Studievereniging Congo

Samenvatting Molecuul tot Cel

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Chapter 1: studying life

1.1 What is biology?

- Biology: the scientific study of living organisms, including their characteristics, functions and interactions.
- All organisms are related to one another through common descent.
- Cells evolved early in the history of life.
- Cellular specialization: allowed multicellular organisms to increase in size and diversity.
- The instructions for a cell are contained in its genome, which consists of DNA molecules made up of sequences of nucleotides.
- Specific segments of DNA called genes contain the information the cell uses to make proteins.
- Photosynthesis: provided a means of capturing energy directly from sunlight and over time changed Earth's atmosphere.
- Evolution: change in the genetic makeup of biological population through time.
- Evolution is a fundamental principle of life.
- Populations evolve through several different processes, including natural selection, which is responsible for the diversity of adaptations found in living organisms.
- 3 ways to reconstruct the history of life:
    - Fossils
    - Anatomical similarities and differences
    - Molecular comparison of genomes
- 3 domains
    - Bacteria
    - Archea
    - Eukarya (yeast, animals, plants, protists)
- Life can be studied at different levels of organization within a biological hierarchy (atoms → molecules → cells → tissues → organs → organ systems → organisms → populations → community → ecosystem).
- Living organisms, whether unicellular or multicellular, must regulate their internal environment to maintain homeostasis: the range of physical conditions necessary for their survival and function.

1.2 How do biologists investigate life?

- Scientific methods combine observation, gathering information (data), experimentation and logic to study the natural world.
- 5 steps:
    - Making observations
    - Asking questions
    - Forming a hypotheses
    - Making predictions
    - Testing those predictions

- Hypotheses: tentative answers to questions.
- Predictions made on the basis of a hypotheses are tested with additional observations and 2 kinds of experiments:
    - Comparative experiments
    - Controlled experiments
- Quantifiable data are critical in evaluating hypotheses.
- Statistical methods are applied to quantative data to establish whether or not the differences observed could be the result of chance.
- These methods start with the null hypothesis: there are no differences.
- Biological knowledge obtained from a model system may be generalized to other species.

1.3 Why does biology matter?

- 5 reasons:
    - Agricultural production
    - Understanding and treating of human disease
    - Advising the government
    - Understanding of the behaviour of organisms
    - Understanding and appreciating the diverse living world

Chapter 4: molecular interactions

4.1 Chemical bonding versus non-covalent interactions

- 6 keys types of non-covalent interaction, other than ionic bonds:
    - Dispersion forces
    - Permanent dipolar interactions
    - Steric repulsion
    - Hydrogen bonds
    - Ionic interaction
    - Hydrophobic forces
- Individual non-covalent interactions are relatively weak but gain significance because many such interactions can occur between two molecules: we see strength in numbers.
- Molecular interactions operate at 2 levels:
    - Intramolecular: between separate parts of the same molecule.
    - Intermolecular: between different molecules.

4.2 Electrostatic forces

- A majority of molecular interactions are electrostatic: they are based on the notion of opposite charges attracting/repelling on another.

- Dipole: consists of a positive charge and a negative charge, which are separated in space within a molecule.
- Dipole moment: the difference in charge between two ends of a dipole.
- Permanent dipole: a molecule that has a permanently partially positively charged region and a permanently partially negatively charged region.
- A molecule that contains polar bonds will be non-polar overall if it comprises identical atoms that are arranged symmetrically relative to one another.

4.3 The van der Waals interaction

- Van der Waals interaction:
    - Dispersion forces
    - Permanent dipolar interactions
    - Steric repulsion
- Dispersion forces occur between all molecules, whether or not these molecules carry an electrical charge.
- As a result of the continuous movement of electrons, the electrons in non-polar molecules are never totally equally distributed.
- The slight negative charge is sufficient to induce a slight positive charge in the neighbouring areas, generating an induced dipole.
- Dispersion force: the force of attraction that exists between the two areas of opposite charge, which form the induced dipole.
- 3 characteristics:
    - They are very short-lived
    - They are very weak
    - They operate over very short distances
- The prevalence of dispersion forces between 2 molecules is influenced by:
    - Their shape
        - Two planar molecules have many points of close association → stronger dispersion forces.
        - Two irregular molecules have few points of close association → weaker dispersion forces.
    - Their size
        - Small molecules have few electrons → limited opportunities for induced dipoles.
        - Larger molecules have more electrons → more opportunities for induced dipoles.
- While dispersion forces are short-lived forces arising from temporary induced dipoles, permanent dipolar interactions are long-lived forces arising from permanent dipoles.
- Induced dipole force: a permanent dipole on a polar molecule induces a temporary dipole in a non-polar molecule.
- Steric repulsion: the electrons on the surface of two molecules carry the same charge, and will therefore repel each other.
- The van der Waals interaction describes the overall level of interaction between two species once both attractive and repulsive forces have been taken into account.

4.4 Other biologically essential interactions

- Hydrogen bond: special class of dipolar interaction.
- Dependent upon the presence of 2 electronegative atoms:
    - Hydrogen bond donor: a hydrogen atom bonded to an electronegative atom.
    - Hydrogen bond acceptor: an electronegative atom, which possesses a non-bonding pair of electrons.
- The electronegative atoms are usually nitrogen, oxygen or fluorine.
- The three nuclei that participate in a hydrogen bond must lie in a straight line for a hydrogen bond to be at its strongest.
- Hydrogen bonding stabilizes the structure of several key biological molecules, including DNA and polypeptides. It also ensures the fidelity of biological processes such as translation.
- Ionic forces: permanent attractive forces that operate between regions of permanent opposite charge within a molecule.
- Salt bridge: the ionic force that operates between 2 oppositely charged amino acid side chains in a protein.
- Broadly speaking:
    - Polar molecules are hydrophilic
    - Non-polar molecules are hydrophobic
- Hydrophobic forces drive the shielding of (parts of) hydrophobic molecules from their aqueous surroundings.

