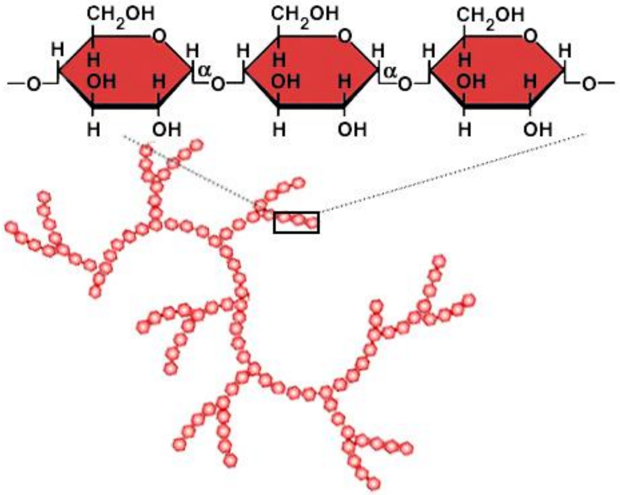
Carbohydrate-2



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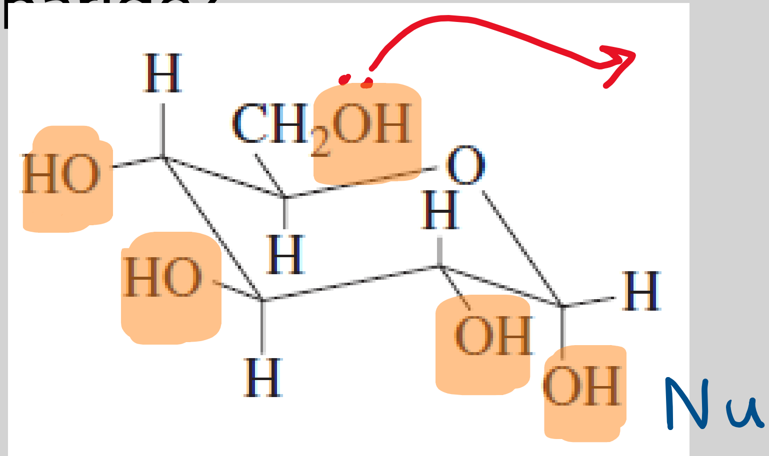
Recommended Textbook:

Chapter 23 in *Organic Chemistry*, 8th Edition, L. G. Wade, Jr., **2010**, Prentice Hall (Pearson Education)

Key concepts:

- How do we modify structure of monosacch

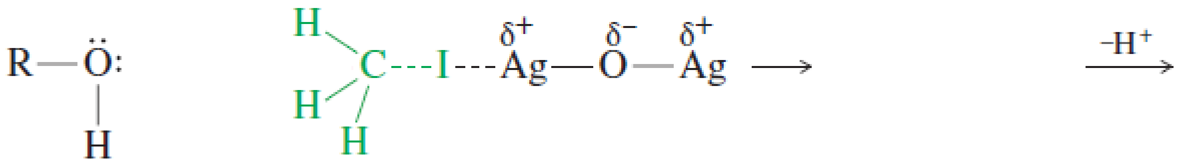


α-D-glucopyranose

(Reaction at the hydroxyl groups)

Monosaccharides – Reactions at hydroxyl groups

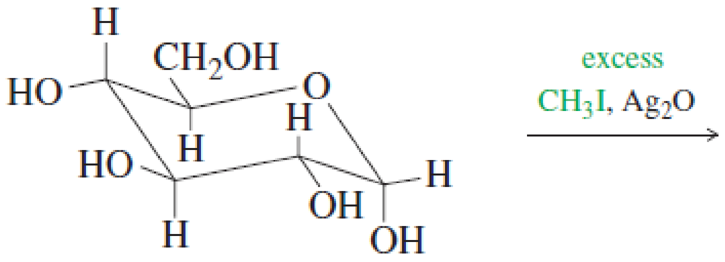
1) Formation of Ethers



sugar hydroxyl group polarized CH_3I ether

- Treating a sugar with **methyl iodide** and **silver oxide** converts the hydroxyl groups to **methyl ethers**
- Silver oxide polarizes the bond, making the methyl carbon strongly electrophilic

