

# Reactions of carbohydrates

Hemiacetal Formation

Reduction

Oxidation

Osazone Formation

Chain Shortening

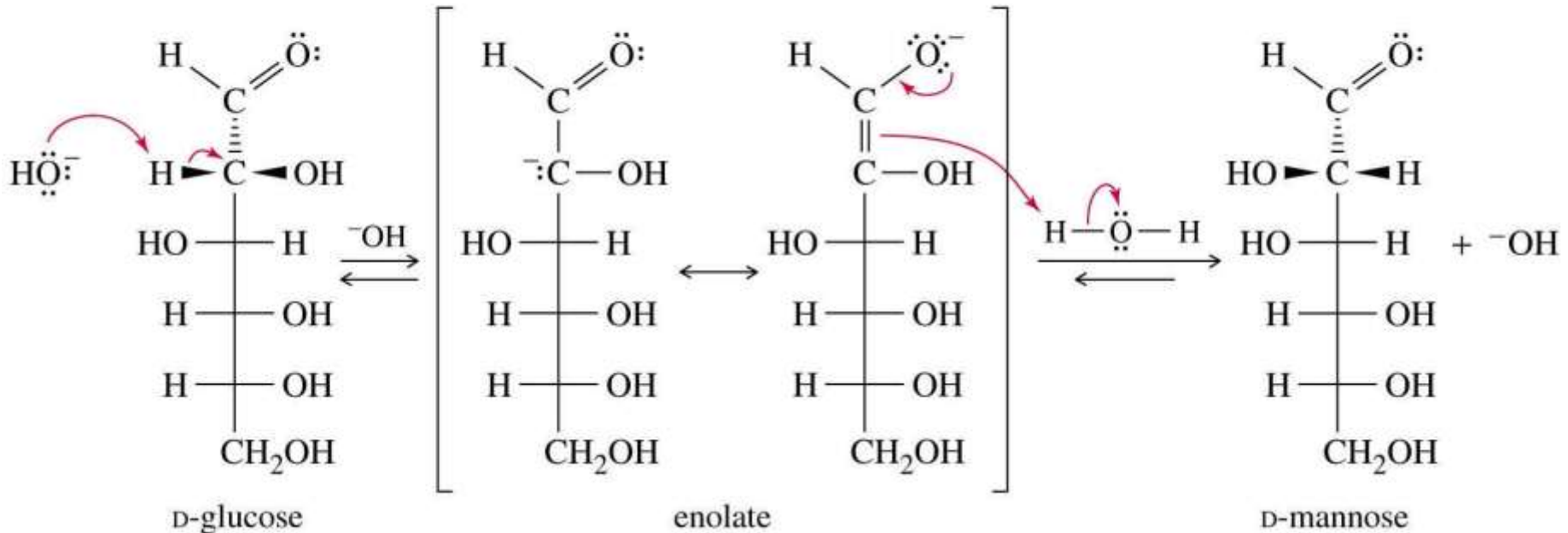
Chain Lengthening

# Epimerization

In base, H on C2 may be removed to form enolate ion.

Abstraction of the  $\alpha$  proton

Reprotonation



# Enediol Rearrangement

In base, the position of the C=O can shift.

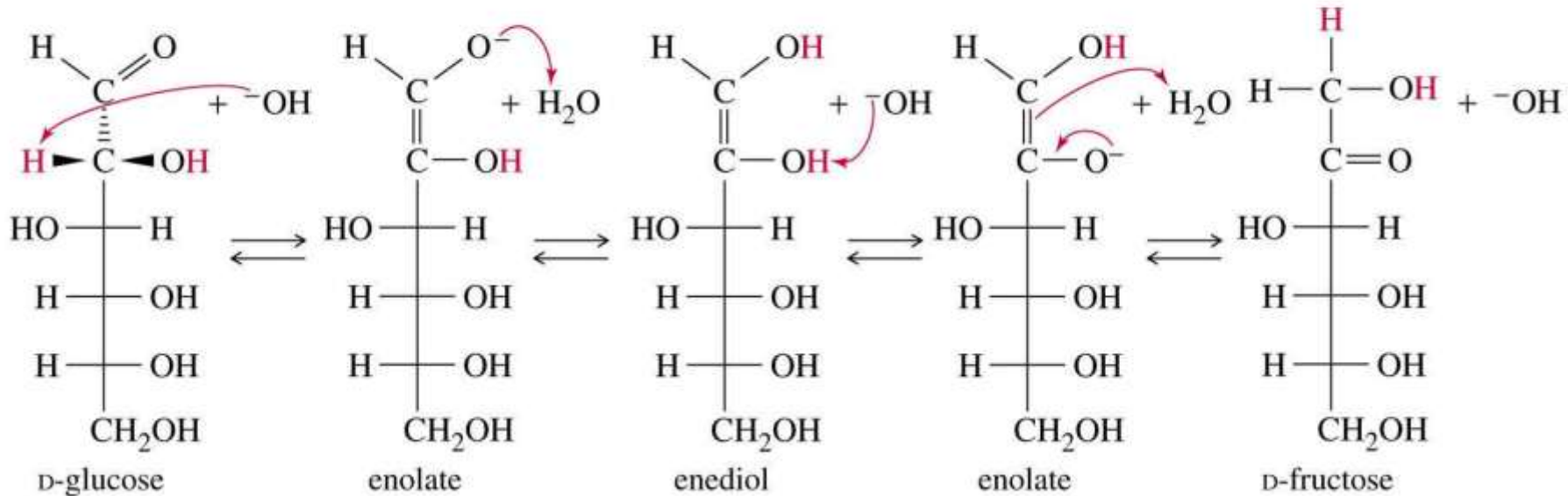
Chemists use acidic or neutral solutions of sugars to preserve their identity.

*Step 1: Remove the  $\alpha$  proton*

*Step 2: Reprotonate on O*

*Step 3: Deprotonate the O on C2*

*Step 4: Reprotonate on C1*

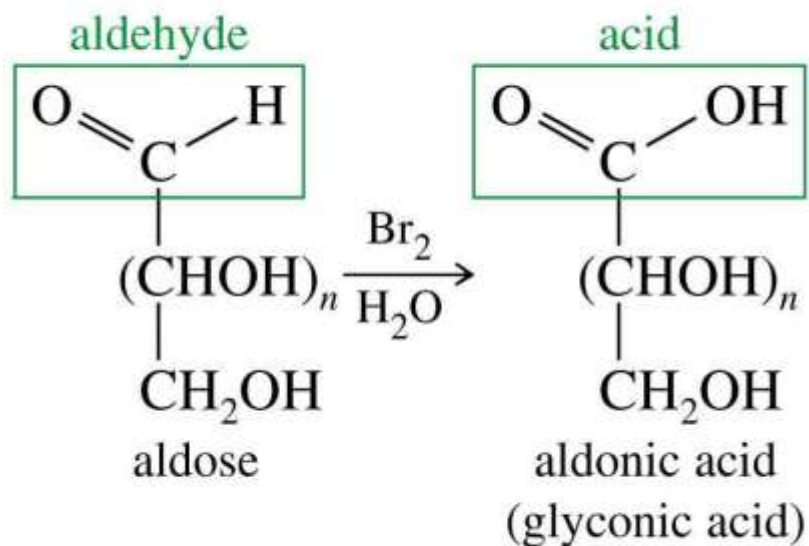


# Reduction of Simple Sugars

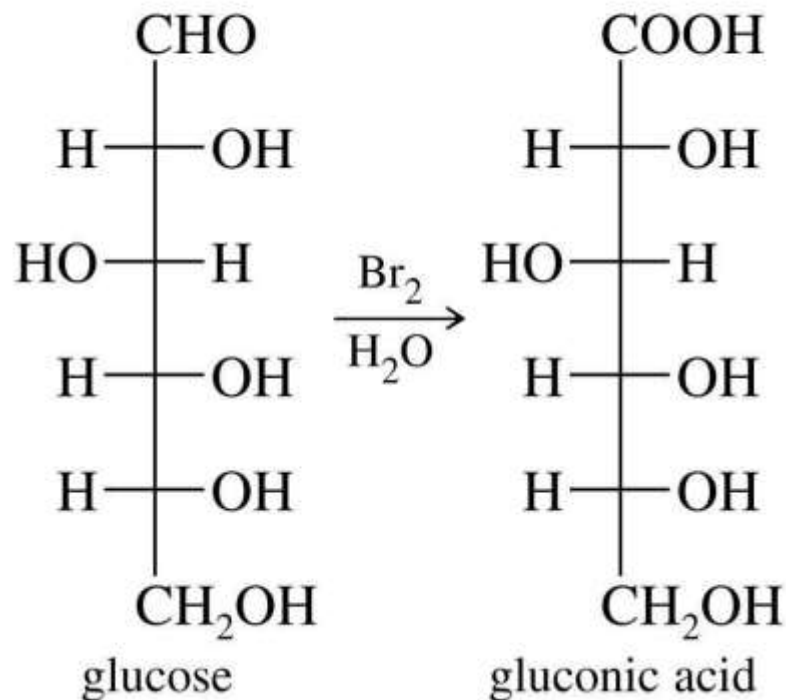
- C=O of aldoses or ketoses can be reduced to C-OH by  $\text{NaBH}_4$  or  $\text{H}_2/\text{Ni}$ .
- Name the sugar alcohol by adding *-itol* to the root name of the sugar.
- Reduction of D-glucose produces
- Reduction of D-fructose produces

# Oxidation by Bromine

Bromine water oxidizes aldehyde, but not ketone or alcohol.

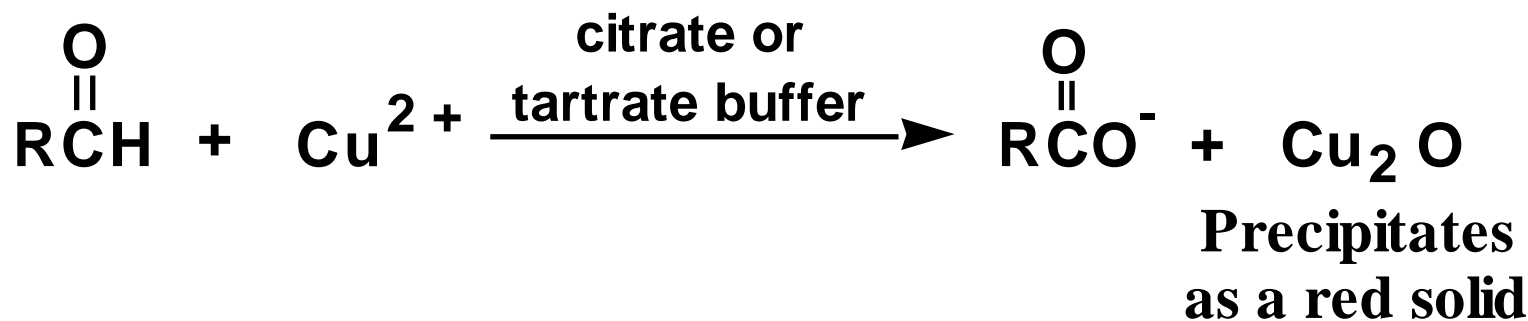
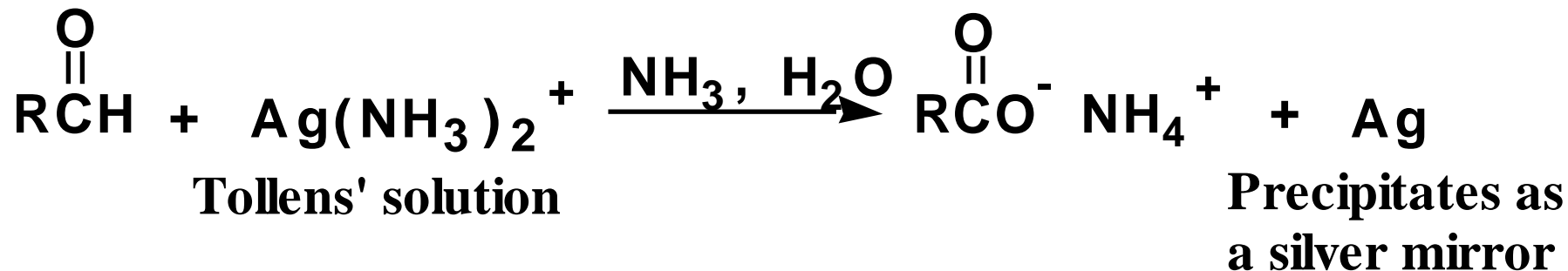


*Example*



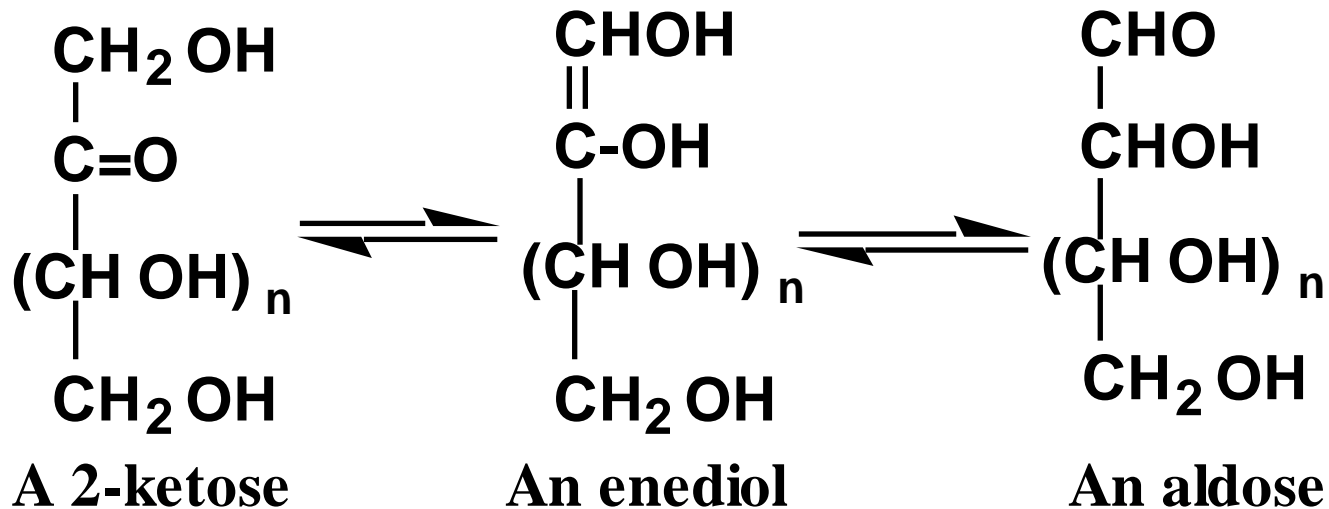
# Aldose Oxidation to Aldonic Acids

- Oxidation of the -CHO group of an aldose to a -CO<sub>2</sub>H group can be carried out using Tollens', Benedict's, or Fehling's solutions



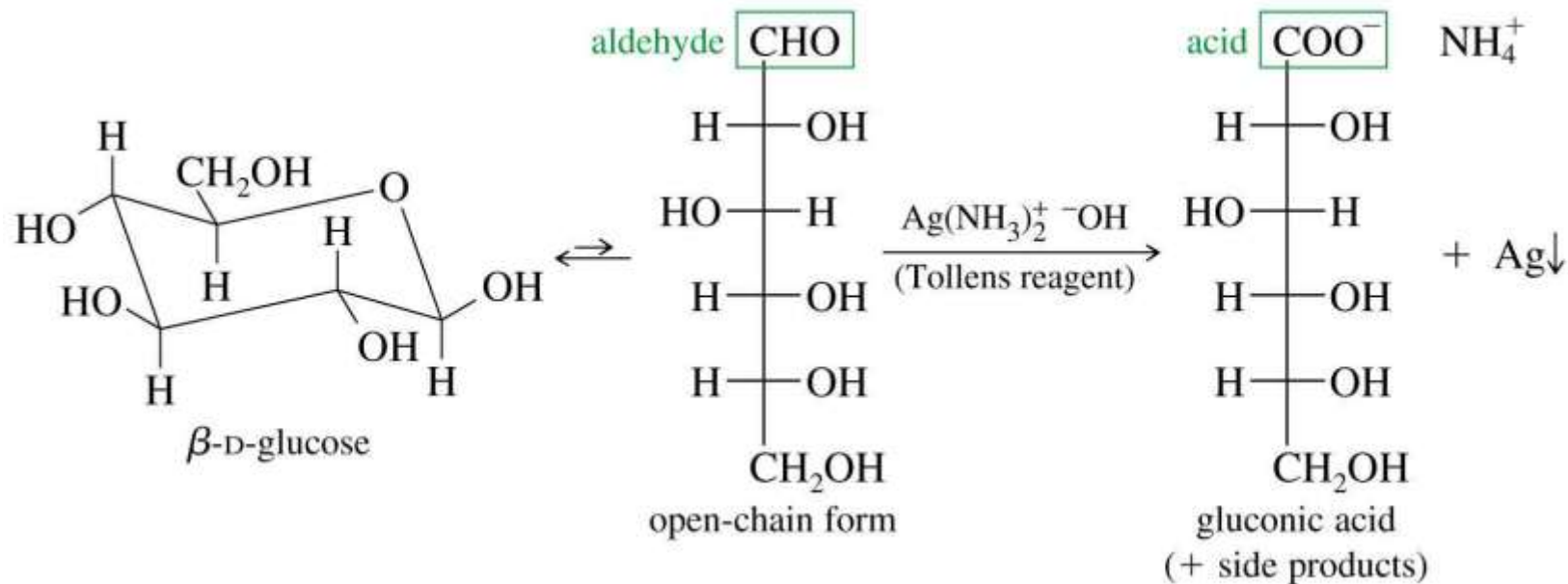
# Ketose Oxidation to Aldonic Acids

- 2-Ketoses are also oxidized by these reagents because, under the conditions of the oxidation, 2-ketoses equilibrate with isomeric aldoses



# Oxidation by Tollens Reagent

- Tollens reagent reacts with aldehyde, but the base promotes enediol rearrangements, so ketoses react too.
- Sugars that give a silver mirror with Tollens are called reducing sugars.
- All monosaccharides are reducing sugars

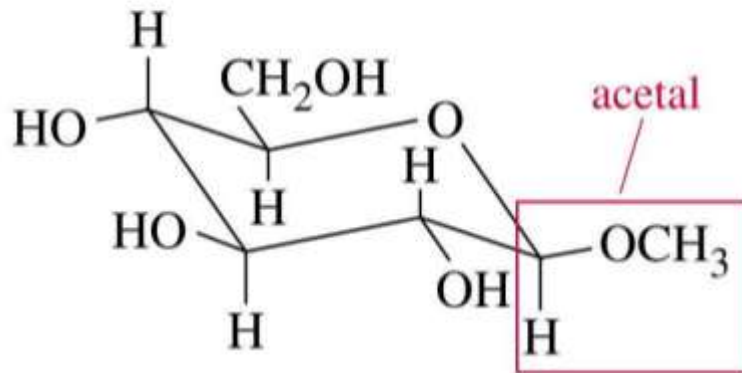




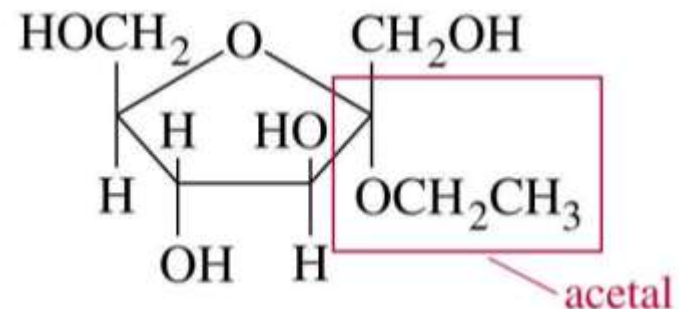
# Nonreducing Sugars

- Glycosides are acetals, which are stable in base, so they do not react with Tollens reagent.
- Some disaccharides are also acetals.
- All polysaccharides are also acetals.

