Chemistry Review: Organic Components—Carbohydrates and Proteins

Lecture 4

Objectives

Understand/know/focus on/note

- the meaning of hydrolysis, condensation, polymer
- chemical features of carbohydrates and names of a few monosaccharides: glucose and its isomers mannose, galactose
- names of disaccharides and monosaccharides composing them: sucrose, lactose
- glucose is stored as polymers: glycogen, starch
- what makes these glucose polymers and that they are branched

Objectives

Understand/know/focus on/note

- oligosaccharides (branched monosaccharide polymers) are attached to proteins and membrane lipids to make glycoproteins and glycolipds, respectively
- basic atomic features of the amino acid
- what peptide bonds are and how they are formed
- the four levels of protein structure
- the chemical bonding discussed previously applies to how proteins fold and amino acids bond with each other: H-bonding, ionic, hydrophobic
- what enzymes are (catalysts made of protein) and the special structural features they have

Terms / Definitions / Descriptions

- Hydrolysis ("cutting with water")

  A chemical reaction in which H_2O is used in the bond breaking of a molecule into two distinct molecules, one taking an H atom and the other the OH atom

- Condensation

  in chemistry, it refers to the opposite of hydrolysis: joining two chemicals in a way that H_2O is released

  both hydrolysis and condensation happen a lot in biochemistry

- Polymer

  A molecule made up of many repeating smaller molecules ("monomers") bonded together in a chemical reaction (polymerization). Polymeric forms of biochemicals are ubiquitous in biological organisms

Terms / Definitions / Descriptions

- Isomer

  A form of a molecule that can have many different structures while the number of the kinds of atoms is identical

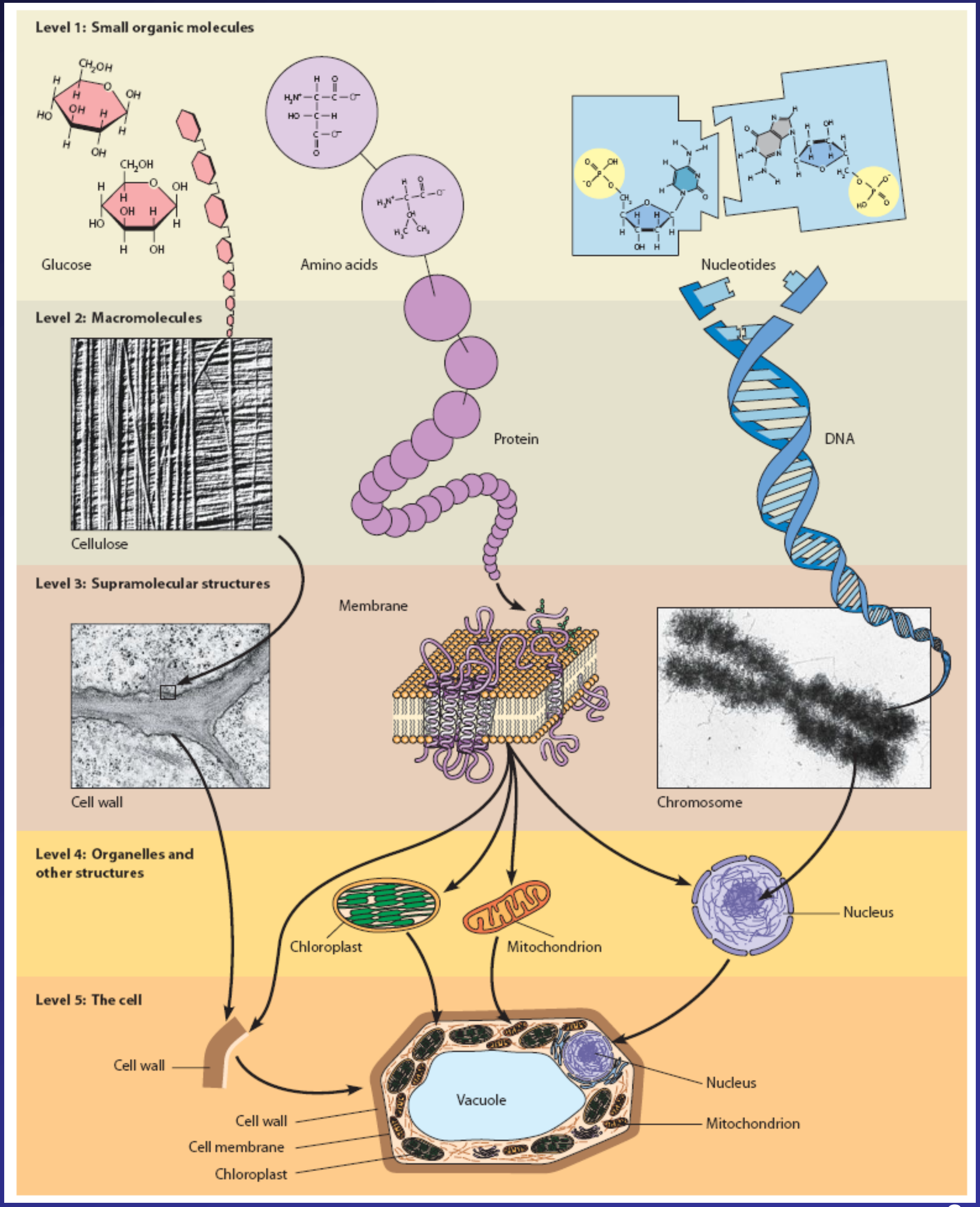
  C_2H_5O: diethyl ether is an isomer of ethanol

$H_3C{-}O{-}CH_3$ diethyl ether

$H_3C{-}CH_2{-}OH$ ethanol

From molecular to cellular

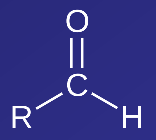
- polymerization of the small molecule monomer to a macromolecule
- macromolecular assembly
- supramolecular interaction to an organelle



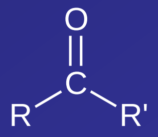
Becker WotC p 28

Carbohydrates

- Have the simple empirical formula CH_2O
- 1:2:1 C:H:O
- Carbohydrates are "sugars"
  - polyhydroxy (poly –OH) aldehydes (aldoses)
  - aldehydes have this structure:



    R groups are usually rest of molecule, where next bonded atom is C
  - polyhydroxy ketones (ketoses)
  - ketones have this structure:



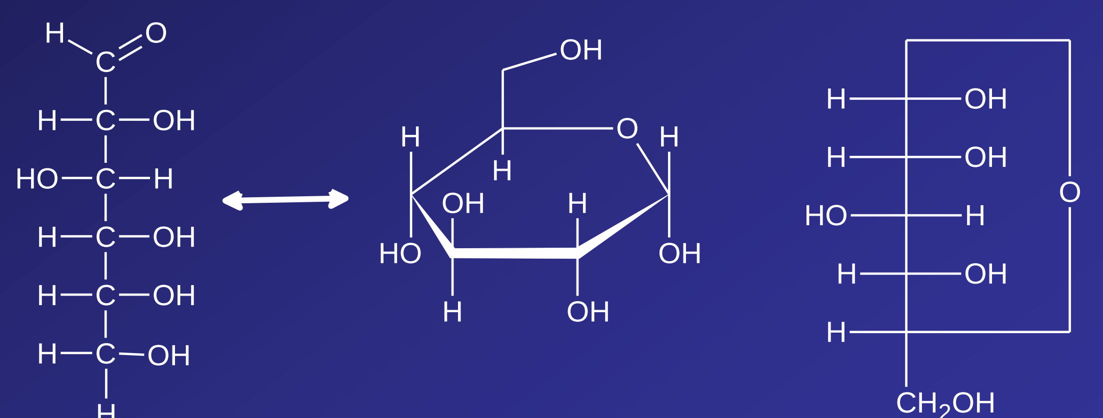
- Monosaccharides refer to the simplest molecules of carbohydrates that can be used to make up repeating chains (polymers)
- Monosaccharide molecules range from 3-carbon molecules to 7-carbon sugar molecules

Glucose

- Glucose is a 6-carbon monosaccharide (sugar) which is all-important in biology

  $C_6H_{12}O_6$

- Made in photosynthesis by leaves of plants
  - $6\ CO_2 + 6\ H_2O + \text{sunlight} \rightarrow C_6H_{12}O_6 + 6\ O_2$
- Broken down in respiration by eukaryote cells to get energy/calories
  - $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + \text{energy (stored as ATP)}$

