Chem 352 – Lecture 5 Carbohydrates

Question for the Day: Unlike amino acids, which owe their diversity to a diverse array of functional groups, monosaccharides feature primarily two functional groups, hydroxyl groups and either a ketone or aldehyde group. What, then, do monosaccharides owe their diversity to?

1

Introduction to Carbohydrates

Carbohydrates are included as one of the major classes of biological molecules:

- Proteins
- Nucleic acids
- Carbohydrates
- Lipids

2

Introduction to Carbohydrates

- Carbohydrates provide a major source of energy for living organisms.
- They also play major structural, protective and communication roles.

3-1

Introduction to Carbohydrates

- Carbohydrates provide a major source of energy for living organisms.
- They also play major structural, protective and communication roles.

3-2

Introduction to Carbohydrates

- Carbohydrates provide a major source of energy for living organisms.
- They also play major structural, protective and communication roles.

3-3

Introduction to Carbohydrates

Carbohydrates are chemically simple, but structurally complex

- $(CH_2O)_n$

Like amino acid, simple sugars (monosaccharides) can combine to form polymers.

- **monosaccharides** (monomer)
- **oligosaccharides** (several monomers linked together)
- **polysaccharides** (many monomers linked together

4

Monosaccharides

Monosaccharides are

- either **Aldoses**
  - polyhydroxylaldehydes
- or **Ketoses**
  - polyhydroxylketones

Classes based on number of carbons

- triose
- tetrose
- pentose
- hexose

5

Monosaccharides

Trioses

- L and D Glyceraldehyde
  - Contains a chiral carbon
  - Fischer projections
- Dihydroxyacetone

6-1

Monosaccharides

Trioses

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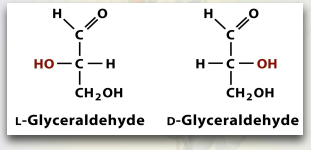
  - Contains a chiral carbon
  - Fischer projections



6-2

Monosaccharides

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6-3

Monosaccharides

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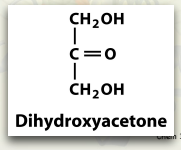

Dihydroxyacetone

6-4

Monosaccharides

Trioses

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  - Contains a chiral carbon
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- Dihydroxyacetone

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6-5

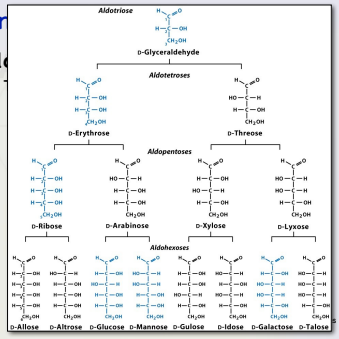
Monosaccharides

- **Aldoses**
  - Tretroses through hexoses

7-1

Mor

- **Al**



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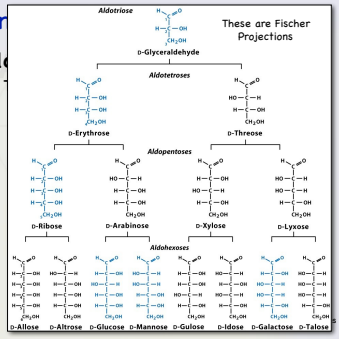
Mor

- **Al**



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7-3

Mor

- **Al**

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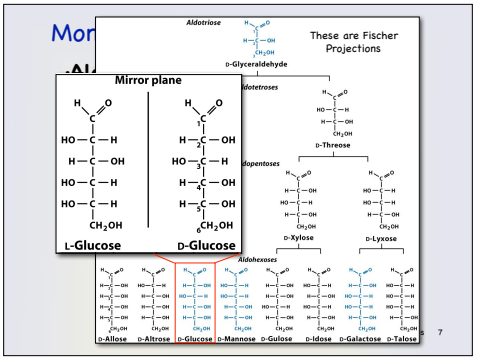

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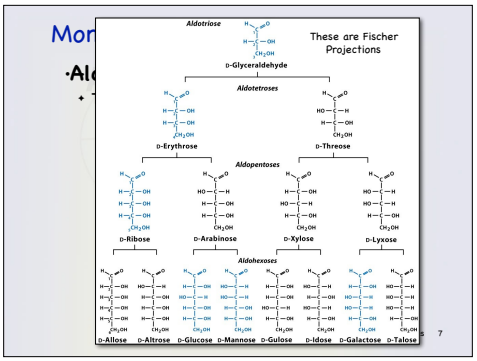

7-5

Monosaccharides

- **Aldoses**
  - Tetroses through hexoses

7-6

Monosaccharides

Tetroses through hexoses

- This figure shows only the D-**enantantiomers**
- The L-**enantiomers** are mirror images of the D-**enantiomers**.
- Members of an enantiomeric pair are are distinguished using the chirial carbon that is **furthest** from the carbonyl group.
- Most of the monosaccharides that we will encounter are D-enantiomers.

8-1

Monosaccharides

Tetroses through hexoses

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- The L es of the D-end
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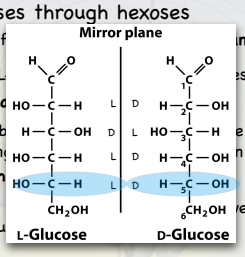

8-2

Monosaccharides

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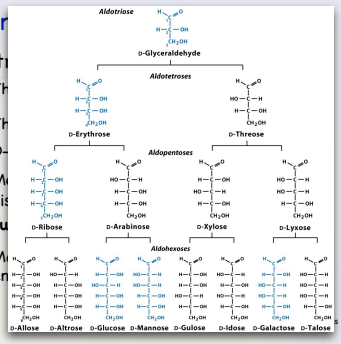

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Monosaccharides

Tretroses through hexoses

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8-5

Monosaccharides

·Types of optical isomers

- **Enantiomers** are stereoisomers that are mirror images of one another
- **Epimer** are stereoisomers having more than one chiral carbon that differ from one another at just one chiral carbon.
- **Diastereomers** are stereoisomers having more than one chiral carbon that differ from one another at multiple chiral carbons.

