1 EVPP 110 Lecture Dr. Largen - Fall 2002

Chemical Nature of Life

(Biological Macromolecules: The Building Blocks of Life)

² Chemical Building Blocks of Life

- ✓ Molecules are the building blocks of life
- √ Four major types of biological macromolecules
 - carbohydrates
 - lipids
 - proteins
 - nucleic acids

3 Molecules are the building blocks of life

- ✓ Molecules
 - consist of 2 or more atoms bound together
 - are small in comparison to what we see with our eyes
 - some are "small"
 - others are "gigantic"
 - · consisting of thousands of atoms
 - · organized into hundreds of smaller molecules linked together into long chains
 - · are almost always synthesized by living things

⁴ Molecules - life's building blocks

- √ The carbon atom plays a central role in organic molecules
 - forms 4 covalent bonds
 - single, double, or triple w/ carbon atoms
 - forms variety of molecular shapes
 - combines with hydrogen to form hydrocarbons
 - bonds with H, N, O, S
 - forms isomers

⁵ ■ Molecules - life's building blocks

- √ Chemistry of carbon
 - forms 4 covalent bonds
 - carbon's outer electron shell, or valence shell, can hold 8 electrons
 - an individual carbon atom contains only 4 electrons in its outer shell

- therefore, carbon can form up to 4 covalent bonds
- 6 🗷
- 7 🗷
- 8 ☐ Molecules life's building blocks
 - √ Chemistry of carbon
 - can form **single**, **double**, **or triple** covalent bonds with other carbon atoms
 - carbon can form single, double or triple bonds with itself
 - therefore, can readily form chains of carbon atoms
 - and molecules with complicated branching

9 ☐ Molecules - life's building blocks

- ✓ Chemistry of carbon
 - forms variety of molecular shapes
 - · carbon chains, can be
 - straight
 - branched
 - closed into rings
 - · can form greater variety of molecules than any other element

¹⁰ ■ Molecules - life's building blocks

- √ Chemistry of carbon
 - combines w/ H, forms hydrocarbons
 - organic molecules consisting of C & H
 - · C H covalent bonds store lot of energy
 - make good fuels (fossil fuels), formed
 - » from organic compounds originating in organisms that lived and died millions of years ago
 - » when O is stripped from organic molecules under anoxic (no O) conditions

¹¹ ■ Molecules - life's building blocks

- √ Chemistry of carbon
 - most biologically important molecules are not hydrocarbons
 - carbon forms bonds with H, N, O, S
 - to form many other biologically significant molecules
 - such as sulfuric acid
 - to form biologically important functional groups

12 The construction of biologically important organic molecules

- ✓ Most biologically important organic molecules are not hydrocarbons
 - in general, any organic molecule can be thought of as a carbon-based core to which specific groups of atoms with specific chemical properties are attached
 - · carbon skeleton or core
 - · functional groups

 groups of atoms attached to C core of organic molecule, with definite chemical properties

13 ☐ The construction of biologically important organic molecules ✓ carbon skeleton or core

- to which specific groups of atoms with definite chemical properties are attached
- represented by **R** =, the"remainder" of the molecule of which the functional groups are a part

√ functional groups

14 The construction of biologically important organic molecules

- √ functional groups (groups of atoms w/specific chemical properties attached to the C core)
 - retain their chemical properties no matter where they occur
 - most compounds present in cells contain two or more different functional groups
 - ex., every amino acid contains at least two functional groups
 - an amino group
 - · a carboxyl group

15 ☐ The construction of biologically important organic molecules ✓ functional groups

- there are several biologically important functional groups
 - hydroxyl (R-OH)
 - carbonyl (R-[C=O]-H, or (R-[C=O]-R)
 - carboxyl (R-[C=O]-OH, R-COOH)
 - amino (R-NH₂)
 - phosphate (R-O-P[=O]-OH]-OH)
 - sulfhydryl (R-SH)
 - methyl (R-CH₃)