Example

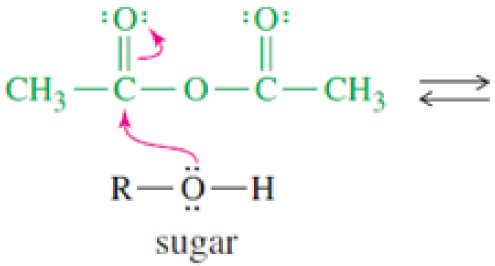


α-D-glucopyranose methyl 2,3,4,6-tetra-*O*-methyl-α-D-glucopyranoside

- Normal sugars contain several hydroxyl groups and are very soluble in water but rather insoluble in organic solvents; **the ethers are more soluble in organic solvents**

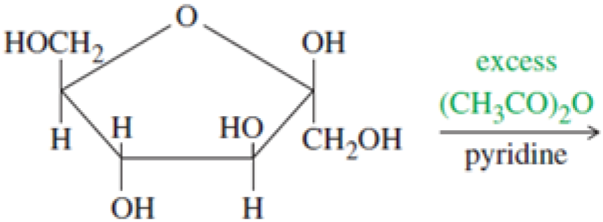
Monosaccharides – Reactions at hydroxyl groups

2) Formation of Esters



- Treatment with **acetic anhydride** and **pyridine** (as a mild basic catalyst) converts sugar hydroxyl groups to **acetate esters**

Example



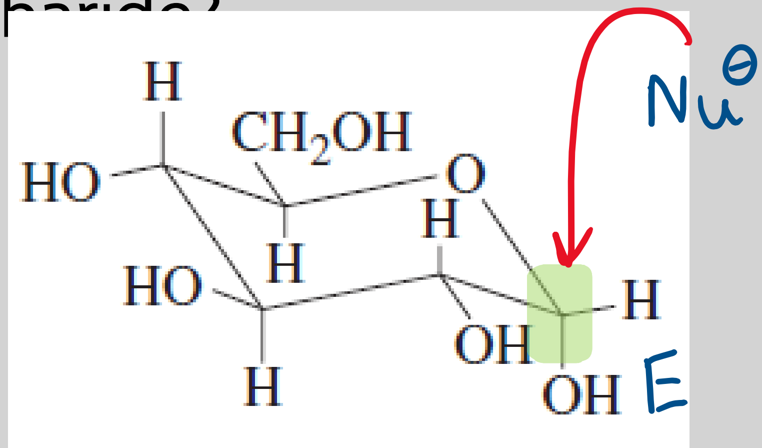
β-D-fructofuranose

penta-*O*-acetyl-β-D-fructofuranoside

- The anomeric C—O bond is not broken in the acylation, and the stereochemistry of the anomeric carbon atom is usually preserved

Key concepts:

- How do we modify structure of monosaccharide?



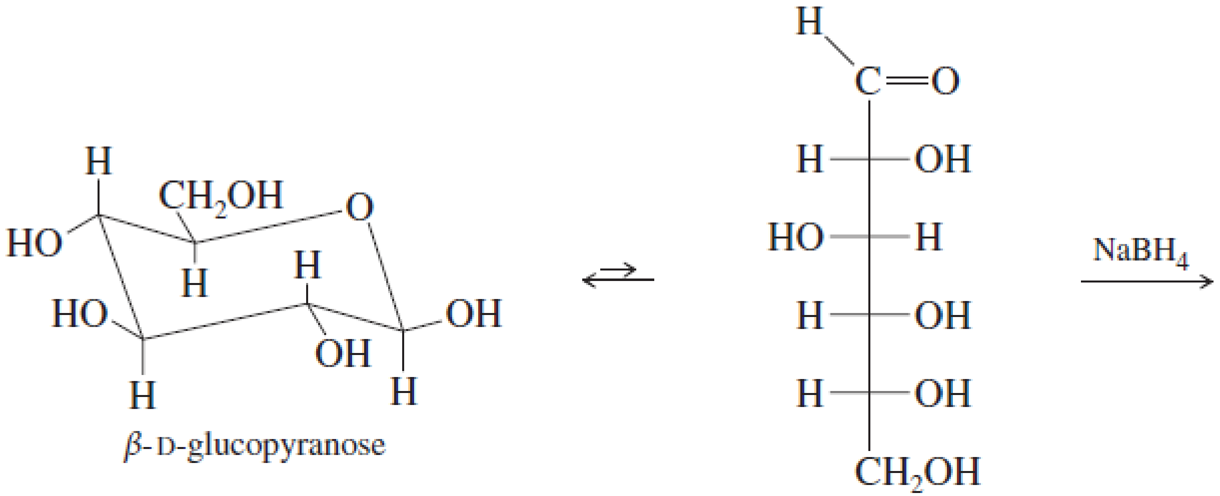
α-D-glucopyranose

(Reaction at the hemiacetal group)