## *Examples of nonreducing sugars*



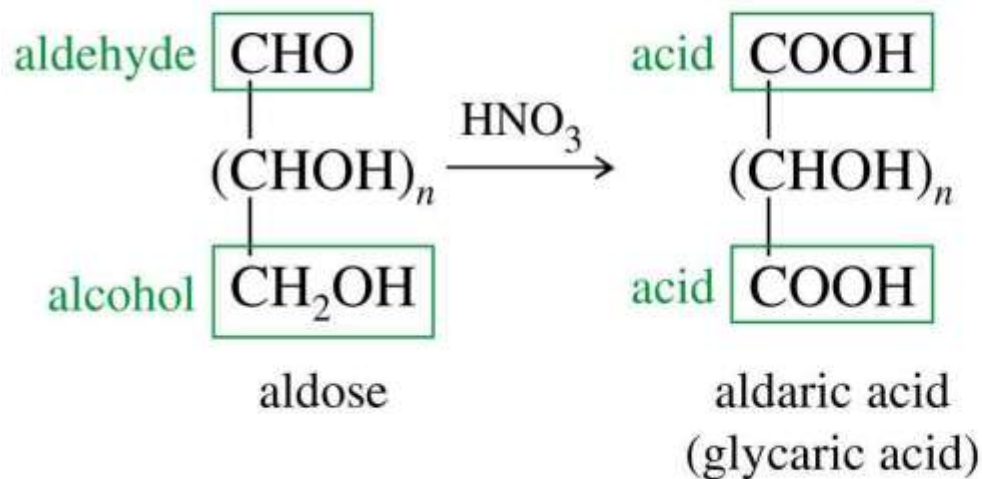
methyl β-D-glucopyranoside  
(or methyl β-D-glucoside)



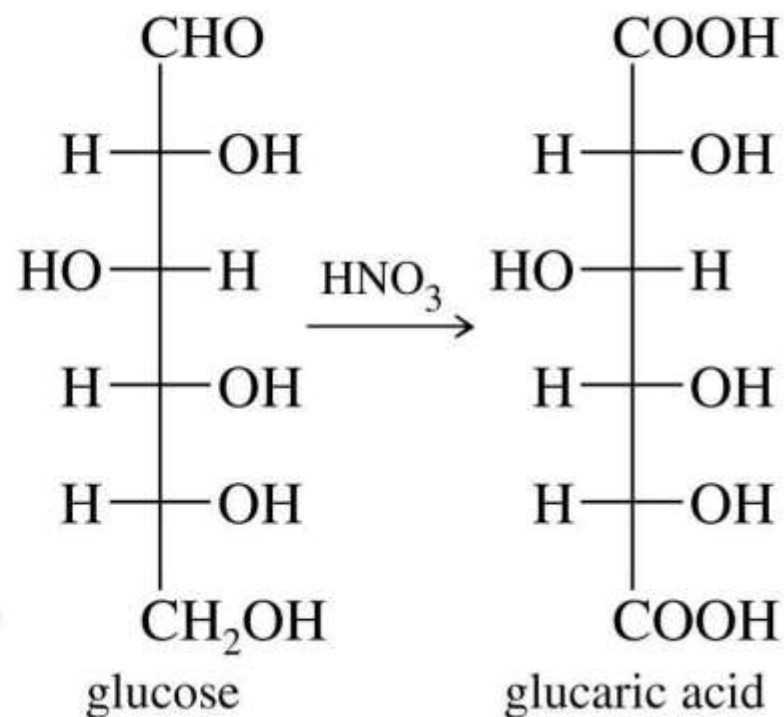
ethyl α-D-fructofuranoside  
(or ethyl α-D-fructoside)

# Oxidation by Nitric Acid

Nitric acid oxidizes both the aldehyde and the terminal alcohol.

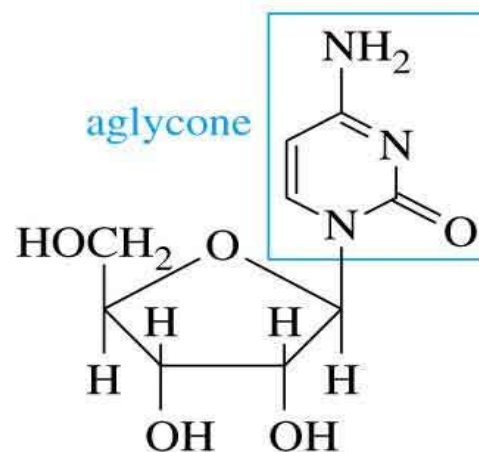
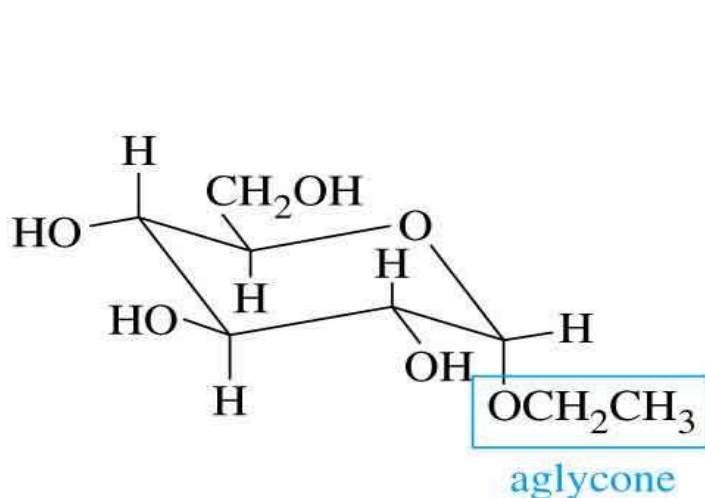


*Example*



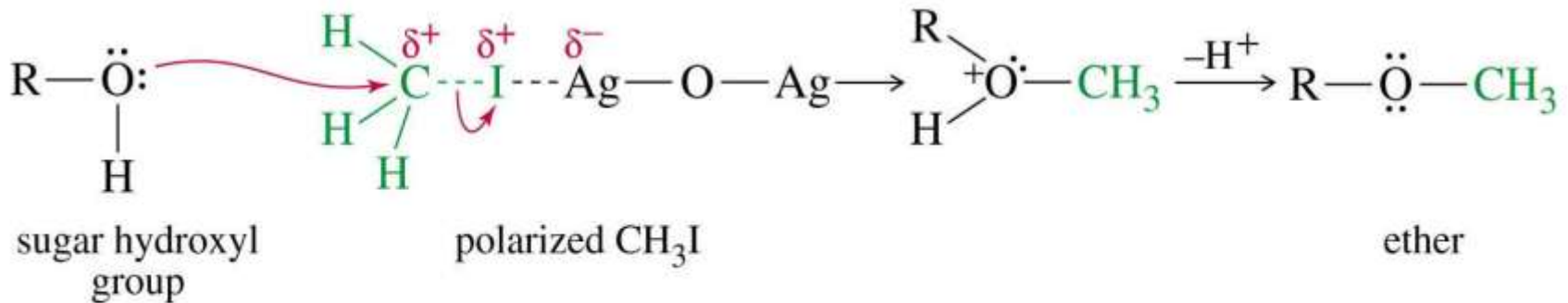
# Formation of Glycosides

- React the sugar with alcohol in acid.
- Since the open chain sugar is in equilibrium with its  $\alpha$ - and  $\beta$ -hemiacetal, both anomers of the acetal are formed.
- Aglycone is the term used for the group bonded to the anomeric carbon.

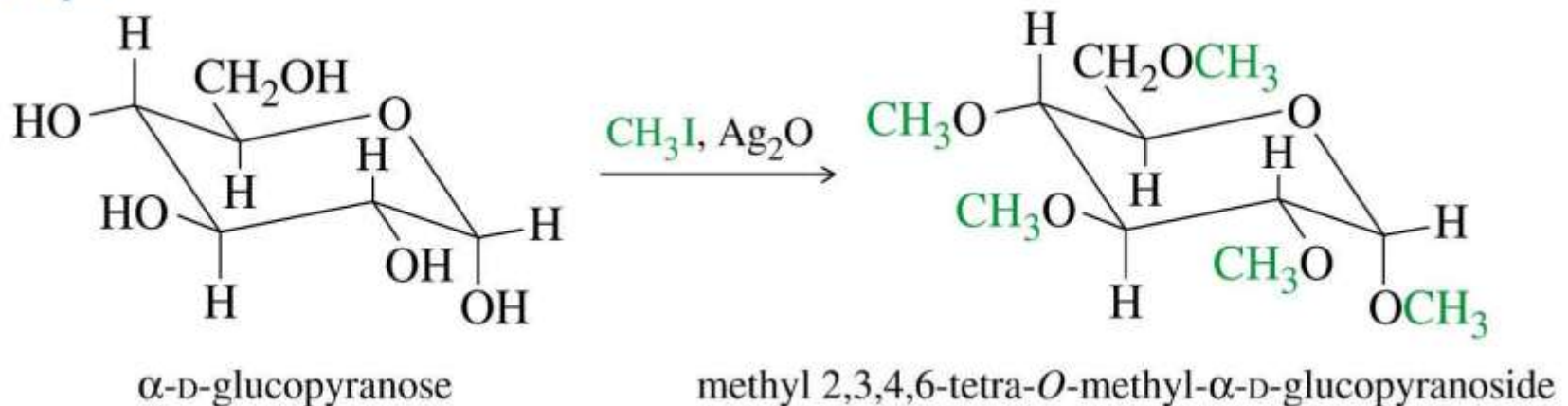


# Ether Formation

- Convert all -OH groups to -OR, using a modified Williamson synthesis, after converting sugar to acetal, stable in base.

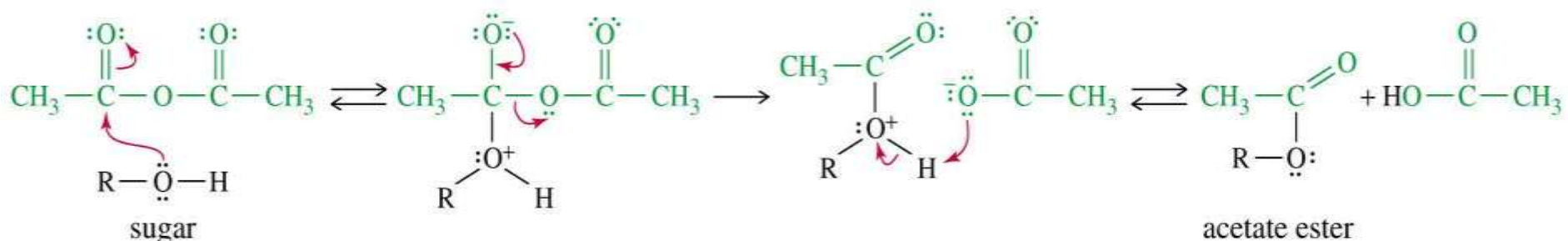


*Example*

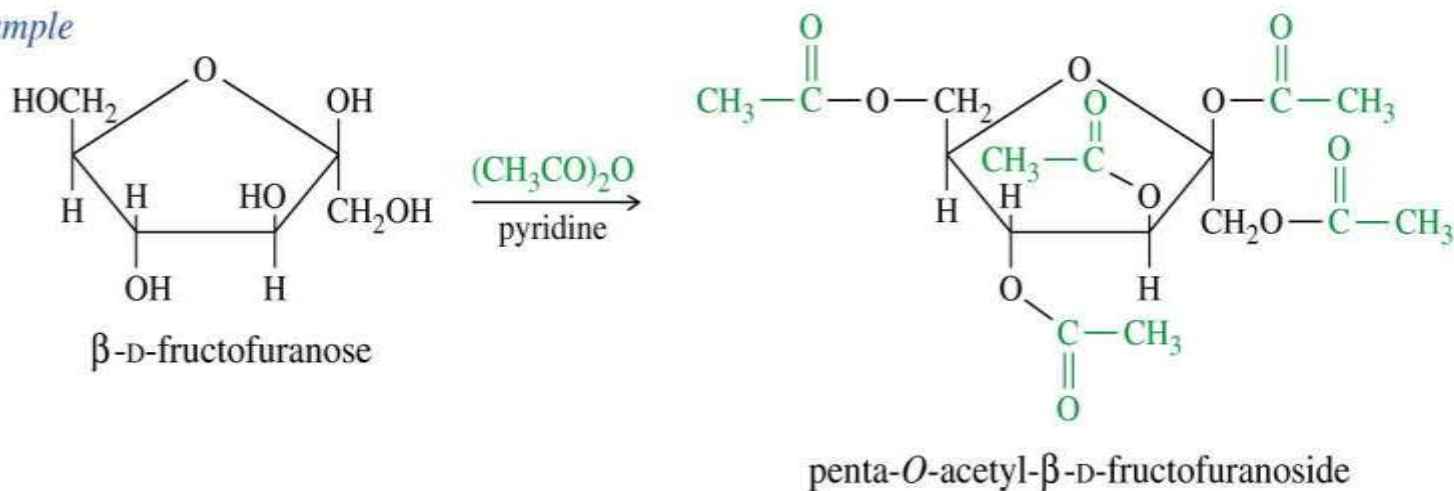


# Ester Formation

Acetic anhydride with pyridine catalyst converts all the oxygens to acetate esters.

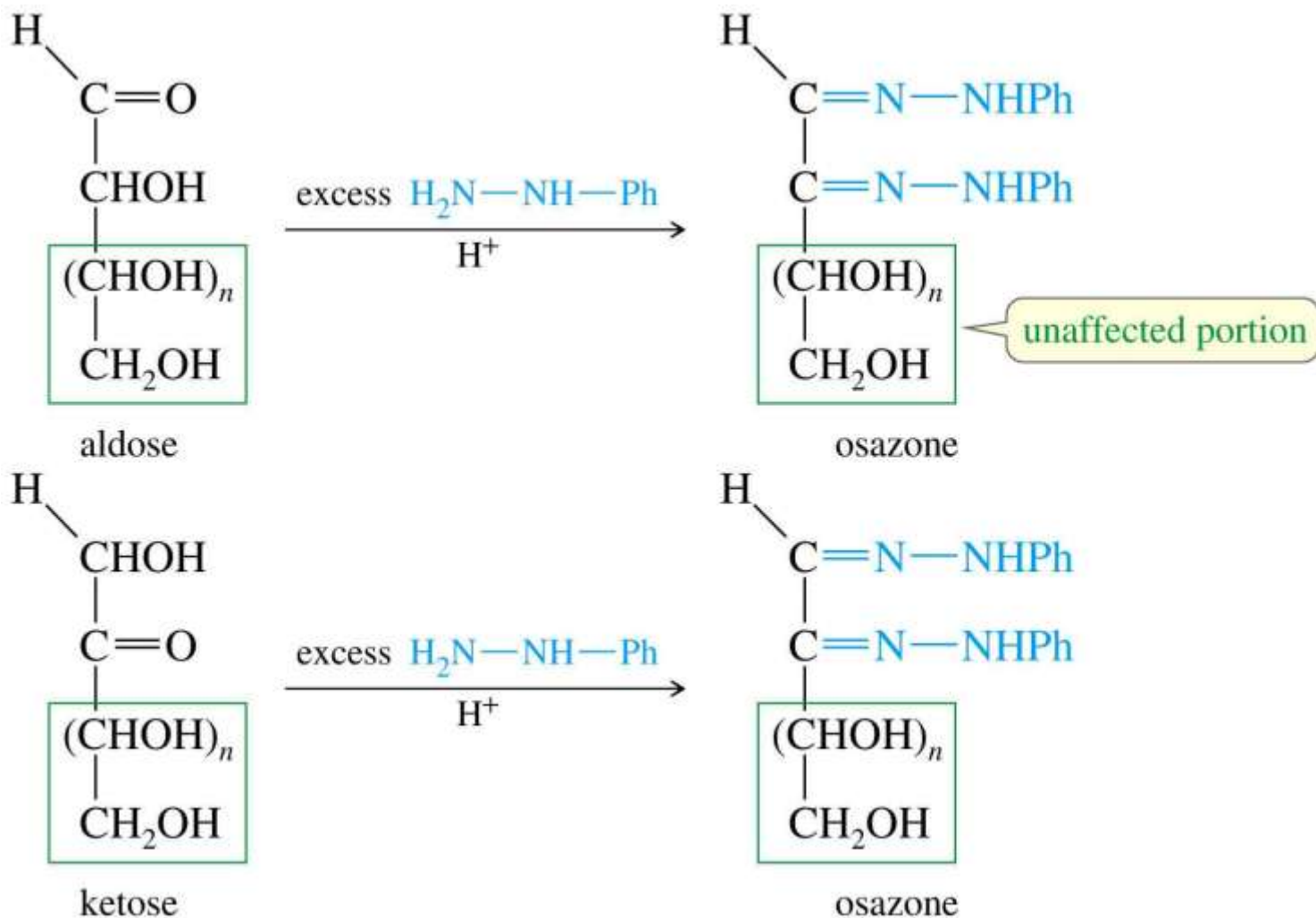


Example

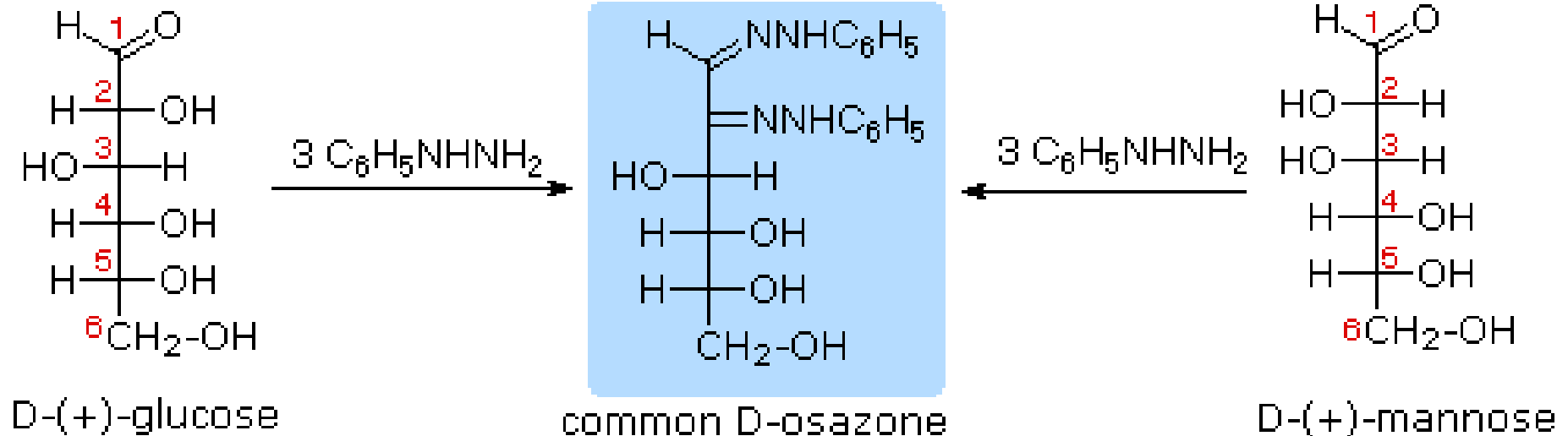
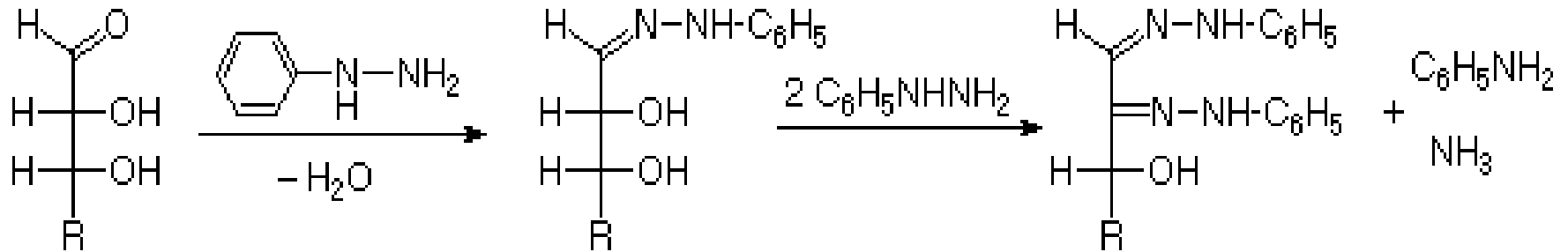


# Osazone Formation

Both C1 and C2 react with phenylhydrazine.