16 🗷

17 Making & Breaking Macromolecules

- ✓ Biological macromolecules (polymers) are made up of repeating subunits
 - although the four categories of biological macromolecules contain different subunits
 - the categories of macromolecules are
 - assembled in the same way
 - » dehydration synthesis
 - disassembled in the same way
 - » hydrolysis
- 18 Making & Breaking Macromolecules

√ dehydration synthesis

- macromolecule is assembled by removing an -OH group from one subunit and an H from other subunit
 - this, in effect, constitutes the removal of a molecule of water (H₂O) for every subunit that is added to a macromolecule
 - also called water-losing reaction
 - · energy is required to break the chemical bonds when water is extracted
 - · cells must supply energy to assemble macromolecules

19 Making & Breaking Macromolecules

√ dehydration synthesis

- anabolic reactions
 - · reactions in which macromolecules are built from smaller subunits, requires
 - energy
 - catalysis
 - » process of positioning (the reacting substances must be held close together)
 - » process of stressing bonds (the correct chemical bonds be stressed and broken)
 - » these processes carried out by a special class of proteins known as enzymes

20 🗷

21 Making & Breaking Macromolecules

- ✓ Cells also disassemble macromolecules into their constituent subunits by performing
 - catabolic reactions
 - reactions in which macromolecules are synthesized by disassembling other macromolecules into their constituent parts
 - · energy released
 - are essentially the reverse of dehydration synthesis, called
 - hydrolysis (digestion)

22 Making & Breaking Macromolecules

√ hydrolysis (digestion)

- macromolecules created by disassembling other macromolecules into their constituent parts by adding an -OH group to form one subunit and an H to form the other subunit
 - this, in effect, constitutes the addition a molecule of water (H₂O) for every macromolecule that is disassembled
 - energy is released when the energy storing bonds are broken

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²⁴ The **4 major classes** of biological macromolecules

√ carbohydrates

- monosaccharides

√ lipids

- glycerol
- fatty acids

✓ proteins

- amino acids

✓ nucleic acids (DNA, RNA)

- nucleotide
- ²⁵ Polymers large molecules consisting of long chains of repeating subunits
- 26 🗷
- 27 ☐ Biological macromolecules have certain functions in organisms✓ carbohydrates
 - loosely defined group of molecules that contain C, H, and O in molecular ratio of 1:2:1, with empirical formula of (CH₂O)_n
 - functions
 - energy storage molecules
 - due to large number of C-H & C-C bonds, which release energy when broken
 - · structural elements
- 28 ☐ Biological macromolecules have certain functions in organisms✓ Carbohydrates
 - are named based on the number of sugar units they contain
 - · monosaccharides
 - one sugar unit (mono-)
 - · disaccharides
 - two sugar units (di-)
 - · polysaccharides
 - many sugar units (poly-)
- 29 ☐ Biological macromolecules have certain functions in organisms
 ✓ carbohydrates
 - monosaccharides
 - function
 - play central role in energy storage
 - » glucose most important, has 6 Cs, w/7 energy storing C-H bonds
 - · examples
 - glucose
 - fructose
 - glyceraldehyde phosphate
- 30 🗷
- 31 Biological macromolecules have certain functions in organisms
 - ✓ Carbohydrates
 - disaccharides

- structure
 - two monosaccharides joined by a covalent bond
- function
 - play a role in the transport of sugars
- · examples
 - » sucrose
 - » lactose
- 32 🗷
- 33 ☐ Biological macromolecules have certain functions in organisms
 ✓ carbohydrates
 - polysaccharides
 - structure
 - many monosaccharides put together
 - » repeating units of simple sugars, usually glucose
 - precise number of sugar units varies
 - » typically, thousands of sugar units are present in a single molecule
 - chains can be single or branched
- 34 ☐ Biological macromolecules have certain functions in organisms

