What is Life?

How do we define life?

The diversity of life can be explained by the process of evolution

- Natural processes
- With a changing environment
- All organisms are connected by lines of descent from common ancestry; barriers to reproduction foster divergence of lineages
- Natural selection acts on phenotypic variation, generating adaptions
- Human interventions – alter course of evolution

Defining Life:

- Composed of a common set of elements
- Grow & change
- Respond to the environment
- Are comprised of cells

"Living Crystals"

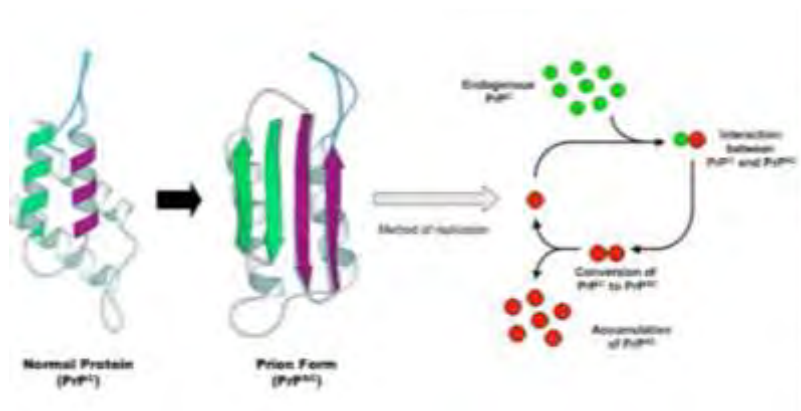
- H_2O_2 → (light) → $H_2O + O_2$
- Not living, but have behaviours of a living organism

Prions: not living

Misfolded proteins that can transmit their misfolded shape onto normal variants of the same protein

- Protein
- Prion disease (TSE) – damage or disease that affects the brain
- Neurological diseases (mad cow disease)

Pros (Alive)	Cons (not Alive)
- Replicate/reproduce - Infect other proteins - Undergo mutations through natural selection ○ Mutation is linked to changes in nucleic acid sequence which lead to resistance (prions show that nucleic acid is not needed for the process of evolution) - Create variants	- No DNA - Survive being boiled, being treated with disinfectants - Infect other brains after they are transferred



Viruses:

Pros (Alive)	Cons (Not Alive)
- Contain nucleic acid - Replicate - Evolve & adapt to the environment	- Not capable of independent replication - Do not contain required metabolic processes

Cells

- Molecular & structural properties of cells define their function
- Bounded by membrane & maintain internal environments that differ from their external environments
- Cells communicate with other cells
- Form organised units capable of more complex functions

Cell Theory:

- Fundamental unit of life
- All living organisms are comprised of cells
- All cells come from pre-existing cells
- Modern cells evolved from a common ancestor

The First Cell:

- Copy informational macromolecules
- Carry out specific catalytic functions
- Couple energy from the environment into usable chemical forms

Protocells & Synthetic Biology:

- Synthetic Biology: redesigning organisms for useful purposes by engineering them to have new abilities
- Top-down approach: building on the biology through modifying existing cellular pathways
- Bottom-up approach: building chemical systems capable of mimicking cellular processes (minimal cells)

Advantages	Disadvantages
- Understanding origins of life - Engineering biology	- Uncontrolled escapes - Generation of pathogen

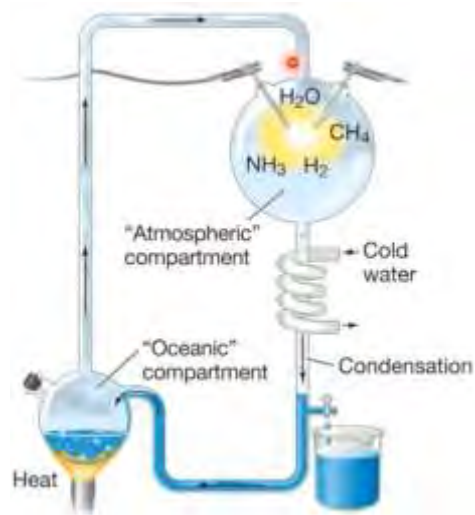
How and when did life begin on Earth?