Monosaccharides – Reactions at anomeric carbon

3) Reduction

- Like other aldehydes and ketones, aldoses and ketoses can be reduced to the corresponding **polyalcohols**, called **sugar alcohols**
- The most common reagents are **sodium borohydride** or **catalytic hydrogenation**
- Sugar alcohols are named by adding the suffix ***-itol*** to the root name of the sugar. The following equation shows the reduction of glucose to **glucitol**, sometimes called ***sorbitol***



β-D-glucopyranose

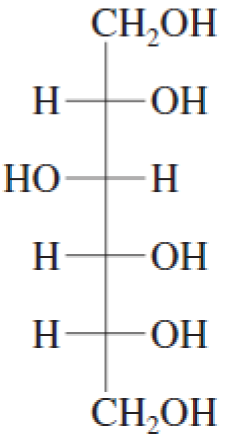
open-chain aldehyde

D-glucitol (D-sorbitol)
an alditol

Monosaccharides – Reactions at anomeric carbon

3) Reduction

- Sorbitol is used as a **sugar substitute**



D-glucitol (D-sorbitol)
an alditol

ใช้เป็นน้ำตาลเทียม
ให้ความหวานประมาณ 60% ของน้ำตาลทราย

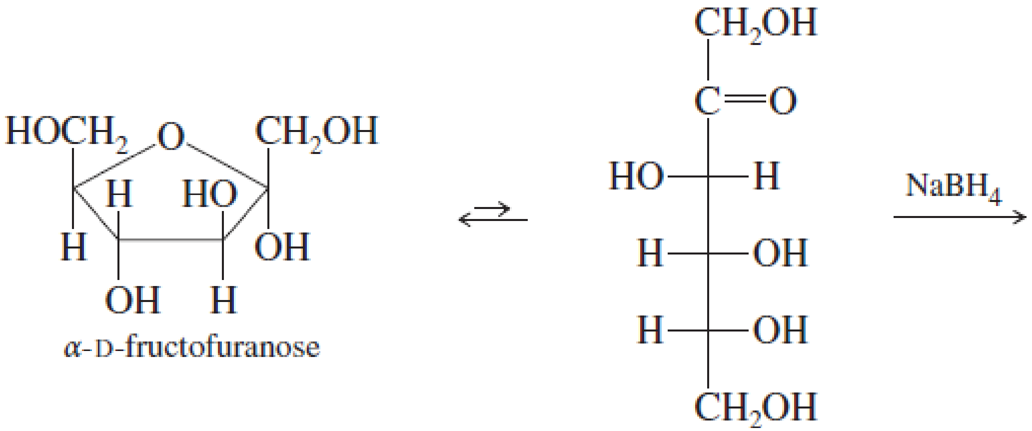
เป็นยาระบายอ่อน ๆ เนื่องจากดูดซึมได้ช้า
ให้พลังงาน 2.6 แคลอรีต่อกรัม

