Biological Building Blocks

monomer		macromolecule
Amino acids	→	Proteins
Nucleotides	→	Nucleic acids
Fatty acids	→	Lipids
Monosaccharides	→	Polysaccharides

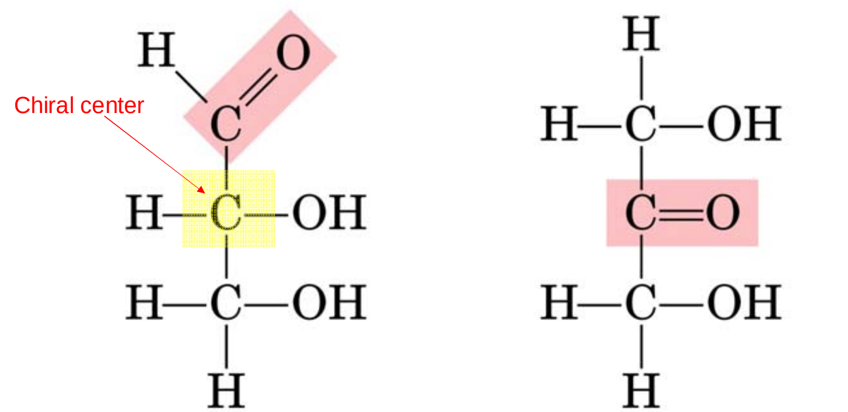
A limited number of different monomeric building blocks are used to build a wide variety of different macromolecules

Carbohydrates (saccharides) "carbon hydrate" ($C \cdot H_2O$)

- Basic units: monosaccharides
- Photosynthesis: $nCO_2 + nH_2O \rightarrow (CH_2O)_n + nO_2$
- Breakdown provides most metabolic energy
- Components of nucleic acids, glycoproteins, glycolipids, some coenzymes
- Small polymers: oligosaccharides
- Long polymers: polysaccharides
  - Energy storage, structural elements, other diverse roles (recognition, communication, glycoproteins and lipids)

Monosaccharides: aldehyde or ketone derivatives of straight-chain polyhydroxyalcohols containing at least 3 carbon atoms. Cannot be hydrolyzed to form simpler saccharides

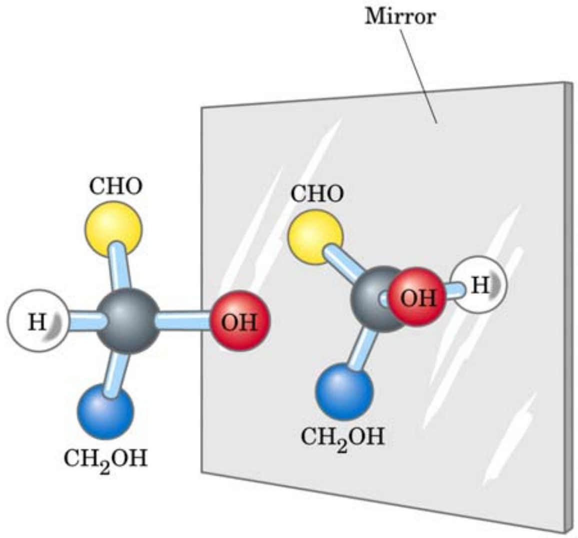
The simplest monosaccharides



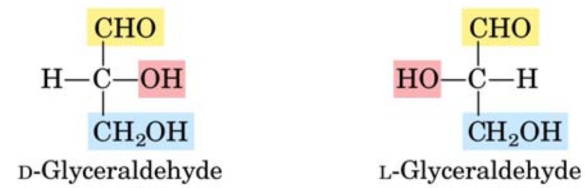
Glyceraldehyde, an aldotriose

Dihydroxyacetone, a ketotriose

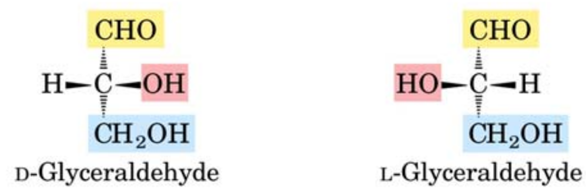
(a)



Ball-and-stick models

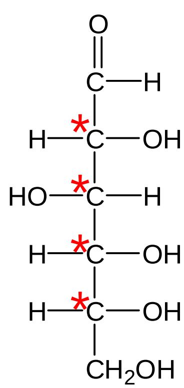


Fischer projection formulas



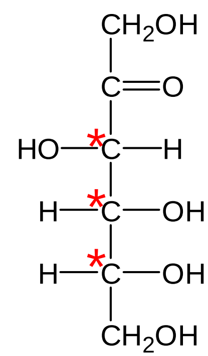
Perspective formulas

How many stereoisomers exist for the 6 C aldoses (aldohexoses)



stereoisomers = 2^{n-2}, where n = # of carbons

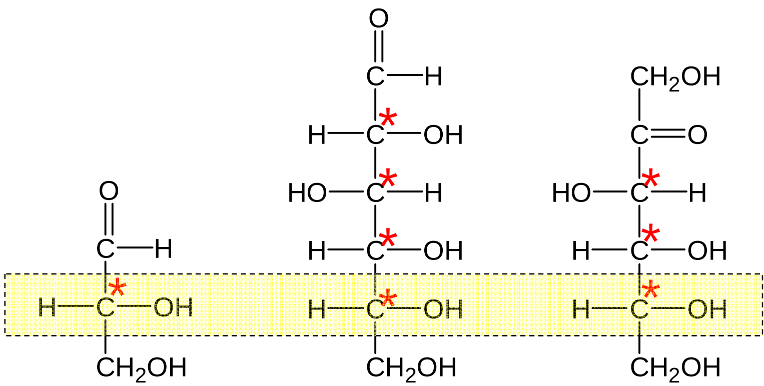
How many stereoisomers exist for the 6 C ketoses (ketohexoses)



stereoisomers = 2^{n-3}, where n = # of carbons

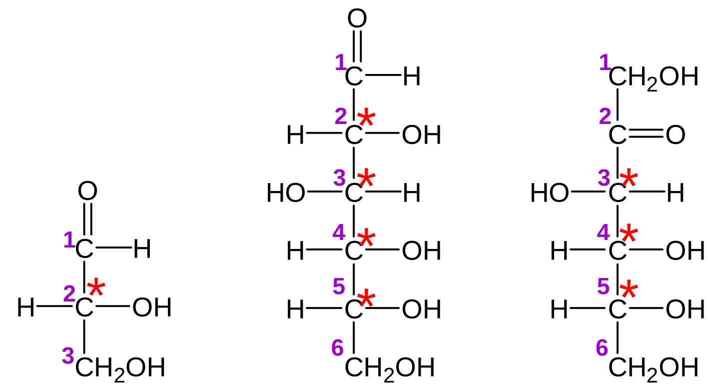
Classification of stereoisomers: D-sugars have the same absolute configuration at the chiral center farthest from carbonyl group as D-glyceraldehyde