 ✓ carbohydrates
 - polysaccharides
 - functions
 - storage of energy
 - » starch = formed in plants, consists of glucose units
 - » glycogen = formed in animals, consists of glucose units
- 35 ☐ Biological macromolecules have certain functions in organisms
 ✓ carbohydrates
 - polysaccharides
 - functions
 - structural
 - » cellulose = formed in plants, consists of glucose units, component of plant cell walls
 - » chitin = formed in insects, fungi and certain other organisms, consists of glucosamine units (contains N)
- 36 🗷
- 37 🗷
- 38 ☐ Biological macromolecules have certain functions in organisms
 ✓Lipids
 - loosely defined group of molecules sharing one main characteristic; insoluble in water
 - · main type
 - fats (triglycerides or triacylglycerols)

- · other types
 - » phospholipids
 - » terpenes
 - » steroids
 - » oils
 - » waxes
- 39 ☐ Biological macromolecules have certain functions in organisms ✓ lipids
 - fats (triglycerides or triacylglycerols)
 - structure = glycerol + 3 fatty acids
 - glycerol = a 3-carbon alcohol with each carbon bearing a hydroxyl group
 - fatty acids = long hydrocarbon chains ending in a carboxyl group
 - » the three fatty acids of a triacylglycerol are not necessarily the same
- 40 ☐ Biological macromolecules have certain functions in organisms

 ✓ Lipids
 - fats (triglycerides or triacylglycerols)
 - · functions
 - energy storage
 - » efficient energy storage molecules because of their high concentrations of C-H bonds
 - insulation
 - cushioning
- 41 🗷
- 42 ☐ Biological macromolecules have certain functions in organisms
 ✓Lipids
 - saturated and unsaturated fats
 - based on absence/ presence of double bonds between carbon atoms and number of hydrogen atoms
- 43 ☐ Biological macromolecules have certain functions in organisms
 ✓Lipids
 - saturated fats
 - all internal C atoms are bound to at least two H atoms, no double bonds between C atoms
 - results in maximum number of H atoms
 - therefore, said to be saturated w/H
 - · tend to be straight and fit close together
 - · most are solid at room temperature
 - such as butter

- 44 🗷
- 45 ☐ Biological macromolecules have certain functions in organisms
 ✓Lipids
 - unsaturated fats
 - · double bonds between at least one pair of C atoms
 - results in less than maximum number of hydrogen atoms
 - » because the double bonds replace some of hydrogen atoms
 - therefore, said to be unsaturated
 - most are liquid at room temp. (ex., oil)
- 46 ☐ Biological macromolecules have certain functions in organisms
 ✓ Lipids
 - unsaturated fats
 - · polyunsaturated fats
 - double bonds between 2+ pairs of C atoms
 - have low melting points because the fatty acids chains can't closely align
 - double bonds cause kinks
 - most are liquid at room temperature
 - » such as corn oil
- 47 🗷
- ⁴⁸ ☐ Biological macromolecules have certain functions in organisms ✓ lipids
 - fats (triglycerides or triacylglycerols)
 - · other types and their function
 - phospholipids
 - » modified fats with two fatty acid chains rather than three
 - » one of the fatty acid chains is replaced by a phosphate group
 - » has hydrophillic head, hydrophobic tail
 - » structure of cell membranes = phospholipid bilayer
- 49 🗷
- 50 ☐ Biological macromolecules have certain functions in organisms

 ✓ lipids
 - fats (triglycerides or triacylglycerols)
 - · other types and their function
 - terpenes
 - » long chain lipids which are components of many biologically important pigments
 - » chlorophyll and other plant pigments
 - » vitamin A (retinol)
 - » retinal visual pigment of eyes of mollusks, insects, and vertebrates
 - » rubber and other plant products
- 51 ☐ Biological macromolecules have certain functions in organisms

✓ lipids

- fats (triglycerides or triacylglycerols)
 - other types and their function
 - prostaglandins = modified fatty acids w/ 2 nonpolar tails attached to 5 C ring
 - » local chemical messengers in animal tissues
 - waxes
 - » waterproof coating on leaves, bird feathers, mammalian skin, arthropod exoskeleton