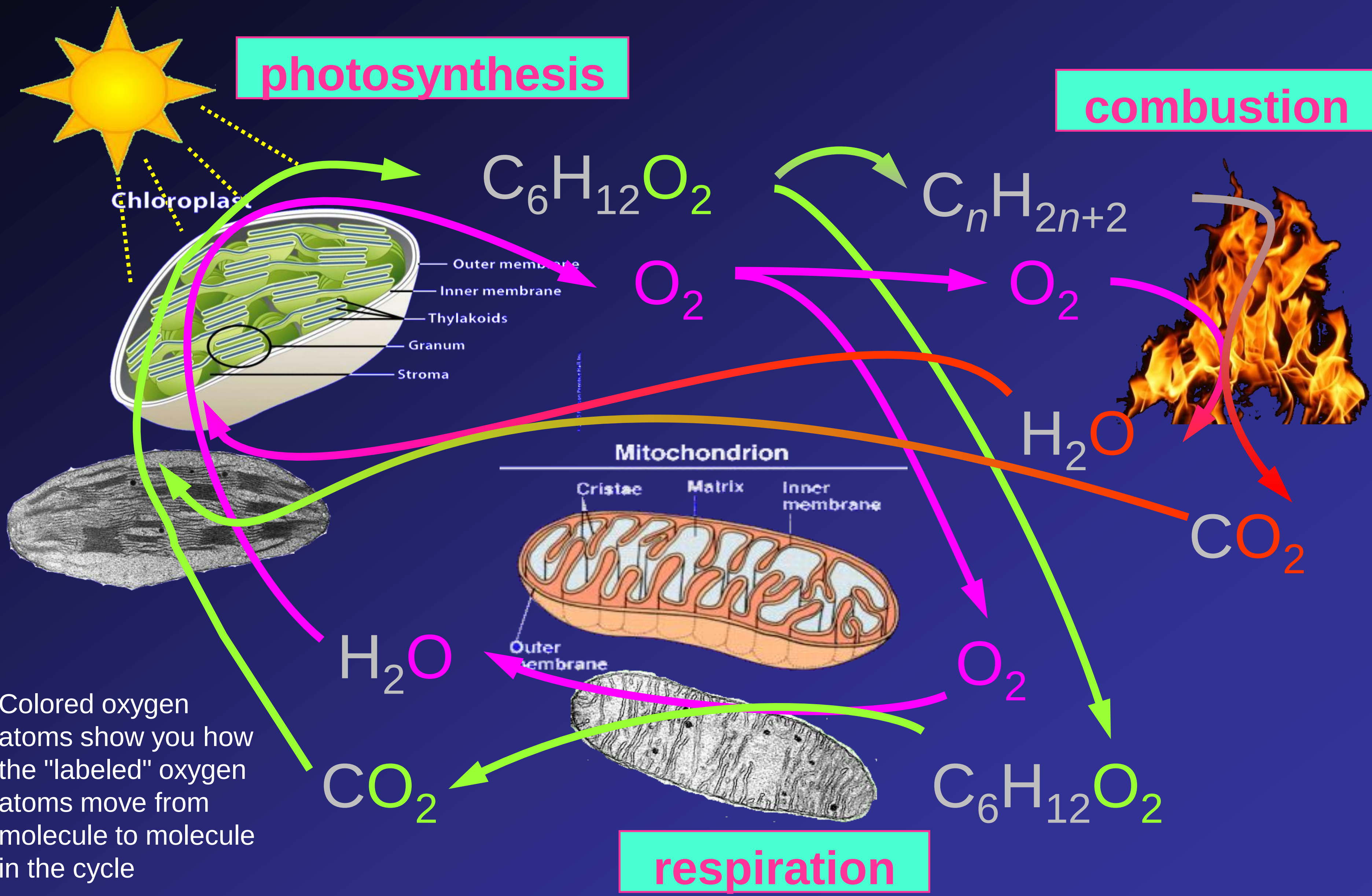


open chain form
(Fischer projection)

ring form
(Haworth projection)

D-glucose

A Combined Carbon & Oxygen Cycle in Biology



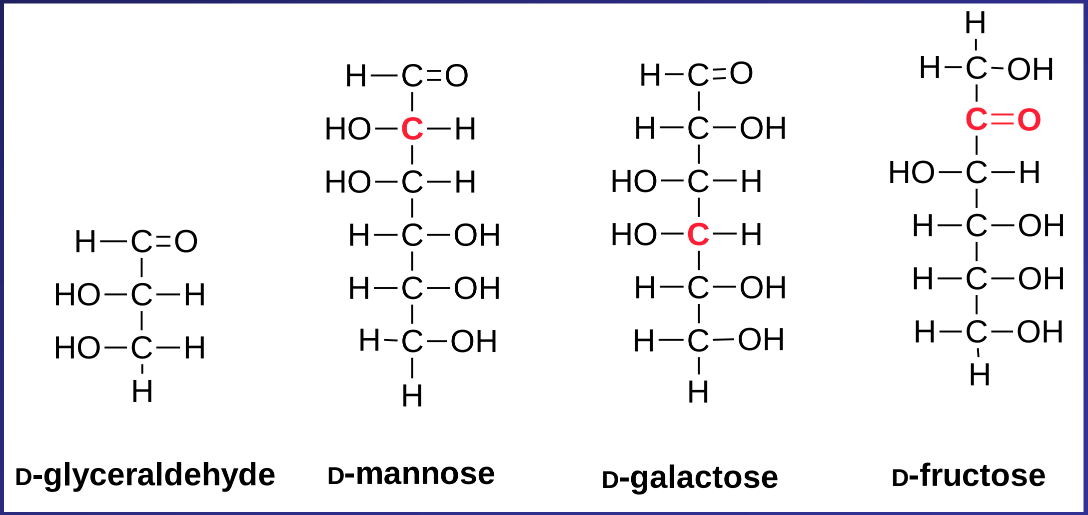
Colored oxygen atoms show you how the "labeled" oxygen atoms move from molecule to molecule in the cycle

Other Monosaccharides

- The monosaccharides range in molecular size from the 3-carbon glyceraldehyde to 7-carbon heptuloses
- Galactose combines with glucose to form the disaccharide lactose ("milk sugar")
- Fructose combines with glucose to form the disaccharide sucrose (table sugar)
- Monosaccharides can condense to form polymeric forms (polysaccharides)
- In cells, mono- and polysaccharides occur in the ring form

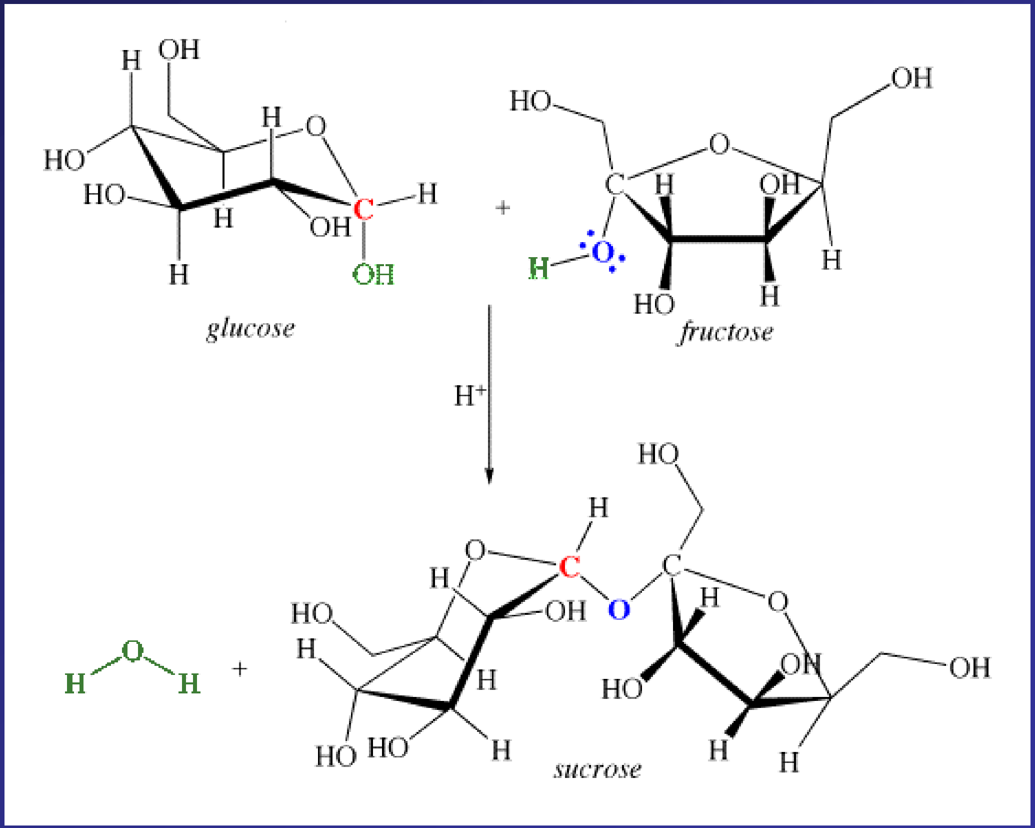
Some Monosaccharide Structures

- Galactose is a C-4 epimer of glucose
- An epimer is an isomer in which two of the groups attached to a chiral carbon are switched stereochemically
- Mannose is a C-2 epimer of glucose: it is particularly important in forming glycoprotein oligosaccharides
- Fructose is a 2-keto isomer of glucose (ketohexose)
- The 3-phospho form of glyceraldehyde is an intermediate in the most vital of metabolic pathways: glycolysis