สามารถนำซอร์บิทอลผสมกับดินประสิว
ใช้เป็นเชื้อเพลิงจรวดได้

ใช้เป็นสารคงความชื้นในเครื่องสำอาง
รวมถึงเป็นสารเพิ่มความเข้มข้นด้วย

ลักษณะเป็นแบบผง ความหวานกลมกล่อม ไม่มีกลิ่น

- Example: reduction of fructose

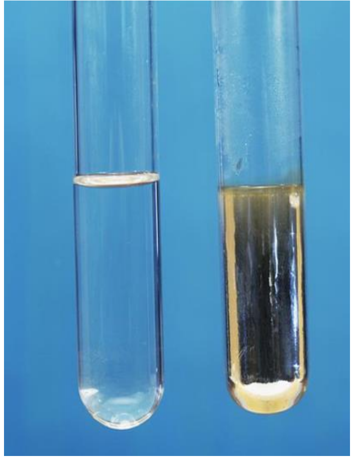


α-D-fructofuranose

open-chain ketone

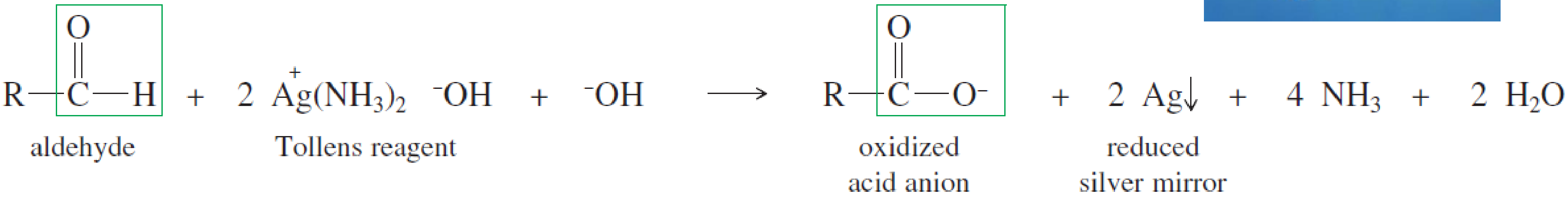
D-glucitol + D-mannitol
a mixture of alditols

Monosaccharides – Reactions at anomeric carbon



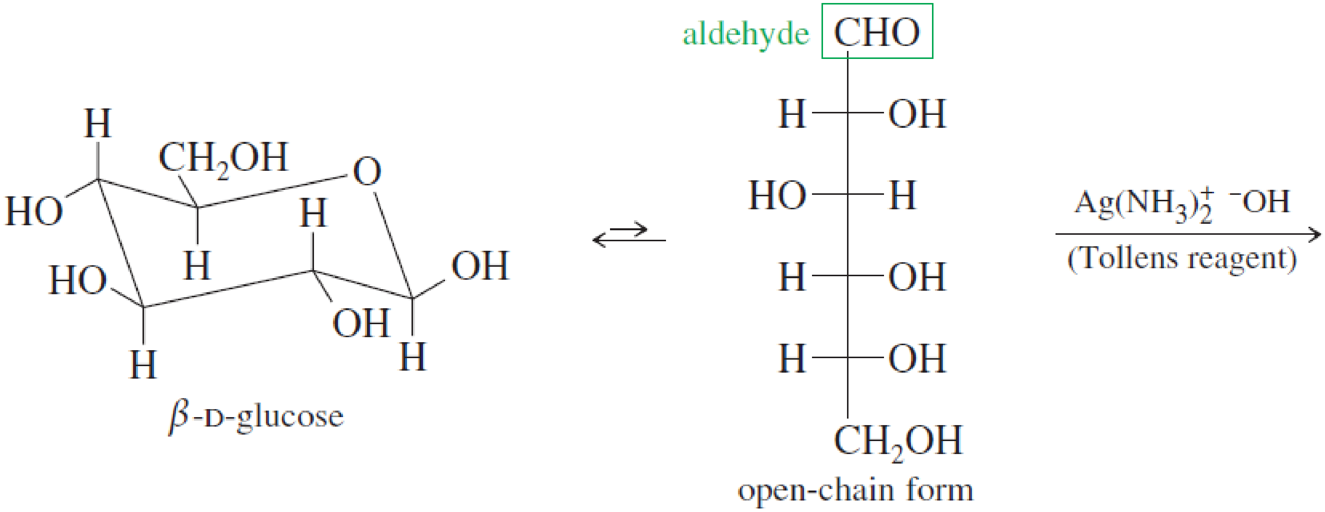
4) Oxidation

- **Tollen's test** detects aldehydes, which react with Tollens reagent to give carboxylate ions and metallic silver, often in the form of a silver mirror on the inside of the container.



$$R{-}\overset{\overset{\large O}{\|}}{C}{-}H + 2\ \overset{+}{Ag}(NH_3)_2\ {}^{-}OH + {}^{-}OH \longrightarrow R{-}\overset{\overset{\large O}{\|}}{C}{-}O^{-} + 2\ Ag\downarrow + 4\ NH_3 + 2\ H_2O$$

