

Chapter 1 - Evolution, the Themes of Biology, and Scientific Inquiry

- **Evolution** is the **fundamental principle of biology**
 - Accounts for unity and diversity of life
- **Higher levels of organization are needed** for the lower level mechanisms to work
 - Arrangement of chloroplasts inside specific complex system allows for photosynthesis
- **Systems biology** - exploration of a biological system by analyzing the interactions among its parts

Biological Organization (Hierarchy)

- 1) **Biosphere** - all life on earth and all places where life exists
- 2) **Ecosystem** - All living things in particular area and its abiotic environment
- 3) **Communities** - All living things in a particular area
- 4) **Populations** - All members of a single species living in a particular area
- 5) **Organisms** - Individual living things
- 6) **Organs and Organ systems** - A body part that carries out a particular function in the body
- 7) **Tissues** - Group of cells that work together, performing a specialized function
- 8) **Cells** - Fundamental unit of structure and function
- 9) **Organelles** - Various functional components in a cell
- 10) **Molecules** - Chemical structure containing of 2 or more atoms

Prokaryote - single celled, no nucleus, no membrane bound organelles, usually smaller

Eukaryote - multi-celled, nucleus, membrane bound organelles

Genome - Complete set of DNA including all its genes

Genomics - Study of whole sets of genes rather than single gene at a time

Proteomics - Study of whole set of proteins encoded by genome (called proteomes) and their interactions

Bioinformatics - Use of computational tools to store, organize, and analyze data

Domains of life

- 1) **Bacteria**
- 2) **Archaea**
- 3) **Eukarya** - divided by modes of nutrition
 - Plantae (produce own sugars via photosynthesis)
 - Fungi (absorb nutrients from their surroundings)
 - Animalia (ingest other organisms)
 - Protists

Inductive reasoning - Using observations to buildup conclusion

Deductive reasoning - Building up a conclusion and seeing if observations match up with set conclusion, if so, it is likely true (impossible to prove a hypothesis to be fully true)

Scientific method

Hypothesis - tentative answer to a well framed question

Experiment - Scientific test carried out under controlled conditions

Chapter 2 - The Chemical Context of Life

Element - a substance that cannot be broken down into other substances by chemical reactions

Compounds - substance consisting of 2 or more different elements combined in a fixed ratio

Energy - The capacity to cause change (ex. by doing work)

Potential energy - Energy matter possesses because of its location or structure

- Ex. water in reservoir on hill has potential energy because of its altitude, when dam opens, water runs down, and the energy can be used to do work, like turning blades of turbines to generate electricity.
 - Since the energy is expended, the water has less energy at bottom of hill than at top
- **Electrons have potential energy** due to their distance from nucleus
 - They are attracted to positively charged nucleus
 - Takes work to move electron farther away from nucleus
 - Thus, the further an electron is from the nucleus (higher energy level), the greater its potential energy
 - When e⁻ loses energy, it is often released as heat, and e⁻ moves down to lower energy level

Molecular shape - determines how biological molecules recognize and respond to one another

Chapter 3 - Water and Life

Cohesion - between water molecules

Adhesion - between water molecules and another substance

Surface tension - caused by strong cohesion of water molecules via hydrogen bonding

- Water can absorb kinetic energy well since it has a **high specific heat capacity**
 - This is due to hydrogen bonding
- Energy released when hydrogen bonds form
 - New bonds form when water cools down, thus more energy released to compensate
- Hydrogen bonds break when energy absorbed
 - When energy is put into water, most of it is used to break hydrogen bonds rather than cause water molecules to move faster

Real life applications?