Forming Disaccharides

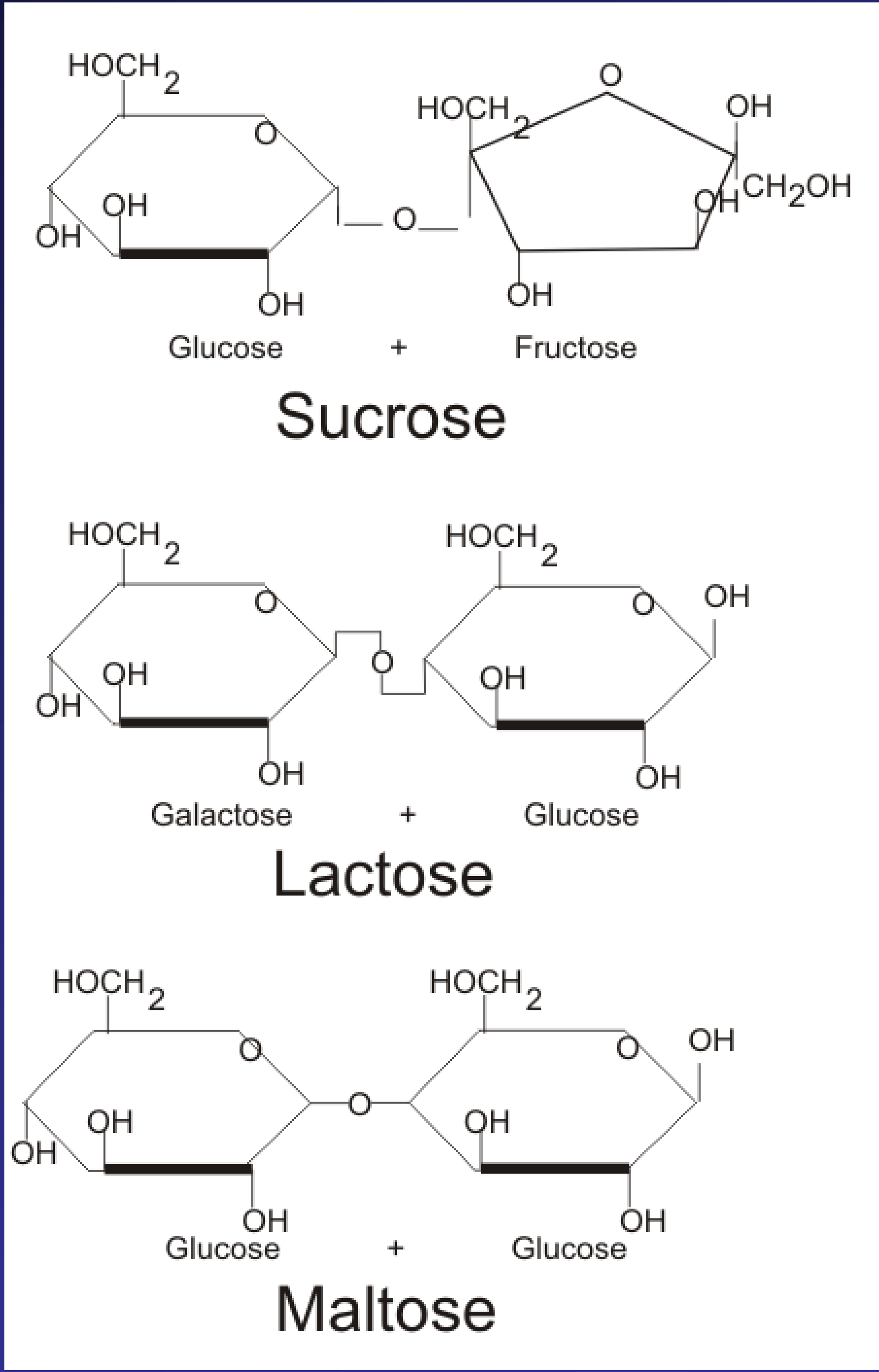
- Two monosaccharides come together by a condensation reaction to form a glycosidic bond
- Note the removal of H_2O to form the bond



Disaccharides

- Sucrose is the synthesis (condensation) of glucose + fructose
- Lactose synthesizes galactose + glucose
- Maltose is the synthesis two glucoses
- Note that sucrose = glucose + fructose in that order

  not fructose + glucose



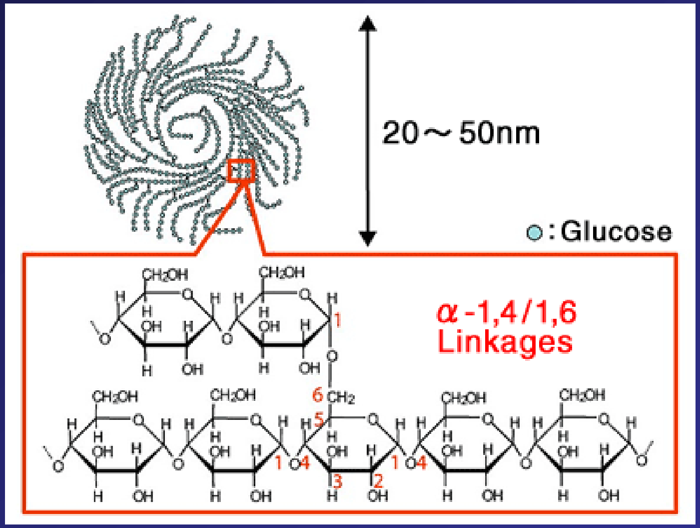
Glucose As A Polymer

- Glucose is how the cell gets the energy it needs to survive. It is transported in the blood as the monosaccharide and then imported into the cell
- When glucose is not immediately utilized, it is stored as a polymer (polysaccharide)
- The polymeric forms of glucose have different names, depending on what type of organism is making and storing them
  - glycogen: poly-glucose as a storage form in animals
  - starch: poly-glucose as a storage form in plants
    - digestible by animals
  - cellulose: poly-glucose used for cell walls by plants
    - not digestible by animals

Glycogen

- When glucose is not utilized in metabolism, it needs to be stored
- In animals, the best storage form is glycogen
- Glycogen is a highly branched polymeric form of glucose
- Glycogen is stored in liver & skeletal muscle typically

the detail of the molecular structure of the linear polymer and its branch point, as well as the size of the molecule



http://www.glico.co.jp/en/material/bioglycogen/image/top/img1a.gif

image shows large molecule of glycogen

http://www.scientificpsychic.com/fitness/glycogen.gif

Starch

- Starch is just like glycogen in that it is a polymer of glucose used as a storage form for glucose
- Starch is a branched form of glucose polymer, although less branched than glycogen
- Starch is the storage form for plants
- Since animals consume plants, they have evolved a set of digestive (hydrolytic) enzymes that allow them to be able to break down starch into its separate monomers (monosaccharides) of glucose and use it