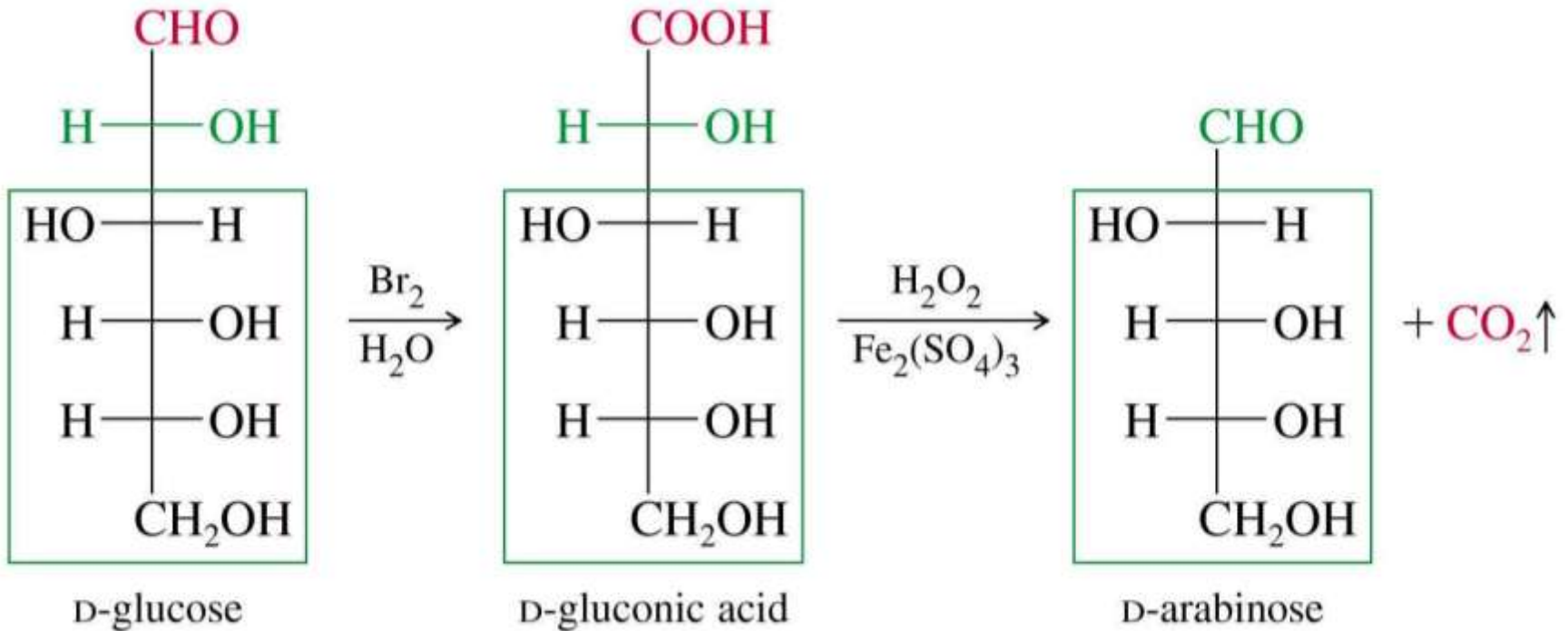


# Osazone



# Ruff Degradation

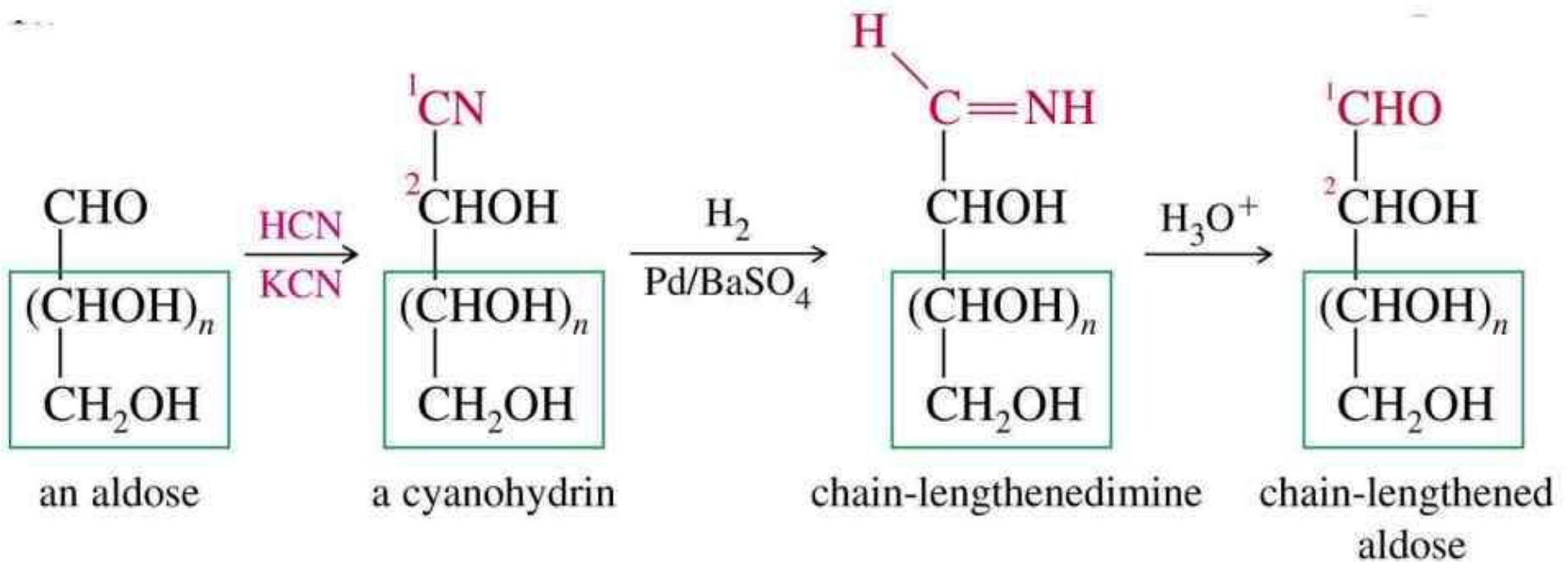
Aldose chain is shortened by oxidizing the aldehyde to -COOH, then decarboxylation.





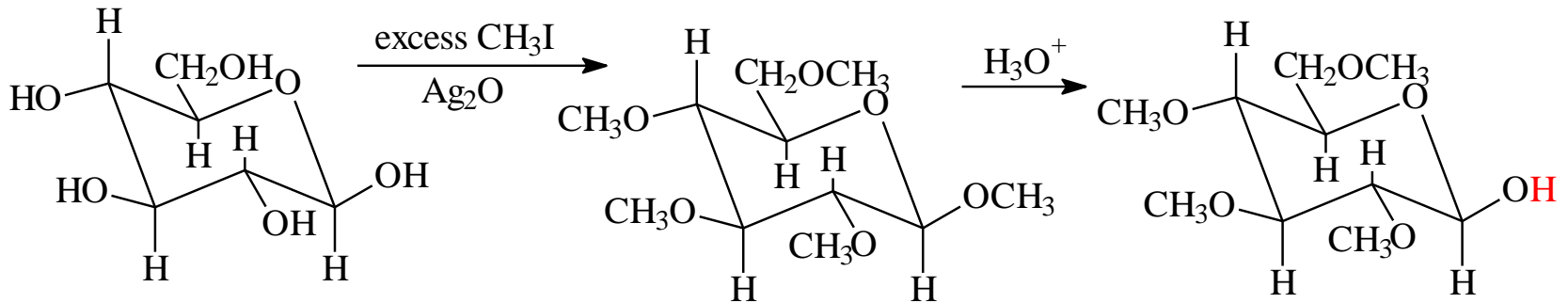
# Kiliani-Fischer Synthesis

- This process lengthens the aldose chain.
- A mixture of C2 epimers is formed.



# Determination of Ring Size

- Haworth determined the pyranose structure of glucose in 1926.
- The anomeric carbon can be found by methylation of the -OH's, then hydrolysis.

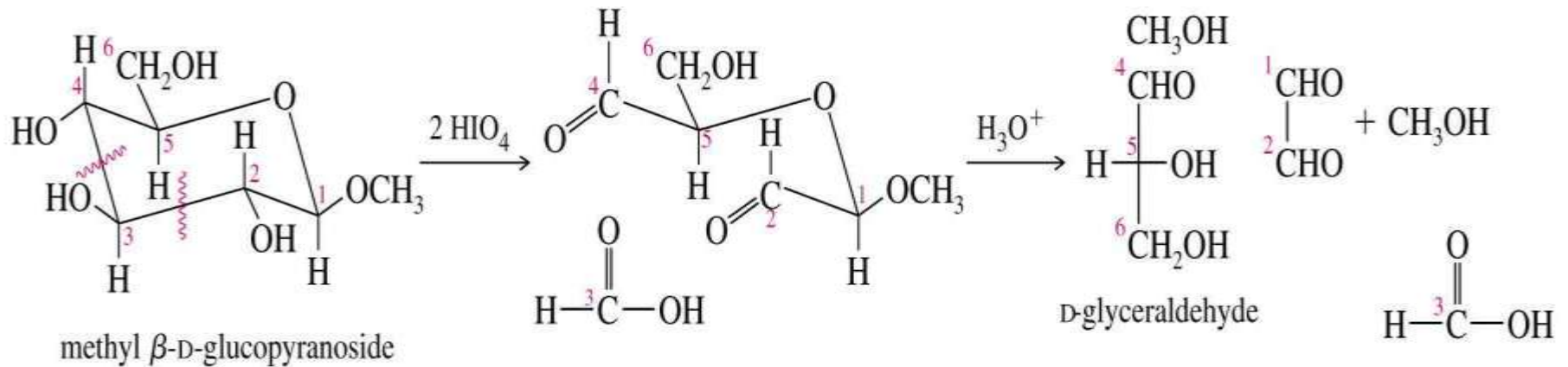


# Periodic Acid Reactions

- Periodic acid (  $\text{HIO}_4$  or  $\text{H}_5\text{IO}_6$  ) cleaves the C-C bond between an alcohol and an adjacent alcohol (vicinal) or carbonyl group.
- Does not affect ethers or acetals.
- Two carbonyl compounds are formed:
  - 1° alcohols oxidize to formaldehyde
  - 2° alcohols oxidize to aldehydes
  - aldehydes oxidize to formic acid
  - ketones oxidize to carboxylic acids
  - carboxylic acids oxidize to  $\text{CO}_2$

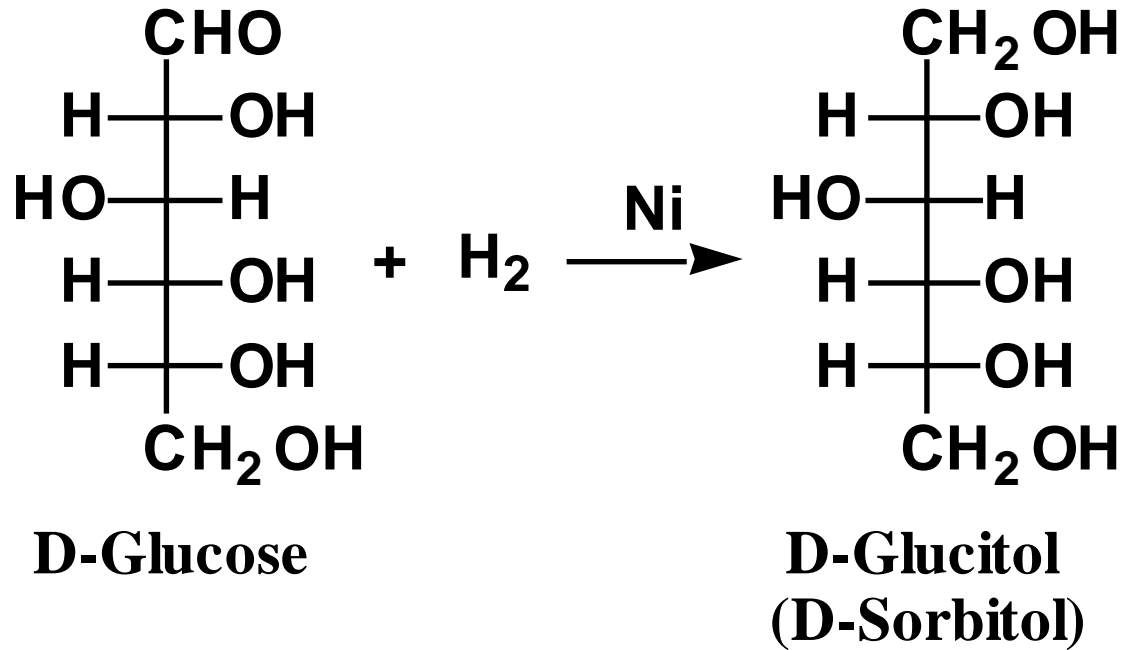
# Use of Periodic Acid Cleavage

- Separation and identification of the products determine the size of the ring.



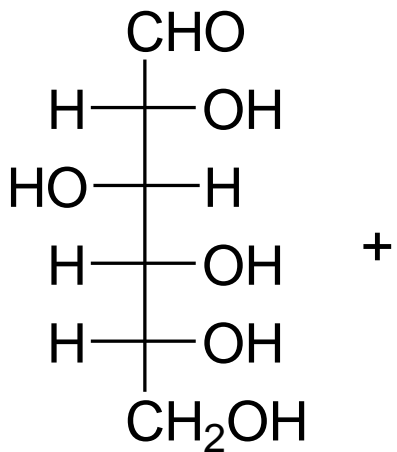
# Reduction to Alditols

- The carbonyl group of a monosaccharide can be reduced to an hydroxyl group by a variety of reducing agents, including  $\text{NaBH}_4$  and  $\text{H}_2/\text{M}$

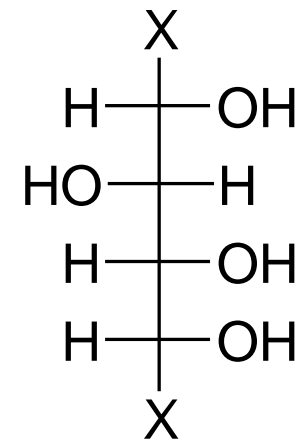
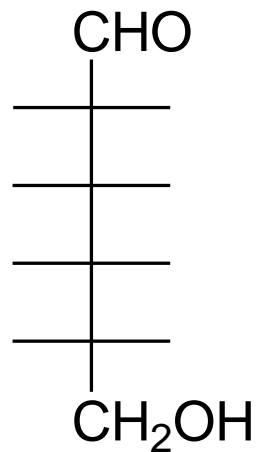


# You try it:

Oxidation of which two hexoses would give the same product?



+

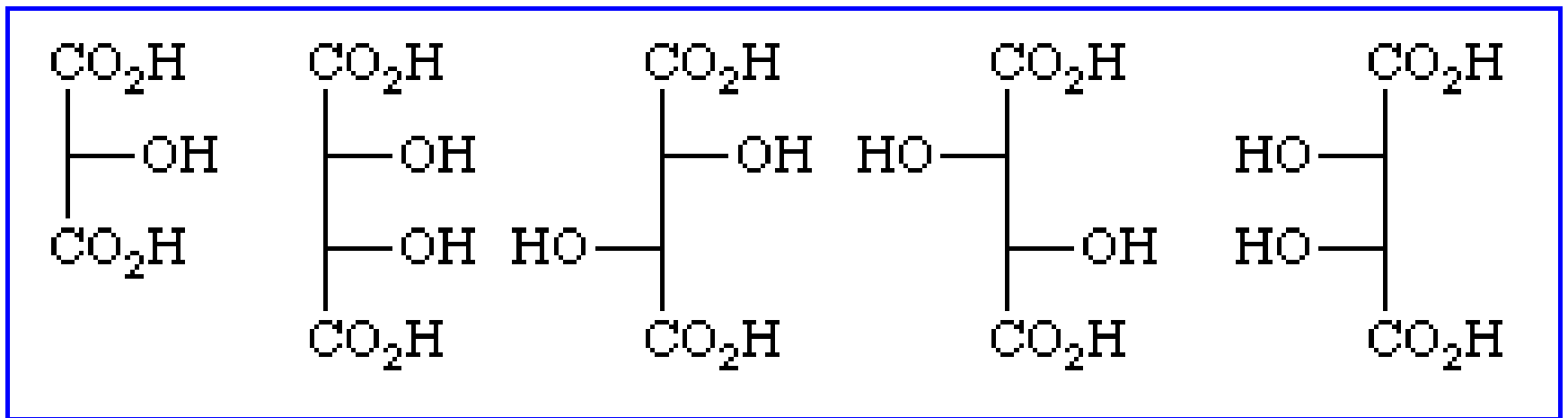


d-(+)- glucose

Same product

# Question #1

Which of the following aldaric acids are optically active?