- Helps to moderate T
- Stores high amount of heat from daytime sunlight while only warming up water a bit
- Cooling water in winter and night can warm the air
- Helps marine life survive
- Helps many organisms (mainly made of water) to limit T fluctuations

Specific heat - amount of heat that must be absorbed or lost for 1g of that substance to change T by 1°C

Water also has **high heat of vaporization**

- Molecules moving fast enough can overcome van der Waals forces and become gas
- Due to strength of hydrogen bonds and how much energy required to break them
- Temperature is only the average kinetic energy of molecules, thus at any given T, there are some molecules moving fast enough to escape into air (evaporate)

Evaporative cooling - as liquid evaporates, the liquid left behind (non-evaporated) cools down as the hottest molecules leave to become gas

Hydration shell - Sphere of water molecules around each dissolved ion (water molecules surround ions, separating and shielding them from one another)

Chapter 4 - Carbon and Molecular Diversity of Life

Major elements of life = C, H, O, N, S, P

Stanley Miller = made experiment to mimic conditions thought to have existed on early Earth.

- The water mixture in “sea” flask was heated, vapour entered the “atmosphere” of flask
- Atmosphere contained mixture of hydrogen gas, methane (CH₄), ammonia (NH₃), H₂O
- Sparks were discharged to mimic lightning
- Condenser cooled atmosphere, raining water and any dissolved molecules down into the sea flask
- Material cycled through apparatus, Miller periodically collected samples for analysis

Conclusion: Identified organic compounds that are common in organisms like formaldehyde (CH₂O) and hydrogen cyanide (HCN), amino acids, and hydrocarbons by end of experiment

Carbon

- Its **electron configuration** allows for its diversity in bonding
- 4 valence shell e⁻, each one can be paired with another e⁻ to complete orbital
- Can form single/double bonds
- Structural isomers, cis-trans isomers (double bonds), enantiomers (mirror images)

Most important function groups in biological processes

- **Hydroxyl (-OH)**
 - Polar, forms hydrogen bonds with water, helps dissolve compounds like sugar
- **Carbonyl (ketone and aldehyde)**
- **Carboxyl (-COOH)**
 - Acts as acid (can donate H+) because covalent bond between oxygen and hydrogen very polar
- **Amino (-NH₂)**
 - Acts as base, accepts protons
- **Sulfhydryl (-SH)**
 - 2 sulfhydryl groups can react, forming “cross-link” to stabilize protein structure
- **Phosphate (-OPO₃²⁻)**
 - Contributes negative charge. When attached, gives molecule ability to react with water, releasing energy
- **Methyl (-CH₃)**
 - Affects expression of genes on DNA, affects shape and function of male/female sex hormones

The first 6 are reactive, and every functional group (except sulfhydryl) is polar (hydrophilic)

Chapter 5 - Structure and Functions of Macromolecules

Macromolecules = large molecules that include **carbohydrates, lipids, proteins, and nucleic acids**

- They are polymers built from monomers (except lipids)
- **Enzymes** help to break down these polymers into monomers
- **Monomers** linked together via **dehydration reactions**
- **Polymers** broken down via **hydrolysis reactions** (lysis meaning breaking apart)

Carbohydrates

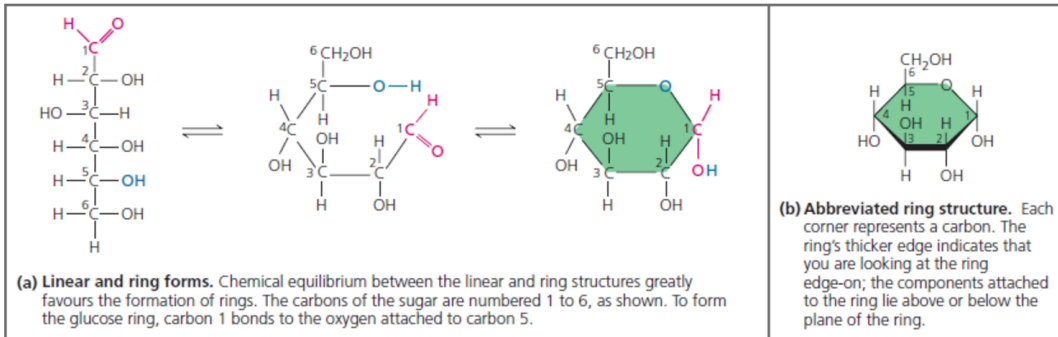
- All the **energy found in bonds** of organic molecules are either the **C-C bonds or C-H bonds, not** functional groups
- **Two types = aldose + ketose sugars**
 - **Aldose** = aldehyde, -C=O bond is at end of molecule
 - **Ketose** = ketone, -C=O bond is in middle of molecule