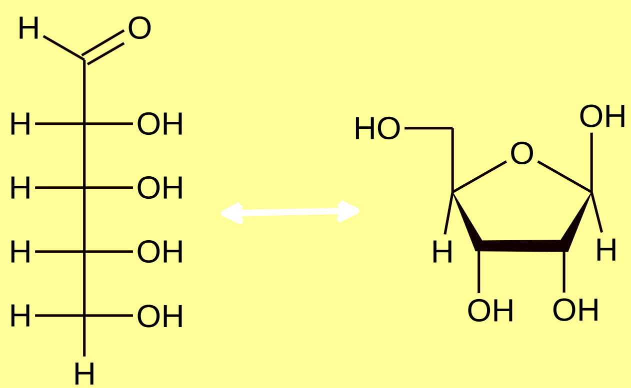
Cellulose

- Cellulose is also a polymeric form of glucose (a polysaccharide)
- But it is not a source of energy for most animals because animals do not have the enzymes to break cellulose down to its glucose monomers (monosaccharides)

  When cows eat grass/hay/weeds, they get glucose from cellulose only because they have bacteria in one of their stomachs that have the enzymes to break it down, but many animals do not have those bacteria
- Cellulose is what plants use to form the "skeletons" for their leaves, stems, roots, and flowers

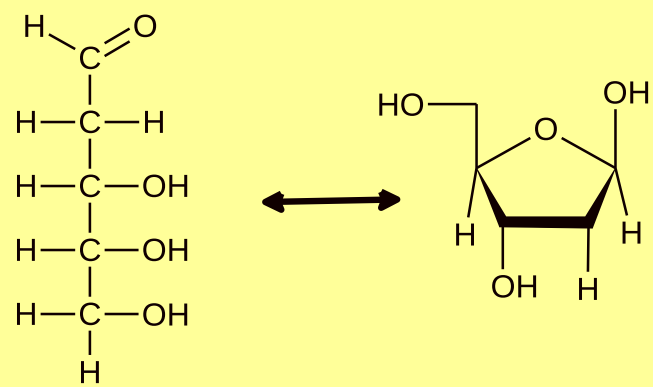
Special Mention: # Ribose & 2-Deoxyribose

- Ribose is a 5-carbon sugar (aldose)
- Ribose is used in the backbone of RNA
- Its 2-deoxyribose form is used in the backbone of DNA



open chain form ring form

D-Ribose



open chain form ring form

2-Deoxyribose

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Polysaccharide Significance

Polysaccharides are important for a variety of functions other than being a storage form for glucose

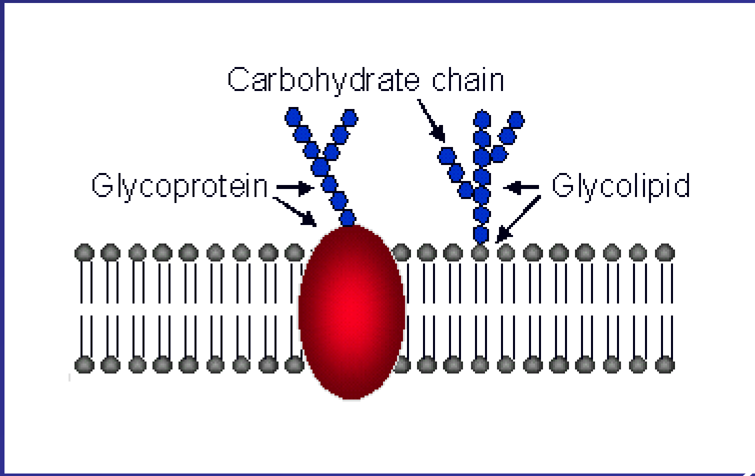
- In plants they form much of the cell wall that is part of the skeleton for the plant (cellulose + lignin)
- Arthropods bodies (exoskeletons) are formed from polysaccharides (chitin)
- Animal cartilage is a polysaccharide matrix (hyalouronic acid)

Glycoproteins

- Oligosaccharides are attached to polypeptides to form glycoproteins
- There are *N*- and *O*-glycoproteins, which indicate the amino acid side chain atom to which the oligosaccharide is attached
  - N-glycoproteins attach to the –NH2 group of the amino acid asparagine (Asn)
  - O-glycoproteins attach to the –OH group of the hydroxyl amino acids serine (Ser) and threonine (Thr)
- Purposes of glycosylating proteins
  - required for particular folding
  - resist degradation, particularly when protein exported
  - indicate destination for the glycoprotein location

Glycolipids

- Oligosaccharides are attached to lipids particularly those that form the cell membrane
- Glycolipids are particularly important for a cell identifying itself to another cell (cell-cell recognition)
- They can also be utilized in metabolism to produce energy

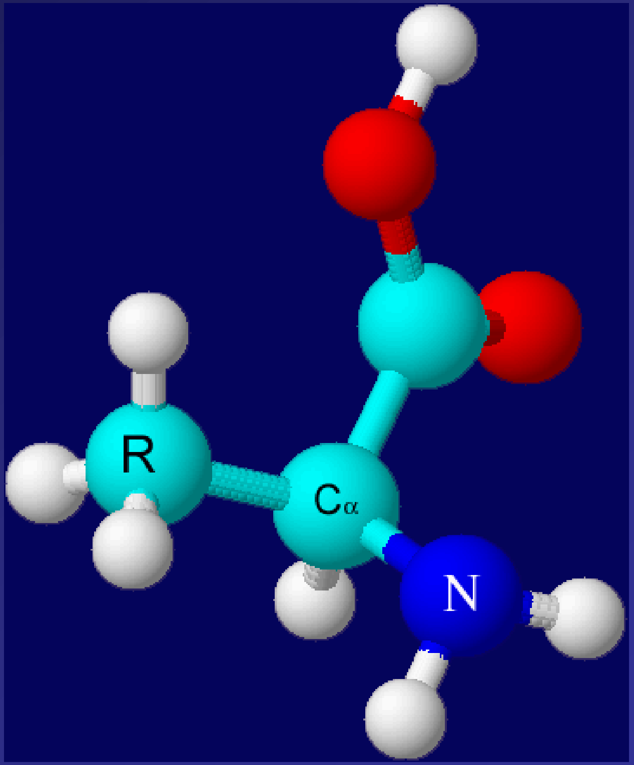


https://animalcellbiology.files.wordpress.com/2011/08/membrane-lipids-and-proteins.gif?w=460

The Amino Acid

Has four basic parts in the chemical structure

1. The "central" alpha-carbon
   this carbon is "chiral," meaning it is bonded to 4 different groups and thus has stereochemistry
2. The amino ($-NH_2$) group
   this group will bond with the –COOH group to form the peptide bond
3. The carboxyl (–COOH) group
   this group will bond with the $-NH_2$ group to form the peptide bond
4. The side ("R") group/chain
   this has 20 different possible groupings of atoms

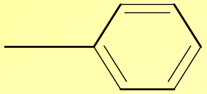
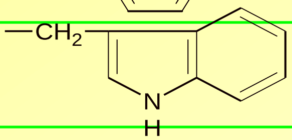
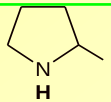


The amino acid L-alanine in 3D (*R*-configuration)

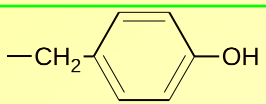
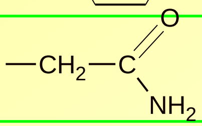
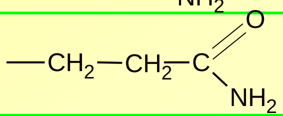
The Natural Amino Acids

- There are 20 natural amino acids in eukaryotes
- The side chain of the amino acid gives it its special chemistry and name
- Because amino acids make up the sequences of polypeptides, biologists/biochemists have created special 1- and 3-letter abbreviations used when discussing proteins
- The chemistry of the side chain allows amino acids to be classed differently
  - ionic/electrostatic
  - polar
  - non-polar, hydrophobic

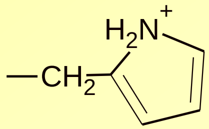
The Amino Acid

	3-letter abbr.	1-letter abbr.	MW	Side-chain structure	pK_a	
Non-polar Amino Acids						
Alanine	Ala	A	89.1	$-CH_3$	**2.35**	α-COOH
					9.69	α-NH_2
Valine	Val	V	117.1	$-HC(CH_3)CH_3$	**2.32**	α-COOH
					9.62	α-NH_2
Leucine	Leu	L	**131.2**	$-CH_2-CH(CH_3)-CH_3$	**2.36**	α-COOH
					9.6	α-NH_2
Isoleucine	Ile	I	**131.2**	$-CH(CH_3)-CH_2-CH_3$	**2.36**	α-COOH
					9.68	α-NH_2
Phenylalanine	Phe	F	165.2		**1.83**	α-COOH
					9.13	α-NH_2
Tryptophan	Trp	W	204.2		**2.38**	α-COOH
					9.39	α-NH_2
Methionine	Met	M	149.2	$-CH_2 \cdot CH_2 S-CH_3$	**2.28**	α-COOH
					9.21	α-NH_2
Proline	Pro	P	115.1		**1.99**	α-COOH
					10.6	α-NH-

