver.

Multiflash Photography

- **Method:** Use time intervals and measure distance to calculate acceleration due to gravity.
- **Observations:** Observations are plotted to create accurate velocity-time graphs.

Important Equations

1. **Displacement:**
$$v = \frac{\Delta s}{\Delta t} \tag{4.10}$$
2. **Velocity:**
$$a = \frac{\Delta v}{\Delta t} \tag{4.11}$$
3. **Area Under Graph (for velocity-time graphs):**
$$\text{Distance Traveled} = v \times t \tag{4.12}$$

1A.3 Adding Forces

Key Definitions

- **Resultant force (合力):** The single total force (vector sum) acting on a body when all individual forces are combined (taking into account their magnitudes (大小) and directions). It produces the same effect as all the forces acting together.
- **Free-body force diagram (受力分析图):** A diagram showing an isolated object and all the forces acting on it, drawn as arrows to indicate their magnitude, direction, and points of action. This helps clarify what forces are involved.

- **<u>Vector</u> (矢量):** A quantity with both magnitude and direction (e.g., forces, <u>displacement</u> (位移), <u>velocity</u> (速度)). Vectors add according to both their size and direction, not just numerically like <u>scalars</u> (标量).

Important Formulae

- **Resultant of forces in a straight line:** If forces act along the same line, the resultant's magnitude is the sum of forces in one direction minus the sum in the oppsite direction. ($F_{\text{resultant}} = F_1 + F_2$ if in same direction; $F_{\text{resultant}} = F_1 - F_2$ if in opposite direction). The direction of the resultant is that of the larger force.

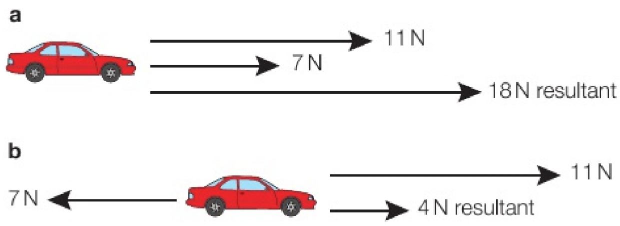


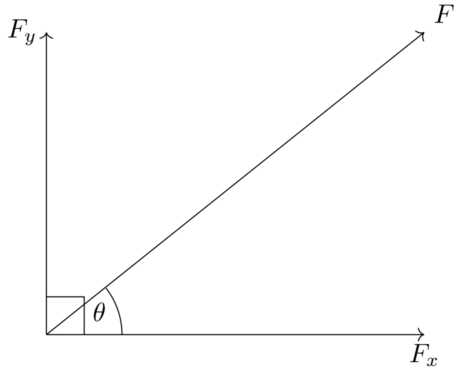
Figure 4.4: Adding forces in the same line requires a consideration of their comparative directions.

- **Resultant of perpendicular forces:** For two forces at right angles, use Pythagoras to find the magnitude of the resultant:

$$F = \sqrt{F_x^2 + F_y^2} \tag{4.13}$$

where F_x and F_y are the component forces. The direction (angle θ of F from one axis) can be found by:

$$\tan\theta = \frac{F_y}{F_x} \tag{4.14}$$



- **Parallelogram rule (vector addition):** For two forces at any angle, draw them to scale from the same point; complete the parallelogram - the diagonal from the common start point gives the resultant in magnitude and direction.

Theoretical Concepts

- **Combining Forces in the Same Line:** When forces act <u>collinearly</u> (共线, along the same straight line), simply add or subtract their magnitudes with proper sign. Forces in the same direction <u>reinforce</u> (加强) each other (add up), while forces in opposite directions <u>counteract</u> (抵消) each other (subtract).

