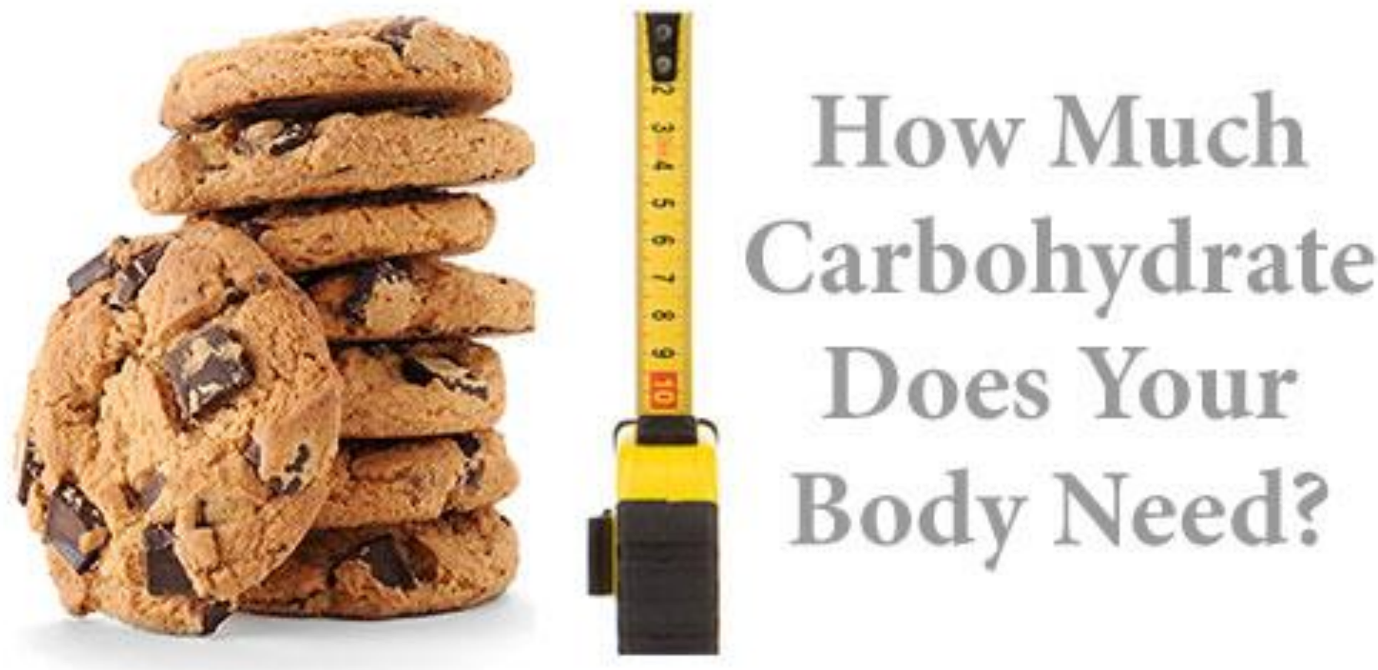
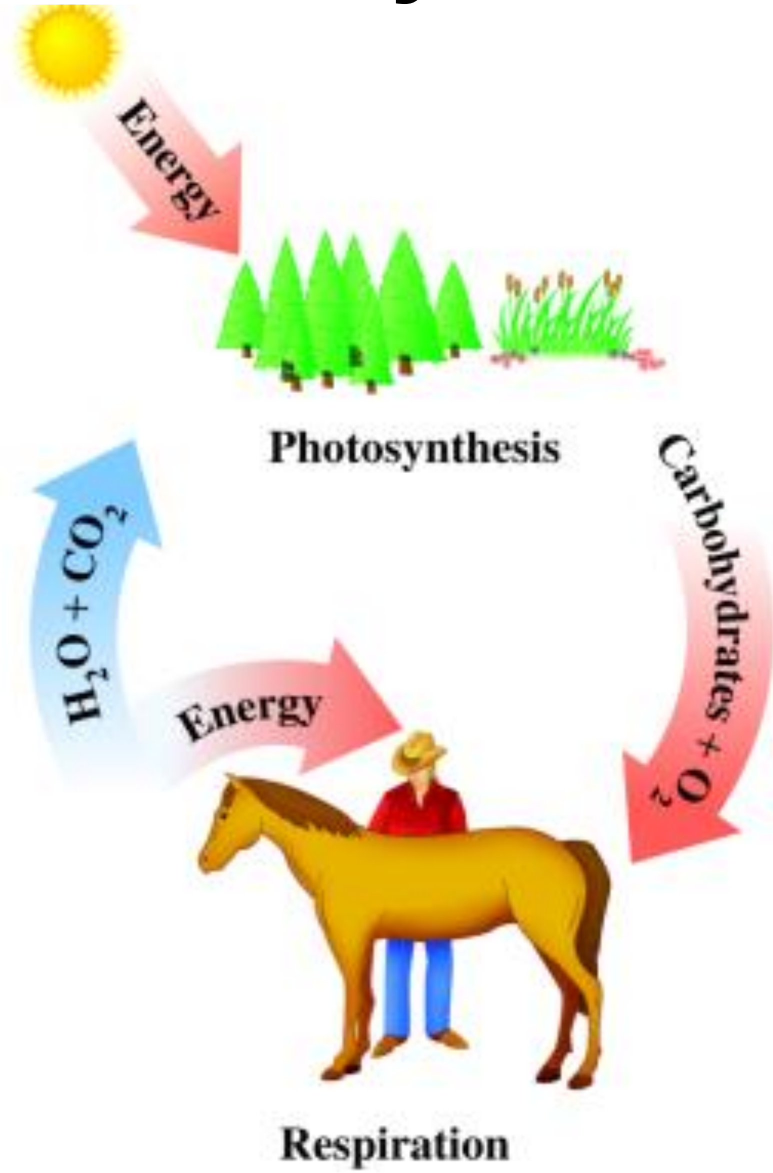
CARBOHYDRATES

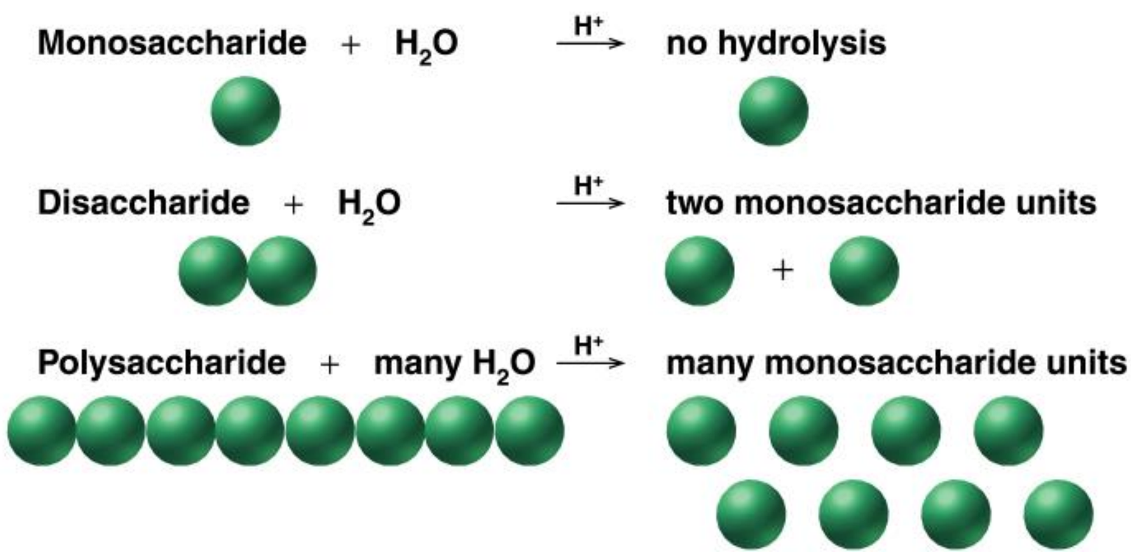


Carbohydrates



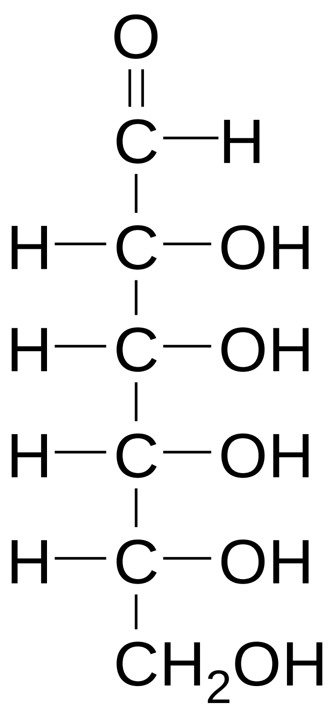
Types of Carbohydrates

- **monosaccharides**
- **disaccharides**
- **oligosacharides**:
- **polysaccharides**



Monosaccharides consist of:

- 3-6 carbon atoms typically.
- a carbonyl group (aldehyde or ketone).
- several hydroxyl groups.
- 2 types of monosaccharide structures: Aldoses and ketoses

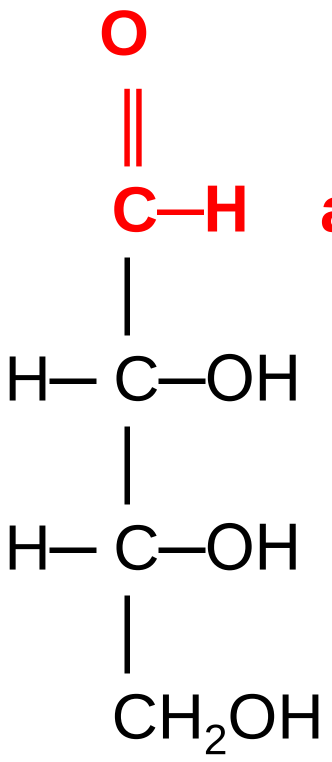


Aldoses

Aldoses are monosaccharides

- with an aldehyde group
- with many hydroxyl (-OH) groups.

triose	(3C atoms)
tetrose	(4C atoms)
pentose	(5 C atoms)
hexose	(6 C atoms)

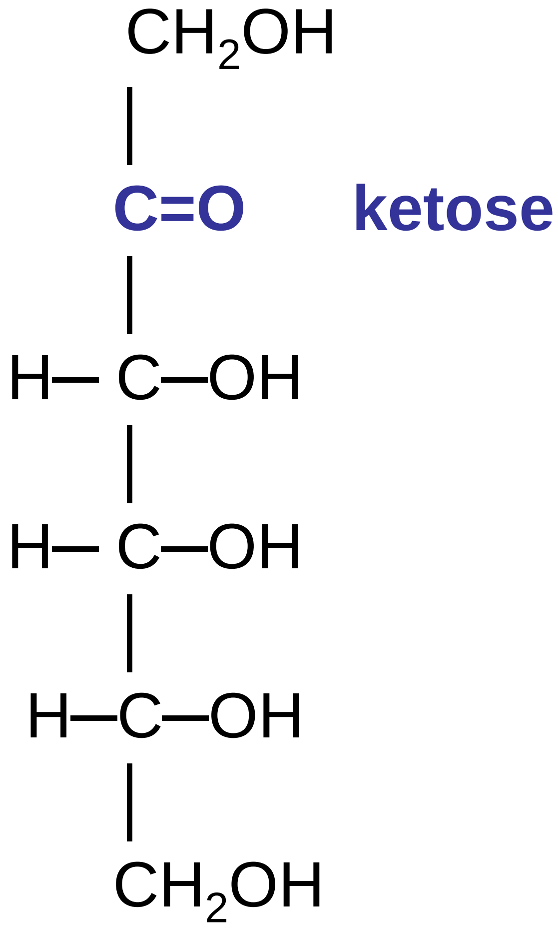


aldose

Ketoses

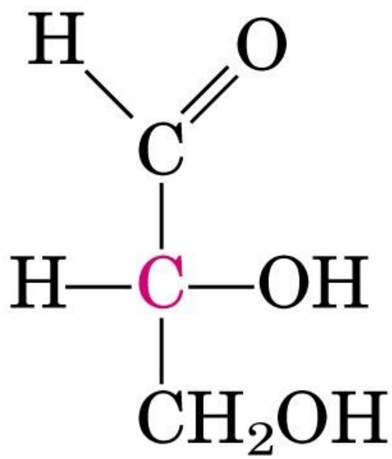
Ketoses are monosaccharides

- with a **ketone group**
- with many hydroxyl (-OH) groups.



