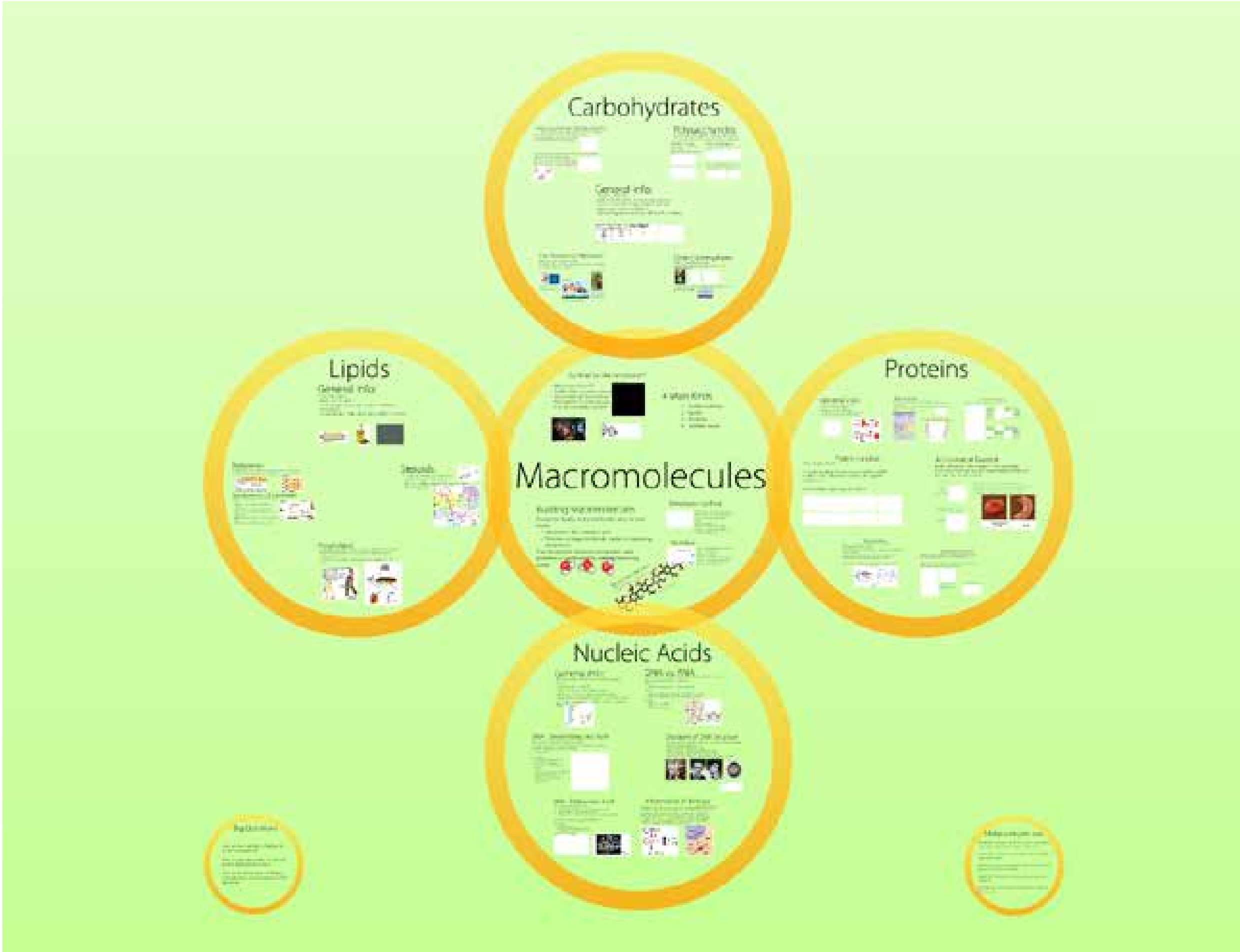


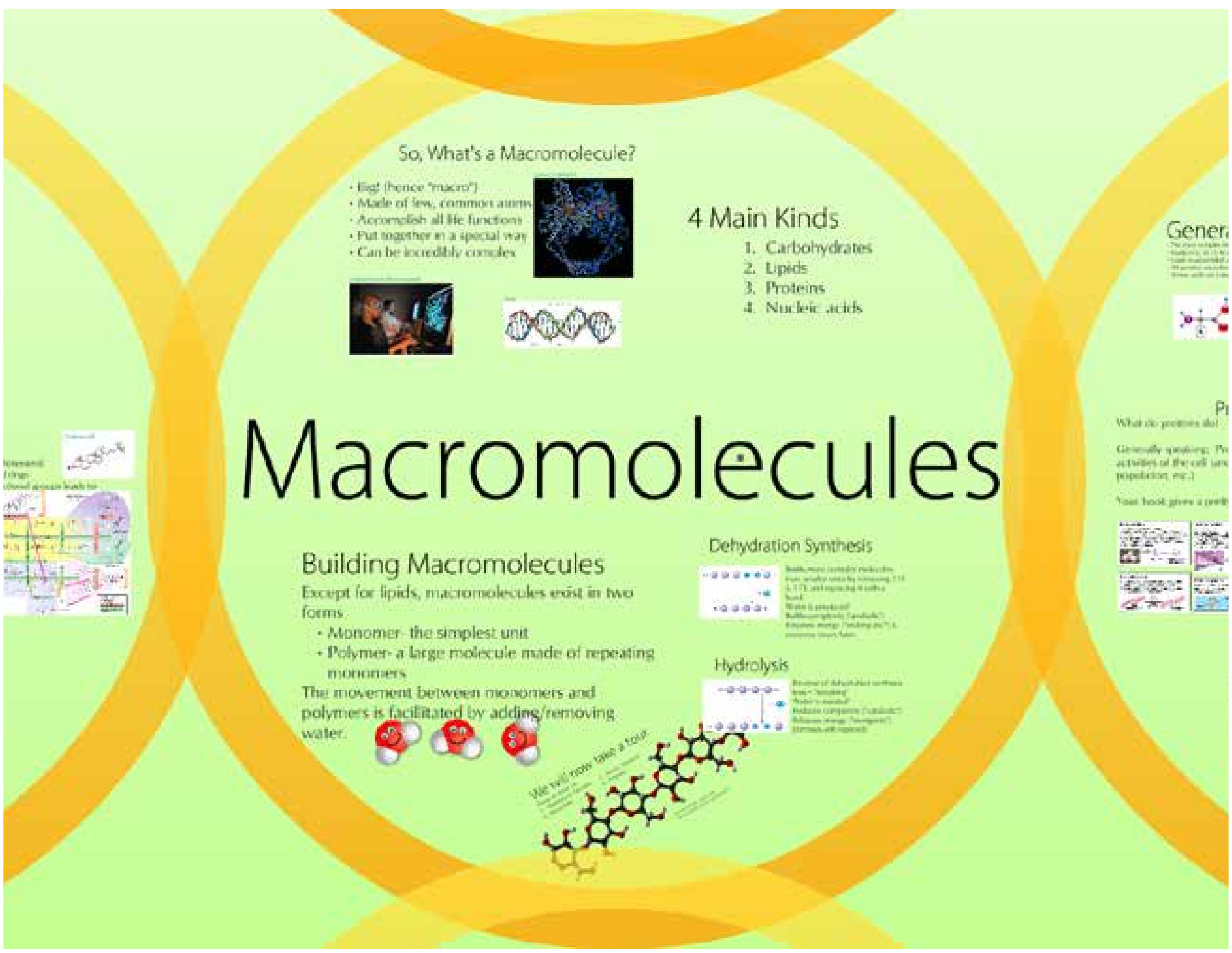
...or how to make a hairless cat (and every other living thing)

Big Questions

How are the molecules of biological systems constructed?

Why are particular groups of molecules needed in biological systems?

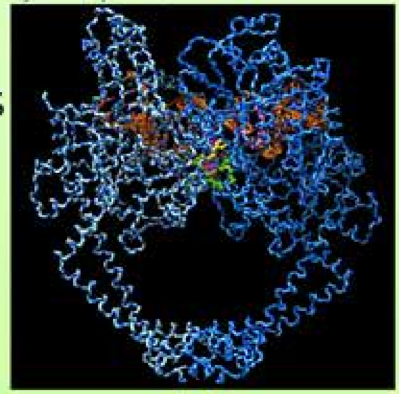
How do the interactions of biological molecules lead to the emergence of life functions?



So, What's a Macromolecule?

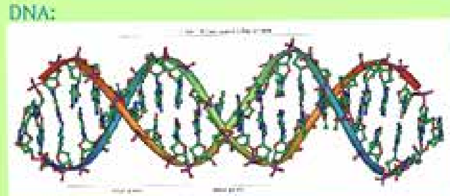
- Big! (hence "macro")
- Made of few, common atoms
- Accomplish all life functions
- Put together in a special way
- Can be incredibly complex

Gyrase (a protein)



Computers are often required!

DNA:



4 Main Kinds

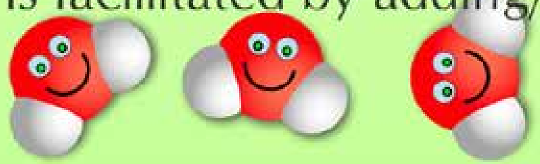
1. Carbohydrates
2. Lipids
3. Proteins
4. Nucleic acids

Building Macromolecules

Except for lipids, macromolecules exist in two forms

- Monomer- the simplest unit
- Polymer- a large molecule made of repeating monomers

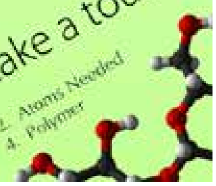
The movement between monomers and polymers is facillitated by adding/removing water.



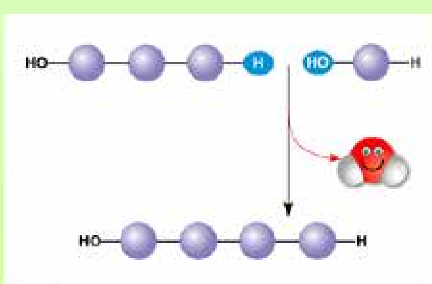
We will now take a tour

2. Atoms Needed

4. Polymer



Dehydration Synthesis



Builds more complex molecules from smaller ones by removing 2 H & 1 O, and replacing it with a bond.

Water is produced!