- **Combining Perpendicular Forces:** Forces acting at right angles (perpendicular) to each other can be combined using geometry. Draw the two force vectors as perpendicular arrows from a common point (forming a right triangle with the resultant as the hypotenuse (斜边)). The magnitude of the resultant can be found by Pythagoras' theorem:

$$F = \sqrt{F_x^2 + F_y^2} \tag{4.15}$$

The direction of the resultant can be found with trigonometry (三角函数): for example [1],

$$\theta = \tan^{-1}\left(\frac{F_y}{F_x}\right) \quad \text{or} \quad \theta = \arctan\left(\frac{F_y}{F_x}\right) \tag{4.16}$$

specifying θ as the angle relative to one of the original force directions. Always state the reference direction for the angle (e.g., θ above the horizontal) for clarity.

Exam Tip: Always carefully state where the angle is measured from (this is best shown on a diagram).

Combining Forces at Angles - Parallelogram Rule When forces are not perpendicular and we need the resultant, we can use a scale diagram method (parallelogram rule). Draw both force vectors from the same point to scale (same scale for both) at the correct angle between them. Then draw parallels to each vector from the tip of each other, forming a parallelogram. The diagonal (对角线) of the parallelogram from the common start point represents the resultant force in both magnitude and direction.

This graphical method is often used in exams if an analytical method is not required or when forces are at awkward angles. If we know how to use trigonometry for non-90° cases, that's fine, but follow the question's instructions - if it asks for a scale drawing, use that approach. to get full marks.

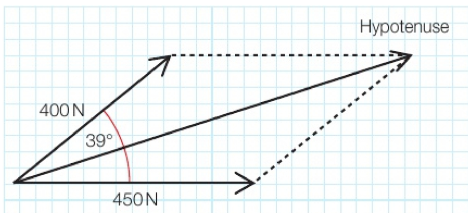


Figure 4.5: Finding the resultant vector using the parallelogram rule.

Co-Planar Forces (共面力) and Multiple Vectors The vector-addition methods (向量加法) above (triangles or parallelograms) work for any vectors as long as they are co-planar (lying in the same plane). In most mechanics problems, forces are co-planar (e.g., acting in a 2D plane like a flat diagram).

If more than two forces are present, we can add them one by one: first find the resultant of two forces, then add that resultant to the next force, and so on. For multiple forces on different lines, it's often easiest to break them into components along perpendicular axes (resolution of vectors) and sum all components in each direction.

[1] **Arctan** (or inverse tangent, denoted as $\tan^{-1} x$ or $\arctan x$) is the inverse function of the tangent function. It returns the angle θ in radians whose tangent x is, typically within the principal range $-\frac{\pi}{2} \leq \theta \leq \frac{\pi}{2}$.

Free-Body Force Diagrams (受力分析图) A free-body force diagram is crucial tool for visualizing forces. In free-body diagram, we draw the object (often as a dot or a simple box) isolated from its surroundings, and then draw all the forces acting on that object as arrows pointing in the direction each force is applied. Each arrow's length should be drawn to scale relative to the force's magnitude (when possible), and it should be labeled with the force value or name.

Forces exerted (施加) by the object on others or forces on other objects are not included - only forces acting on the chosen object. Free-body diagrams help in applying Newton's laws [2] or in setting up equilibrium equations (平衡方程) by clearly showing all forces for vector addition.

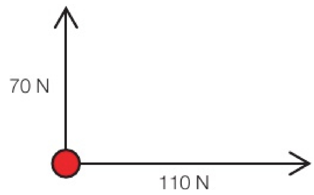


Figure 4.6: Free-body force diagram of a rugby player (red circle). The forces from the tacklers are marked on as force arrows.

Exam Tips

- **Indicate Directions:** Always indicate the direction of resultant force (e.g., '18N to the right' or 'Resultant = 5N at 30° above the horizontal'). Merely (仅仅只是) giving a magnitude is not sufficient (足够的) for full marks.
- **State Angle Reference:** When giving an angle for a resultant, state what it's measured from (horizontal, vertical, etc.). This avoids ambiguity (模棱两可) in answers.
- **Use Scale Drawings Correctly:** If a question specifies a scale drawing or the parallelogram / triangle method, do so. Use a ruler for straight lines and a protector for angles to ensure accuracy. Label the scale (e.g., '1cm = 10N'). In calculation questions, directly use trig and Pythagoras, but still draw a quick diagram to guide the work.
- **Co-Planar Assumption:** All these addition methods assume forces lie in the same plane. This is usually the case in exam problems. If forces are not