52 ☐ Biological macromolecules have certain functions in organisms ✓lipids

- fats (triglycerides or triacylglycerols)
 - other types and their function
 - steroids = lipids composed of 4 carbon rings
 - » hormones
 - » regulatory
 - » cholesterol
 - » found in eukaryotic cell membrane
 - » bile salts (emulsify fats)

53 ☐ Biological macromolecules have certain functions in organisms ✓ proteins

- perform many functions, are all polymers of only 20 amino acids
 - structure
 - amino acids joined by peptide bonds
 - · levels of structure
 - functions
 - types of

54 ☐ Biological macromolecules have certain functions in organisms ✓ proteins

- structure
 - made up of various combinations of 20 types of repeating subunits called <u>amino</u> acids
 - are joined together by peptide bonds
 - are organic molecules
 - consist of
 - » two characteristic end groups
 - » a side group (or side chain)

55 ☐ Biological macromolecules have certain functions in organisms

- ✓ structure of amino acids
 - two end groups
 - an amino group (-NH₂)
 - a carboxyl group (-COOH)

- a side group
 - bonded to the C atom between the two end groups
 - · varies from one amino acid to another
 - · determines the unique chemical properties of the amino acid
- ⁵⁶ ☐ Biological macromolecules have certain functions in organisms
 - ✓ Examples of amino acid side groups
 - leucine
 - serine
 - cysteine
- 57 ☐ Biological macromolecules have certain functions in organisms
 - ✓ proteins
 - structure
 - · amino acids
 - grouped into 5 chemical classes based on their side groups
 - » nonpolar
 - » polar
 - » ionizable
 - » aromatic (rings)
 - » special function
- 58 ☐ Biological macromolecules have certain functions in organisms
 - ✓ proteins
 - structure
 - peptide bonds join amino acids together
 - covalent
 - » forms by dehydration reaction btwn amino and carboxyl groups on a pair of amino acids
 - has partial double bond characteristic
 - is stiff
 - » amino acids are not free to rotate around the C-N linkage
 - » makes it possible for chains of amino acids to form coils and other regular shapes
- 59 🗷
- 60 ☐ Biological macromolecules have certain functions in organisms

 ✓ proteins
 - levels of structure
 - primary
 - · secondary
 - motifs
 - tertiary
 - domains
 - quaternary
- 61 ☐ Biological macromolecules have certain functions in organisms

 ✓ proteins
 - levels of structure

•	n	rı	m	а	r۷

- result from the specific amino acid sequence
- one dimensional

62 🗷

63 ☐ Biological macromolecules have certain functions in organisms

✓ proteins

- levels of structure

- · secondary
 - results from hydrogen bonding between individual amino acids
 - two dimensional
 - two patterns of hydrogen bonding
 - **→ b** pleated sheets
 - →a helix

64 🗷

65 ☐ Biological macromolecules have certain functions in organisms✓ proteins

- levels of structure
 - tertiary
 - final folded shape of protein resulting from hydrophobic interactions with water, globular (three dimensional)
 - domains
 - when different sections of a protein fold into a structurally independent globular protein like knots on a rope

66 🗷

67 ☐ Biological macromolecules have certain functions in organisms

✓ proteins

- levels of structure
 - quaternary
 - when two or more polypeptide chains associate to form a functional protein

68 🗷

69 🗷

70 ☐ Biological macromolecules have certain functions in organisms

✓ proteins

- levels of structure
 - · how proteins fold and unfold
 - denaturation

- » process by which a protein changes its shape (secondary & + structure) or even unfolds when its "tolerance range" for some factor is exceeded
- » results from breaking hydrogen bonds, disrupting polar nonpolar interactions

71 ☐ Biological macromolecules have certain functions in organisms ✓ proteins

- levels of structure
 - · how proteins fold and unfold
 - denaturation can be caused by
 - » heats
 - » acids
 - » bases
 - » salts
- 72 🗷
- 73 ☐ Biological macromolecules have certain functions in organisms

 ✓ proteins
 - functions
 - regulation
 - structural
 - · contractile
 - transport
 - · energy storage
 - defense
 - · osmotic regulation
- 74 ☐ Biological macromolecules have certain functions in organisms