Builds complexity ("anabolic")

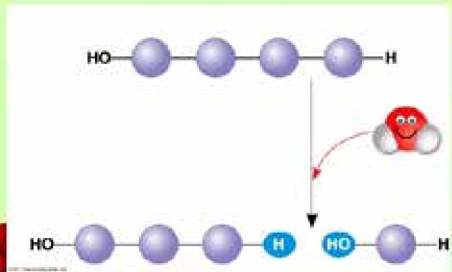
Requires energy ("endergonic") & enzymes (more later)

Hydrolysis

Reverse of dehydration synthesis

Builds complexity ("anabolic")
Requires energy ("endergonic") & enzymes (more later)

Hydrolysis



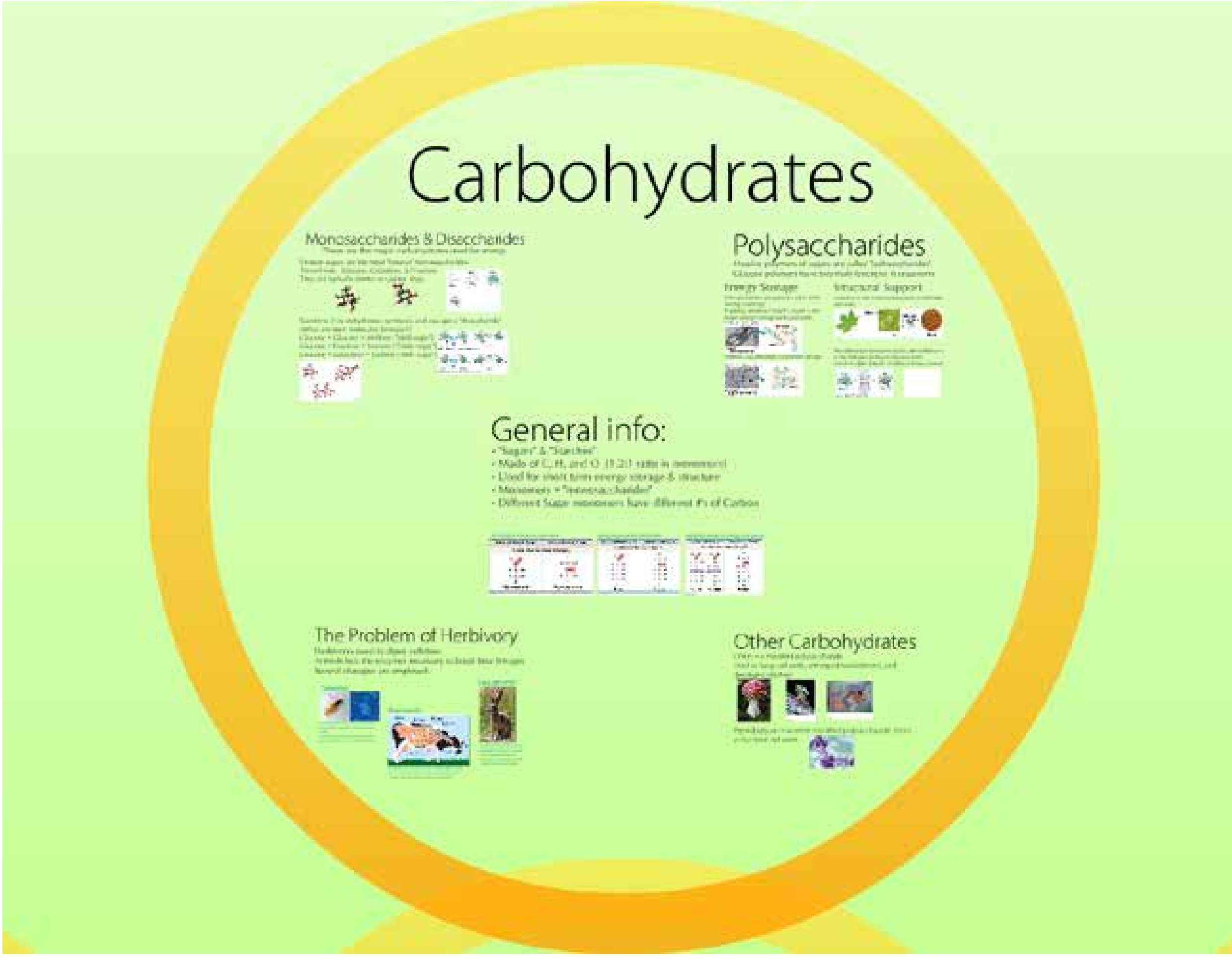
Reverse of dehydration synthesis
lysis = "breaking"
Water is needed!
Reduces complexity ("catabolic")
Releases energy ("exergonic")
Enzymes still required!

We will now take a tour

Things to focus on:

1. Structure & Function
2. Atoms Needed
3. Monomer
4. Polymer

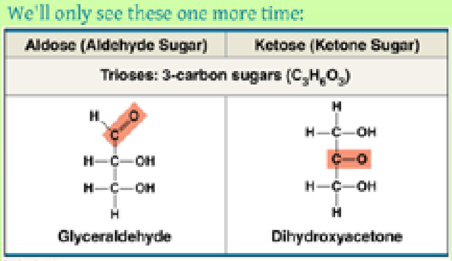
It's easy to
Don't hesita



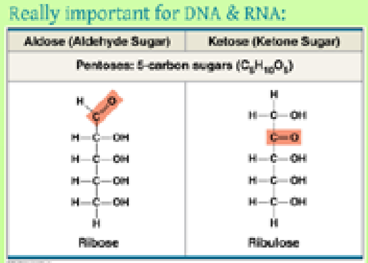
General info:

- "Sugars" & "Starches"
- Made of C, H, and O (1:2:1 ratio in monomers)
- Used for short term energy storage & structure
- Monomers = "monosaccharides"
- Different Sugar monomers have different #'s of Carbon

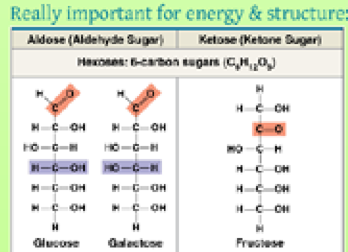
We'll only see these one more time:



Really important for DNA & RNA:



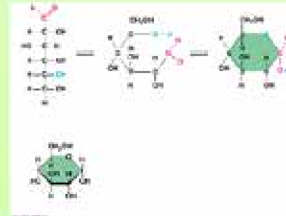
Really important for energy & structure:



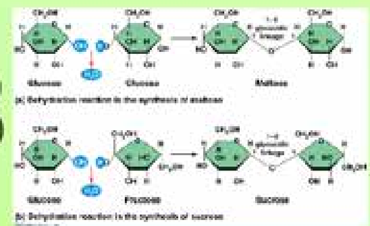
Monosaccharides & Disaccharides

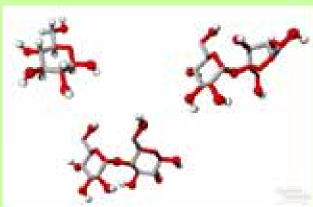
These are the major carbohydrates used for energy

Hexose sugars are the most "famous" monosaccharides
Three kinds: Glucose, Galactose, & Fructose
They are typically shown as carbon rings.



Combine 2 by dehydration synthesis, and you get a "disaccharide"
(What are their molecular formulas?)
Glucose + Glucose = Maltose ("Malt sugar")
Glucose + Fructose = Sucrose ("Table sugar")
Glucose + Galactose = Lactose ("Milk sugar")



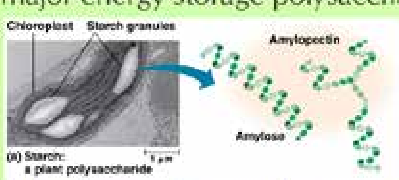


Polysaccharides

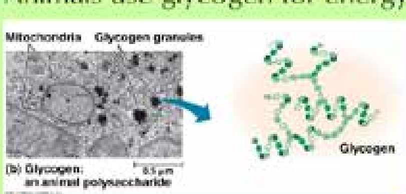
Massive polymers of sugars are called "polysaccharides"
Glucose polymers have two main functions in organisms

Energy Storage

Polysaccharides are great for short term storing of energy.
In plants, amylose ("starch") starch is the major energy storage polysaccharide.

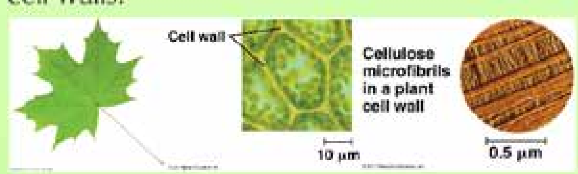


Animals use glycogen for energy storage

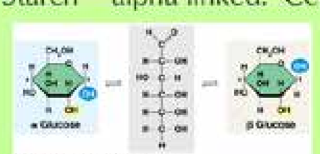


Structural Support

Cellulose is the major component of plant-like cell walls.



The difference between starch and cellulose is in the linkages between glucose units.
Starch = alpha linked. Cellulose = beta linked



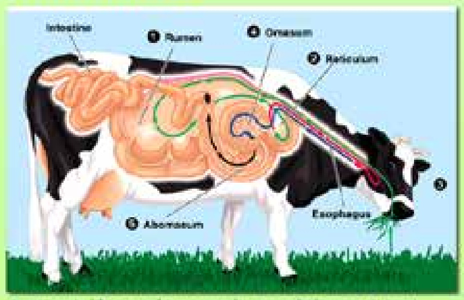
The Problem of Herbivory

Herbivores need to digest cellulose.
Animals lack the enzymes necessary to break beta linkages
Several strategies are employed.

Termites!


The most famous wood-eater of the animal kingdom has a symbiotic relationship with a protist.
In exchange for a place to live (the termite gut), the protist does the cellulose digestion

Ruminants!

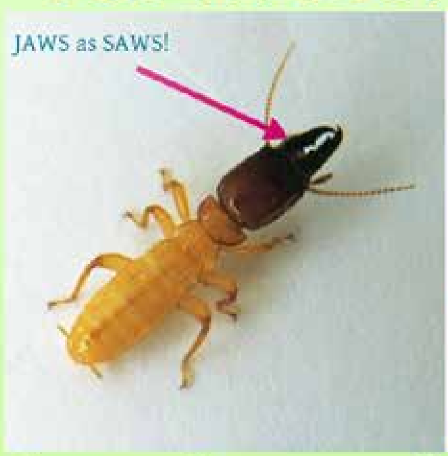


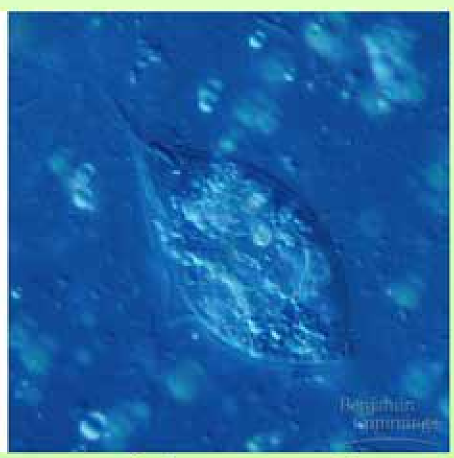
Ruminants like cows have a vastly expanded upper GI tract. The action of bacteria, and continual regurgitation and chewing of "cud" leads to the digestion of cellulose

Caecophores!

Caecophores like bunnies have an expanded lower GI tract. Food can not be regurgitated, but there is still a way to put partially digested cellulose back in to the animal...

Termites!





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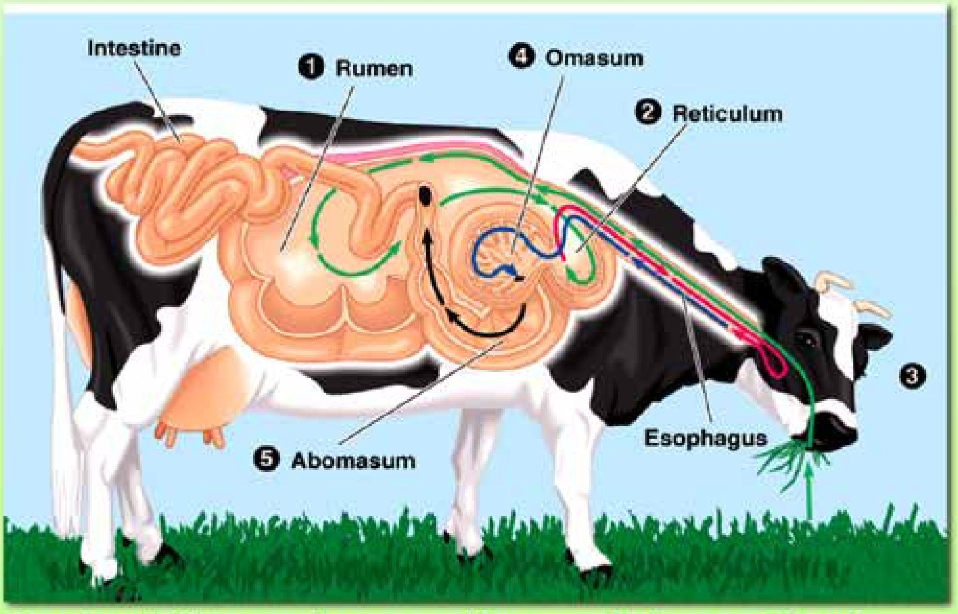
Ruminants!