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Monosaccharides

Ketoses

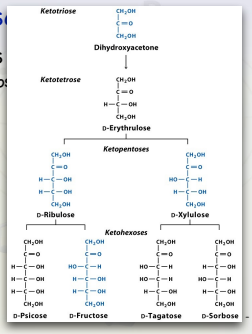
- Tretroses through hexoses

10-1

Monos

Ketoses

- Tetros



10-2

Monosaccharides

Ketoses

- Tetroses through hexoses

10-3

Monosaccharides

- The ones to remember
  - Aldoses
    - trisoes
      - D-glyceraldehyde
    - pentoses
      - D-ribose
    - hexoses
      - D-glucose
      - D-mannose
      - D-galactose

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Mo

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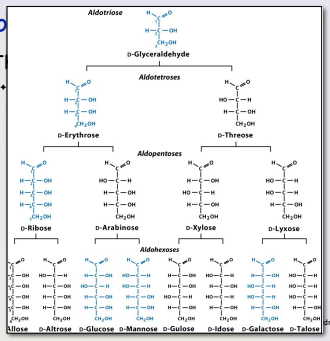

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Mo

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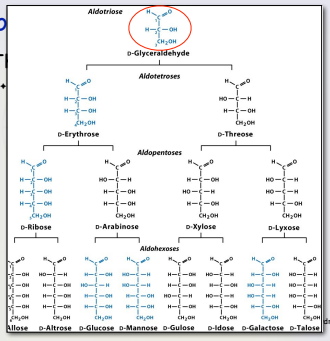

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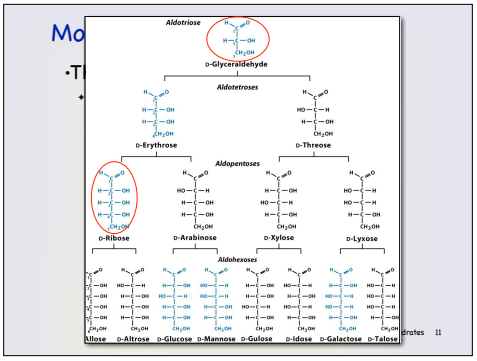

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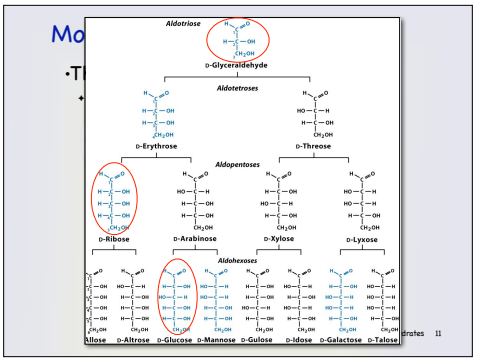

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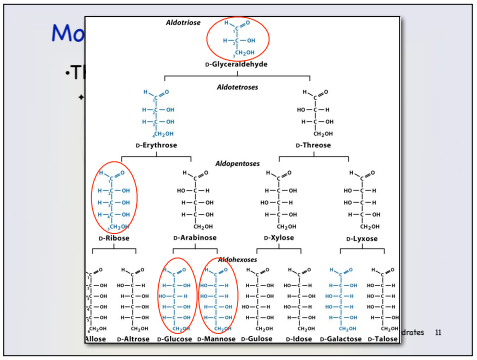

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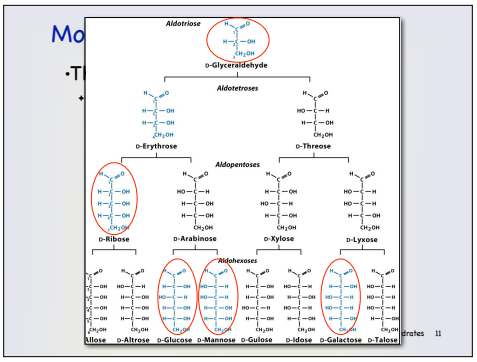


11-7

Monosaccharides

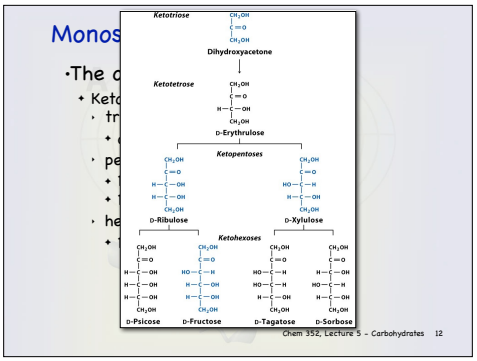
- The ones to remember
  - Aldoses
    - trioses
      - D-glyceraldehyde
    - pentoses
      - D-ribose
    - hexoses
      - D-glucose
      - D-mannose
      - D-galactose

11-8

Monosaccharides

- The ones to remember
  - Ketoses
    - trisoes
      - dihydroxyacetone
    - pentoses
      - D-ribulose
      - D-xylulose
    - hexoses
      - D-fructose

12-1



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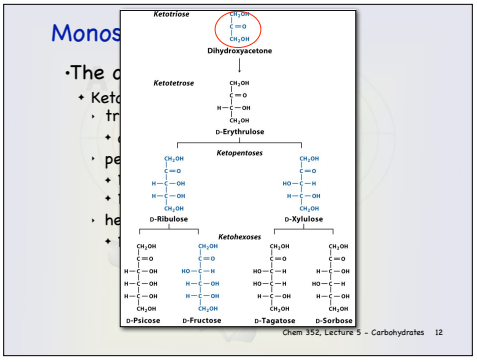