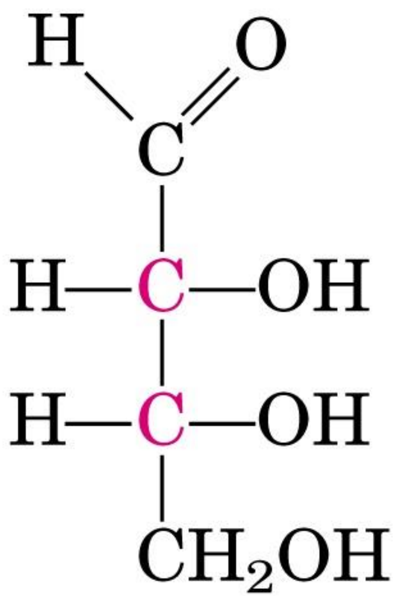
Fructose, a ketohexose

Three carbons

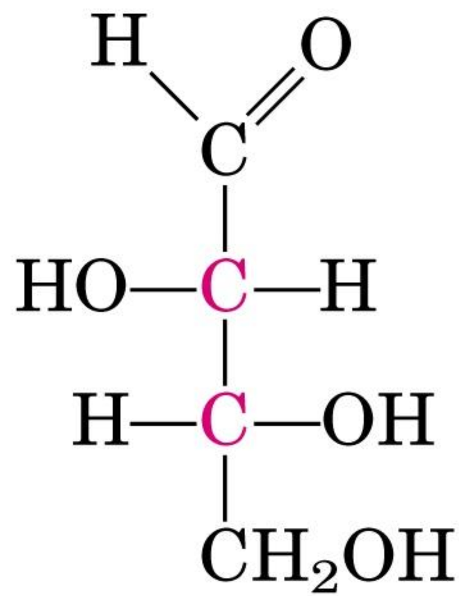


D-Glyceraldehyde

Four carbons

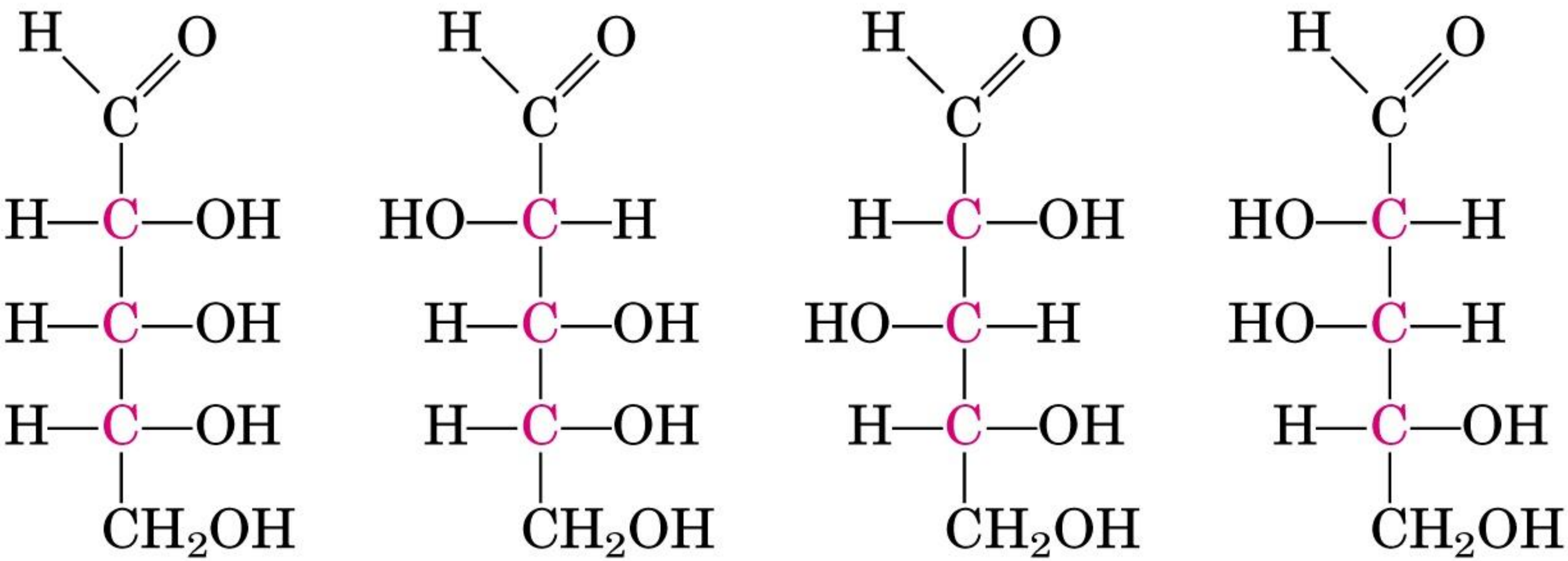


D-Erythrose



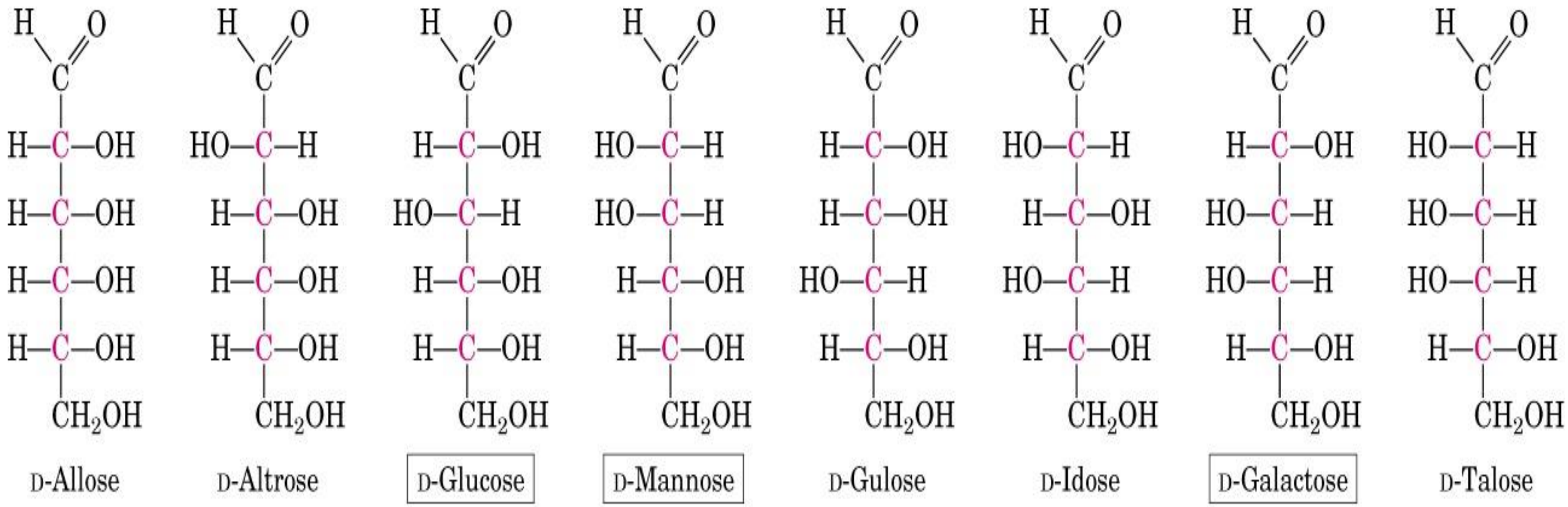
D-Threose

Five carbons



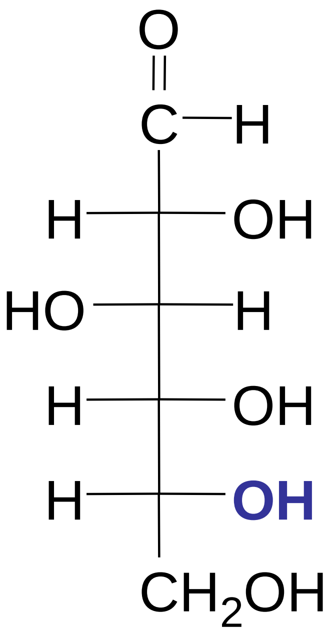
D-Ribose | D-Arabinose | D-Xylose | D-Lyxose

Six carbons

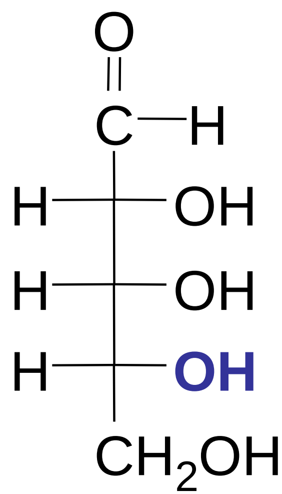


D-Aldoses
(a)

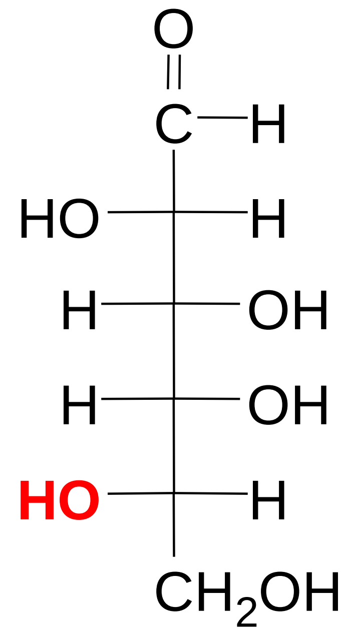
Examples of D and L Isomers of Monosaccharides



D-glucose



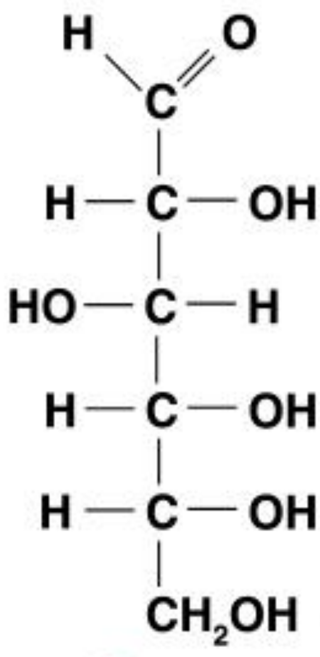
D-ribose



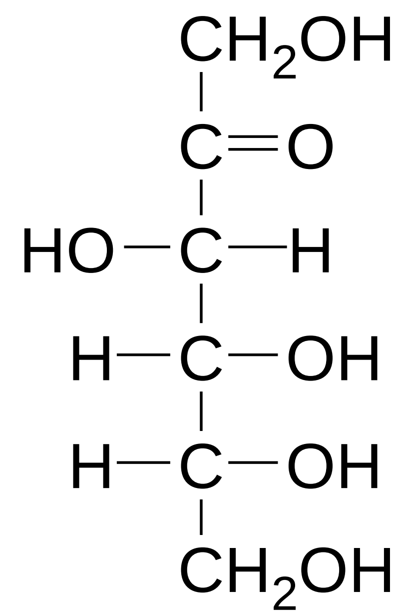
L-galactose

D-Glucose

D-Fructose



D-Glucose

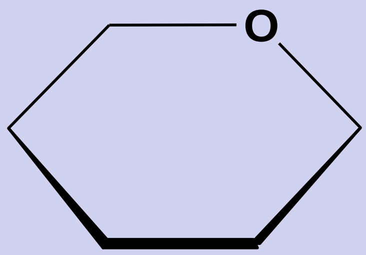


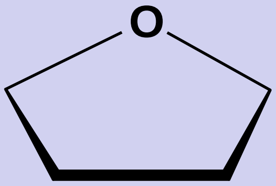
D-Fructose

Cyclic Structures

Cyclic structures

- are the prevalent form of monosaccharides with 5 or 6 carbon atoms.

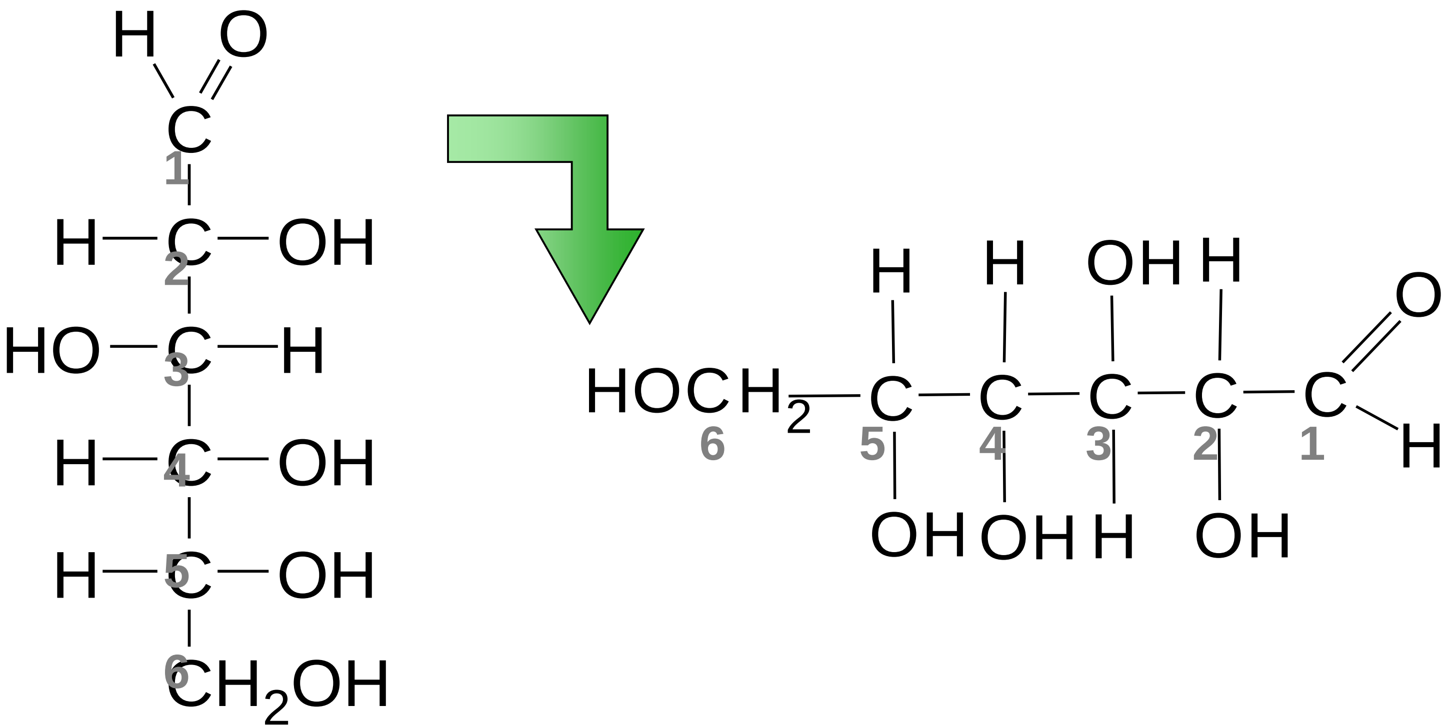




- form when the hydroxyl group on C-5 reacts with the aldehyde group or ketone group.

