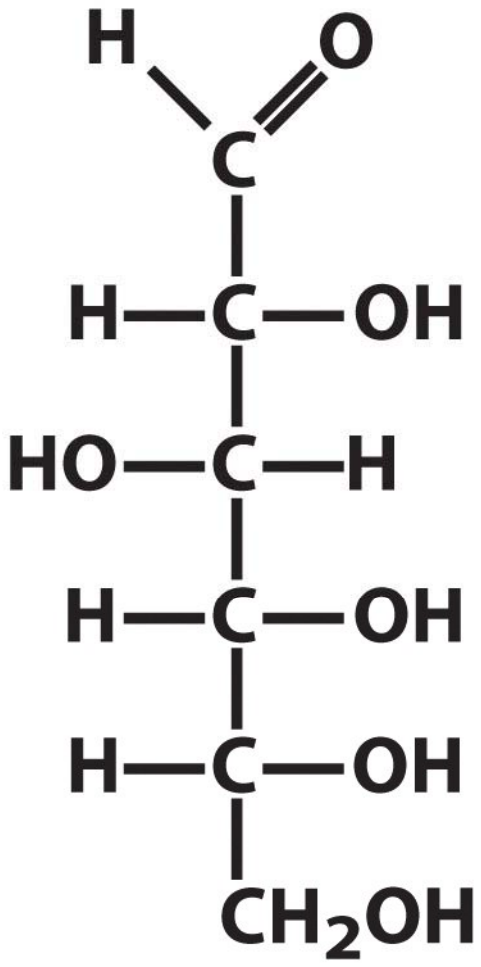
David L. Nelson and Michael M. Cox

Lehninger Principles of Biochemistry

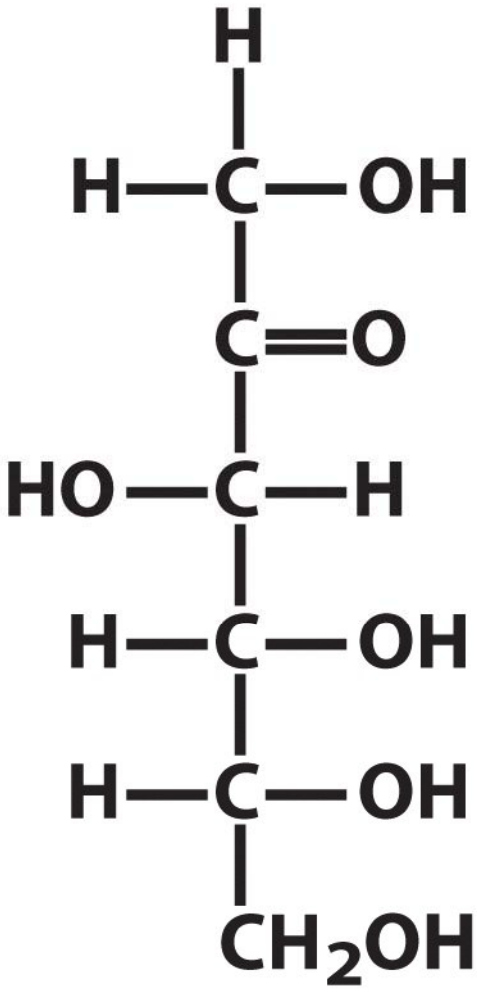
Fourth Edition

Chapter 7:

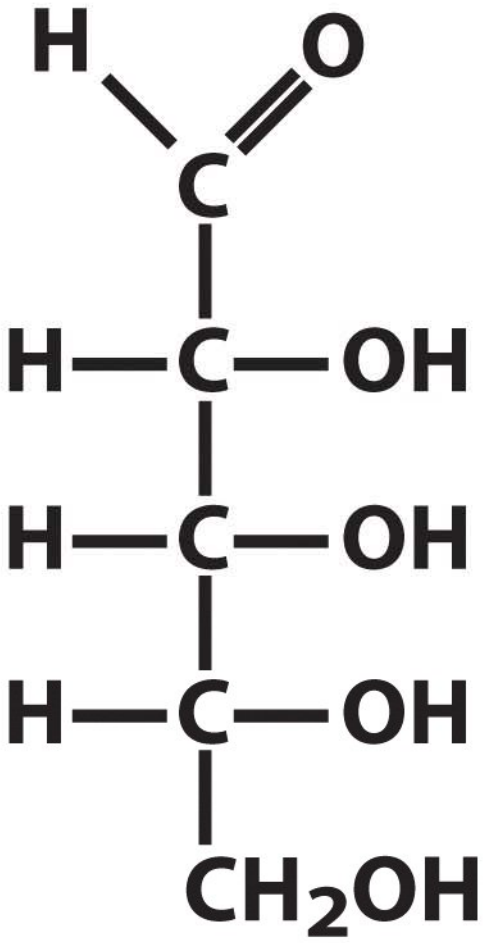
Carbohydrates and Glycobiology



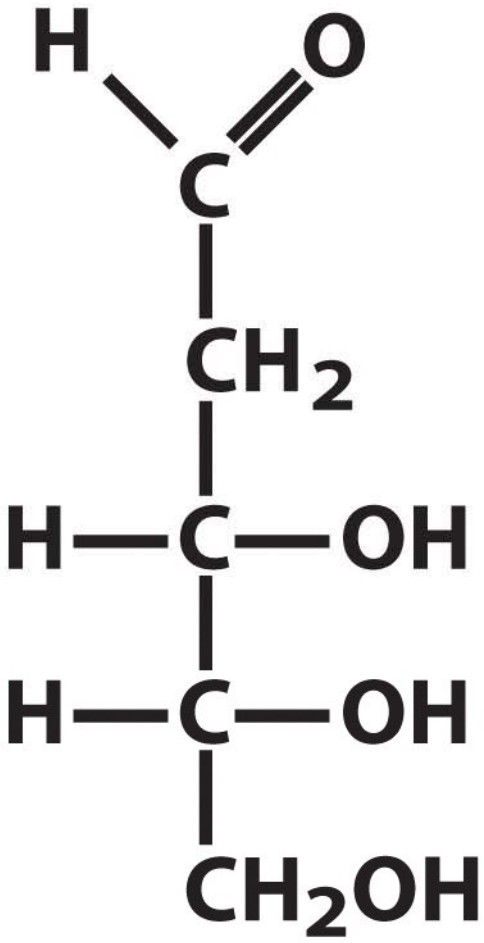
D-Glucose,
an aldohexose



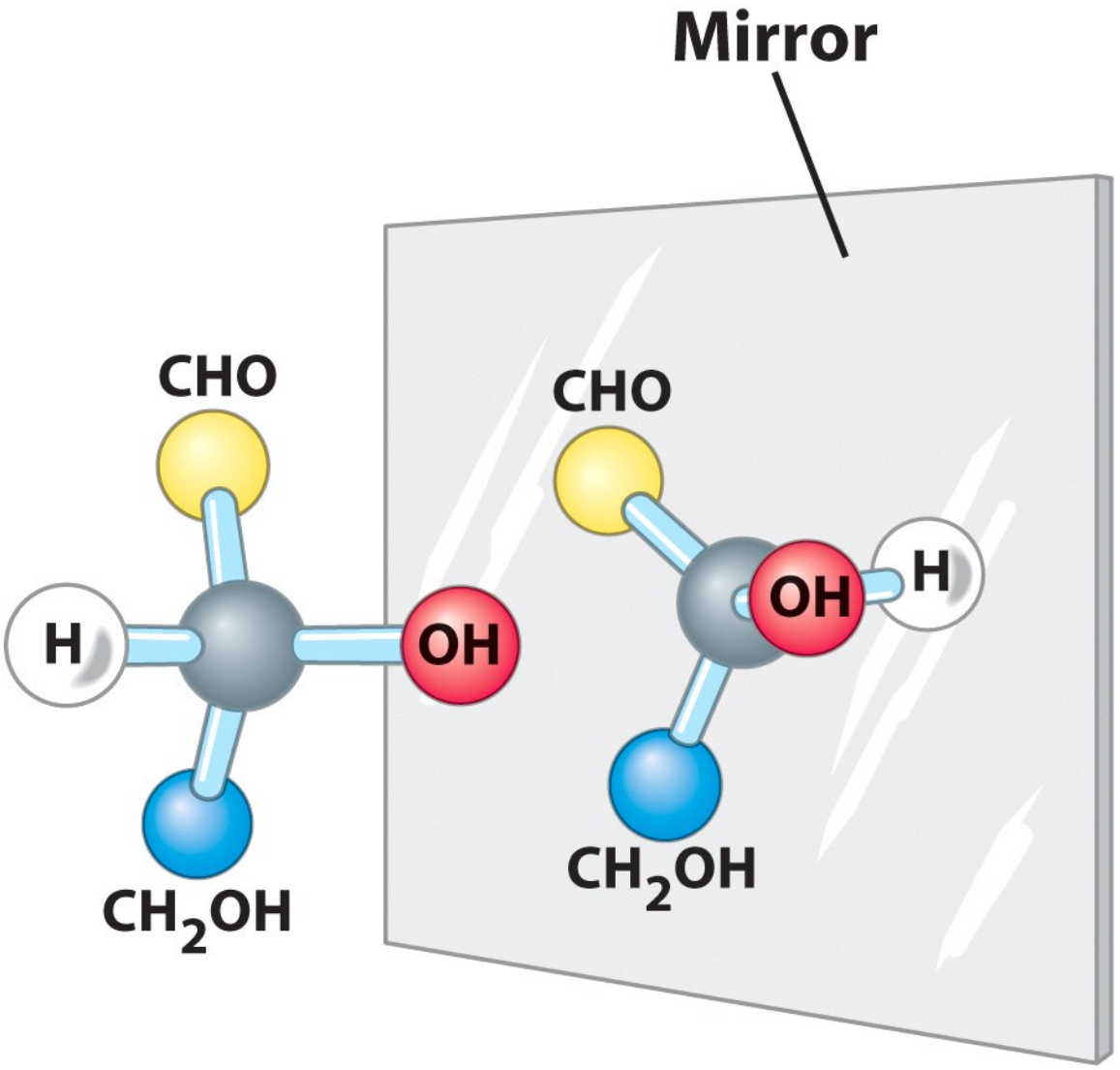
D-Fructose,
a ketohexose



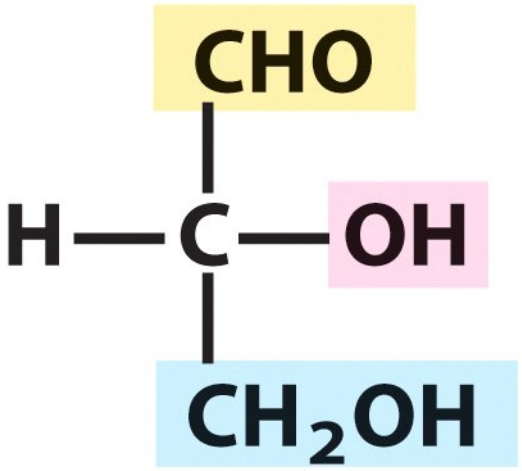
D-Ribose,
an aldopentose



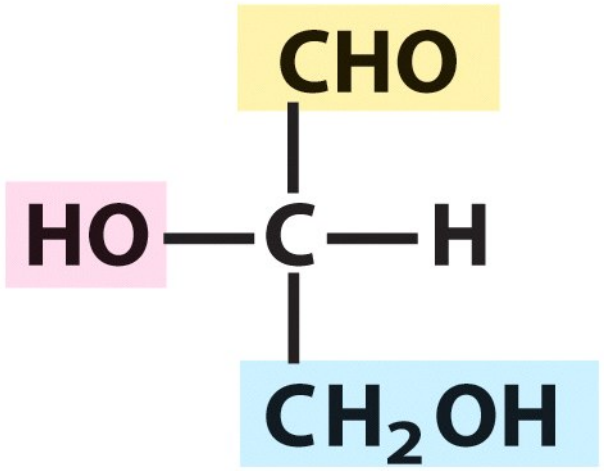
2-Deoxy-D-ribose,
an aldopentose



Ball-and-stick models

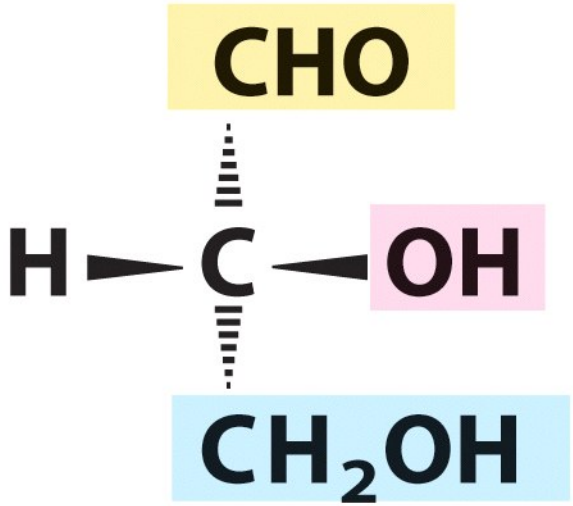


D-Glyceraldehyde

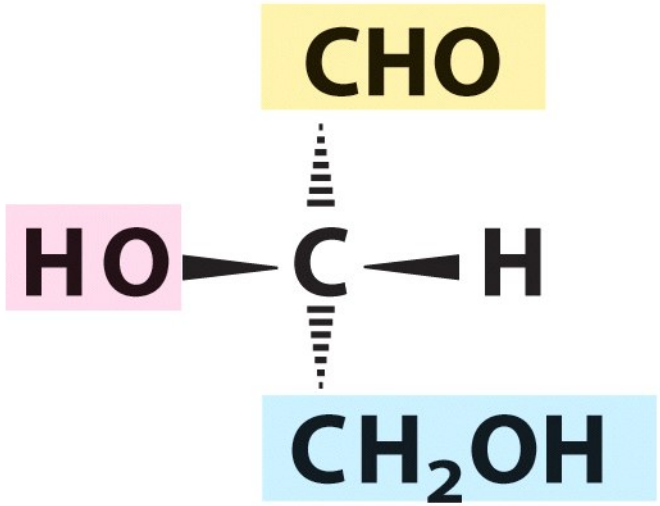


L-Glyceraldehyde

Fischer projection formulas



D-Glyceraldehyde

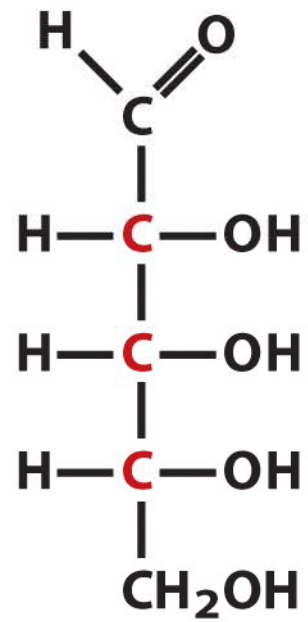


L-Glyceraldehyde

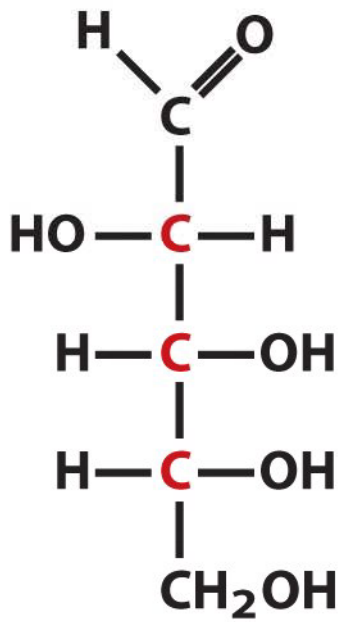
Perspective formulas

D-Aldoses

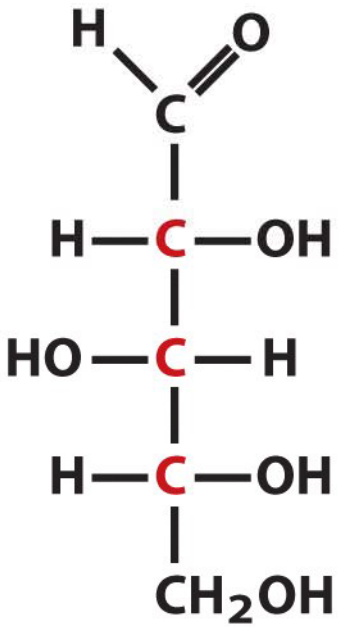
Five carbons



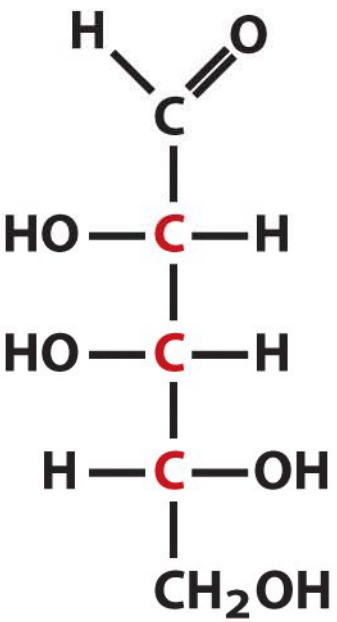
D-Ribose



D-Arabinose



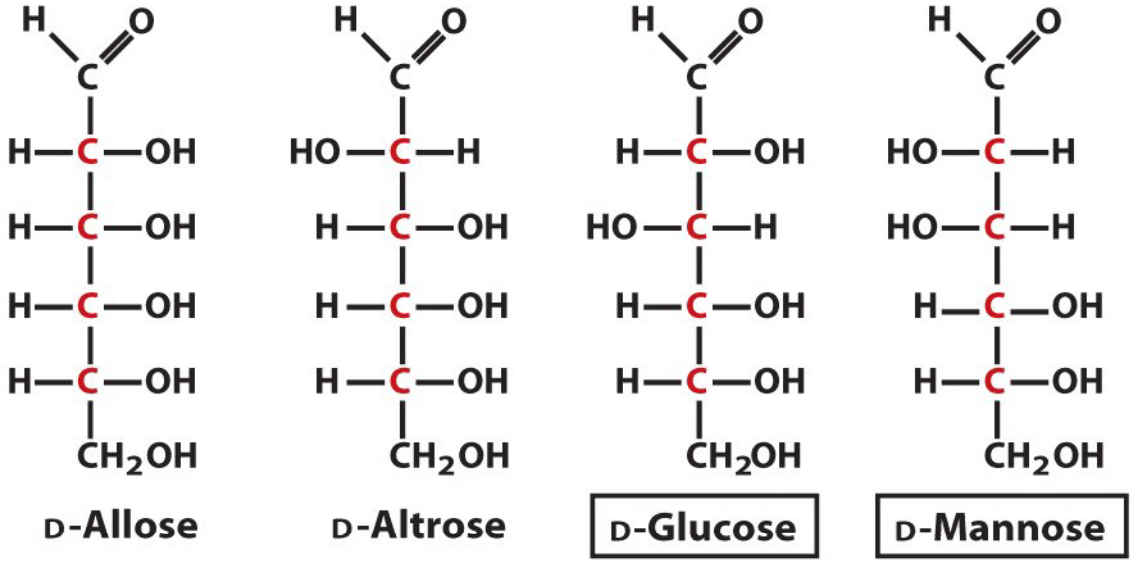
D-Xylose



D-Lyxose

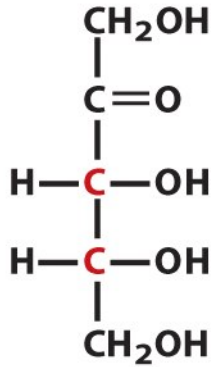
D-Aldoses

Six carbons

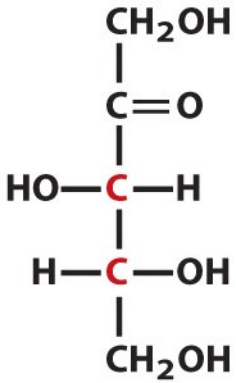


D-Ketoses

Five carbons

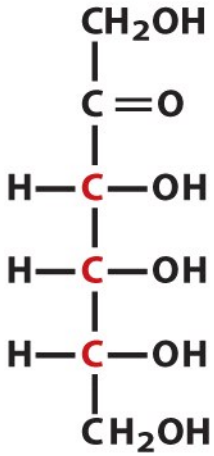


D-Ribulose

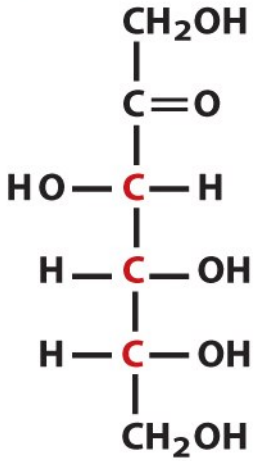


D-Xylulose

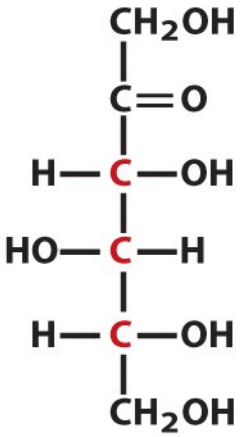
Six carbons



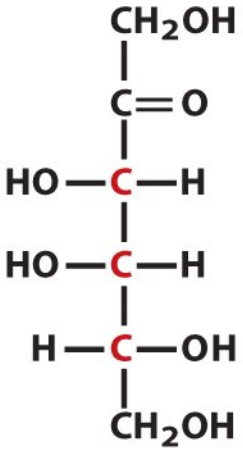
D-Psicose



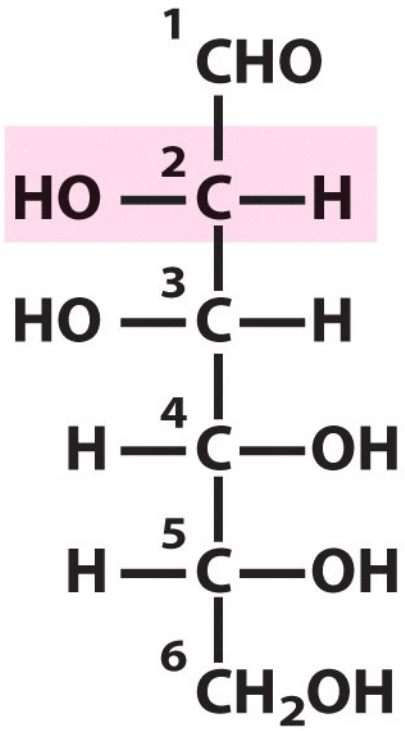
D-Fructose



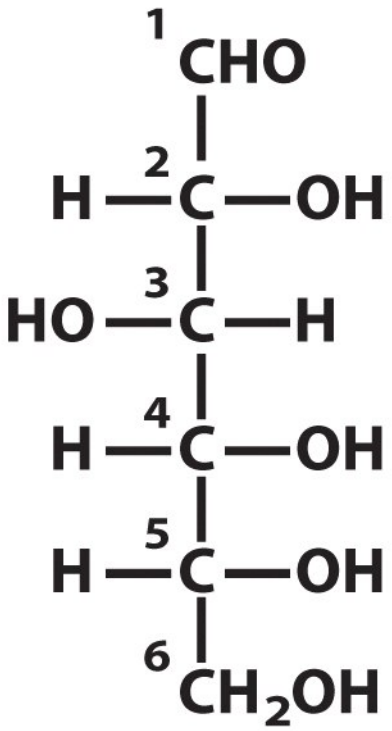
D-Sorbose