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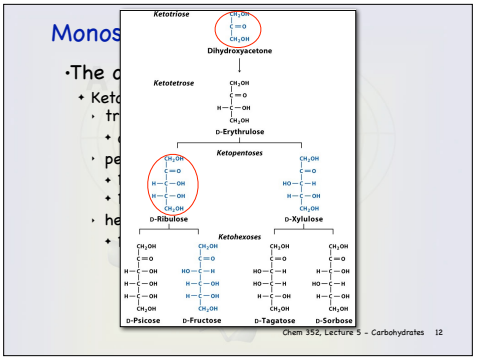

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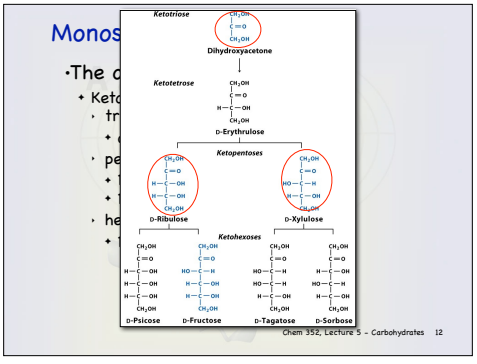

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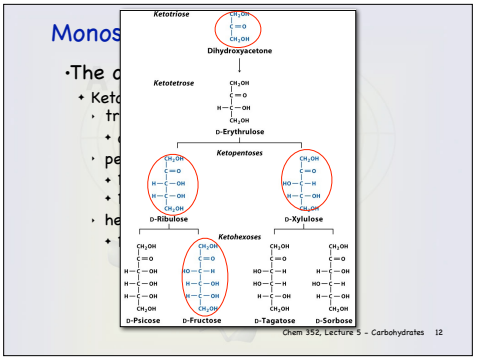


12-6

Monosaccharides

- The ones to remember
  - Ketoses
    - trisoes
      - dihydroxyacetone
    - pentoses
      - D-ribulose
      - D-xylulose
    - hexoses
      - D-fructose

12-7

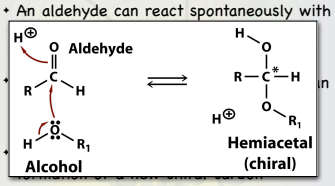
Monosaccharides

- Cyclization of aldoses and ketoses
  - An aldehyde can react spontaneously with an alcohol to form a **hemiacetal**.
  - A ketone can react spontaneously with an alcohol to form a **hemiketal**.
  - Both of these reactions leads to the formation of a new chiral carbon

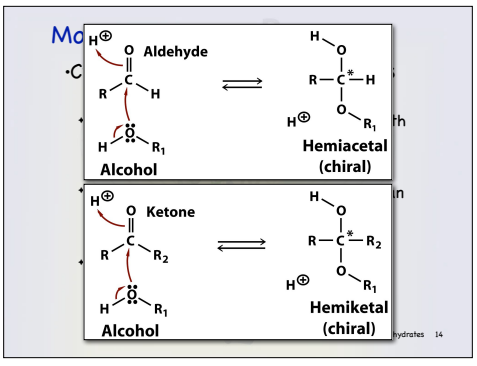
13-1

Monosaccharides

- Cyclization of aldoses and ketoses
  - An aldehyde can react spontaneously with



13-2



14-1

Monosaccharides

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14-2

Monosaccharides

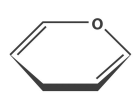
- Cyclization of aldoses and ketoses
  - The six-member rings are called **pyranose** rings
  - The five-member rings are called **furanose** rings.

15-1

Monosaccharides

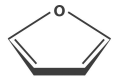
- Cyclization of aldoses and ketoses
  - The six- **pyranose** rings
  - The five- **furanose** rings.

(a)



Pyran

(b)



Furan

15-2

Monosaccharides

- Cyclization of aldoses and ketoses
  - The six-member rings are called **pyranose** rings
  - The five-member rings are called **furanose** rings.

15-3

Monosaccharides

- Cyclization of aldoses and ketoses
  - For aldoses and ketoses, this reaction occurs intramolecularly and leads to a cyclic molecule.
  - The chiral hemiacetal or hemiketal carbon is called the **anomeric carbon.**
    - The new stereoisomers are designated α (-OH down) and β **anomers** (-OH up).
  - **Haworth projections** are used to represent the cyclic form of monosaccharides.

16-1

Monosaccharides

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- Fo… occurs in… m…
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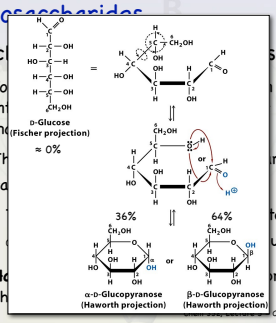
  - …ted
- He… resent th…



16-2

Monosaccharides

·Cyclization of aldoses and ketoses

- For aldoses and ketoses, this reaction occurs intramolecularly and leads to a cyclic molecule.
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16-3

Monosaccharides

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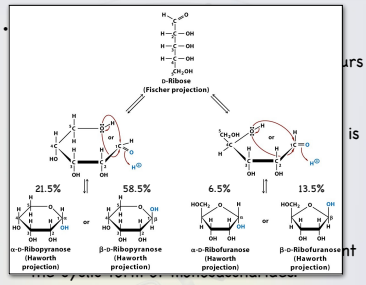

16-4

Monosaccharides

·Cyclization of aldoses and ketoses

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- **Haworth projections** are used to represent the cyclic form of monosaccharides.