4.5 The impact of molecular interactions on water solubility

- Solution: comprises of solvent in which a solute is dissolved.
- A water-soluble compound can mix completely with molecules of water.
- The mixing of water-soluble compounds with water can be stabilized by either hydrogen bonds or by hydratation.
- A water-soluble compound may be soluble in a different solvent.

4.6 The three phases of matter

- The phase of a substance at a given temperature is determined by the nature and extent of the molecular interactions it experiences.

	Number of molecular interactions	Shape of substance	Degree of movement of molecules	Relative energy
Solid Liquid Gas	Many Few Virtually none	Fixed Variable Unrestricted	Virtually none Moderate High	Low Medium High

- A substance's phase is influenced by how much energy it possesses – which determines the degree of movement of its composite molecules.
- The phase of a substance can be changed by heating or cooling.
- Melting: the transition from solid to liquid, associated with a decrease in intermolecular forces.
- Vaporization: the transition from liquid to gas, associated with a further decrease in intermolecular forces.
- Condensation: the transition from gas to liquid, associated with an increase in intermolecular forces.
- Solidification: the transition from liquid to solid, associated with a further increase in intermolecular forces.
- Sublimation: the transition from solid to gas, without passing through a liquid phase.
- Deposition: the transition from gas to solid, without passing trough a liquid phase.
- Polar molecules have relatively high melting points and boiling points.
- Non-polar molecules have relatively low melting points and boiling points.

Chapter 5: cells

5.1 What features make cells the fundamental units of life?

- Cell theory:
  - Cells are the fundamental units of life
  - All living organisms are composed of cells
  - All cells come from preexisting cells
- Plasma membrane: surface of every cell, and it has more or less the same structure in every cell.
- It consists of a phospholipid bilayer with protein and other molecules embedded.
- Functions:
  - Selectively permeable barrier
  - Allows the cell to maintain a constant internal membrane.
  - Important in communication and receiving signals.
  - Often have proteins for binding/adhering to adjacent cells.
- 2 types of cells:
  - Prokaryotes: no nucleus or other membrane-enclosed compartments; lack distinctive organelles.
    - Bacteria, archea
  - Eukaryotes: nucleus and other membrane-enclosed compartments and organelles.
    - Yeist, plants, animals

5.2 What features characterize prokaryotic cells?

- All prokaryotic cells have the same basic structure:
    - Enclosed in a plasma membrane.
    - DNA is contained in the nucleoid.
    - The rest of the material enclosed in the plasma membrane is the cytoplasm, which consists of cytosol and insoluble particles.
    - Contain free ribosomes.
- Eukaryotic cells are much larger than prokaryotic cells.
- Most prokaryotes have a cell wall located outside the plasma membrane, which supports the cell and determines its shape.
- Some prokaryotes swim by using flagella.

5.3 What features characterize eukaryotic cells?

- Compartmentalization is the key to eukaryotic cell function.
- Each organelle has a specific role defined by chemical processes.
- Nucleus: contains most of the genetic information, largest organelle.
- Functions:
    - DNA replication
    - Site where gene transcription is turned on or off.
    - Assembly of ribosomes begins in the nucleolus.
- Nucleus is surrounded by the nuclear envelope: separates DNA transcription from DNA translation (nuclear pores).
- The nuclear envelope is continuous with the ER.
- Nuclear lamina: network of filaments inside the nuclear envelope, which interacts with chromatin to support the envelope.
- Ribosomes:
    - Site of protein synthesis.
        - Prokaryotes: free in cytoplasm.
        - Eukaryotes: free or attached to ER in cytoplasm; inside mitochondria; inside chloroplasts (plastids).
    - Consist of RNA and 50 other proteins.
- Endomembrane system: includes plasma membrane, nuclear envelope, ER, Golgi apparatus, lysosomes, endosomes.
- Membrane surrounded vesicles shuttle substances between the various components.
- ER (endoplasmatic reticulum):
    - RER: major site of protein synthesis; modification of proteins in lumen; has ribosomes attached.
    - SER: more tubular; modification of small toxic molecules; glycogen degradation (in animals); synthesis of lipids/steroids; stores calcium ions; no ribosomes attached.
- Golgi apparatus: composed of flattened sacs (cisternae) and small membrane enclosed vesicles.
- Functions:
    - Receives protein-containing vesicles from ER
    - Modifies/concentrates/packages/sorts proteins
    - Adds carbohydrates to proteins