A

B

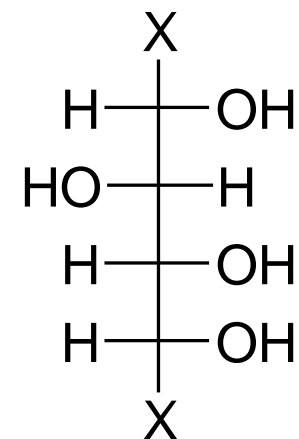
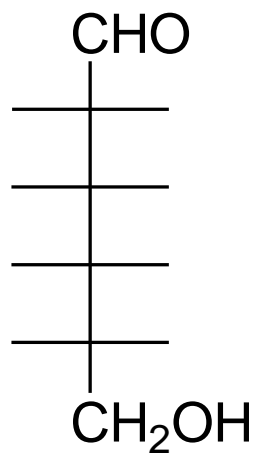
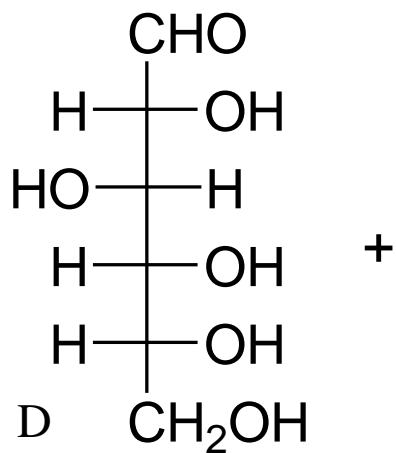
C

D

E

# Question #2

Draw a hexose that would give the same aldaric acid product as D-Glucose



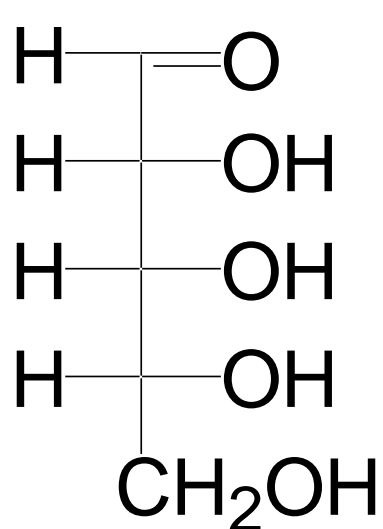
d-(+)- glucose

Same product

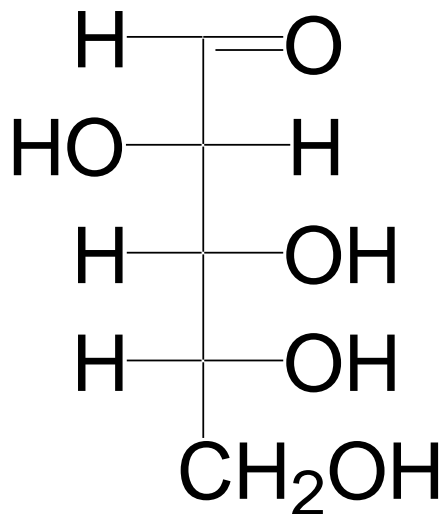


# Question #3

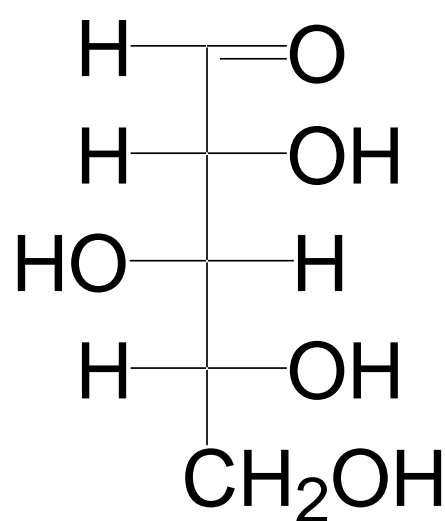
There are four D-aldopentoses. Draw Fischer projections of each of them. Then draw Fischer projections of the aldaric acids they would yield. Label each center as a R or S configuration. Circle the aldaric acids that are optically inactive?



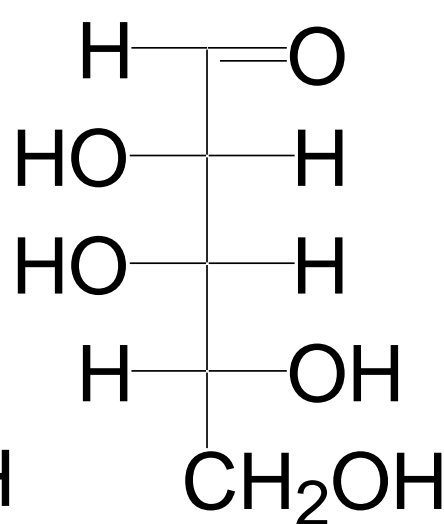
D-Ribose



D-Arabinose



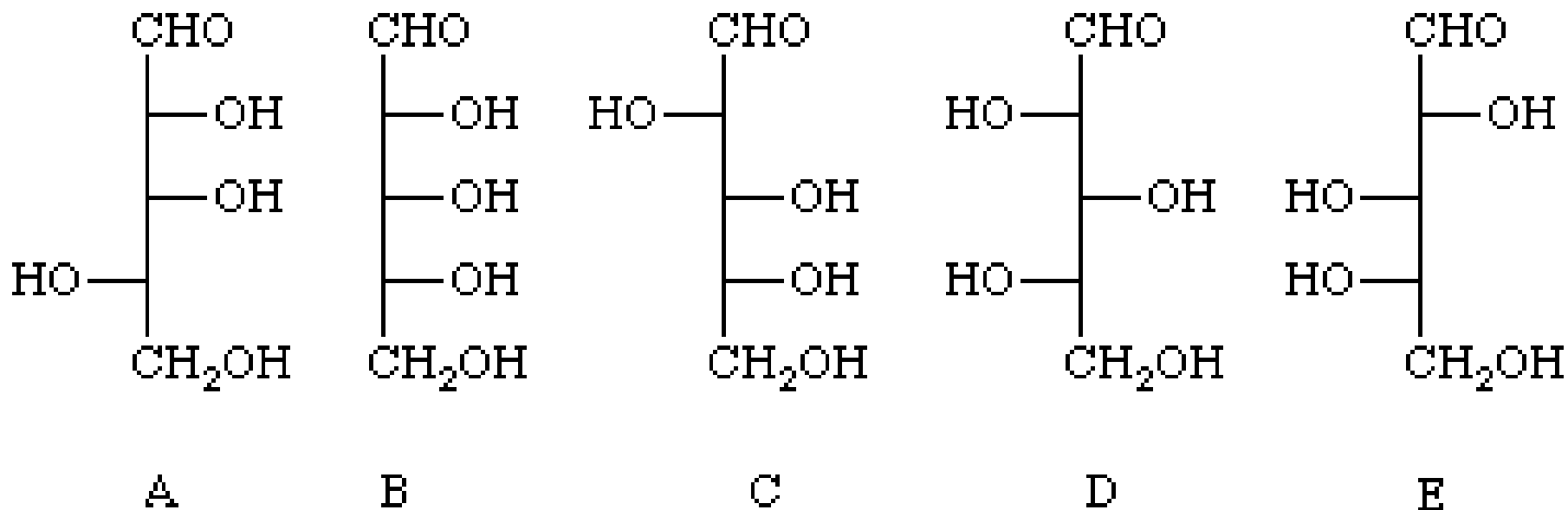
D-Xylose



D-Lyxose

# Question #4

Select the compounds that would produce the same osazone.



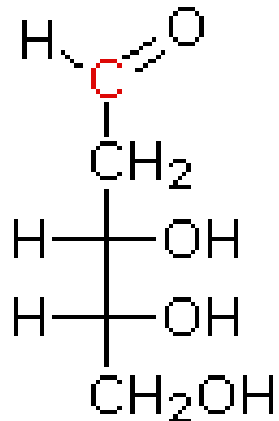
# Common Modifications to monosaccharides

Deoxy sugars

Amino sugars

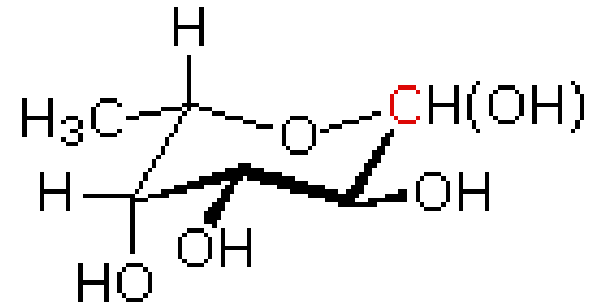
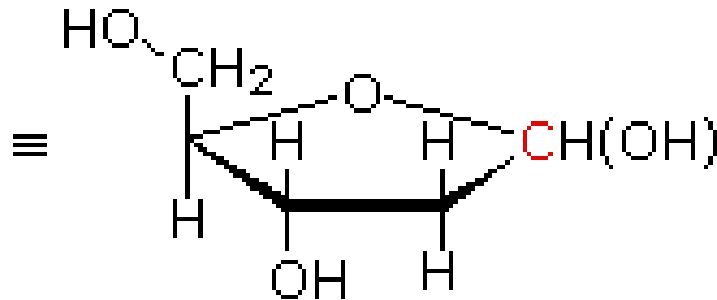
Glycosides (acetal)

# Deoxy Sugar



2-deoxy-D-ribose

(an important component of DNA)



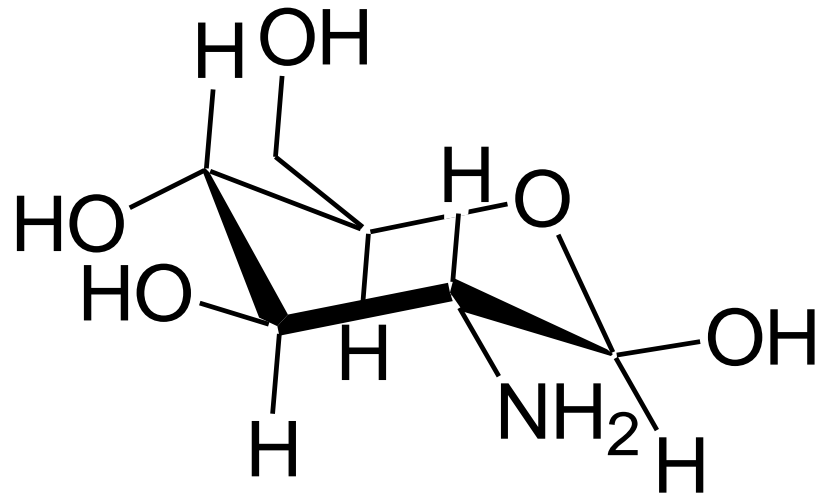
L-Fucose

6-deoxy-L-galactose

(found in seaweed)

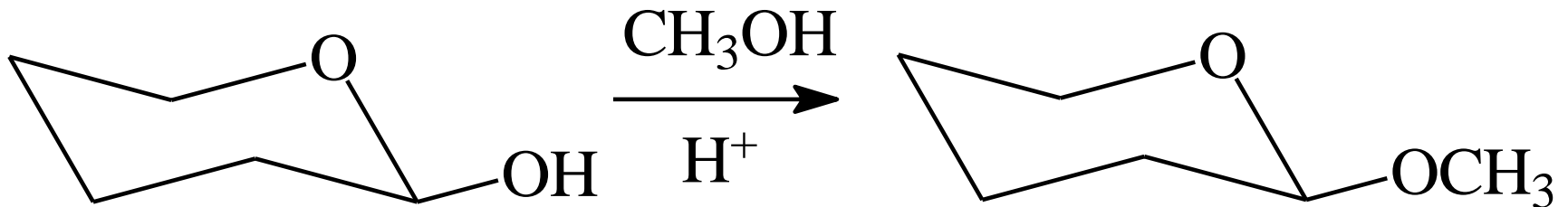
# Amino Sugar

## Glucosamine



# Formation of Glycosides - Acetals

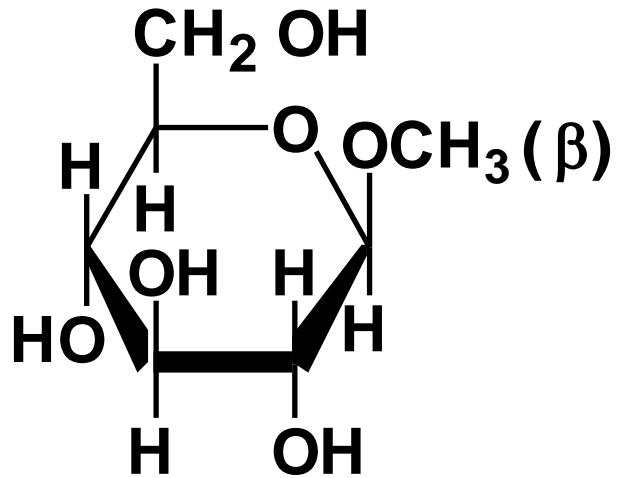
- A monosaccharide hemiacetal can react with a second molecule of an alcohol to form an



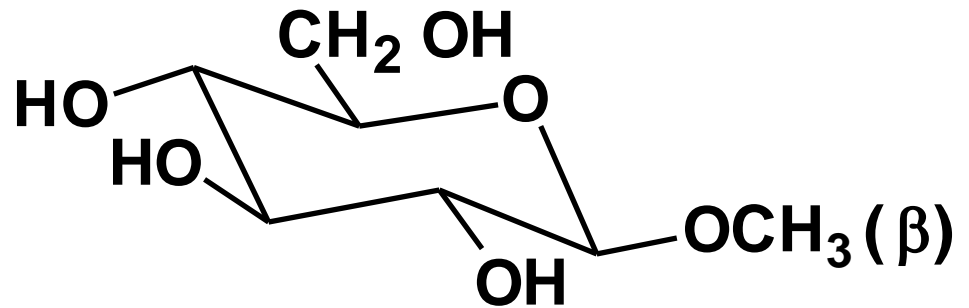
# Glycosides

- **Glycoside bond:** the bond from the anomeric carbon of the glycoside to an -OR group.
- Cyclic acetals are *not* in equilibrium with their open chain carbonyl-containing forms. Glycosides do **NOT** undergo mutarotation.
- List the name of the alkyl or aryl group attached to oxygen followed by the name of the carbohydrate with the ending -e replaced by -ide
  - methyl  $\beta$ -D-glucopyranoside
  - methyl  $\alpha$ -D-ribofuranoside

# Formation of Glycosides



**Haworth projection**



**Chair conformation**

Is this a reducing sugar glycoside?



# Disaccharides

Maltose

Lactose

Sucrose

Cellobiose

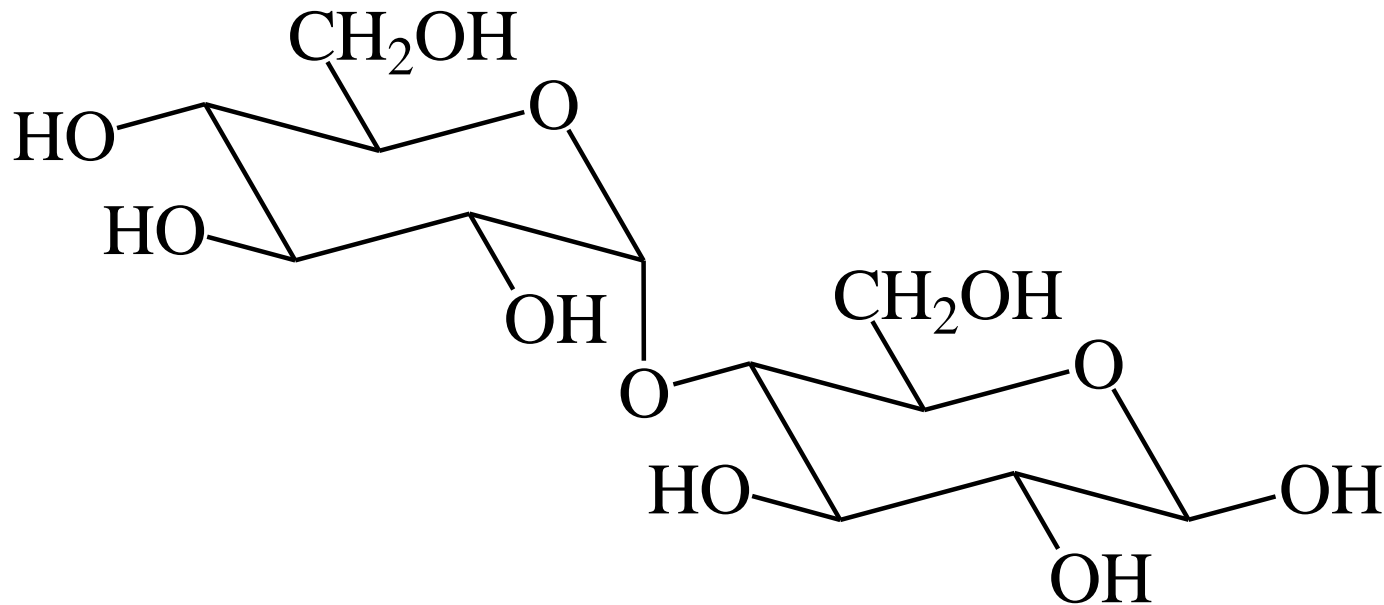
# Disaccharides

- Three naturally occurring glycosidic linkages:
- 1-4' link: The anomeric carbon is bonded to oxygen on C4 of second sugar.
- 1-6' link: The anomeric carbon is bonded to oxygen on C6 of second sugar.
- 1-1' link: The anomeric carbons of the two sugars are bonded through an oxygen.

# Maltose

- From malt, the juice of sprouted barley and other cereal grains. (Cellulose)

*4-O-( $\alpha$ -D-glucopyranosyl)-D-glucopyranose*



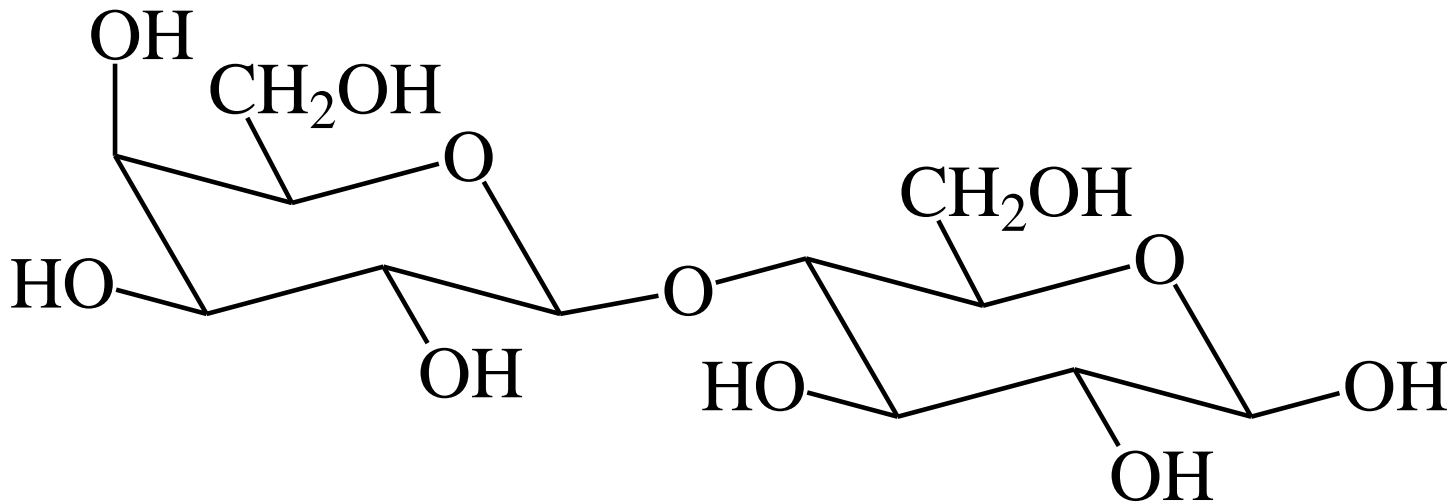
- Is this a reducing sugar?