16-5

Monosaccharides

·Cyclization of aldoses and ketoses

- **pyranose** rings
  - D-glucopyranose (aldohexose)
  - D-mannopyranose (aldohexose)
  - D-galactopyranose (aldohexose)
- **furanose** rings
  - D-fructofuranose (ketohexose)
  - D-ribofuranose (aldopentose)

17

Monosaccharides

- Cyclization of aldoses and ketoses
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  - A ketone can react spontaneously with an alcohol to form a **hemiketal**.
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18-1

Monosaccharides

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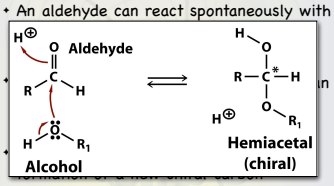


18-2

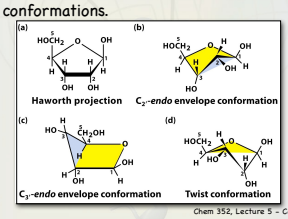
Monosaccharides

- Conformations of Monosaccharides
  - Monosaccharides can have different conformations.

19-1

Monosaccharides

- Conformations of Monosaccharides
  - Monosaccharides can have different conformations.



19-2

Monosaccharides

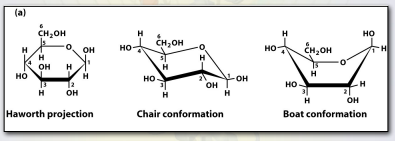
- Conformations of Monosaccharides
  - Monosaccharides can have different conformations.

19-3

Monosaccharides

·Conformations of Monosaccharides

- Monosaccharides can have different conformations.



19-4

Monosaccharides

·Conformations of Monosaccharides

- Monosaccharides can have different conformations.

19-5

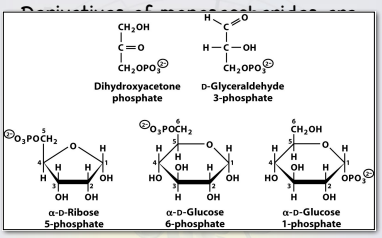
Monosaccharides

·Derivatives of monosaccharides are produced by chemical modifications.

- **Phosphate esters**
- **Deoxy sugars**
  - One of the hydroxyl groups is replaced with a hydrogen
- **Amino sugars**
  - One of the hydroxyl groups is replaced with an amino group.

20-1

Monosaccharides



20-2

Monosaccharides

·Derivatives of monosaccharides are produced by chemical modifications.

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20-3

Monosaccharides

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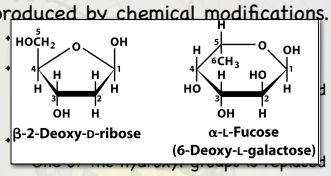

20-4

Monosaccharides

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  - **Deoxy sugars**
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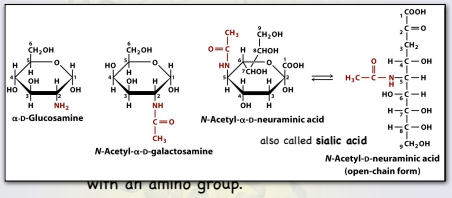
20-5

Monosaccharides

- Derivatives of monosaccharides are



with an amino group.

20-6

Monosaccharides

- Derivatives of monosaccharides are produced by chemical modifications.
  - **Phosphate esters**
  - **Deoxy sugars**
    - One of the hydroxyl groups is replaced with a hydrogen
  - **Amino sugars**
    - One of the hydroxyl groups is replaced with an amino group.

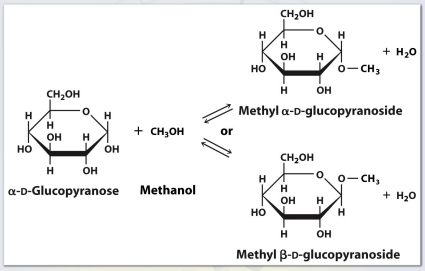
20-7

Glycosides

- The **hemiacetal** or **hemiketal** carbon can go on to react with the **hydroxyl group** from another molecule to form an **acetal** or **ketal**.
  - The bond formed is called a **glycosidic bond**.
  - Glycosidic bonds are used to connect one monosaccharide to another.

21-1

Glycosides



21-2

Glycosides

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  - The bond formed is called a **glycosidic bond**.
  - Glycosidic bonds are used to connect one monosaccharide to another.

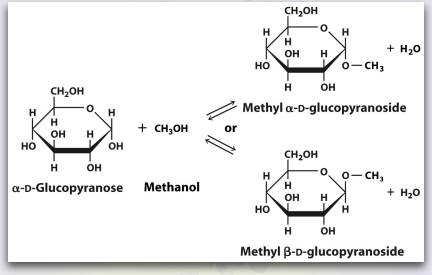
21-3

Glycosides

- Unlike hemiacetals and hemiketals, acetals and ketals cannot open and close dynamically,
  - The glycosidic bond blocks a pyranose or furanose ring from reopening again.
- In cells, glycosidic bond formation is enzyme catalyzed and requires a source of free energy.

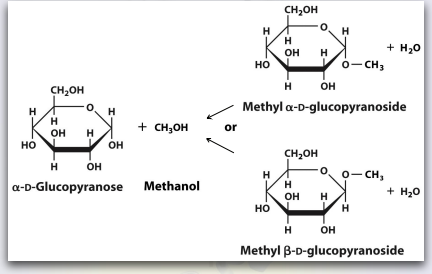
22-1

Glycosides



22-2

Glycosides



22-3

Glycosides

- Unlike hemiacetals and hemiketals, acetals and ketals cannot open and close dynamically,
  - The glycosidic bond blocks a pyranose or furanose ring from reopening again.
- In cells, glycosidic bond formation is enzyme catalyzed and requires a source of free energy.