D sugars are the biologically important form



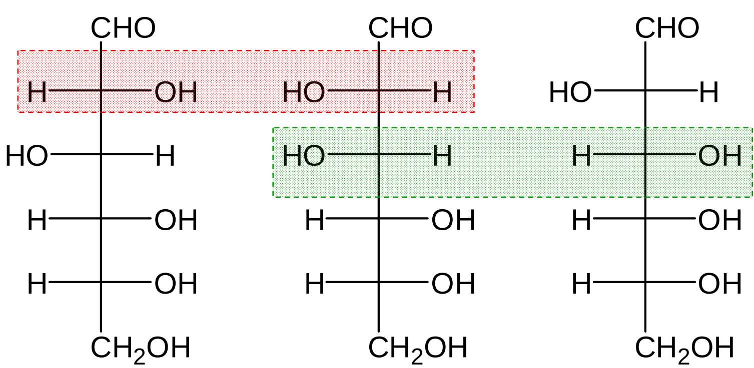
D-glyceraldehyde D-glucose D-fructose

Numbering: from carbon atom at end of chain nearest the carbonyl carbon



D-glyceraldehyde D-glucose D-fructose

Epimers: sugars that differ only by the configuration about <u>one</u> C atom

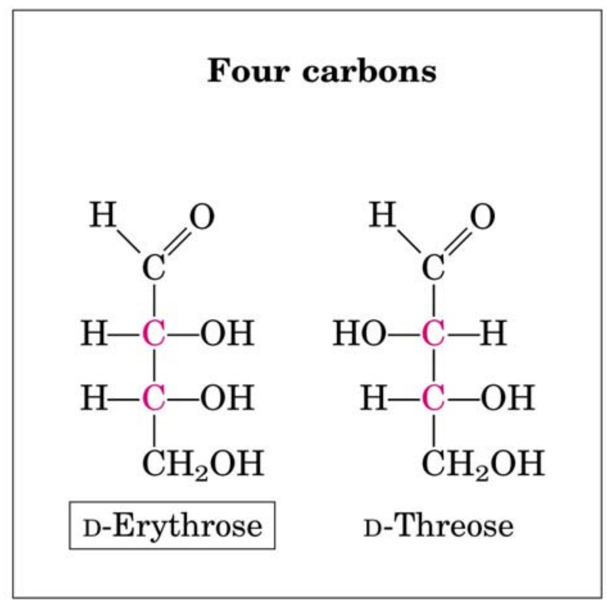


D-glucose D-mannose D-altrose

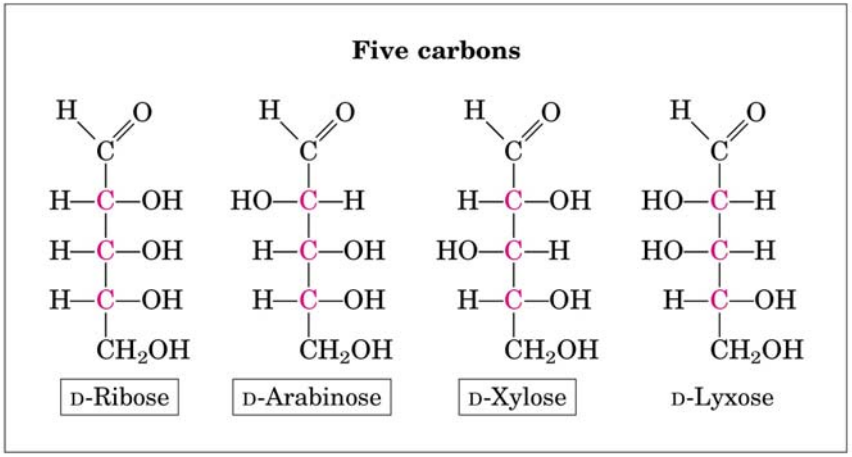
D-glucose and D-mannose are epimers

D-mannose and D-altrose are epimers

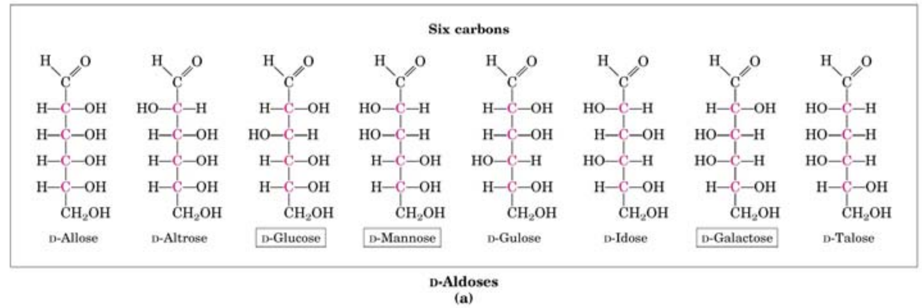
The C4 aldoses # stereoisomers = $2^{n-2} = 4$



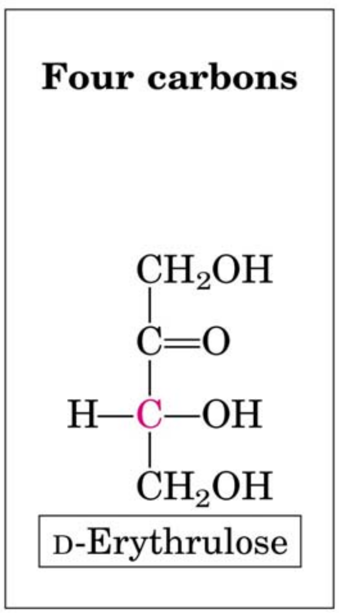
The C5 aldoses   # stereoisomers = $2^{5-2} = 8$



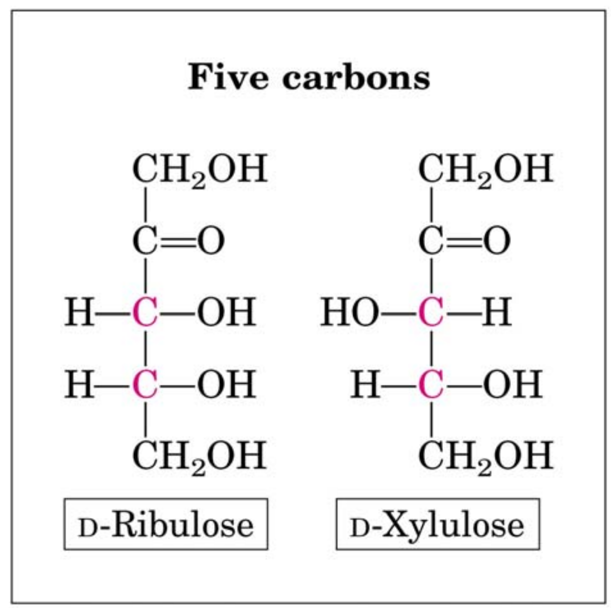
The C6 aldoses   # stereoisomers = $2^{6-2} = 16$



The C4 ketoses   # stereoisomers = $2^{4-3} = 2$

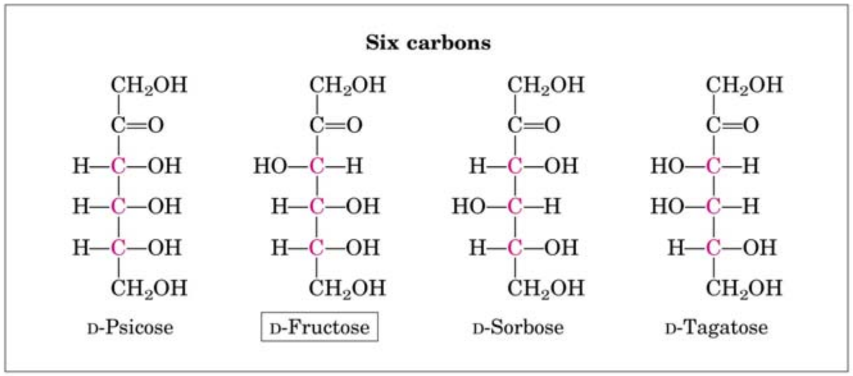


The C5 ketoses   # stereoisomers = $2^{5-3} = 4$



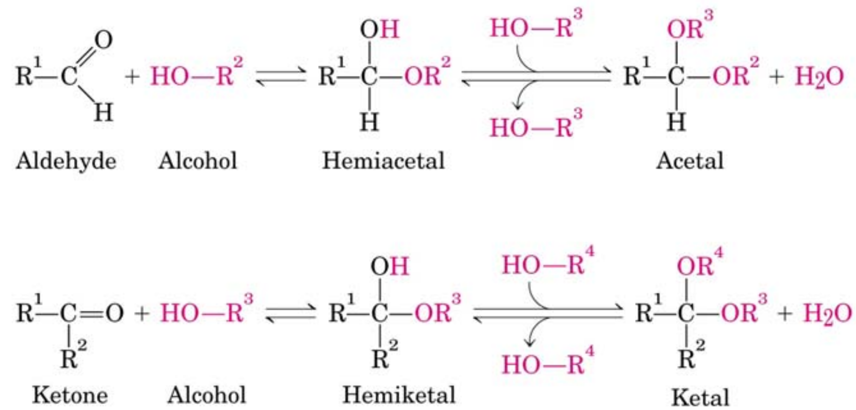
The C6 ketoses

stereoisomers = $2^{6-3} = 8$

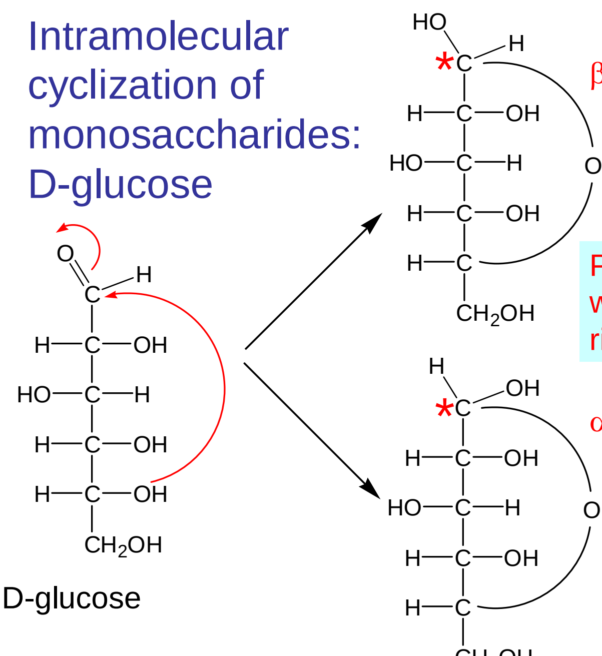


D-Ketoses
(b)