Ruminants like cows have a vastly expanded upper GI tract. The action of bacteria, and continual regurgitation and chewing of "cud" leads to the digestion of cellulose

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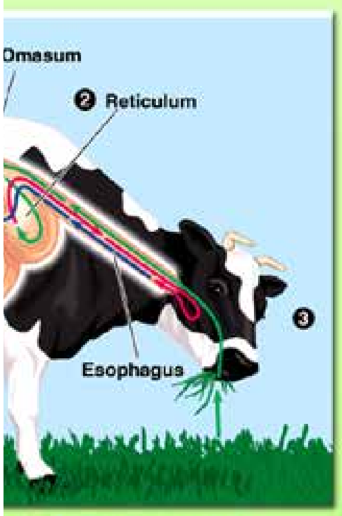
Caecophores!

Caecophores like bunnies have an expanded lower GI tract. Food can not be regurgitated, but there is still a way to put partially digested cellulose back in to the animal...



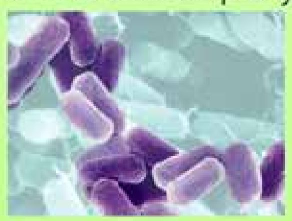
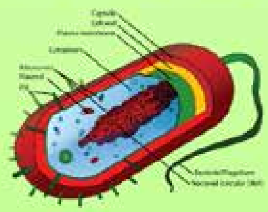
panded upper GI tract.
regurgitation and

Other Carbohydrates

Chitin = a modified polysaccharide.
Used in fungi cell walls, arthropod exoskeletons, and dissolving stitches!



Peptidoglycan = another modified polysaccharide. Used in bacterial cell walls

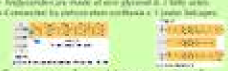



Lipids

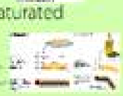
General info:



Triglycerides



Saturated vs. Unsaturated



Steroids


Phospholipids

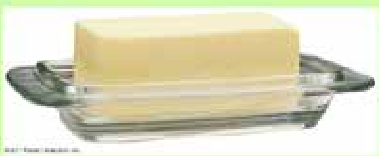

Ma

Buildi

Except fo
forms
• Mono
• Polym
mono
The move
polymers
water.

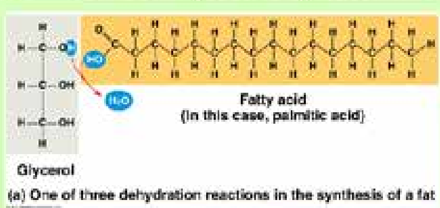
General info:

- Fats, Oils, Waxes
- Made of C, H, and O
- Used for long term energy storage & insulation
- No polymers.
- 3 major groups: triglycerides, phospolipids, & steroids

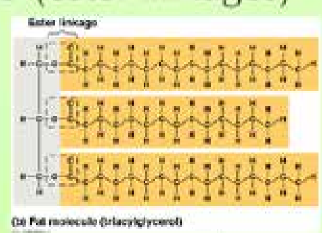


Triglycerides

- Triglycerides are made of one glycerol & 3 fatty acids.
- Connected by dehydration synthesis x 3 (ester linkages)



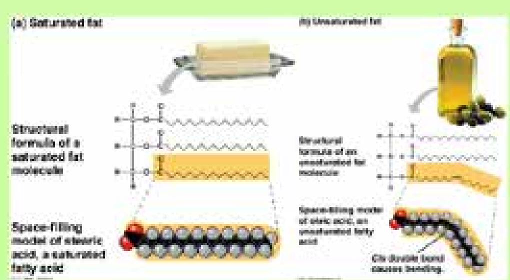
(a) One of three dehydration reactions in the synthesis of a fat



(b) Fat molecule (triacylglycerol)

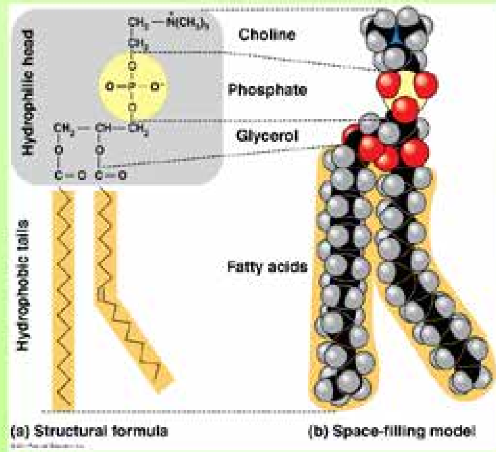
Saturated vs. Unsaturated

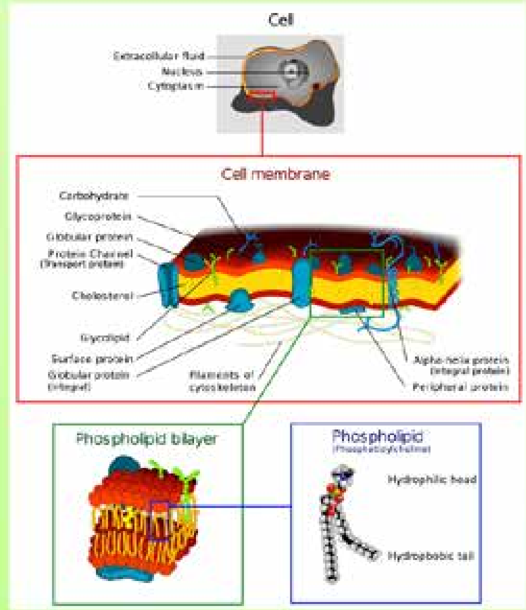
- Refers to the bonding of carbon in the fatty acids.
- Saturated = no double bonds between carbons.
- Unsaturated = at least one double bond.
- Influences shape which influences properties.
- Oils vs. fats
- Which ones stay liquid at lower temperatures? Why?
- Which ones are healthier for you? Why?



Phospholipids

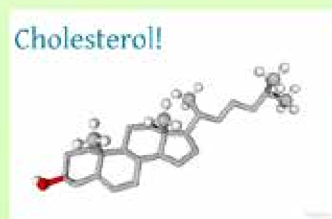
- Modified triglycerides. Replace on fatty acid with a phosphate
- Makes the molecule have a polar and a non-polar region ("amphipathic")
- The major component of cell membranes (arranged as a "bi-layer"