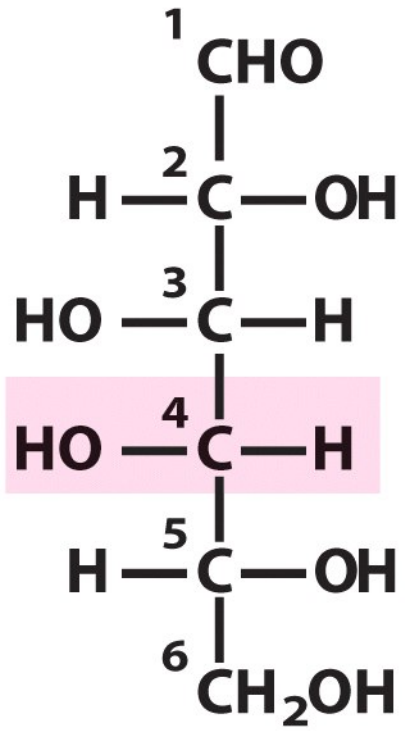
D-Tagatose



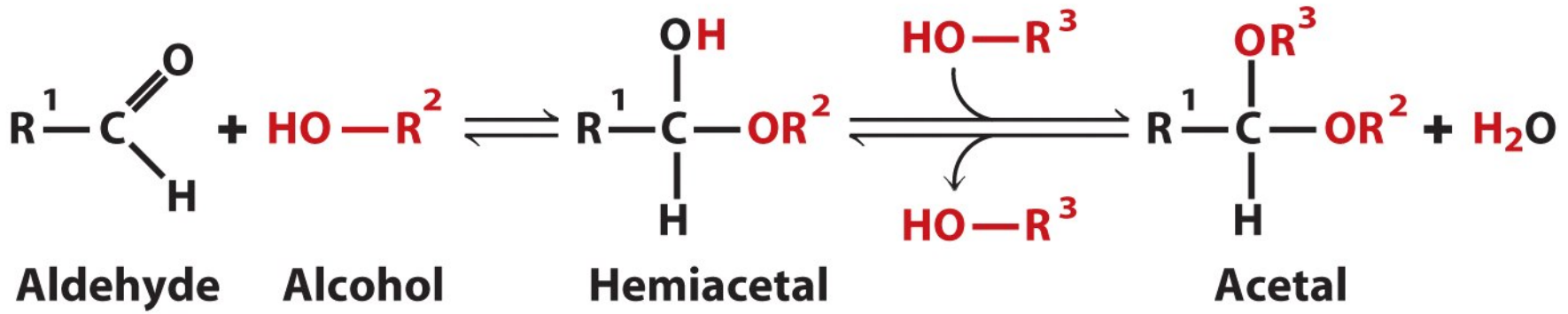
D-Mannose
(epimer at C-2)

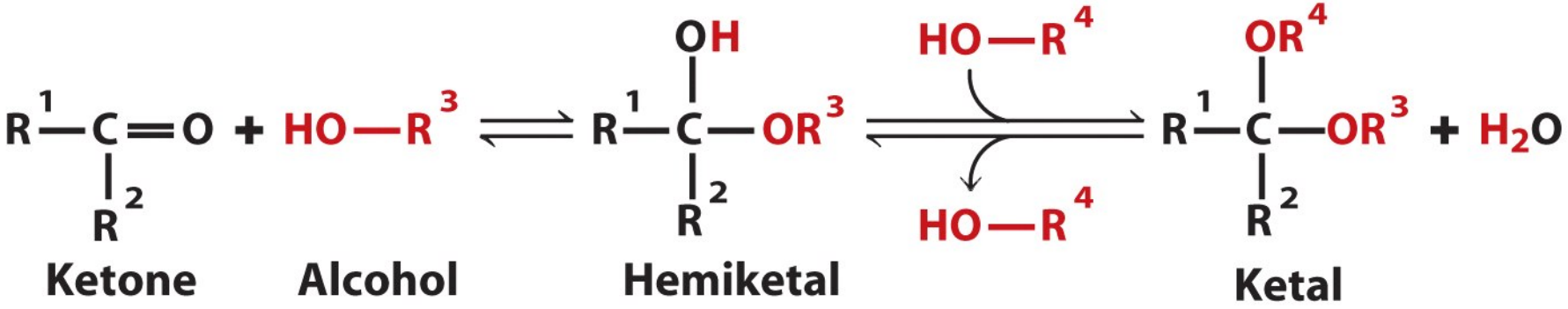


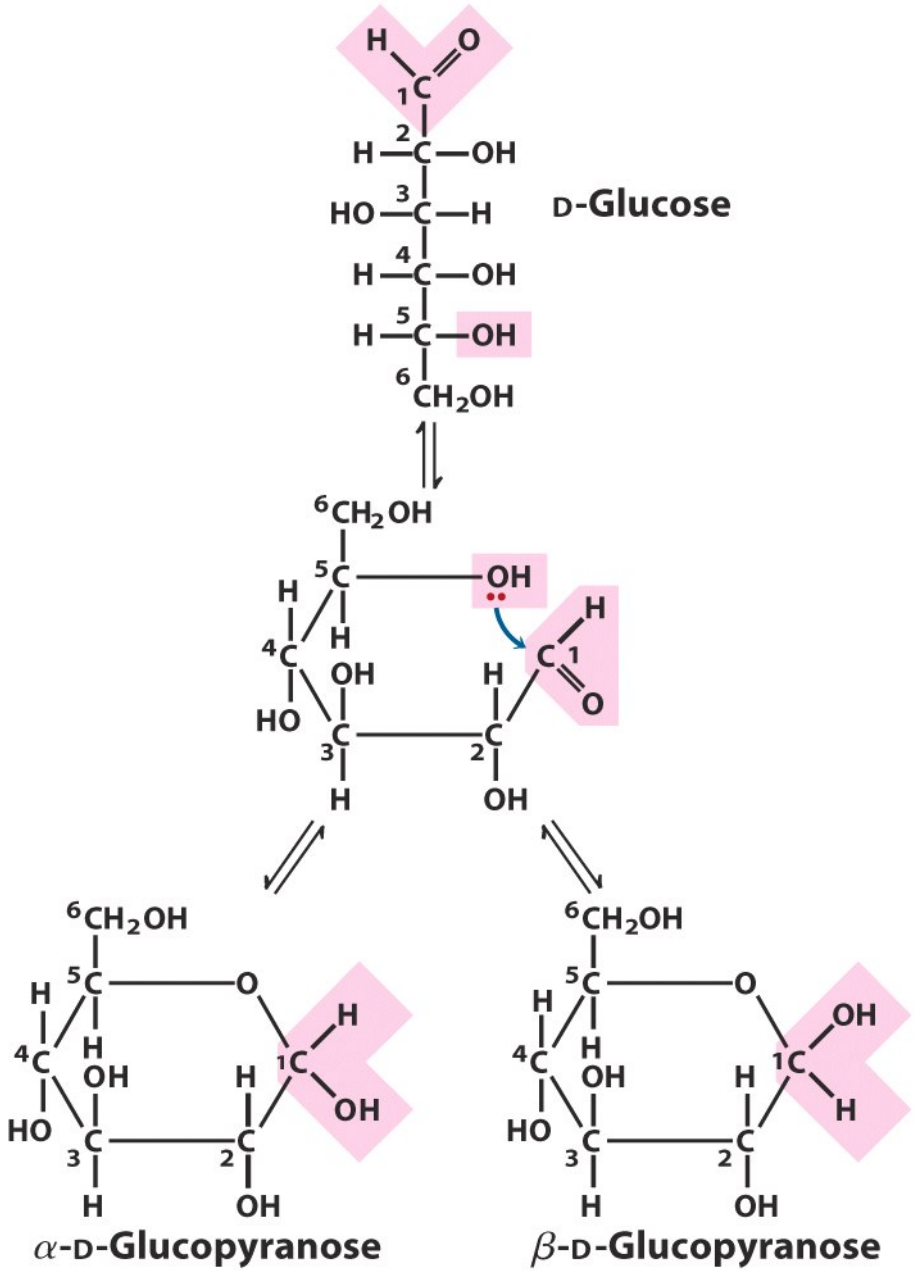
D-Glucose

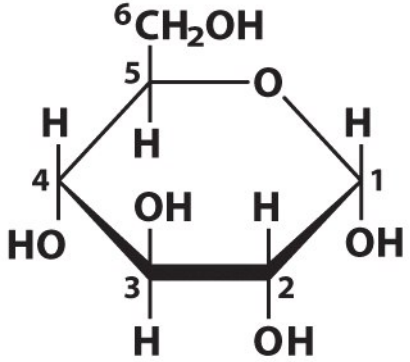


D-Galactose
(epimer at C-4)

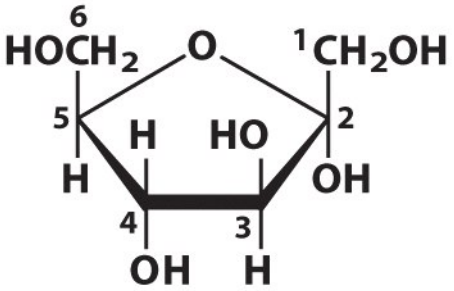

Aldehyde
Alcohol
Hemiacetal
Acetal


Ketone
Alcohol
Hemiketal
Ketal

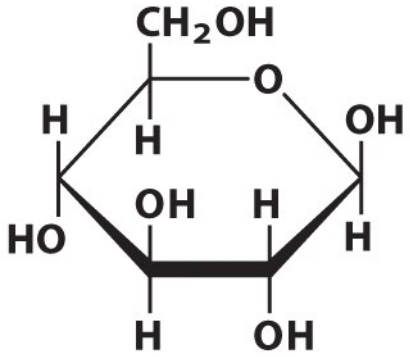

D-Glucose
α-D-Glucopyranose
β-D-Glucopyranose



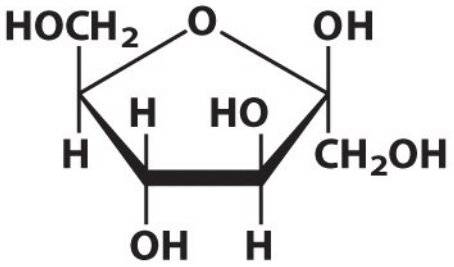
α-D-Glucopyranose



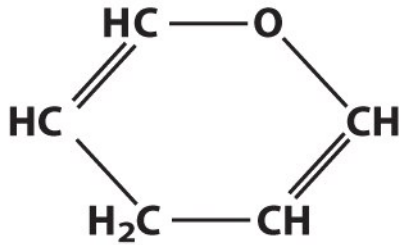
α-D-Fructofuranose



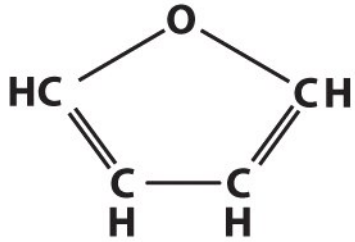
β-D-Glucopyranose



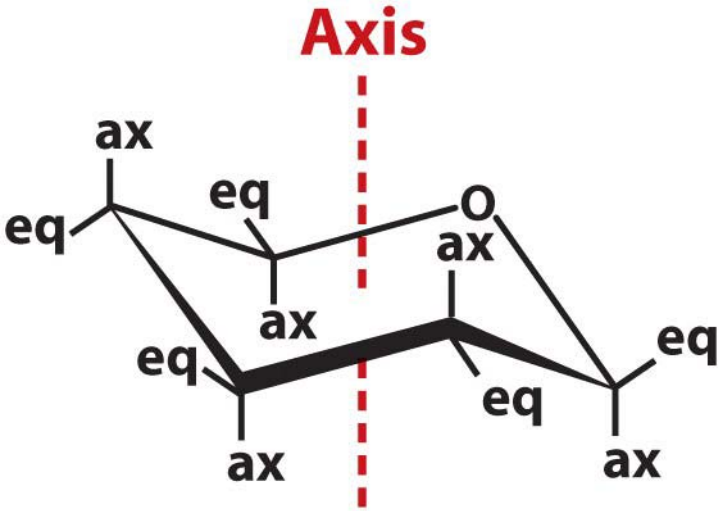
β-D-Fructofuranose

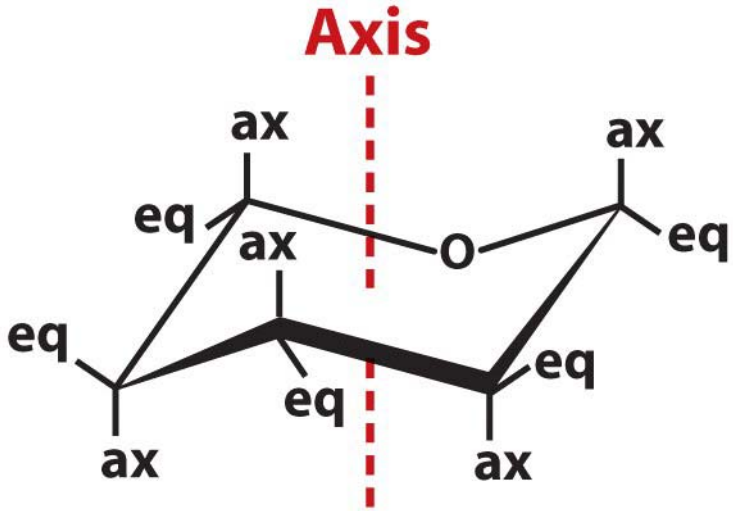


Pyran

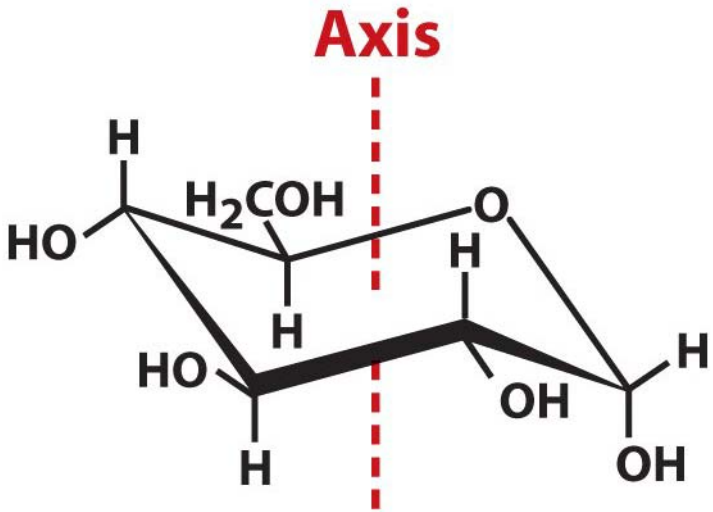


Furan

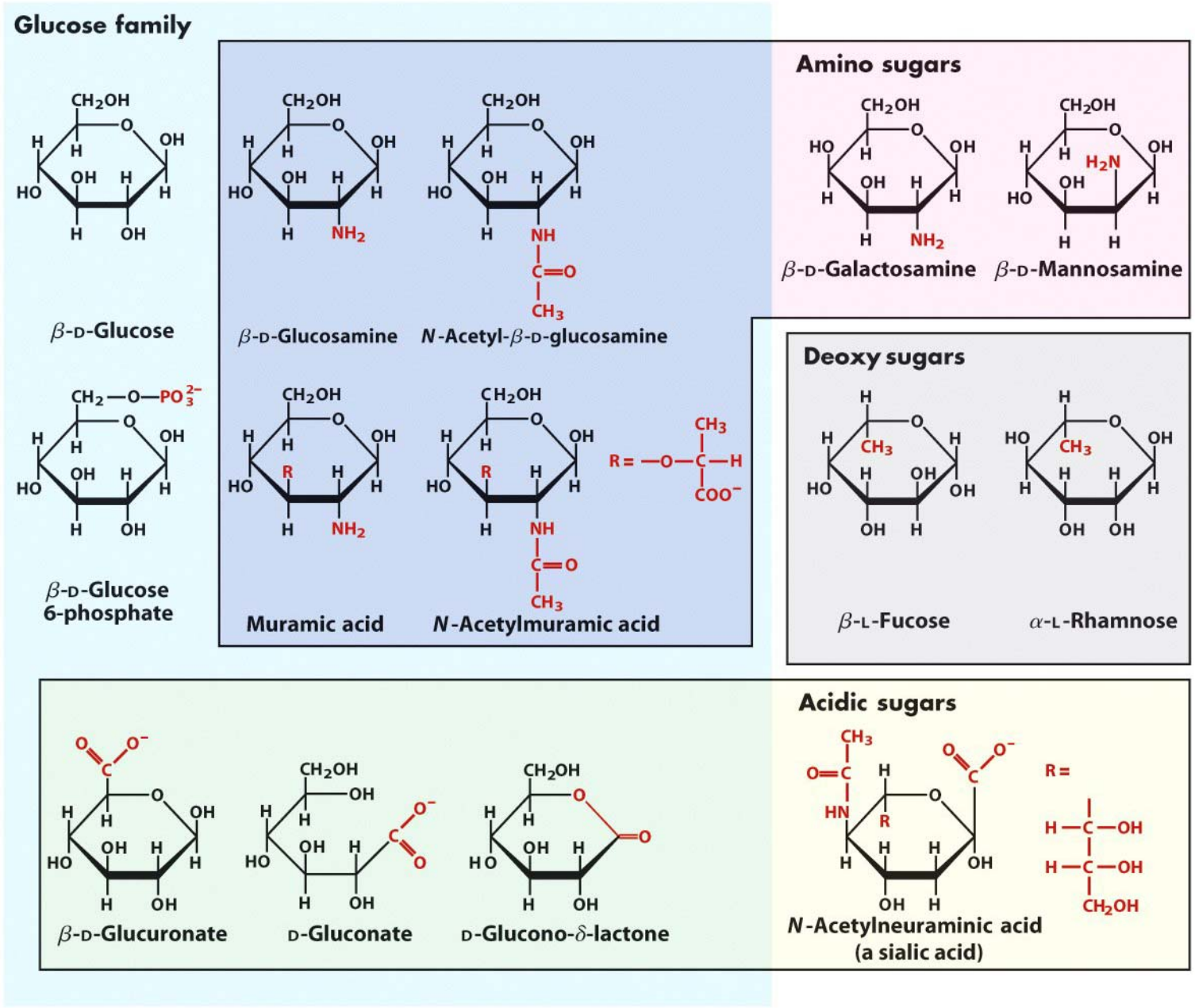




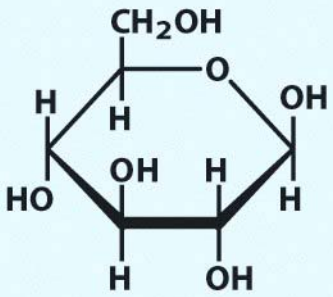
Two possible chair forms



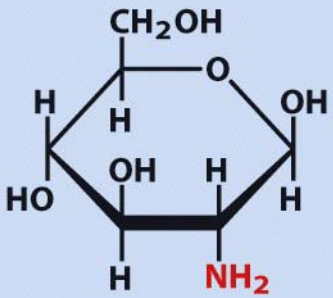
α -D-Glucopyranose


Glucose family
β-D-Glucose
β-D-Glucosamine
N-Acetyl-β-D-glucosamine
β-D-Glucose 6-phosphate
Muramic acid
N-Acetylmuramic acid
Amino sugars
β-D-Galactosamine
β-D-Mannosamine
Deoxy sugars
β-L-Fucose
α-L-Rhamnose
Acidic sugars
β-D-Glucuronate
D-Gluconate
D-Glucono-δ-lactone
N-Acetylneuraminic acid
(a sialic acid)