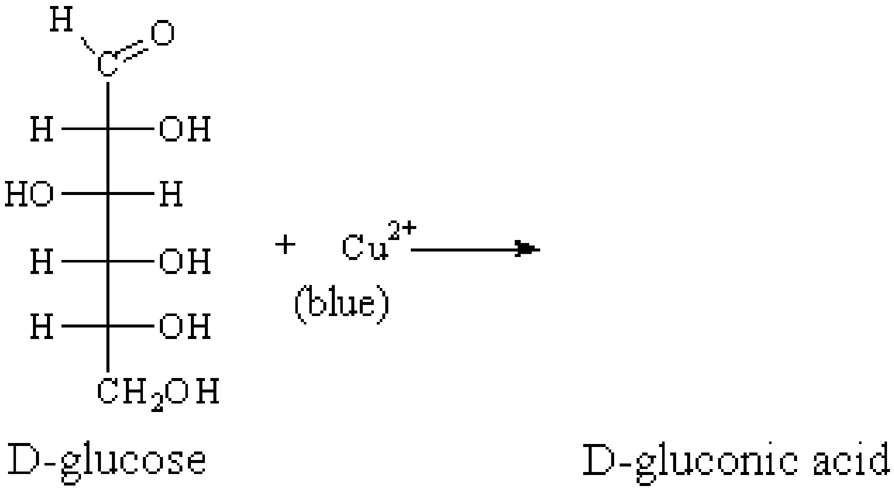
- Sugars that reduce Tollens reagent to give a silver mirror are called **reducing sugars** (mostly, **aldose in the open-chain form**)



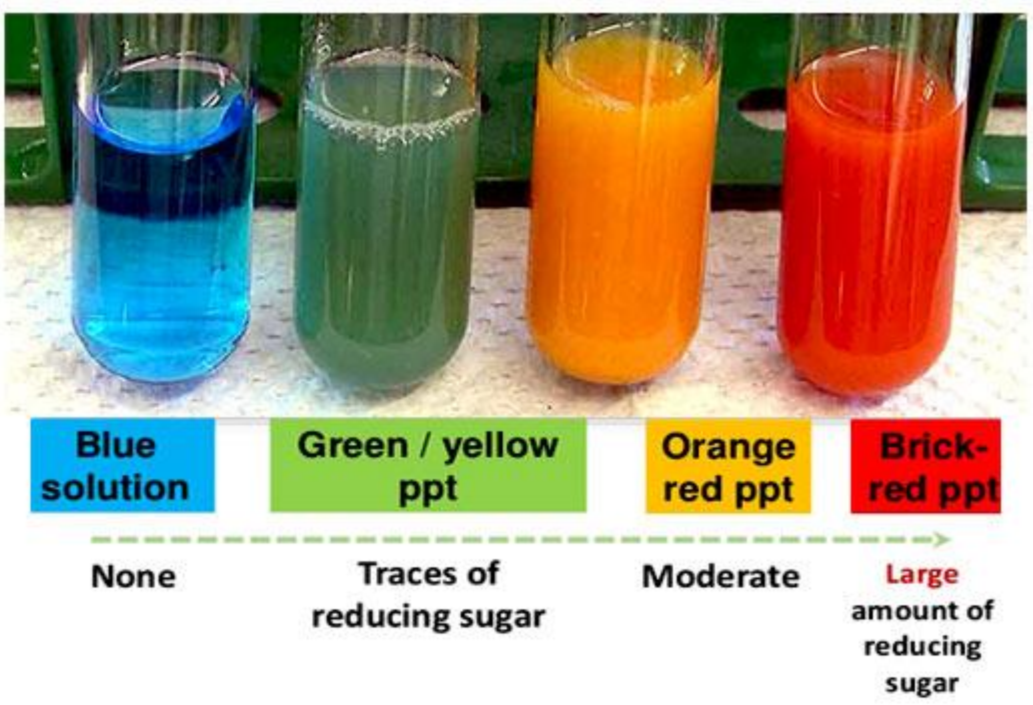
Monosaccharides – Reactions at anomeric carbon

4) Oxidation

- **Benedict's test** is a complex mixture of sodium carbonate, sodium citrate and **copper(II)** sulfate pentahydrate