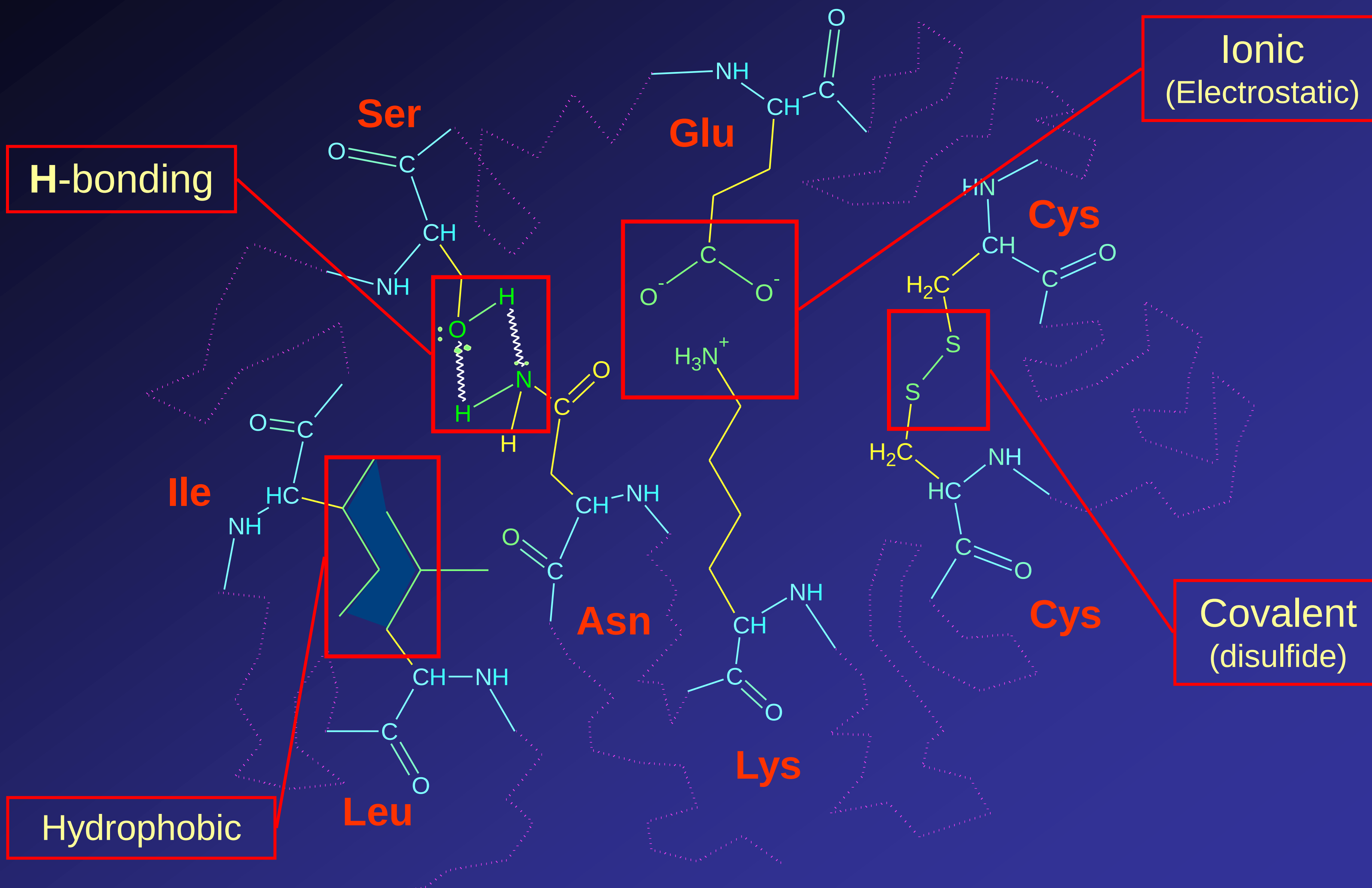
The Amino Acid

	3-letter abbr.	1-letter abbr.	MW	Side-chain structure	pK_a	
Polar Amino Acids						
Glycine	Gly	G	75.1	$-H$	**2.34**	α-COOH
					9.6	α-NH_2
Serine	Ser	S	105.1	$-CH_2-OH$	**2.21**	α-COOH
					9.15	α-NH_2
Threonine	Thr	T	119.1	$-CH(OH)-CH_3$	**2.63**	α-COOH
					9.15	α-NH_2
Cysteine	Cys	C	121.2	$-CH_2-SH$	**1.71**	α-COOH
					8.33	side chain
					10.78	α-NH_2
Tyrosine	Tyr	Y	181.2		**2.2**	α-COOH
					9.11	α-NH_2
Asparagine	Asn	N	132.1		**2.02**	α-COOH
					8.8	α-NH_2
Glutamine	Gln	Q	146.1		**2.17**	α-COOH
					9.13	α-NH_2

The Amino Acid

	3-letter abbr.	1-letter abbr.	MW	Side-chain structure	pK_a	
Ionic Amino Acids						
					2.09	α-COOH
Aspartic Acid	Asp	D	133.1	$-CH_2-C(=O)O^-$	**3.86**	side chain
					9.82	α-NH_2
					2.19	α-COOH
Glutamic Acid	Glu	E	147.2	$-CH_2CH_2C(=O)O^-$	**4.25**	side chain
					9.67	α-NH_2
					2.18	α-COOH
Lysine	Lys	K	146.2	$-CH_2CH_2CH_2CH_2NH_3^+$	**10.53**	side chain
					8.95	α-NH_2
					2.17	α-COOH
Arginine	Arg	R	174.2	$-CH_2CH_2CH_2NH-C(=NH)NH_3^+$	**12.48**	side chain
					9.04	α-NH_2
					1.82	α-COOH
Histidine	His	H	155.2		**6.00**	side chain
					9.17	α-NH_2

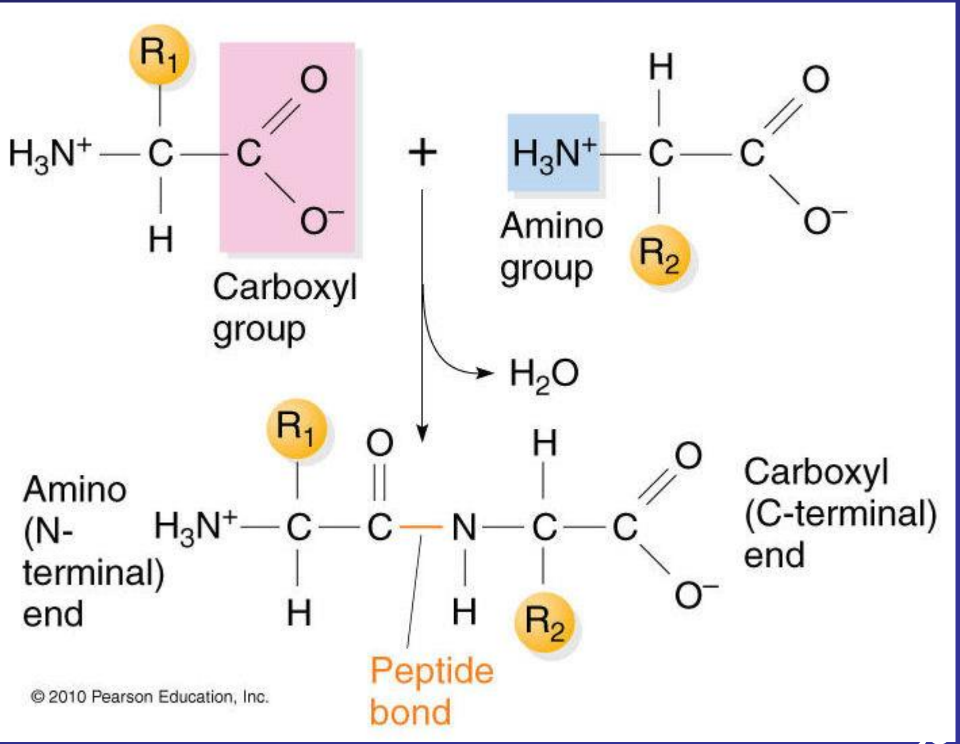
Chemical Bonding In The Polypeptide



The Peptide Bond

- The peptide bond is the name of the link that describes the amino acid polymer (polypeptide)
- Chemically it is an amide (covalent) bond
- It forms as a result of the condensation between the –COOH group of one amino acid (*N*) and the $–NH_2$ group of the next amino acid (*N*+1)
- Note the loss of H_2O in forming the bond