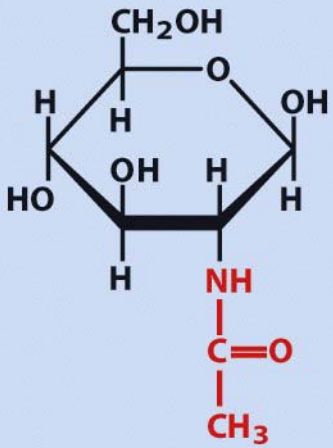
Glucose family



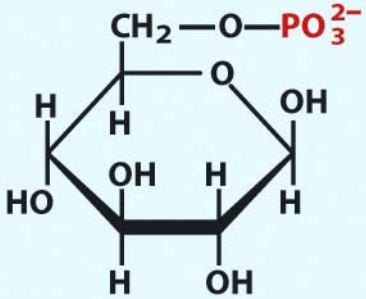
β-D-Glucose



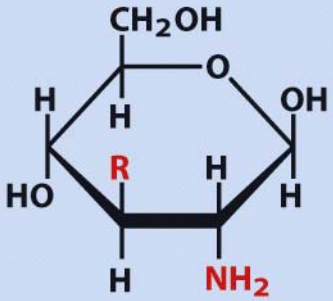
β-D-Glucosamine



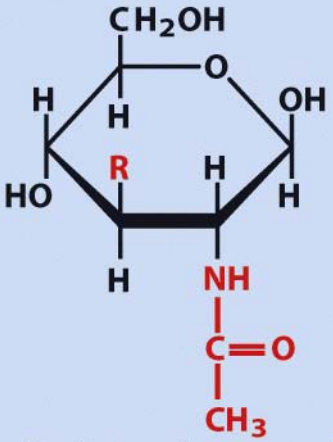
N-Acetyl-β-D-glucosamine

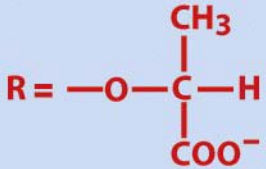


β-D-Glucose 6-phosphate



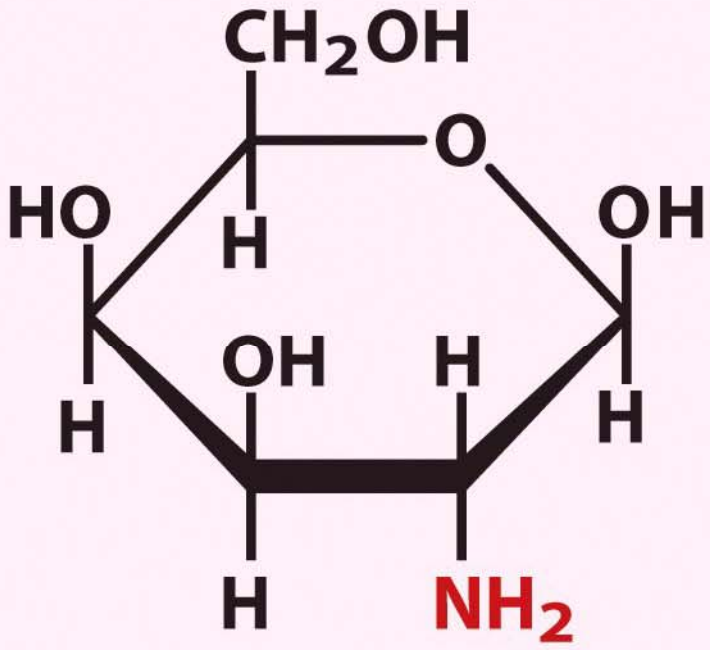
Muramic acid



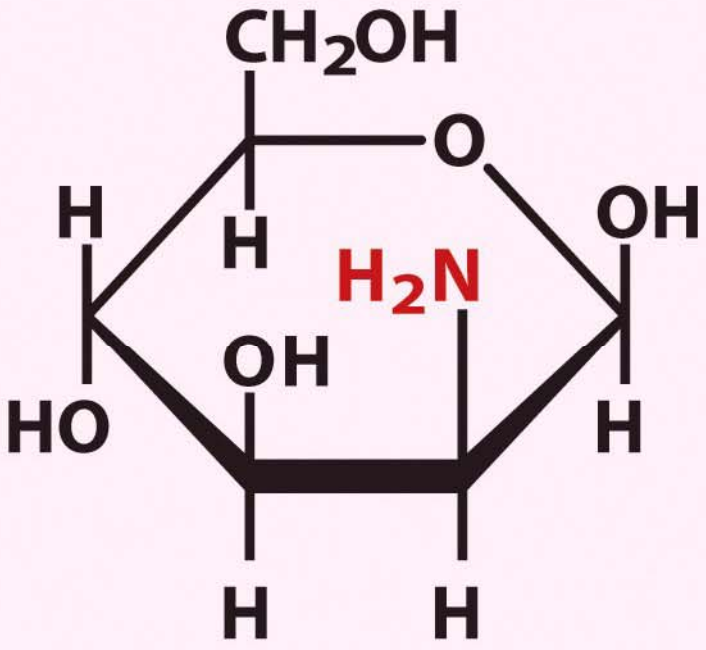


N-Acetylmuramic acid

Amino sugars

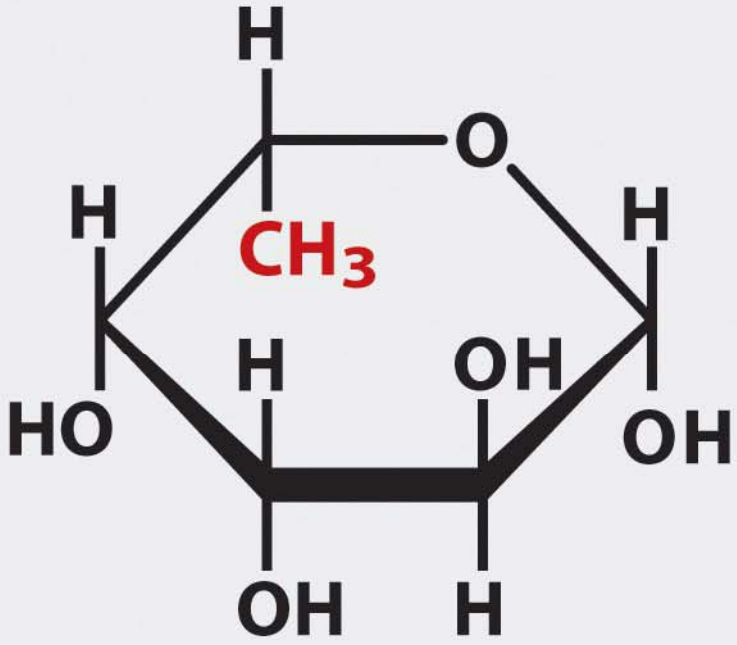


β-D-Galactosamine

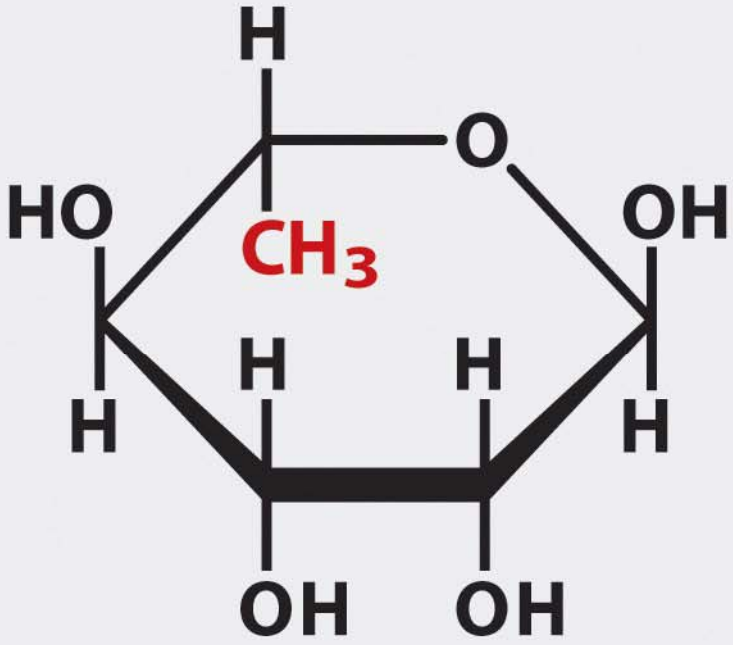


β-D-Mannosamine

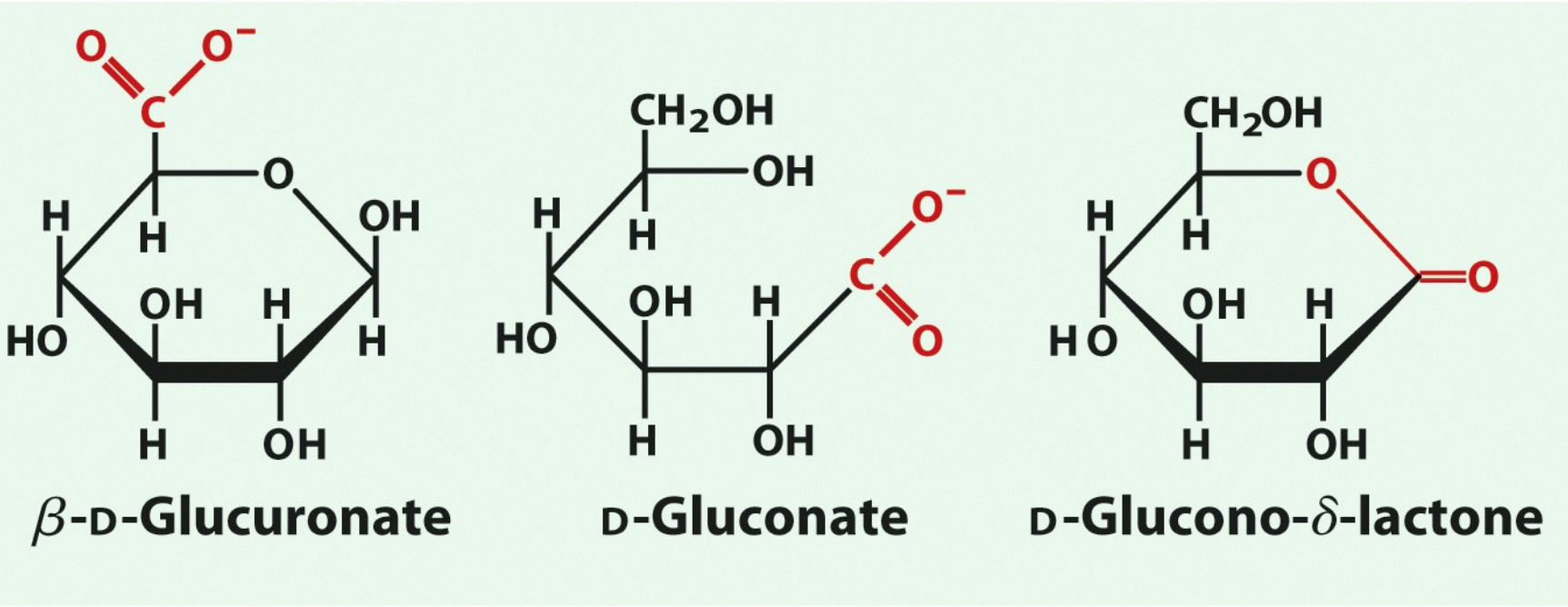
Deoxy sugars



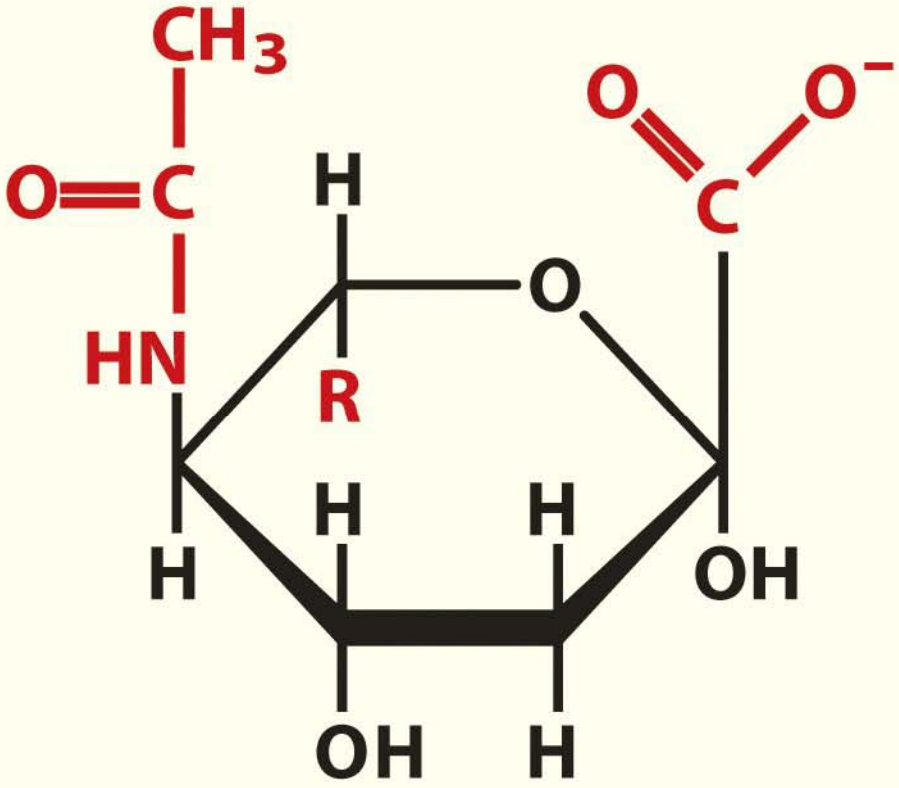
β-L-Fucose

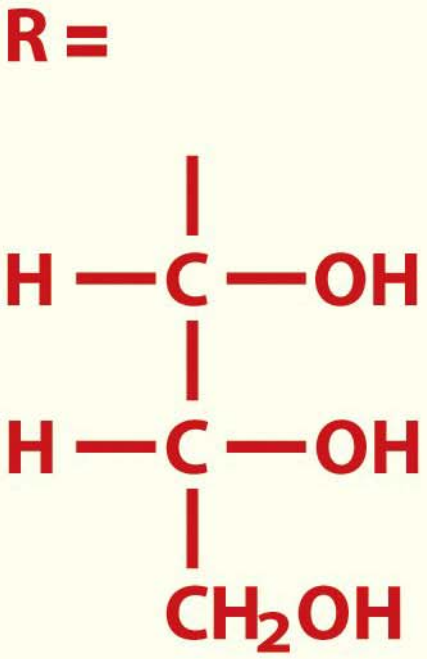


α-L-Rhamnose

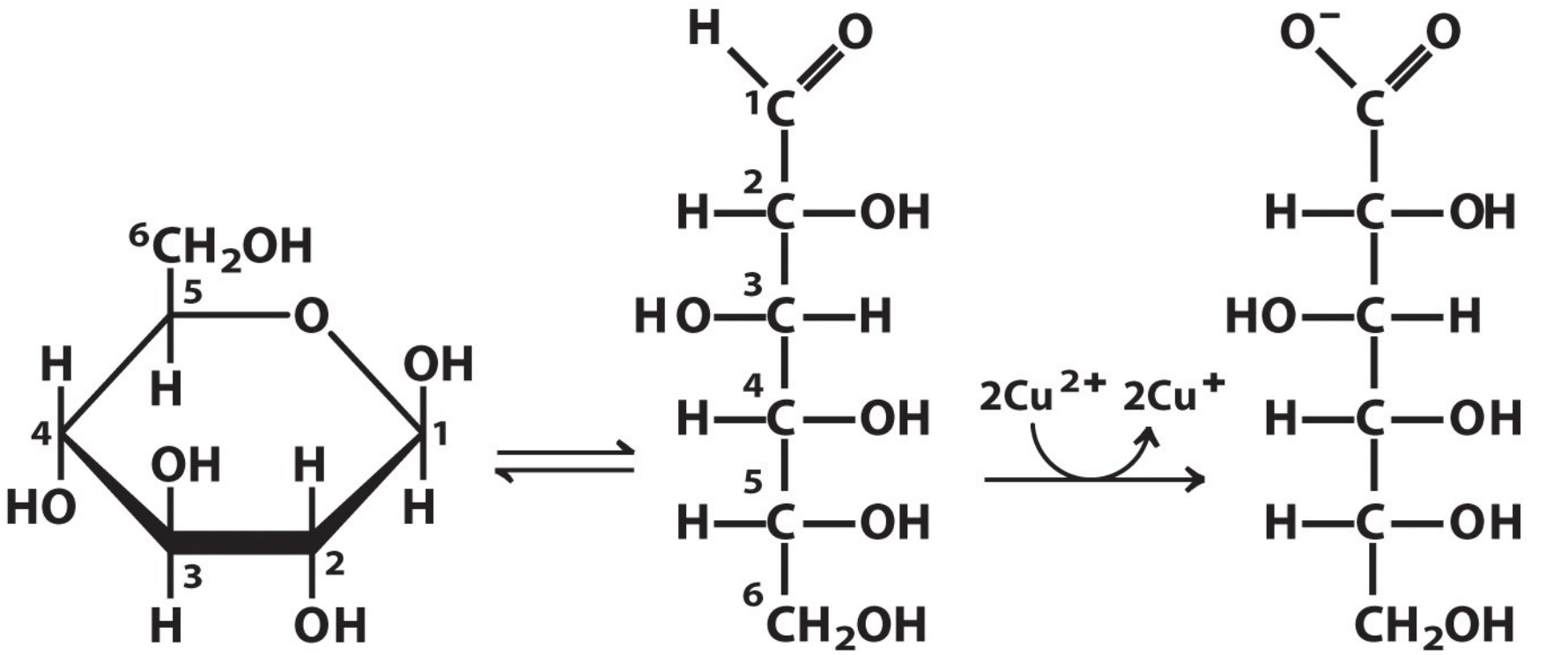

β-D-Glucuronate
D-Gluconate
D-Glucono-δ-lactone

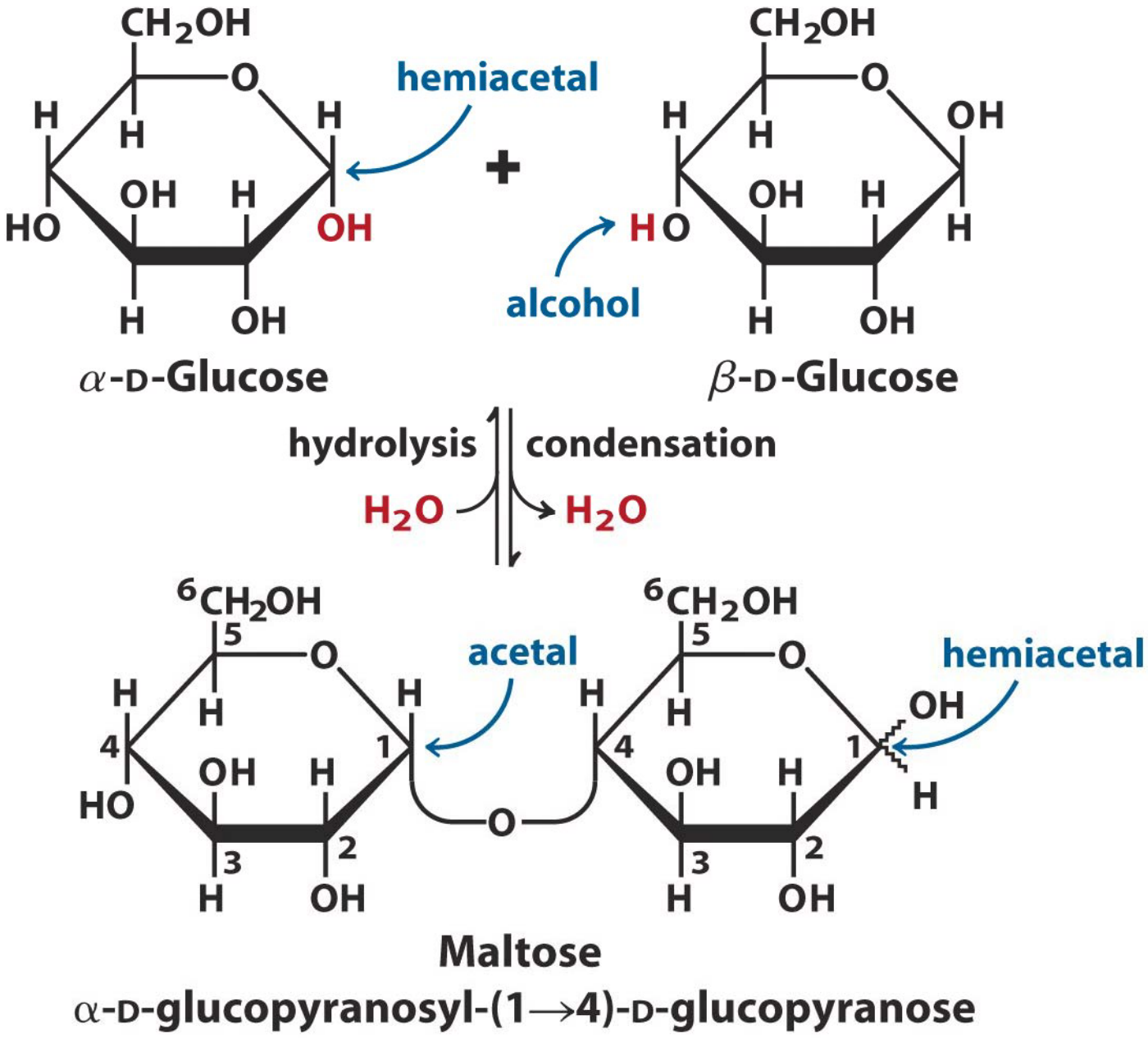
Acidic sugars

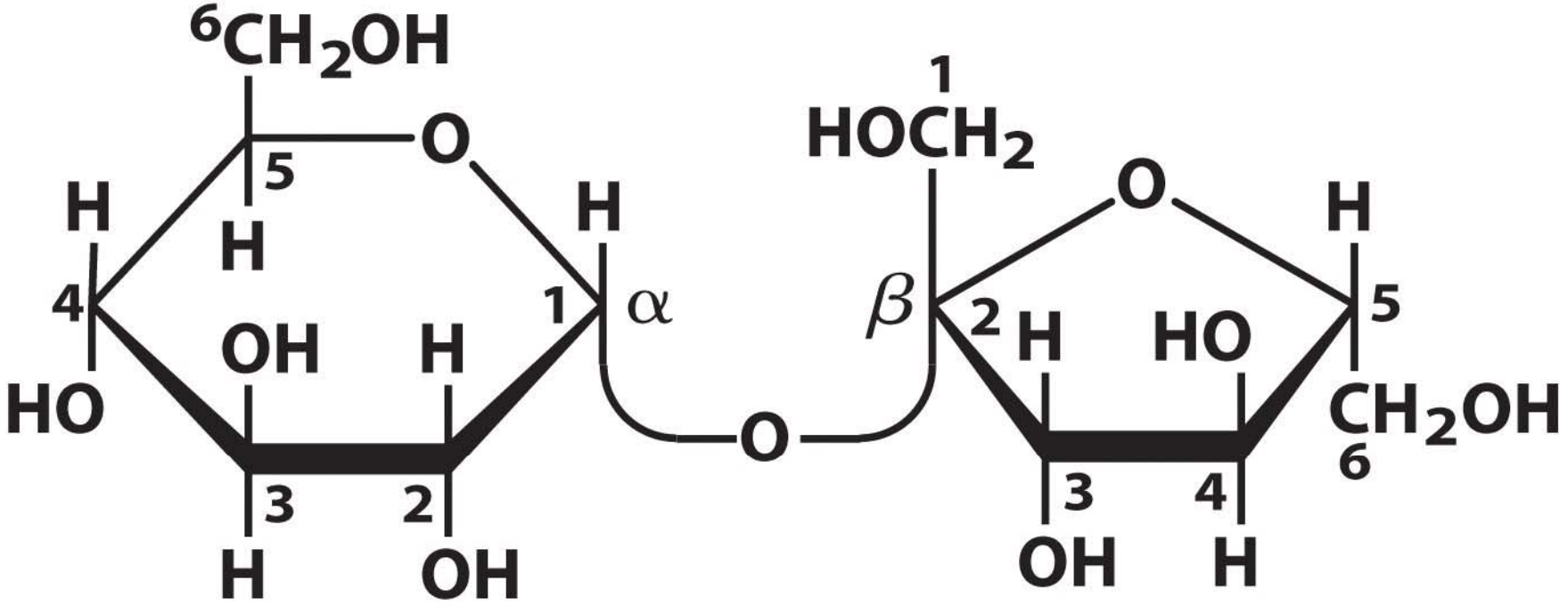




***N*-Acetylneuraminic acid**
(a sialic acid)


β-D-Glucose
D-Glucose
(linear form)
2Cu2+ 2Cu+
D-Gluconate

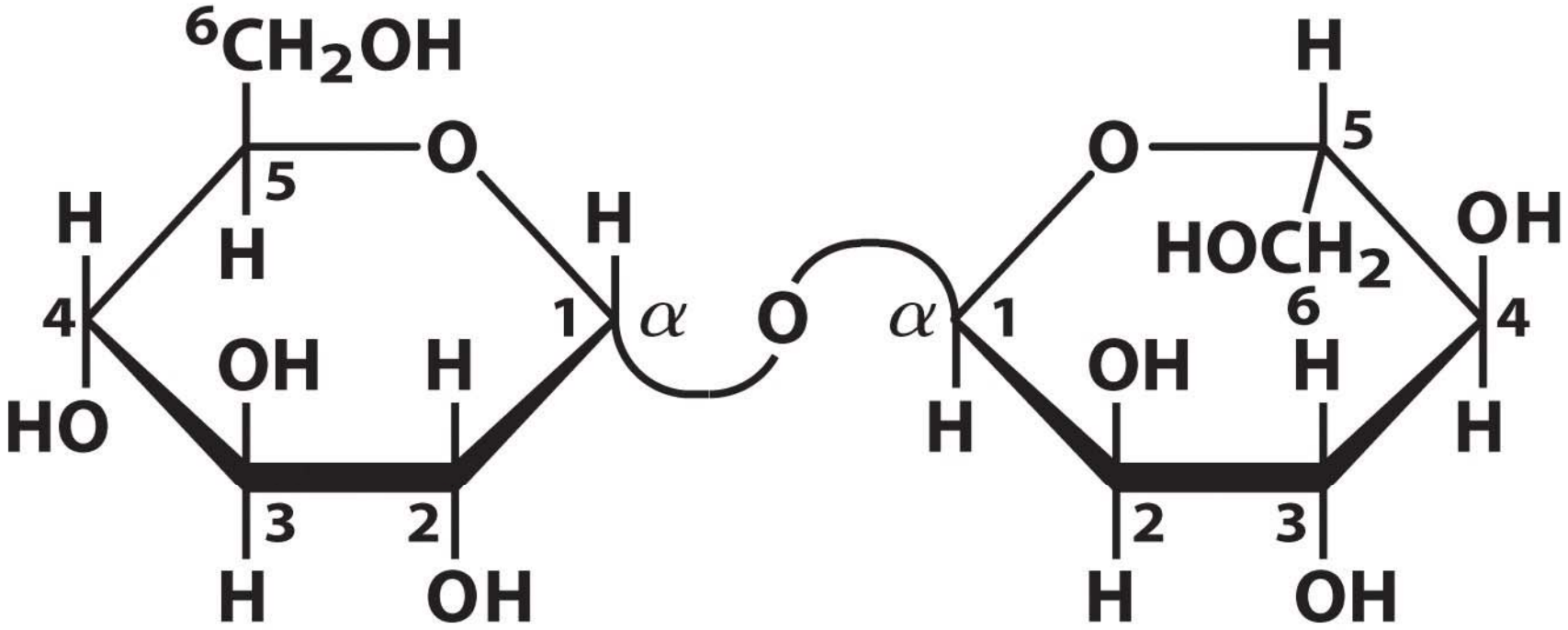

CH2OH
O
H
OH
HO
hemiacetal
alcohol
α-D-Glucose
β-D-Glucose
hydrolysis
condensation
H2O
H2O
6CH2OH
5
4
1
2
3
acetal
hemiacetal
Maltose
α-D-glucopyranosyl-(1→4)-D-glucopyranose



Sucrose

α-D-glucopyranosyl β-D-fructofuranoside

Glc(α1$\leftrightarrow$2β)Fru



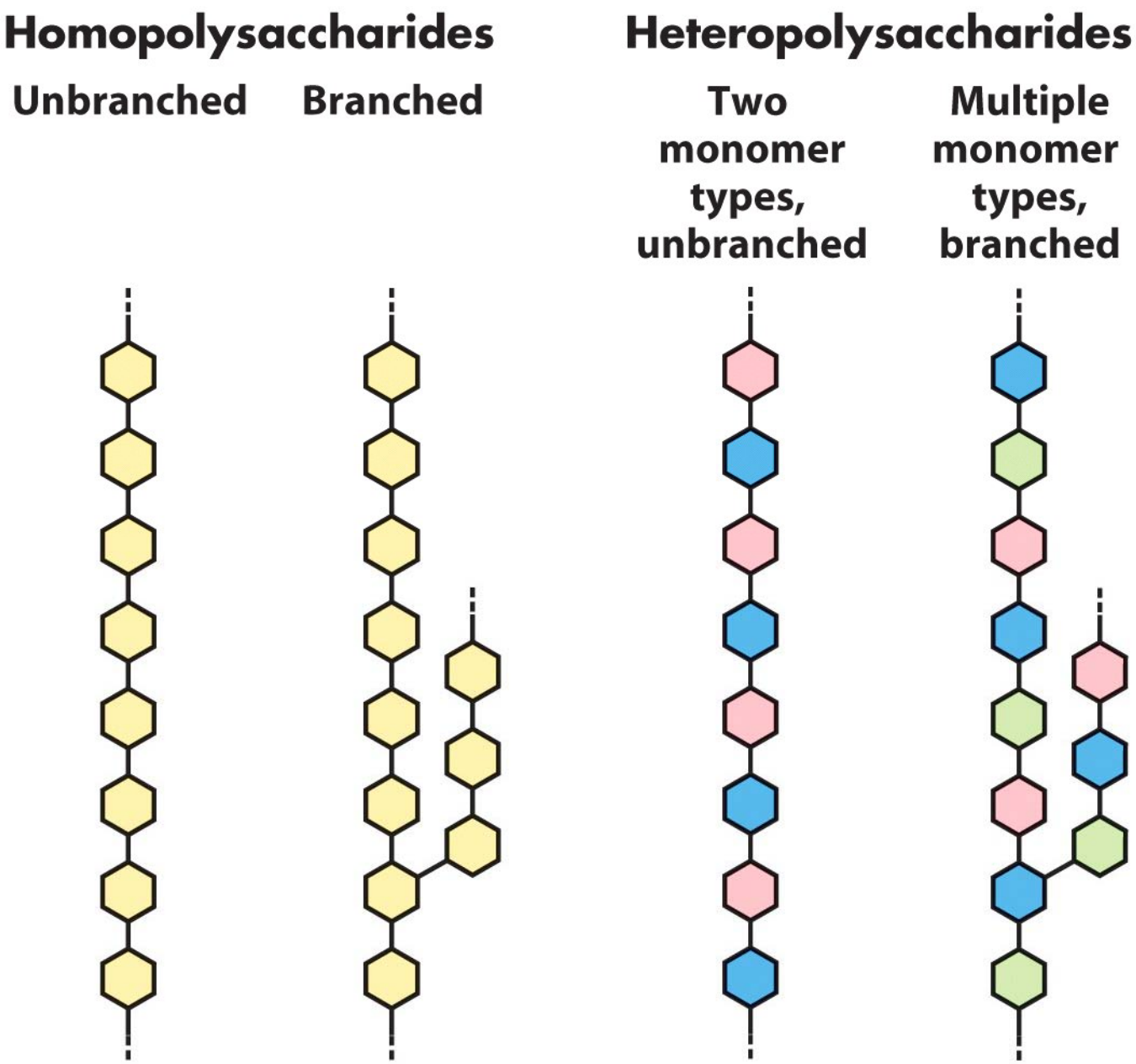
Trehalose

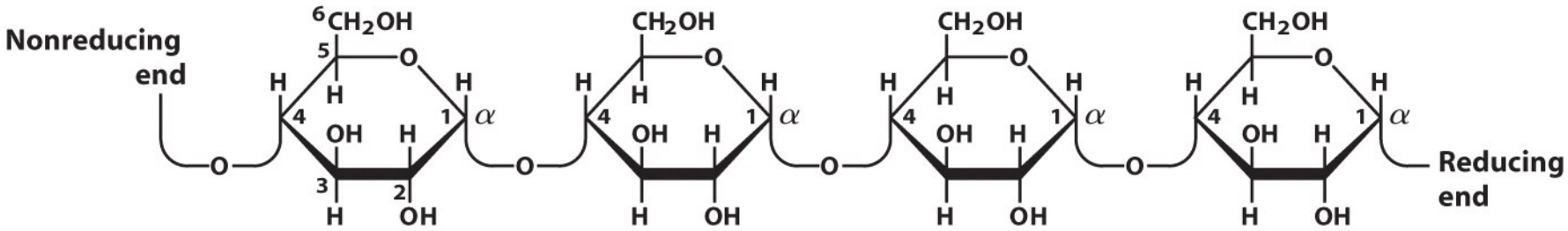
α-D-glucopyranosyl α-D-glucopyranoside

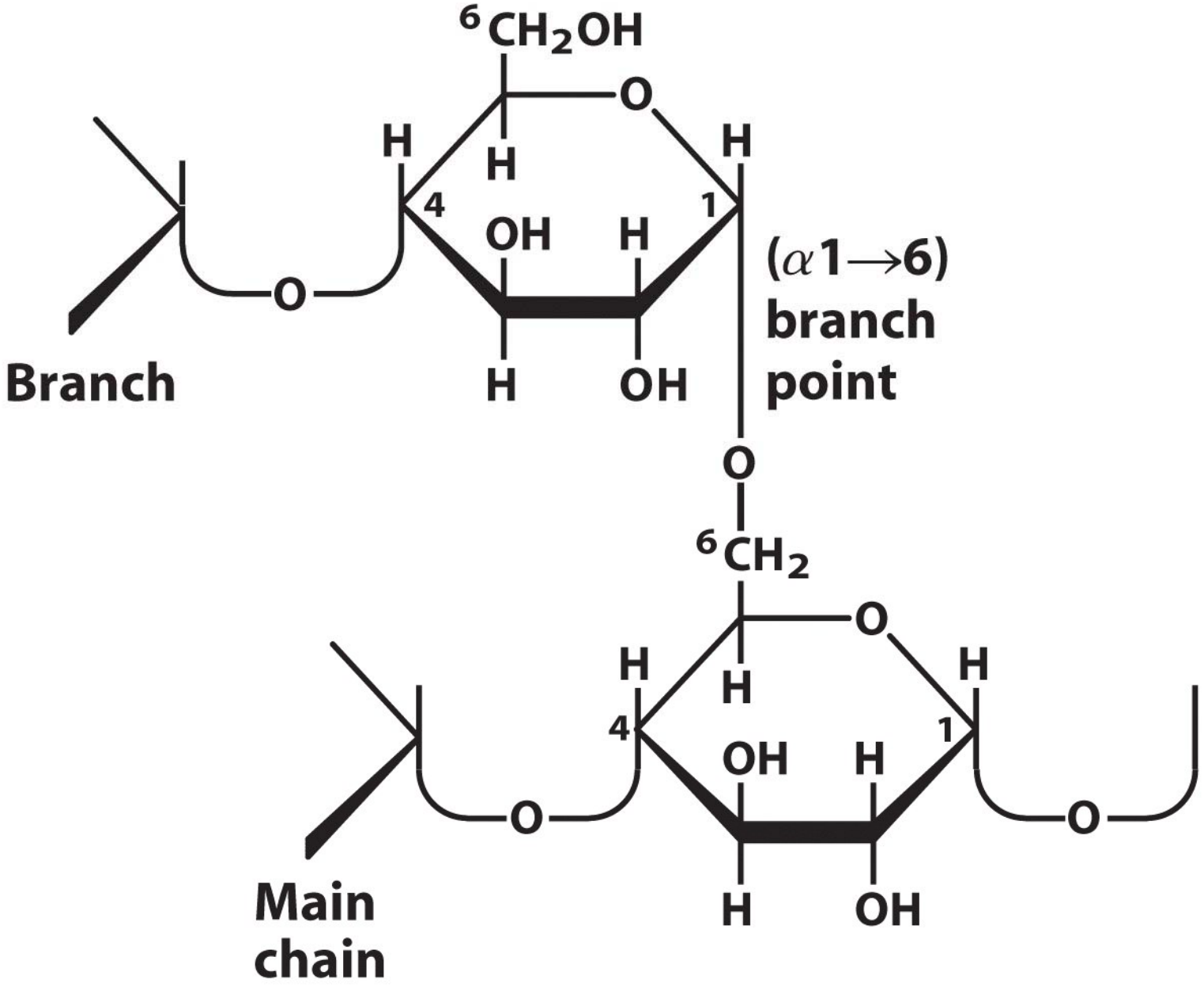
Glc(α1$\leftrightarrow$1α)Glc

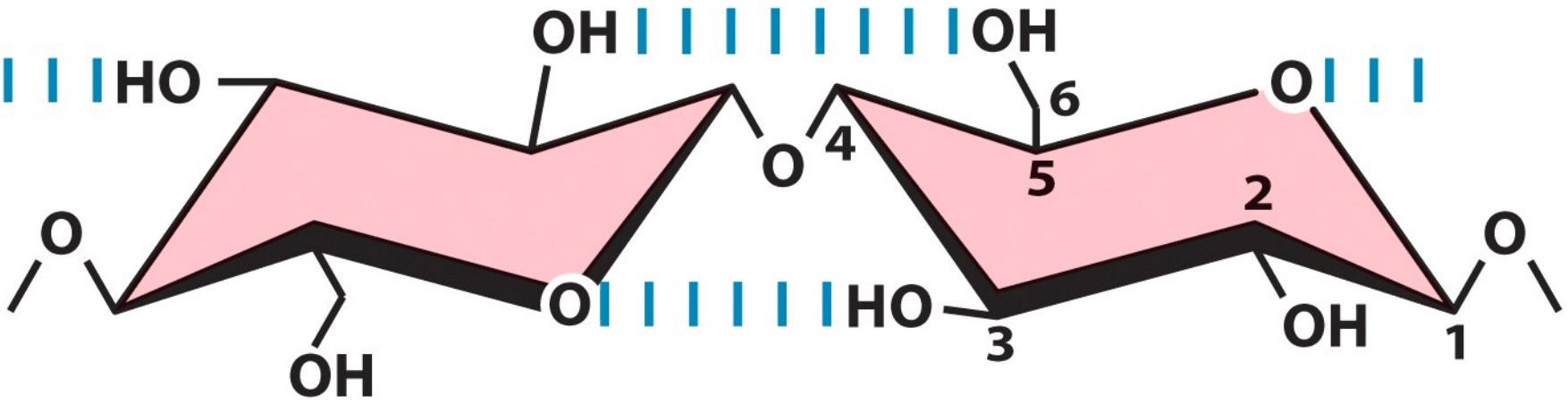
TABLE 7–1 Abbreviations for Common Monosaccharides and Some of Their Derivatives