[2]**Newton's Laws of Motion**

- **Newton's First Law (牛顿第一定律 / 惯性定律, Law of Inertia):** An object at rest stays at rest, and an an object in motion stays in motion with the same velocity unless acted upon by an external force. This means that in the absence (缺乏) of an unbalanced force, and object will maintain its current state of motion.
- **Newton's Second Law (牛顿第二定律 / 动力定律, Law of Acceleration):** The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass, given by the equation:

$$F = ma$$

  where F is the net force (in Newtons), m is the object's mass (in kg), and a is the acceleration (in m/s^2). This law explains how forces affect motion.
- **Newton's Third Law (牛顿第三定律 / 作用与反作用定律, Law of Action-Reaction):** For every action, there is an equal and opposite reaction. This means that whenever one object exerts (施加) a force on another, the second object exerts an equal force in the opposite direction on the first object.

co-planar (rare at this level), you would handle one plane at a time or resolve into components in 3D - but typically stick to 2D planes.

- **Add Iteratively (反复 / 迭代) for Many Forces:** When more than two forces act, add them stepwise (逐步地). Combine two into a resultant, then combine that resultant with the next force, etc. This incremental (递增的) approach reduces confusion and is less error-prone (易错) than trying to do all at once.
- **Check Equilibrium Conditions:** If the question implies an object is in equilibrium (not accelerating), the resultant force should come out to zero. Use this as a check: forces should balance out in all directions. A common exam trick is to have forces that cancel out; recognizing equilibrium can simplify the problem.

1A.4 Moments

Key Definitions

- **Moment of a force:** The tendency (趋势) of a force to cause rotation about a point or pivot (支点). It is equal to the force multiplied by the perpendicular distance from the pivot to the line of action of the force. Formula [3]:

$$\begin{aligned} \text{Moment} &= F \times d_{\perp} \\ &= Fx \end{aligned} \tag{4.17}$$

measured in newton-meters (N·m). Sometimes called torque (扭矩) or turning force.

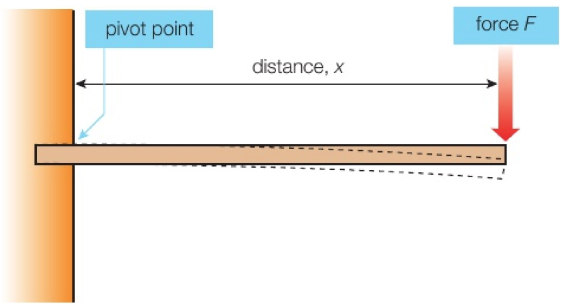


Figure 4.7: A force acts on a beam fixed at a point. The movement of a force causes rotation or, in case, blending.

[3]In the formula for moment (or torque):

$$\text{Moment} = F \times d_{\perp}$$

the symbol $\perp$ (perpendicular) in $d_{\perp}$ has a specific meaning related to the lever arm [4] (力臂) in rotational mechanics.

- **Measuring of $d_{\perp}$:** The quantity $d_{\perp}$ is the perpendicular distance from the axis of rotation (or pivot point) to the line of action of the force F. It represents the shortest possible distance between the pivot and the force's direction.
- **Use of $d_{\perp}$**
  * The movement (torque) measures how effectively a force causes rotation about a pivot.
  * The greater the perpendicular distance ($d_{\perp}$), the larger the turning effect (moment) for the same applied force F.
  * If a force acts directly through the pivot (so $d_{\perp} = 0$), no moment is produced, meaning the force cannot create rotation.