Drawing the Cyclic Structure for Glucose

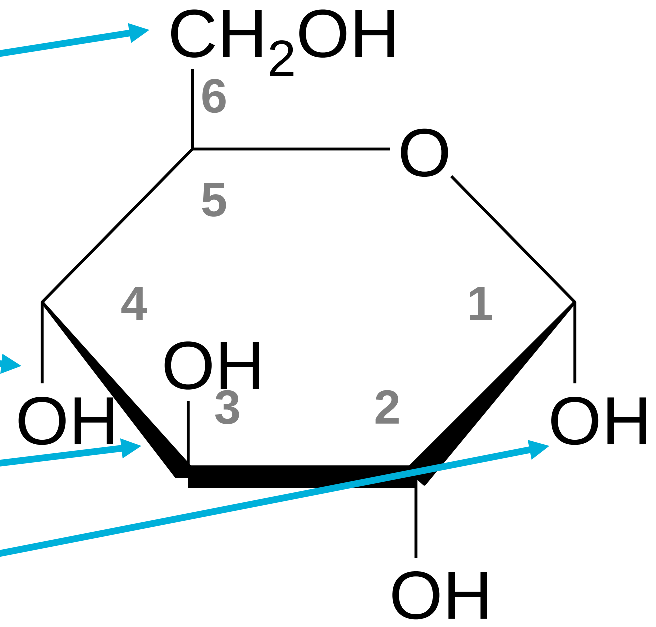
STEP 1 Number the carbon chain and turn clockwise to form a linear open chain.



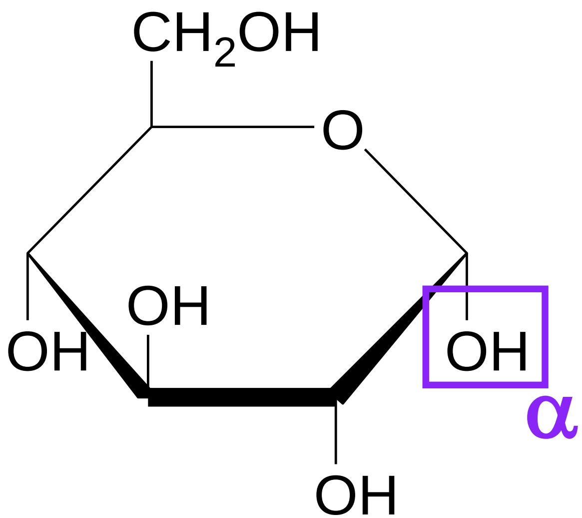
Cyclic Structure for Glucose

STEP 2 Fold into a hexagon.

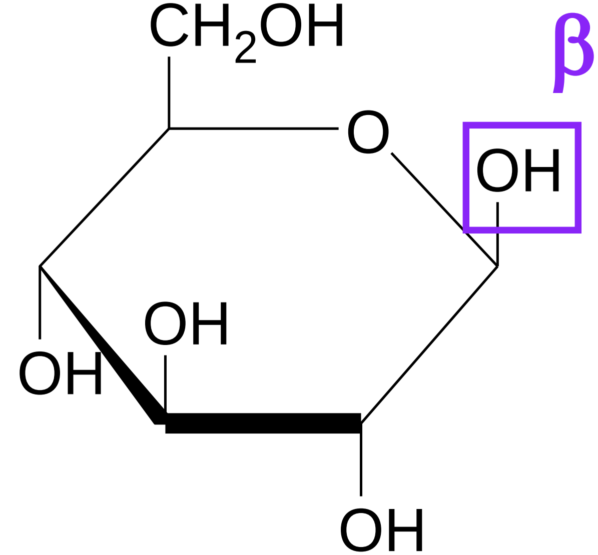
- Bond the C5 –O– to C1.
- Place the C6 group above the ring.
- Write the –OH groups on C2 and C4 below the ring.
- Write the –OH group on C3 above the ring.
- Write a new –OH on C1.



Cyclic Structure for Glucose



α-D-Glucose

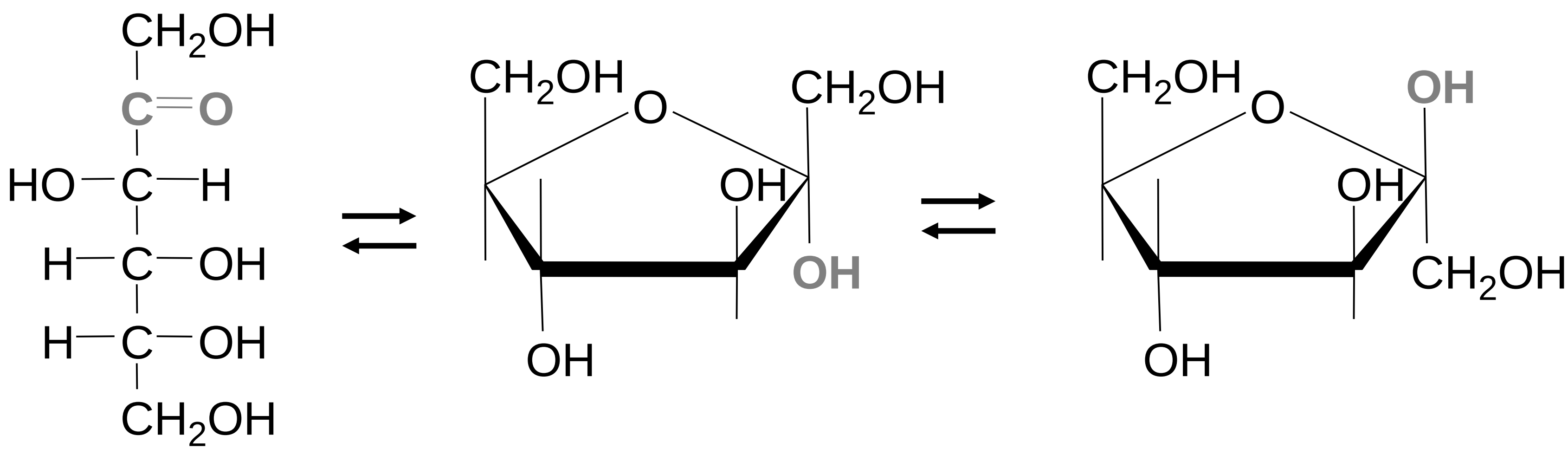


β-D-Glucose

Cyclic Structure of Fructose

Fructose

- is a ketohexose.
- forms a cyclic structure.
- reacts the —OH on C-5 with the C=O on C-2.



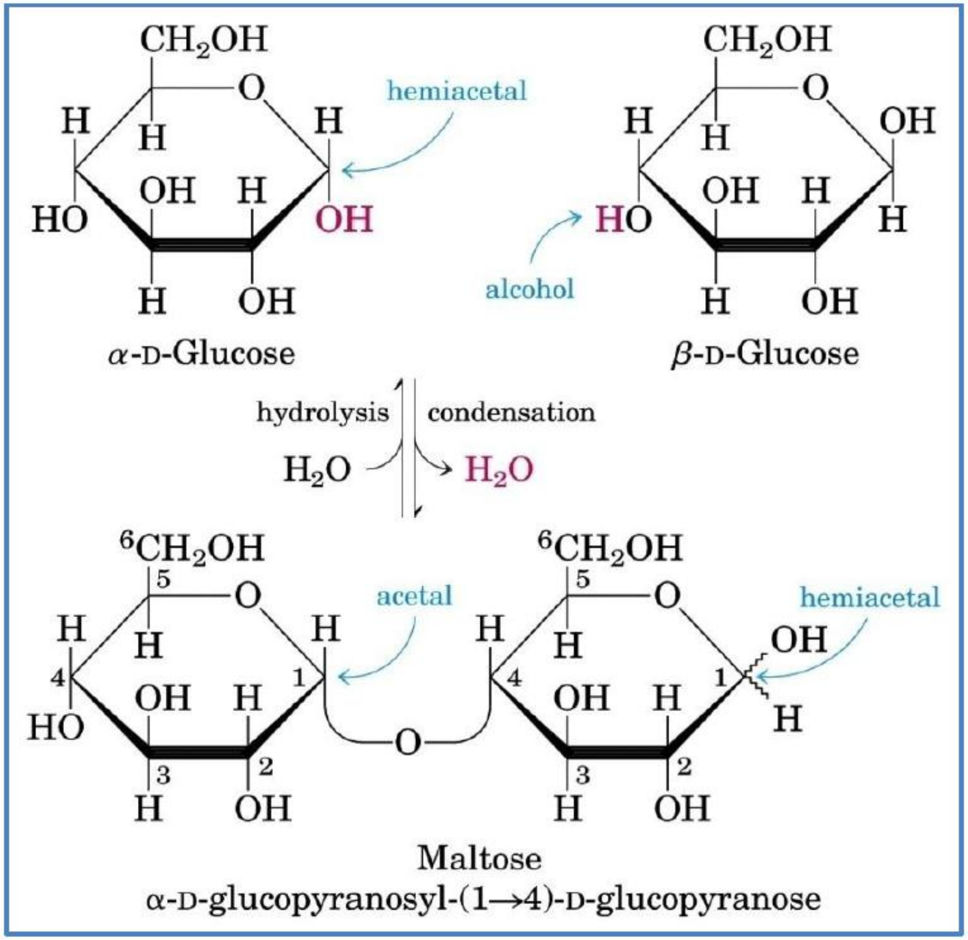
D-fructose α-D-fructose β-D-fructose

Important Disaccharides

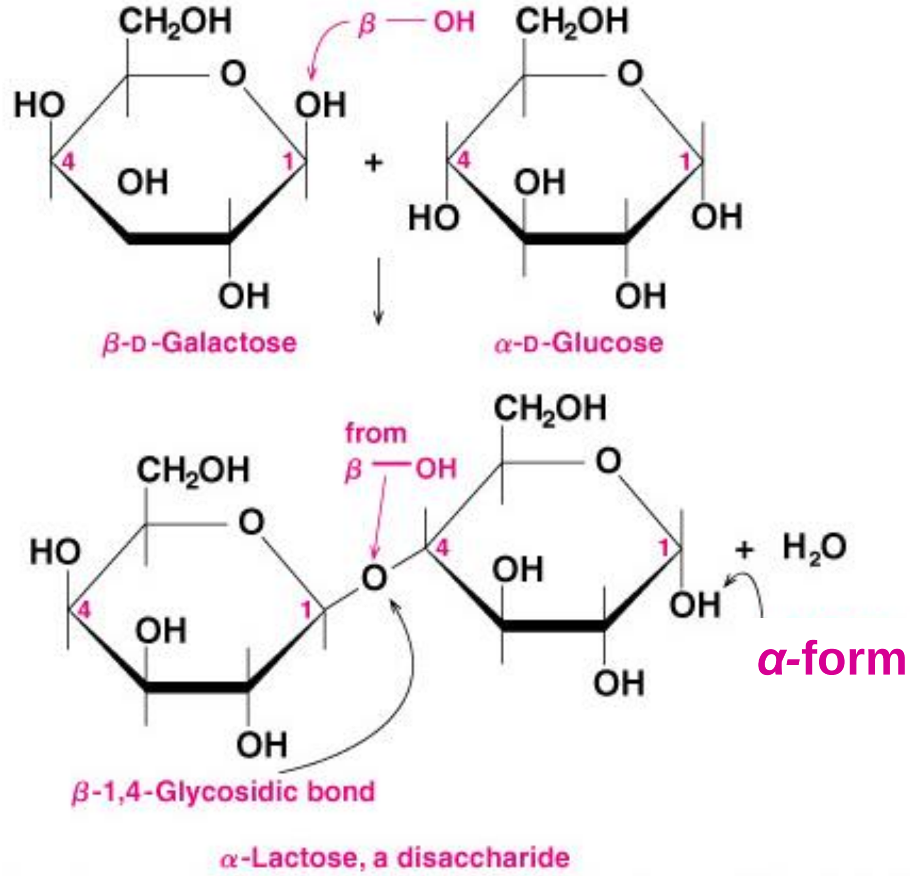
A **disaccharide** consists of two monosaccharides.