# Lactose

The principle sugar present in milk

5% - 8% in humans, 5% in cow's milk

*4-O-(β-D-galactopyranosyl)-D-glucopyranose*



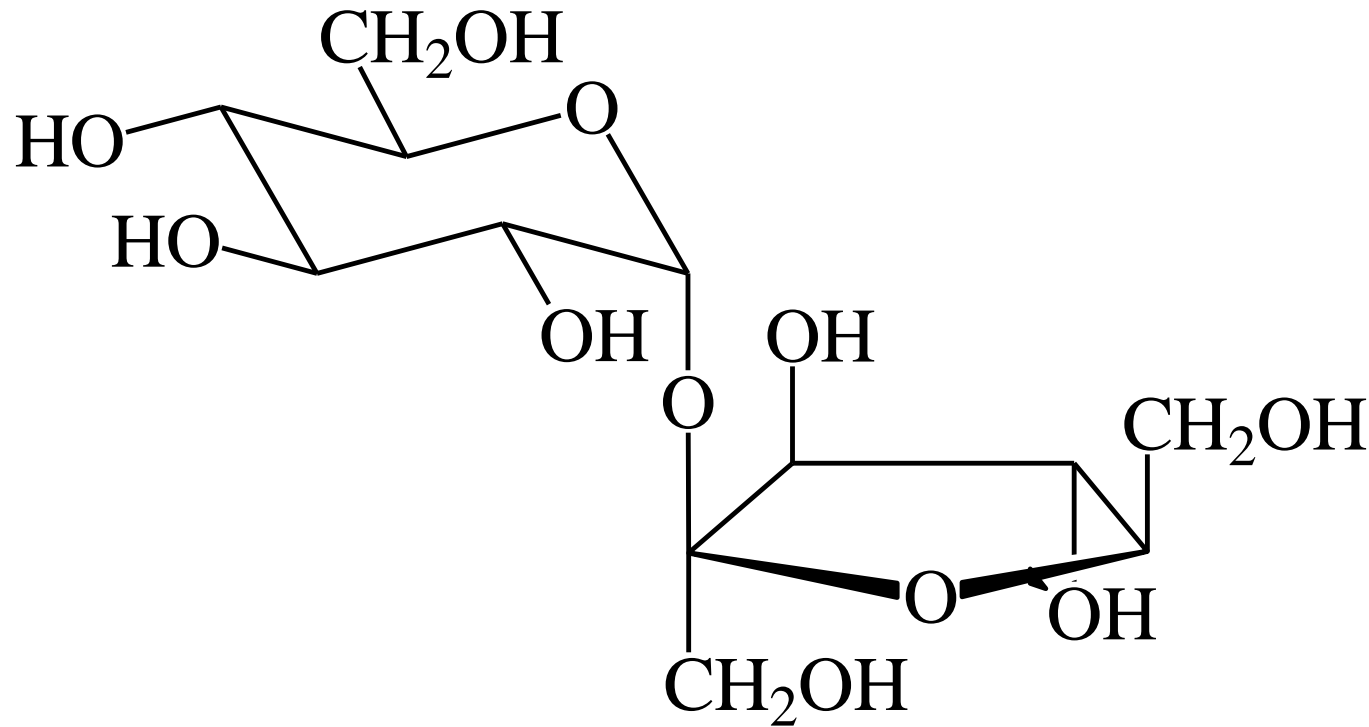
•Is this a reducing sugar?

# Sucrose

- Table sugar, obtained from the juice of sugar cane and sugar beet.

*1-O-( $\alpha$ -D-galactopyranosyl)- $\beta$ -D-fructofurananoside*  
OR

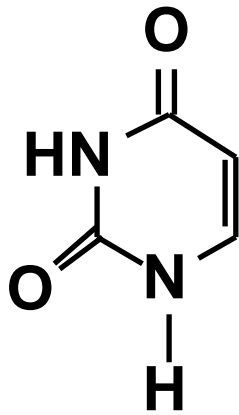
*1-O-( $\beta$ -D-fructofurananosyl)- $\alpha$ -D-galactopyranoside*



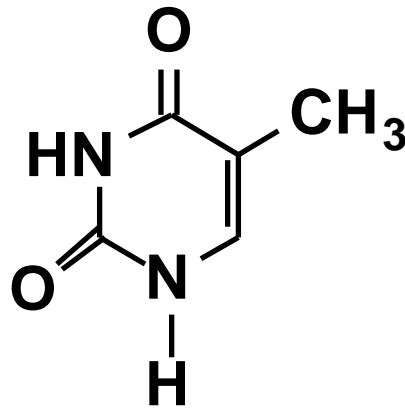
- Is this a reducing sugar?

# N-Glycosides

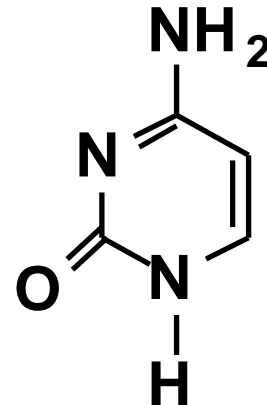
- The anomeric carbon of a cyclic hemiacetal undergoes reaction with the N-H group of an amine to form an N-glycoside
  - N-glycosides of the following purine and pyrimidine bases are structural units of nucleic acids



**Uracil**

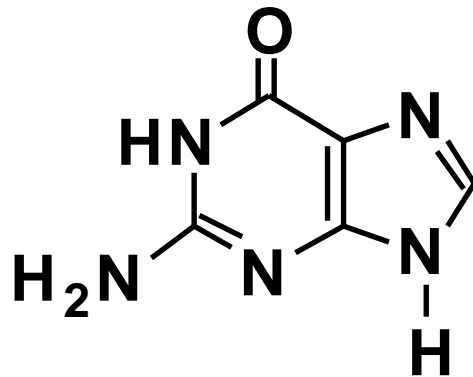


**Thymine**

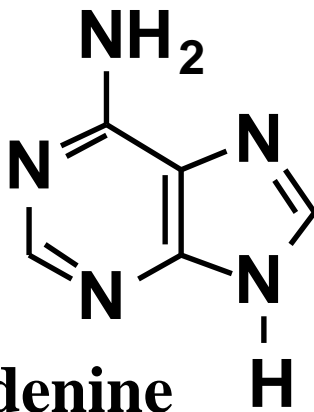


**Cytosine**

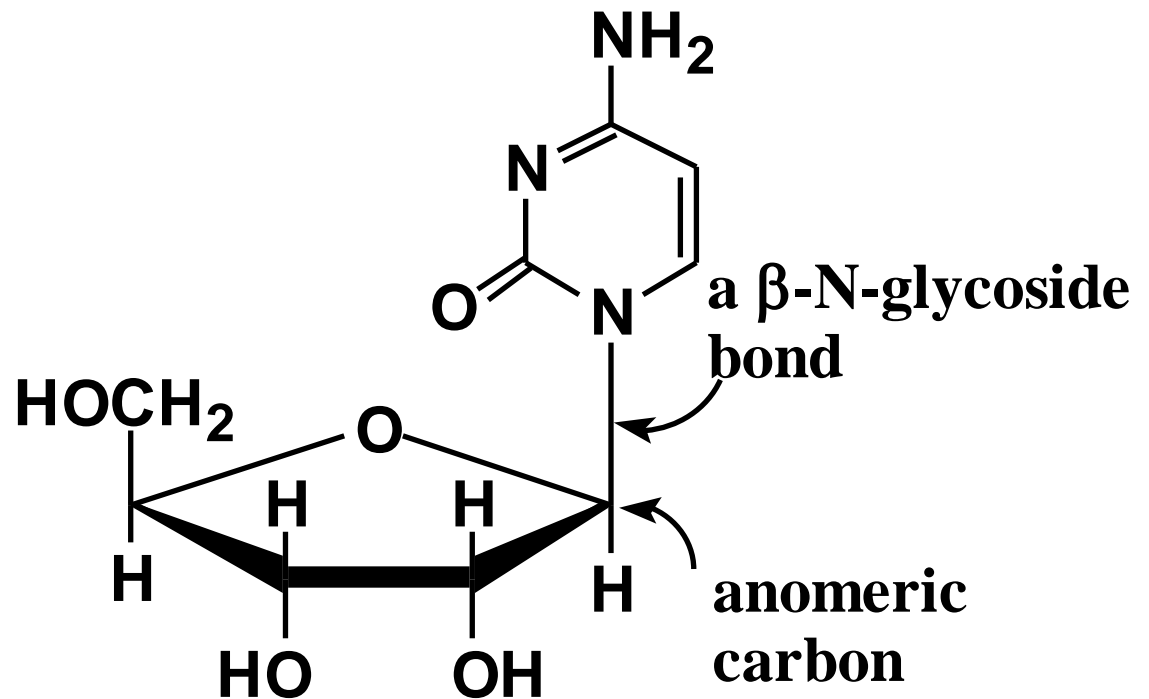
# N-Glycosides



**Guanine**

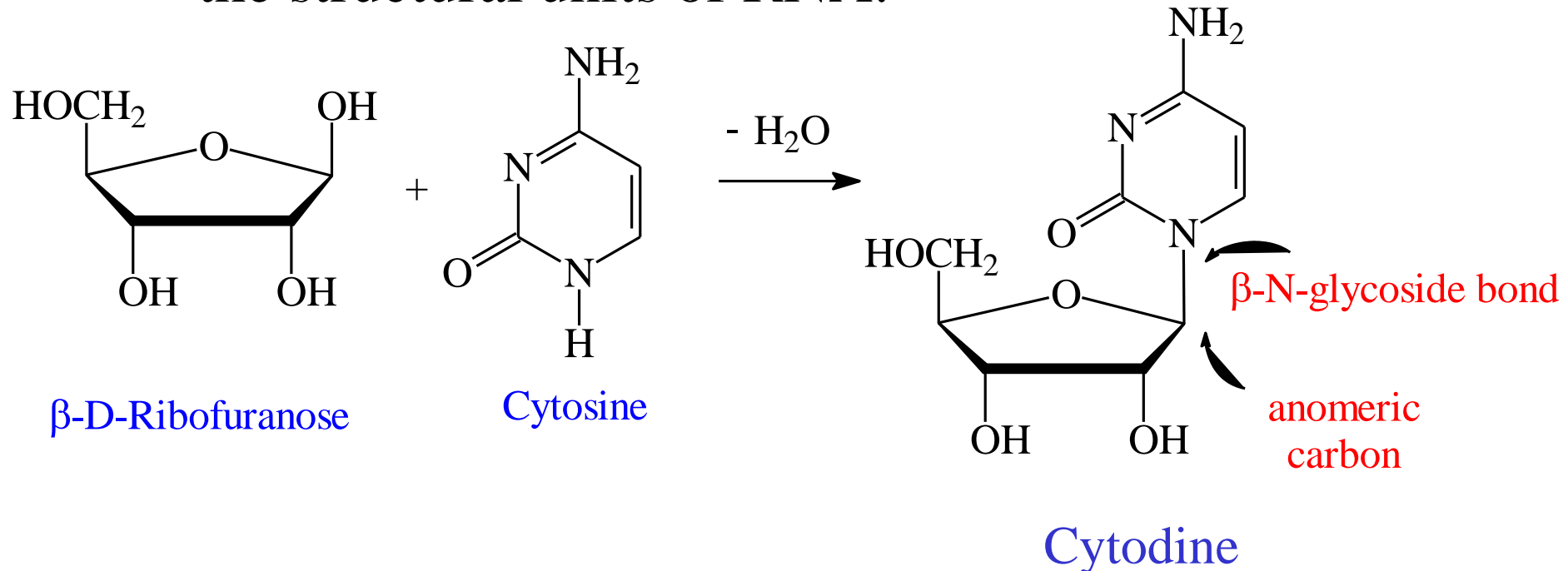


**Adenine**



# Formation of N-Glycosides (Nucleosides)

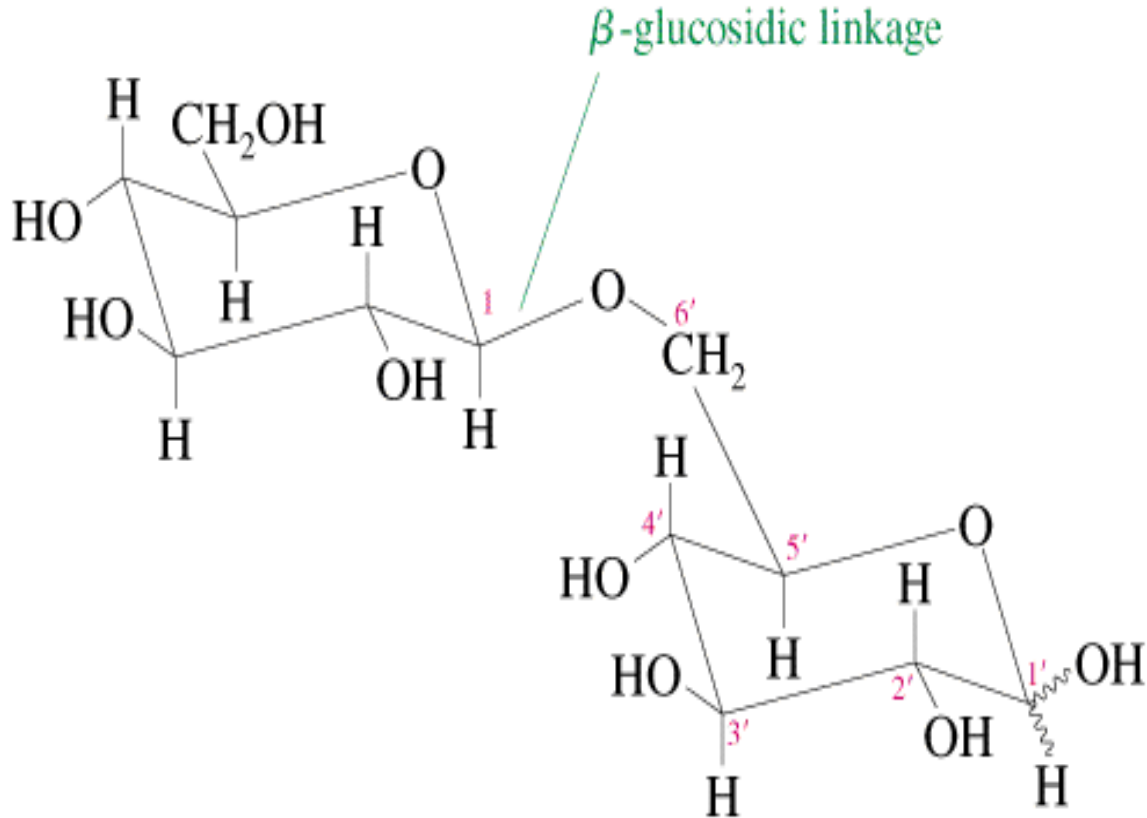
- For example, reaction between  $\beta$ -D-ribofuranose and cytosine produces water and cytosine, one of the structural units of RNA:





# Gentiobiose

*Gentiobiose, 6-O-(β-D-glucopyranosyl)-D-glucopyranose*



- Two glucose units linked 1-6'.
- Common carbohydrate branch point

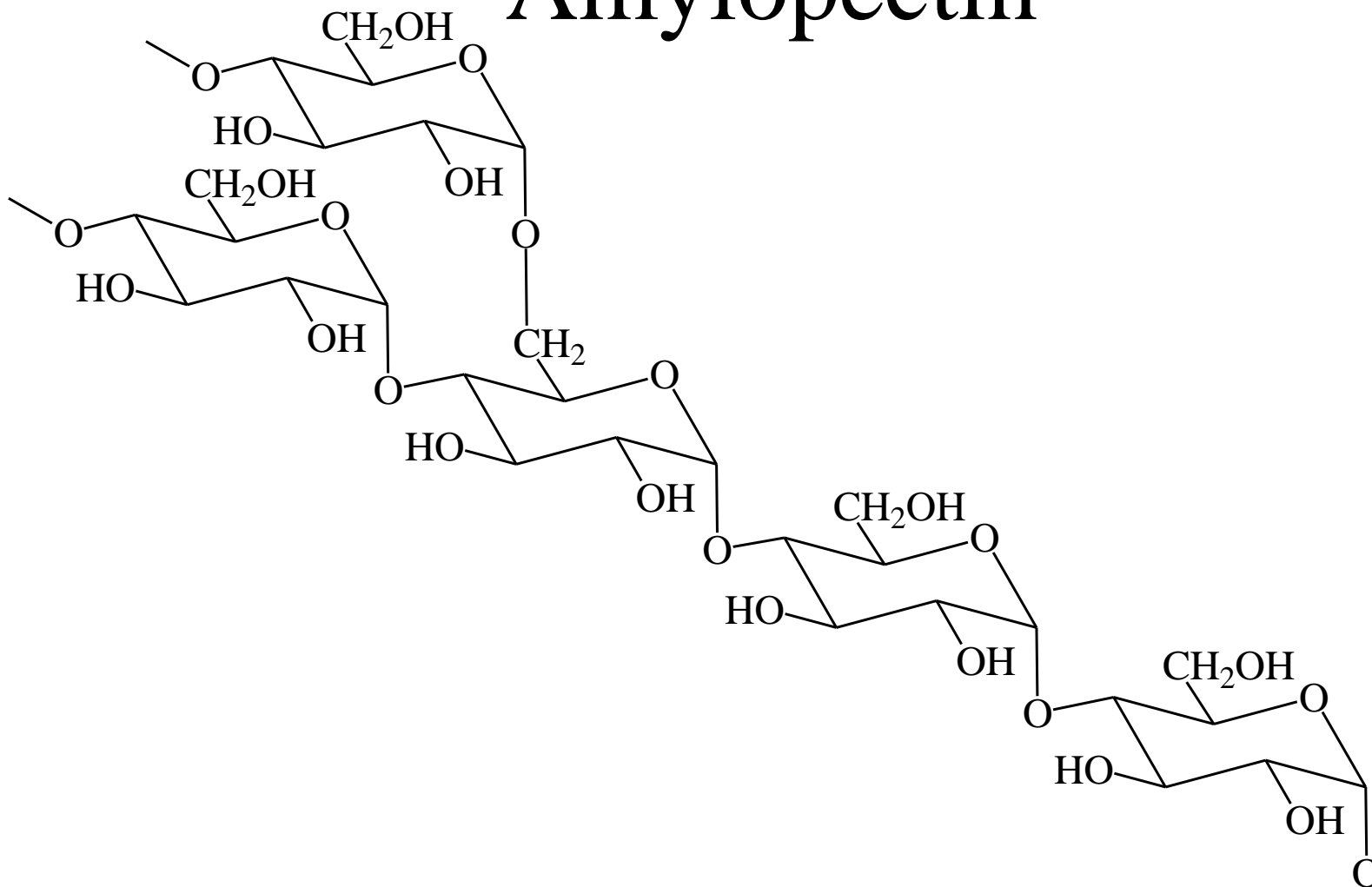
# Polysaccharides

- Polysaccharides are chains of five or more monosaccharide:
  - **Starch** – a glucose polymer that is the storage carbohydrate used by plants.
  - **Glycogen** – a glucose polymer that is the storage carbohydrate used by animals.
  - Cellulose – a glucose polymer that is a major component of the cell wall in plants & algae.
  - **Agar** – natural component of certain seaweed polymer of galactose & sulfur containing carbohydrates.
  - Chitin – polymer of glucosamine (a sugar with an amino functional group).