22-4

Monosaccharides

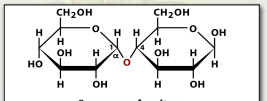
Cyclized aldoses and ketoses tend to get locked into the following ring configurations

- pyranose rings
  - D-glucopyranose (aldohexose)
  - D-mannopyranose (aldohexose)
  - D-galactopyranose (aldohexose)
- furanose rings
  - D-fructofuranose (ketohexose)
  - D-ribofuranose (aldopentose)

23

Glycosides

- The glycosidic bond can be used to connect two monosacchrides together to form **disaccharides**.
- Important disaccharides include:
  - **Maltose** (obtained from starch)

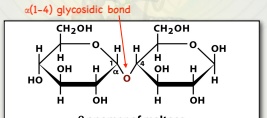


β anomer of maltose
(α-D-Glucopyranosyl-(1→4)-β-D-glucopyranose)

24-1

Glycosides

- The glycosidic bond can be used to connect two monosacchrides together to form **disaccharides**.
- Important disaccharides include:
  - **Maltose** (obtained from starch)

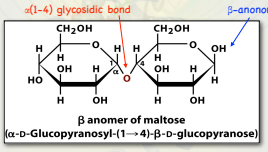


β anomer of maltose
(α-D-Glucopyranosyl-(1→4)-β-D-glucopyranose)

24-2

Glycosides

- The glycosidic bond can be used to connect two monosacchrides together to form **disaccharides**.
- Important disaccharides include:
  - **Maltose** (obtained from starch)

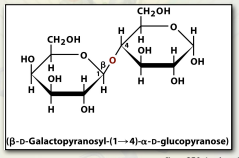


β anomer of maltose
(α-D-Glucopyranosyl-(1→4)-β-D-glucopyranose)

24-3

Glycosides

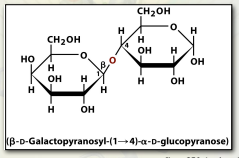
- The glycosidic bond can be used to connect two monosacchrides together to form a **disaccharides**.
- Important disaccharides include:
  - **Lactose**



25-1

Glycosides

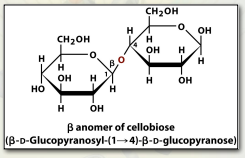
- The glycosidic bond can be used to connect two monosacchrides together to form a **disaccharides**.
- Important disaccharides include:
  - **Lactose** (milk sugar)



25-2

Glycosides

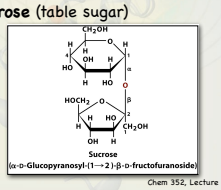
- The glycosidic bond can be used to connect two monosacchrides together to form a **disaccharides**.
- Important disaccharides include:
  - **Cellobiose** (obtained from cellulose)



26

Glycosides

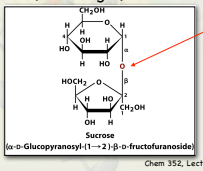
- The glycosidic bond can be used to connect two monosacchrides together to form a **disaccharides**.
- Important disccharides include
  - **Sucrose** (table sugar)



27-1

Glycosides

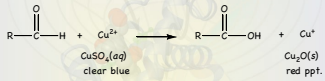
- The glycosidic bond can be used to connect two monosacchrides together to form a **disaccharides**.
- Important disccharides include
  - **Sucrose** (table sugar)



27-2

Glycosides

- Because a hemiacetal or hemiketal can easily open to expose either an aldehyde or ketone, they can still serve as reducing agents.



  - This is used to distinguish the two monosaccharides in a disaccharide as the **reducing** and the **nonreducing** ends.

28

Glycosides

Not all disaccharides have a reducing end

- For example, the disaccharide sucrose contains both and acetal and a ketal, but no hemiacetal or hemiketal.

29-1

Glycosides

Not

end

- F

b

h

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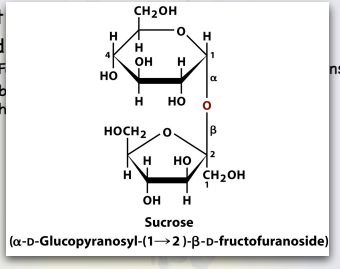


Sucrose

(α-D-Glucopyranosyl-(1→2)-β-D-fructofuranoside)

29-2

Glycosides

Not all disaccharides have a reducing end

- For example, the disaccharide sucrose contains both and acetal and a ketal, but no hemiacetal or hemiketal.

29-3

Glycosides

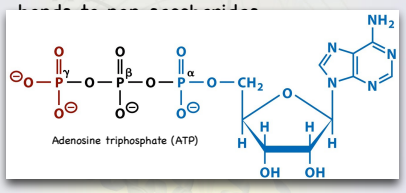
Monosaccharides also from glycosidic bonds to non-saccharides.

- For example, nucleotides.
  - ATP
  - UDP-glucose
  - NAD and NADP
  - FMN and FAD

30-1

Glycosides

Monosaccharides also from glycosidic bonds to non-saccharides.



30-2

Glycosides

Monosaccharides also from glycosidic bonds to non-saccharides.

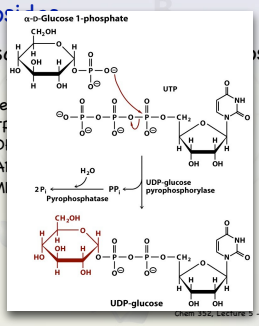
- For example, nucleotides.
  - ATP
  - UDP-glucose
  - NAD and NADP
  - FMN and FAD

30-3

Glycosides

Monosaccharides also from glycosidic bonds to non-saccharides.

- For example, nucleotides.
  - ATP
  - UDP-glucose
  - NAD and NADP
  - FMN and FAD



30-4

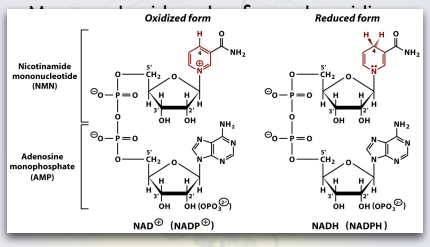
Glycosides

Monosaccharides also from glycosidic bonds to non-saccharides.