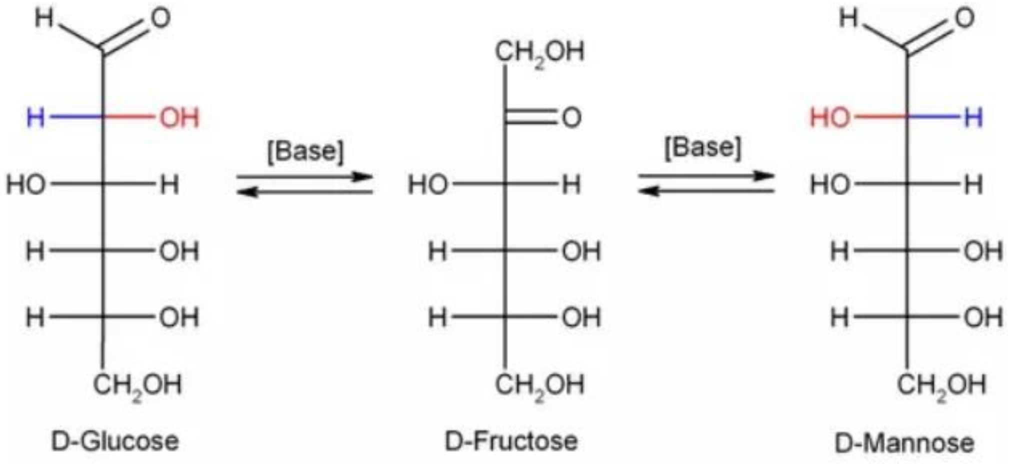
- It is commonly used to detect the presence of **reducing sugars**



Monosaccharides – Reactions at anomeric carbon

4) Oxidation • **How about ketoses?**

- Fructose undergoes rearrangement called lobrey-de bruyn-wankenstein rearrangement with the base as shown



(reducing sugars)

Monosaccharides – Reactions at anomeric carbon

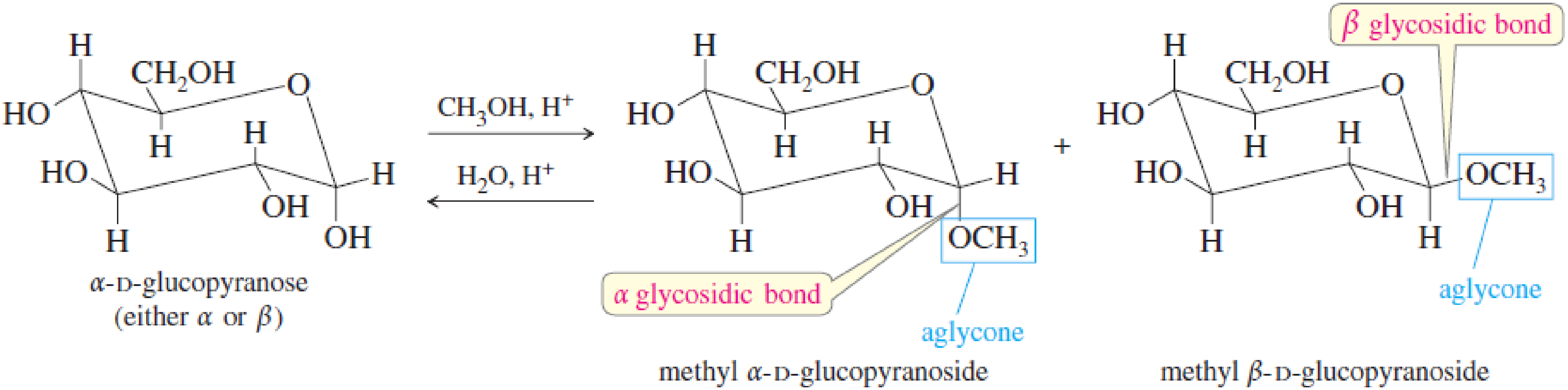
5) Formation of Glycoside **(Nonreducing sugars)**

Let’s recap the chemistry of aldehyde-ketone / hemiacetal / acetal first!

Monosaccharides – Reactions at anomeric carbon

5) Formation of Glycoside (Nonreducing sugars)

- Treatment with an alcohol and a trace of acid catalyst converts aldoses and ketoses to the **acetals** we call **glycosides**.
- Both anomers of the glycoside are formed (as an equilibrium mixture). The more stable anomer predominates.