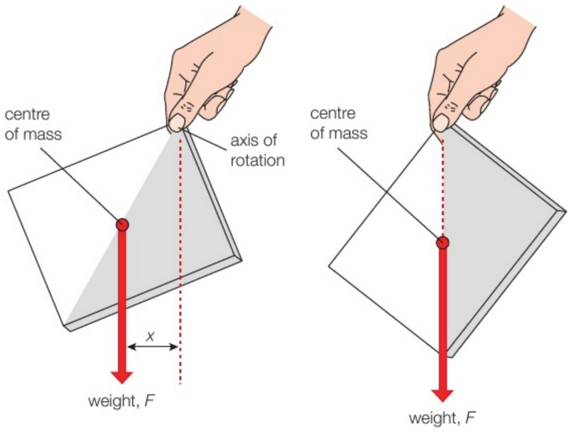


Figure 4.8: The calculation of moment only considers the perpendicular distance between the line of action of the force and the axis of rotation, through the pivot. When free to retate, a body will turn in the direction of any net moment.

- **Principle of moments:** In equilibrium, for an object that can rotate, the sum of all clockwise moments about any pivot equals the sum of all anticlockwise moments about that pivot. This is a condition for rotational equilibrium - no net turning effect (合力转动效应).
- **Centre of gravity (centre of mass):** The point in an object at which the entire weight can be considered to act. In uniform gravity, this coincides (符合) with the centre of mass. For symmetric (对称) objects, it lies at the intersection of symmetry lines. For irregular objects, its position can be found experimentally (e.g., by balancing).

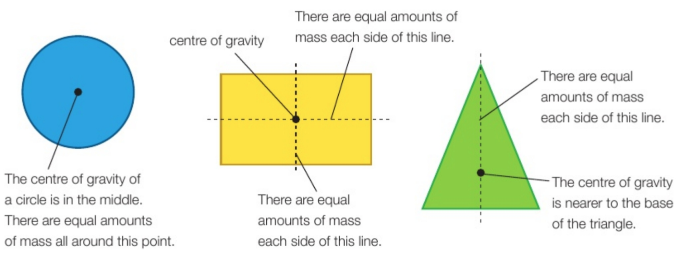


Figure 4.9: The centre of gravity of a symmetrical object lies at the intersection of all lines of symmetry.

- **Equilibrium:** A state where a body has zero resultant force and zero resultant moment acting on it, resulting in no acceleration (no linear acceleration and no angular acceleration). An object in equilibrium remains at rest or continues to move at constant velocity (and, if rotating, at constant angular velocity).

[4]**Lever arm** is the perpendicular distance from the axis of rotation (pivot point) to the line of action of the applied force. It determines how effectively the force can cause rotational motion. The lever are is denoted as $d_\perp$, and it can be calculated using:

$$d_\perp = d \sin\theta$$

where d is the distance from the pivot to the point where the force is applied, and θ is the angle between the force and the radial line from thee pivot.

Important Formulae

- **Moment of a force:**

$$\begin{aligned}\text{Moment} &= F \times d_{\perp} \\ &= Fx\end{aligned} \tag{4.18}$$

where F is the force and $d_{\perp}$ is the perpendicular distance from the pivot to the force's line of action.

- **Principle of moments (equilibrium condition):** [4]

$$\sum M_{\text{clockwise}} = \sum M_{\text{anticlockwise}} \tag{4.19}$$

for a system in rotational equilibrium.

- **Centre of gravity via moments:** In a balance scenario (情景),

$$\begin{aligned}\text{Clockwise Moment} &= \text{Anticlockwise Moment} \\ mg \times d &= Mg \times x \\ x &= \frac{md}{M}\end{aligned} \tag{4.20}$$

can be used to find the center of gravity of an object of mass M balanced by a smaller mass m at a known distance d (g cancels out), while x is the distance from the pivot to the center of gravity.

Theoretical Concepts **Moment (Turning Effect) of a Force** A force can only push or pull an object in a line, but also make it turn or rotate about a pivot. The moment (or turning effect) of a force quantifies how much the force tends to rotate the object. It depends on two factors:

- The magnitude of the force F.
- The perpendicular distance $d_{\perp}$ from the pivot to the line of action of the force.

[4] The $\sum$ (sigma) symbol in mathematical notation represents summation, which is the process of adding a sequence of numbers. It is commonly used in statistics, calculus, and algebra to denote the sum of terms following a specific pattern.