Monosaccharides		**Disaccharide**
glucose + glucose	→	maltose + H_2O
glucose + galactose	→	lactose + H_2O
glucose + fructose	→	sucrose + H_2O

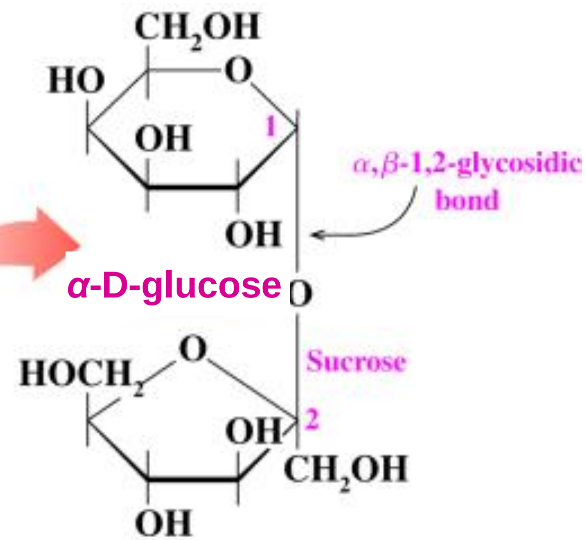
Formation of maltose



Lactose


CH₂OH
β — OH
CH₂OH
O
HO
OH
O
4
1
+
4
1
OH
OH
HO
OH
OH
OH
β-D-Galactose
α-D-Glucose
CH₂OH
from
β — OH
CH₂OH
O
O
HO
4
1
+ H₂O
O
OH
4
1
OH
OH
OH
OH
α-form
β-1,4-Glycosidic bond
α-Lactose, a disaccharide

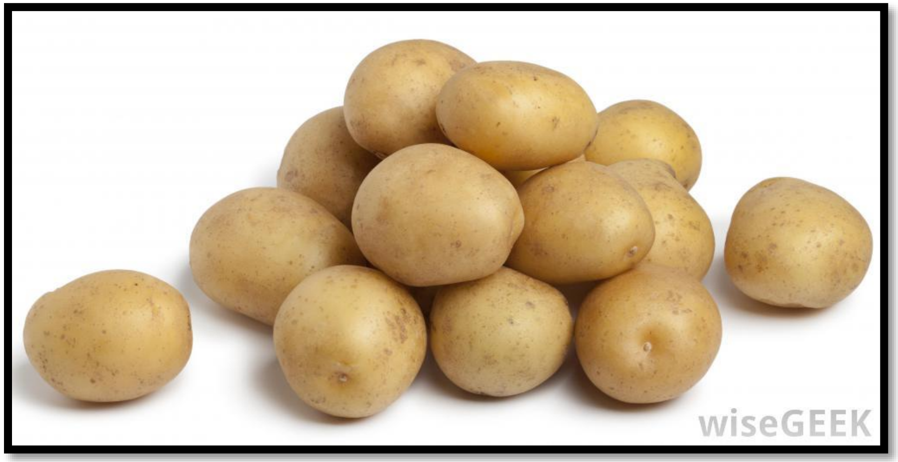
Sucrose



α-D-glucose

β -D-fructose

Polysaccharides



Polysaccharides

- are polymers of D-glucose.
- Include:

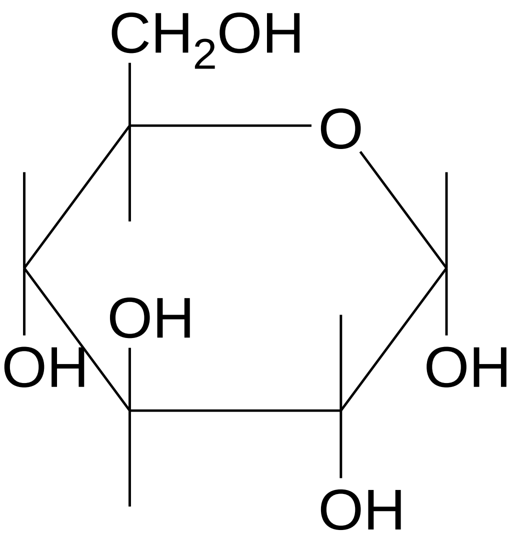
1. Starches (amylose and amylopectin)

2. glycogen

(animal starch in muscle

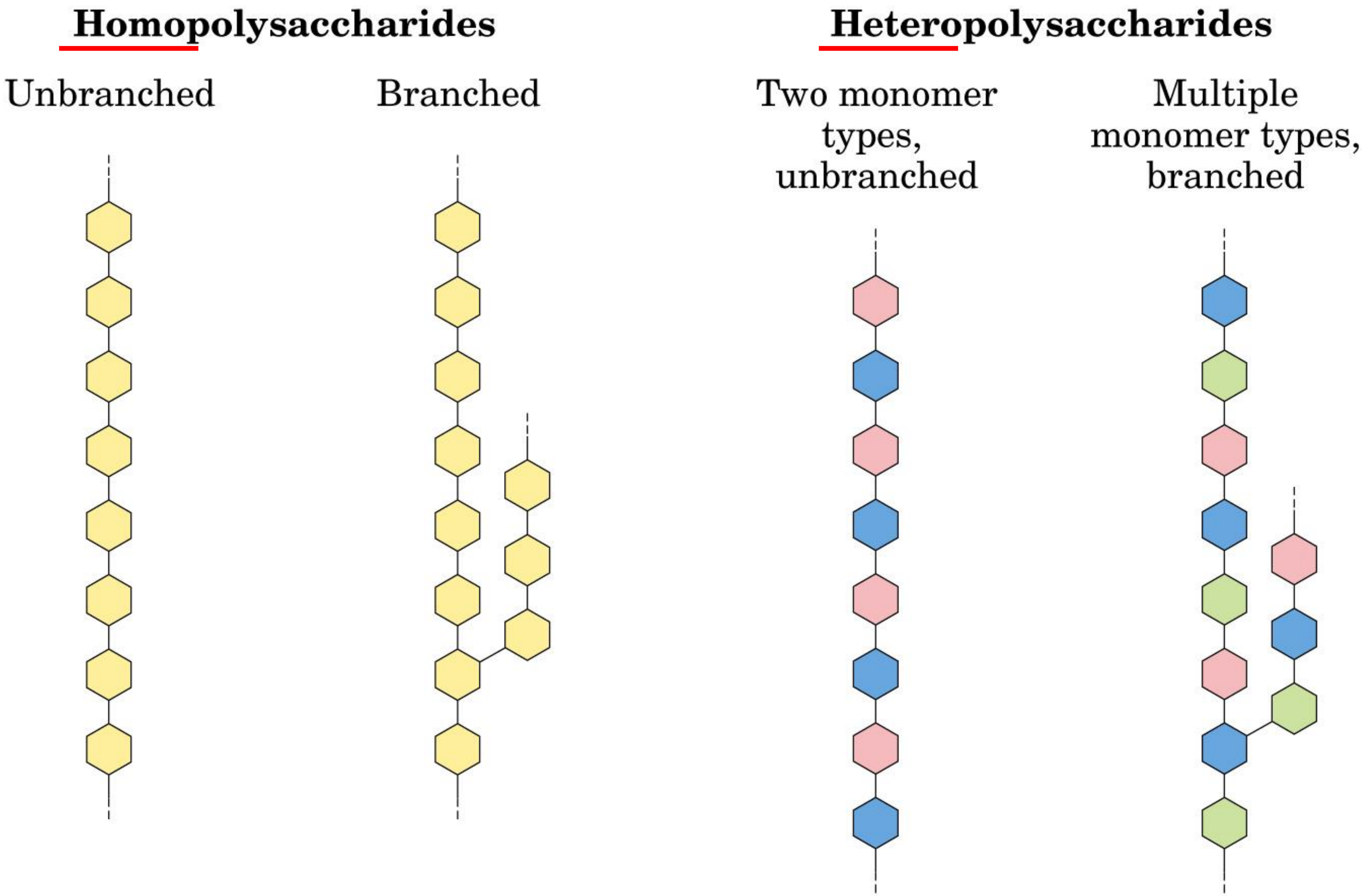
3. cellulose

(plants and wood)



α-D-Glucose

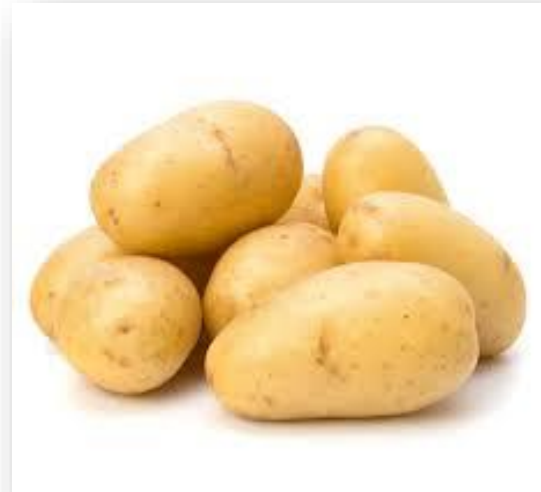
Polysaccharides

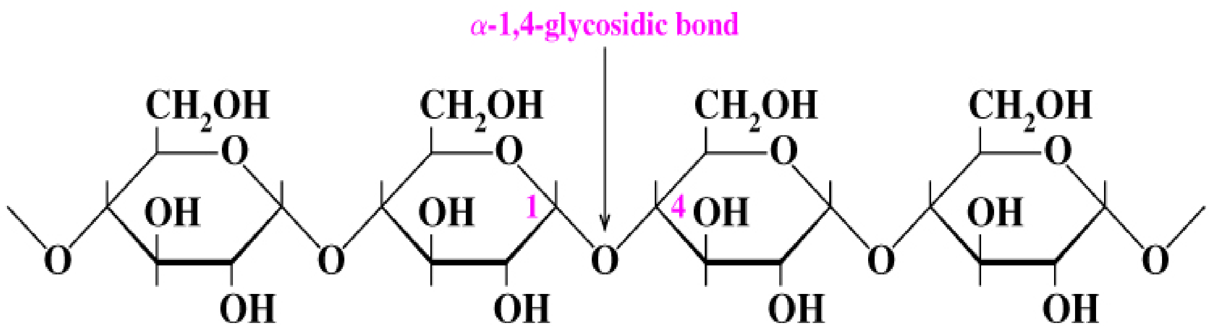


Amylose

Amylose is

- a polymer of α-D-glucose molecules.
- linked by α-1,4 glycosidic bonds.
- a continuous (unbranched) chain.