    - Synthesis of polysaccharides (in plants)
- Cis region: receives vesicles from ER
- Trans region: vesicles bud off to plasma membrane.
- Vesicles: vesicles containing digestive enzymes that originate from Golgi; sites for breakdown of food and other foreign material by phagocytosis.
- Autophagy: digestion of spend cellular energy in lysosomes.
- Mitochondria: the production of ATP, using fuel molecules and oxygen (cellular respiration); cells that require a lot of energy have a lot of mitochondria.
- Mitochondria have 2 membranes: outer lipid bilayer and a highly folded inner membranes (folding gives rise to cristae).
- Mitochondrial matrix: region enclosed by inner membrane; contains DNA, ribosomes and various proteins.
- Plastids:
    - Chloroplasts: site of photosynthesis
        - Double membrane: internal membrane is arranged as thylakoids and grana (contain chlorophyll/pigments).
        - Grana are suspended in the stroma (contains ribosomes and DNA).
- Peroxisomes: organelles that are specialized to compartmentalize toxic peroxides, and break them down using enzymes.
- Glyoxysomes: organelles that are specialized to convert lipids into carbohydrates for growth (in plants).
- Vacuoles: only in plants and protists.
- Functions:
    - Storage of waste products and toxic compounds.
    - Provide structure for plant cells (turgor).
    - Storage of anthocyanins in flowers and fruits.
    - The vacuoles in seeds contain enzymes that hydrolize stored proteins for early growth.
- Cytoskeleton: network of fibers in cells.
- Functions:
    - Support and maintains cell shape
    - Holds organelles in position
    - Moves organelles
    - Involved in cytoplasmic streaming
    - Interacts with extracellular structures to hold the cell in place.
- 3 components:
    - Microfilaments (actine)
    - Intermediate filaments (keratin)
    - Microtubulus (tubulin)
- Microfilaments: smallest diameter, made up out of actine.
- Actin has “plus” and “minus” ends (permit actine to interact with one another to form long, double helical chains, reversible).
- Functions:
    - Help entire cells or parts of the cell to move.
    - Determine and stabilize cell shape.
    - Cytoplasmic streaming.
    - In muscle cells: microfilaments and myosine (motor proteins) strand together to drive the contraction of muscles.

    - Involved in the formation of pseudopodia (cellular extension that allow the cell to move).
    - Support the microvilli the line the intestine.
- Intermediate filaments: made up out of keratin, tough, rope-like.
- Functions:
    - Anchor cell structure in place (desmosomes)
    - Resist tension
    - Make up the nuclear lamina
- Microtubulus: largest diameter, made up out of tubulin.
- Long, hollow cylinders, which has “plus” and “minus” ends.
- Tubulin consists of 2 subunits: alpha-tubulin and beta-tubulin: microtubuli lengthen and shorten by adding or subtracting tubulin dimers.
- Functions:
    - Form a rigid internal skeleton for some cells.
    - Act as framework along which motor proteins can move structures within a cell.
- Dynein: binds to microtubuli (doublets) and allows them to slide past each other.
- Kinensin: binds to a vesicle and “walks” it along by changing shape (from “minus” to “plus”).
- Cilia and flagella are made of microtubulus.
- Cilia: short, usually many present, move with stiff power and flexible recovery stroke.
- Flagella: longer, usually one or two present, move like a snake.
- Nexin: cross-links the doublets and prevents them from sliding.
- Dyneine and nexin cause friction together, which results in bending of the cilia and flagella.

5.4 What are the roles of extracellular structures?

- Extracellular structures: secreted to the outside of the plasma membrane (in eukaryotes: prominent fibrous molecule in a gel-like medium).
- Plant cell wall: composed of cellulose fibers embedded in a matrix of other complex polysaccharides and proteins.
- Functions:
    - Provides support by remaining rigid
    - Barrier to infection
    - Adjecent plant cells are interconnected by the plasmamodesmata through the cell walls.
- Multicellular animals have an extracellular matrix composed of fibrous proteins (such as collagen) and glycoproteins (such as proteoglycans).
- Function:
    - Holds cells together in tissues.
    - Contributes to bone, cartilage, skin, etc.
    - Filters material passing between tissues.
    - Orients cell movement in development and repair.
    - Chemical signalling.

5.5 How did eukaryotic cells originate?

- Endosymbiosis: mitochondria and chloroplasts were prokaryotic organisms, which somehow became incorporated in a larger cel.
- Mitochondria and chloroplast have their own DNA, ribosomes, double membrane, etc.

Chapter 6 – cell membranes

6.1 What is the structure of a biological membrane?

- The general structure of membranes is known as the fluid mosaic model.
    - Mosaic: made up of many discrete components.
    - Fluid: the components can move freely.
- The lipids in biological membranes are usually phospholipids.
- Structure of phospholipids:
    - Hydrophilic regions: phosphorus containing “head”, polar.
    - Hydrophobic regions: fatty acid “tails”, non polar.
- All biological membranes have a similar structure, but they differ in the kinds of proteins and lipids they contain.
- Phospholipids can differ in terms of:
    - Fatty acid chain length (number of carbon atoms)
    - Degree of saturation (number of double bonds)
    - Polar groups
- Membranes may be up to 25% cholesterol.
- Fluidity depends on:
    - Temperature
    - Lipid composition
- Lateral diffusion: exchange with neighbours in the same monolayer.
- Flip-flop: exchange between monolayers.
- Rotation: turning around the lipid axis.
- A fatty acid chain with a double bond is unsaturated; a fatty acid chain without a double bond is saturated.
- The fluidity of membranes is increased by:
    - Shorter fatty acid chain length
    - Unsaturated lipids
    - Increasing temperature
    - Decreasing cholesterol
- Plants have more unsaturated lipids (lower temperature).
- Mammals have more saturated lipids (higher temperature).
- Membranes contain proteins.
- Two general types of membrane proteins:
    - Integral membrane proteins: at least partly embedded in the phospholipid bilayer, hydrophilic and hydrophobic regions.