Pentose = 5 carbon sugar (ribose, ribulose)

Hexose = 6 carbon sugar (glucose, galactose, fructose)

- In **aqueous solutions**, sugars (like glucose) form into a **ring structure**

- **Glucose** easy to extract energy and carbon skeleton serve as raw material for synthesis of amino acids, fatty acids, and other small organic molecules



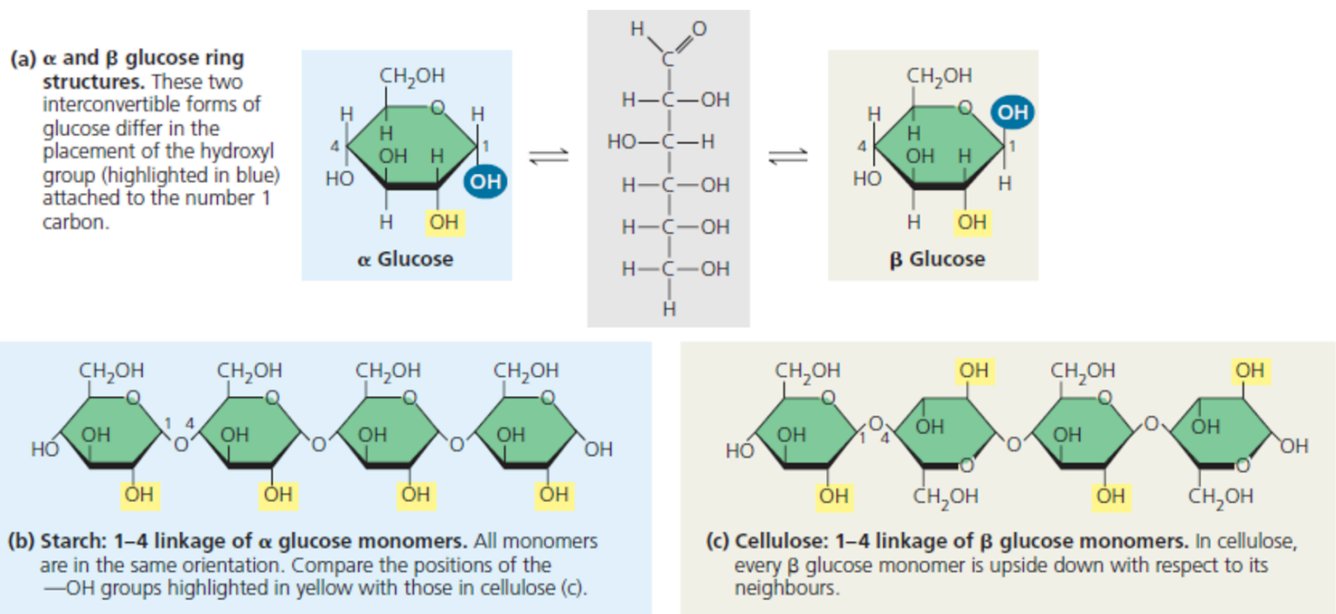
- **Disaccharide** = linked via **glycosidic linkage** (eg. maltose, sucrose, lactose)

Polysaccharides of Glucose

	Cellulose	Starch		Glycogen
		Amylose	Amylopectin	
Source	Plant	Plant	Plant	Animal
Subunit	β -glucose	α -glucose	α -glucose	α -glucose
Bonds	1-4	1-4	1-4 and 1-6	1-4 and 1-6
Branches	No	No	Yes (~per 20 subunits)	Yes (~per 10 subunits)
Diagram				
Shape				