Organic chemistry review:



Intramolecular cyclization of monosaccharides: D-glucose



D-glucose

β-D-glucopyranose

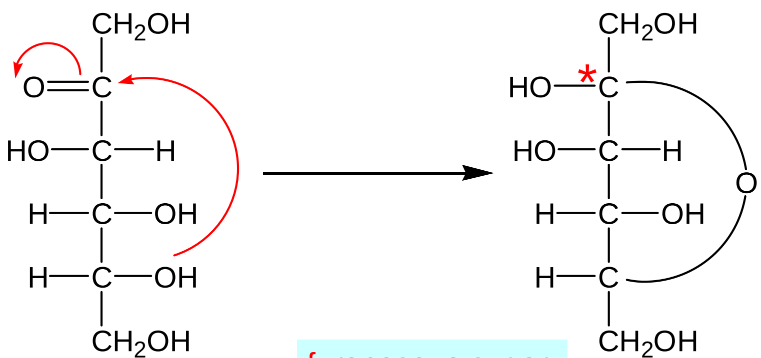
α-D-glucopyranose

Pyranose: a sugar with a six member ring

Anomers: isomeric forms of monosaccharides that differ in the configuration about the hemiacetal or hemiketal carbon

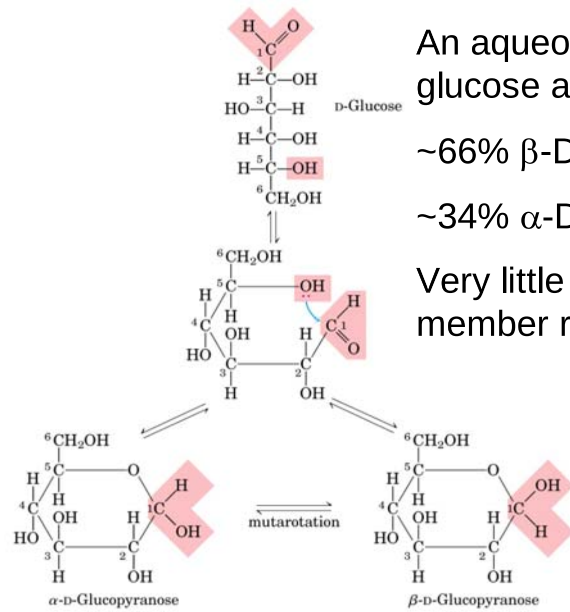
Intramolecular cyclization of monosaccharides: D-fructose

α–and β-D-fructofuranose



D-fructose

furanose: a sugar with a five member ring

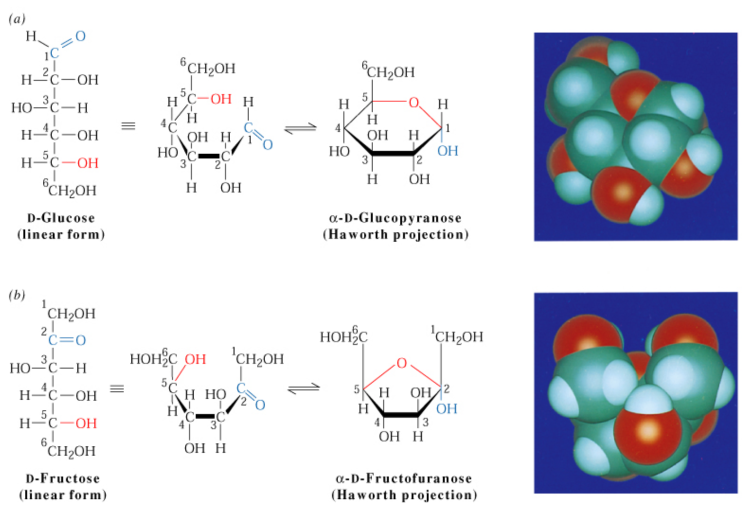


An aqueous solution of glucose at equlibrium:

~66% β-D-glucopyranose

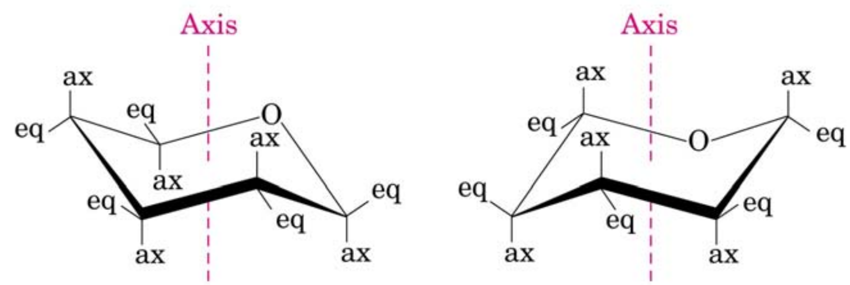
~34% α-D-glucopyranose

Very little linear or five member ring forms



An aqueous solution of fructose at equilibrium:
~67% pyranose!
~33% furanose!
So why do we always draw fructose as fructofuranose??

Recall "chair" and "boat" conformations of six membered rings



Two possible chair forms
(a)

Where do you want your bulky groups (OH and CH_2OH): equatorial or axial?

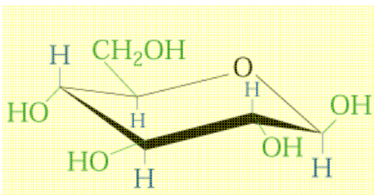
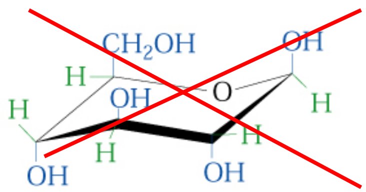
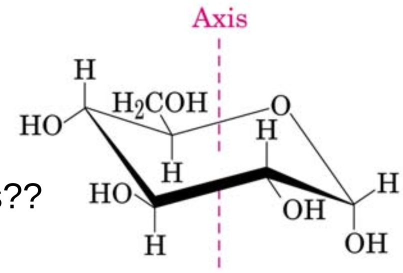


Figure 8-5. The two chair conformations of β-D-glucopyranose.