        - Transmembrane proteins: extend all the way through the phospholipid bilayer, hydrophilic ends on either side.
    - Peripheral membrane proteins: not embedded in the bilayer.
- Transmembrane proteins may have different domains on either side of the membrane.
- Membranes have carbohydrates on the outer surface that serve as recognition sites for other cells and molecules.
    - Glycolipids: carbohydrate + lipid
    - Glycoproteins: carbohydrate + protein
- Some membrane proteins can move freely within the bilayer, while some are anchored to a specific region.

6.2 How is the plasma membrane involved in cell adhesion and recognition?

- Glycoproteins are involved in:
    - Cell recognition, in which one cell specifically binds to another cell of a certain type.
    - Cell adhesion, in which the connection between two cells is strengthened.
- Homotypic binding: the same molecules stick out of both cells and the exposed surfaces bind to each other.
- Heterotypic binding: different molecules stick out of both cells and the exposed surfaces bind to each other.
- Cell junctions: specialized structures that hold cells together.
- 3 types:
    - Tight junctions
        - Link adjacent epithelial cells
        - Prevent substances from moving between adjacent cells.
    - Desmosomes
        - Hold neighbouring cells firmly together.
        - Provides mechanical stability for tissues such as skin.
    - Gap junctions
        - Channels that run between membrane pores in adjacent cells.
        - Allow substances to pass between cells.
- The transmembrane protein integrin binds to the extracellular matrix outside the cell and to the actin filaments inside the cell, noncovalent and reversible.
- Cells can move within a tissue by the binding and reattaching of integrin to the extracellular matrix (important for cell movement within developing embryos).

6.3 What are the passive processes of membrane transport?

- Membranes have selective permeability: some substances can pass through, but other cannot.
- 2 types:
    - Passive transport: requires no energy.
    - Active transport: requires energy.

- The energy for passive transport of a substance comes from the difference between its concentration on one side of the membrane and its concentration on the other side: concentration gradient.
- Diffusion: the process of random movement toward equilibrium.
- How fast a substance diffuses depends on 3 factors:
    - Diameter of the molecules or ions
    - Temperature of the solution
    - Concentration gradient
- Small molecules can move across the lipid bilayer by simple diffusion.
- Polar and charged molecules cannot move a readily across the lipid bilayer (except water).
- Osmosis: the diffusion of water; water diffuses from a region of its higher concentration (low concentration of solutes, hypotonic solution) to a region of its lower concentration (higher concentration of solutes, hypertonic solution).
- 3 terms:
    - Hypertonic solution: high solute concentration than the other solution.
    - Isotonic solution: equal solute concentration.
    - Hypotonic solution: lower solute concentration than the other solution.
- Facilitated diffusion: substances diffuse according to their concentration gradients, but diffusion is facilitated by:
    - Channel proteins
    - Carrier proteins
- Ion channels: specific channel proteins with hydrophilic pores, gate opens when the channel protein is stimulated to change shape, the stimulus can be:
    - Molecule (ligand-gated)
    - Electrical charge (voltage-gated)
- Aquaporins: channel proteins specific to water.

6.4 What are the active processes of membrane transport?

- Active transport: moves substances against their concentration and/or electrical gradient, requires energy (often ATP).
- 3 types of proteins:
    - Uniporters: moves a single substance in one direction.
    - Symporter: moves two substances in the same direction.
    - Antiporter: moves two substances in opposite directions.
- 2 types:
    - Primary active transport: involves the direct hydrolysis of ATP.
    - Secondary active transport: does not use ATP directly, energy is supplied by an ion concentration gradient that is established by primary active transport.

	Simple diffusion	Facilitated diffusion (through channel or carrier)	Active transport
Cellular energy required?	No	No	Yes

Driving force	Concentration gradient	Concentration gradient	ATP hydrolysis (against concentration gradient)
Membrane protein required?	No	Yes	Yes
Specifity	No	Yes	Yes

6.5 How do large molecules enter and leave a cell?

- Macromolecules (proteins, polysaccharides, nucleic acids) are too large to cross the membrane.
- They can be taken in or secreted by means of membrane vesicles.
- Endocytosis: a group of processes that bring small molecules, macromolecules, large particles and even small cells into the eukaryotic cell.
- 3 types:
    - Phagocytosis: part of the plasma membrane engulfs large particles or even entire cells, relatively non-specific.
    - Pinocytosis: part of the plasma membrane engulfs small dissolved substances or fluids, much smaller vesicles than phagocytosis, relatively non-specific.
    - Recepter-mediated endocytosis: highly specific, depends on receptor proteins (integral membrane proteins) to bind to specific substances, sites are coated pits (coated with clathrin, which strengthens and stabilizes the vesicle).
- In all three, the plasma membrane invaginates, forming a small pocket around materials from the environment, which then deepens, forming a vesicle, which separates from the plasma membrane and migrates with its content to the cell.
- Mammalian cells take in cholesterol by receptor-mediated endocytosis:
    - In the liver, cholesterol is packaged into LDL, and secreted into the bloodstream.
    - Cells that need cholesterol have receptors for the LDLs in the coated pits.
    - Hypercholesterolemia: deficient LDL receptor, resulting in dangerously high levels of cholesterol in the blood.
- Exocytosis: the process in which materials (indigestible materials, digestive enzymes, neurotransmitters, et cetera) packaged in vesicles are secreted from a cell when the vesicle membrane fuses with the plasma membrane.