Abequose	Abe	Glucuronic acid	GlcA
Arabinose	Ara	Galactosamine	GalN
Fructose	Fru	Glucosamine	GlcN
Fucose	Fuc	*N*-Acetylgalactosamine	GalNAc
Galactose	Gal	*N*-Acetylglucosamine	GlcNAc
Glucose	Glc	Iduronic acid	IdoA
Mannose	Man	Muramic acid	Mur
Rhamnose	Rha	*N*-Acetylmuramic acid	Mur2Ac
Ribose	Rib	*N*-Acetylneuraminic acid (a sialic acid)	Neu5Ac
Xylose	Xyl		

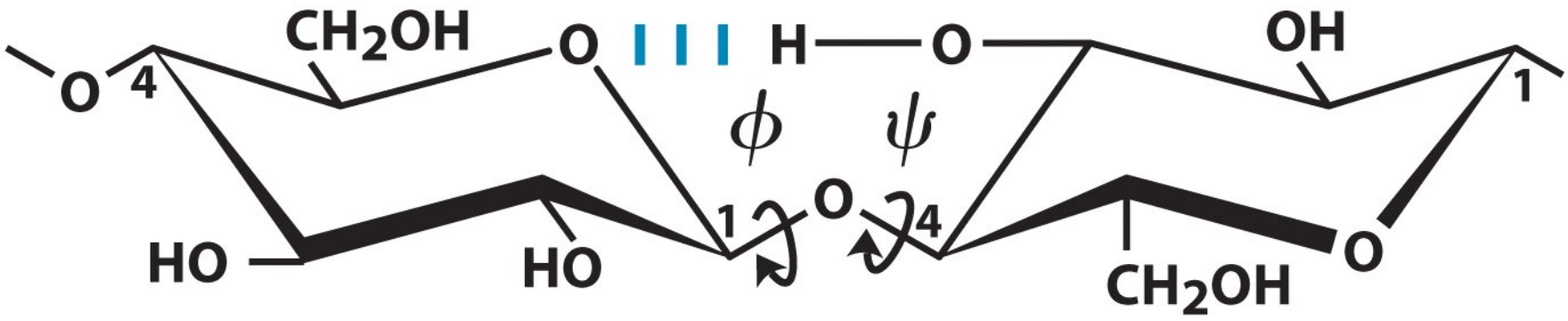

Homopolysaccharides
Unbranched
Branched
Heteropolysaccharides
Two monomer types, unbranched
Multiple monomer types, branched


Nonreducing end
Reducing end
amylose


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

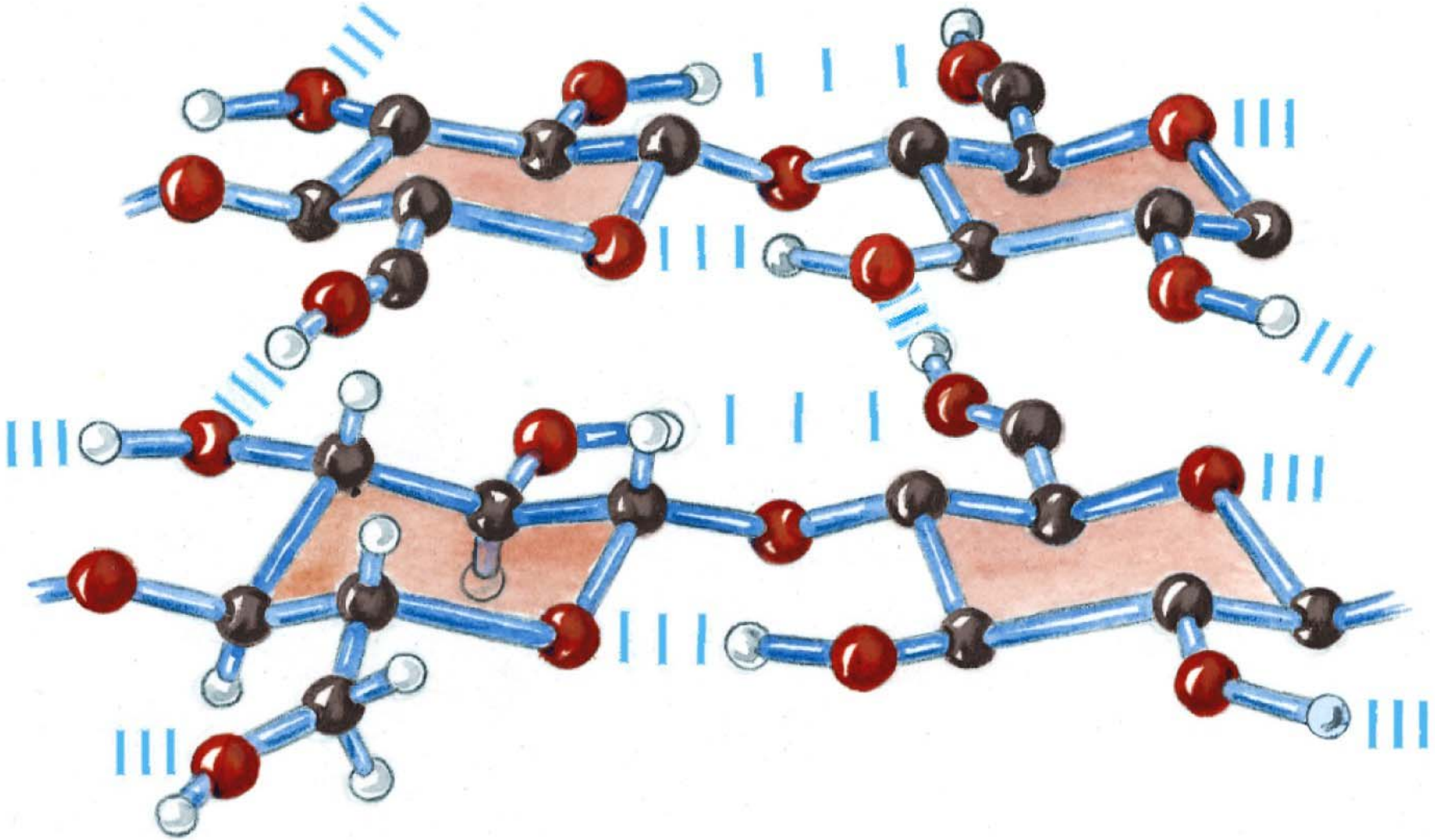


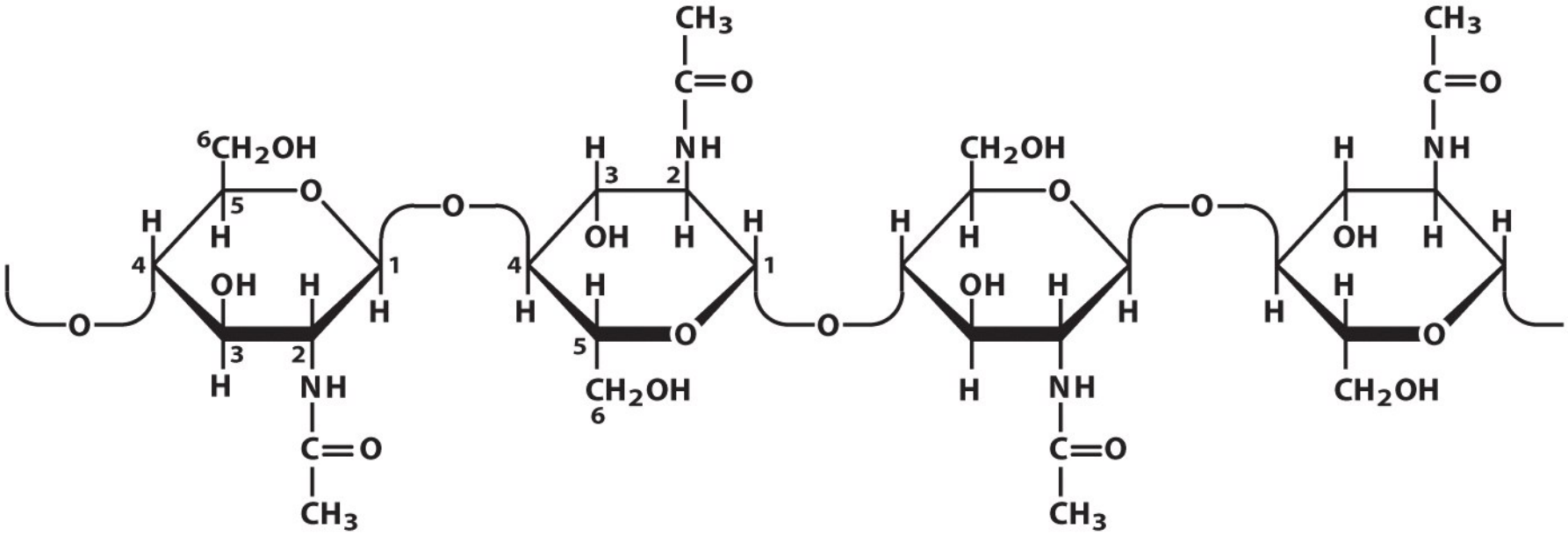
(β1$\rightarrow$4)-linked D-glucose units