# Starch

- Starch is used for energy storage in plants
  - it can be separated into two fractions; amylose and amylopectin. Each on complete hydrolysis gives only D-glucose
  - **amylose** is composed of continuous, unbranched chains of up to 4000 D-glucose units joined by  $\alpha$ -1,4-glycoside bonds
  - **amylopectin** is a highly branched polymer of D-glucose. Chains consist of 24-30 units of D-glucose joined by  $\alpha$ -1,4-glycoside bonds and branches created by  $\alpha$ -1,6-glycoside bonds

# Amylopectin



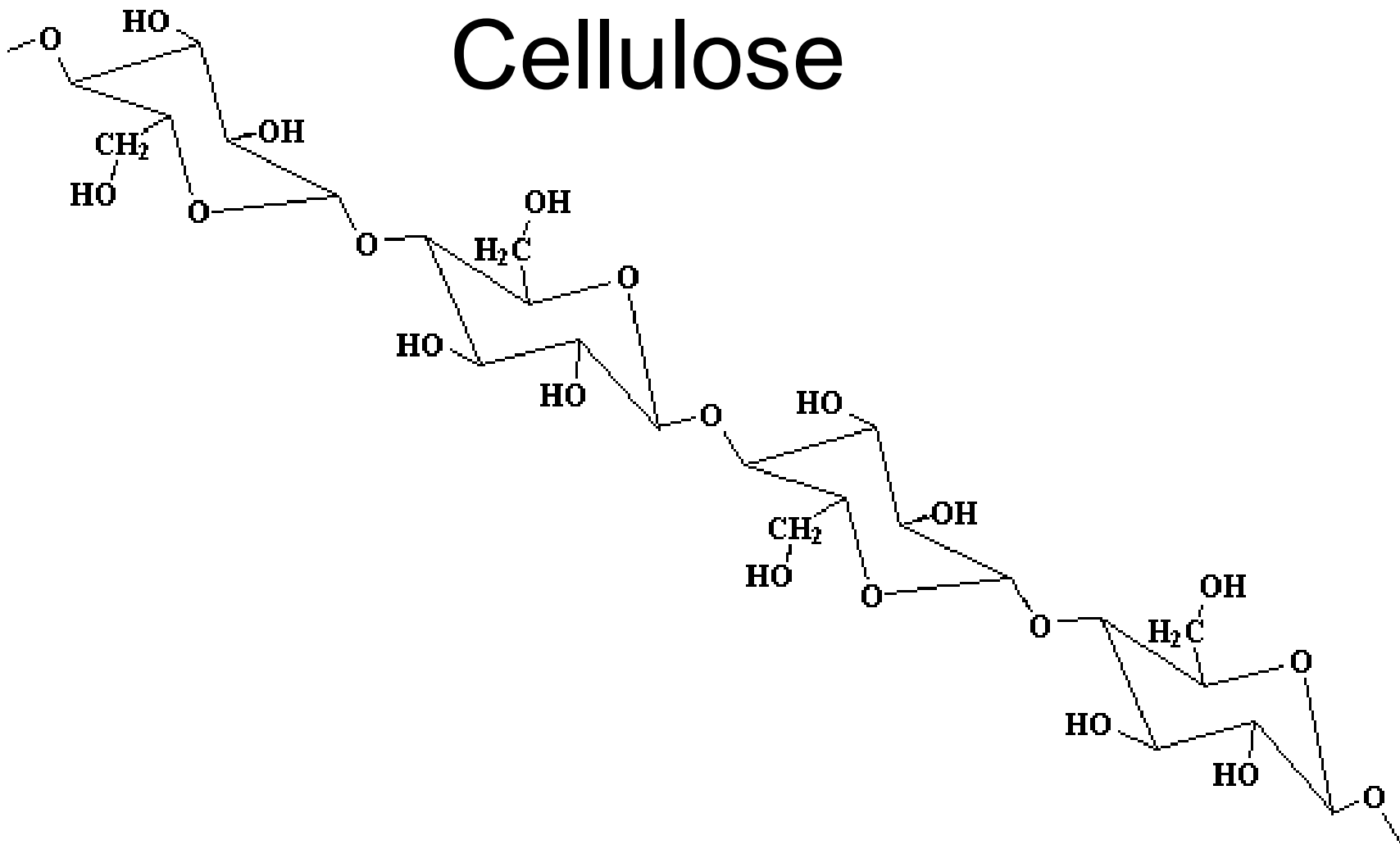
# Glycogen

- The reserve carbohydrate for animals
  - a nonlinear polymer of D-glucose units joined by  $\alpha$ -1,4- and  $\alpha$ -1,6-glycoside bonds
  - the total amount of glycogen in the body of a well-nourished adult is about 350 g (about 3/4 of a pound) divided almost equally between liver and muscle

# Cellulose

- Cellulose is a linear polymer of D-glucose units joined by  $\beta$ -1,4-glycoside bonds
  - it has an average molecular weight of 400,000, corresponding to approximately 2800 D-glucose units per molecule

# Cellulose

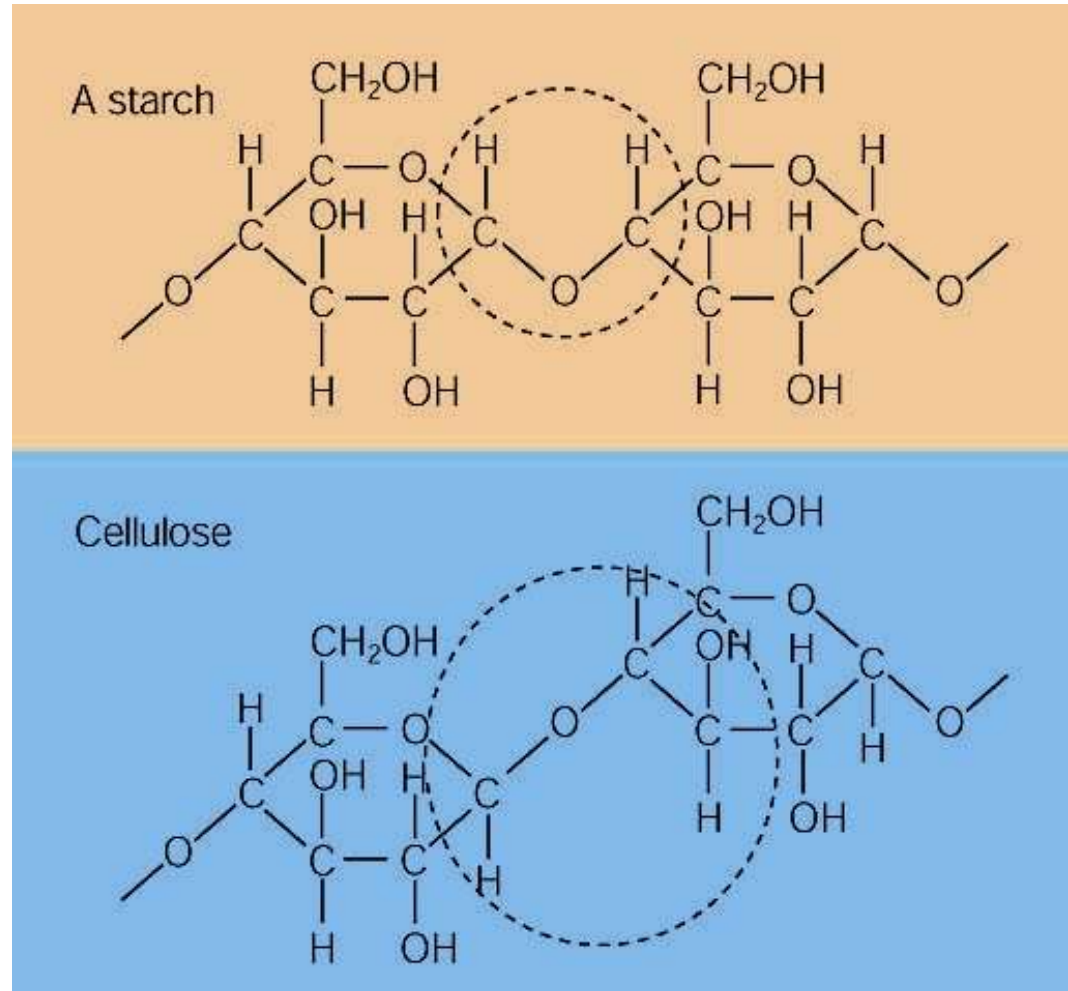


# Polysaccharides Digestion

Polymers of Glucose

Starch is digestible

Cellulose is **not**  
digestible by humans

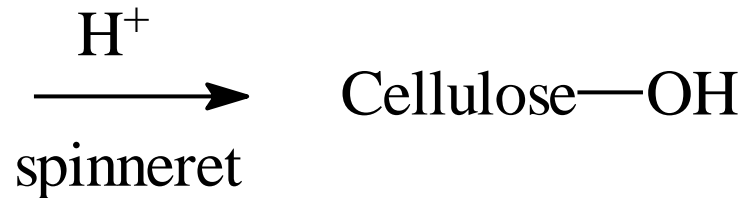
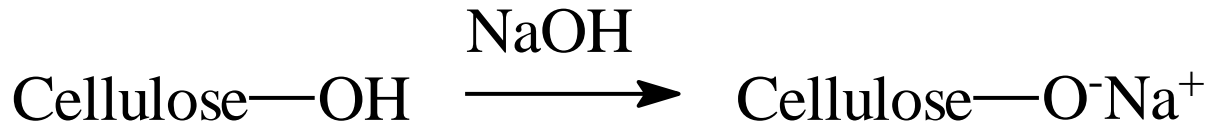




# Modification of Cellulose

- Cellulose Nitrate called guncotton
- Pyroxylin Partially nitrated  
photographic film and lacquers
- Cellulose Acetate film explosive
- Cellulose reprocessed Rayon via  
carbon disulfide

# Cellulose fibre - Rayon



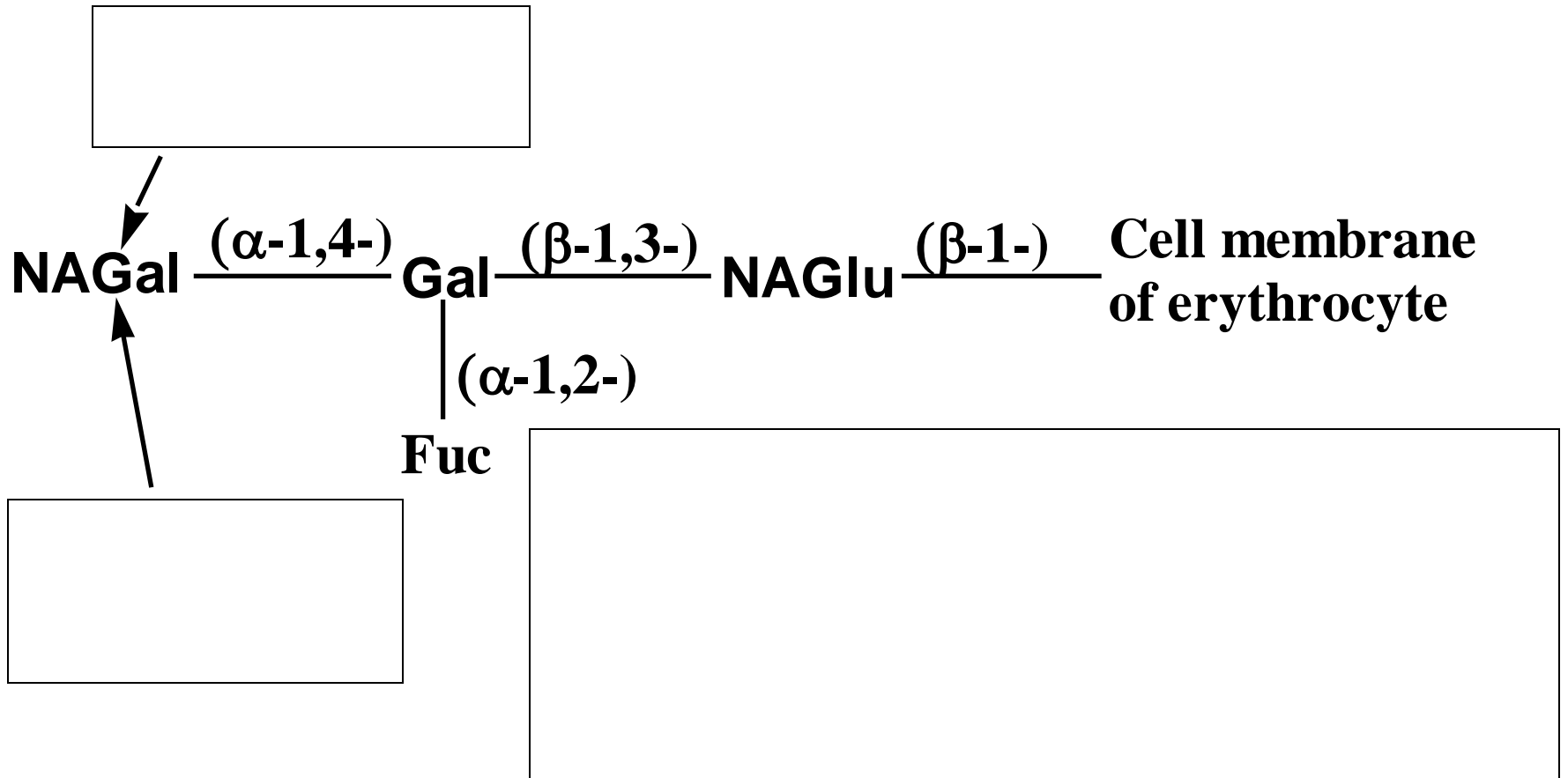
# Membrane Carbohydrates

- Membranes of animal plasma cells have large numbers of relatively small carbohydrates bound to them
  - these membrane-bound carbohydrates are part of the mechanism by which cell types recognize each other; they act as antigenic determinants
  - Early discovery of these antigenic determinants are the **blood group substances**

# ABO Blood Classification

- In the ABO system, individuals are classified according to four blood types:  
A, B, AB, and O
  - at the cellular level, the biochemical basis for this classification is a group of relatively small membrane-bound carbohydrates

# ABO Blood Classification



# ABO and Disease

Some infectious disease organisms have ABO antigens on their cell walls conferring resistance to those that can produce the antibodies and increases the susceptibility of those whose blood type matches the antigens.

## A

- Syphilis, Smallpox, Bronchial Pneumonia, Rheumatic Heart Disease

## B

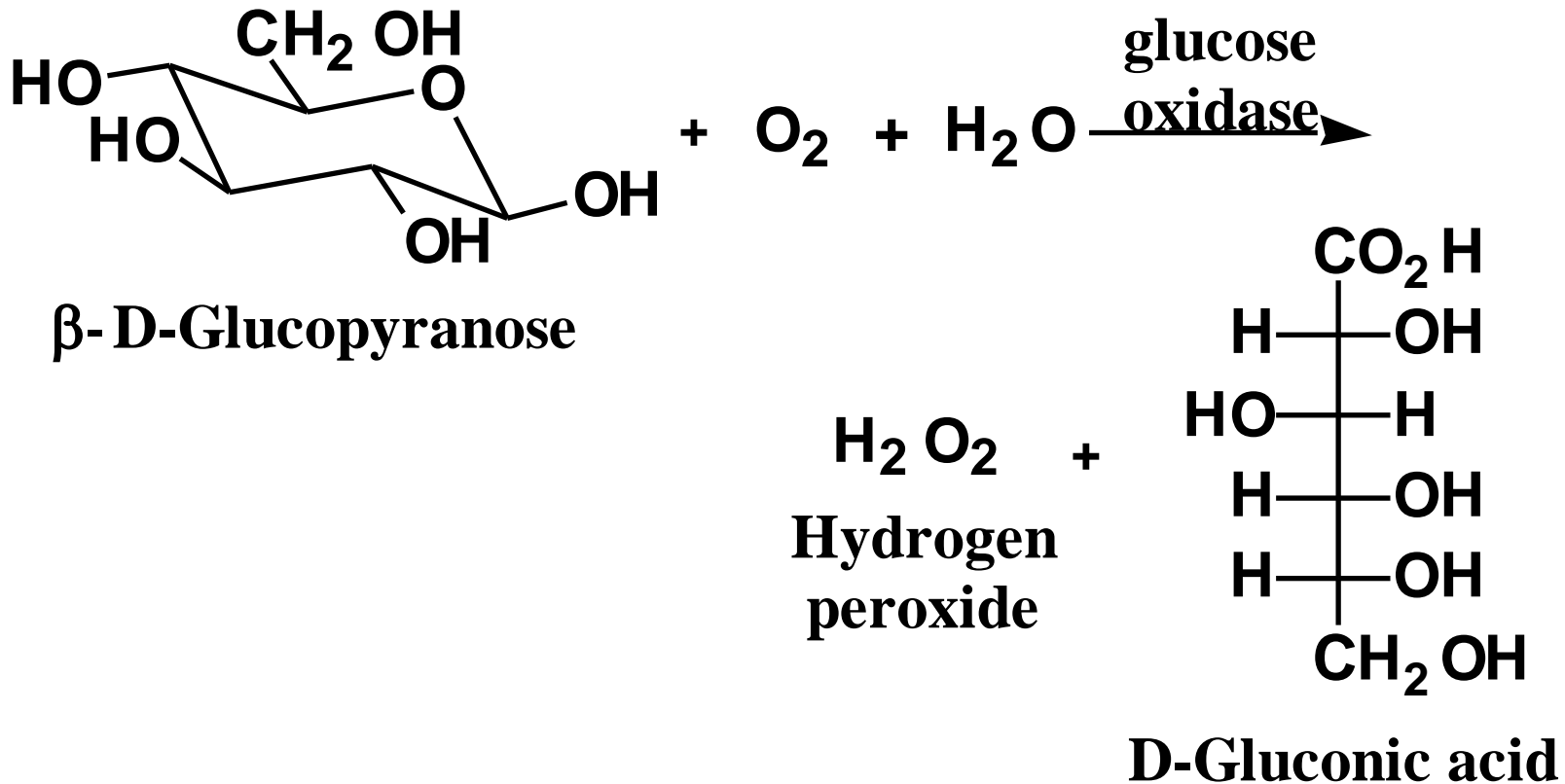
- Infantile Diarrhea, Typhoid Fever, Scarlet Fever