- **Function of $\sum$**
  * It compacts summation expression, replacing long addition sequences with a concise (简洁) notation.
  * It defines a range of summation using lower and upper limits.
  * It helps in formulating mathematical formulas, especially in series, sequences, and probability.
- **Usage of $\sum$**
  * **General Form**

$$\sum_{i=1}^{n} f(i) = f(1) + f(2) + f(3) + \cdots + f(n)$$

    This means adding up all values of $f(i)$ for $i = a$ to $i = b$.
  * **Common Applications:**
    - Arithmetic and geometric series.
    - Probability and statistics.
    - Matrix operations and calculus.

A larger force or a longer leverage (杠杆作用, distance) gives a larger moment.

For example, pushing a door near the hinges (铰链) versus (相对于) at the handle: the same force at the handle (far from the hinges) produces a greater moment (easier to rotate the door) than near the hinge. The direction of rotation can be specified as clockwise or anticlockwise based on the force's tendency.

Why perpendicular distance? Only the component of the force that is perpendicular to the line from the pivot causes rotation. If a force acts directly through the pivot ($d_\perp = 0$), it produces no moment (no rotation). If the force is at an angle, we always take the perpendicular distance to calculate the effective turning leverage. Equivalently (等效于), one can use the component of the force perpendicular to the lever arm.

Equilibrium and the Principle of Moments For an object to be in equilibrium (completely balanced and not accelerating in any way), two conditions must me met:

1. The resultant force on it is zero (no linear acceleration).

2. The resultant moment on it is zero (no angular acceleration).

The second condition is the principle of moments in action: all the clockwise moments about any chosen pivot must equal all the anticlockwise moments. When this holds, the net turning effect is zero, so the object will not start to rotate (or if already rotating, it continues at constant angular speed).

In practical terms, to apply the principle of moments:

- Choose a pivot point (often a support or hinge).

- Calculate the moment of each force about that pivot. Take care to assign a sense to each moment.

- Set the sum of clockwise moments equal to the sum of anticlockwise moments if the object is balanced.

- Solve for the unknown if required.

This principle is used in many contexts, e.g. balancing beams (梁), seesaws, weighing scales, and determining forces on supports. Each individual moment was calculated, then summed for clockwise and equated to the sum of anticlockwise moments to solve for the unknown weight of the beam.

Solving Moment Problems - Strategy In moment problems, list all forces and their distances from the chosen pivot. Decide which side (or direction of rotation) each force would cause. Then write an equation equating the total moment causing clockwise rotation to the total moment causing anticlockwise rotation (if in equilibrium). If not in equilibrium, we might be computing a net moment instead.

Important: We cannot add forces directly to get a total moment; we must add their moments.

Also, ensure consistent units (convert all distances to meters, forces to newtons). The solution should be laid out with clear steps: identify pivot, write down moments on each side, etc., to get high marks. This approach also reduces mistakes.

Center of Gravity (Center of Mass) The center of gravity of an object is the point at which the weight of the object can be considered to act. In uniform gravity

[5] (均衡重力场), it's the same as the object's center of mass. If support an object at its center of gravity, it will balance perfectly (no net moment due to gravity on either side). For regularly shaped, uniform objects, the center of gravity is at the geometric center or along lines of symmetry.

For irregular objects or non-uniform objects, the center of gravity is not obvious

[5]**Uniform garvity:** In physics, uniform gravity refers to a gravitational field [6] (引力场) in which the acceleration due to gravity is constant in both magnitude and direction throughout a given region. This assumption simplifies calculations and is commonly used in problems involving motion near the Earth's surface, where gravitational acceleration (g) is approximately $9.81\,\mathrm{m\,s^{-2}}$ and acts downward.

[6]**Gravitational field:** A gravitational field is a region in space where a mass experiences a gravitational force due to the presence of another mass. The strength and direction of the field at any point are defined by the gravitational field strength (g), which is the force per unit mass exerted (施加) on a small test mass placed at that point.

Center of gravity vs. center of mass: For most physics problems on Earth, we treat them as the same point. A Learning Tip in the textbook notes that the terms can be used interchangeably for objects that are small relative to Earth. Only in varying gravitational fields would the distinction (区别) matter.