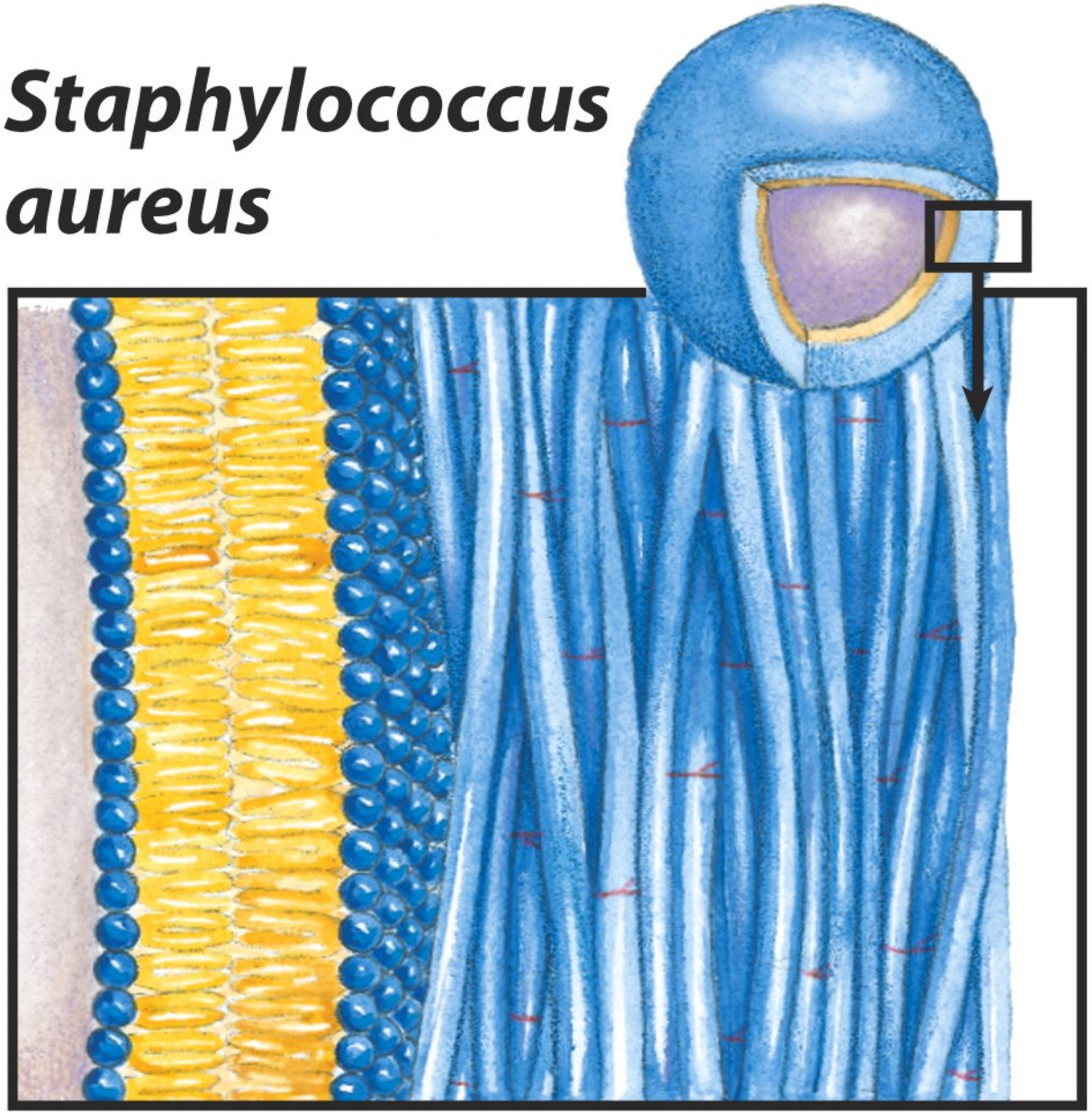
Cellulose

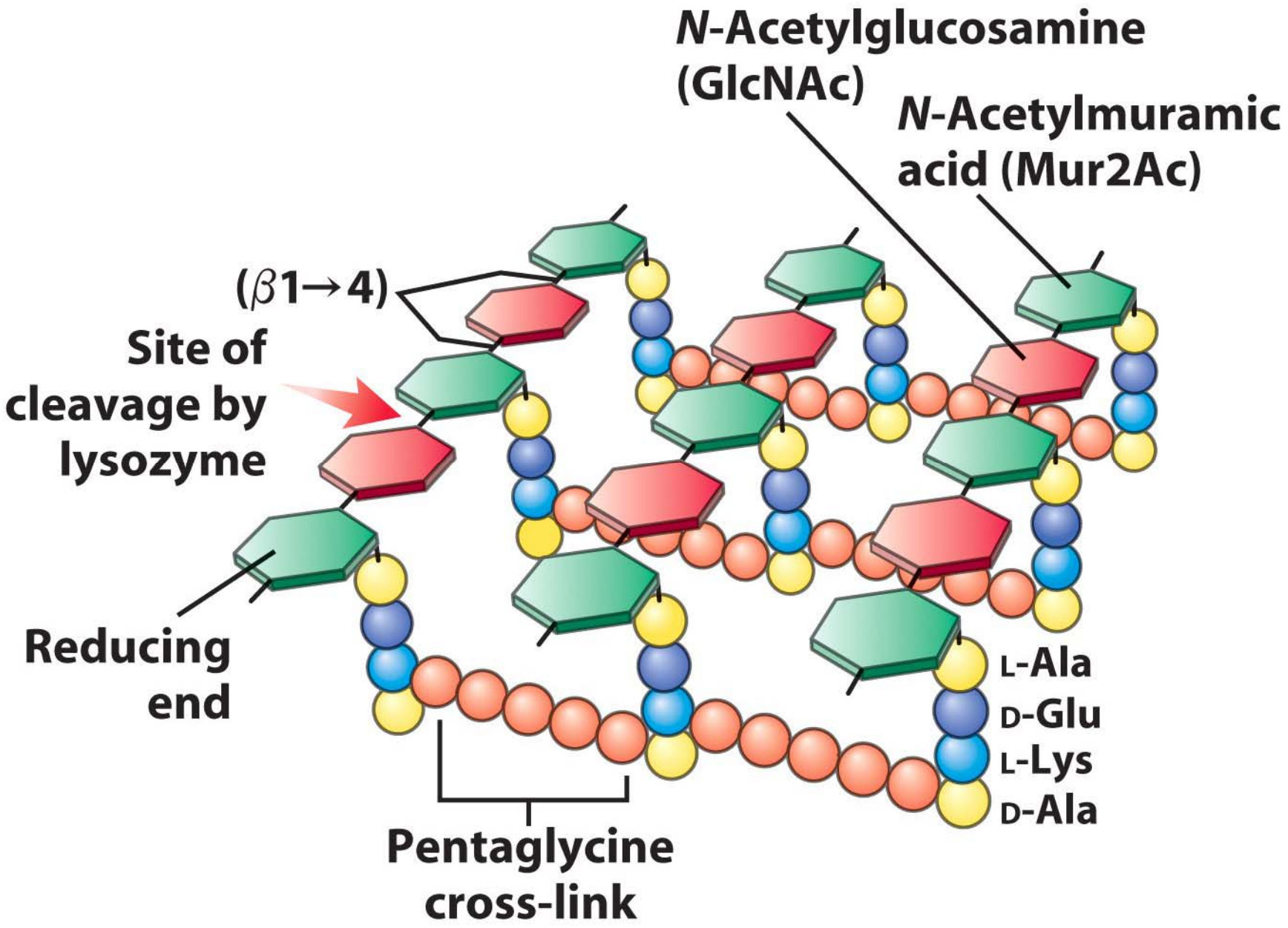
(β1→4)Glc repeats

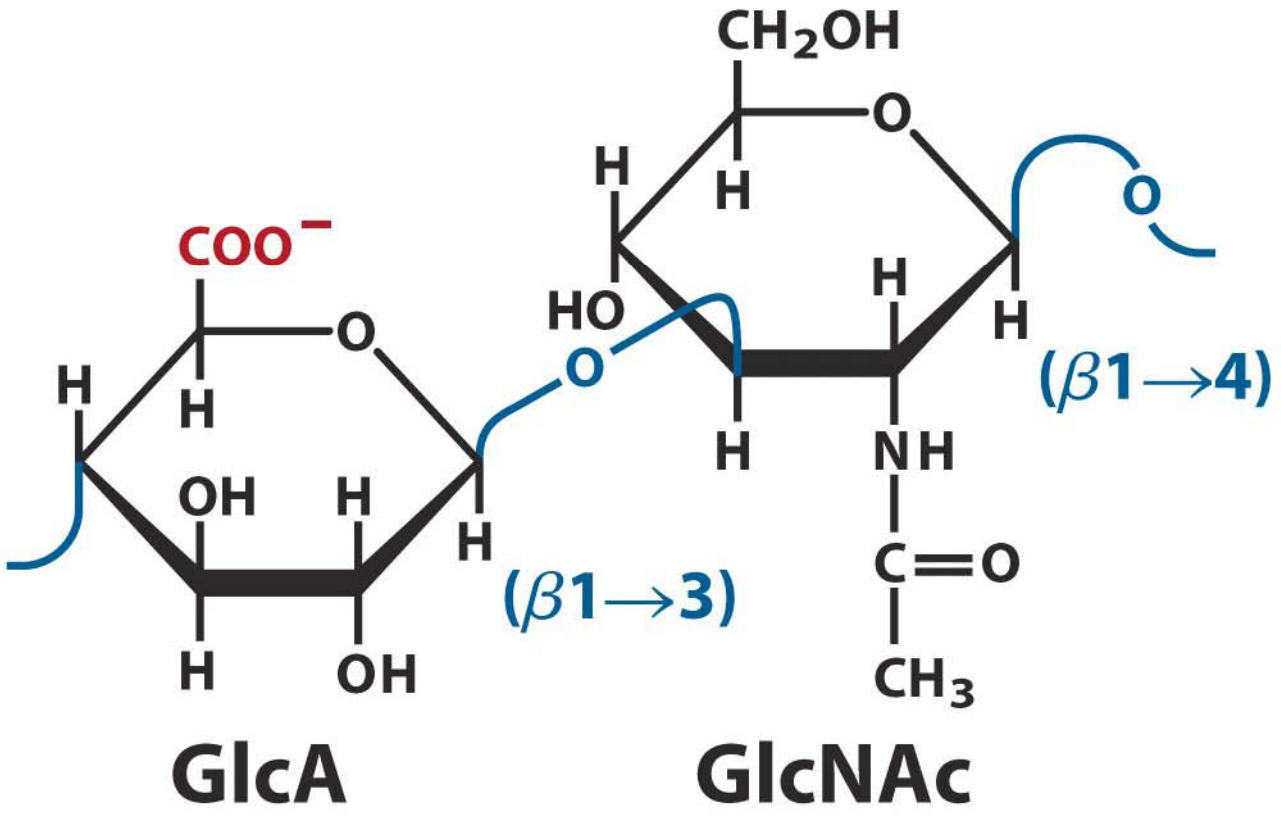


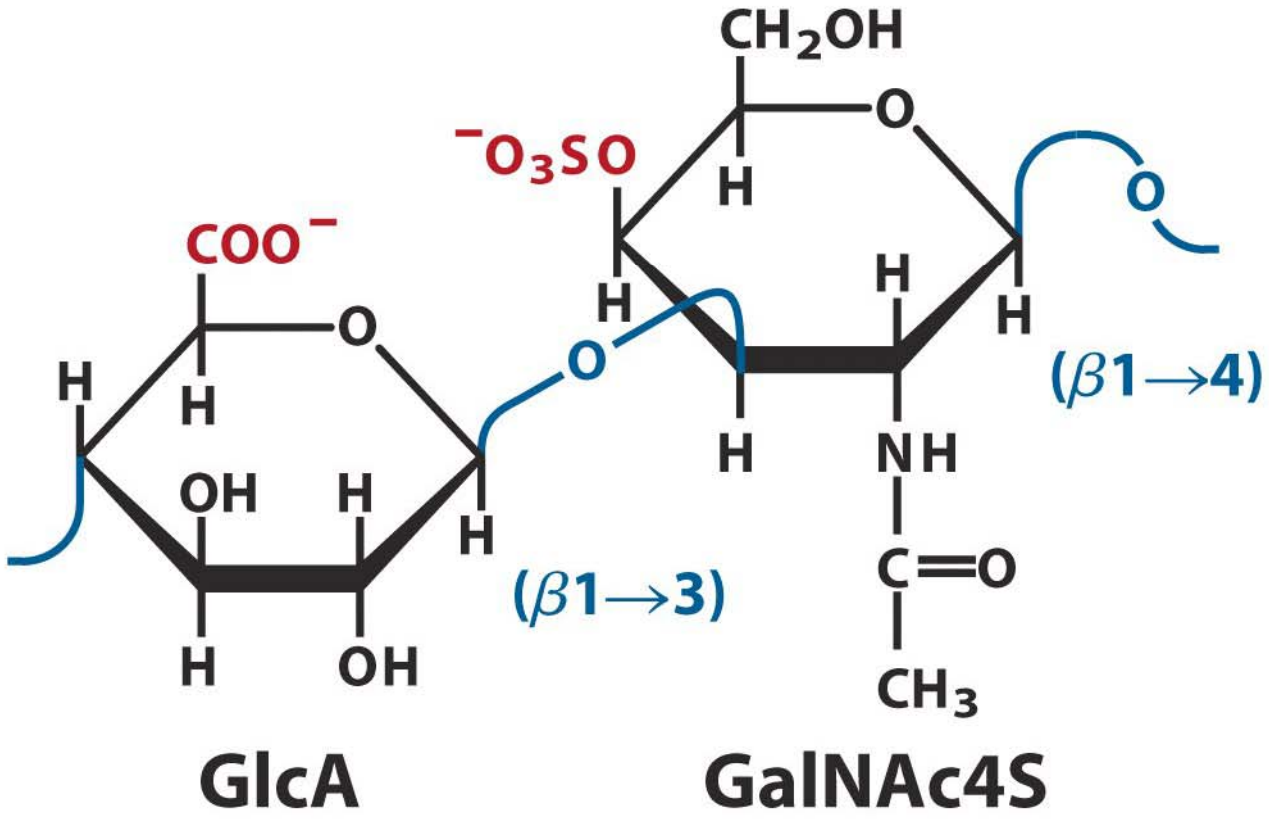

CH3
C=O
NH
6CH2OH
O
5
H
4
OH
H
1
3
2
CH2OH
6

Staphylococcus aureus




N-Acetylglucosamine (GlcNAc)
N-Acetylmuramic acid (Mur2Ac)
(β1→4)
Site of cleavage by lysozyme
Reducing end
L-Ala
D-Glu
L-Lys
D-Ala
Pentaglycine cross-link

Glycosaminoglycan	Repeating disaccharide
Hyaluronate	
~50,000	

Glycosaminoglycan	Repeating disaccharide
Number of disaccharides per chain	
Chondroitin 4-sulfate	
20–60	

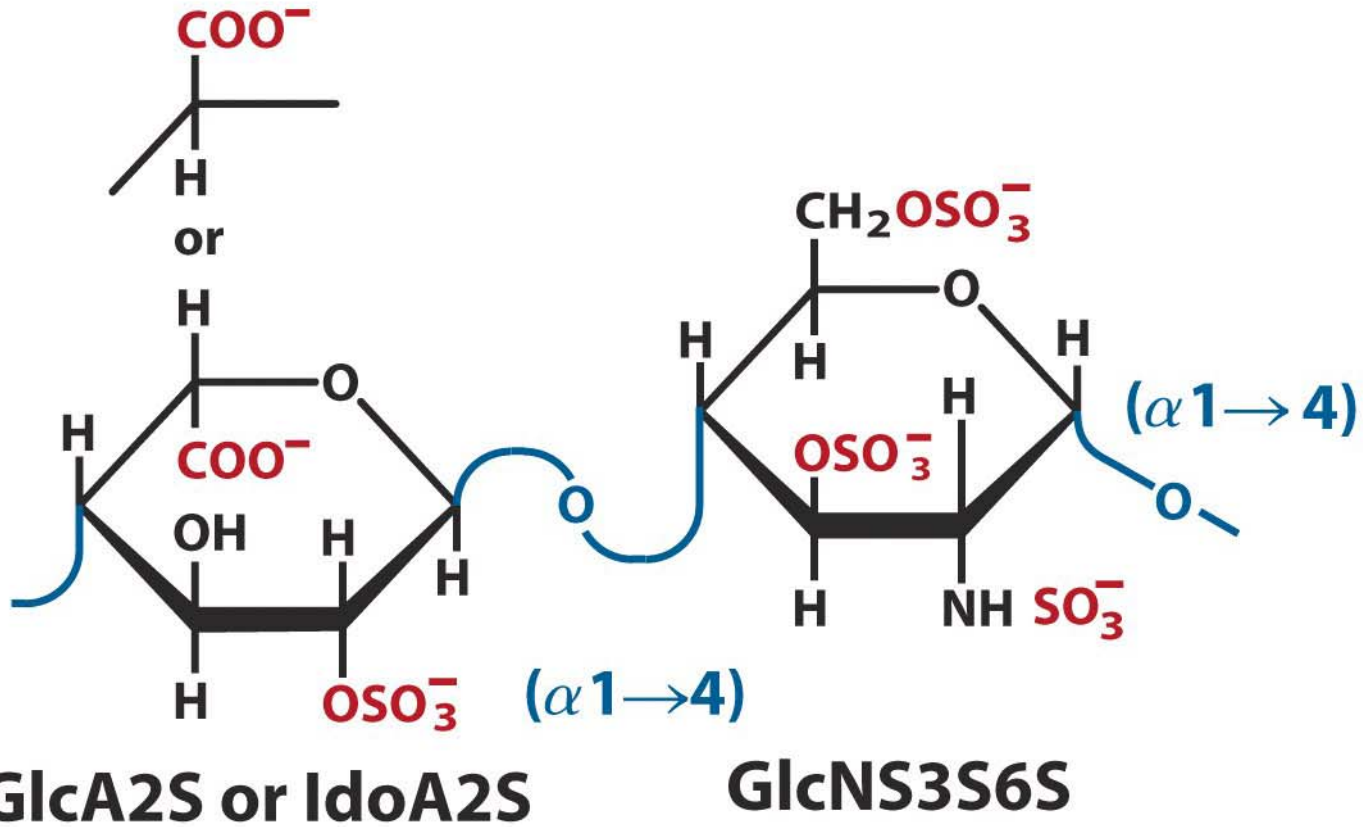
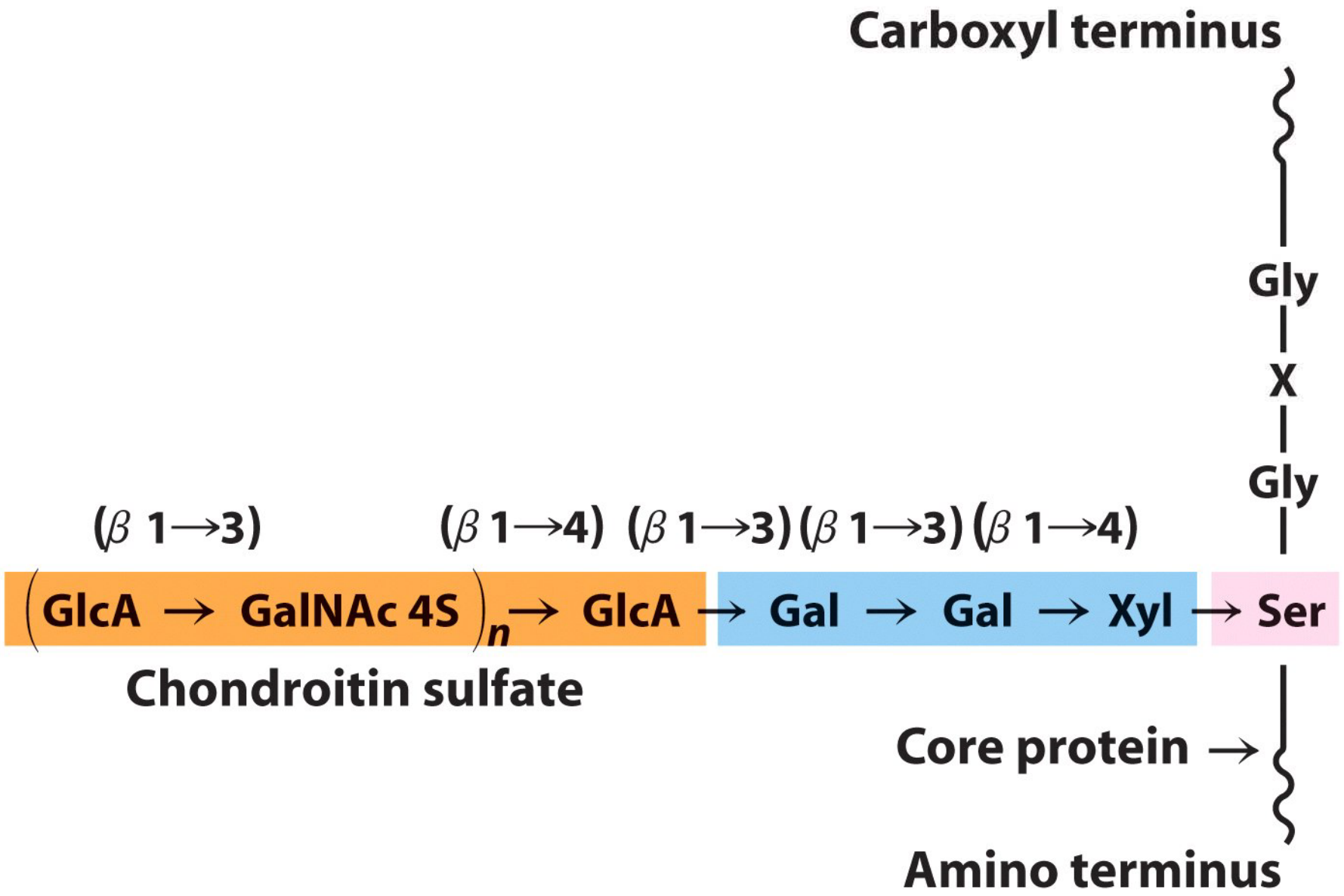
Glycosaminoglycan	Repeating disaccharide
Heparin	
Number of disaccharides per chain	
15–90	

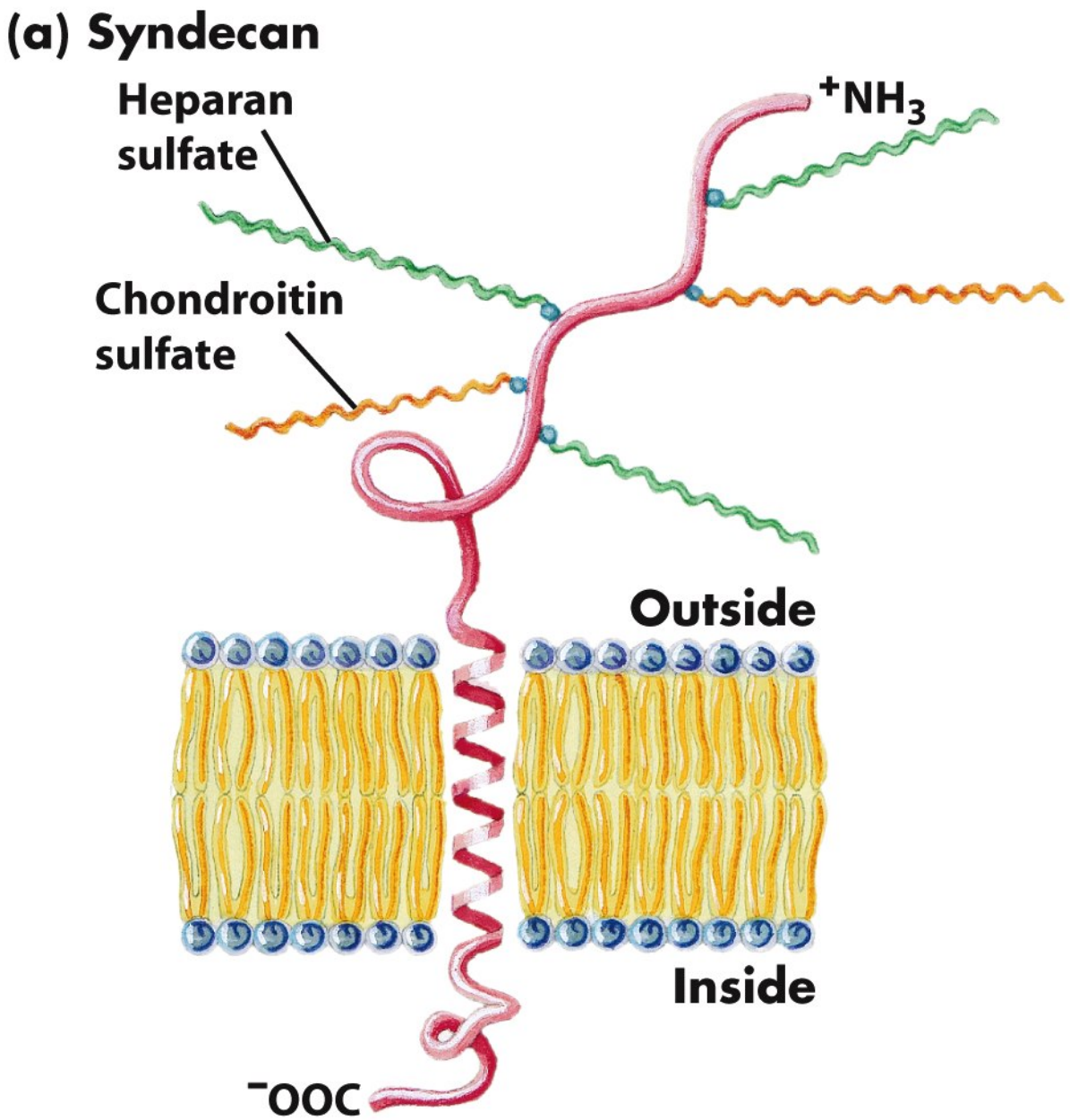
TABLE 7–2 Structures and Roles of Some Polysaccharides

Polymer	*Type**	*Repeating unit*†	*Size (number of monosaccharide units)*	*Roles/significance*
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 24–30 residues	Up to 10^6	
Glycogen	Homo-	(α1→4)Glc, with (α1→6)Glc branches every 8–12 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
Dextran	Homo-	(α1→6)Glc, with (α1→3) branches	Wide range	Structural: in bacteria, extracellular adhesive
Peptidoglycan	Hetero-; peptides attached	4)Mur2Ac(β1→4) GlcNAc(β1	Very large	Structural: in bacteria, gives rigidity and strength to cell envelope
Agarose	Hetero-	3)D-Gal(β1→4)3,6-anhydro-L-Gal(α1	1,000	Structural: in algae, cell wall material
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

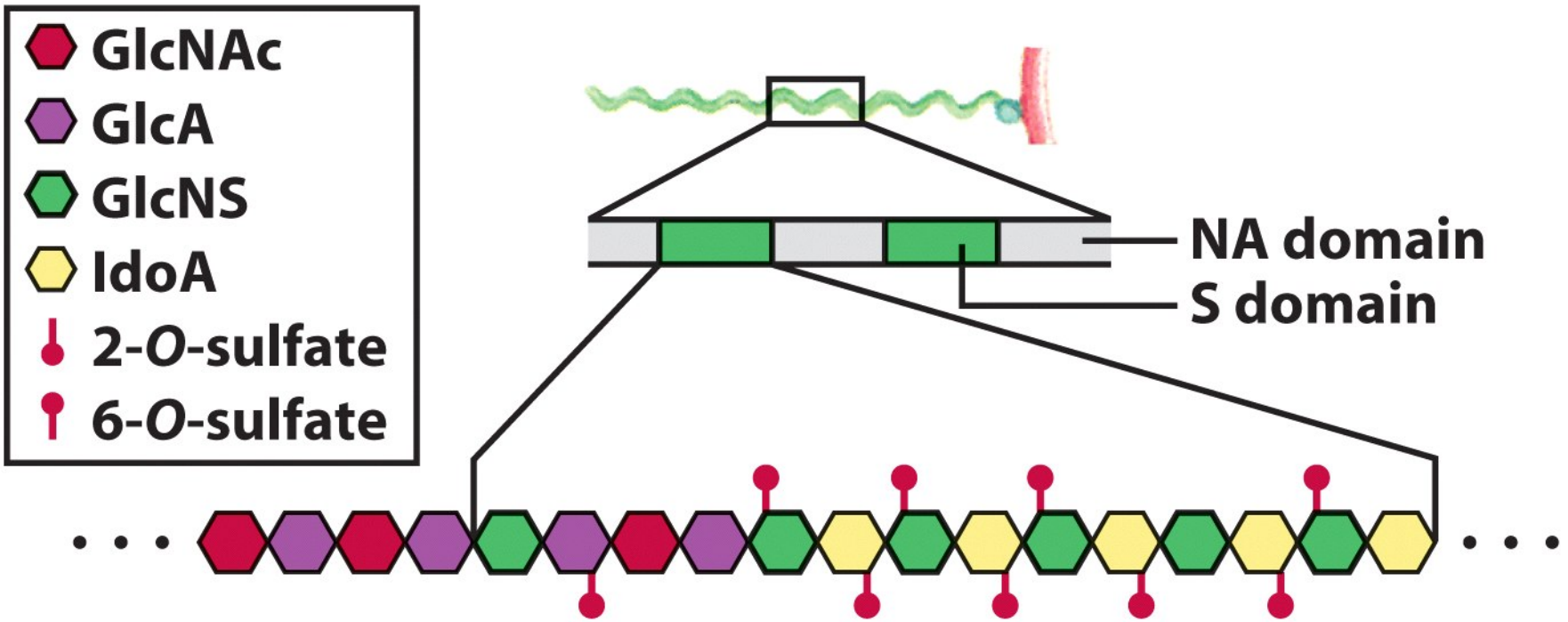
*Each polymer is classified as a homopolysaccharide (homo-) or heteropolysaccharide (hetero-).