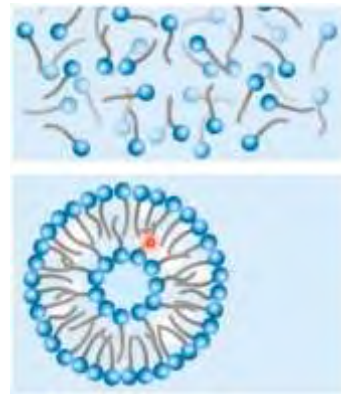
Can biological molecules be formed from chemicals present in Earth's early atmosphere?

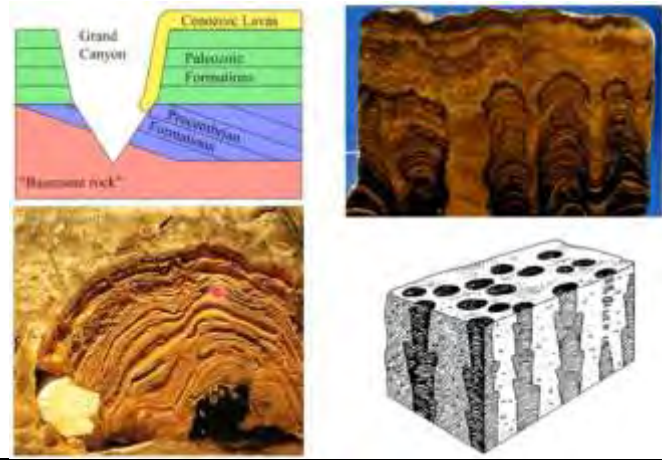
Early Earth atmosphere = "primordial soup"

Miller-Urey experiments:

- A series of experiments
- Mimic conditions of the primordial soup
- Production of macromolecules
- These early conditions on Earth could result in the production of organic products:
  - Bases present in DNA & RNA (A,C,G,T,U)
  - All 20 amino acids found in proteins
  - A range of 3- & 6- carbon sugars
  - Fatty acids
  - Vitamin B6, NAD & other organic acids



	Formation of protocells from fatty acids: *How do we go from these organic macromolecules into living organisms?* - Lipids (fatty acids) placed in an aqueous environment will spontaneously form cell-like structures - Lipids can form "protocells" - Head: hydrophilic - Tails: hydrophobic - Other macromolecules can pass through bilayer for protection *Next step: replicating these molecules* - RNA molecules can mimic enzymes – self-replicate   **Murchison meteorite:** - Life or its building blocks/preliminary components of life may have originated elsewhere (presumably under similar conditions as that identified in the Miller-Urey experiments) - Arrived on Earth via meteorites *What forces created life on Earth?* 1. Life formed spontaneously on early Earth (a reducing environment facilitated organic molecule formation i.e. DNA bases) 2. Extra-terrestrial origin – life from another planet or comet (panspermia) Panspermia – theory that life exists throughout the universe *What do the similarities among living organisms indicate?* - All life on Earth has a common ancestry - All organisms have arisen from earlier, more primitive forms through the process of evolution - Because all organisms are related, share the same genetic code, chemical composition & cellular structure ("biochemical unity of life") *Evolution occurs by natural selection (Charles Darwin)* - Wide range of variation - "Fitter" individuals with characteristics best suited to the environment are more likely to survive & reproduce - Given time, a species may evolve into a new form
Connection between water & life	- "Matrix of Life" - Human lysozyme protein: water molecules completely embedded in the protein structure - Universal solvent - Most of the water is in the form of ice - Ice cannot act as a lubricant for the molecular processes of life - Evidence for liquid water 3.8 billion years ago: pillow basalt - Europe (moon of Jupiter): south polar water vapor plume - Water – microbes
Evidence of early life on Earth	**The Cambrian Explosion:** - A rapid diversification of life (~541 million years ago) - Most major animal groups