Mathematically, it is expressed as:

$$g = \frac{F}{m}$$

where F is the gravitational force experienced by an object of mass m.

Types of Gravitational Fields

- **Uniform Gravitational Field (均匀重力场)**
  - In small regions, such as near Earth's surface, gravity can be approximated as uniform (均一的).
  - The field lines are parallel and equally spaced, indicating that the gravitational force is the same in magnitude and direction at every point.
  - The acceleration due to gravity is nearly constant at $9.81\mathrm{m/s^2}$ near Earth's surface.
- **Radial Gravitational Field (径向重力场)**
  - For larger distances from a mass (such as planets or stars), the gravitational field is no longer uniform but radial.
  - The strength of the field follows Newton's inverse-square law [7] (平方反比定律), given by:

    $$g = \frac{GM}{r^2}$$

    where:
    * g is the gravitational field strength.
    * G is the gravitational constant ($6.67 \times 10^{-11}\,\mathrm{N\,m^2\,kg^{-2}}$).
    * M is the mass creating the gravitational field.
    * r is the distance from the center of the mass of the object.
    * The field lines point radially inward, indicating that gravity always pulls objects toward the center of the mass causing the field.

Key Properties of a Gravitational Field

- **Attractive Force:** Gravity always pulls masses toward each other; it never repels.
- **Infinite Range:** Although gravity weakens with distance, it theoretically extends to infinity.
- **Superposition Principle:** The resultant gravitational field at any point due to multiple masses is the vector sum of the individual fields.

In astrophysics (天体物理学), gravitational fields determine planetary orbits (轨道), tides (潮汐), and even the bending of light in strong gravitational fields (gravitational lensing (引力透镜效应)).

[7]**Inverse-Square Law:** The inverse-square law states that a physical quantity (such as gravitational force, electric field, or light intensity) decreases in proportion to the square of the distance from the source. This principle applies to gravity, where the gravitational field strength (g) and gravitational force (F) follow the relationship:

$$F = \frac{GMm}{r^2}$$

where:

by symmetry. We can find it experimentally by the principle of moments or by

---

- F is the gravitational force between two masses.
- G is the gravitational constant ($6.67 \times 10^{-11}\,\mathrm{N\,m^2\,kg^{-2}}$).
- M and m are the masses involved.
- r is the distance between their centers of mass.

Gravitational Field Strength and Inverse-Square Law
The gravitational field strength (g) at a distance r from a mass M is given by:

$$g = \frac{F}{m} = \frac{GM}{r^2}$$

This equation shows that as the distance r doubles, the gravitational field strength becomes one-forth of its original value:

$$g' = \frac{GM}{(2r)^2} = \frac{GM}{4r^2} = \frac{1}{4}g$$

General Mathematical Form of the Inverse-Square Law
For any physical quantity I (such as intensity of light, force, or field strength) that follows the inverse-square law:

$$I \propto \frac{1}{r^2}$$

which can be written as:

$$I = \frac{k}{r^2}$$

where k is a constant depending on the system. This relation holds for:

- **Gravitational Force**
$$F = \frac{GMm}{r^2}$$
- **Gravitational Field Strength**
$$g = \frac{GM}{r^2}$$
- **Electric Field Strength (Coulomb's Law)**
$$E = \frac{kQ}{r^2}$$
- **Intensity of Light**
$$I = \frac{k}{r^2}$$

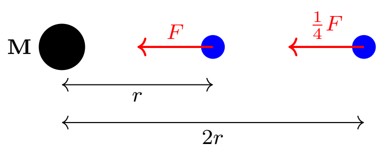
Visualization of the Inverse-Square Law
A simple way to understand the inverse-square law is to visualize how the influence of a source spreads over an increasing area.
Area Expression Concept: The surface area of a sphere increases with the square of the radius:

$$A = 4\pi r^2$$

Since the same amount of force or energy is spread over this area, the intensity at a given point decreases proportionally:

$$I = \frac{\text{Total Energy or Force}}{4\pi r^2}$$

Diagram Representation



where:

- Mass M at the center of generates a gravitational field.
- Test mass at distance r experiences a force F.
- Test mass at distance $2r$ experiences a force $\frac{1}{4}F$.
- The arrows represent gravitational force decreasing as distance increases.

suspension: e.g., we can balance the object on a narrow support (like finding the balance point of a broom). In the broom experiment, a known smaller mass was used to balance the broom at a certain point; by equating moments (mass × distance), the distance to the broom's center of gravity could be calculated. Another simple method is to hang the object from different points and use a plumb line - the lines of action of gravity will intersect at the center of gravity.

1A.5 Newton's Laws of Motion

Key Definitions

- **Newton's First Law of Motion:** An object will remain at rest, or continue at constant velocity in a straight line, unless acted upon by a resultant external force. This is the principle of inertia (惯性) - no change in motion without an unbalanced force.
- **Newton's Second Law of Motion:** The acceleration of an object is directly proportional to the ner force acting on it and inversely proportional to its mass. In formula form:

$$\begin{aligned} \text{Force} &= \text{Mass} \times \text{Acceleration} \\ F &= ma \\ &= mg \\ \therefore \quad g &= \frac{F}{m} \end{aligned}$$

  A resultant force F (in newtons, N) acting on mass m (in kilograms, kg) produces acceleration a (in meters per second squared, m/s^2) in the same direction.
- **Newton's Third Law of Motion:** For every action force, there is an equal and opposite reaction force. This means that if object A exerts (施加) a force on object B, then object B simultaneously (同时) exerts an equal force in the opposite direction on object A. These two forces are an interaction pair and of the same type.

Theoretical Concepts

- **Inertia and Newton's First Law:** Newton's first law defines inertia: an object's tendency to resist changes in motion. If no resultant force acts on an object, its velocity remains constant (if stationary, it stays at rest; if moving, it continues at the same speed in the same direction). In practical items, a book on a table will remain stationary until a net force (e.g. a push) is applied.
- **Newton's Second Law and Acceleration:** Newton's second law quantifies how forces affect motion. It says acceleration a is proportional to force F and inversely proportional to mass m. For a given mass, a larger force produces a larger acceleration; for a give force, a larger mass yields a smaller acceleration.

  For example, pushing two carts with the same force, the lighter cart accelerates more. This law also implies (表明) the direction of the acceleration is the same as the direction of the net force. If multiple forces act, we sum them vectorially (矢量地) to get the resultant force ΣF and then apply $F = ma$. (If $\Sigma F = 0$, then $a = 0$, consistent with the first law.)

- **Newton's Third Law and Interaction Pairs:** Newton's third law emphasizes that forces always come in pairs. These acrion-reaction pairs (相互作用对) act on different objects but are equal in magnitude and opposite in direction.

  For instance, consider a skateboarder pushing against a wall: the skateboarder exerts a force on the wall, and the wall exerts an equal and opposite force back on the skateboarder. Only because these forces act on different bodies can both objects accelerate (the skateboarder lunches backward while the wall remains essentially unmoved due to its large mass).

  It's crucial to note the two forces in a third-law pair do not cancel out because they act on different systems. The third law is often demonstrated (证实) by the example of a kicking a football: the foot exerts a force on the ball, and the ball exerts an equal and opposite force on the foot. This reaction force is what causes the sensation (感觉) of the kick.

- **Equilibrium:** When all forces on an object balance out (net force = 0), the object is in equilibrium. According to Newton's first law, it will either remain at rest or move with constant velocity. For example, a book resting on a table is in equilibrium: the upward normal force from the table equals the book's weight (downward force of gravity), resulting in no acceleration.

Bibliography

[1] Ann Fullick with Frank Sochacki. *Pearson Edexcel International AS/A Level Biology Student Book 1*. Pearson Edexcel, 2021.

[2] Ann Fullick with Frank Sochacki. *Pearson Edexcel International AS/A Level Biology Student Book 2*. Pearson Edexcel, 2021.