†The abbreviated names for the peptidoglycan, agarose, and hyaluronate repeating units indicate that the polymer contains repeats of this disaccharide unit. For example, in peptidoglycan, the GlcNAc of one disaccharide unit is (β1→4)-linked to the first residue of the next disaccharide unit.

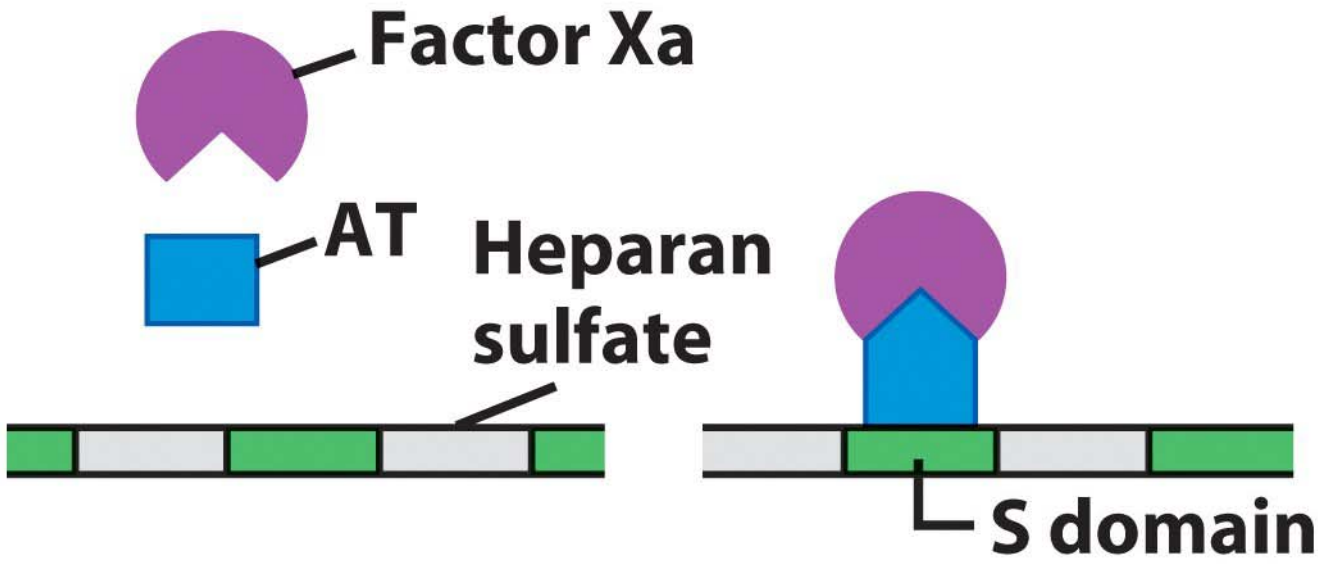

Carboxyl terminus
Gly
X
Gly
(β 1→3)
(β 1→4)
(β 1→3)
(β 1→3)
(β 1→4)
GlcA → GalNAc 4S
n
→ GlcA → Gal → Gal → Xyl → Ser
Chondroitin sulfate
Core protein →
Amino terminus


(a) Syndecan
Heparan sulfate
Chondroitin sulfate
+NH3
Outside
Inside
−OOC

Heparan sulfate

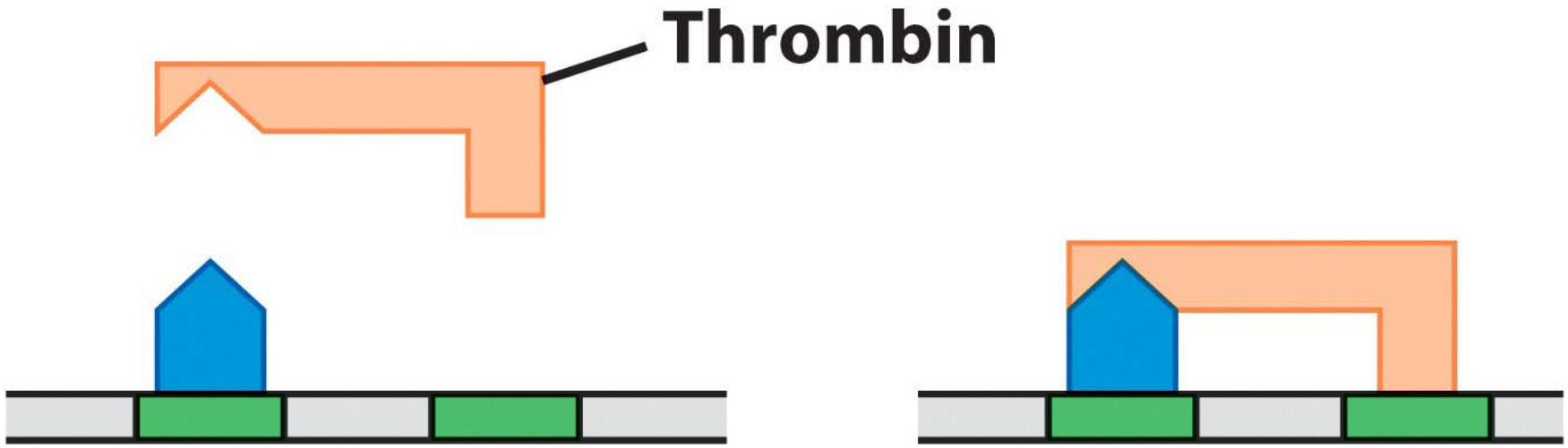


(a) Conformational activation

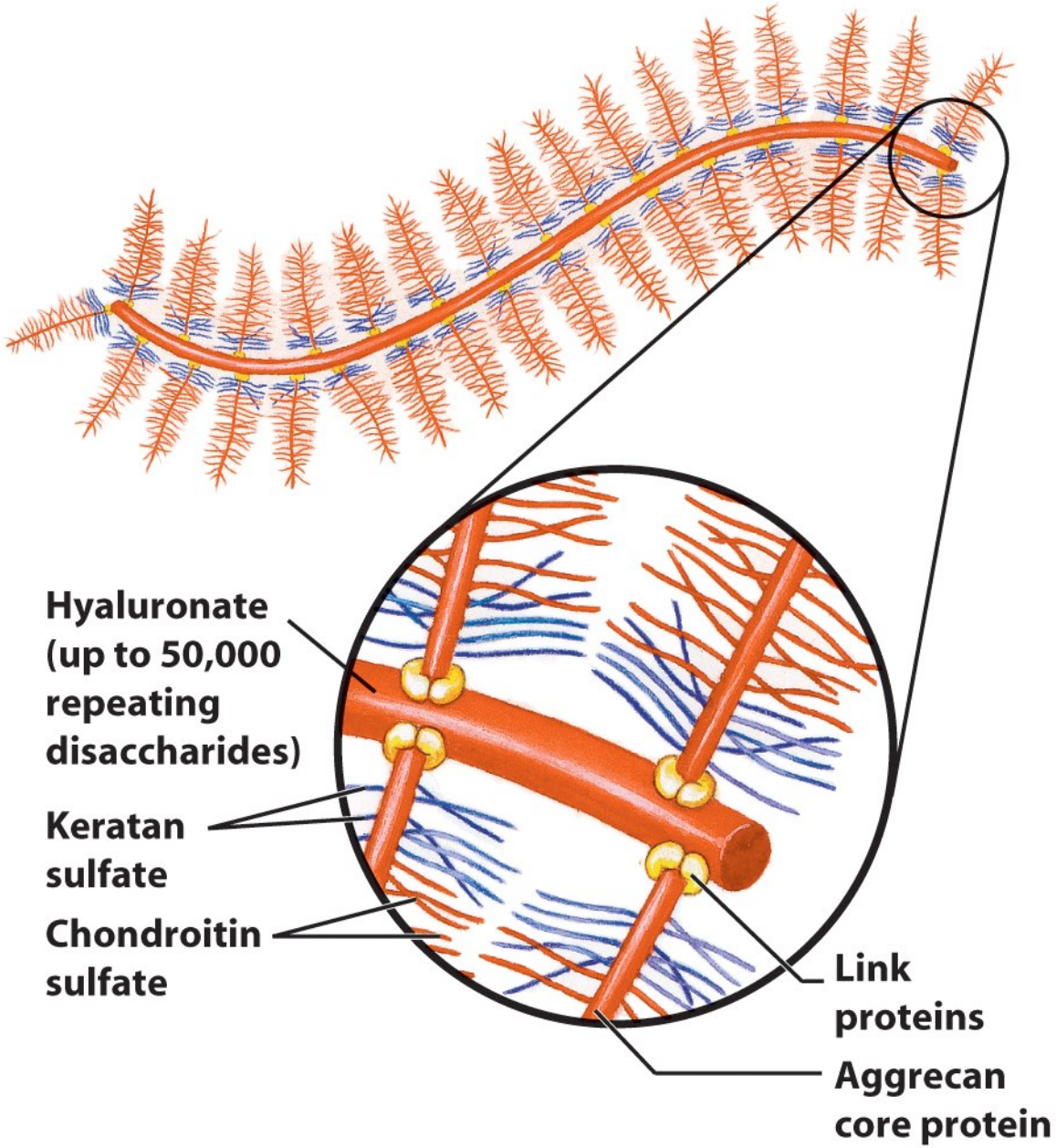


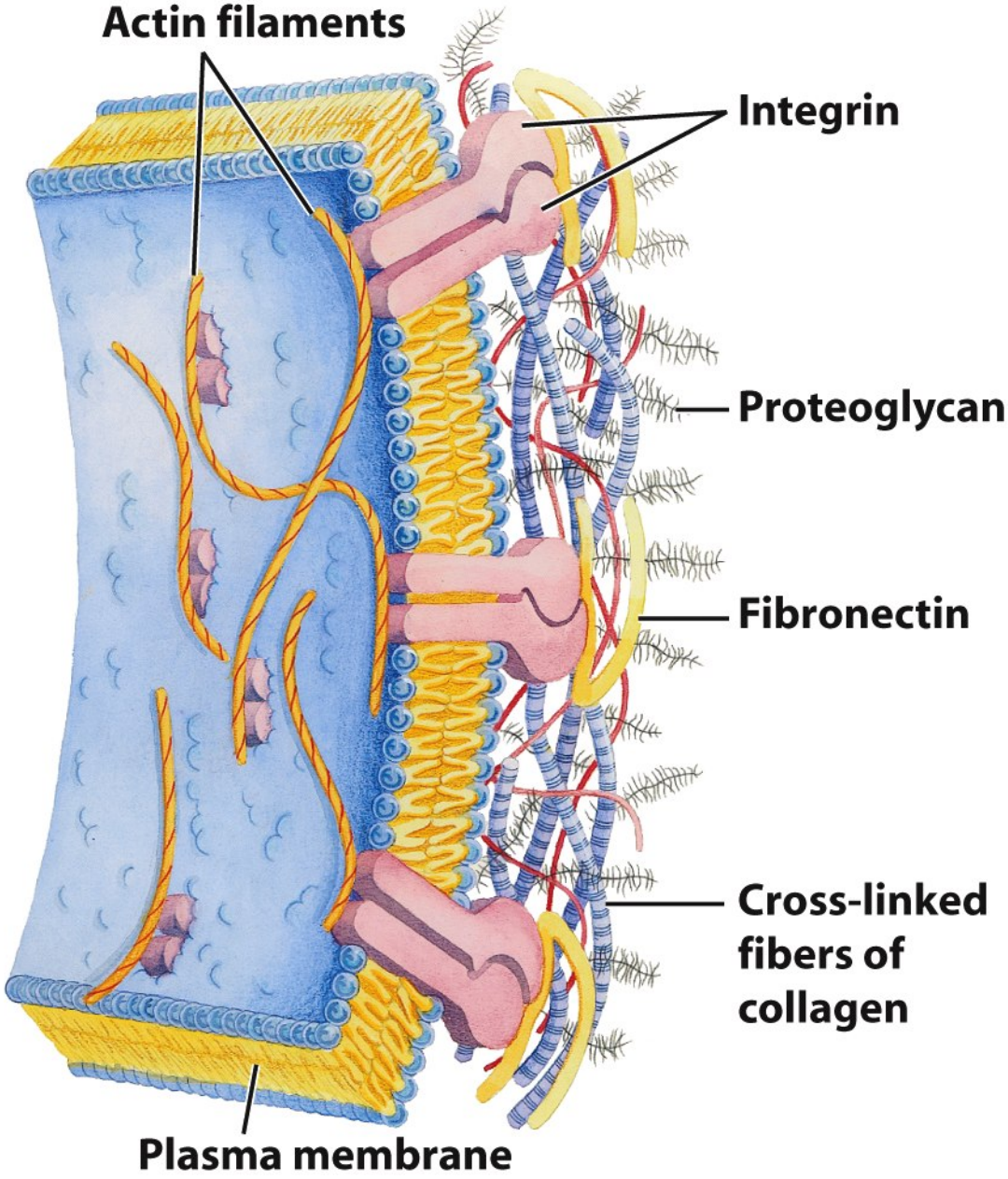
A conformational change induced in the protein antithrombin (AT) on binding a specific pentasaccharide S domain allows its interaction with Factor Xa, a blood clotting factor, preventing clotting.

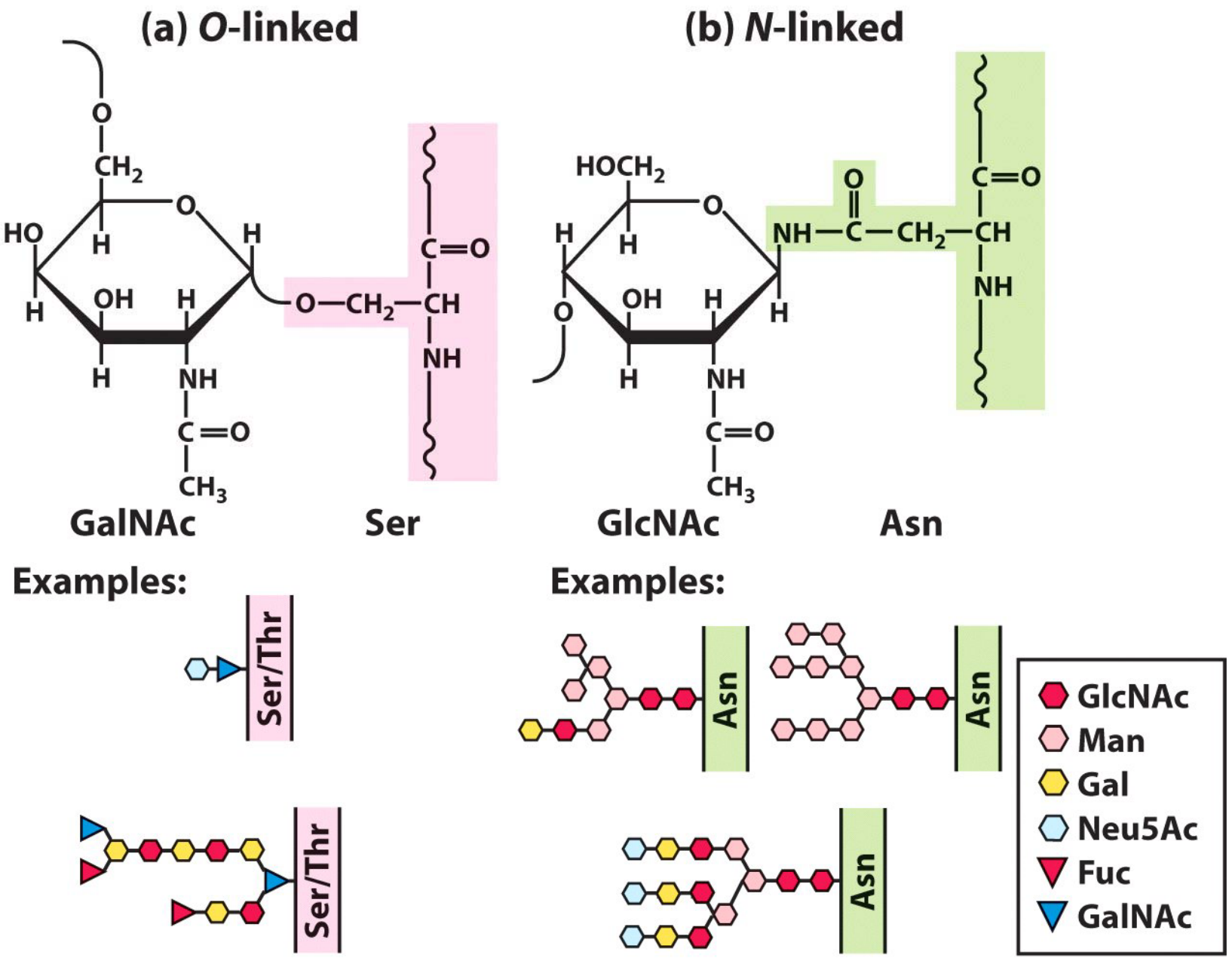
(b) Enhanced protein-protein interaction