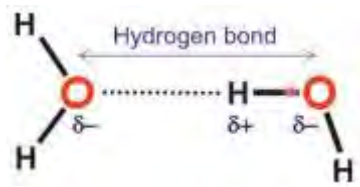
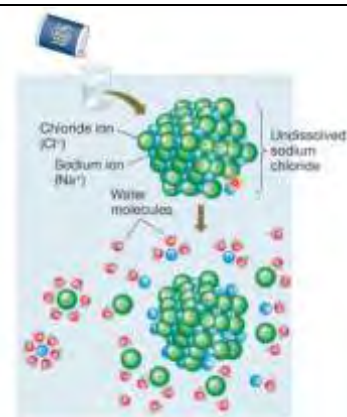
	- Fossil record
	 
	Stromatolites:
	- "living fossils"
	- Surface – bacteria (photosynthetic organism)
	- As they grow, they embed sediment on the surface of the rock
	- Fossilised stromatolites (Grand Canyons)
	- Fossilised sign of bacteria (cyanobacteria ~ 3.5 billion years old)
	- Representative of what early life looked like:
	  - Salty water
	  - Initial phases of photosynthesis
	  - Harvesting light energy – ability to take from environment
	  - Reproduce
	 

Summary	- Definition of life is complicated - Life arose through the formation of large molecules from smaller molecules on early Earth (and/or beyond) - Water – key component - Life – after formation of liquid water - Stromatolites – evidence of early types of life

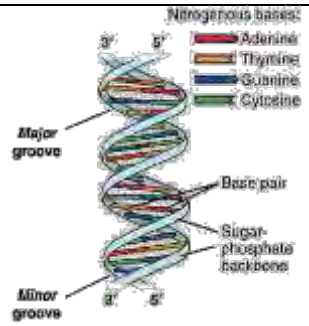
Molecules of Life 1

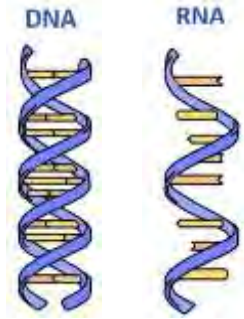
Major Biomolecules (macromolecules) + water

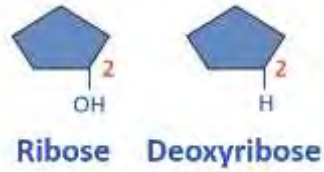
- Water
- Proteins (polypeptides)
- Nucleic Acids
- Carbohydrates (polysaccharides)
- Lipids

Elements of Nature (C,H,N,O)	Major elements: C, H, N, O Smaller amounts: P, S, Ca, Na, Mg, Cl, K **Carbon:** basis of most biomolecules - 4 bonds - Stable - Interact with other molecules **Hydrogen Bond:**  **Phosphorus vs Sulfur:** - Phosphorus – essential element in nucleic acid - Very little in primordial soup - Scientists hypothesise that sulfur-based compounds may have filled some of the roles that phosphorus plays in modern biochemistry *What is the difference between phosphorus & sulfur that could account for the replacement of the latter over evolutionary time?* - Backbone of DNA - Driving the cell's energy currency (ATP) - Metabolism - Phosphate-free metabolism & reactions – rich in iron-sulfur clusters
Water is the matrix of life	**Water & Ions:** role of water - Water molecules surround ions & molecules through ionic interactions & maintain them in solution - Biological solvent – surrounds enzymes & maintains their function - Metabolism – metabolic function is greatly increased due to water 

Nucleic Acids (DNA, RNA, DNA replication)	- DNA: Deoxyribo Nucleic Acid
	  - Double stranded
	- Nucleotides (4): Adenine (A), Thymine (T), Cytosine (C), Guanine (G)
	- RNA: Ribo Nucleic Acid
	  - Thymine is replaced by the related nucleotide Uracil (U)
	- Both form long, linear chains (polynucleotides) that never branch