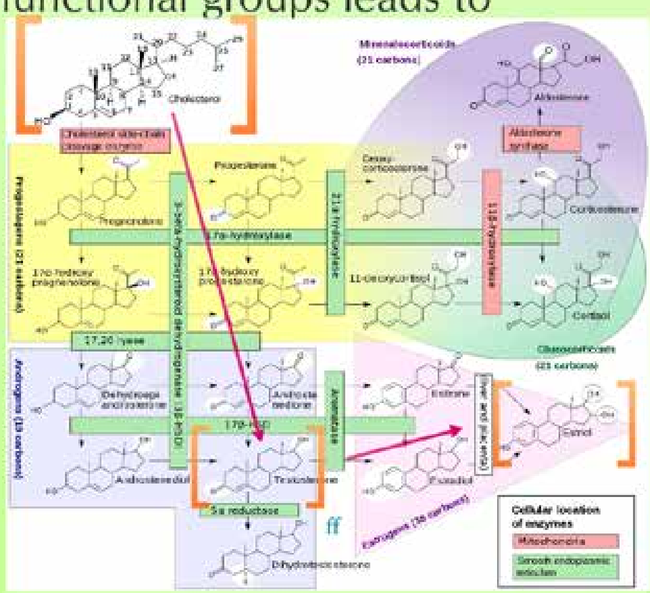


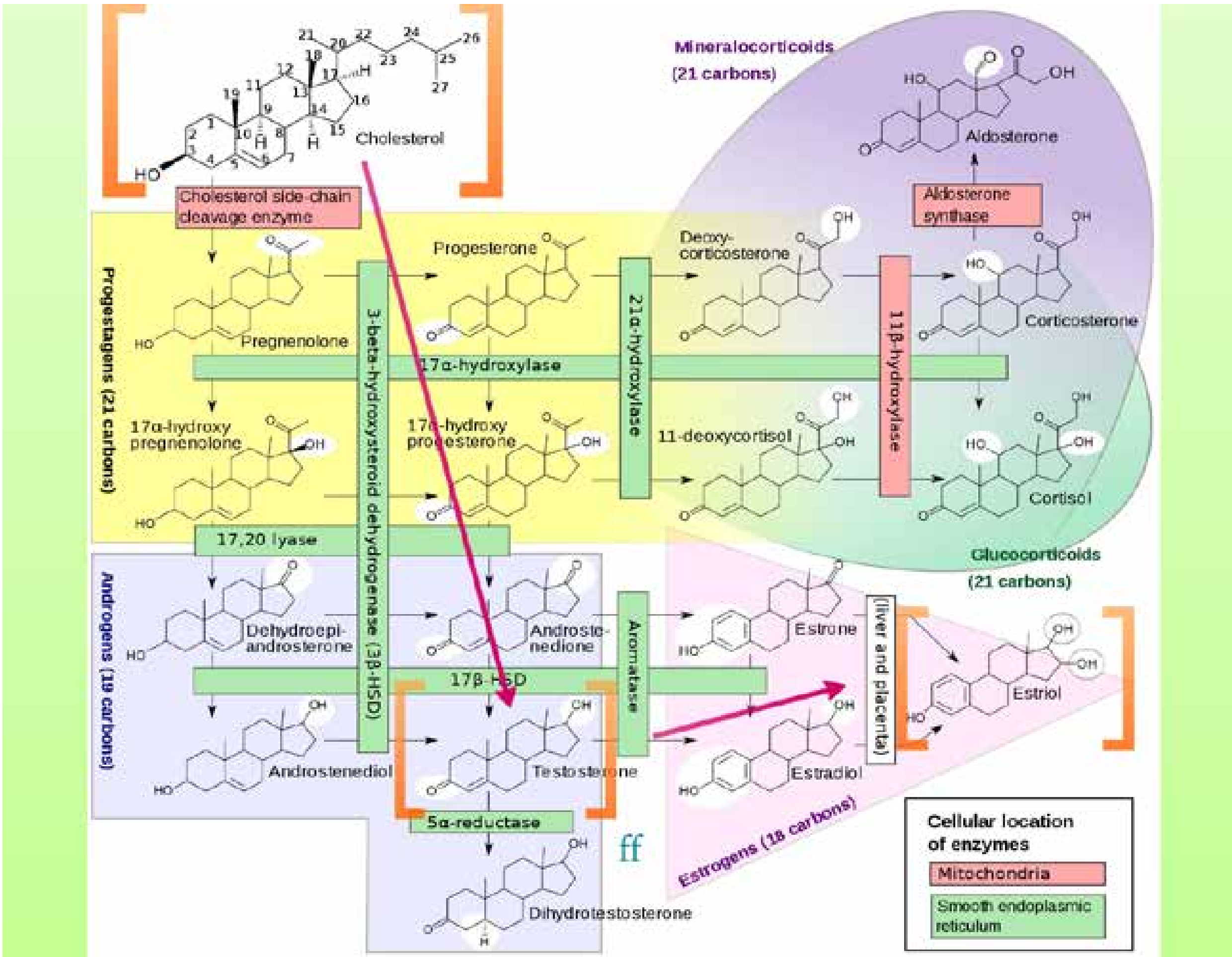


Steroids

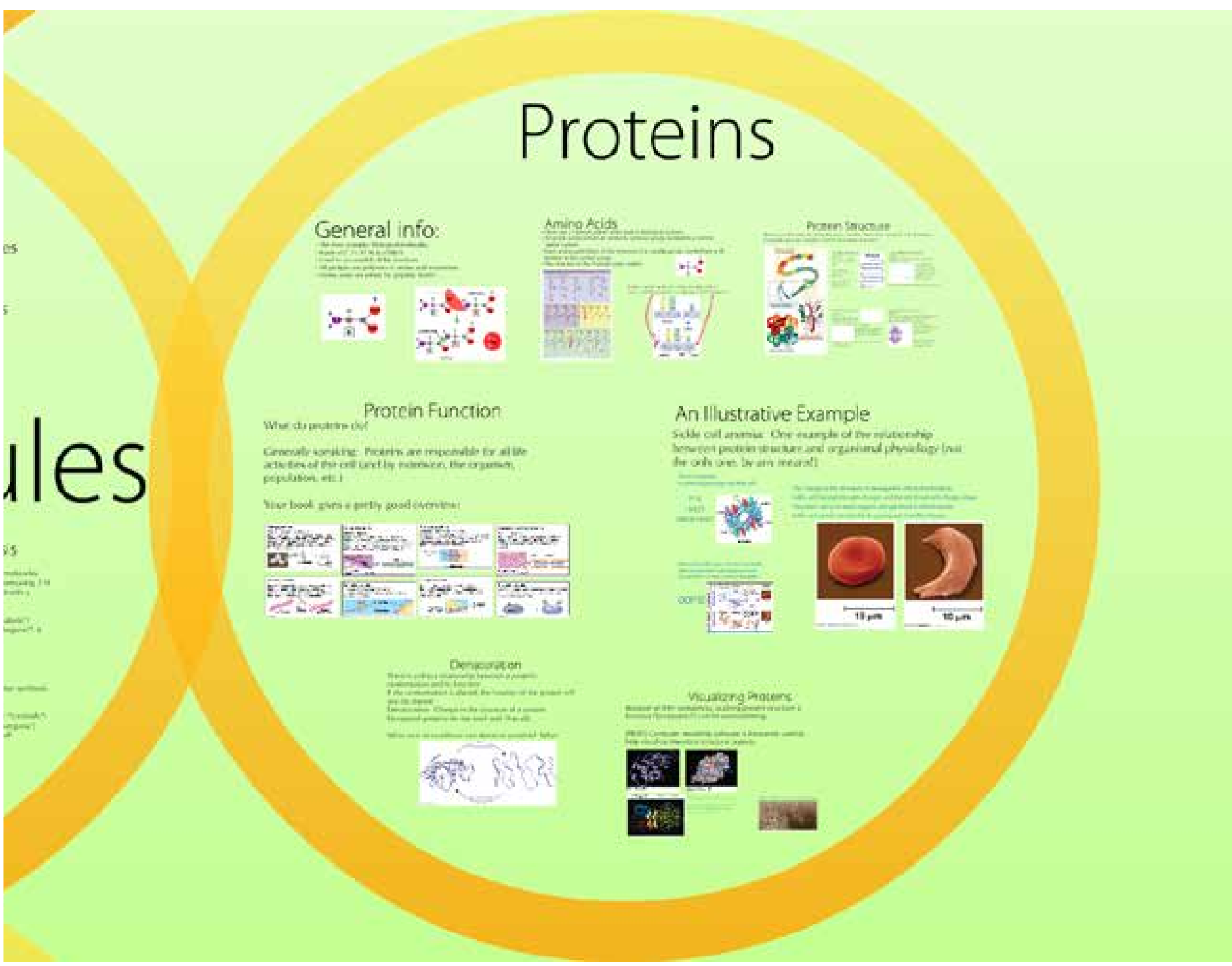
- 1 class of hormones, & cholesterol.
- Notable structure = fused rings
- Presence of different functional groups leads to different functions







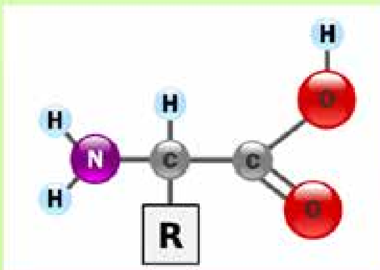
Cholesterol
Cholesterol side-chain cleavage enzyme
Mineralocorticoids (21 carbons)
Aldosterone
Aldosterone synthase
Progestagens (21 carbons)
Pregnenolone
Progesterone
Deoxy-corticosterone
Corticosterone
3-beta-hydroxysteroid dehydrogenase (3β-HSD)
21α-hydroxylase
11β-hydroxylase
17α-hydroxylase
17α-hydroxy pregnenolone
17α-hydroxy progesterone
11-deoxycortisol
Cortisol
Glucocorticoids (21 carbons)
17,20 lyase
Androgens (19 carbons)
Dehydroepi-androsterone
Androste-nedione
Aromatase
Estrone
(liver and placenta)
Estriol
17β-HSD
Androstenediol
Testosterone
Estradiol
5α-reductase
Dihydrotestosterone
Estrogens (18 carbons)
Cellular location of enzymes
Mitochondria
Smooth endoplasmic reticulum

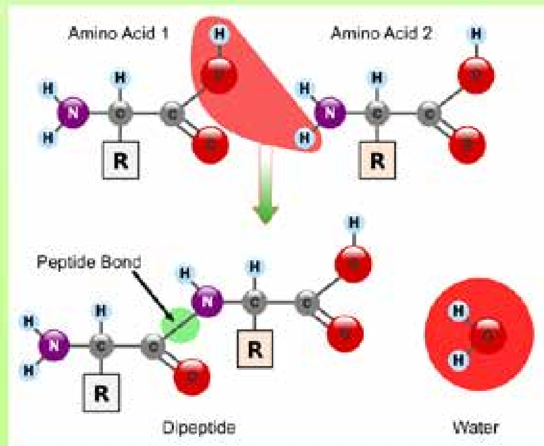


Proteins
General info:
Amino Acids
Protein Structure
Protein Function
What do proteins do?
Generally speaking: Proteins are responsible for all life activities of the cell (and by extension, the organism, population, etc.)
Your book gives a pretty good overview:
An Illustrative Example
Sickle cell anemia: One example of the relationship between protein structure and organismal physiology (not the only one, by any means!)
Denaturation
Visualizing Proteins
ules

General info:

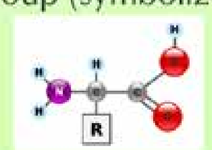
- The most complex biological molecules.
- Made of C, H, O, N & a little S
- Used to accomplish all life functions
- All proteins are polymers of amino acid monomers
- Amino acids are joined by "peptide bonds"

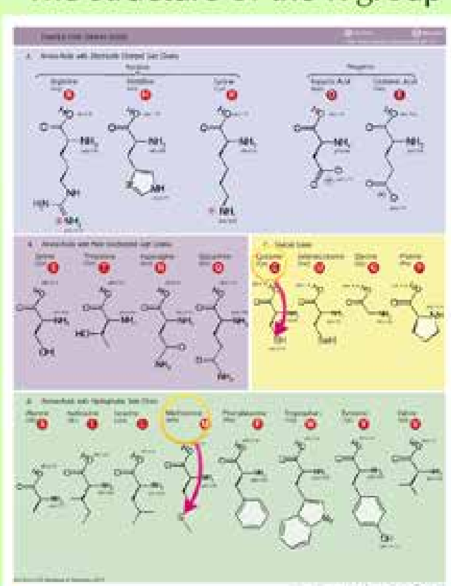




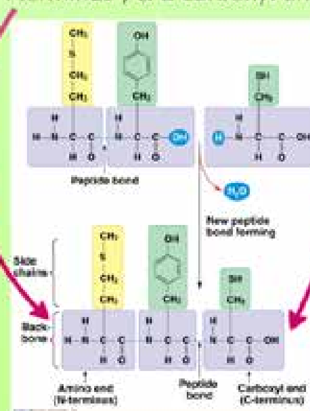
Amino Acids

- There are 21 known amino acids used in biological systems.
- All amino acids contain an amino & carboxyl group, bonded to a central "alpha" carbon.
- Every amino acid differs in the structure of a variable group (symbolized as R) bonded to the central group.
- The structure of the R-group varies widely.