Chapter 7: cell communication and multicellularity

7.1 What are signals, and how do cells respond to them?

Signal transduction pathway: a sequence of molecular events and chemical reactions that lead to a cells response to a signal.

Chemical signaling systems:

Autocrine signals bind to receptors on the same cell that secretes them.

Juxtacrine signals bind to receptors on adjacent cells.

Paracrine signals bind to receptors on nearby cells.

Hormones are transported by the circulatory system and bind to receptors on distant cells.

Crosstalk: interactions between different signal transduction pathways.

7.2 How do signal receptors initiate a cellular response?

Ligand: a molecule that binds to a receptor site on another molecule; binding of the ligand causes the receptor protein to change its 3D-shape and that conformational change initiates a cellular response.

Affinity: the likelihood that the receptor will bind to the ligand at any given ligand concentration.

R + L <——> RL

Rate of binding: $K_1[R][L]$

Rate of dissociation: $K_2[RL]$

$K_1[R][L]=K_2[RL]$

$([R][L])/[RL]=K_2/K_1=KD$

Dissociation constant (KD): a measure of the affinity of the receptor for its ligand; the lower the KD of a receptors, the more sensitive the cell will be to the ligand.

An **inhibitor/antagonist** can also bind to a receptors protein, instead of a normal ligand.

Example: caffeine binds to the adenosine receptor instead of adenosine (neurotransmitter; reduces brain activity) itself, but does not initiate a signal transduction pathway.

Two locations for receptors:

Membrane receptors (large or polar ligands)

Ion channel receptors

Example: acetylcholine binds to two of the five AChR subunits, causing the channel to change shape and open; the channel is lined with negatively charged amino acids, allowing sodium ions to flow into the cell; sodium ion buildup in the cell leads to muscle contractions.

Protein kinase receptors

Example: the alfa subunits of the receptor bind insulin; a conformational change in the beta subunits transmit a signal to the cytoplasm that insulin is present; the insulin signal activates the receptor's protein kinase domain in the cytoplasm, which phosphorylates insulin-response substrates, triggering a cascade of chemical responses inside the cell.

G protein-linked receptors (intermediary between receptor and effector)

Example: hormone binding to the receptor activates the G protein, GDP is replaced by GTP; part of the activated G protein activates an effector protein that causes changes in cell function; GTP on the G protein is hydrolyzed to GDP.

Intracellular receptors (small or nonpolar ligands)

Chapter 8: energy, enzymes and metabolism

8.1 What physical principles underlie biological energy transformations?

Chemical reaction: occurs when atoms have sufficient energy to combine to change their bonding partners.

Metabolism: the sum total of all the chemical reactions occurring in a biological system at any given time.

Energy (in biochemistry): the capacity for change.

Two basic types of energy:

Potential energy: energy of state or position.

Kinetic energy: energy of movement.

Potential energy can be converted into kinetic energy and vice versa, and the form that the energy takes can also be converted.

Anabolic reactions (collectively **anabolism**): link simple molecules to form more complex molecules; require an input of energy; energy is captured in the chemical bonds that are formed.

Catabolic reactions (collectively **catabolism**): break down complex molecules into simpler ones and release the energy stored in the chemical bonds.

First law of thermodynamics: energy is neither created nor destroyed; the total energy before and after the conversion is the same.
Second law of thermodynamics: when energy is converted from one form to another, some of that energy becomes unavailable for doing work.
Entropy (S): a measure of the disorder in a system.
Enthalpy (H): in biological systems, the total energy.
Free energy (G): the useable energy that can do work.
H=G+TS
G=H-TS
dG(reaction)=G(products)-G(reactants)
dG=dH-TdS
If dG is negative (dG < 0), free energy is released; if dG is positive (dG > 0), free energy is required.
The second law of thermodynamics also predicts that, as a result of energy transformations, disorder tends to increase; some energy is always lost to random thermal motion (entropy).
Catabolic reactions may break down an ordered reactant into smaller, more randomly distributed products.
Exergonic reactions: reactions that release free energy (-dG); complex molecules —> free energy + small molecules.
Anabolic reactions may make a single product out of many smaller reactants.
Endergonic reactions: reactions that require free energy (+dG): free energy + small molecules —> complex molecules.
Chemical equilibrium: the balance between forward and reverse reactions.
8.2 What is the role of ATP in biochemical energetics?
Free energy that is released by exergonic reactions is captured in **ATP** from **ADP** and **Pi.**
ATP releases a relatively large amount of energy when hydrolyzed to ADP and Pi.
Phosphorylation: the donation of a phosphate group.
ATP can phosphorylate many different molecules, which gain some of the energy that was stored in ATP.
An ATP molecule consists of the nitrogenous base **adenine** bonded to **ribose**, which is attached to a sequence of three **phosphate groups**.
A molecule of ATP can be hydrolyzed either to ADP and Pi or to **AMP** and **Pi**.