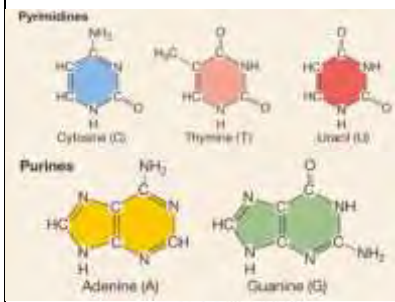


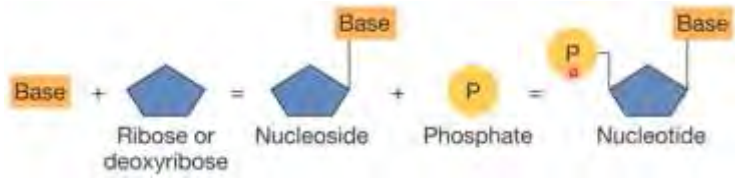


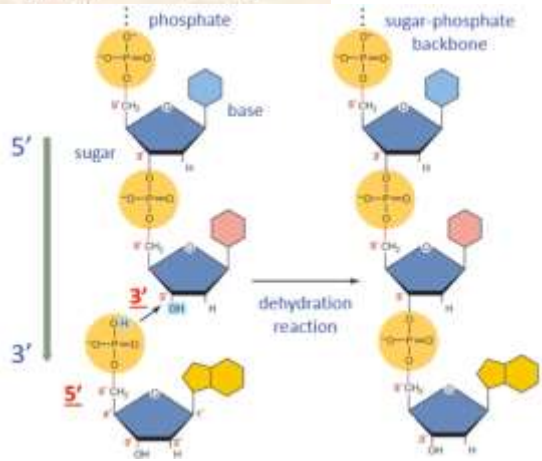


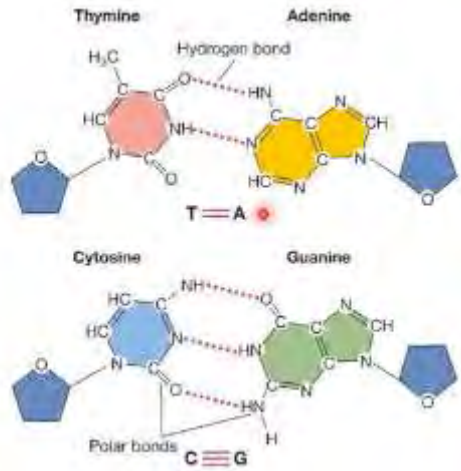
Nucleotides: building blocks of nucleic acids

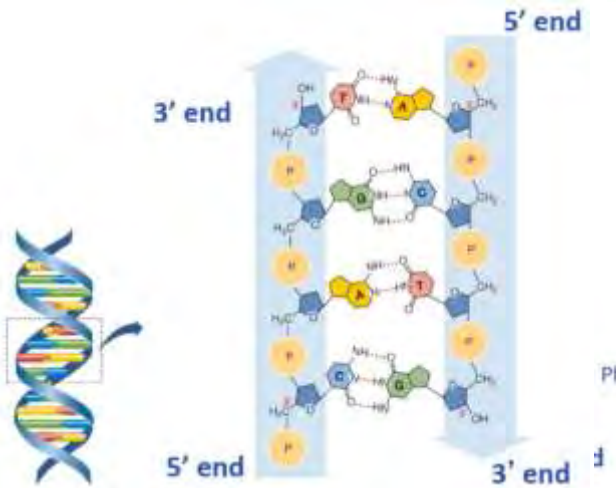
- Deoxyribose – sugar
- Nucleotides are linked together by phosphodiester bonds to form nucleic acids
- Dehydration reaction: covalently links phosphate to ribose
- DNA extended at 3-prime end
- Prime – refers to carbons