- For example, nucleotides.
  - ATP
  - UDP-glucose
  - NAD and NADP
  - FMN and FAD

30-5

Glycosides



30-6

Glycosides

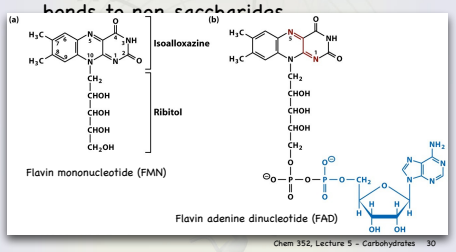
Monosaccharides also from glycosidic bonds to non-saccharides.

- For example, nucleotides.
  - ATP
  - UDP-glucose
  - NAD and NADP
  - FMN and FAD

30-7

Glycosides

Monosaccharides also from glycosidic bonds to non-saccharides.



30-8

Glycosides

Monosaccharides also from glycosidic bonds to non-saccharides.

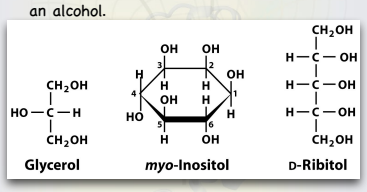
- For example, nucleotides.
  - ATP
  - UDP-glucose
  - NAD and NADP
  - FMN and FAD

30-9

Glycosides

Ribitol is an example of a **sugar alcohol**.

- Where the aldehyde or ketone is reduced to an alcohol.



31

Polysaccharides

Expanding the formation of glycosidic bonds can be extended to form polymers of monosaccharides called **glycans**.

- **Homoglycans** contain repeating units of the same monosaccharide.
- **Heteroglycans** contain multiple units of different monosaccharides

32-1

Polysaccharides

TABLE 8.2 Structures of some common polysaccharides

Polysaccharide[a]	Component(s)[b]	Linkage(s)
Storage homoglycans		
Starch		
Amylose	Glc	α-(1 → 4)
Amylopectin	Glc	α-(1 → 4), α-(1 → 6) (branches)
Glycogen	Glc	α-(1 → 4), α-(1 → 6) (branches)
Structural homoglycans		
Cellulose	Glc	β(1 → 4)
Chitin	GlcNAc	β(1 → 4)
Heteroglycans		
Glycosaminoglycans	Disaccharides (amino sugars, sugar acids)	Various
Hyaluronic acid	GlcUA and GlcNAc	β(1 → 3), β(1 → 4)

[a]Polysaccharides are unbranched unless otherwise indicated.
[b]Glc, Glucose; GlcNAc, *N*-acetylglucosamine; GlcUA, D-glucuronate.

32-2

Polysaccharides

Expanding the formation of glycosidic bonds can be extended to form polymers of monosaccharides called **glycans**.

- **Homoglycans** contain repeating units of the same monosaccharide.
- **Heteroglycans** contain multiple units of different monosaccharides

32-3

Polysaccharides

Storage forms of glucose

- Starch (plants)
  - Amylose
  - Amylopectin
- Glycogen (animals)

Structural polysaccharides

- Cellulose (plant)
- Chitin (animals)

33-1

Polysaccharides

St

-
-

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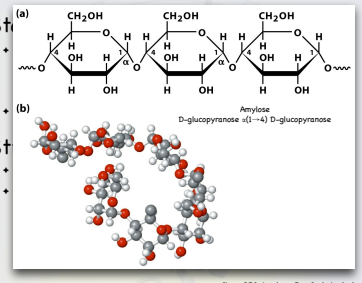
-
-



33-2

Polysaccharides

Storage forms of glucose

- Starch (plants)
  - Amylose
  - Amylopectin
- Glycogen (animals)

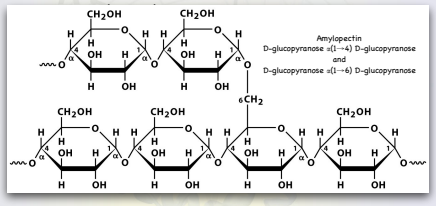
Structural polysaccharides

- Cellulose (plant)
- Chitin (animals)

33-3

Polysaccharides

Storage forms of glucose



33-4

Polysaccharides

Storage forms of glucose

- Starch (plants)
  - Amylose
  - Amylopectin
- Glycogen (animals)

Structural polysaccharides

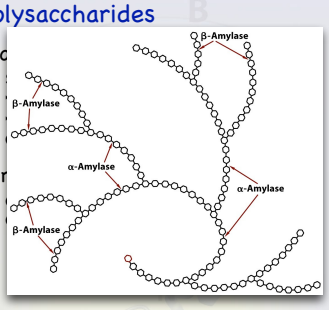
- Cellulose (plant)
- Chitin (animals)

33-5

Polysaccharides

Sto

Str

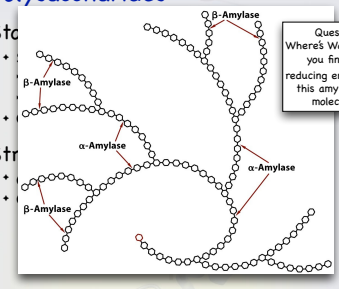


33-6

Polysaccharides

Sto

Str



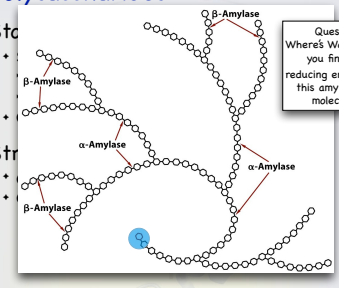
Question
Where's Waldo? Can you find the reducing end of this this amylopectin molecule?

33-7

Polysaccharides

Sto

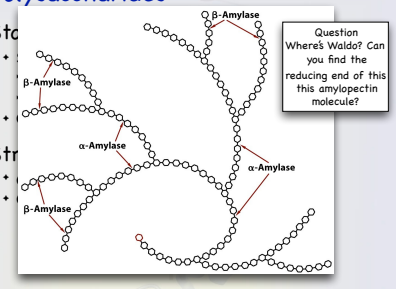
Str



Question
Where's Waldo? Can you find the reducing end of this this amylopectin molecule?