## O

- Bubonic Plague, Paratyphoid, Scarlet Fever, Cholera

# Glucose Assay

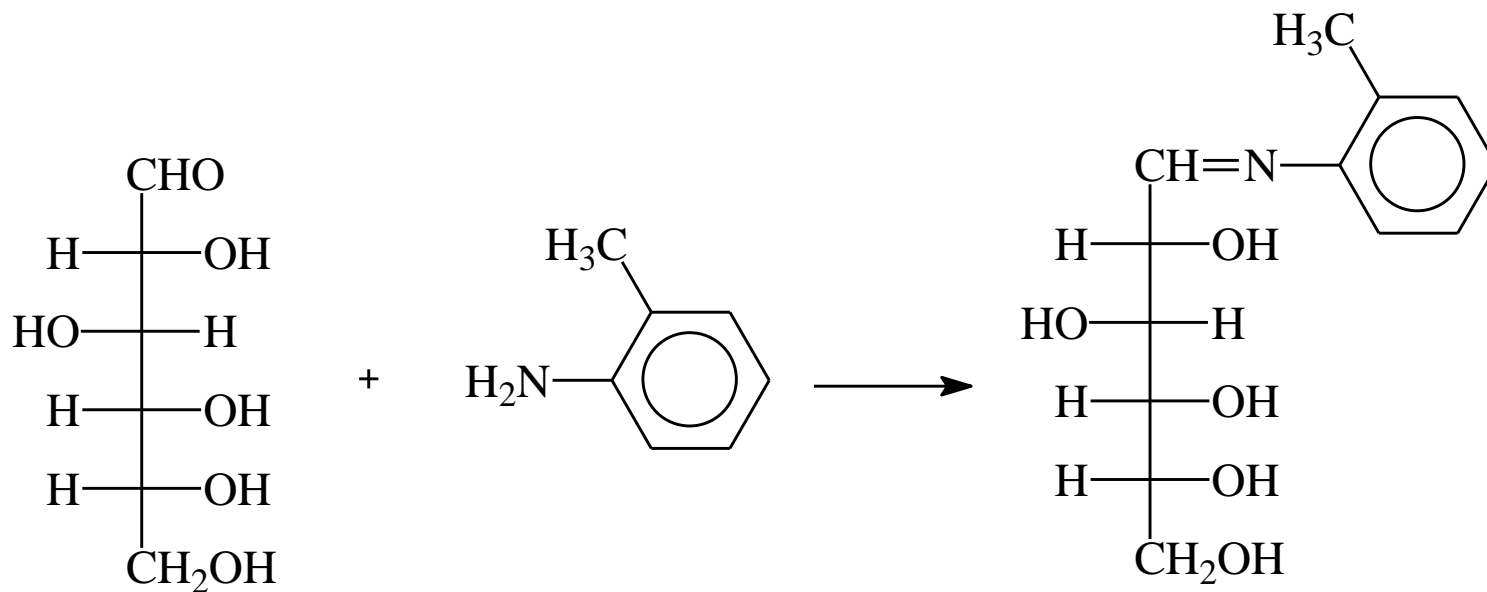
- The glucose oxidase method is completely specific for D-glucose



# 'Chemstrip Kit'

Blood glucose test for diabetics

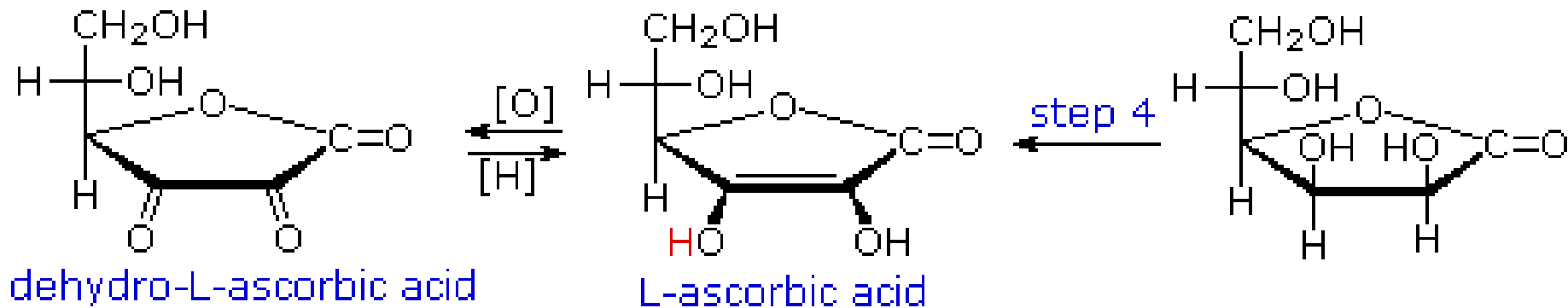
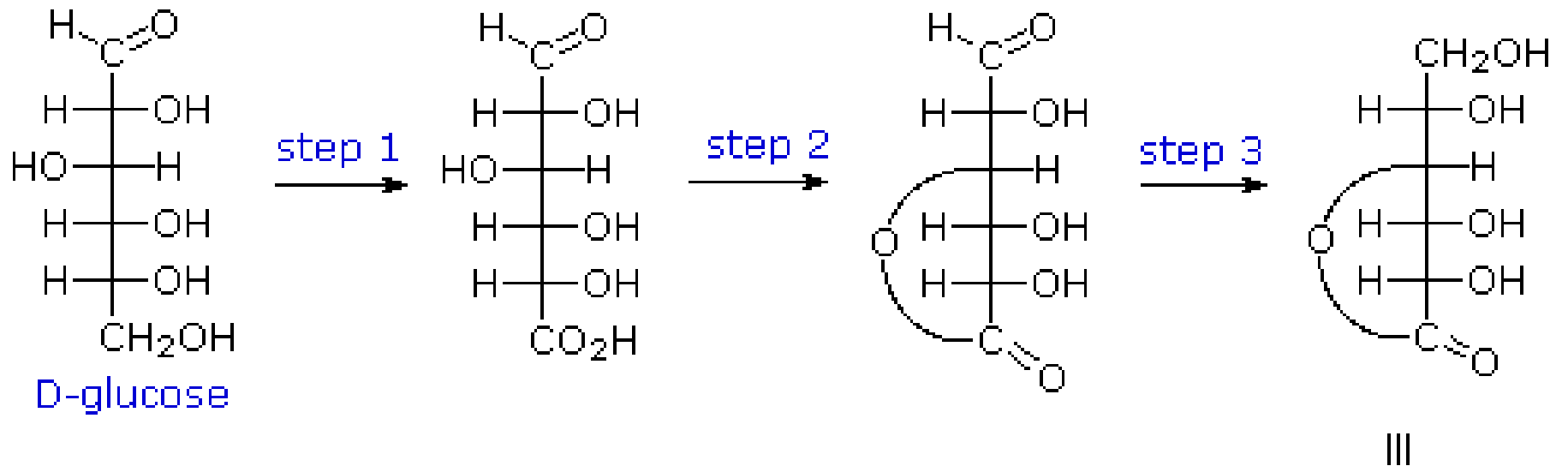
Based on reaction of o-toluidine with glucose





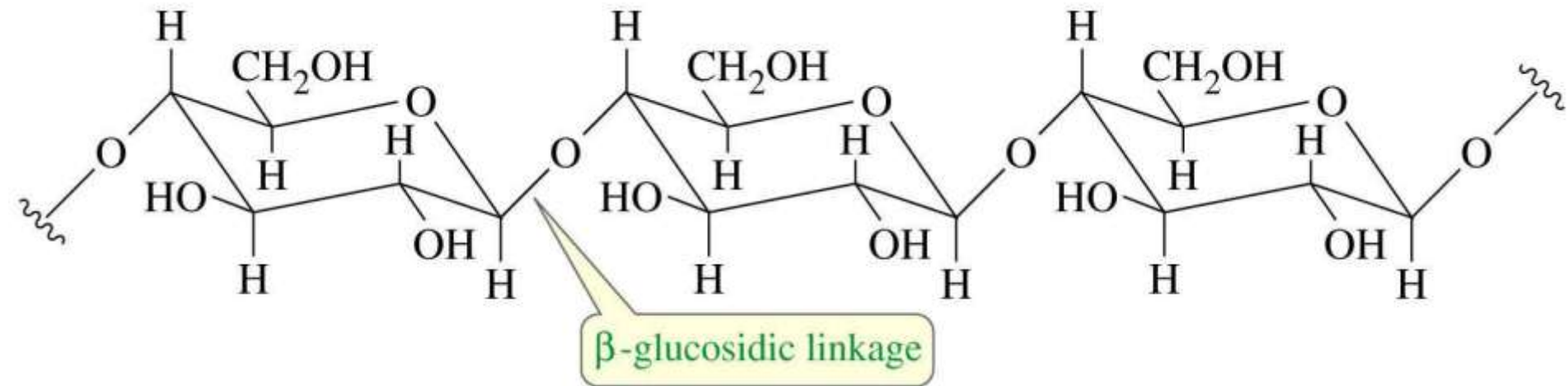
# Biosynthesis with Glucose

## Biosynthesis of Vitamin C from Glucose



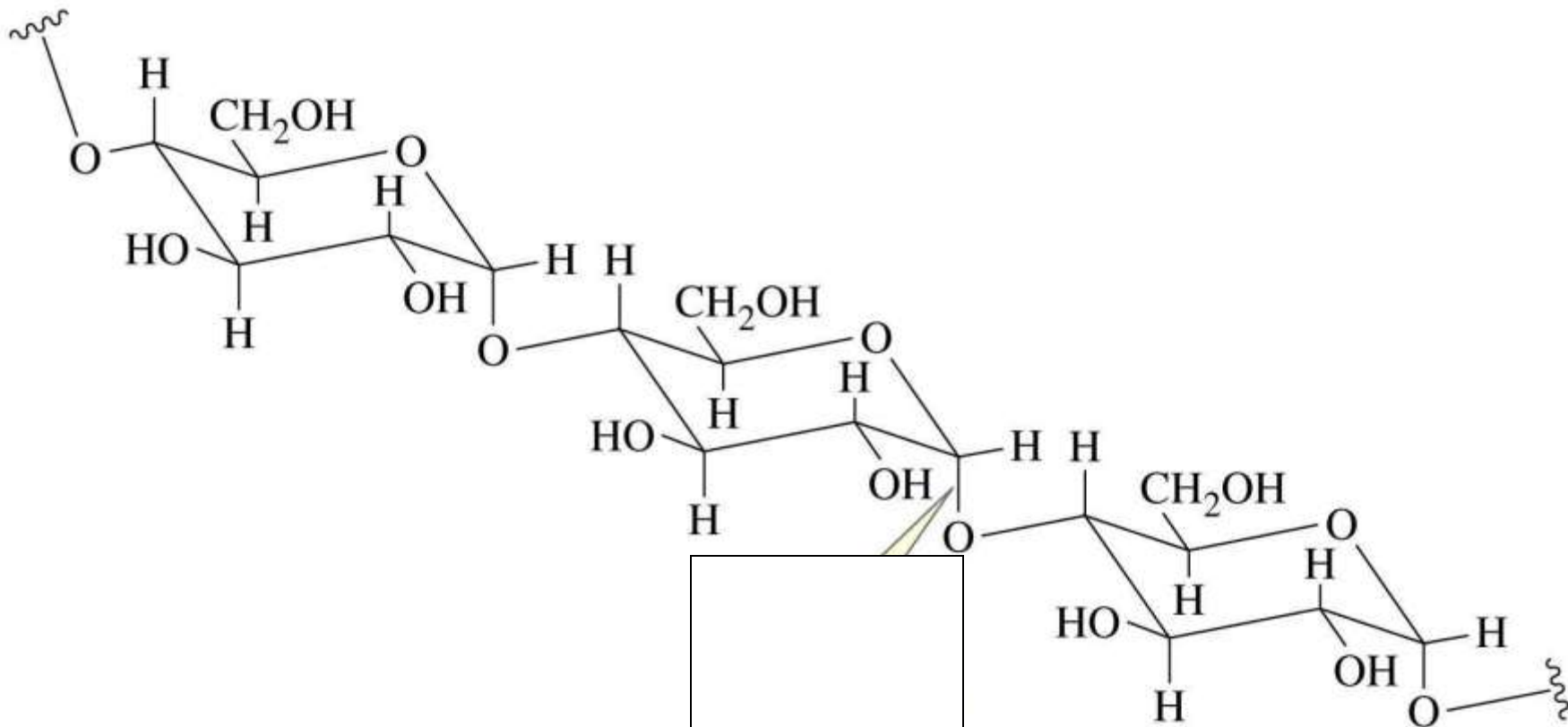
# Cellulose

- Polymer of D-glucose, found in plants.
- Mammals lack the  $\beta$ -glycosidase enzyme.



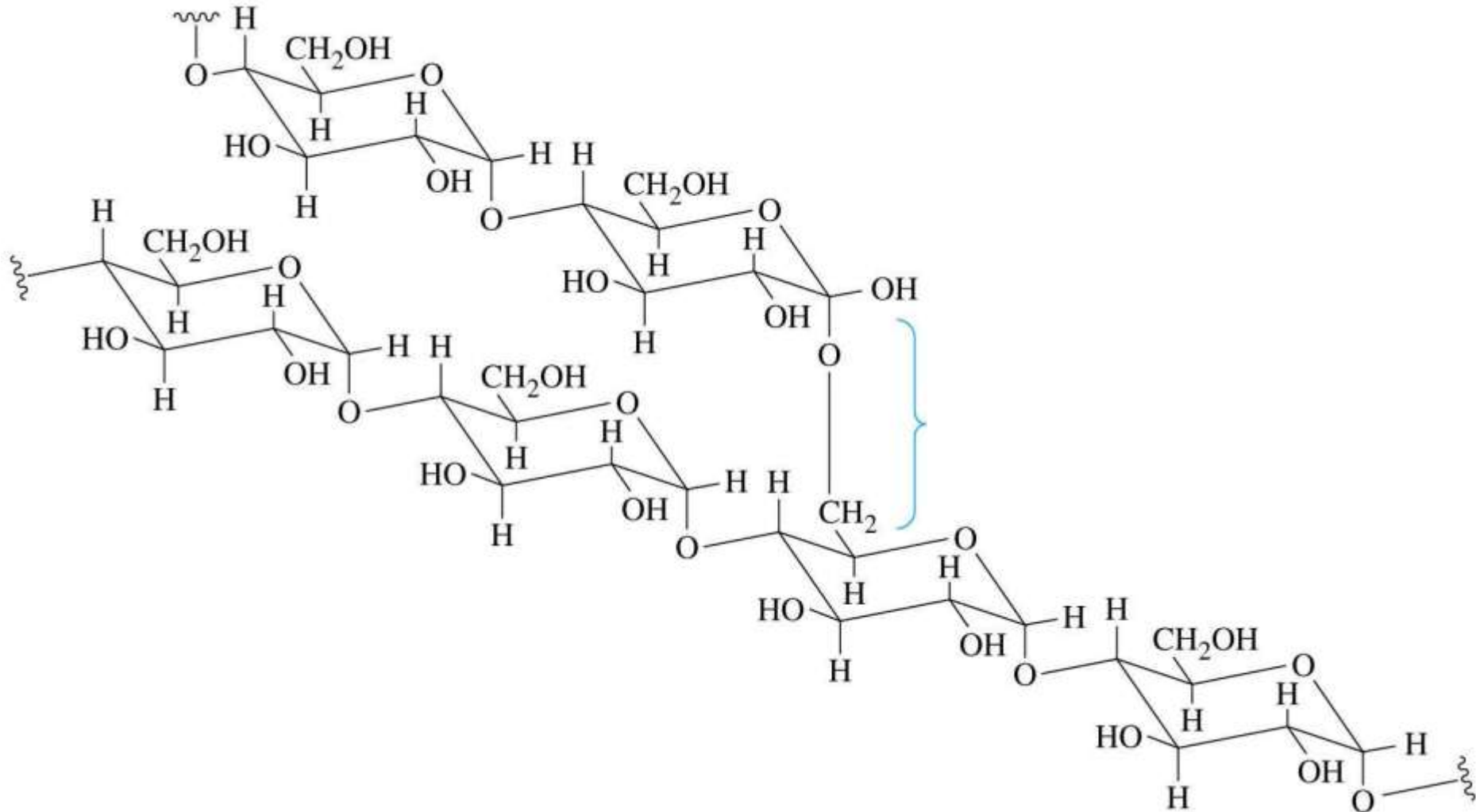
# Amylose

- Soluble starch, polymer of D-glucose.
- Starch-iodide complex, deep blue.



# Amylopectin

Branched, insoluble fraction of starch.



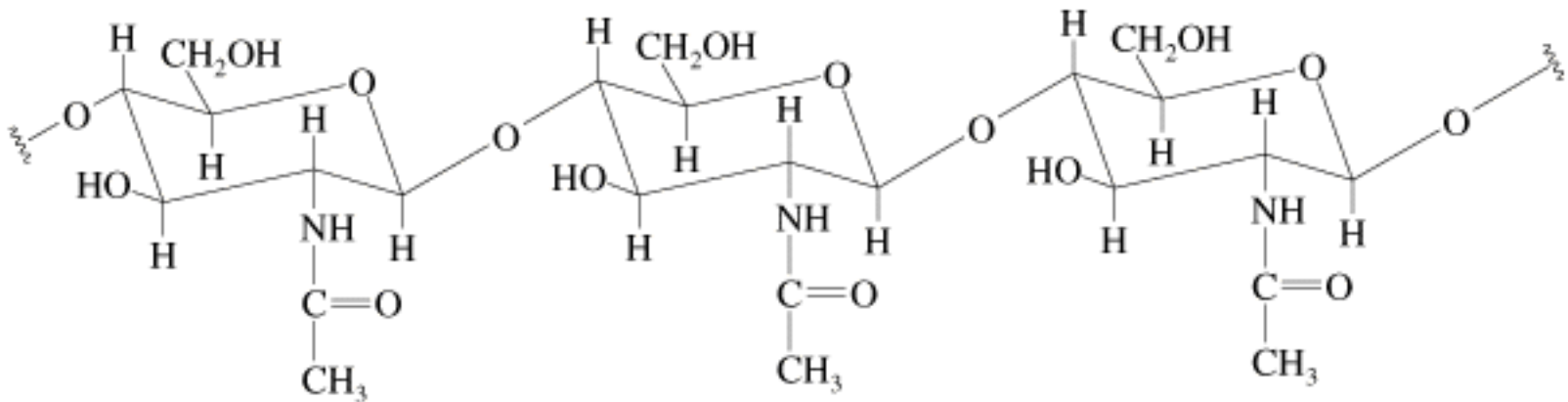
# Glycogen

- Glucose polymer, similar to amylopectin, but even more highly branched.
- Energy storage in muscle tissue and liver.
- The many branched ends provide a quick means of putting glucose into the blood.

# Chitin

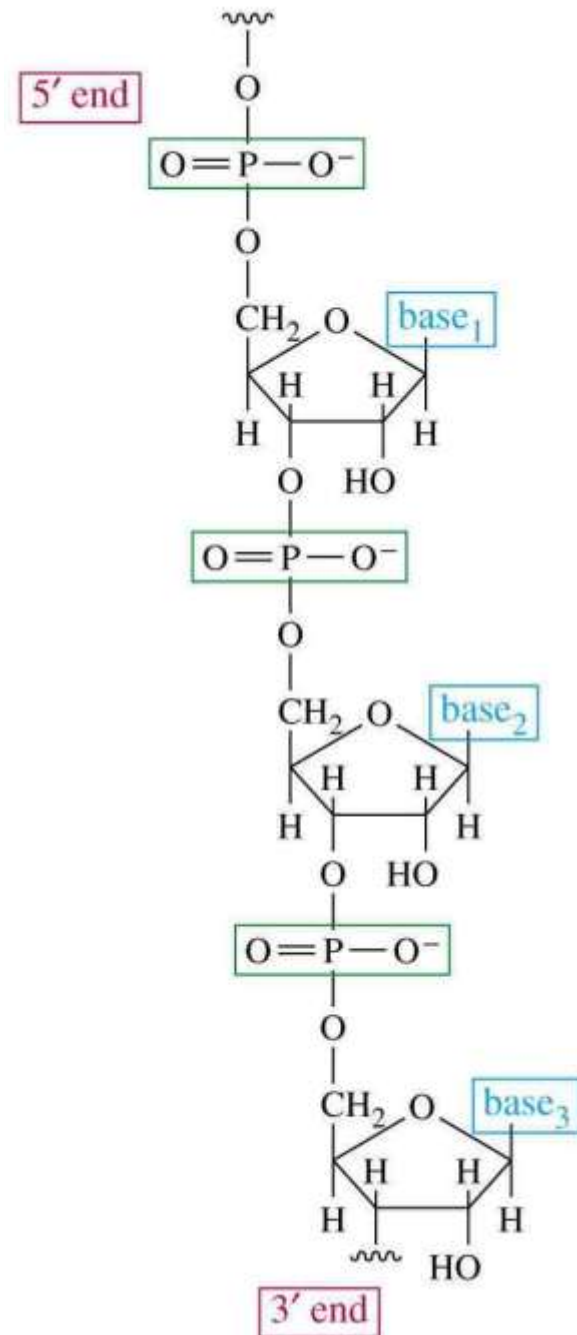
- Polymer of *N*-acetylglucosamine.
- Exoskeleton of insects.