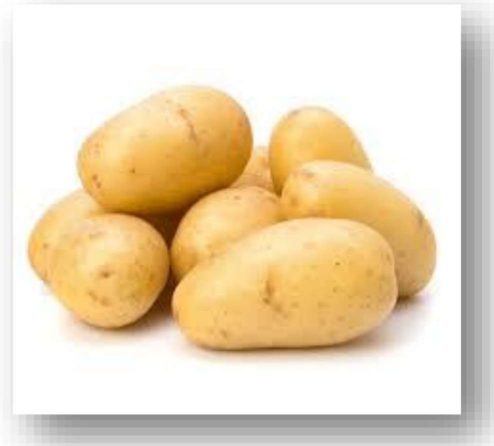


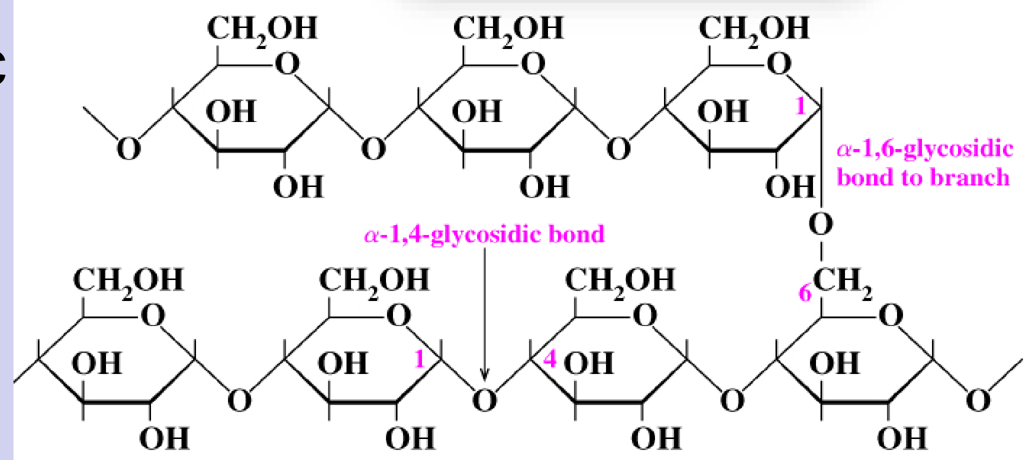
(a) Unbranched chain of amylose

Amylopectin

Amylopectin

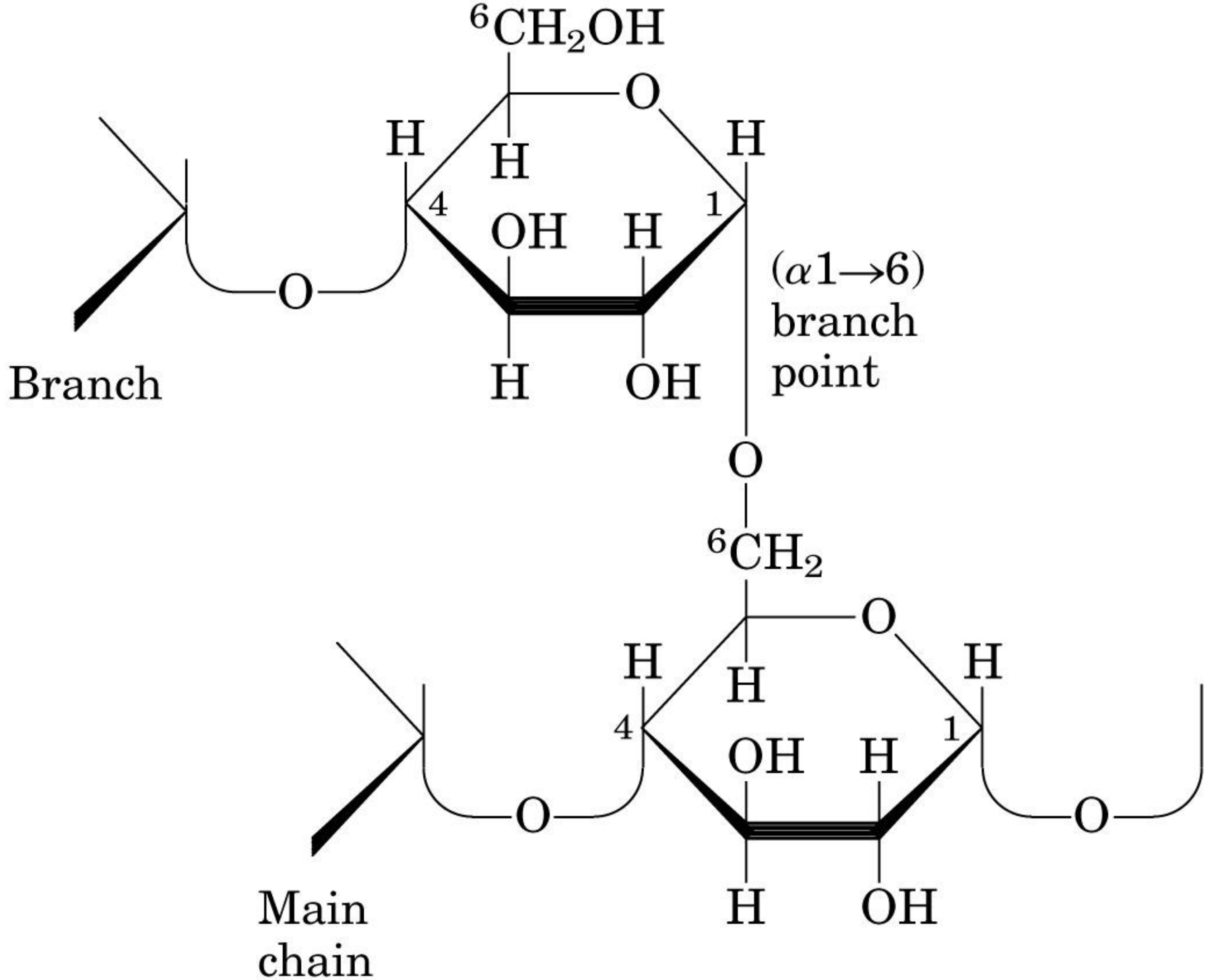
- is a polymer of α-D-glucose molecules.
- is a branched-chain polysaccharide.
- has α-1,4-glycosidic bonds between the glucose units.
- has *α*-1,6 bonds to branches.





Branched chain of amylopectin

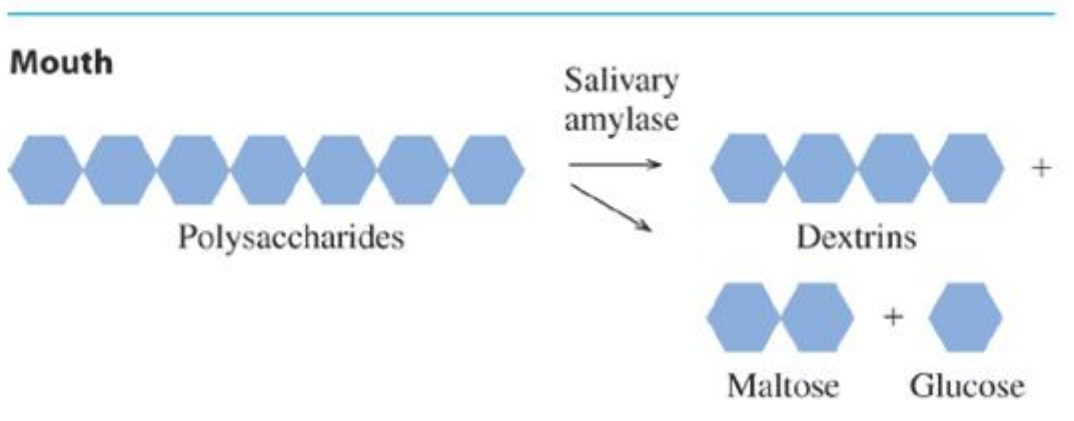
α-1,6 bond



6CH2OH
O
H
H
H
4
1
OH
H
(α1→6)
branch
point
O
H
OH
Branch
O
6CH2
O
H
H
H
4
1
OH
H
O
O
H
OH
Main
chain

Dextrins

- Starches like amylose and amylopectin hydrolyze to dextrins (smaller polysaccharides)
- Contain <u>3-8</u> glucose units



Glycogen

Glycogen

- is the polysaccharide that stores α-D-glucose in muscle.
- is similar to amylopectin, but is more highly branched.

Cellulose

- is a polysaccharide of glucose units in unbranched chains.
- has β-1,4-glycosidic bonds.
- cannot be digested by humans because humans cannot break down β-1,4-glycosidic bonds.

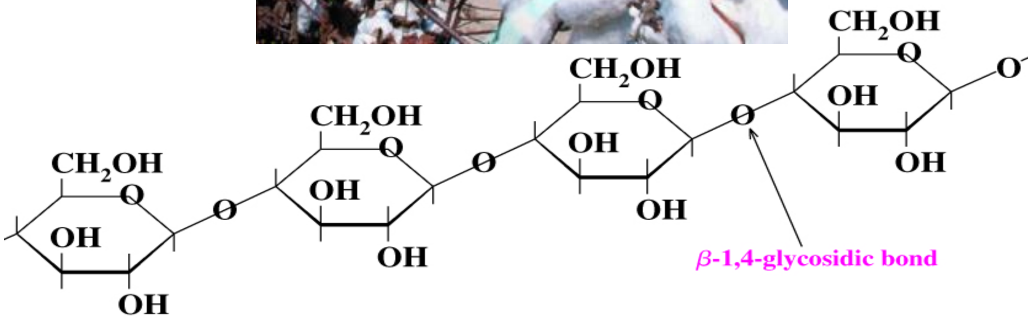


table 9–2

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.

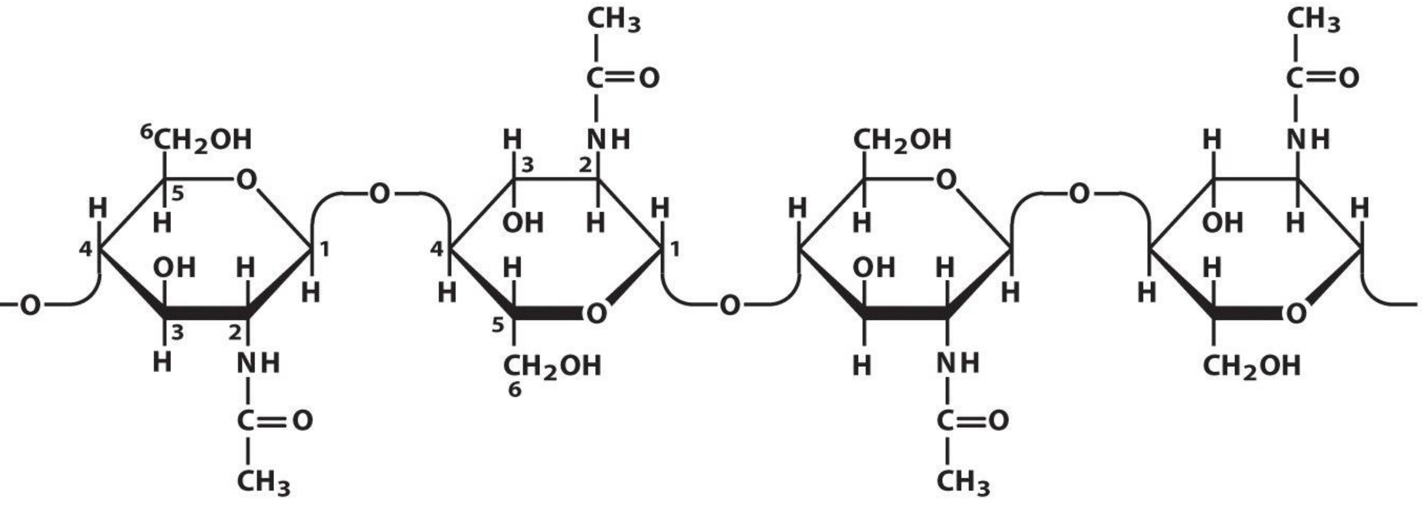
Why not to store glucose in monomeric form?

Glycogen vs. Glucose

- Solubility
- Osmolarity

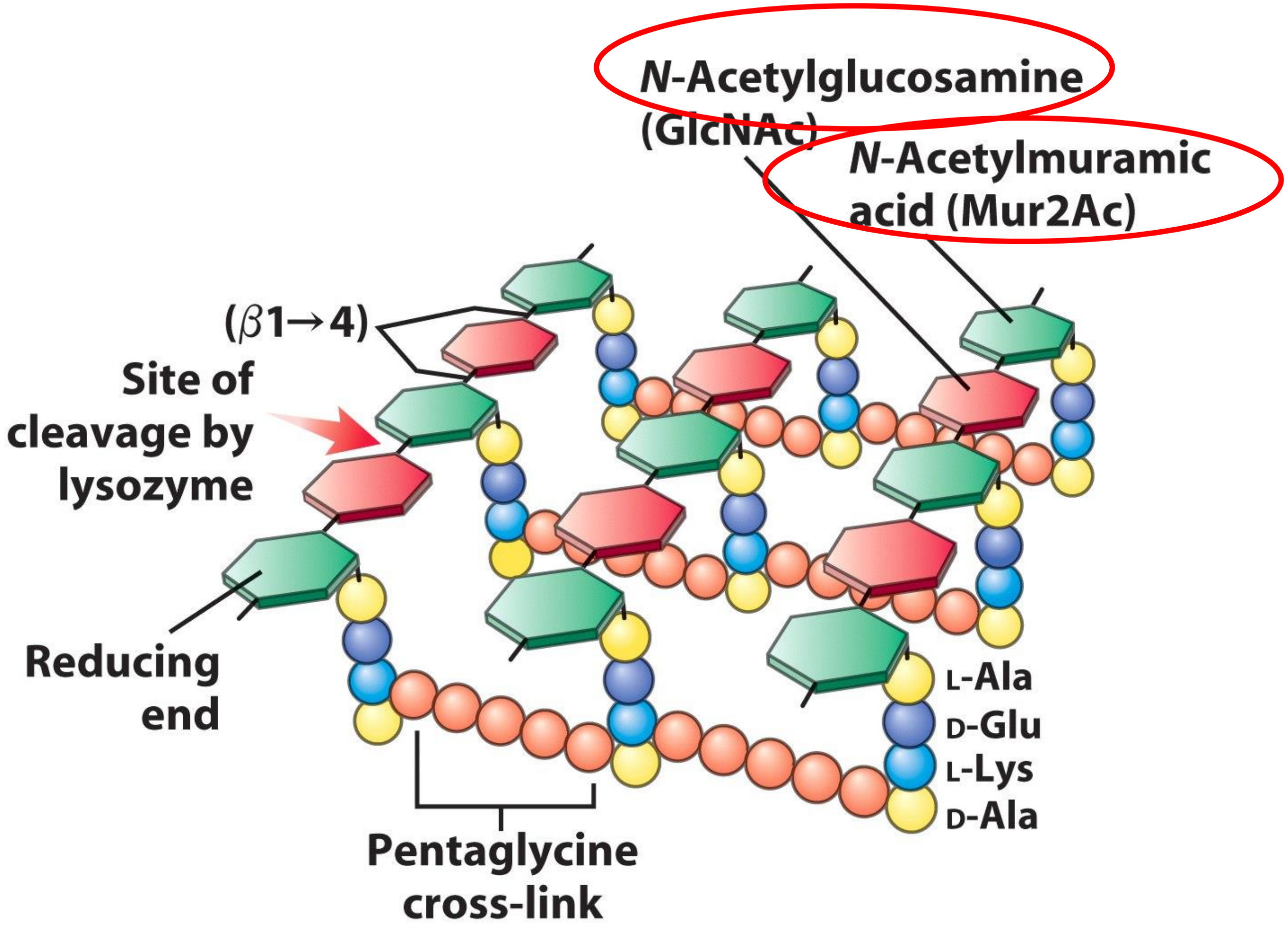
Chitin

1. Is the principle component of the hard <u>exoskeletons</u> of arthropods.
2. Is linear <u>homopolysaccharide</u> composed of <u>N-acetylglucoseamine</u> residues in β linkage.
3. Is <u>similar to cellulose</u>



Peptidoglycans (Bacterial cell wall)

- Heteropolymer of (β1→4)- linked
- N-acetylglucosamine and N-acetylmuramic acid residues.