33-8

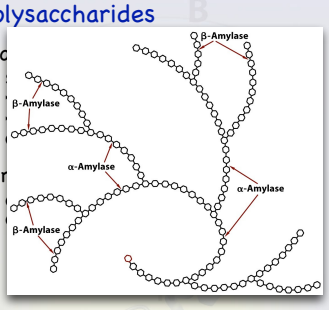
Polysaccharides



Question
Where's Waldo? Can you find the reducing end of this this amylopectin molecule?

33-9

Polysaccharides



33-10

Polysaccharides

Storage forms of glucose

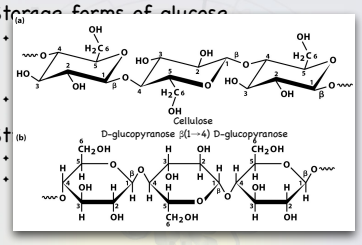
- Starch (plants)
  - Amylose
  - Amylopectin
- Glycogen (animals)

Structural polysaccharides

- Cellulose (plant)
- Chitin (animals)

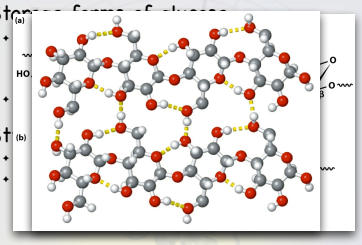
33-11

Polysaccharides



33-12

Polysaccharides



33-13

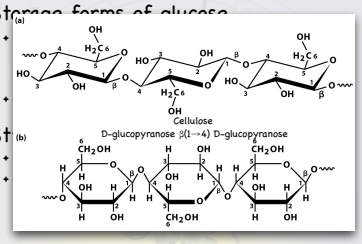
Polysaccharides

Storage forms of glucose

- Starch (plants)
  - Amylose
  - Amylopectin
- Glycogen (animals)

Structural polysaccharides

- Cellulose (plant)
- Chitin (animals)



33-14

Polysaccharides

Storage forms of glucose

- Starch (plants)
  - Amylose
  - Amylopectin
- Glycogen (animals)

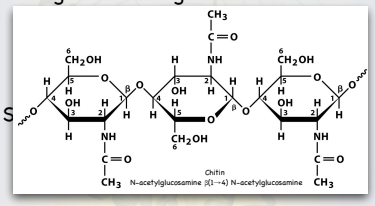
Structural polysaccharides

- Cellulose (plant)
- Chitin (animals)

33-15

Polysaccharides

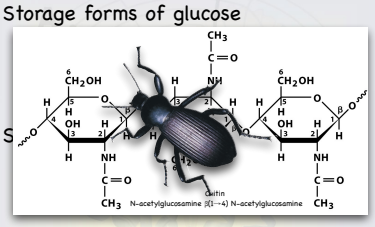
Storage forms of glucose



33-16

Polysaccharides

Storage forms of glucose



33-17

Polysaccharides

Storage forms of glucose

- Starch (plants)
  - Amylose
  - Amylopectin
- Glycogen (animals)

Structural polysaccharides

- Cellulose (plant)
- Chitin (animals)

33-18

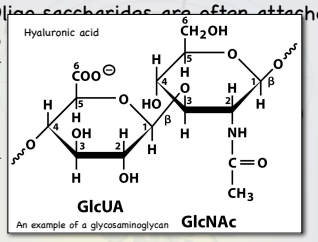
Glycoconjugates

- Oligo saccharides are often attached to biological molecules
  - To proteins and peptides
    - **Proteoglycans (connective tissue)**
    - **Peptidoglycans (bacterial cell walls)**
    - **Glycoproteins**
  - To lipids
    - **Glycolipids**

34-1

Glycoconjugates

- Oligo saccharides are often attached to

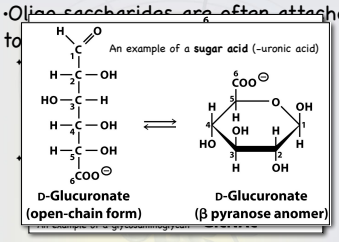


An example of a glycosaminoglycan

34-2

Glycoconjugates

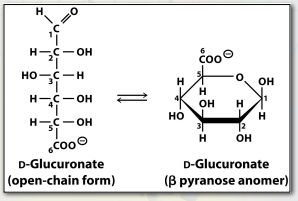
- Oligo saccharides are often attached to



34-3

Monosaccarides

- **Sugar acids** are sugars in which either the aldehyde or primary alcohol is oxidized to a carboxylic acid.



35

Monosaccarides

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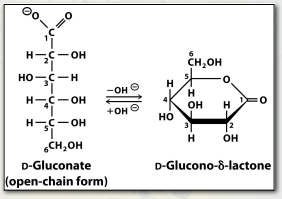


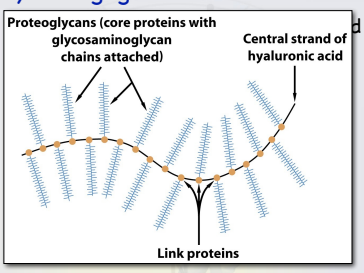
36

Glycoconjugates

- Oligo saccharides are often attached to biological molecules
  - To proteins and peptides
    - **Proteoglycans (connective tissue)**
    - **Peptidoglycans (bacterial cell walls)**
    - **Glycoproteins**
  - To lipids
    - **Glycolipids**