Chapter 9: pathways that harvest chemical energy
9.1 How does glucose oxidation release chemical energy?
Five principles govern metabolic pathways:
A complex chemical transformation occurs in a series of separate reactions that form a metabolic pathway.
Each reaction is catalyzed by a specific enzyme.
Many metabolic pathways are similar in all organisms.
In eukaryotes, many metabolic pathways are compartmentalized.
Some key enzymes in each metabolic pathway can be inhibited or activated.
Three catabolic processes:
Glycolysis: glucose is converted to two molecules of **pyruvate** and a small amount of energy is formed; anaerobic.
Cellular respiration: pyruvate is completely converted into three molecules of **CO2** through **pyruvate oxidation**, **the citric acid cycle/the Krebs cycle** and the **respiratory chain**; aerobic.
Fermentation: pyruvate is converted into lactic acid or ethanol, which are still relatively energy-rich molecules; anaerobic.
The coenzyme NAD+ acts as an **electron carrier** in **redox reactions**.
NAD+ exists in two chemically distinct forms, one **oxidized (NAD+)** and the other **reduced (NADH)**.
9.2 What are the aerobic pathways of glucose catabolism?
Chapter 9: isomerism

9.1 What are isomers?
Isomers: groups of compounds that comprise exactly the same atoms, but have different structures and often different physical and chemical properties too.
2 types:
Structural isomers: comprise the same atoms, joined together in different ways - they exhibit different **connectivities**.
Stereoisomers: comprise the same atoms, which are connected to one another in the same way, but they exhibit different **configurations** (how their atoms are arranged in 3D space).
9.2 Structural isomers
Structural formula: tells us how different atoms are connected to one another in a molecule.
The number of possible structural isomers increases dramatically as we consider hydrocarbon chains of increasing length.
2 possible sources for structural isomerism:
The position of functional groups
The structure of the carbon framework
Structural isomers may belong to different families of organic compound.
Tautomers: pairs of structural isomers, which differ only in the position of a hydrogen atom.
Tautomerism: the conversion between the two structural isomers.
Example: **keto-enol tautomerism**
9.3 Cis-trans isomerism
Cis-trans isomers: share the same atoms, which are joined to one another in the same way, but have different configurations.
2 characteristics:
The molecules possess at least one double bond.
The molecules are cyclic.
In a **cis isomer** the groups lie on the same side of the double bond.
In a **trans isomer** the groups lie on opposite sides of the double bond.
Cis-trans isomerism occurs only when the carbon atom at each end of the double bond has different groups attached to it.
Cis-trans isomers are distinguished by using the **E/Z nomenclature**.
Cyclic structures can also exhibit cis-trans isomerism:
Cis: groups are oriented in the same way relative to the plane of the ring.
Trans: groups are oriented in opposite directions relative to the plane of the ring.
9.4 Enantiomers and chirality
Enantiomers: molecules whose atoms are the same, are joined together in exactly the same way, but which occupy different positions in space (thus, stereoisomers, like cistransisomers);
pairs of different molecules that are non-superimposable **mirror images** of one another.
Structures that cannot be superimposed upon their mirror image are **chiral**.
Enantiomers are chiral molecules.
Diastereoisomers: pairs of stereoisomers that are not mirror images (and so are not enantiomers).
A chiral object lacks a plane of symmetry - it as **asymmetric**.Glycolysis takes place in the cytosol, and involves ten enzyme catalyzed reactions.
Glycolysis can be divided into two stages:
Energy-investing reactions
Energy-harvesting reactions
Two types of reactions that occur repeatedly in glycolysis:
Oxidation-reduction (example: the energy is trapped via the reduction of NAD+ to NADH)
Substrate-level phosphorylation (example: a phosphate is directly transferred from the substrate to ADP, forming ATP).
To summarize:

Each glucose yields: two pyruvate, 2ATP and 2NADH + H+.
Pyruvate is transported into the mitochondrial matrix, where pyruvate oxidation occurs to produce a two-carbon compound **acetate** and CO_2; acetate is bound to **coenzyme A** to form **acetyl CoA**.
Acetyl CoA is the starting point for the citric acid cycle, by donating its acetyl group to the four-carbon compound **oxaloacetate**, forming the six-carbon compound **citrate**.
The citric acid cycle consists of eight reactions to completely oxidize acetyl CoA to two molecules of CO_2.
To summarize:
The inputs to the citric cycle are acetyl CoA, water, GDP and NAD+/FAD.
The outputs are CO_2, NADH/$FADH_2$ and a small amount of GTP (which is transferred to ATP).
So during glycolysis, pyruvate oxidation and the citric acid cycle $6CO_2$, 10NADH, $2FADH_2$ and 4ATP is produced.
9.3 How does oxidative phosphorylation form ATP?
Oxidative phosphorylation: the overall process of ATP synthesis resulting from the oxidation of electron carriers in the presence of O_2.
Electron transport: the electrons from NADH and $FADH_2$ pass through the