*Chitin, or poly(1,4'-O-β-2-acetamido-2-deoxy-D-glucopyranoside), a β-1,4-linked polymer of N-acetylglucosamine*



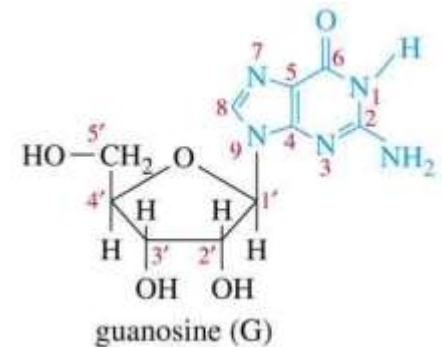
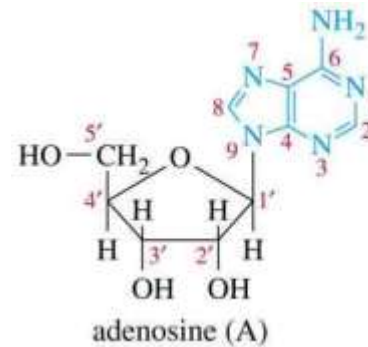
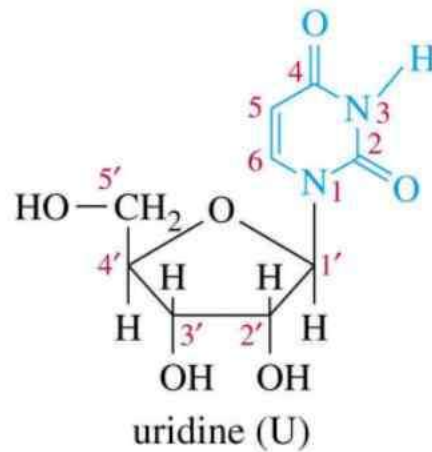
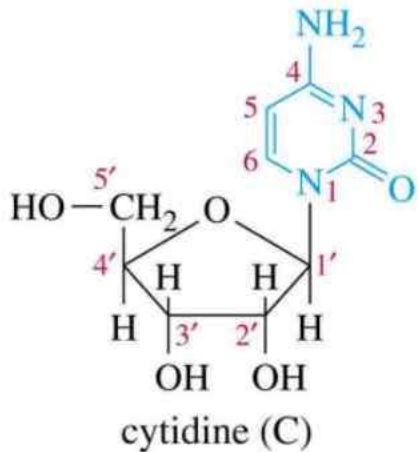
# Nucleic Acids

- Polymer of ribofuranoside rings linked by phosphate ester groups.
- Each ribose is bonded to a base.
- Ribonucleic acid (RNA)
- Deoxyribonucleic acid (DNA)



# Ribonucleosides

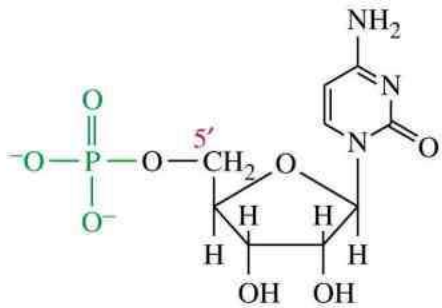
A  $\beta$ -D-ribofuranoside bonded to a heterocyclic base at the anomeric carbon.



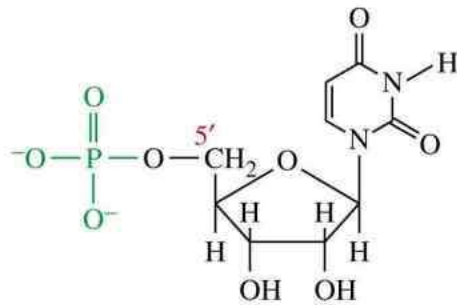


# Ribonucleotides

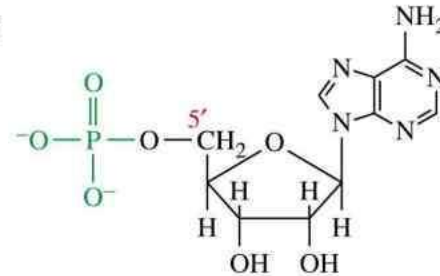
Add phosphate at 5' carbon.



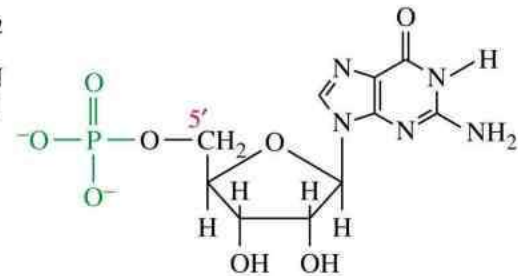
cytidine monophosphate,  
CMP (cytidylic acid)



uridine monophosphate,  
UMP (uridylic acid)

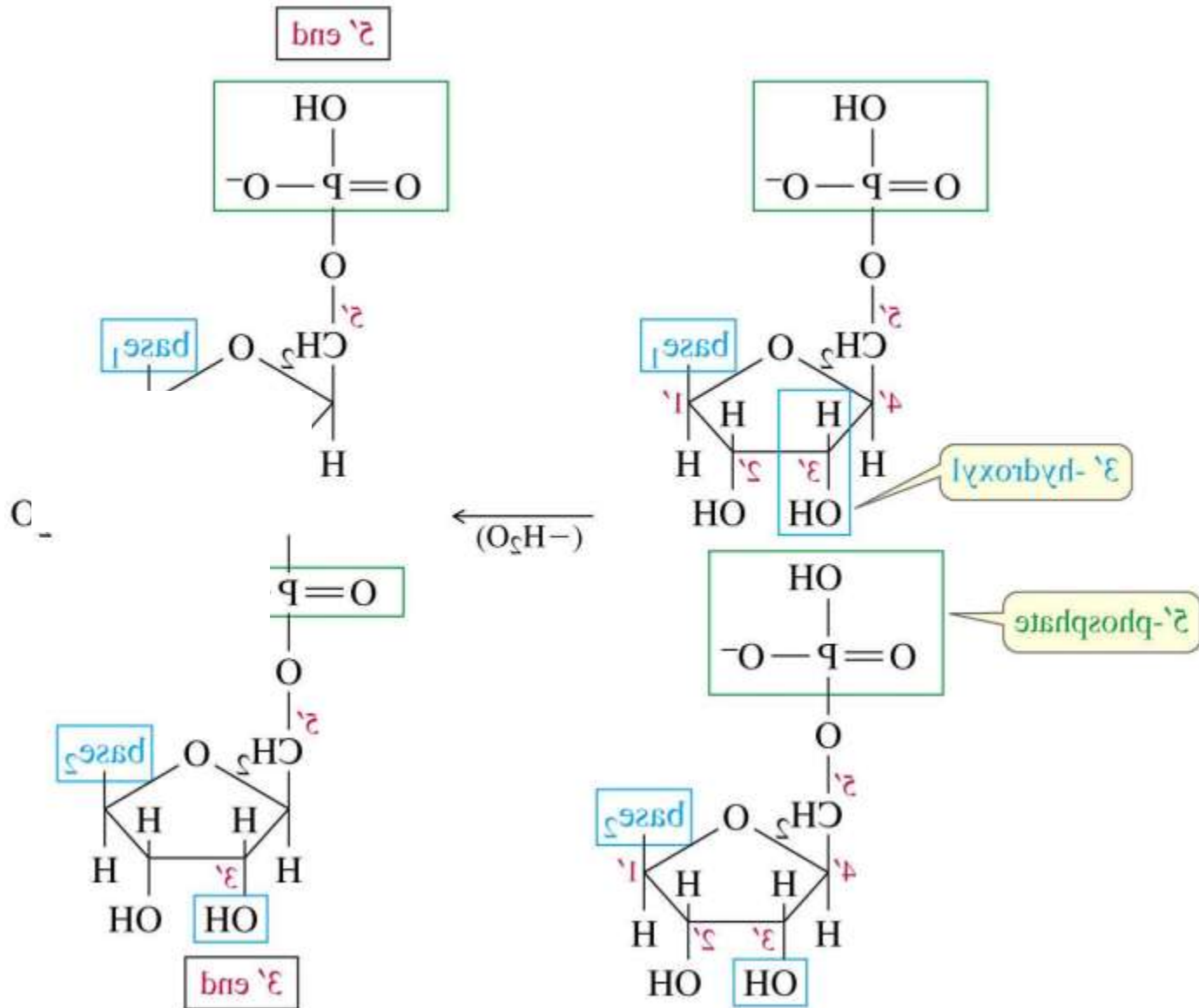


adenosine monophosphate,  
AMP (adenylic acid)



guanosine monophosphate,  
GMP (guanidylic acid)

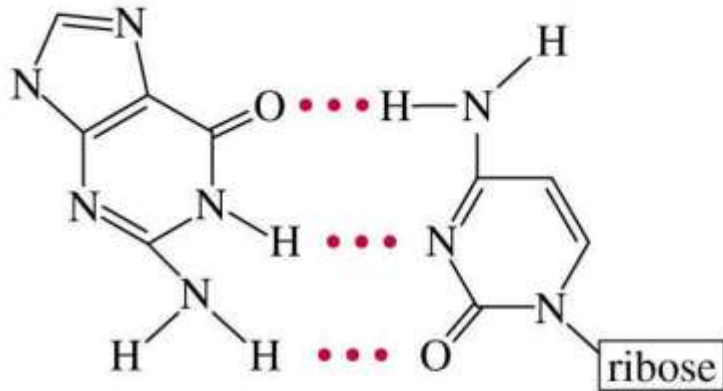
# Structure of RNA



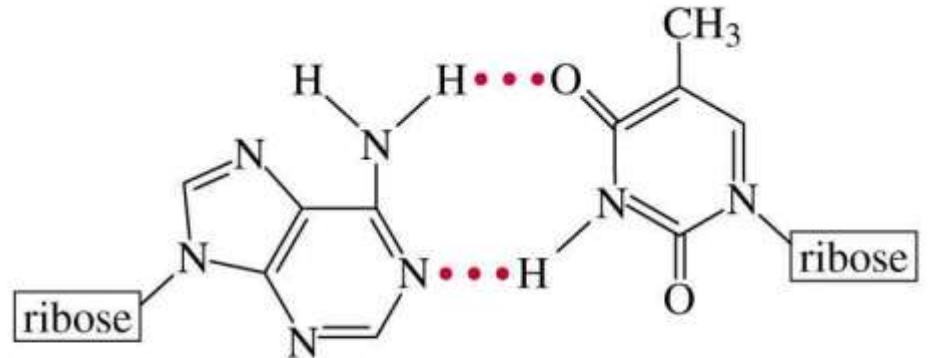
# Structure of DNA

- $\beta$ -D-2-deoxyribofuranose is the sugar.
- Heterocyclic bases are cytosine, thymine (instead of uracil), adenine, and guanine.
- Linked by phosphate ester groups to form the primary structure.

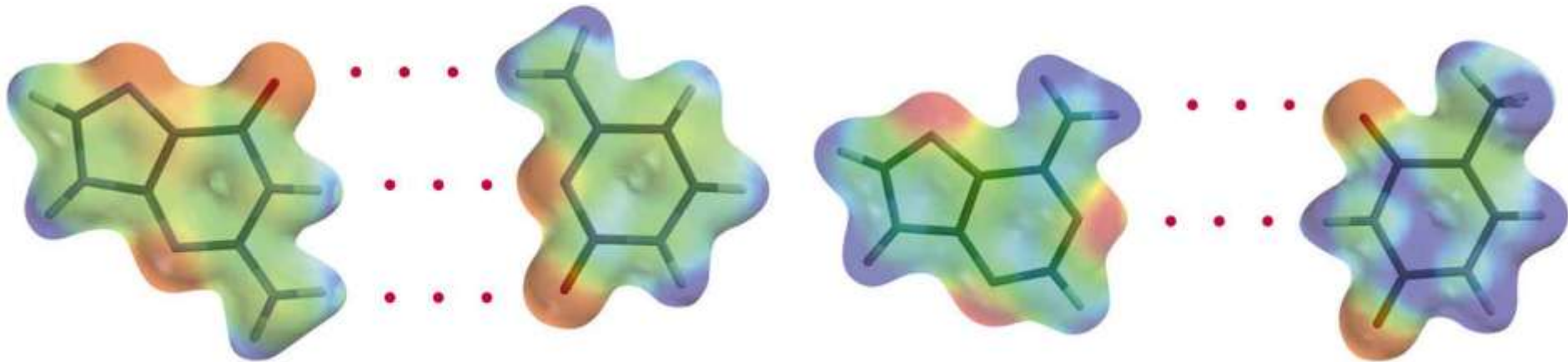
# Base Pairings



guanine      G : : : C      cytosine

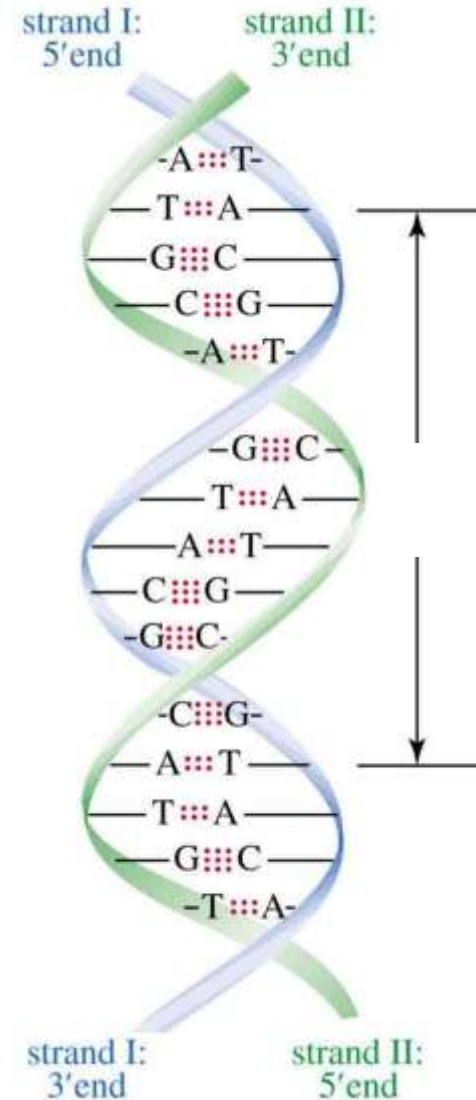


adenine      A : : : T      thymine

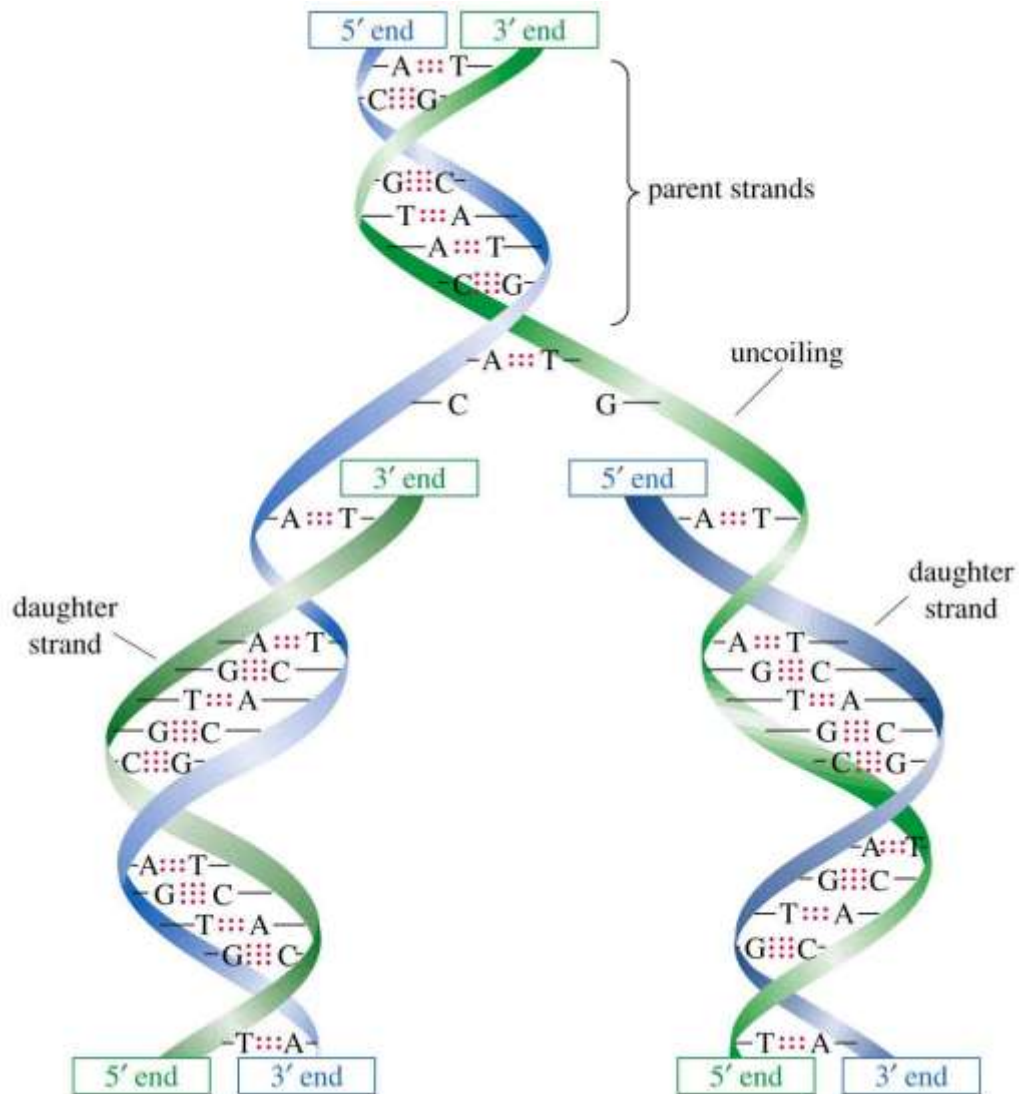


# Double Helix of DNA

- Two complementary polynucleotide chains are coiled into a helix.
- Described by Watson and Crick, 1953.



# DNA Replication



# Additional Nucleotides

- Adenosine monophosphate (AMP), a regulatory hormone.
- Nicotinamide adenine dinucleotide (NAD), a coenzyme.
- Adenosine triphosphate (ATP), an energy source.