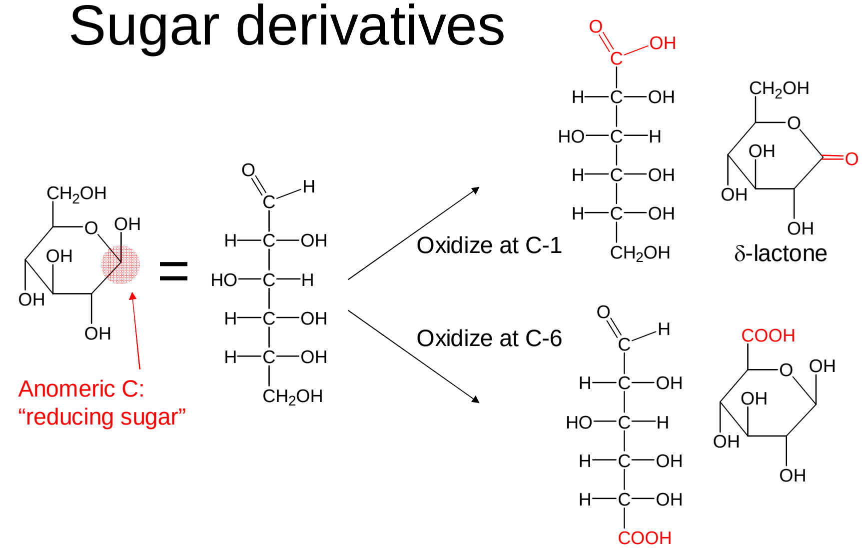


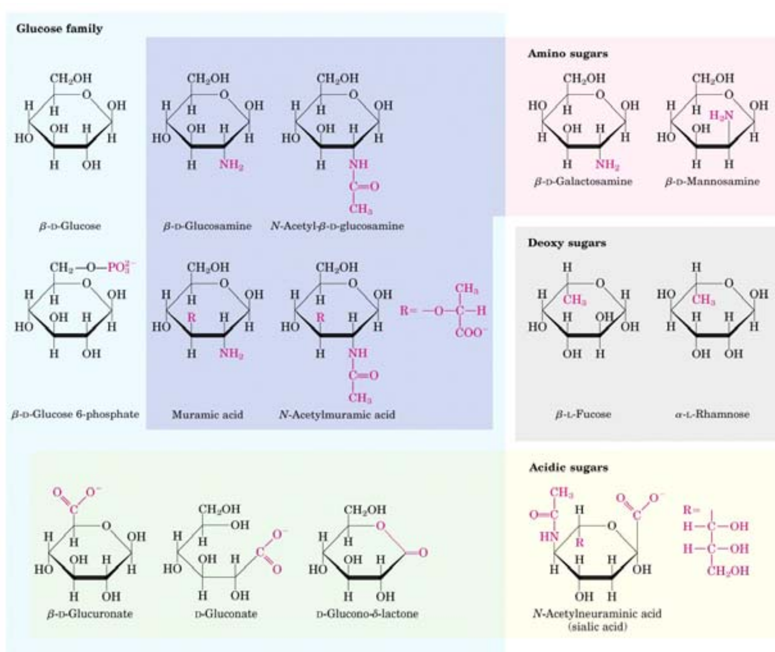
Compare β-D and α-D-glucopyranose.
What is special about β-D-glc among all the pyranose sugars??



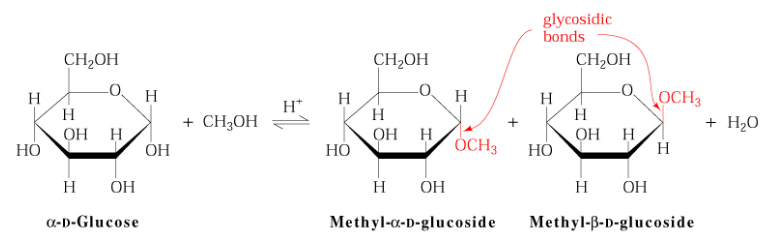
α-D-Glucopyranose
(b)

Sugar derivatives

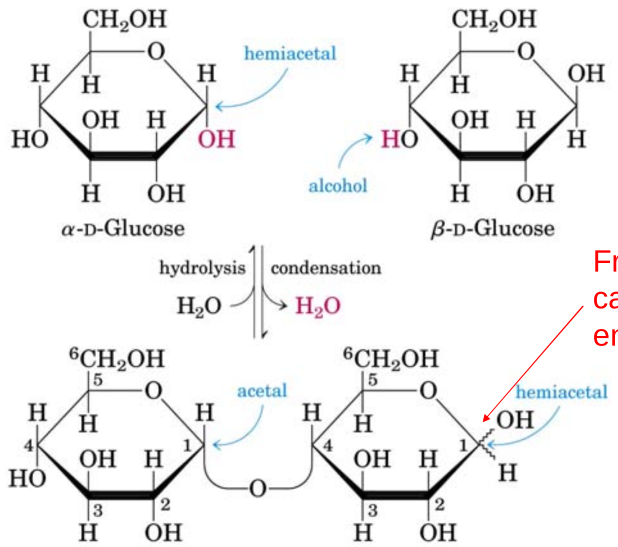




O-glycosidic bond: an ether linkage



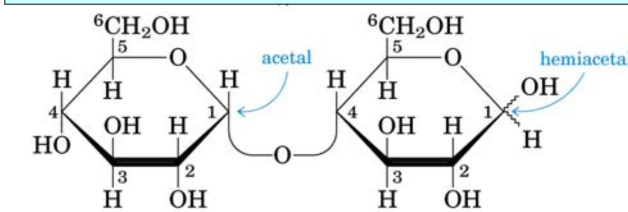
Disaccharides: 2 monosaccharides linked by an O-glycosidic bond



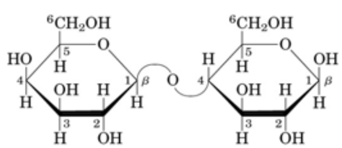
Free anomeric carbon: reducing end

Maltose
α-D-glucopyranosyl-(1→4)-D-glucopyranose

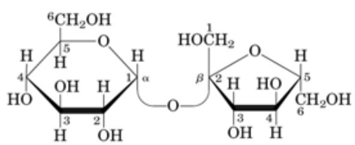
- Naming disaccharides:
- Nonreducing end to the left
- Specify:
    - component monosaccharides
    - ring types
    - anomeric forms
    - how they are linked together



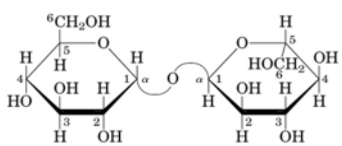
Maltose
α-D-glucopyranosyl-(1→4)-D-glucopyranose



Lactose (β form)
β-D-galactopyranosyl-(1→4)-β-D-glucopyranose
Gal(β1→4)Glc

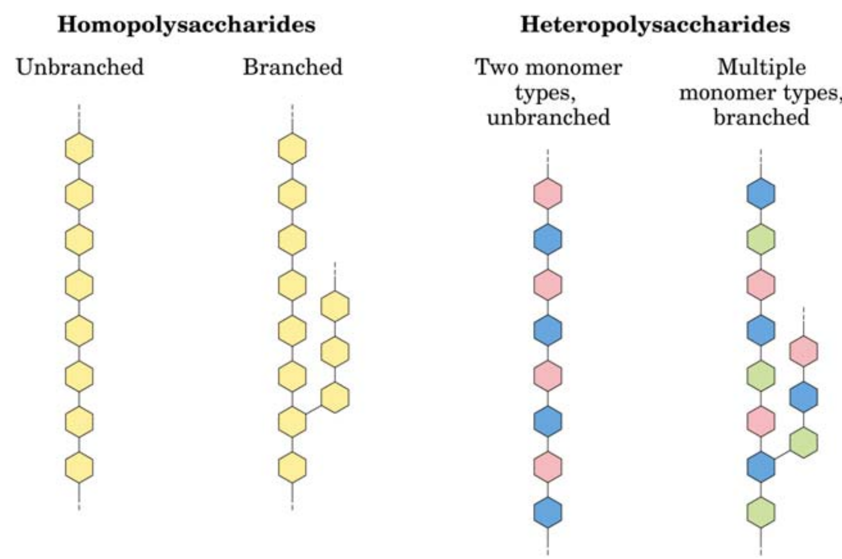


Sucrose
β-D-fructofuranosyl α-D-glucopyranoside
Fru(β2↔1α)Glc

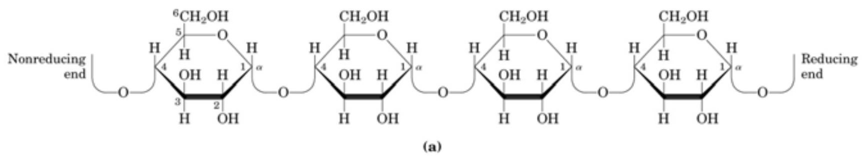


Trehalose
α-D-glucopyranosyl α-D-glucopyranoside
Glc(α1↔1α)Glc

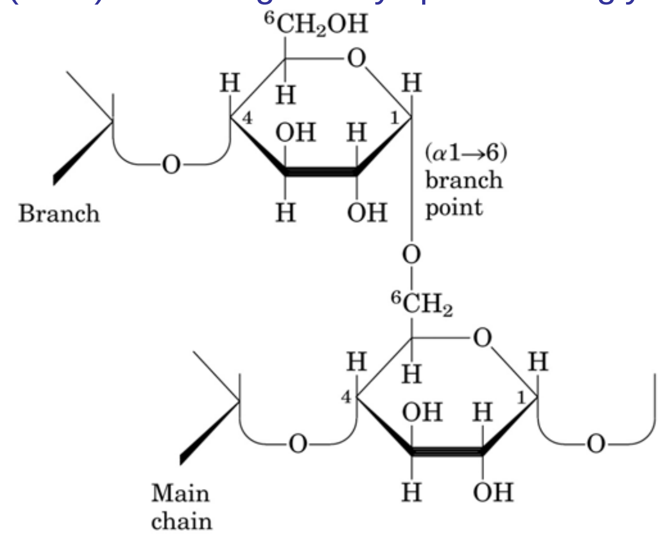
Are these reducing or nonreducing disaccharides?