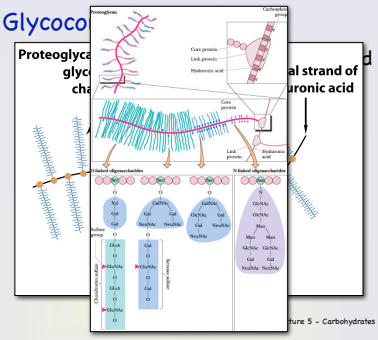
37-1

Glycoconjugates



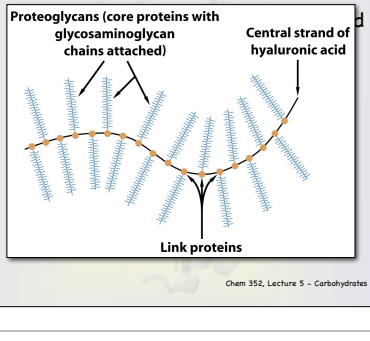
37-2

Glycoconjugates



37-3

Glycoconjugates



37-4

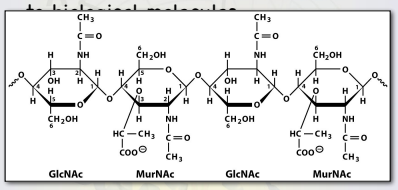
Glycoconjugates

- Oligo saccharides are often attached to biological molecules
  - To proteins and peptides
    - **Proteoglycans (connective tissue)**
    - **Peptidoglycans (bacterial cell walls)**
    - **Glycoproteins**
  - To lipids
    - **Glycolipids**

37-5

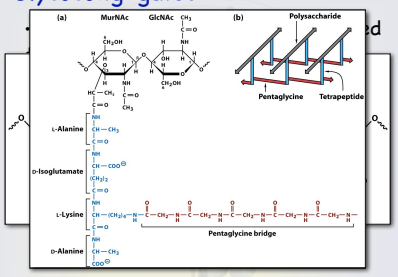
Glycoconjugates

•Oligo saccharides are often attached



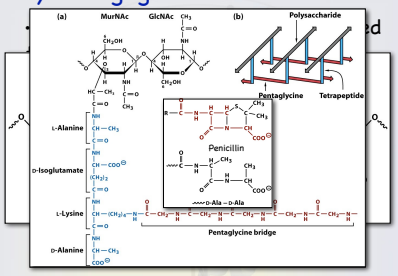
37-6

Glycoconjugates



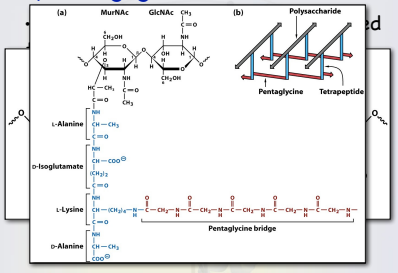
37-7

Glycoconjugates



37-8

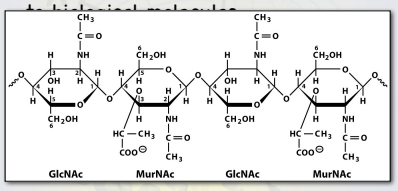
Glycoconjugates



37-9

Glycoconjugates

•Oligo saccharides are often attached



37-10

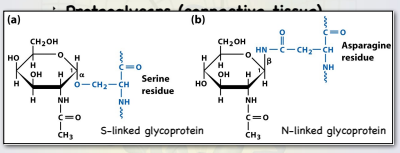
Glycoconjugates

- Oligo saccharides are often attached to biological molecules
  - To proteins and peptides
    - **Proteoglycans (connective tissue)**
    - **Peptidoglycans (bacterial cell walls)**
    - **Glycoproteins**
  - To lipids
    - **Glycolipids**

37-11

Glycoconjugates

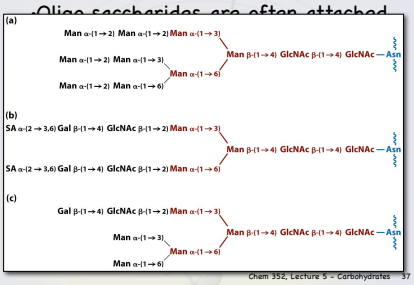
- Oligo saccharides are often attached to biological molecules
  - To proteins and peptides



37-12

Glycoconjugates

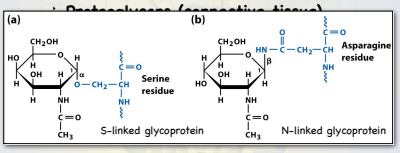
- Oligo saccharides are often attached to biological molecules
  - To proteins and peptides



37-13

Glycoconjugates

- Oligo saccharides are often attached to biological molecules
  - To proteins and peptides



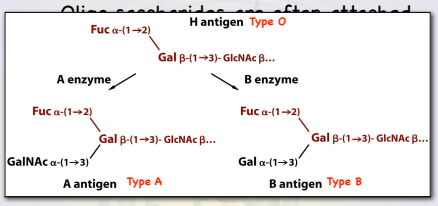
37-14

Glycoconjugates

- Oligo saccharides are often attached to biological molecules
  - To proteins and peptides
    - **Proteoglycans (connective tissue)**
    - **Peptidoglycans (bacterial cell walls)**
    - **Glycoproteins**
  - To lipids
    - **Glycolipids**

37-15

Glycoconjugates



37-16

Glycoconjugates

- Oligo saccharides are often attached to biological molecules
  - To proteins and peptides
    - **Proteoglycans (connective tissue)**
    - **Peptidoglycans (bacterial cell walls)**
    - **Glycoproteins**
  - To lipids
    - **Glycolipids**

37-17

Which Structures Do I Need to Know?

- Monosaccharide
  - D-glucose
  - D-galactose
  - D-mannose
  - D-fructose
  - D-ribose
- Disaccharides
  - D-lactose
  - D-maltose
  - D-cellobiose
  - D-sucrose

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Which Structures Do I Need to Know?

- Monosaccharide Derivatives
  - D-glucosamine
  - N-acetyl-D-glucosamine
  - D-gluconic acid
  - D-glucuronic acid
  - D-ribitol
- Polysaccharides
  - amylose
  - amylopectin
  - glycogen
  - cellulose
  - chitin

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Next Up

- Lecture 6 - Lipids and Membranes (Chapter 9)

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