 ✓ proteins
 - functions
 - regulation
 - enzymes catalysts in metabolic pathways
 - hormones
 - in gene expression
- 75 ☐ Biological macromolecules have certain functions in organisms✓ proteins
 - functions
 - structural
 - cell membranes
 - cell cytoskeleton components
 - collagen
 - elastin
 - keratin

76 🗖	Biological macromolecules have certain functions in organisms ✓ proteins - functions • contractile - muscle fibers • transport - hemoglobin - myoglobin
77 🗷	
78	Biological macromolecules have certain functions in organisms ✓ proteins – functions • energy storage – egg albumin – plant seeds • defense – antibodies • osmotic regulation
70 🗐	- globulins Riological macromologules have certain functions in organisms
/ 7	Biological macromolecules have certain functions in organisms Include: Any organisms
	 are the information storage devices of cells long polymers of repeating subunits called nucleotides two types DNA deoxyribonucleic acid RNA ribonucleic acid
80 🗖	Biological macromolecules have certain functions in organisms
81 🗷	 ✓ nucleic acids – nucleotides • consist of three components – a five-carbon sugar » ribose in RNA » deoxyribose in DNA – a phosphate group – a nitrogenous base
82 🗖	Biological macromolecules have certain functions in organisms nucleic acids

– nucleotides
 two types of organic nitrogen-containing bases occur in nucleotides purines
– pyrimidines
83 Biological macromolecules have certain functions in organism
√nucleic acids
– nucleotides
two types of organic bases
- purines = large, double-ringed molecules
» adenine (A) - found in RNA and DNA
» guanine (G) - found in RNA and DNA
84 Biological macromolecules have certain functions in organism
✓nucleic acids
- nucleotides
two types of organic bases pyrimidines — smaller single ringed melecules
 pyrimidines = smaller, single-ringed molecules cytosine (C) – found in RNA and DNA
* thymine (T) – found in DNA only
» uracil (U) – found in RNA only
85 =
86 ☐ Biological macromolecules have certain functions in organism ✓ nucleic acids – nucleotides
 nucleotides are linked together with phosphodiester bonds result when the phosphate group of one nucleotide binds to the hydroxyl group of another nucleotide, releasing water
87 🗷
88 🗷
89 ☐ Biological macromolecules have certain functions in organism ✓ nucleic acids

- types of and functions
 - DNA
 - RNA
 - ATP and other high energy molecules
- 90 ☐ Biological macromolecules have certain functions in organisms
 - ✓ nucleic acids
 - types of and functions
 - DNA

- forms genetic blueprint in genes or chromosomes
- organisms encode the information specifying the amino acid sequences of their proteins as sequences of nucleotides

91 🗷

92 Biological macromolecules have certain functions in organisms

✓ nucleic acids

- types of and functions
 - RNA
 - interprets genetic blueprint through protein synthesis
 - transcribing the DNA message into a chemically different molecule such as RNA allows the cell to tell which is the original information storage molecule and which is the transcript

93 Biological macromolecules have certain functions in organisms

✓ nucleic acids

- types of and functions
 - RNA
 - 3 types
 - » mRNA = messenger RNA
 - » tRNA = transfer RNA
 - » rRNA = ribosomal RNA

94 ☐ Biological macromolecules have certain functions in organisms ✓ nucleic acids

- types of and functions
 - ATP and other high energy molecules)
 - nucleotides play critical roles in molecules which serve as the energy currency of the cell
 - ATP = adenosine triphosphate
 - NAD+ = nicotinamide adenine dinucleotide
 - FAD+ = flavin adenine dinucleotide

95 🗷

96 Biological macromolecules have certain functions in organisms

✓ nucleic acids

- which came first DNA or RNA
 - by storing the information in DNA while using a complimentary RNA sequence to actually direct protein synthesis, the cell does not expose the information-encoding DNA chain to the dangers of single-strand cleavage every time the information is used
 - DNA is thought to have evolved from RNA as a means of preserving the genetic information and protecting it from the ongoing wear and tear associated with cellular activity