The α(1→4) linkage of starch and glycogen



The α(1→6) branching in amylopectin and glycogen

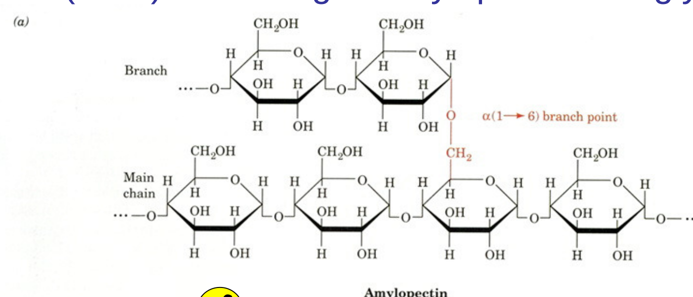


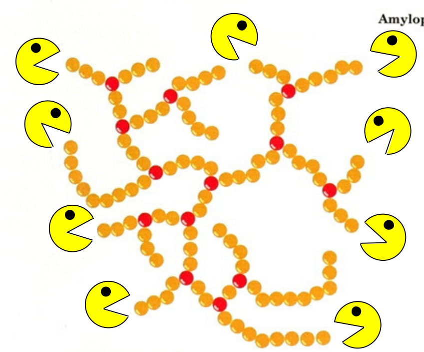
(b)

Glycogen and amylopectin

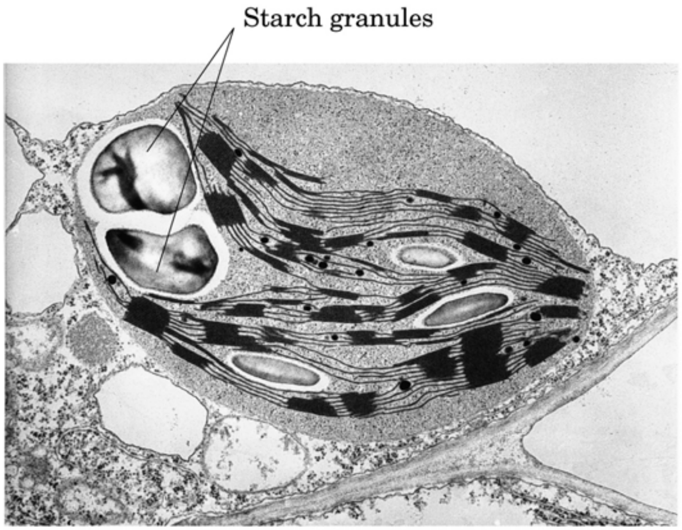
- Amylopectin: branches every 24-30 residues
- Glycogen: branches every 8-12 residues

The α(1→6) branching in amylopectin and glycogen

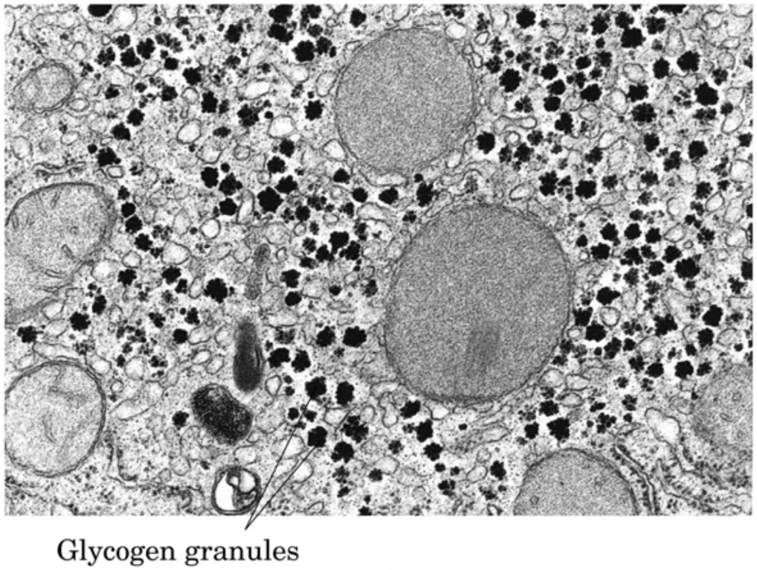




Branching provides many nonreducing ends for simultaneous hydrolysis by α-amylases

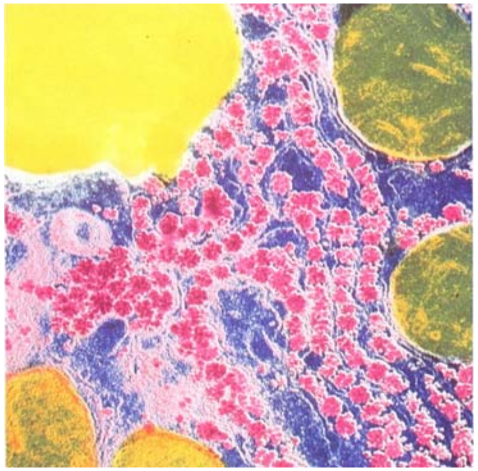


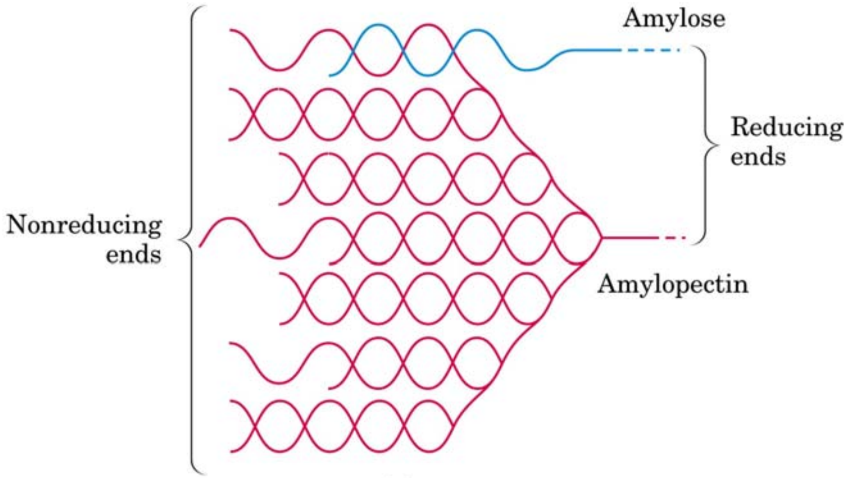
(a)



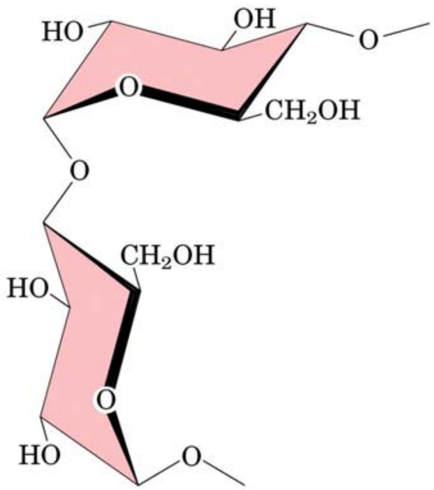
(b)

- Glycogen most prevalent in liver and muscle
- Up to 10% wet weight of liver
- Why not store glucose as monomers?