The details of how the cell actually produces the peptide bond will be discussed later in the protein synthesis lecture



Polypeptides

- Polypeptides are the single molecule that represents the polymer of amino acids
- They have a directionality
  - an amino terminus
    - also often written as N-terminus or NH_2-terminus
  - a carboxyl terminus
    - also often written as C-terminus or COOH-terminus
  - usually sequences are written left to right where the left end is the N-terminus and the right is the C-terminus
- Polypeptides are synthesized from the N-terminus to the C-terminus as well

Protein Structure

Proteins have four levels of structure

- Primary (1°)
- Secondary (2°)
- Tertiary (3°)
- Quaternary (4°)

Primary Structure of Proteins

- This is the amino acid sequence itself
- The amino acids and the order they appear have most, if not all, the information to direct the folding of the polypeptide to its higher levels of structure

the amino acid sequence of α_2-macroglobulin shown with its 1-letter abbreviations

```
   1 mgknkllhps lvllllvllp tdasvsgkpq ymvlvpsllh tettekgcvl lsylnetvtv
  61 saslesvrgn rslftdleae ndvlhcvafa vpksssneev mfltvqvkgp tqefkkrttv
 121 mvknedslvf vqtdksiykp gqtvkfrvvs mdenfhplne liplvyiqdp kgnriaqwqs
 181 fqlegglkqf sfplssepfq gsykvvvqkk sggrtehpft veefvlpkfe vqvtvpkiit
 241 ileeemnvsv cglytygkpv pghvtvsicr kysdasdchg edsqafcekf sgqlnshgcf
 301 yqqvktkvfq lkrkeyemkl hteaqiqeeg tvveltgrqs seitrtitkl sfvkvdshfr
 361 qgipffgqvr lvdgkgvpip nkvifirgne anyysnattd ehglvqfsin ttnvmgtslt
 421 vrvnykdrsp cygyqwvsee heeahhtayl vfspsksfvh lepmshelpc ghtqtvqahy
 481 ilnggtllgl kklsfyylim akggivrtgt hgllvkqedm kghfsisipv ksdiapvarl
 541 liyavlptgd vigdsakydv enclankvdl sfspsqslpa shahlrvtaa pqsvcalrav
 601 dqsvllmkpd aelsassvyn llpekdltgf pgplndqdde dcinrhnvyi ngitytpvss
 661 tnekdmysfl edmglkaftn skirkpkmcp qlqqyemhgp eglrvgfyes dvmgrgharl
 721 vhveephtet vrkyfpetwi wdlvvvnsag vaevgvtvpd titewkagaf clsedaglgi
 781 sstaslrafq pffveltmpy svirgeaftl katvlnylpk cirvsvqlea spaflavpve
 841 keqaphcica ngrqtvswav tpkslgnvnf tvsaealesq elcgtevpsv pehgrkdtvi
 901 kpllvepegl ekettfnsll cpsggevsee lslklppnvv eesarasvsv lgdilgsamq
 961 ntqnllqmpy gcgeqnmvlf apniyvldyl netqqltpei kskaigylnt gyqrqlnykh
1021 ydgsystfge rygrnqgntw ltafvlktfa qarayifide ahitqaliwl sqrqkdngcf
1081 rssgsllnna ikggvedevt lsayitiall eipltvthpv vrnalfcles awktaqegdh
1141 gshvytkall ayafalagnq dkrkevlksl neeavkkdns vhwerpqkpk apvghfyepq
1201 apsaevemts yvllayltaq paptsedlts atnivkwitk qqnaqggfss tqdtvvalha
1261 lskygaatft rtgkaaqvti qssgtfsskf qvdnnnrlll qqvslpelpg eysmkvtgeg
1321 cvylqtslky nilpekeefp falgvqtlpq tcdepkahts fqislsvsyt gsrsasnmai