Peptidoglycan of the bacterial cell walls (Gram-positive)

Peptidoglycans (Bacterial cell wall)

Lysozyme:

- ➢ kills bacteria by hydrolyzing the (β1→4) glycosidic bond.
- Present in tears as a defense against bacterial infections of the eye.
- Produced by certain bacterial viruses to ensure their release from the host bacterial cell, an essential step of the viral infection cycle.

Peptidoglycans (Bacterial cell wall)

Penicillin and related antibiotics kill bacteria by preventing the synthesis of cross-links.

As a result the cell wall is too weak to resist osmotic lysis.

Extracellular matrix & Glycosaminoglycans

- holds the cells together
- provides a porous pathway for the diffusion of nutrients and oxygen to cells.

Extracellular matrix & Glycosaminoglycans

- Composed of (a meshwork):

1. Glycosaminoglycans:

   heteropolysaccarides composed of repeating disaccharides

   one of them is always N-acetylglucosamine or

   N-acetylgalactoseamine.

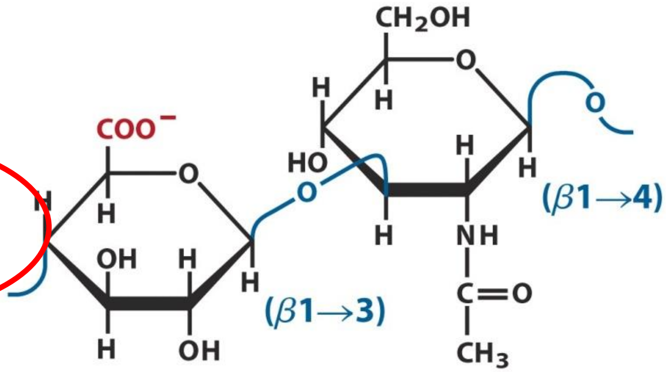
   e.g. hyaluronic acid

Glycosaminoglycan — **Repeating disaccharide**

Number of disaccharides per chain

Hyaluronate

~50,000



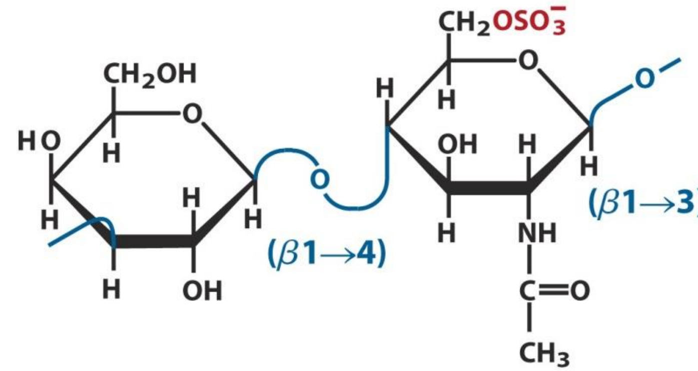
GlcA GlcNAc

Glycosaminoglycan — **Repeating disaccharide**

Number of disaccharides per chain

Keratan sulfate

~25



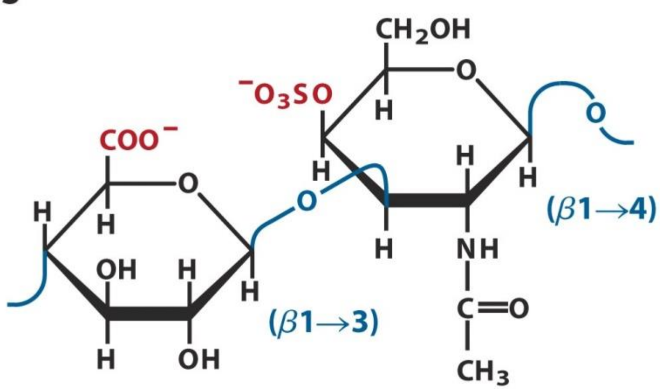
Gal GlcNAc6S

Glycosaminoglycan — **Repeating disaccharide**

Number of disaccharides per chain

Chondroitin 4-sulfate

20–60



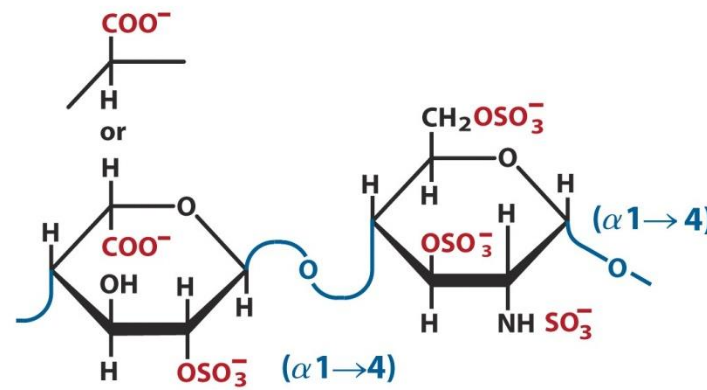
GlcA GalNAc4S

Glycosaminoglycan — **Repeating disaccharide**

Number of disaccharides per chain

Heparin

15–90



GlcA2S or IdoA2S GlcNS3S6S

Extracellular matrix & Glycosaminoglycans

- Composed of (a meshwork):

1. Glycosaminoglycans:

   heteropolysaccarides composed of repeating disaccharides

   one of them is always N-acetylglucosamine or

   N-acetylgalactoseamine.

   e.g. hyaluronic acid

2. Fibrous proteins:

   collagen, elastin, fibronectin & laminin.

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Roles of Polysaccharides

- Stored fuel
- Structural material
- <u>Information carrier</u>
- Mediators of interactions (cell-cell, cell-extracellular matrix)
- Cell-cell recognition / adhesion
- Cell migration
- Clotting
- Immune response
- Wound heeling

Roles of Polysaccharides

Glycoconjugates:

- informational carbohydrates joined to a protein or to a lipid.
- biologically active

Glycoconjugates

1. <u>Proteoglycans</u>

Macromolecules of the cell surface or extracellular matrix in which one or more glycosaminoglycan chains are joined covalently to a membrane protein or a secreted protein.

2. <u>Glycoproteins</u>

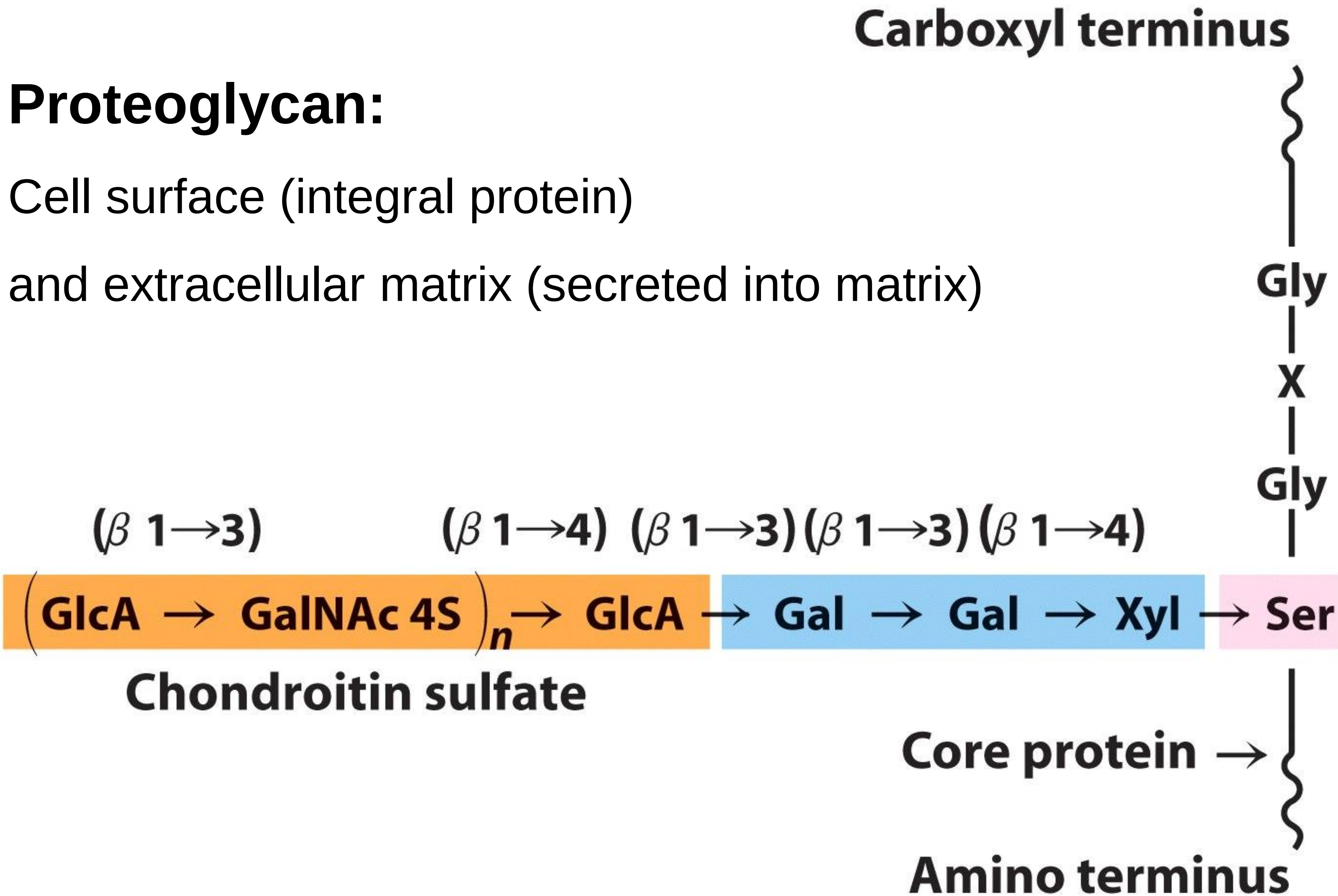
A protein containing carbohydrate group (covalent) that are found:

- Outer face of cell (extracellular matrix, blood)
- Inside the cell (organelles: Golgi complexes, secretory granules, lysosomes).

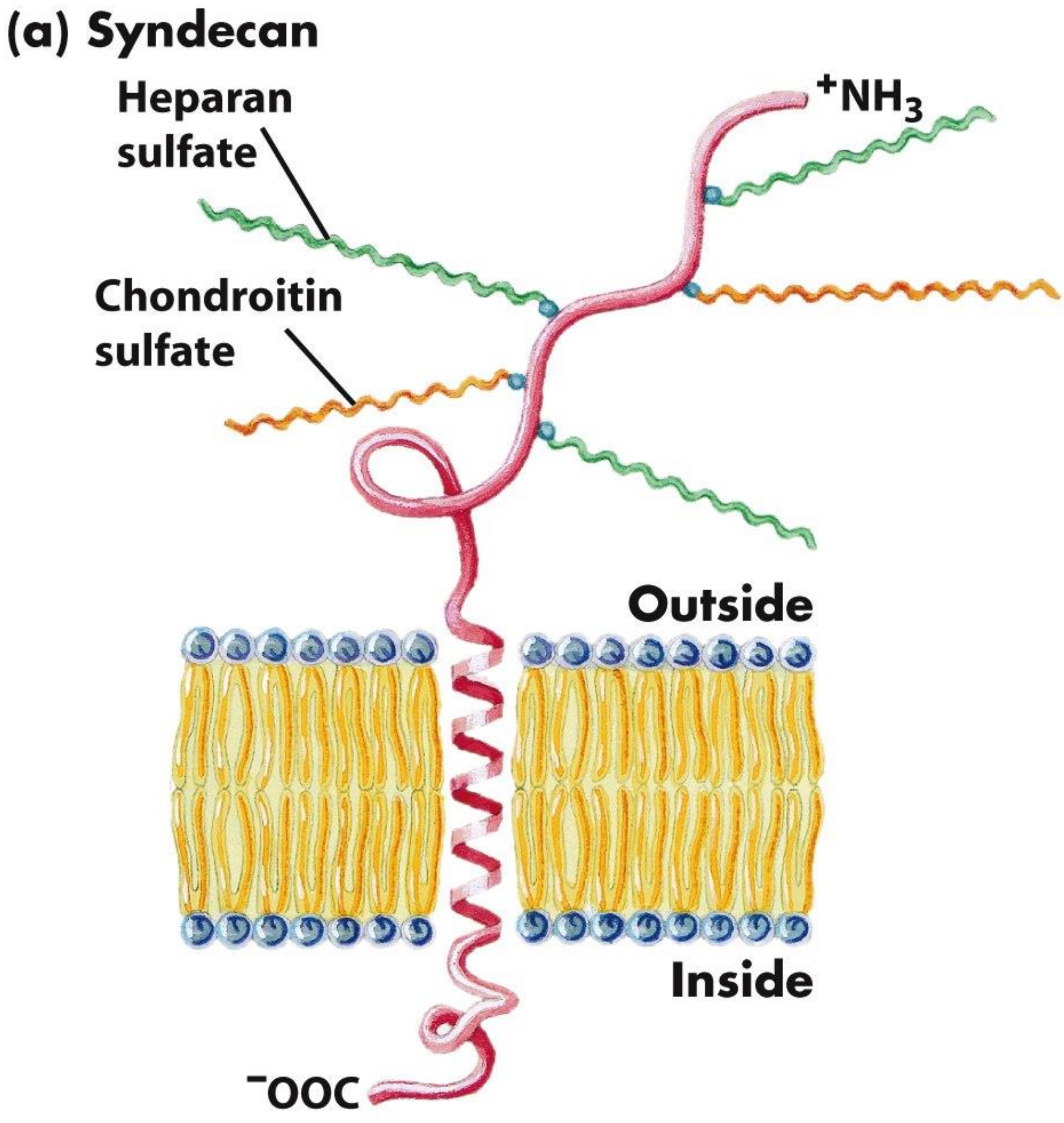
Proteoglycan:

Cell surface (integral protein)

and extracellular matrix (secreted into matrix)



Proteoglycan structure of an integral membrane proteins



Glycoconjugates

3. Glycolipids

A membrane lipids in which the hydrophilic head groups are polysaccharides

- Oligosaccharide portion of **glycoproteins** are:

  1. less monotonous than the glycosaminoglycan chains of proteoglycans

  2. rich in information

Proteoglycan: more polysaccharide than protein

Glycoprotein:

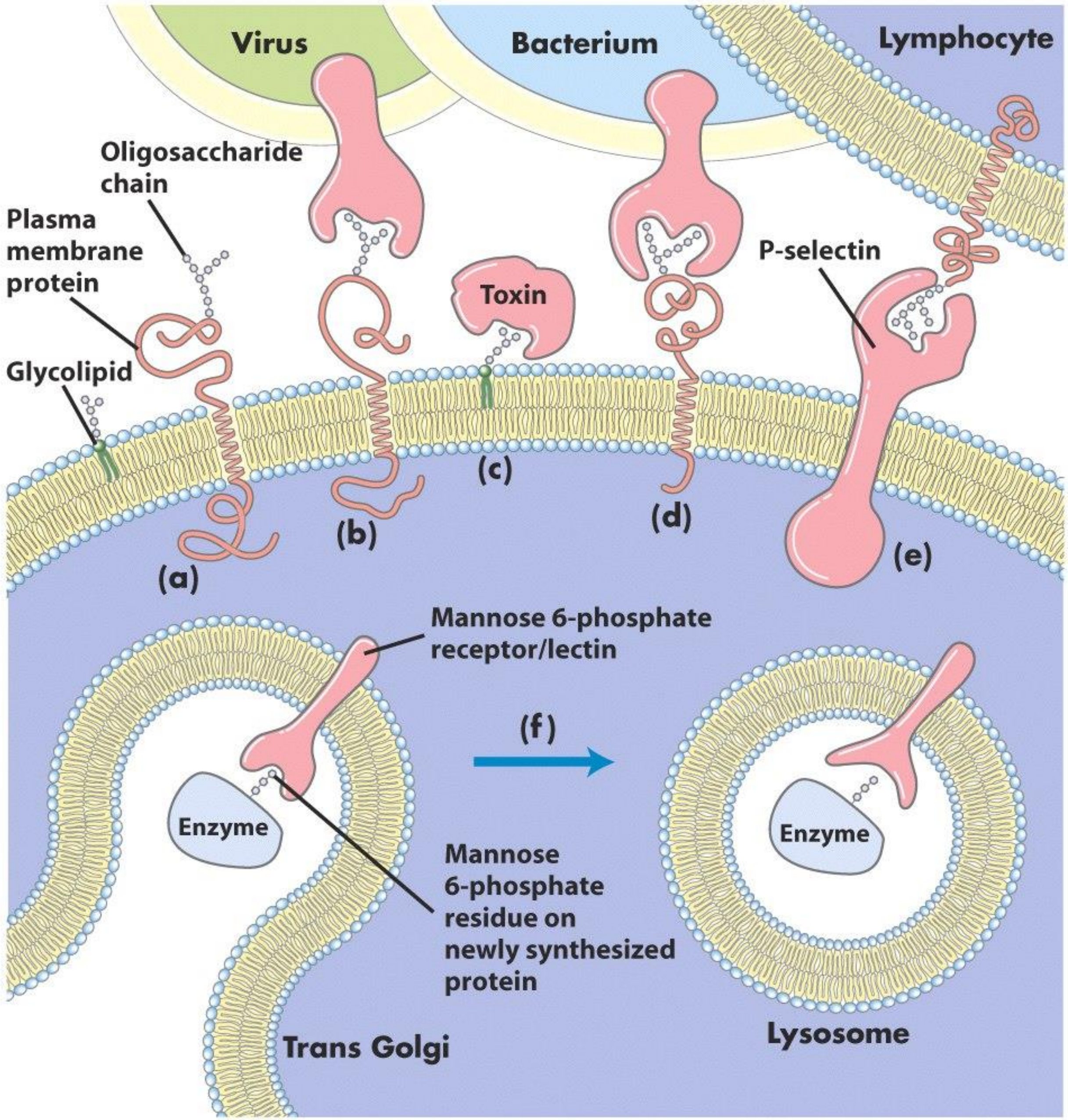
More protein than carbohydrates

Glycolipids:

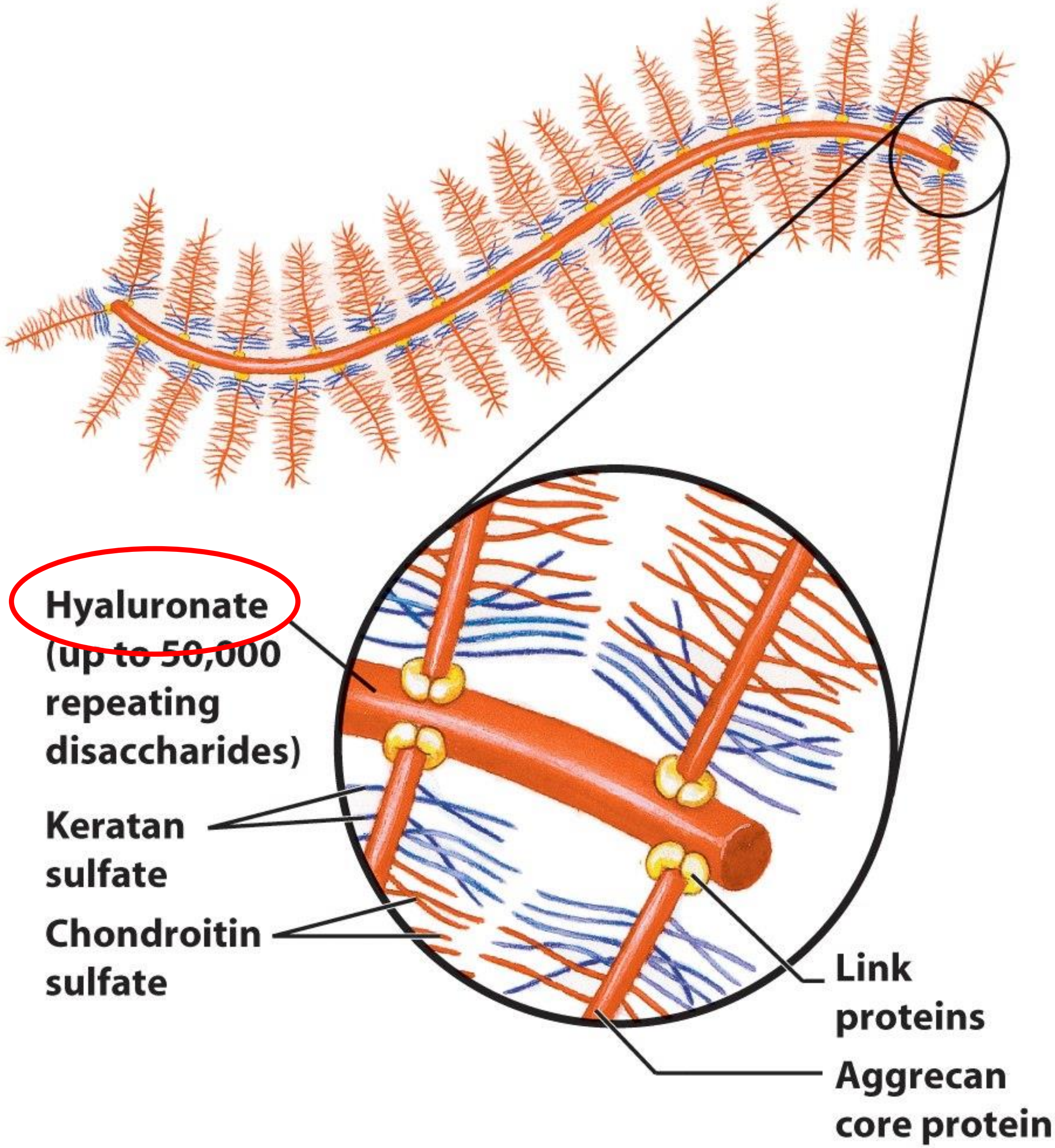
Lipids with (poly)saccharides

Lipopolysaccharides:

More polysaccharides than lipids



Proteoglycan aggregates



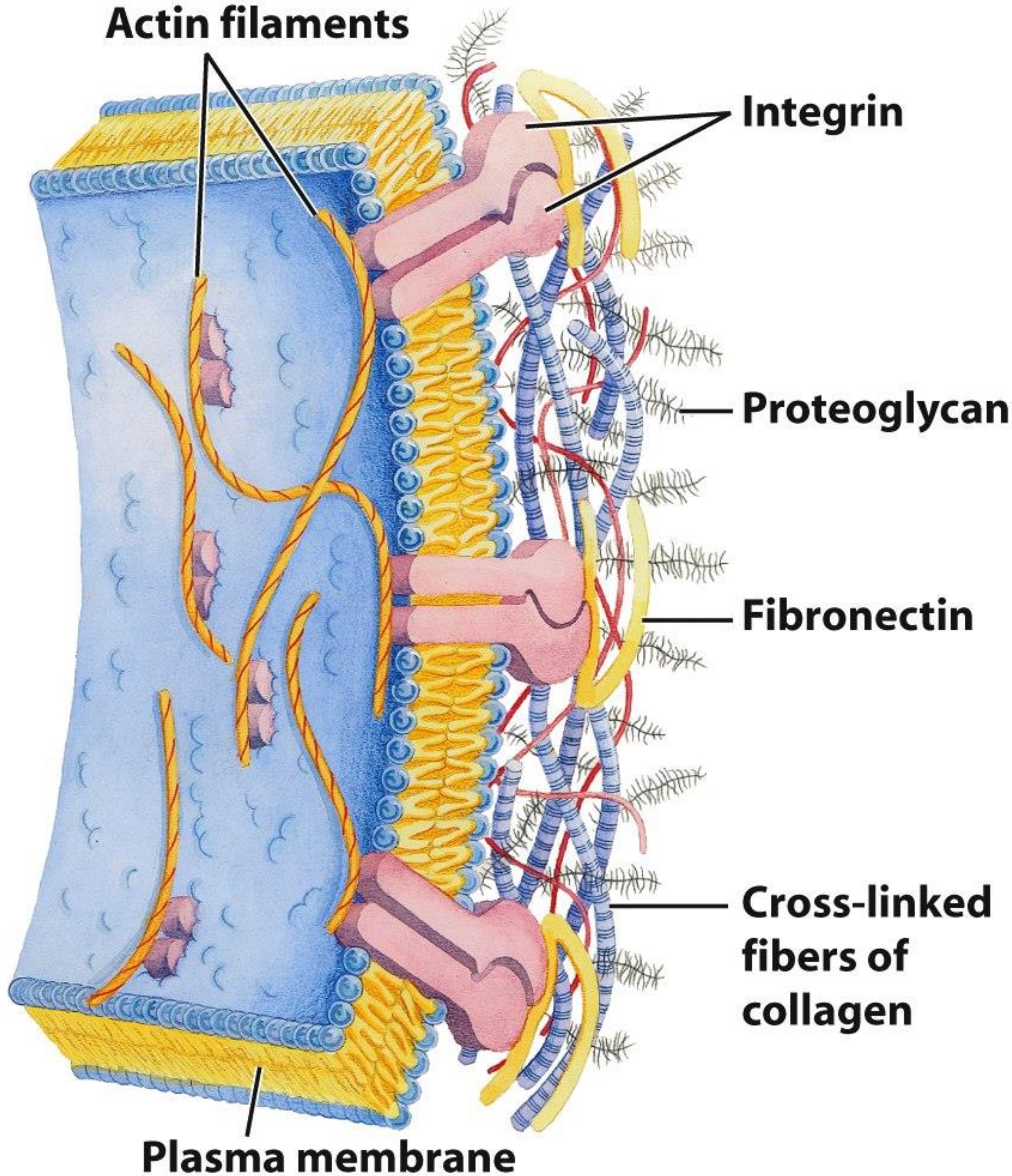
Proteoglycan aggregates

Extracellular proteoglycans:

1. **Fibrous matrix proteins (collagen, elastin, fibronectin) forming a cross-linked meshwork that gives the whole extracellular matrix strength and resilience.**

2. **Some of them are multiadhesive (a single protein having binding sites for several different matrix proteins).**

3. **Essential in the response of cells to certain extracellular growth factors.
e.g. fibroblast growth factor (FGF) stimulates cell division.**


Actin filaments
Integrin
Proteoglycan
Fibronectin
Cross-linked fibers of collagen
Plasma membrane

Many of the proteins secreted by eukaryotic cells are glycoproteins:

•Antibodies

•Hormones (FSH, LH, TSH,…)

WHY???