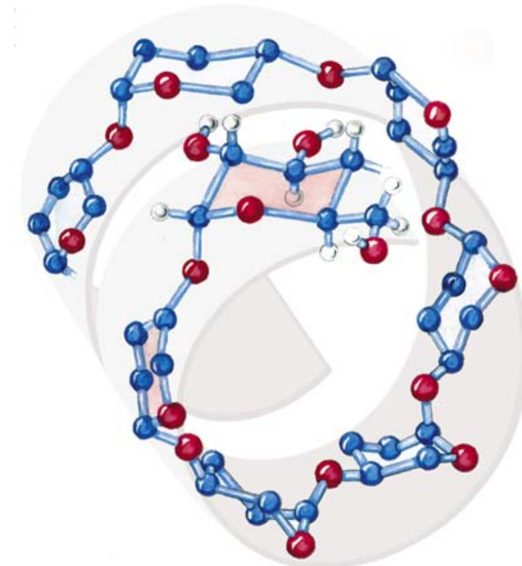


(c)



(α1→4)-linked D-glucose units

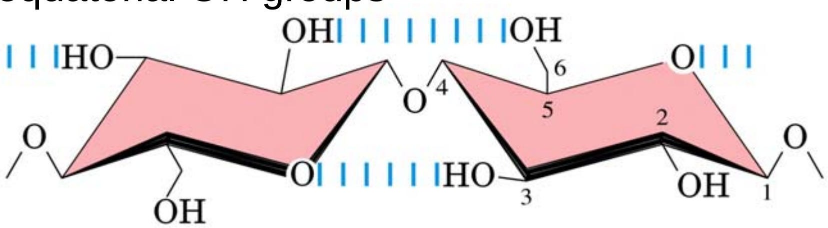
(a)



(b)

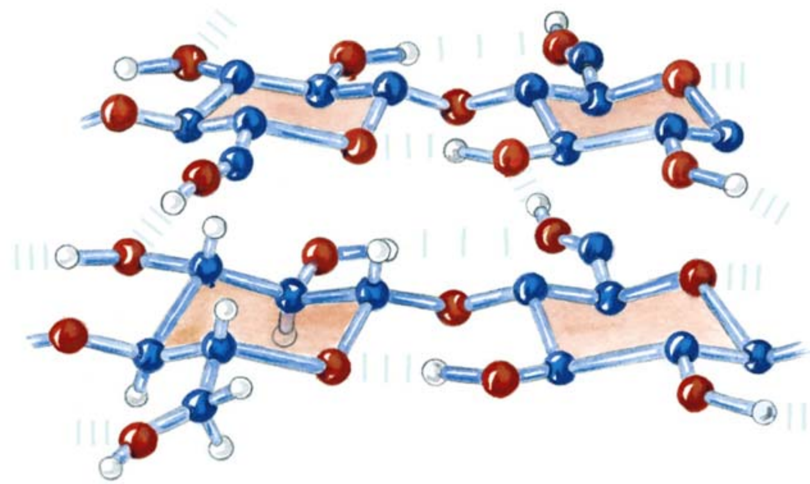
Cellulose

- Primary structural component of plant cell walls
- Linear polymer of D-glc in β(1→4) linkage
- Chair conf., each residue turned 180° relative to preceding residue
- Intra- and interchain network of H-bonding by equatorial OH groups

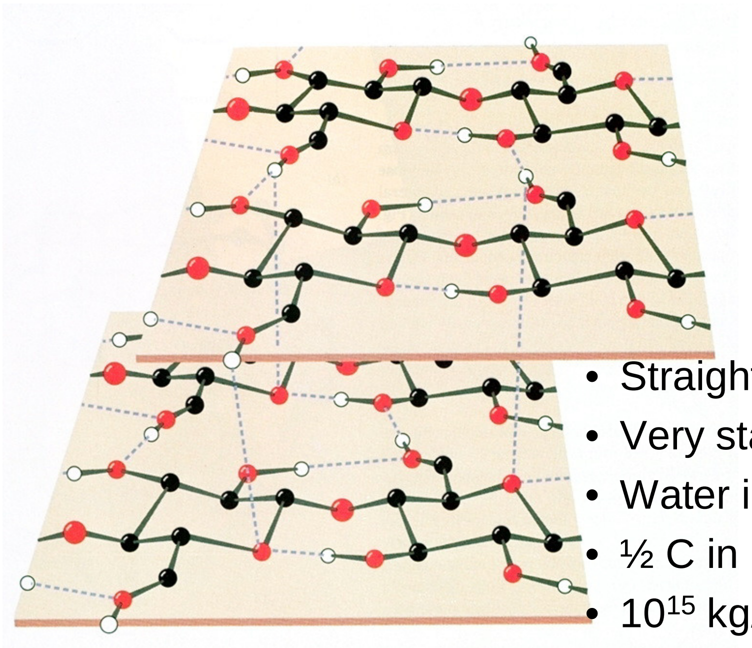


(β1→4)-linked D-glucose units

Compare to coiled structure of amylose



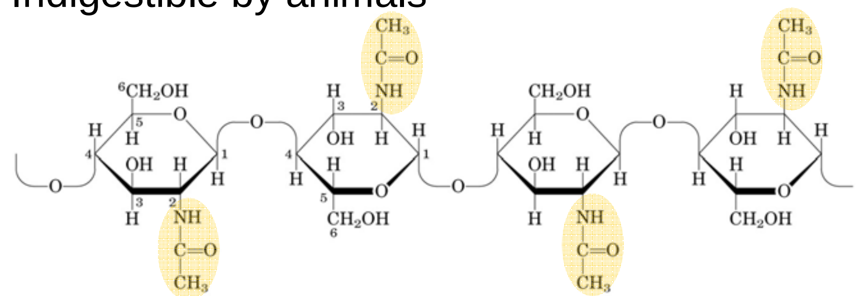
(b)



- Straight chains
- Very stable
- Water insoluble
- ½ C in biosphere
- 10^{15} kg/year

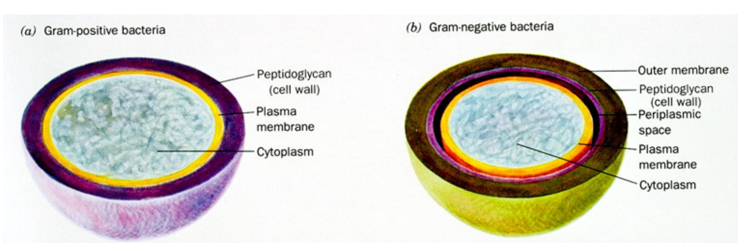
Chitin

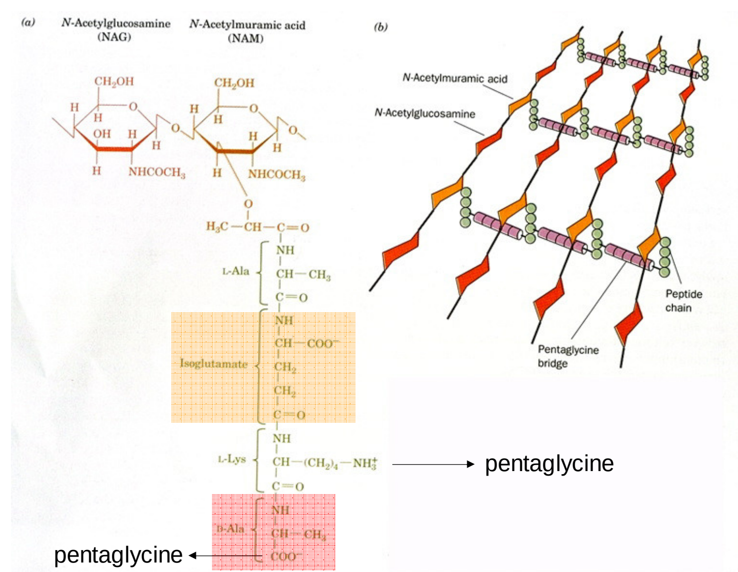
- Principle structural component of exoskeletons of invertebrates
- Cell walls, fungi and algae
- 2nd most abundant biopolymer
- β(1→4) N-acetylglucosamine residues
- Indigestible by animals