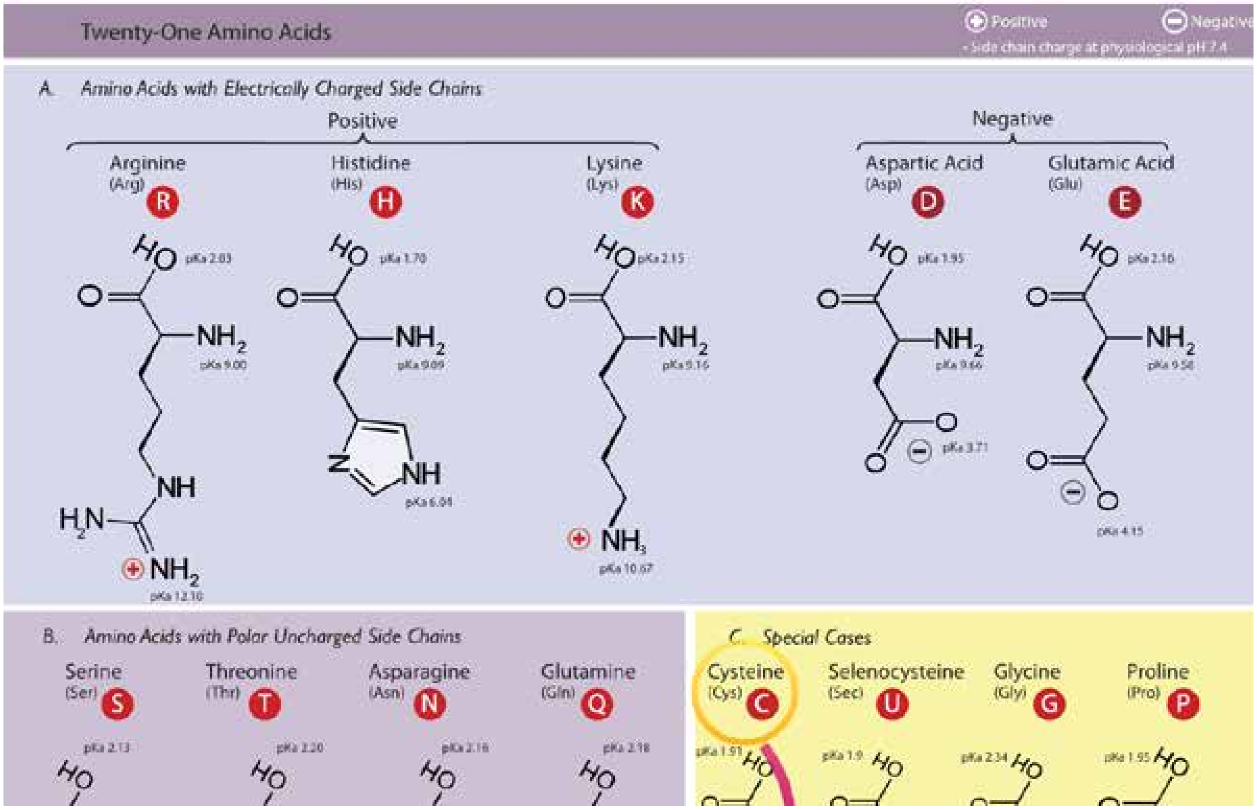


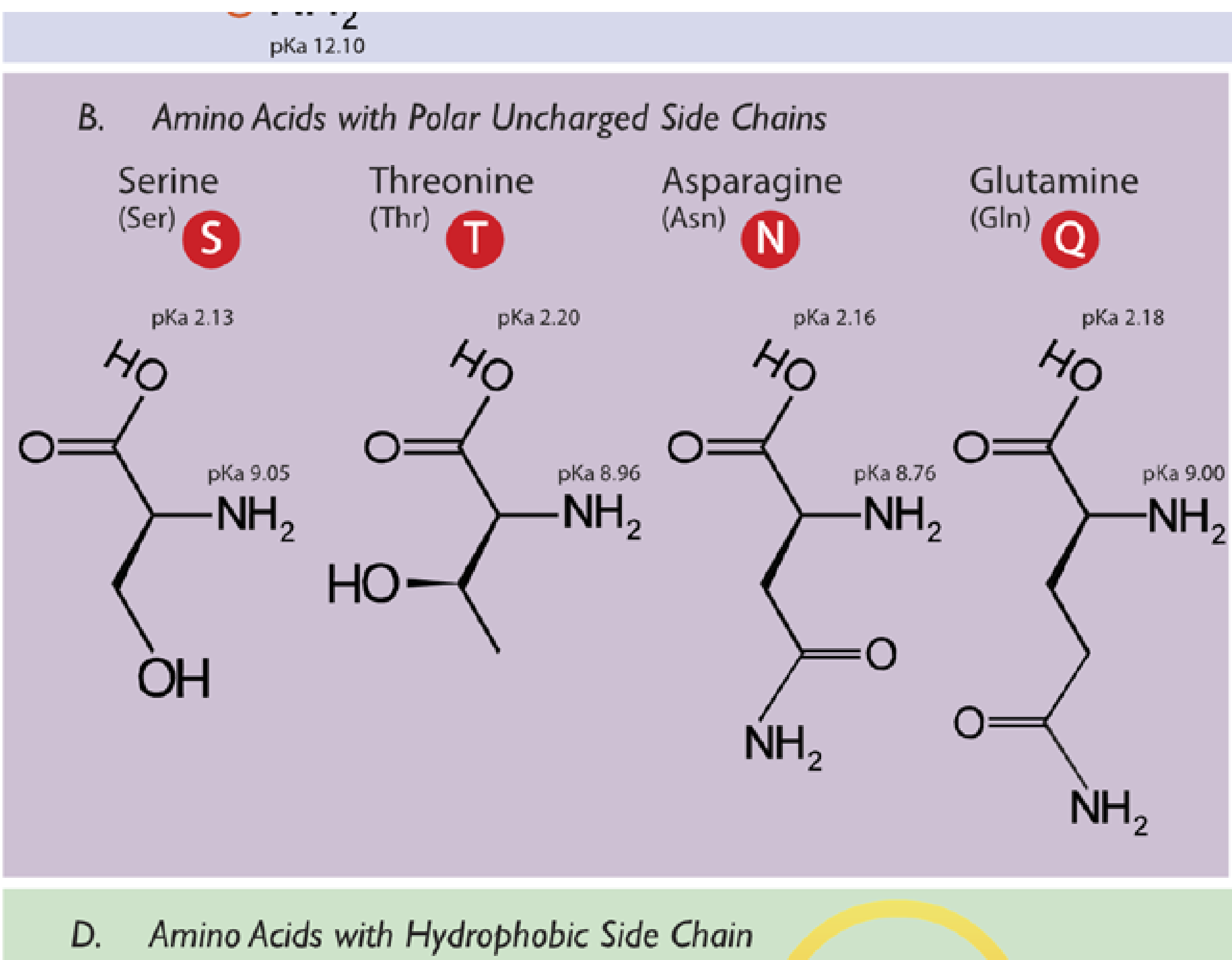


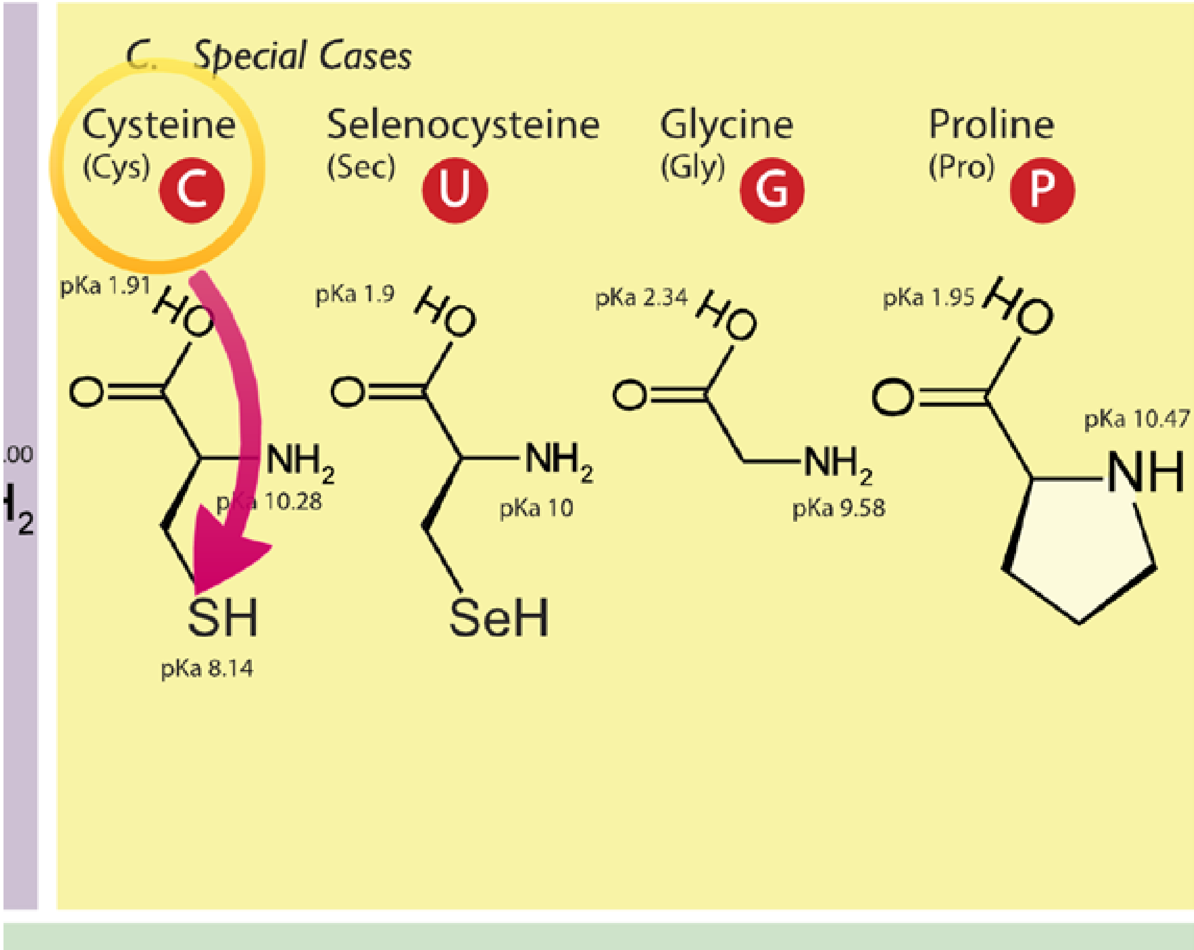
Chains of amino acids have a directionality, with an amino end ("N-terminus") & a carboxyl end ("C-terminus")