1381 vdvkmvsgfi plkptvkmle rsnhvsrtev ssnhvliyld kvsnqtlslf ftvlqd[illegible]r
1441 dlkpaivkvy dyyetdefai aeynapcskd lgna
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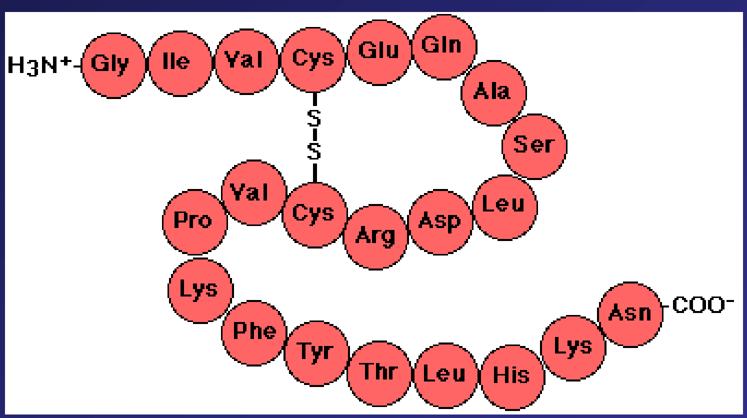
amino acids of a short peptide shown with their 3-letter abbreviations



Secondary Structure of Proteins

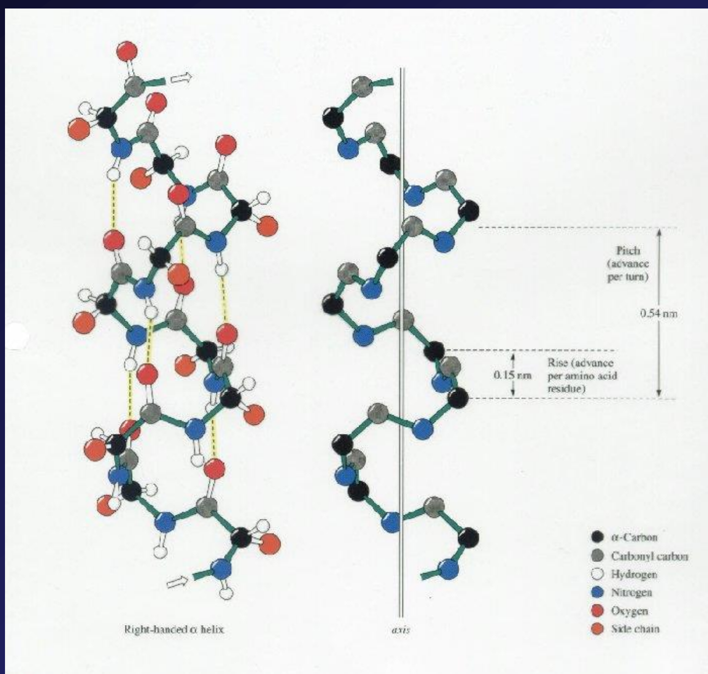
- These are special structural formations of the polypeptide that are created by atoms in the backbone of the polymer (polypeptide) forming hydrogen bonds with other atoms in the backbone
- alpha (α) helix

  the polypeptide forms a helical twist using the atoms in the "backbone," which form hydrogen bonds (H-bonds) with each other
- beta (β) sheet

  the polypeptide forms long linear tracks with atoms in the "backbone," which form H-bonds in a way that forms a flat sheet; the polypeptide also forms loops or turns at the end so that it can do this; when the backbone has the same N→C directionality, they form parallel sheets, whereas if the directionality is opposing, they form less-strained antiparallel sheets

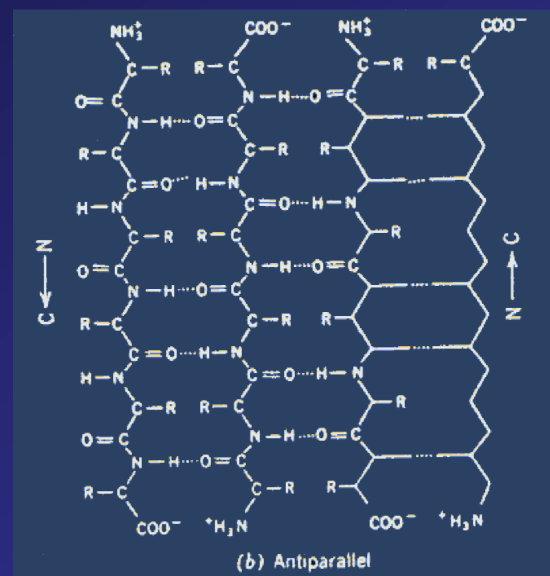
2° Structures

α-helix

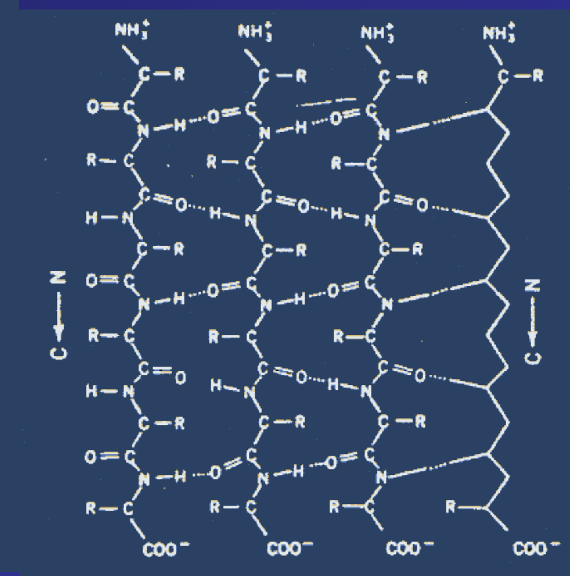


β-sheet

anti-parallel



parallel



Expected learning: you should know that polypeptides have secondary structure and that this is alpha helix and beta sheet, and that atoms of the backbone form them by hydrogen bonding. You do not need to know the two forms of beta sheet or be able to diagram their chemical structures.

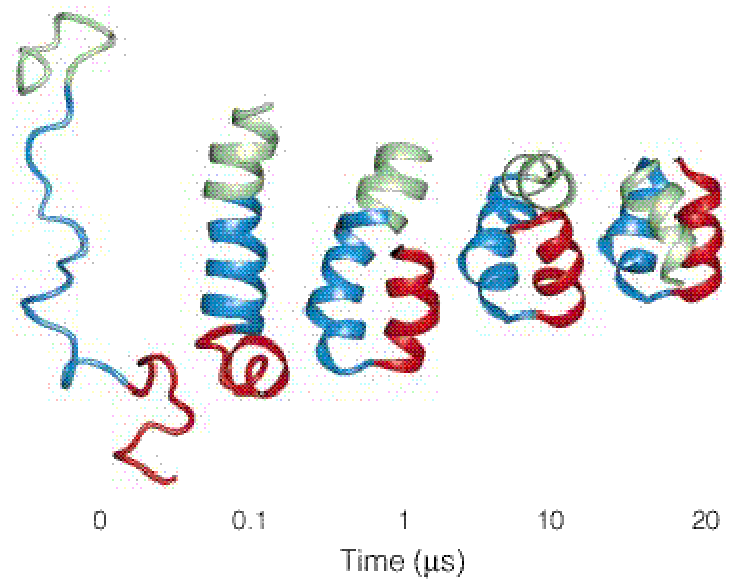
http://web.campbell.edu/faculty/nemecz/323_lect/proteins/images/alpha_helix.jpg

Tertiary Structure of Proteins

Tertiary (3°) structure is created by a number of bond/interaction types (ionic, hydrophobic, H-bond, even covalent) that cause the polypeptide to fold, coil, curl, etc. The 2° α-helices and β-sheets are preserved

In the figure at right, molecular dynamics computations are used to show the formation of the tertiary structure of the villin polypeptide.

For a half century, scientists have been working on predicting 3° structure (folding) from 1° structure (the amino acid sequence)



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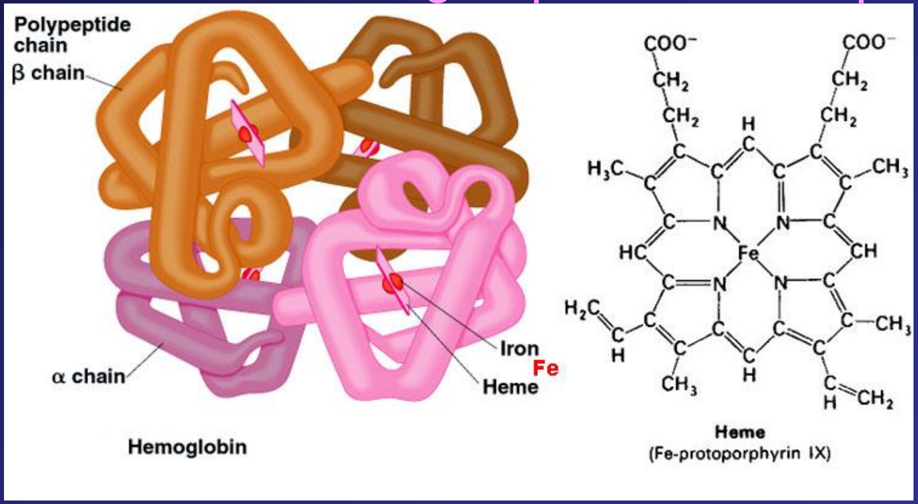
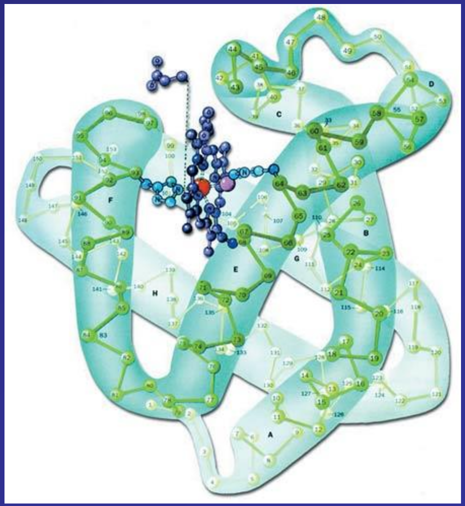
Quaternary Structure of Proteins

- After the polypeptide completes its three levels of structure, it may associate with other polypeptides that are identical to it or different from it
- These are multi-subunit proteins: that is, polypeptides that associate with identical or different polypeptides have 4° structure
- Hemoglobin (Hb) has 4° structure: two α and two β subunits, each binding a heme group that coordinates Fe^{2+}