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Chapter 10: photosynthesis: energy from sunlight
10.1 What is photosynthesis?
Photosynthesis: an anabolic process by which the energy of sunlight is captured and used to convert CO_2 into more complex carbon-containing compounds.
Two main pathways:
Light reactions: convert light energy into chemical energy in the form of ATP and NADPH.
Light-independent reactions: do not use light directly, but use ATP, NADPH (made by the light reactions) and CO_2 to produce carbohydrates.
The reactions of both pathways occur within the **chloroplast**, but in different parts of the organelle.
10.2 How does photosynthesis convert light energy into chemical energy?
Light: form of **electromagnetic radiation** (particles and waves).
When a photon meets a molecule, one of three things can happen:
The photon may bounce off the molecule - it may be scattered or reflected.
The photon may pass through the molecule - it may be **transmitted**.
The photon may be absorbed by the molecule, adding energy to the molecule.
When the molecule acquires energy of the photon, it is raised from a **ground state** (with lower energy) to an **excited state** (with higher energy).
Pigments: molecules that absorb wavelengths in the visible spectrum (for example: chlorophyll alfa, chlorophyll beta, carotene).
Absorption spectrum: the light absorbed by a pigment plotted against the wavelength.
Action spectrum: the rate of photosynthesis carried out by an organism plotted against the wavelengths to light to which it is exposed.
Chlorophyll alfa has a complex ring structure, with an magnesium ion at the center; the long hydrocarbon tail anchors chlorophyll alfa to proteins within the photosystem.
Chlorophyll alfa and various accessory pigments are arranged into **light-harvesting complexes**.
Multiple light-harvesting complexes surround a single **reaction center** within the photosystem.
Light is captured by the light-harvesting complex and transferred to the reaction center, where chlorophyll alfa converts light energy to chemical energy, which leads to the oxidization of chlorophyll alfa (Chl*).
Within a light-harvesting complex, the energy released by a pigment molecule is absorbed by other, adjacent pigment molecules and passed from molecule to molecule until it reaches a chlorophyll alfa molecule at the reaction center of the photosystem.
Two photosystems:

Photosystem I: absorbs light energy best at 700 nm; passes excited electrons to NADP+, reducing it to NADPH.
Photosystem II: absorbs light energy best at 680 nm; oxidizes water molecules and passes excited electrons through a series of carriers to produce ATP.
Noncyclic electron transport uses the two photosystems.
Cyclic electron transport traps light energy as ATP: the Chl* in the reaction center of photosystem I passes electrons to **ferredoxin**, leaving a positively charged chlorophyll alfa (Chl+); the carrier of the electron transport chain is in turn reduced; energy from electron flow is captured for chemiosmotic synthesis of ATP; the last reduced electron carrier passes electrons to electron-deficient chlorophyll alfa, allowing the reactions to start again.
The mechanism of chemiosmotic synthesis of ATP in chloroplasts are similar to chemiosmosis in the mitochondrion; in chloroplasts, protons flow out of the thylakoid

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Chapter 10: biological macromolecules
10.1 Amino acids and proteins
To the central carbon in an amino acid are 4 different groups attached:
An amino group (-NH2)
A carboxyl group (-COOH)
A hydrogen atom (-H)
A variable side chain
Zwitterion: a single species containing both positively- and negatively-charged regions, but which carries no overall charge (for example: amino acid).
The twenty amino acids each have contrasting chemical characteristics that are determined by the composition of the variable side chain.
Hydrophobic - hydrophilic
Acids - bases
Polypeptides are **polymers** of amino acids.
Multiple polypeptides form **proteins.**
Neighbouring amino acids residues in a polypeptide chain are joined by a **peptide bond**.
A polypeptide has an:
N-terminus: -NH2
C-terminus: -COOH
The structure of proteins is build up on 4 levels:
Primary structure: describes the identity of amino acids that have joined to form the polypeptide, and the order in which they have joined.
Secondary structure: describes the way that the primary structure folds into regions exhibiting characteristic 3D shapes; different amino acids favor the formation of different secondary structures.
Alfa-helices: regions of coiled polypeptide
Beta-sheets: stacked 'sheets' of polypeptide
Beta-turns: link the stacked sheets of a beta-sheet.
Tertiary structure: describes the packing of regions of secondary structures into a defined 3D shape.
Beta-barrel: formed from the curling round of beta-sheets.
Coiled coil: formed from the packing of neighbouring is alfa-helices; stabilized by hydrophobic interactions between helices.
Quaternary structure: describes the way in which the component subunits of a protein assemble to form the complete, functional entity.
Protein structure is stabilized by non-covalent interactions (hydrogen bonds and hydrophobic interactions) and covalent bonding (disulfide bonds).
10.2 Nucleic acids
2 types of nucleic acids:
DNA
RNA
DNA and RNA are polymers of nucleotides.

Nucleotides comprise 3 elements:
A nitrogenous base
A sugar (5 carbon pentose)
A phosphate group
DNA contains 4 different bases:
Adenine (A)
Cytosine (C)
Guanine (G)

Chapter 11: the cell cycle and cell division
11.1 How do prokaryotic and eukaryotic cells divide?
In order for a cell to divide, 4 events must occur:
Reproductive signal
Replication of DNA
Segregation
Cytokinesis
Most prokaryotes have one circular chromosome.
Prokaryotes divide by **binary fission**:
Most prokaryotes have one circular chromosome.
As the DNA replicates, each of the two resulting chromosomes attaches to the plasma membrane.
New plasma membrane is added between attachment points, and the chromosomes move apart.
Cytokinesis separates one cell into two daughter cells, each with one chromosome.
11.2 How is eukaryotic cell division controlled?
The reproduction of eukaryotic cells is typically characterized by 3 steps:
The replication of the DNA within the nucleus.
The packaging and segregation of the replicated DNA into two new nuclei (= **nuclear division**).
The division of the cytoplasm (= **cytokinesis**)
Meiosis: results in four different daughter cells (basis of **sexual reproduction**).
Mitosis: results in two identical daughter cells, thus **clones** (basis of **asexual reproduction**).
Cell cycle: the period from one cell division to the next.
Interphase (the phase between two cell divisions; longest phase) has 3 sub phases:
G1 phase: each chromosome is a single, unreplicated DNA molecule with associated proteins; cells that do not divide are usually arrested during G1.
S phase: DNA replication occurs; each chromosome is duplicated and thereafter consists of two sister chromatids.
G2 phase: the cell makes preparations for mitosis.
Transitions from G1 to S and G2 to M depend on the activation of **cyclin-dependent kinases/Cdk's**.
The binding of **cyclin** to Cdk's exposes the active site of the Cdk; a protein substrate and ATP can bind to Cdk; the protein substrate is phosphorylated; the phosphorylated protein regulates the cell cycle.
Retinoblastoma/RB blocks the cell cycle (at a **restriction point**); to begin S phase, a cell must get by the RB block; so: RB (active, blocks cell cycle progress) —> cyclin-Cdk —> RB-P (inactive, allows cell cycle progress).
The different cyclin-Cdk's act at cell cycle checkpoints, signaling pathways that regulate the cell cycle's progress.
G1: DNA damage
S: incomplete replication or DNA damage
G2: DNA damage
M: chromosome unattached to spindle.
Growth factors can stimulate cells to divide.
11.3 What happens during mitosis?