- **Plants** store **starch** as granules within **plastids** (which include chloroplasts)
 - Synthesizing starch enables plant to stockpile surplus glucose
 - Starch is thus stored energy
 - Later be used to be broken down via hydrolysis and used to make ATP
- **Animals** store **glycogen** for energy stockpile
 - Mainly stored in liver and muscle cells
 - Extensively **branched structure of glycogen** allows for more free ends available for hydrolysis

- **Cellulose** = most abundant organic compound on Earth, used for cell walls in plants
 - Glucose can have 2 different ring forms
 - Alpha and beta rings
 - **Alpha** = both hydroxyl groups on bottom side
 - **Beta** = one hydroxyl group down, one up
- In **starch**, all are **alpha glucose**, thus have **helical structure**
- In **cellulose**, all monomers are **beta glucose**, thus have **straight structure**
 - Never branched
 - Some -OH groups on its glucose monomers are free to hydrogen bond with -OH of other cellulose molecules parallel to it
 - In plant cell walls, parallel cellulose molecules held together in this way are grouped into units called **microfibrils**
 - **Microfibrils** thus are strong building material for plants
- **Enzymes** that digest starch by **hydrolyzing alpha linkages can't hydrolyze beta linkages**
 - This is due to **different shapes** of molecules
 - Not many animals contain enzyme to digest cellulose, including humans



- **Chitin** = polysaccharide used by arthropods (insects) to build exoskeleton or by fungi to build cell walls
 - **Has beta linkages**, but **glucose monomers have nitrogen-containing appendage**

Lipids

- **Hydrophobic** (due to large hydrocarbon chains), **no true polymers**
- Include **fats, phospholipids, steroids**

Fats

- Assembled via dehydration reactions
- **Saturated** (all single bonds) and **unsaturated fats** (has double bonds)
- Unsaturated fats include **Cis** (H on same side of double bond) and **trans fats** (H on opposite sides)
- **Cis has kink shape while trans is straight**

- Saturated fats (straight in shape) can pack together tightly (via intermolecular forces) and thus are solid at room temperature
 - Thus, they are bad for you

- Made of **glycerol** (an alcohol) and **fatty acids** (hydrocarbon chain with carboxyl group -COOH at end)

- Fatty acids and glycerol joined via **ester linkage** (dehydration reaction **via hydroxyl and carboxyl group**)

- Resulting fat/product is a **triglyceride** (contains glycerol + 3 fatty acids)

Function: energy storage, stored in adipose cells, adipose cells cushion vital organs and insulates body

Phospholipids

- Make up cell membrane, phospholipid bilayer
- Made of phosphate group (negatively charged) + glycerol + 2 fatty acids
- Many types of phosphate groups (eg. choline), thus different types of phospholipids
- Amphipathic (both hydrophilic and hydrophobic regions)

Steroids

- Lipids with carbon skeleton consisting of **four fused rings**
- Different steroids have **different functional groups**
- Example of steroid is **cholesterol** (made in liver and obtained in diet for vertebrates)

Proteins

- Over 50% of dry mass of most cells come from proteins
- **Ex.** enzymes, transport proteins, cell communication, transport, etc.
- Made of the possible **20 amino acids** monomers (has amino -NH₂ and carboxyl group -COOH and R side chain (different for each amino acid))
- Linked via **peptide bond** (long chain forms polypeptide backbone)
- Polymer is called **polypeptide**
- **Protein** = made of 1 or more polypeptides and is biologically functional

- Each polypeptide has free amino and carboxyl group at each end
 - C-terminus and N-terminus

- **Globular proteins** (spherical) and **fibrous proteins** (shaped like long fibres)

Amino acids are usually found in **ionized form** given pH found in cell

- Different R side chains determines functional role in polypeptide
- Grouped according to side chain (ex. non polar, polar, and negative charged side chains (due to carboxyl group, ionized at cellular pH))
- **Basic amino acids** have **amino groups in side chains** that are **positively charged**
- **Acidic amino acids are negatively charged**
- **Acidic and basic amino acids** are **hydrophilic (polar) due to charge**