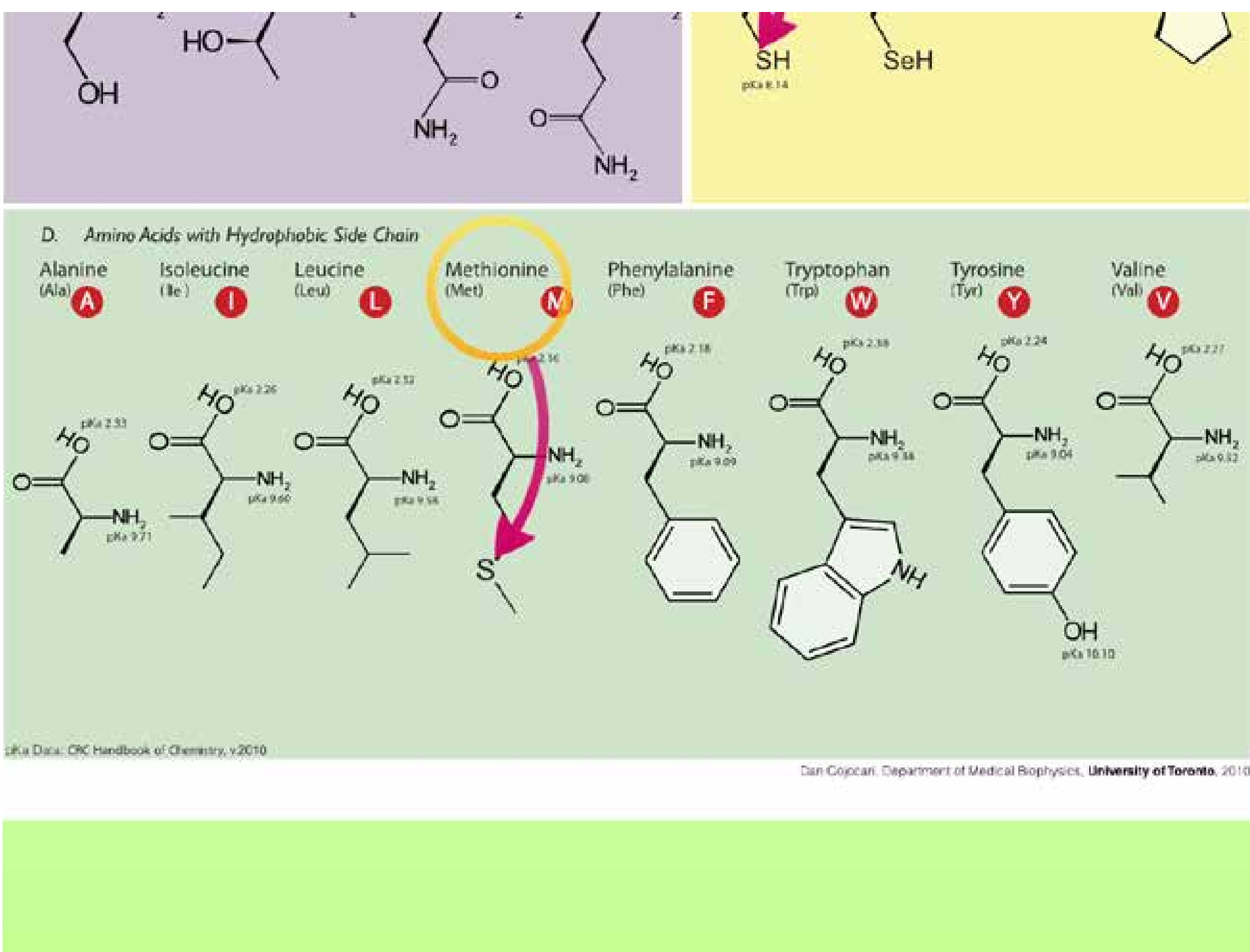


The structure of the R-group

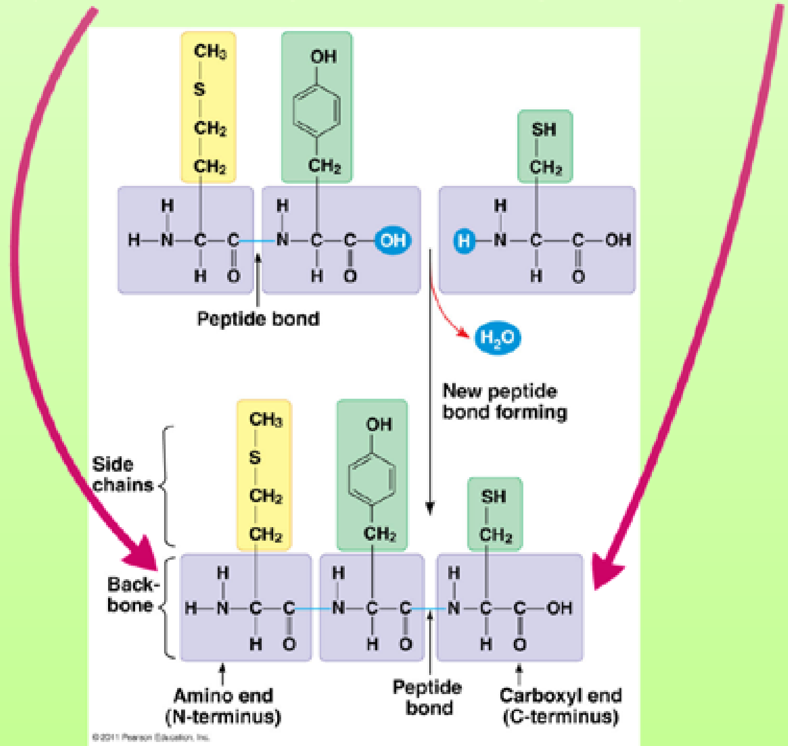





C. Special Cases
Cysteine
(Cys) C
Selenocysteine
(Sec) U
Glycine
(Gly) G
Proline
(Pro) P
pKa 1.91
HO
O
NH2
pKa 10.28
SH
pKa 8.14
pKa 1.9
HO
O
NH2
pKa 10
SeH
pKa 2.34
HO
O
NH2
pKa 9.58
pKa 1.95
HO
O
pKa 10.47
NH

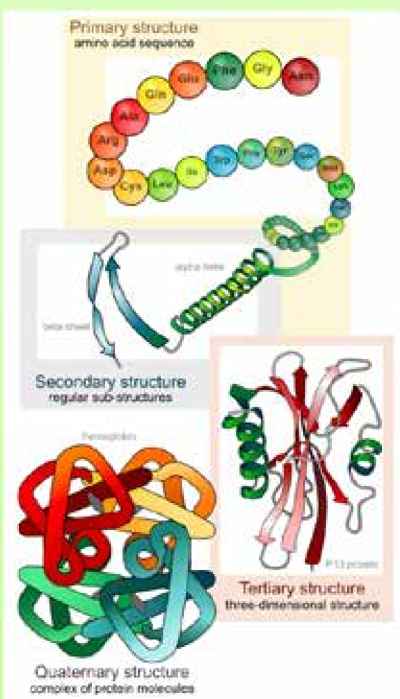

HO
OH
O
NH2
O
NH2
SH
SeH
D. Amino Acids with Hydrophobic Side Chain
Alanine
(Ala) A
Isoleucine
(Ile) I
Leucine
(Leu) L
Methionine
(Met) M
Phenylalanine
(Phe) F
Tryptophan
(Trp) W
Tyrosine
(Tyr) Y
Valine
(Val) V
HO
O
NH2
S
NH
OH
pKa Data: CRC Handbook of Chemistry, v.2010
Dan Cojocari, Department of Medical Biophysics, University of Toronto, 2010

Chains of amino acids have a directionality, with an amino end ("N-terminus") & a carboxyl end ("C-terminus")



Protein Structure

Because of the diversity of amino acids, proteins have very complex 3-D structures. Generally, we can consider 4 levels of protein structure:



Primary Structure

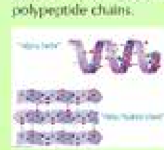
What it is:
The sequence of amino acids in one polypeptide chain

How it happens:
Peptide bonds between amino acids.

How does the cell "know" the order of amino acids?

Secondary Structure

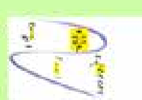
What it is:
Regular, repeating 3D structures found in all polypeptide chains.



How it happens:
Hydrogen bonding between atoms in the CN backbone of the polypeptide (no R-groups involved)

Why do all proteins have similar secondary structures?

Tertiary Structure



What it is:
The specific 3D shape of a particular polypeptide chain (aka the "conformation")

How it happens:
Interactions between R-group atoms with other R-groups and the local environments of the cell

What kinds of interactions can occur to determine tertiary structure?

Quartenary Structure

What it is:
The specific 3D shape of any protein that is made of more than one polypeptide chain (many are).
The only "optional" level of structure.

How it happens:
The overall structure when multiple chains form a functional protein.

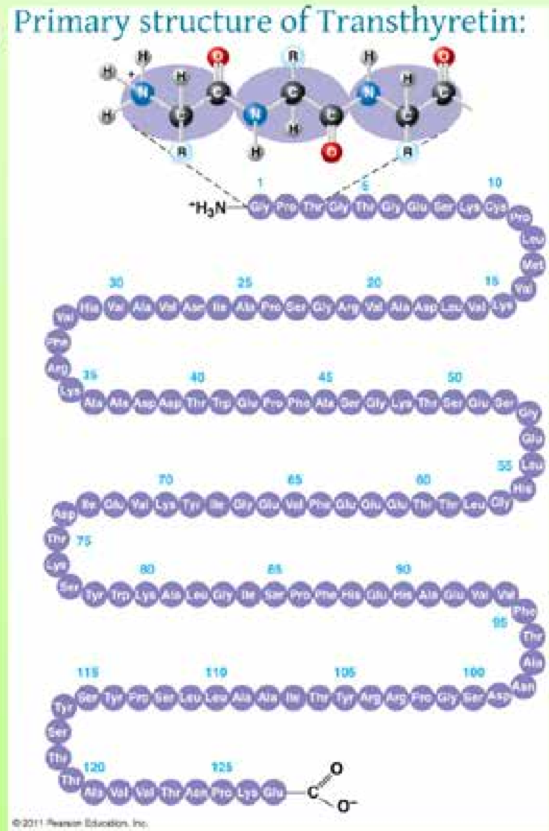
Why do some proteins consist of more than 1 polypeptide chain?

Primary Structure

What it is:
The sequence of amino acids in one polypeptide chain

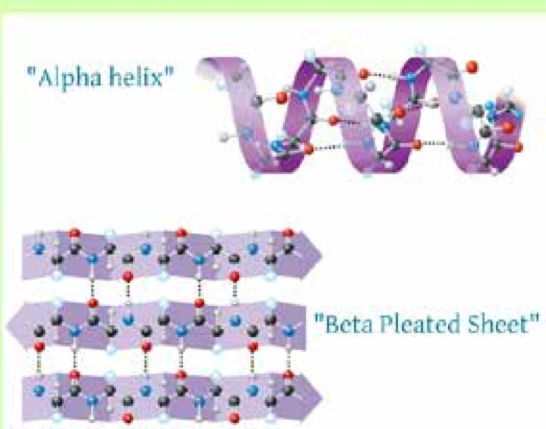
How it happens:
Peptide bonds between amino acids.

How does the cell "know" the order of amino acids?



Secondary Structure

What it is:
Regular, repeating 3D structures found in all polypeptide chains.

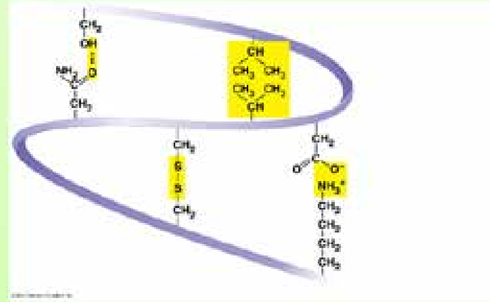


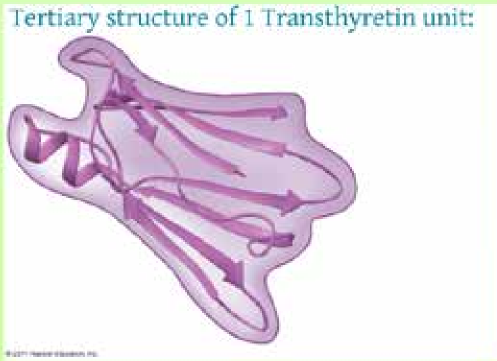
How it happens:
Hydrogen bonding between atoms in the CN backbone of the polypeptide (no R-groups involved)

Why do all proteins have similar secondary structures?

Tertiary Structure

What it is:
The specific 3D shape of a particular polypeptide chain (aka the "conformation")



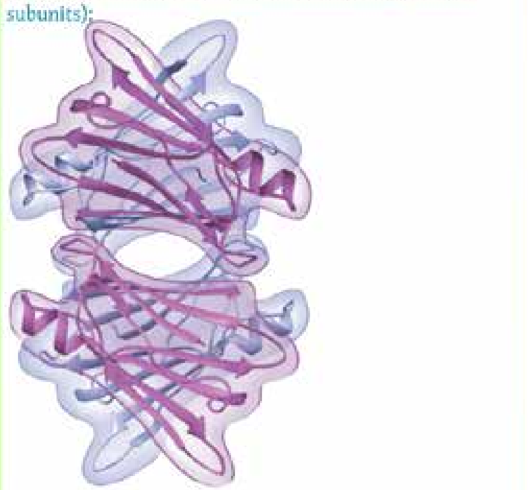

Tertiary structure of 1 Transthyretin unit:

How it happens:
Interactions between R-group atoms with other R-groups and the local environments of the cell

What kinds of interactions can occur to determine tertiary structure?

Quartenary Structure

What it is:
The specific 3D shape of any protein that is made of more than one polypeptide chain (many are).
The only "optional" level of structure.


Quaternary structure of Transthyretin (four identical subunits):

How it happens:
The overall structure when multiple chains form a functional protein.

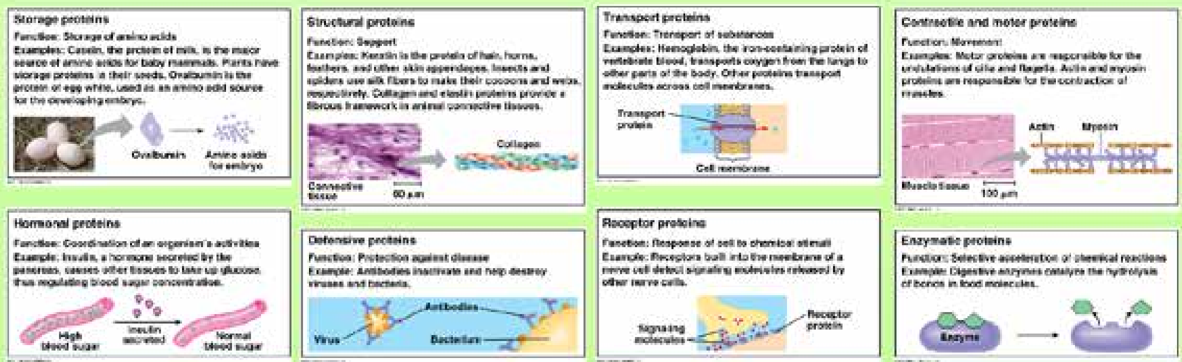
Why do some proteins consist of more than 1 polypeptide chain?