Chapter 12: chemical reactions I

12.1 What is chemical reaction?

Chemical reaction: chemical change occurring within one compound, or an interaction between two or more starting compounds, to form one or more end compound, which are different from the compound(s) we started with.

Reactants: starting compounds.

Products: compounds generated by the chemical reaction.

Reaction scheme: depicts the overall chemical change that occurs when reactants form products.

A reaction scheme tells us 2 things:

The identity of the reactants and products

The relative quantities of the reactants and products

Stoichiometry: the relative quantities of reactants and products associated with a particular reaction.

Stoichiometric coefficient: the relative number of species participating in the reaction (indicated by the number in front of the chemical formula).

12.2 The molecular basis of chemical reactions

Chemical reactions involve the **breaking** of bonds between atoms in molecules and the **formation** of new bonds between different groups of atoms to form products.

Breaking of existing bonds and formation of new bonds involves the **redistribution** of valence electrons.

2 ways of redistribution:

A pair of valence electrons moves together, remaining as a pair.

A pair of valence electrons splits up and they move separately, as single entities.

Heterolytic cleavage: occurs when the valence electrons are distributed differently between two atoms when a bond joining them is broken.

Homolytic cleavage: occurs when the valence electrons are distributed the same way between two atoms when a bond joining them is broken.

Reaction scheme: just gives a molecular overview of how two or more reactants interact to form new products.

Reaction mechanism: fills in the details, telling us how electrons are redistributed during the change from reactants to products.

Fish hooks: denote the movement of single electrons.

Curly arrows: denote the movement of a pair of electrons.

12.3 Heterolytic reactions

Nucleophile: an electron-rich species, which has an electron pair that can be donated to form a covalent bond.

2 key groups of nucleophile:

Molecules or ions with non-bonding pairs of electrons

Molecules with a multiple (double or triple) covalent bond

Electrophile: an electron-poor species, which can accept a complete electron pair and share it with the nucleophile as a covalent bond.

For an electrophile to accept a pair of electrons and for a covalent bond to be formed, the electrophile must possess (or be able to possess) an empty orbital.

The orbital may become empty when an electronegative atom within the electrophile withdraws electrons from an orbital of another atom within the same molecule.

Nucleophilic attack: a nucleophile seeks out an electrophile; electrons are donated from the nucleophile to the electrophile.

Chapter 13: chemical reactions II

13.1 An introduction to reaction mechanisms

There are 4 key reaction mechanisms:

Substitution

Addition

Elimination

Condensation

Transition state: the point of highest energy of a chemical reaction and so represents an energy barrier to the progress of the reaction.
During a multi-step reaction the reacting species from an **intermediate compound**; this intermediate compound undergoes further chemical change to form the final product.
Remember:
An intermediate is of higher energy than the reactants and products.
A transition state is of higher energy than the reactants, products and intermediates.
Each step in a chemical reaction involves a high-energy, unstable transition state.
A one-step reaction passes through one transition state; a two-step reaction passes through two transition states; et cetera.

13.2 Substitution reactions

Substitution reaction: an atom (or groups of atoms) on the reactant molecule is replaced by a different atom (or groups of atoms).
2 types:**Nucleophilic substitution reactions**: the groups acting as the substituent are nucleophiles.
Electrophilic substitution reactions: the groups acting as the substituent are electrophiles.
The best **leaving group** during a nucleophilic substitution is the most electronegative species attached to the atom attacked by the nucleophile.
Sn2-reaction - one-step reaction- : (step 1) the nucleophile attacks the target molecule, which passes through transition state, before forming the product of the reaction.
Sn1-reaction - two-step reaction- : (step 1) an intermediate cation is formed; (step 2) the nucleophile attacks the cation, which passes through transition state, before forming the product of the reaction.
Electrophilic substitution is a two-step reaction; involving a carbocation as an intermediate.
During electrophilic aromatic substitution, two electrons in the pi system on an aromatic ring attack an electrophile (acting as a nucleophile).

13.3 Nucleophilic addition reactions

Addition reaction: two molecules combine with one another such that the product contains all the atoms of both molecules; the component atoms of one molecule are added to the atoms of another.
The most common and widespread reactions involve the addition of small molecules to double bonds of **alkenes** and **carbonyl groups**.
During an addition reaction, the components of a molecule become added across a double bond of another molecule.
During an addition reaction, one component of the molecule being added acts an electrophile, and accepts a pair of electrons from the double bond.
Hydratation: addition processes that result in the net addition of components of a