- Myoglobin (Mb) [lower right] is an oxygen (O_2)-binding protein like Hb with Fe^{2+}-heme group but has no quaternary structure



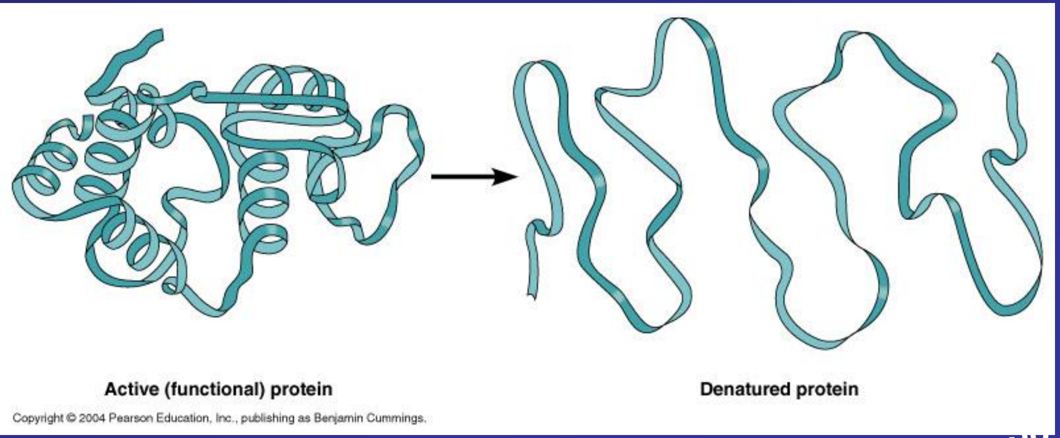


https://aberdeenc.files.wordpress.com/2013/02/hemoglobin.jpg

The Complete Protein

- Remember, the protein represents a single functional entity
- It might be composed of a single polypeptide or it might be composed of multiple subunits
- It also may be composed of other ions and/or molecules that are not proteinaceous (amino acid oligo- or polymers), such as metal cation cofactors or coenzymes
- Proteins must be folded into their "native" functional, active structure to work (see figure)
- When heated in boiling water for just a few minutes, proteins unfold into a "denatured" form that may not reform to the active

when you cook eggs, the formation of the whites is protein denaturation



http://classes.midlandstech.com/carterp/Courses/bio225/chap05/05-06_Denaturation_1.jpg

Various Functions (Purposes) of Proteins

- Enzymes
- Structural Proteins
- Membrane Proteins
  - receptors
  - channels
  - transporters
  - exchangers

Enzymes

- Catalyze (perform) biochemical reactions
- Essential proteins in every metabolic pathway
  - biosynthesis
  - catabolism

- As catalysts, they lower the activation enegy of the reaction
- Enzymes bind substrates (the reactants)
- Enzymes provide the products

Enzyme Structure

- Substrate-binding site(s)

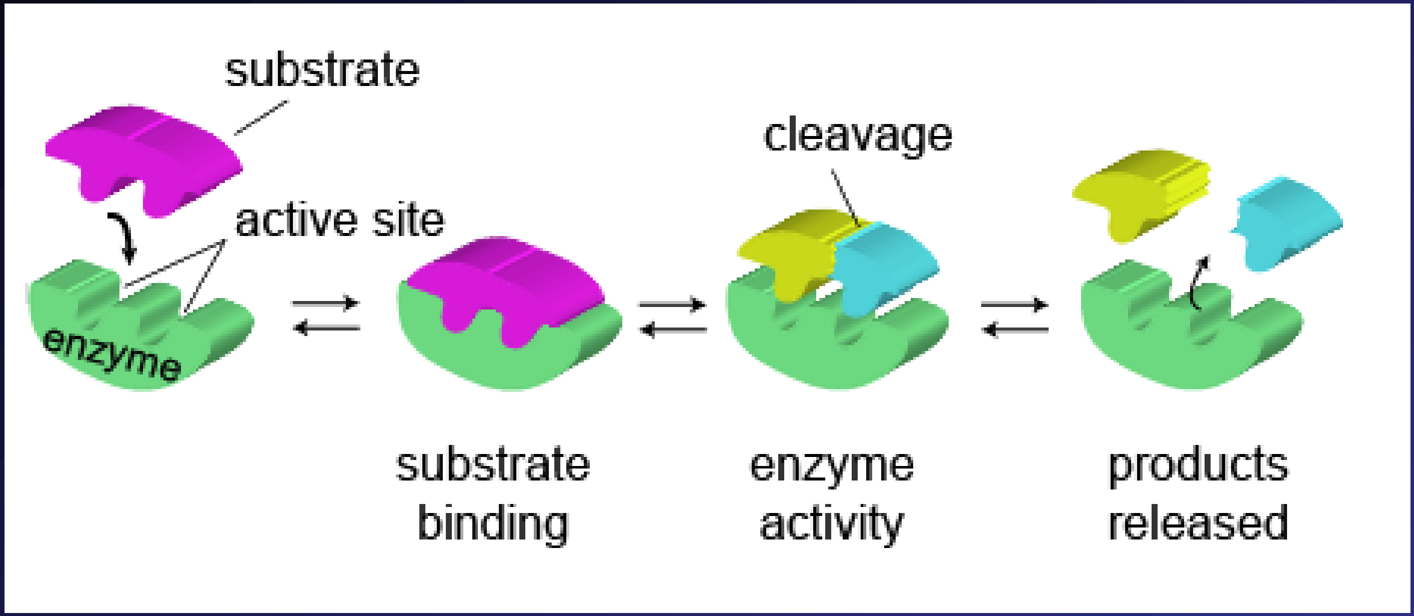
  The amino acids that are involved with positioning the substrates in the enzyme for catalysis

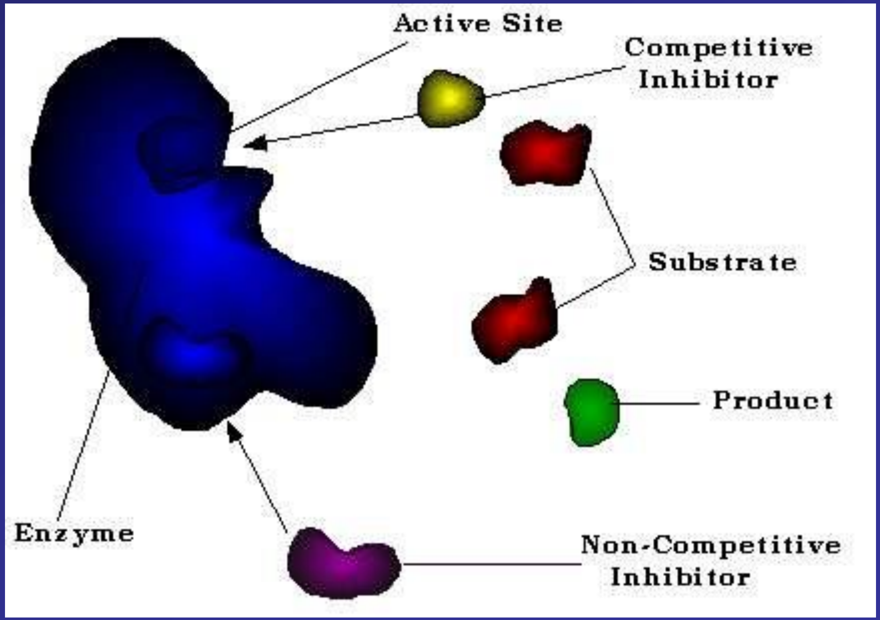
- Active site

  This is the catalytic center, where the reaction takes place

  The amino acids that are involved in the reaction form the active site

- Regulatory sites
  - Inhibitory: the amino acids that bind metabolites to stop or reduce the rate of enzyme's activity (negative feedback)
  - Activating: the amino acids that bind metabolites that increase the rate of enzyme's activity (positive feedback)
- Enzyme kinetics studies the rates of catalysis, the concentrations of all components, and the regulation by inhibitors and activators



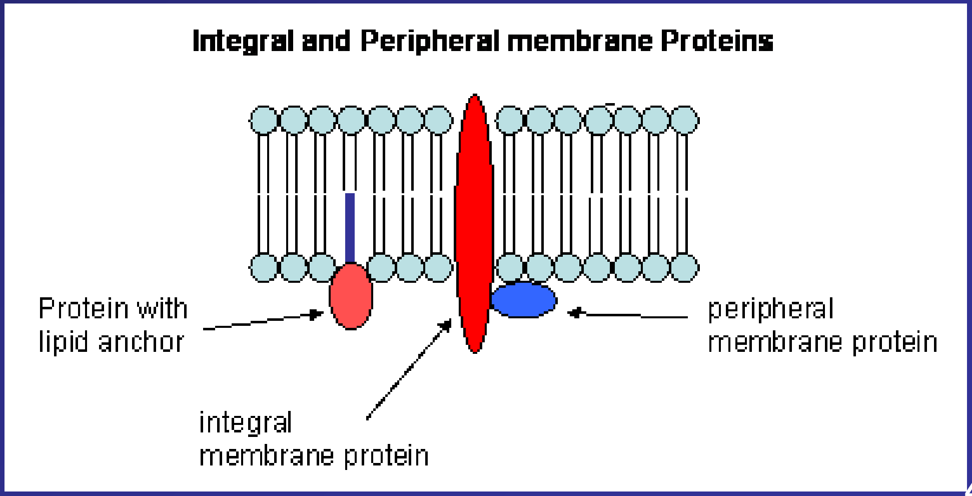


http://media1.shmoop.com/images/biology/biobook_flow_5a.png

http://web.fscj.edu/David.Byres/inhibitors.gif

Membrane Proteins

- Proteins attached to ("peripheral") or embedded in ("integral") the cell membranes
- Integral membrane proteins that span the membrane include many types
  - Receptors
  - Transporters + Exchangers
  - Channels
- We'll talk about these protein types later



Reading (Sources)

- Marieb: Chapter 2, pp 43-45, 49-53
- Becker's WotC: pp 41-53, 60-65
- Raven: Chapter 3.2, 3.4