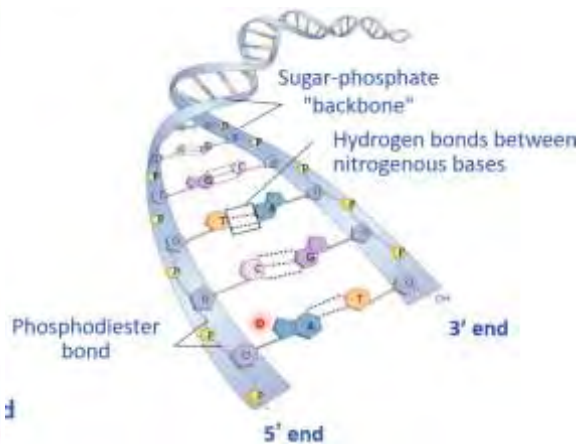












RNA:

- Single stranded
- Bases can also bond
- Fold with itself
- mRNA – messenger
- tRNA – transfer
- rRNA – ribosomal

mRNA: transmits the encoded information (gene) to produce a certain protein

Genes:

- Sections of DNA are a gene (coding regions)
- Non-coding regions - regions in between genes
- Unravel chromosomes into linear strands of DNA

Polymerase Chain Reaction (PCR)

- Technology in molecular biology
- Enables amplification of small amounts of DNA (or RNA)
- Rapidly make millions/billions of copies of a specific region of DNA

1. Denaturation – sample heated (94-98°C) separate double stranded DNA into 2 single strands
2. Annealing – (55-72°C) primers complement specific sections of the RNA strand
   Optimum annealing T_m for a primer pair is found by experimentation
   Annealing T_m - 3-5°C lower than the lower primer T_m
3. Extension – (68-72°C) enzyme extends the primer molecules (i.e. fills in the gaps)

How does the %GC influence the melting temperature of a primer?

- GC bonds are more stable
- Increase melting temperature

Matched primer pairs:

- %GC & T_m have to be matched
- T_m too high, the primer with the lower T_m may not function at all
- T_m too low, the higher T_m has a greater chance of mis-priming

Protein (amino acids, enzymes)

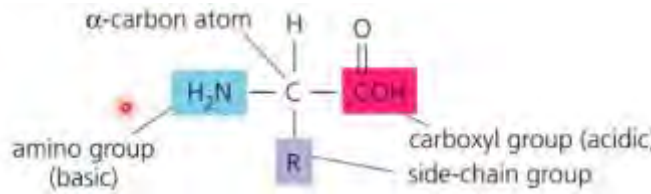
- DNA encodes information used to help create proteins
- Decode the information in the coding strand into a protein sequence
- Proteins are also responsible in coding the creation of RNA
- Digested into small peptides & amino acids in duodenum

Functional Diversity:

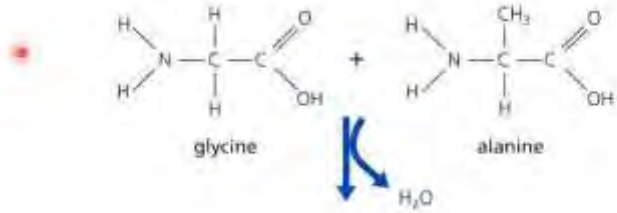
- Structural (hair – keratin)
- Hormones (insulin)
- Muscles (contractile – myosin)

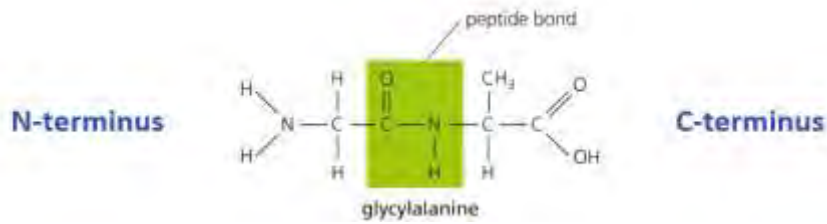
- Enzymes (CO_2 → glucose)
- Defence (antibodies)
- Mucilage (cartilage, mucus)
- Transport (through membranes)
- Storage