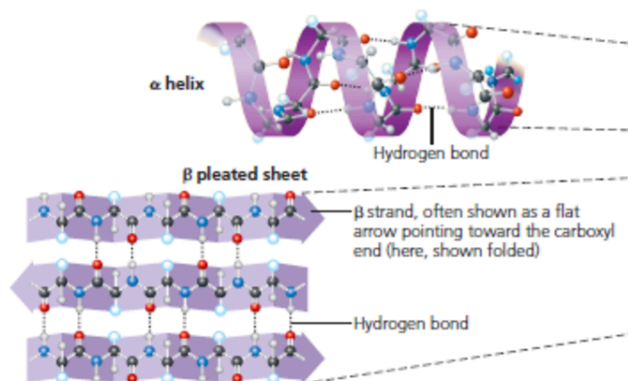
4 levels of protein structure

1. Primary

- **Sequence of amino acids in protein**
- Determines secondary and tertiary structure due to chemical nature of backbone and side chains (R groups)

2. Secondary

- **Coils and folds in protein**
- **Alpha helix** or **beta pleated sheets**
- **Due to hydrogen bonds** between **repeating units of polypeptide backbone (not R side chains)**
 - This is because within backbone, O atoms have partial negative charge and the H attached to nitrogens have partial positive charge, thus hydrogen bonding forms between these atoms



3. Tertiary

- Overall **3-D shape of protein**, determined by primary structure
- Results from **side chain interactions (R groups)**
- Ex. **hydrophobic interaction** (non polar regions cluster up), **hydrogen bond**, **disulphide bridges** (covalent bonds where 2 cysteine monomers which have sulfhydryl groups are brought closer together by folding of protein)

4. Quaternary

- Occurs when **2 or more polypeptide chains** aggregated into one functional protein
- Ex. collagen, haemoglobin (2 alpha and 2 beta subunits), etc.

Sickle celled anaemia = valine replaces glutamic acid in haemoglobin in primary structure

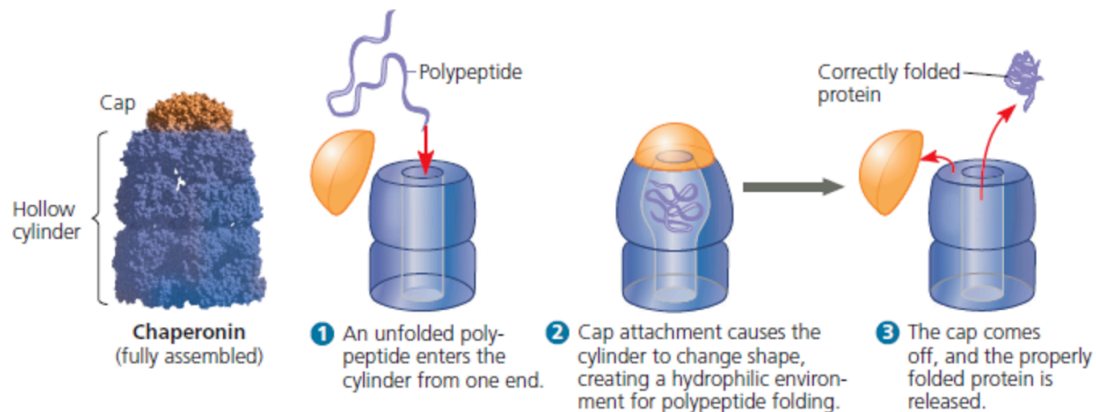
- **Protein structure altered** as well due to environmental changes that break or weaken bonds (ex. **pH**, **T**, **salt concentration**, etc.)