■ **The biological advantage of adding oligosaccharides to proteins are not fully understood. …**

Oligosaccharide-Lectin interactions mediate many biological processes

Lectins :

- Are proteins that bind carbohydrates with high affinity & specificity.

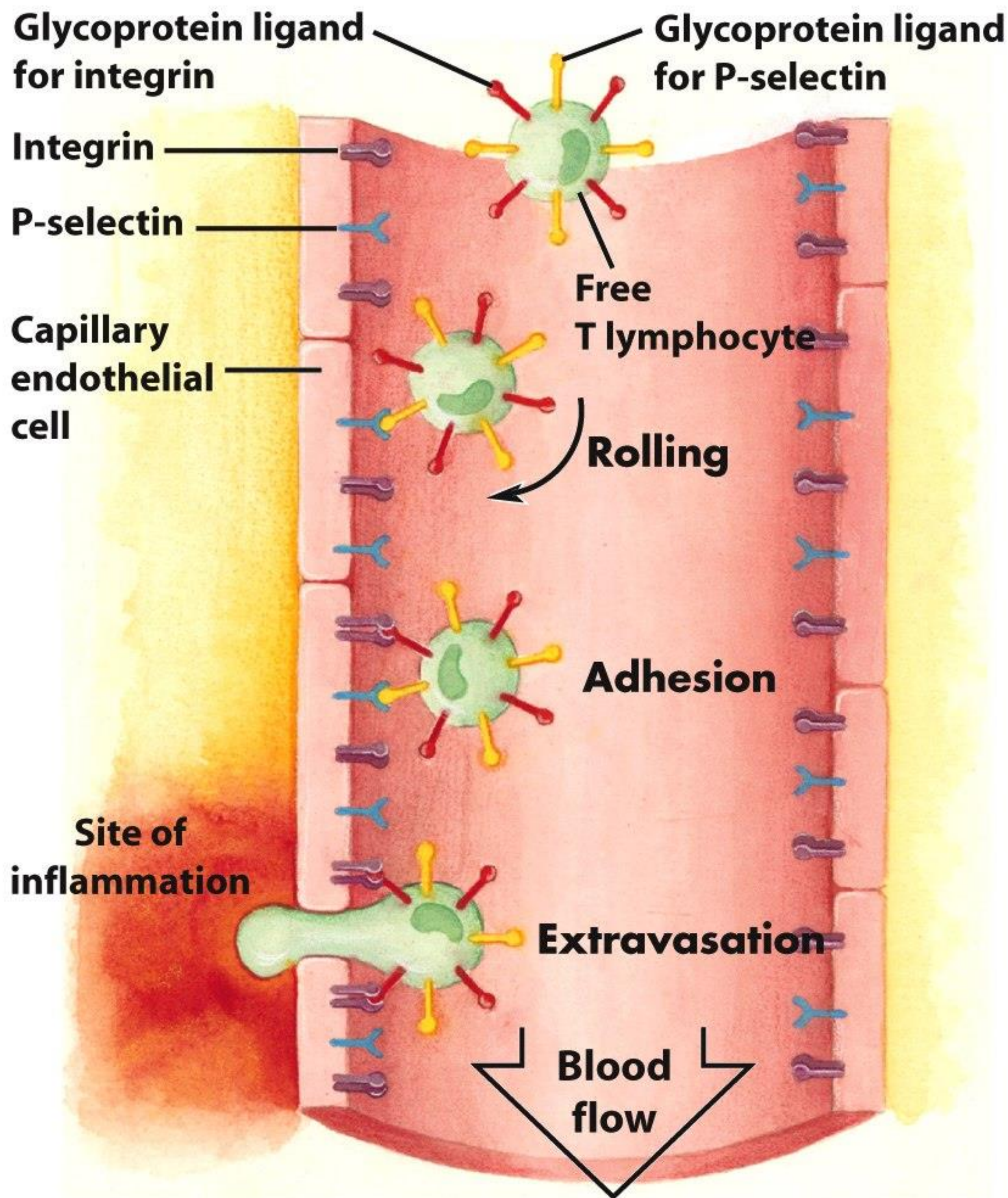
- Serve in a wide variety of cell-cell recognition & adhesion processes:

➢ The sialic acid

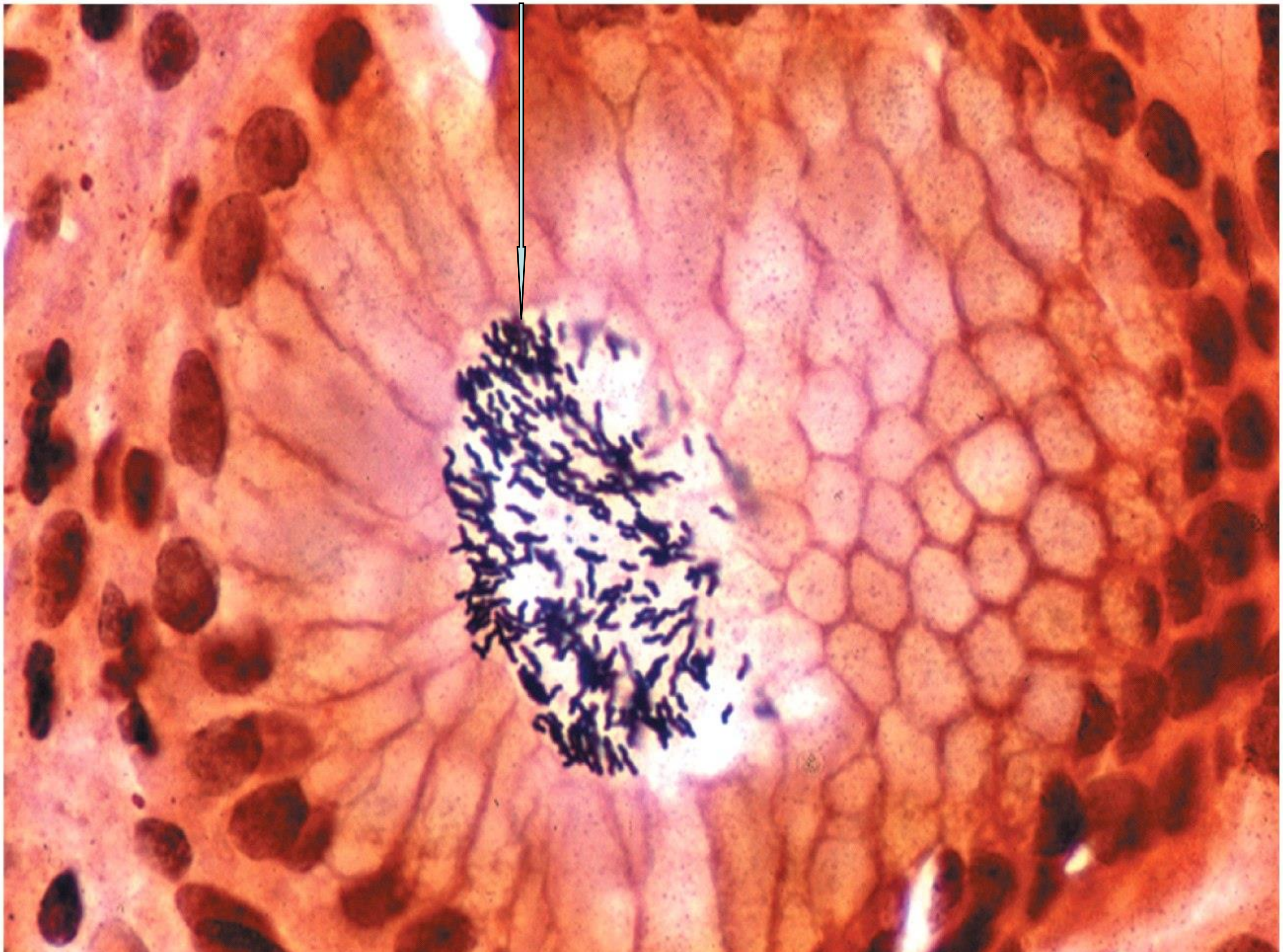
Selectins: Family of lectins (found in plasma memb.) that mediate cell-cell recognition & adhesion in a wide range of cellular processes.

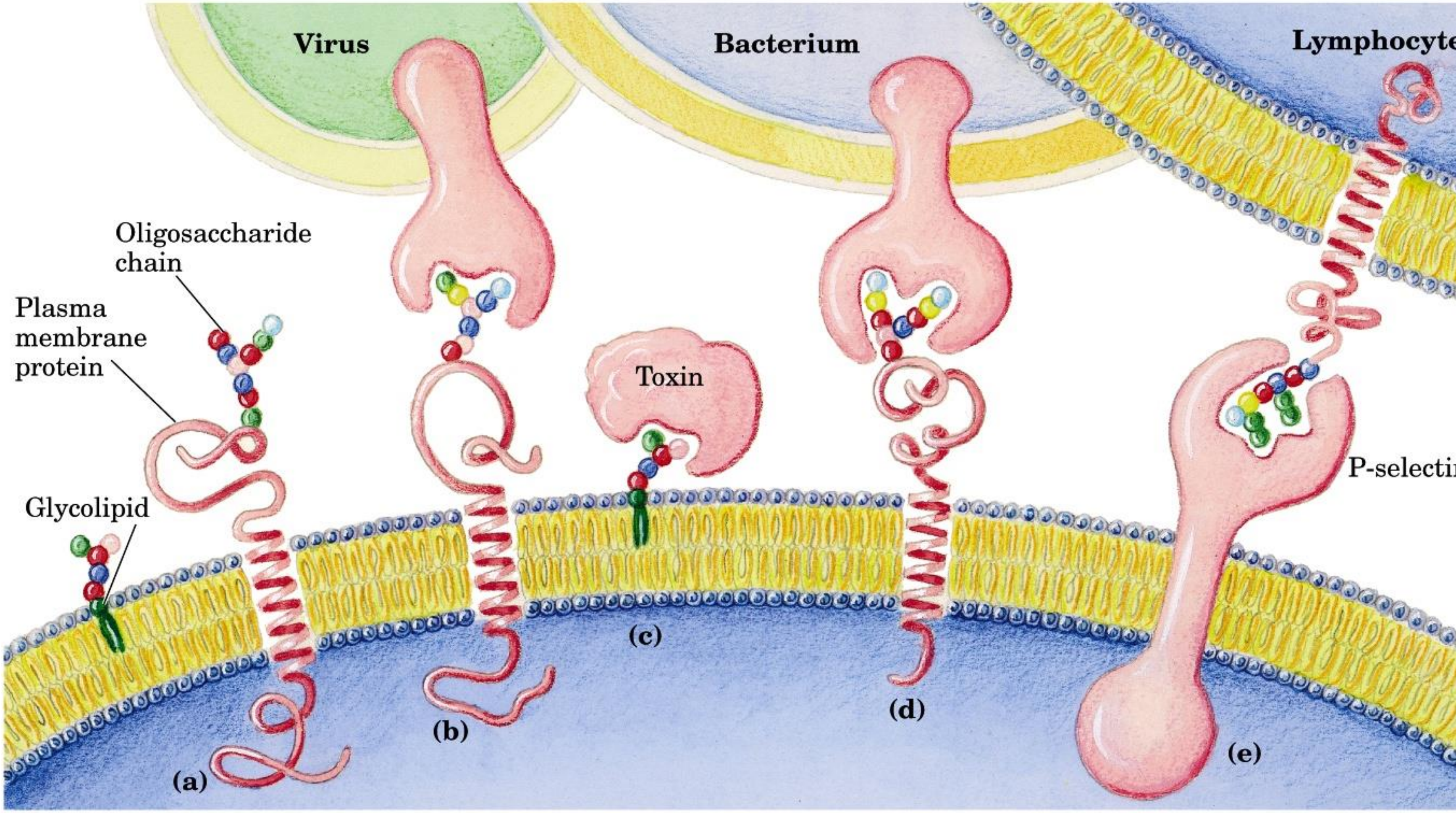
- The movement of **T lymphocytes**
- microbial **pathogens**

Lectin-Ligand interactions in T-lymphocyte movement to the site of an infection.



Gastric ulcers caused by *Helicobacter pylori* adhesion via the bacterial membrane lectins and gastric endothelial specific membrane oligosaccharides interaction




Virus
Bacterium
Lymphocyte
Oligosaccharide chain
Plasma membrane protein
Toxin
Glycolipid
P-selectin
(a)
(b)
(c)
(d)
(e)