Protein Function

What do proteins do?

Generally speaking: Proteins are responsible for all life activities of the cell (and by extension, the organism, population, etc.)

Your book gives a pretty good overview:



Storage proteins

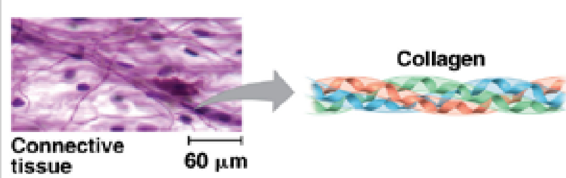
Function: Storage of amino acids

Examples: Casein, the protein of milk, is the major source of amino acids for baby mammals. Plants have storage proteins in their seeds. Ovalbumin is the protein of egg white, used as an amino acid source for the developing embryo.

Structural proteins

Function: Support

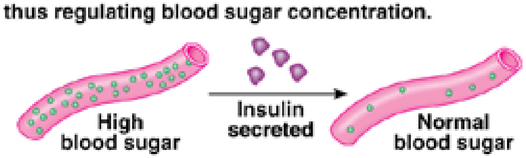
Examples: Keratin is the protein of hair, horns, feathers, and other skin appendages. Insects and spiders use silk fibers to make their cocoons and webs, respectively. Collagen and elastin proteins provide a fibrous framework in animal connective tissues.



Hormonal proteins

Function: Coordination of an organism's activities

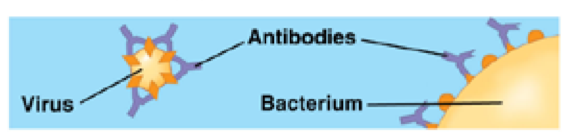
Example: Insulin, a hormone secreted by the pancreas, causes other tissues to take up glucose, thus regulating blood sugar concentration.



Defensive proteins

Function: Protection against disease

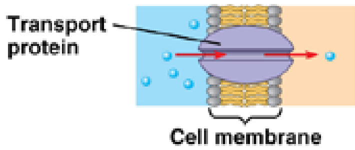
Example: Antibodies inactivate and help destroy viruses and bacteria.



Transport proteins

Function: Transport of substances

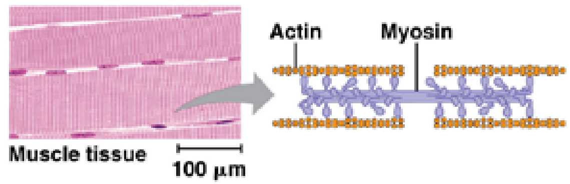
Examples: Hemoglobin, the iron-containing protein of vertebrate blood, transports oxygen from the lungs to other parts of the body. Other proteins transport molecules across cell membranes.



Contractile and motor proteins

Function: Movement

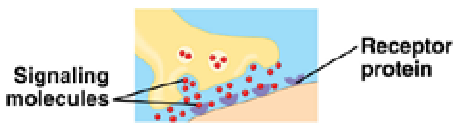
Examples: Motor proteins are responsible for the undulations of cilia and flagella. Actin and myosin proteins are responsible for the contraction of muscles.



Receptor proteins

Function: Response of cell to chemical stimuli

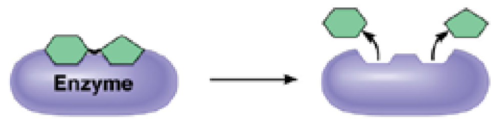
Example: Receptors built into the membrane of a nerve cell detect signaling molecules released by other nerve cells.



Enzymatic proteins

Function: Selective acceleration of chemical reactions

Example: Digestive enzymes catalyze the hydrolysis of bonds in food molecules.

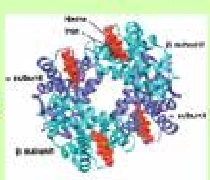


An Illustrative Example

Sickle cell anemia: One example of the relationship between protein structure and organismal physiology (not the only one, by any means!)

This is Hemoglobin!
It carries oxygen in your red blood cells

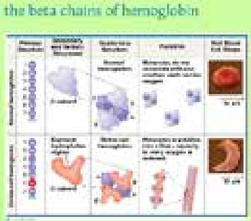
IT IS CRAZY IMPORTANT!



This change in the structure of hemoglobin affects the function.
Sickle-cell hemoglobin gets clumpy, and the red blood cells change shape.
They don't carry as much oxygen, and get stuck in blood vessels.
Sickle-cell anemic people die at a young age from the disease.

Some unlucky folks have a mutation that results valine (hydrophobic) replacing glutamic acid (hydrophilic) in the beta chains of hemoglobin

OOPS!



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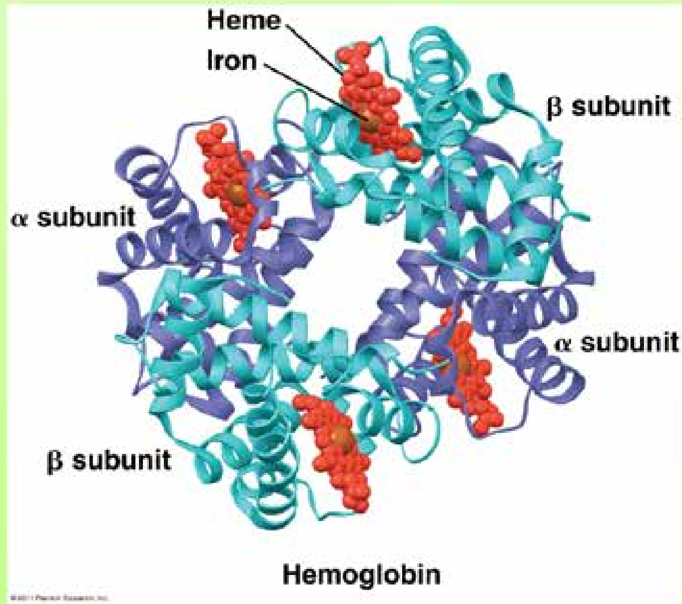

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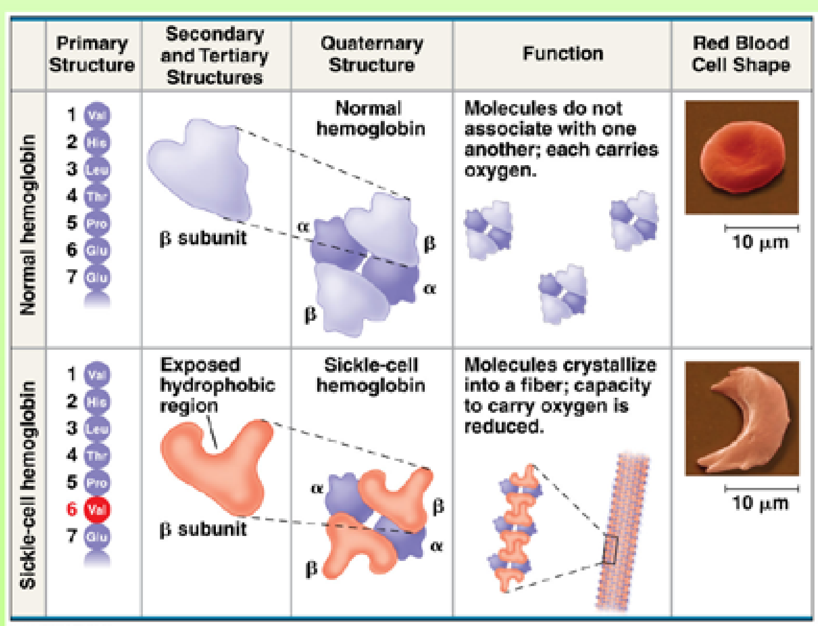

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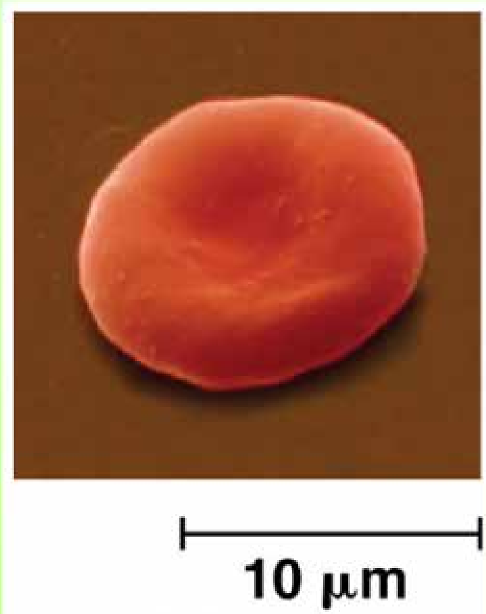
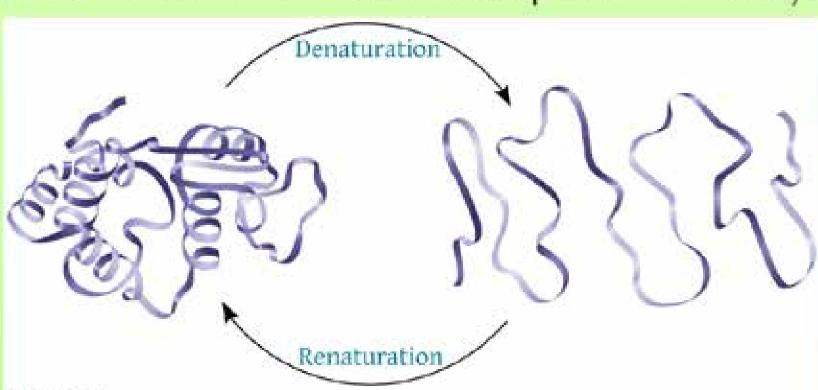


Denaturation

There is a direct relationship between a protein's conformation and its function.
If the conformation is altered, the function of the protein will also be altered.
Denaturation: Change in the structure of a protein.
Denatured proteins do not work well (if at all).

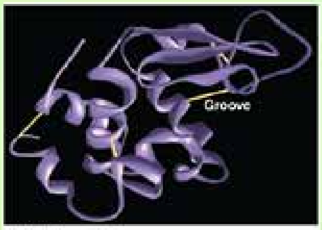
What sorts of conditions can denature proteins? Why?



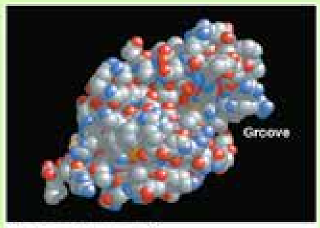
Visualizing Proteins

Because of their complexity, studying protein structure & function ("proteomics") can be overwhelming.

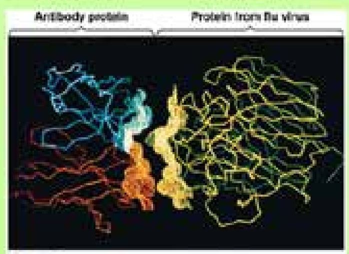
(FREE!) Computer modeling software is frequently used to help visualize important structural aspects.