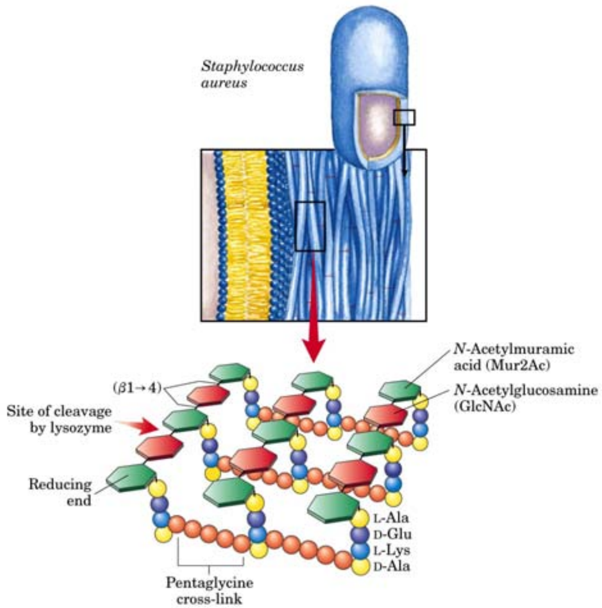


Peptidoglycan

- Bacterial cell wall
- Heteropolymer, N-acetylglucosamine and N-acetylmuramic acid residues ((NAG-NAM) repeating unit)
- Crosslinked by a tetrapeptide and pentaglycine

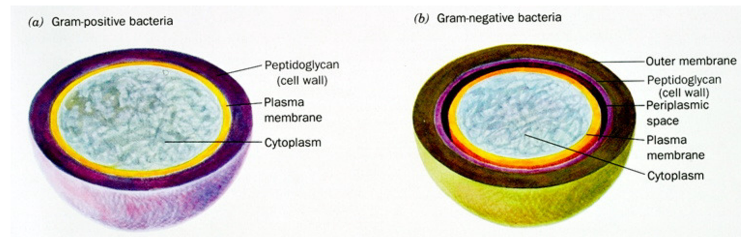


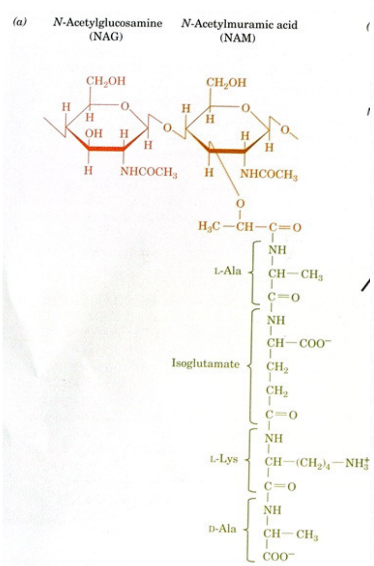


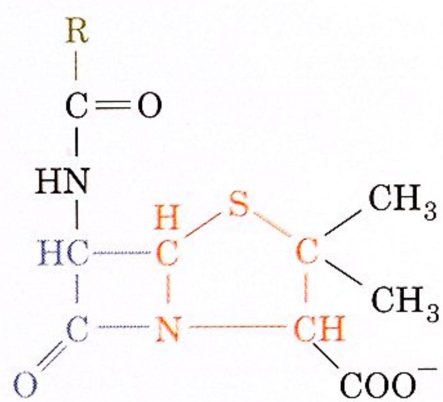


Killing bacteria by destroying the cell wall

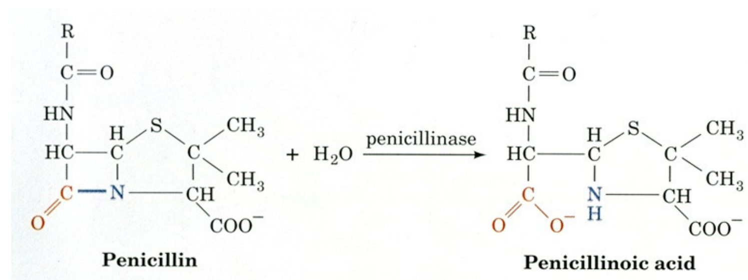
- Lysozyme (tears, mucus, egg white): hydrolyzes β(1→4) NAG-NAM linkage
- Penicillin: binds to and inactivates enzymes that crosslink polysaccharide strands via peptide links





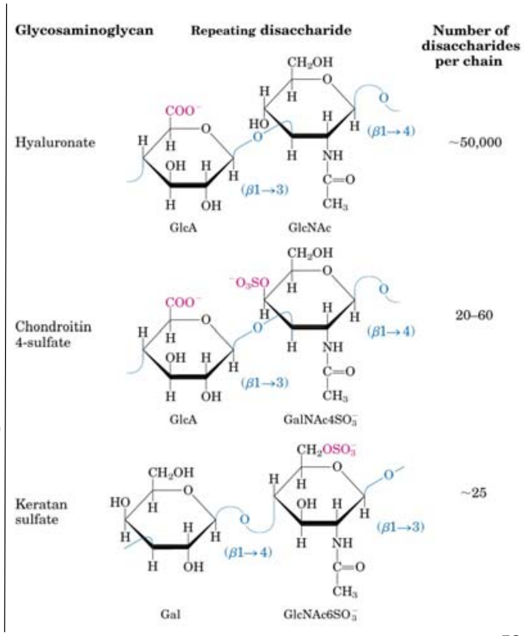


Penicillin

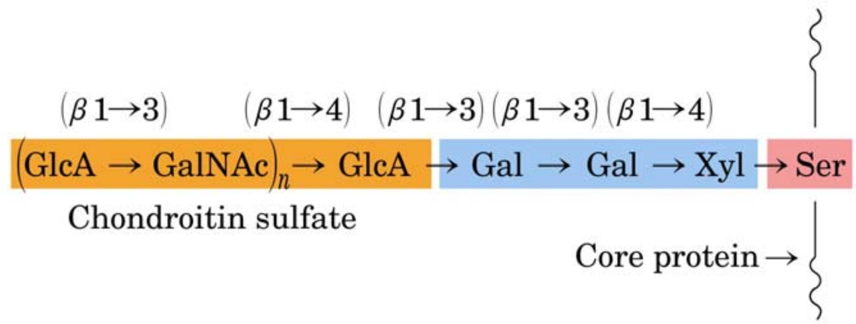


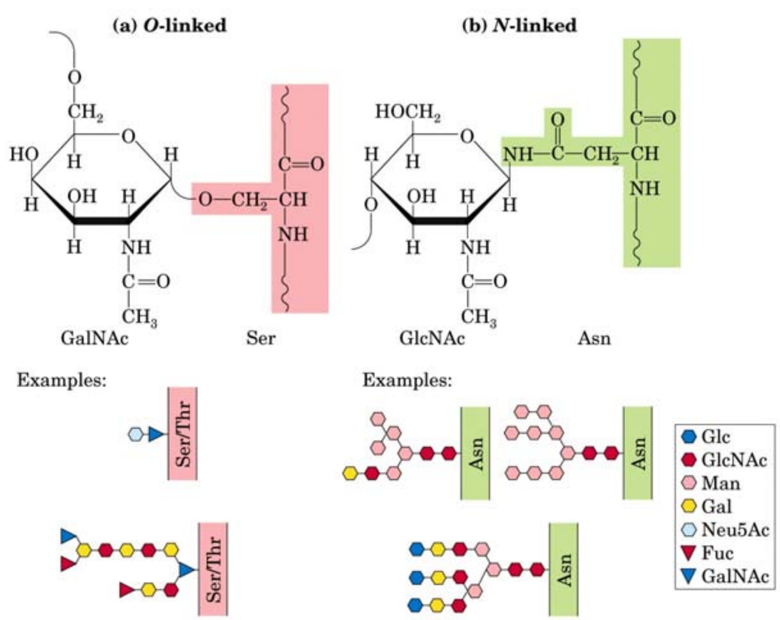
Glycosaminoglycans

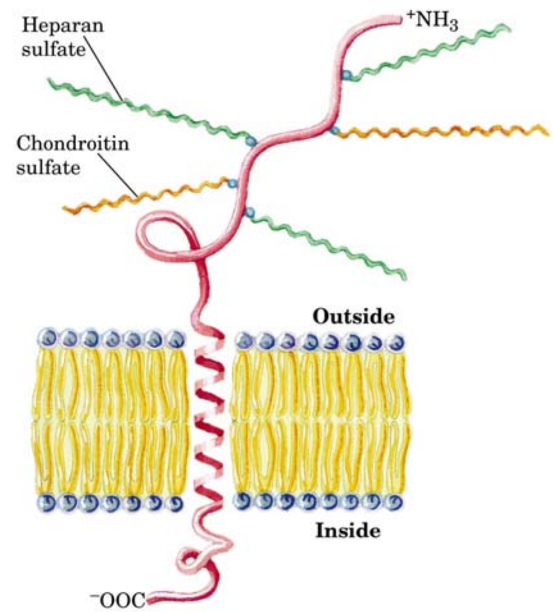
- Present in animals
- Extracellular matrix
- Linear polymers, repeating disaccharides
- High density, negative charges
- Assume extended conformation (β anomers)
- Viscous
- Extracellular proteins + glycosaminoglycans = proteoglycans