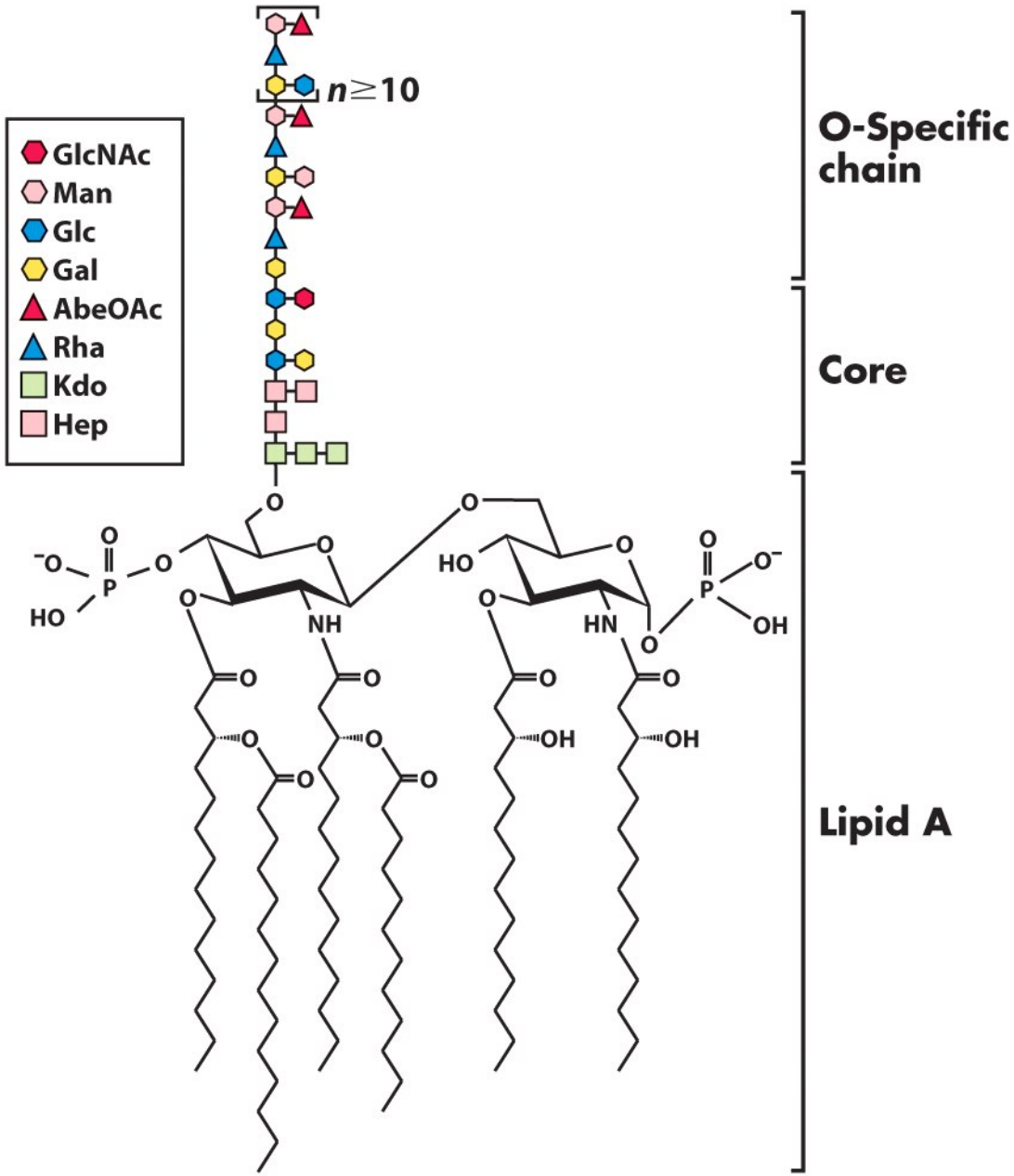


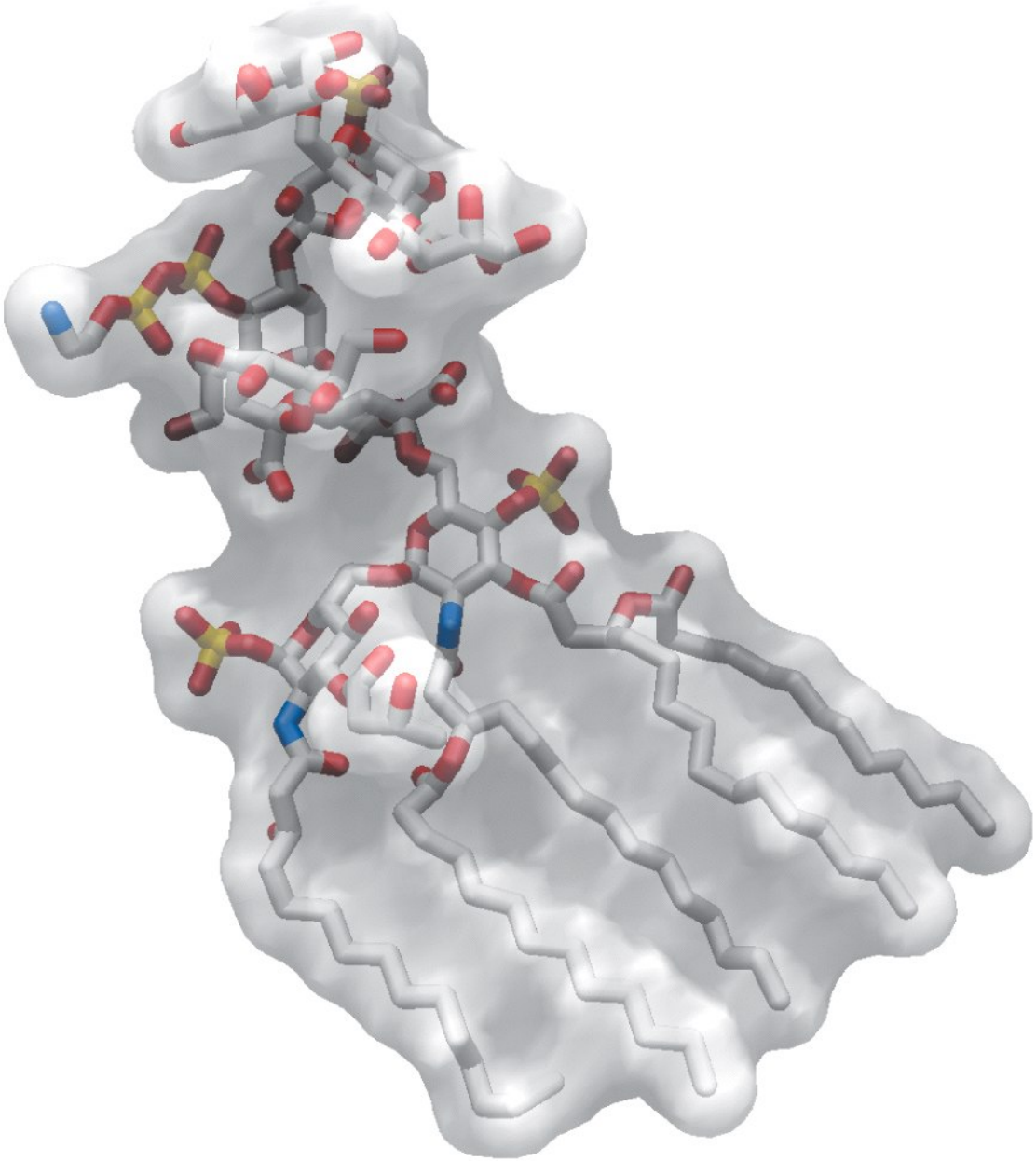
Binding of AT and thrombin to two adjacent S domains brings the two proteins into close proximity, favoring their interaction, which inhibits blood clotting.

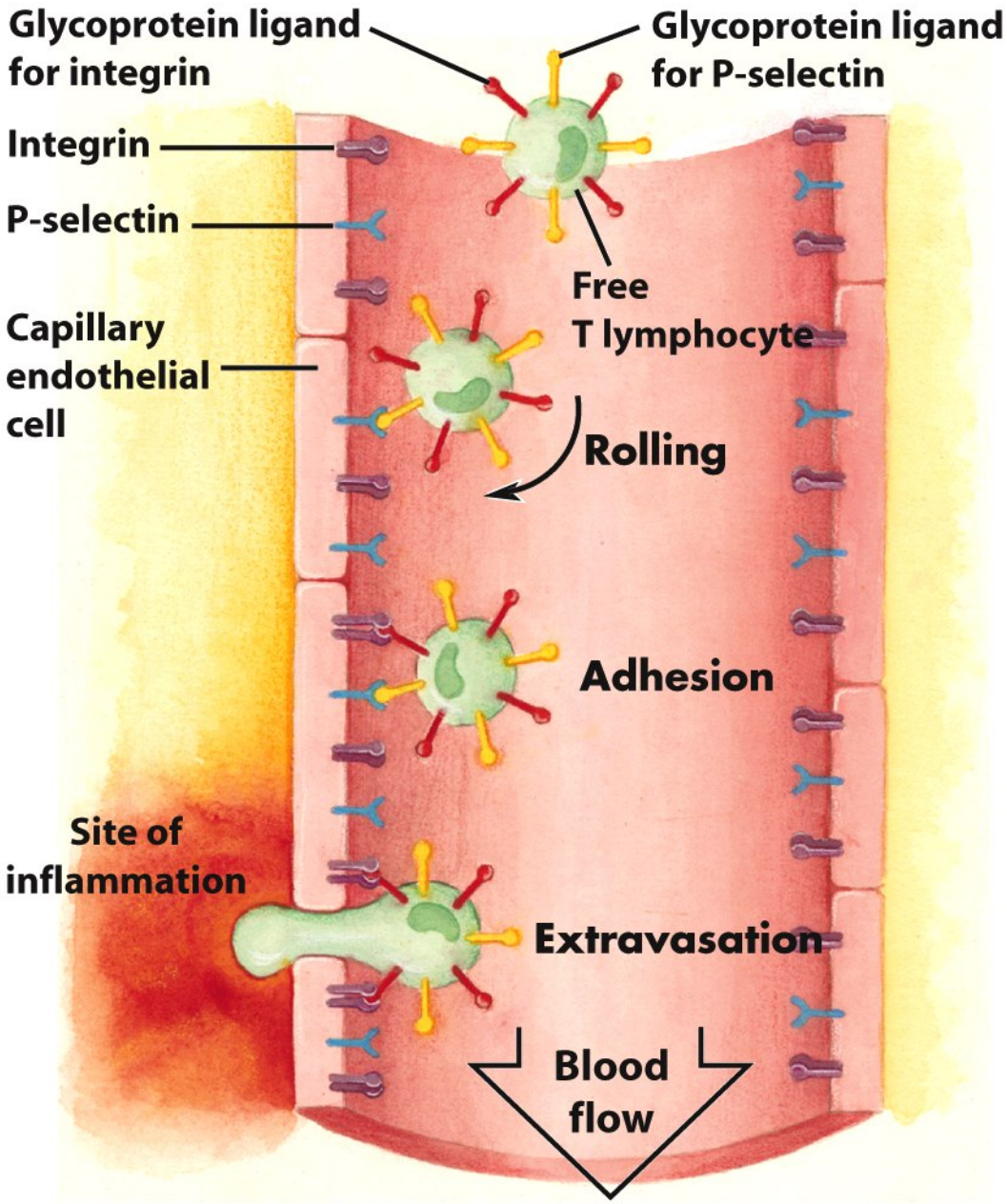

Hyaluronate
(up to 50,000
repeating
disaccharides)
Keratan
sulfate
Chondroitin
sulfate
Link
proteins
Aggrecan
core protein

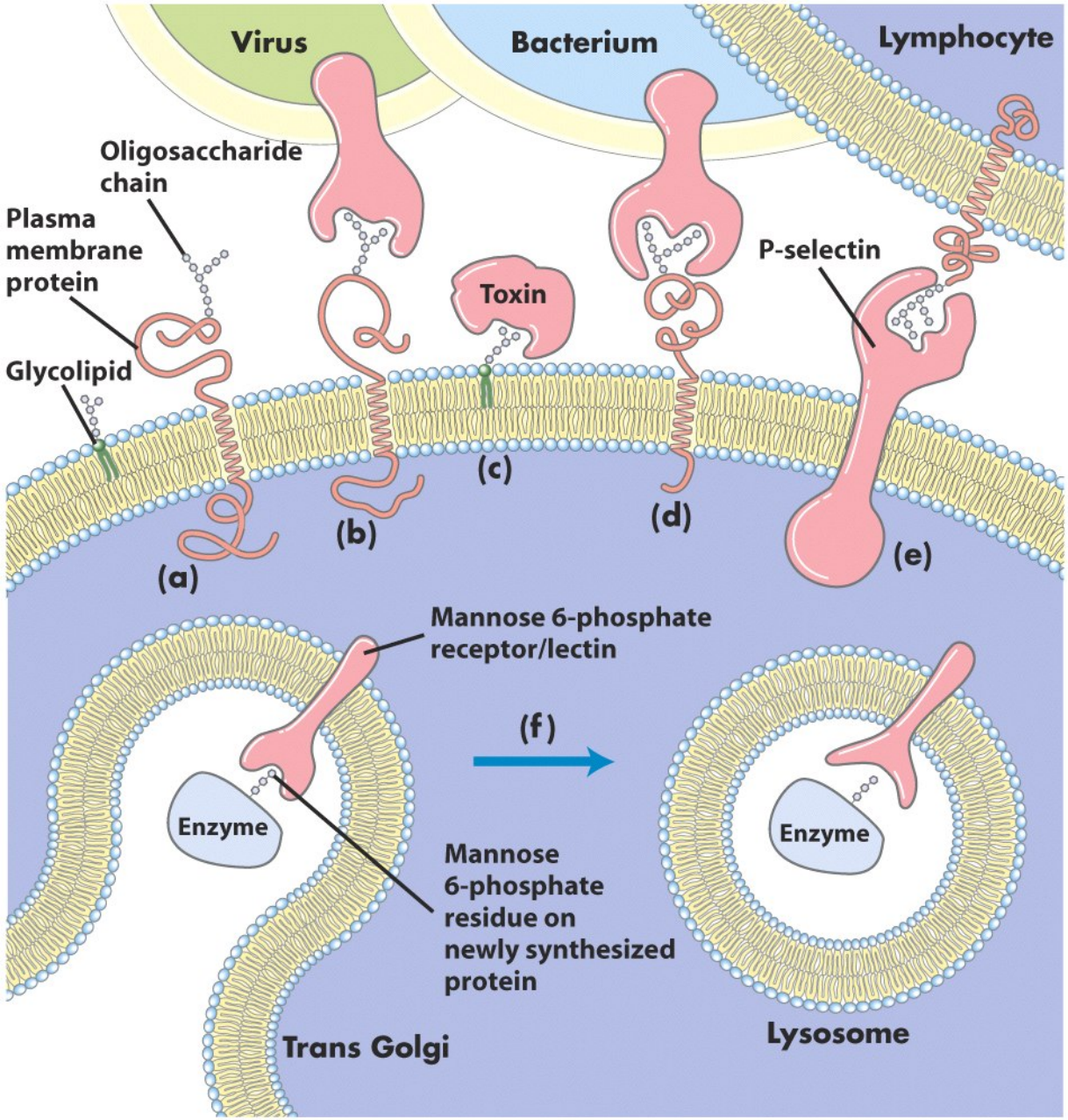

Actin filaments
Integrin
Proteoglycan
Fibronectin
Cross-linked fibers of collagen
Plasma membrane

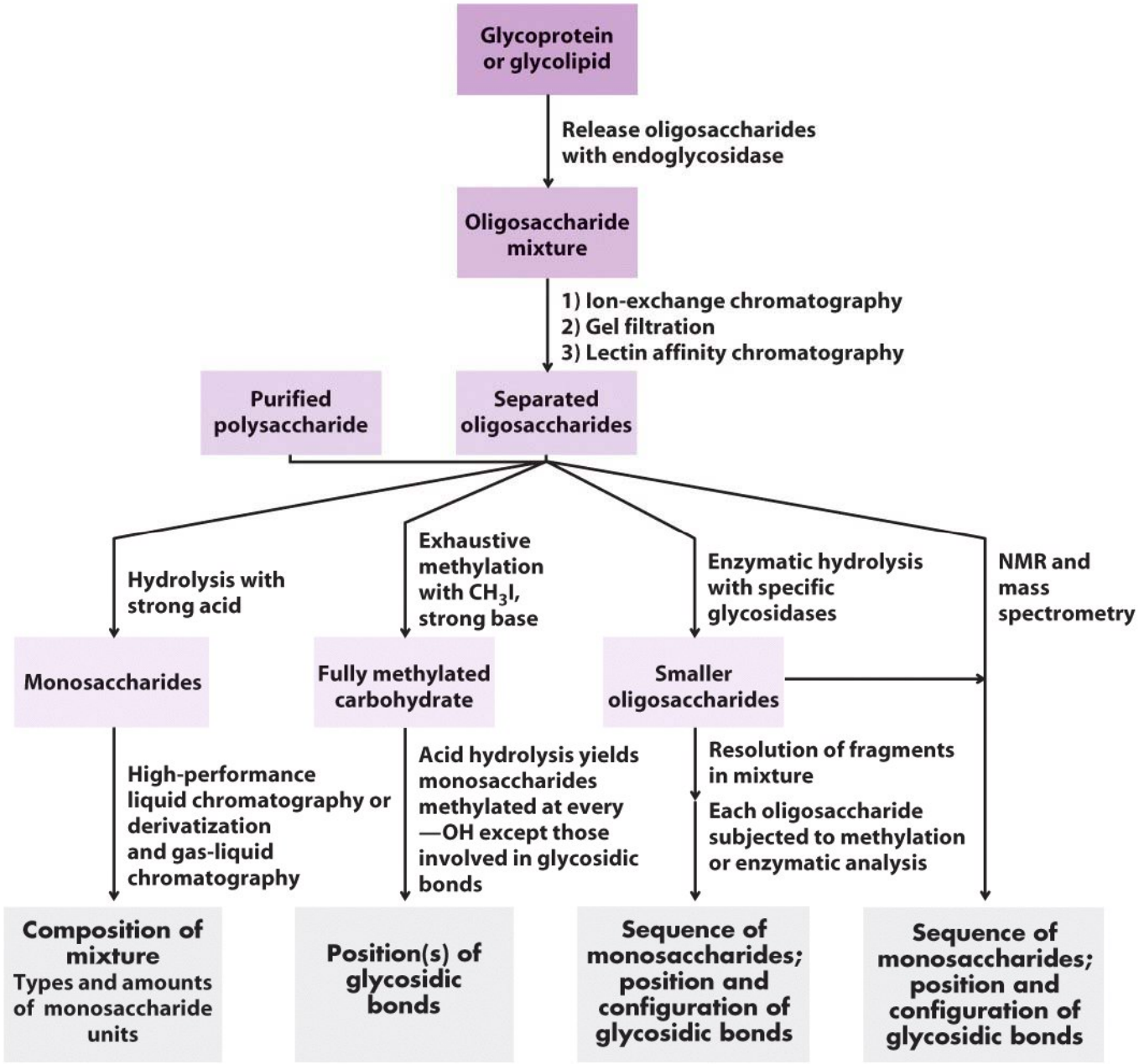

(a) O-linked
(b) N-linked
GalNAc
Ser
GlcNAc
Asn
Examples:
Examples:
Ser/Thr
Ser/Thr
Asn
Asn
Asn
GlcNAc
Man
Gal
Neu5Ac
Fuc
GalNAc


GlcNAc
Man
Glc
Gal
AbeOAc
Rha
Kdo
Hep
n≥10
O-Specific chain
Core
Lipid A




Glycoprotein ligand for integrin
Glycoprotein ligand for P-selectin
Integrin
P-selectin
Free T lymphocyte
Capillary endothelial cell
Rolling
Adhesion
Site of inflammation
Extravasation
Blood flow


Virus
Bacterium
Lymphocyte
Oligosaccharide chain
Plasma membrane protein
Glycolipid
Toxin
P-selectin
(a)
(b)
(c)
(d)
(e)
Mannose 6-phosphate receptor/lectin
(f)
Enzyme
Mannose 6-phosphate residue on newly synthesized protein
Trans Golgi
Enzyme
Lysosome


Glycoprotein or glycolipid
Release oligosaccharides with endoglycosidase
Oligosaccharide mixture
1) Ion-exchange chromatography
2) Gel filtration
3) Lectin affinity chromatography
Purified polysaccharide
Separated oligosaccharides
Hydrolysis with strong acid
Exhaustive methylation with CH_3I, strong base
Enzymatic hydrolysis with specific glycosidases
NMR and mass spectrometry
Monosaccharides
Fully methylated carbohydrate
Smaller oligosaccharides
High-performance liquid chromatography or derivatization and gas-liquid chromatography
Acid hydrolysis yields monosaccharides methylated at every —OH except those involved in glycosidic bonds
Resolution of fragments in mixture
Each oligosaccharide subjected to methylation or enzymatic analysis
Composition of mixture
Types and amounts of monosaccharide units
Position(s) of glycosidic bonds
Sequence of monosaccharides; position and configuration of glycosidic bonds
Sequence of monosaccharides; position and configuration of glycosidic bonds