(a) A ribbon model



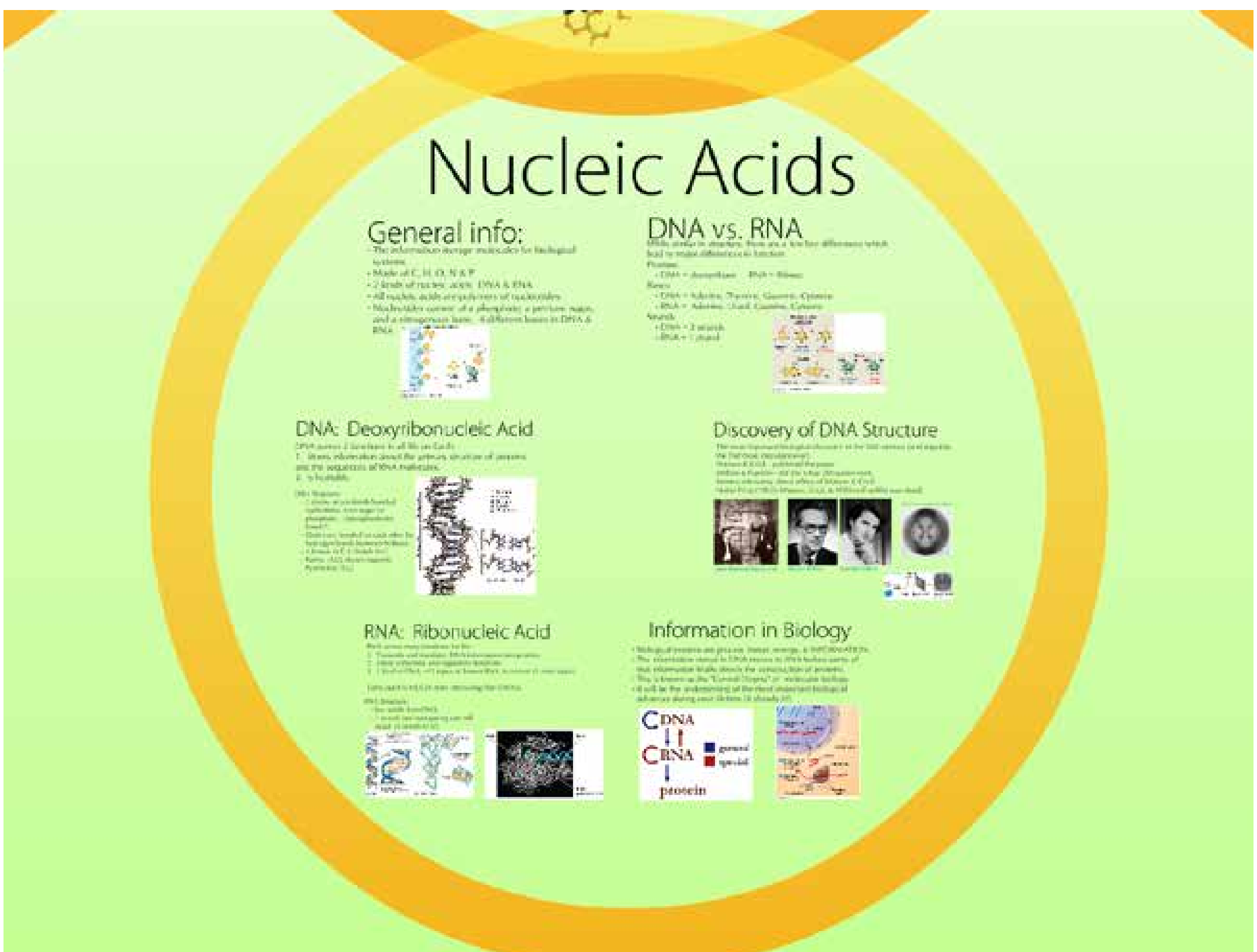
(b) A space-filling model



a & b: two different views of the lysozyme protein

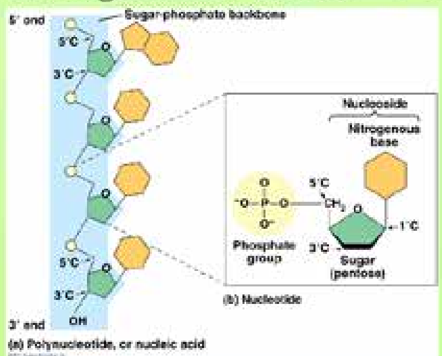
By only focusing on the interacting elements of the flu virus and an antibody, scientists can better understand these interactions

Plenty of proteins can be seen with the naked eye!



General info:

- The information storage molecules for biological systems.
- Made of C, H, O, N & P
- 2 kinds of nucleic acids: DNA & RNA
- All nucleic acids are polymers of nucleotides.
- Nucleotides consist of a phosphate, a pentose sugar, and a nitrogenous base. 4 different bases in DNA & RNA



DNA vs. RNA

While similar in structure, there are a few key differences which lead to major differences in function.

Pentose:

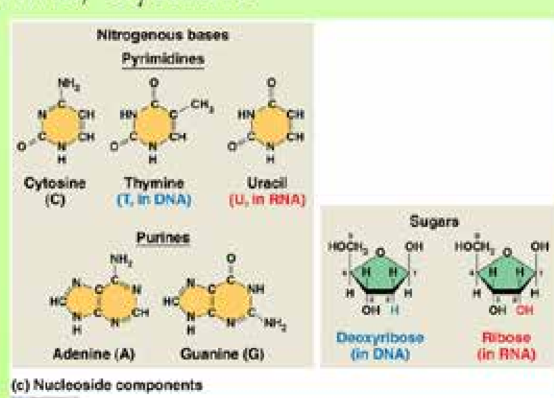
- DNA = deoxyribose   RNA = Ribose

Bases:

- DNA = Adenine, Thymine, Guanine, Cytosine
- RNA = Adenine, Uracil, Guanine, Cytosne

Strands

- DNA = 2 strands
- RNA = 1 strand



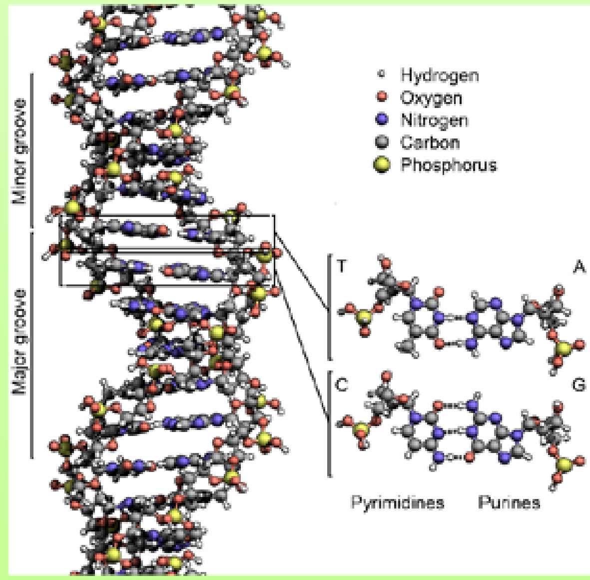
DNA: Deoxyribonucleic Acid

DNA serves 2 functions in all life on Earth:

1. Stores information about the primary structure of proteins, and the sequences of RNA molecules.
2. Is heritable.

DNA Structure:

- 2 chains of covalently bonded nucleotides, from sugar to phosphate... ("phosphodiester bonds")
- Chains are bonded to each other by hydrogen bonds between N Bases.
- A bonds to T, G bonds to C.
- Purine (A,G) always opposite Pyrimidine (T,C)



Discovery of DNA Structure

The most important biological discovery of the 20th century (and arguably, the 2nd most important ever).

Watson & Crick - published the paper

Wilkins & Franklin - did the X-Ray diffraction work

Some controversy about ethics of Watson & Crick.

Nobel Prize (1962)- Watson, Crick, & Wilkins (Franklin was dead)


James Watson & Francis Crick


Maurice Wilkins

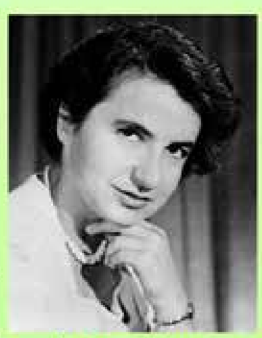
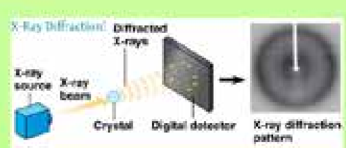

Rosalind Franklin

Photo 51: X marks the helix!

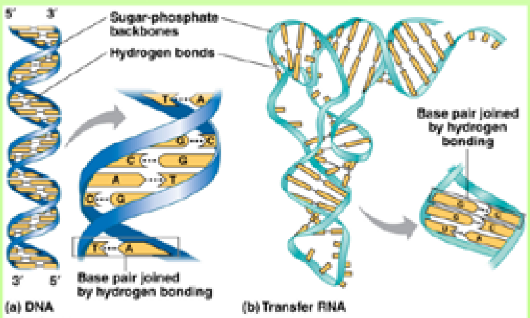


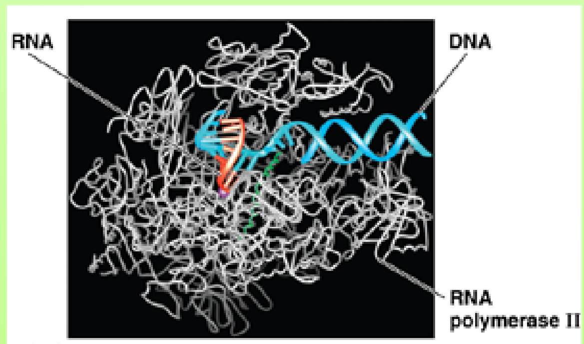
RNA: Ribonucleic Acid

RNA serves many functions for life:
1. Transmits and translates DNA information into protein.
2. Many enzymatic and regulatory functions.
3. 1 kind of DNA, ~15 types of known RNA at current (3 main types)

Turns out it is MUCH more interesting than DNA is.

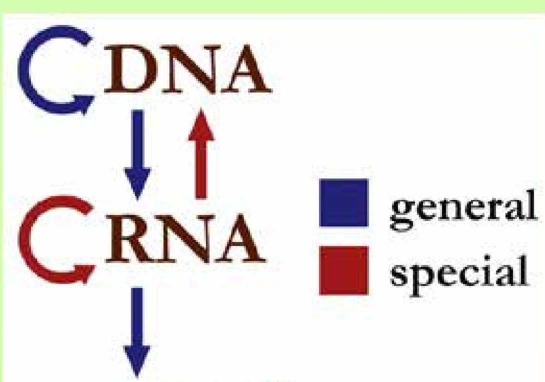
RNA Structure:
- less stable than DNA.
- 1 strand, but base-paring can still occur (A bonds to U)

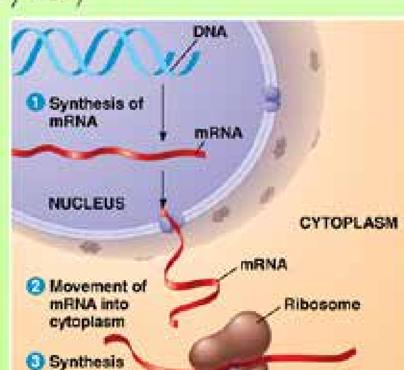




Information in Biology

- Biological systems are process matter, energy, & INFORMATION.
- The information stored in DNA moves to RNA before some of that information finally directs the construction of proteins.
- This is known as the "Central Dogma" of molecular biology.
- It will be the underpinning of the most important biological advances during your lifetime (it already is!)





Make sure you can

Identify the structures of the monomers and polymers of the four major classes of macromolecules.

Diagram the synthesis and hydrolysis of carbohydrates and polypeptides.

Explain the biological functions of all of the molecules discussed in this presentation.

Explain the emergence of all four levels of protein structure.

Describe the role of general role of nucleic acids in living systems.