Linking glycosaminoglycans to proteins

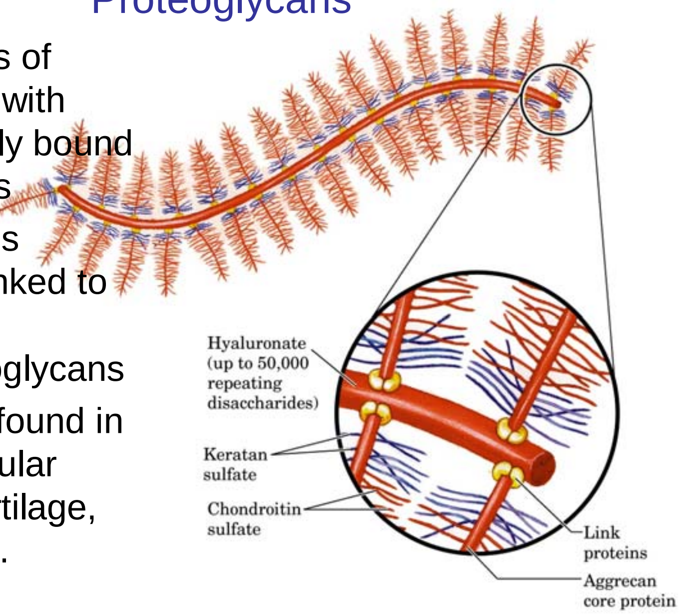






Proteoglycans

- Long strands of hyaluronate with noncovalently bound core proteins
- Core proteins covalently linked to shorter glycosaminoglycans
- This stuff is found in the extracellular matrix of cartilage, tendons, etc.



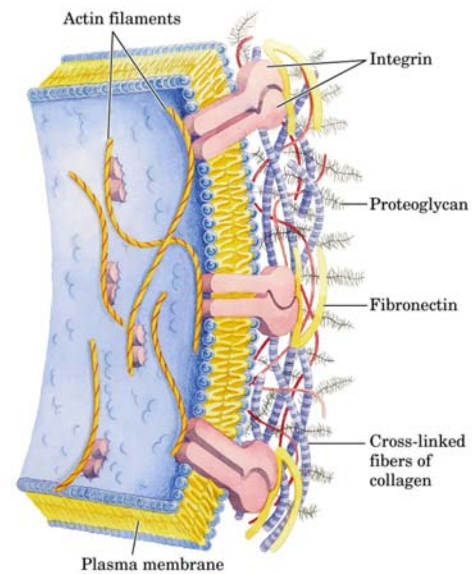


table 9–2

Structures and Roles of Some Polysaccharides

Polymer	Type*	Repeating unit†	Size (number of monosaccharide units)	Roles
Starch				Energy storage: in plants
Amylose	Homo-	(α1→4)Glc, linear	50–5,000	
Amylopectin	Homo-	(α1→4)Glc, with (α1→6)Glc branches every 24 to 30 residues	Up to 10^6	
Glycogen	Homo-	(α1→4)Glc, with (α1→6)Glc branches every 8 to 12 residues	Up to 50,000	Energy storage: in bacteria and animal cells
Cellulose	Homo-	(β1→4)Glc	Up to 15,000	Structural: in plants, gives rigidity and strength to cell walls
Chitin	Homo-	(β1→4)GlcNAc	Very large	Structural: in insects, spiders, crustaceans, gives rigidity and strength to exoskeletons
Peptidoglycan	Hetero-; peptides attached	4)Mur2Ac(β1→4) GlcNAc(β1	Very large	Structural: in bacteria, gives rigidity and strength to cell envelope
Hyaluronate (a glycosamino-glycan)	Hetero-; acidic	4)GlcA(β1→3) GlcNAc(β1	Up to 100,000	Structural: in vertebrates, extracellular matrix of skin and connective tissue; viscosity and lubrication in joints

* Each polymer is classified as a homopolysaccharide (homo-) or heteropolysaccharide (hetero-).

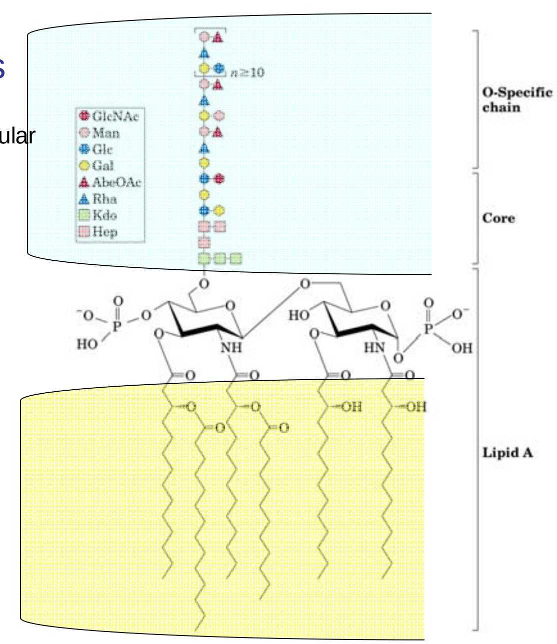
†The abbreviated names for the peptidoglycan and hyaluronate repeating units indicate that the polymer contains repeats of this disaccharide unit, with the GlcNAc of one disaccharide unit linked β(1→4) to the first residue of the next disaccharide unit.

Sugars as receptors (antennas)

Imbedded in the lipid bilayer membrane of cells, with the antennas sticking outside

Extracellular matrix

Lipid bilayer



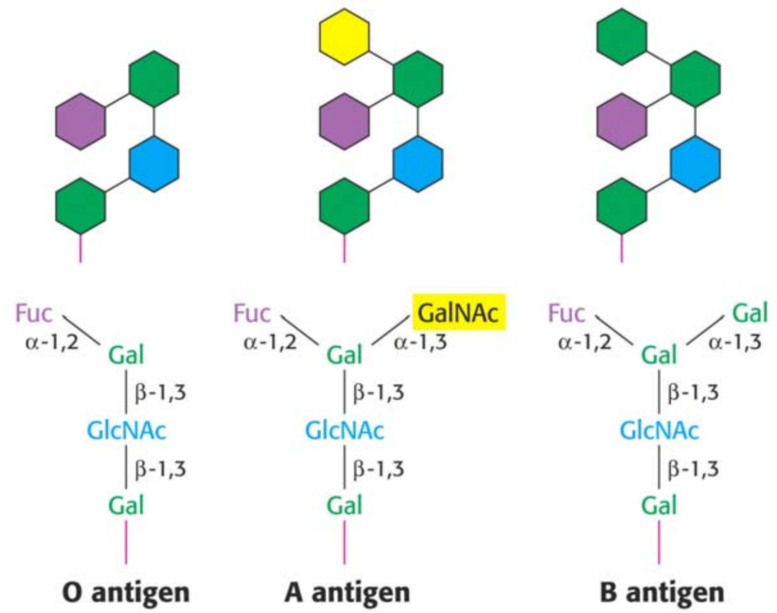


table 9–3

Lectins and the Oligosaccharide Ligands That They Bind

Lectin family and lectin	Abbreviation	Ligand(s)
Plant		
Concanavalin A	ConA	Manα1—OCH_3
Griffonia simplicifolia lectin 4	GS4	Lewis b (Le^b) tetrasaccharide
Wheat germ agglutinin	WGA	Neu5Ac(α2→3)Gal(β1→4)Glc GlcNAc(β1→4)GlcNAc
Ricin		Gal(β1→4)Glc
Animal		
Galectin-1		Gal(β1→4)Glc
Mannose-binding protein A	MBP-A	High-mannose octasaccharide
Viral		
Influenza virus hemagglutinin	HA	Neu5Ac(α2→6)Gal(β1→4)Glc
Polyoma virus protein 1	VP1	Neu5Ac(α2→3)Gal(β1→4)Glc
Bacterial		
Enterotoxin	LT	Gal
Cholera toxin	CT	GM1 pentasaccharide

Source: Weiss, W.I. & Drickamer, K. (1996) Structural basis of lectin-carbohydrate recognition. *Annu. Rev. Biochem.* **65,** 441–473.