- **Denaturation or renaturation** of protein can occur
- Most **proteins denature** if transferred from **polar environment (aq environment) to non polar solvent** (eg. chloroform)

Folding of proteins

Scientists use **chaperonin** (a protein) that **assists in folding of other proteins** to gain knowledge on how proteins fold

- They do not specific final structure of polypeptide however
- They keep new polypeptide segregated from disruptive chemical conditions in cytoplasm while in folds
- Misfolding of proteins can cause cystic fibrosis, Alzheimer's, etc.
- X-ray crystallography helped to determine 3-D shape of proteins
- However, currently finding out actual process of protein is too complicated and involves countless atoms and steps not known



Nucleic Acids

- Nucleic acids are made of **nucleotide** monomers (made of nitrogenous base (GC-AT), pentose sugar, and phosphate group)
- **Nucleic acids** exist as polymers called **polynucleotides** (linked via dehydration reactions to form **phosphodiester bond**)
 - Each polynucleotide contains nucleotide monomers
 - Nucleotides in polynucleotide only have 1 phosphate group
 - Portion of nucleotide without any phosphate groups is called **nucleoside**
 - Linked nucleotides forms **sugar-phosphate backbone** to nucleic acid (nitrogenous base not part of backbone)
- Genes determine proteins via transcription and translation
- 2 types: **RNA and DNA**
- DNA helps with RNA synthesis, and RNA controls protein synthesis
 - Entire process called **gene expression**

Pyrimidine = Cytosine (**C**), Thymine (**T**), Uracil (**U**) (CaI University)

- Smaller
- Has six-membered ring of carbon and nitrogen atoms

Purines = Adesine (**A**), Guanine (**G**) (Are Gay)

- Larger
- Six-membered ring attached to five-membered ring

• **Thymine** = DNA, **Uracil** = RNA

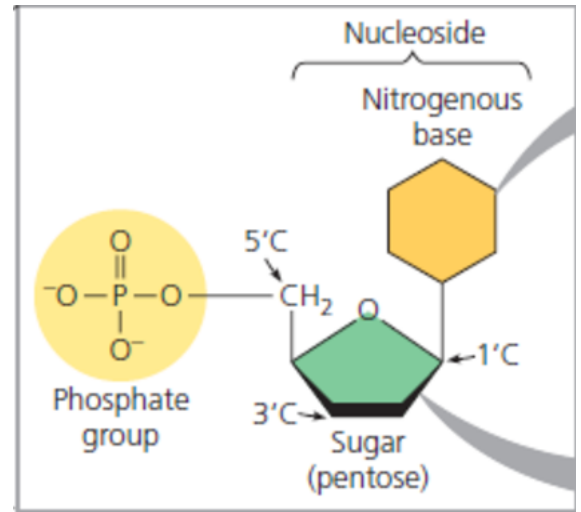
• **DNA sugar** is **deoxyribose** (lacks O atom on 2nd carbon in ring), while **RNA is ribose**

• **Built 5' to 3'**

• **DNA is double helix** and made of 2 strands that are **anti-parallel** to one another (5' to 3' end and 3' to 5' end), thus the strands are **complimentary** to one another, allowing for **semi-conservative replication of DNA**

• The 2 strands are held together at nitrogenous base via **hydrogen bonds**

• Nitrogenous base pairing is always (**G with C**) and (**A with T**)



(b) Nucleotide

Bioinformatics = use of computer software and other computational tools that handle large data sets (ex. to sequence human genome)

Genomics = analyzing biological problems via analysis of large sets of genes or whole genomes of different species

Proteomics = analyzing biological problems via analysis of large sets of proteins and their sequences

Metabolomics = analysis of metabolites (intermediate and end products of metabolism)

Other notes

- **Water** is said to have **colligative** properties meaning solutes (ex. adding salt) can affect melting and boiling T
 - **ex.** Adding a salt will **lower freezing point** T (thus you need lower T to freeze it)
 - **AND** It will **increase boiling point** (higher T to boil it)
 - Essentially making T range at which water remains a liquid larger

- **Why does ATP contain so much energy?**

- The bonds that hold ATP are not particularly high energy but...
- Because ATP and ADP + Pi has a great difference in energy state (ADP more stable state)
- ATP's 3 phosphates are all negatively charged, making it highly unstable
- Hydrolysis reaction that occurs for ADP and Pi with water creates new bonds that release a lot of energy