Amino Acids:

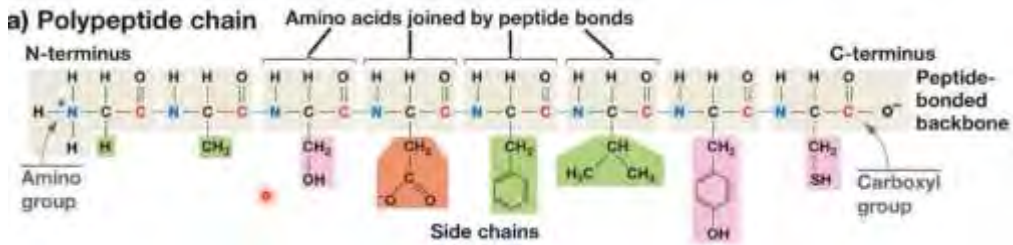


- Amino group
- Carboxyl group
- R group (side chain)
- Peptide bond formations: dehydration/condensation reaction (losing water)





Polypeptides: hundreds/thousands of amino acids long

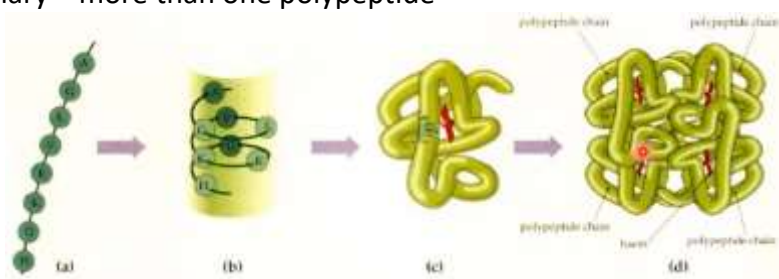


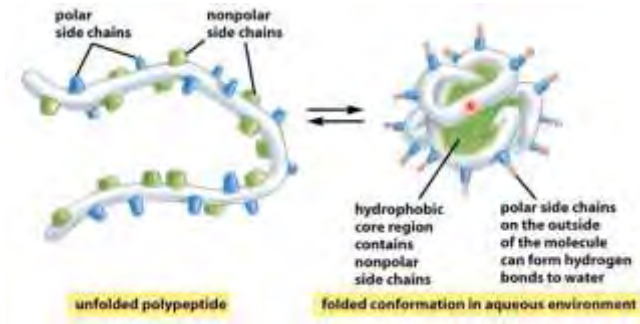
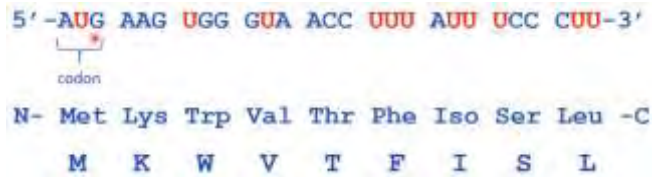
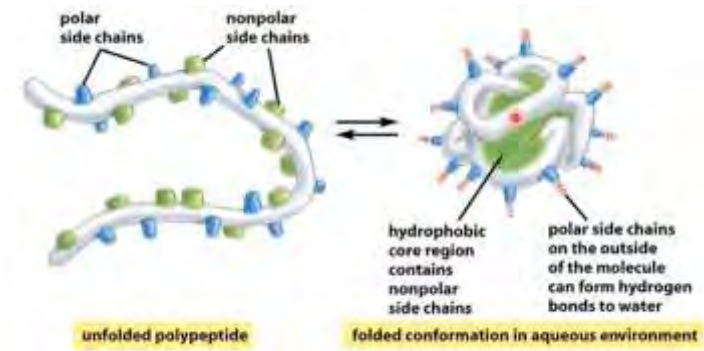
R-groups:

- Non-polar – hydrophobic
- Polar – hydrophilic
- Charged – hydrophilic

Structure: protein

- Primary – amino acid sequence
- Secondary – conformation changes in primary structure due to the formation of electrostatic & H-bonds between nearby amino acids (α-helix, β-pleated)
- Tertiary – ultimate configuration that a polypeptide chain takes in reaching the configuration of minimal free energy (fully-functioning protein)
- Quaternary – more than one polypeptide

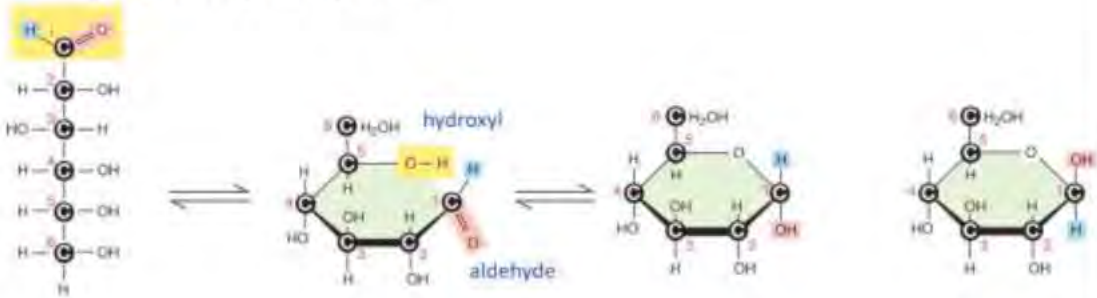


	- Sidechains drive proteins folding (secondary → tertiary) - "The hydrophobic effect" 
Central Dogma (transcription & translation)	**Transcription:** make the mRNA in the gene **Translation:** decode the information from the coding strand into a protein - Codon: sets of 3 nucleotides  **Central Dogma:** 
Summary	- C,H,O & N are fundamental elements of biomolecules - C can form 4 bonds making it a pivotal part of biomolecules - DNA is comprised of 4 nucleotides (A, C, G, T) & is a double stranded biomolecule of 2 complementary strands - RNA is comprised of 4 nucleotides (A, C, G, U) & is single stranded & mRNA is the intermediate between DNA & proteins - Proteins are comprised of 20 amino acids & are encoded by genes found in DNA - Proteins have a variety of roles in biology including enabling a range of biochemical reactions that maintain life

Molecules of Life 2

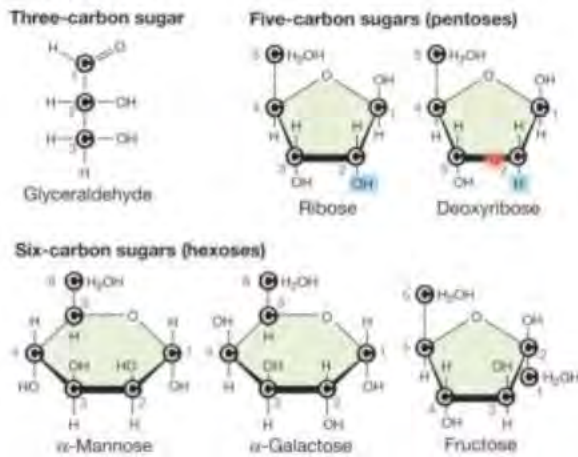
Carbohydrates (sugars, starch, polysaccharides)

- Source of chemical energy
- Form structural components (cell wall in plants)
- General formula: (CH2O)*n*
- *n* – 3-8
- alpha glucose, beta glucose



Monosaccharides: simple sugars

- building blocks for biological molecules (DNA & RNA)
- Biochemical intermediates (carbon skeletons)
- Source of energy (glycogen)



Disaccharides: union of 2 monosaccharides

- Glycosidic linkage
- Dehydration/condensation reaction