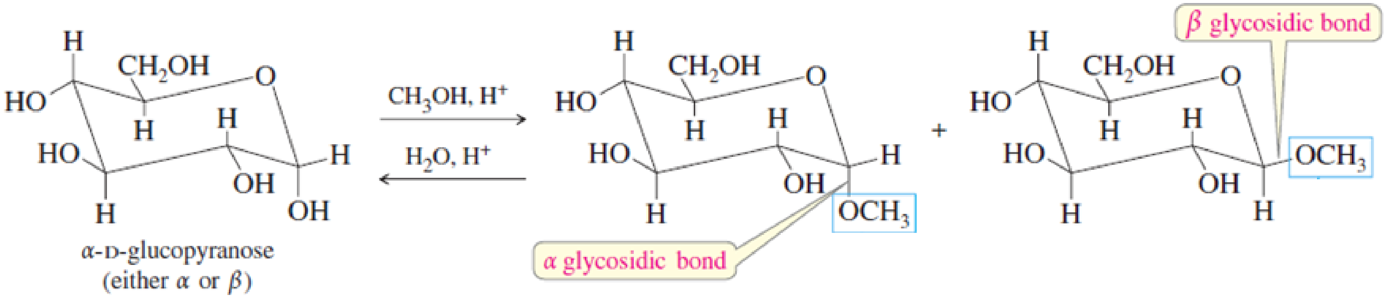


- Like other acetals, glycosides **are stable to basic conditions**, but they **hydrolyze in aqueous acid to a free sugar and an alcohol**.

Monosaccharides – Reactions at anomeric carbon

5) Formation of Glycoside **(Nonreducing sugars)**

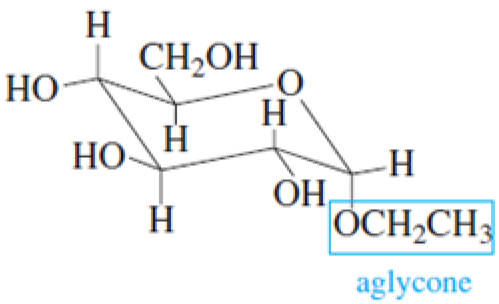
Mechanism:



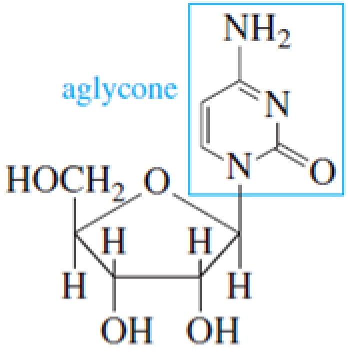
Monosaccharides – Reactions at anomeric carbon

5) Formation of Glycoside

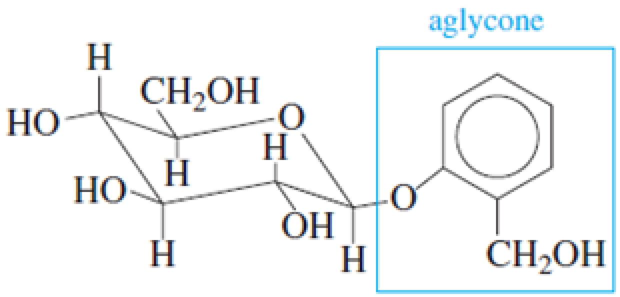
An **aglycone** is the group bonded to the anomeric carbon atom of a glycoside.



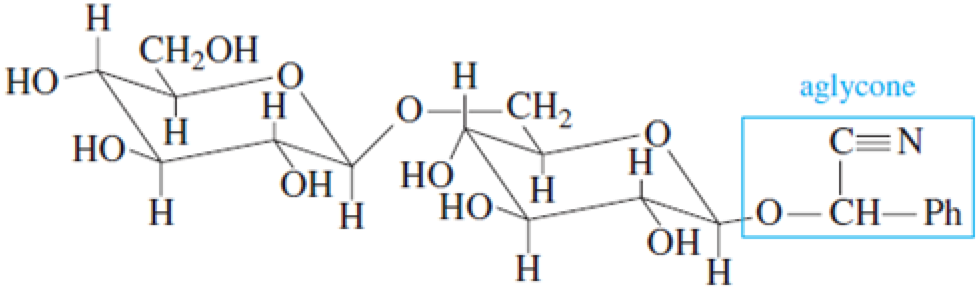
ethyl α-D-glucopyranoside



cytidine, a nucleoside

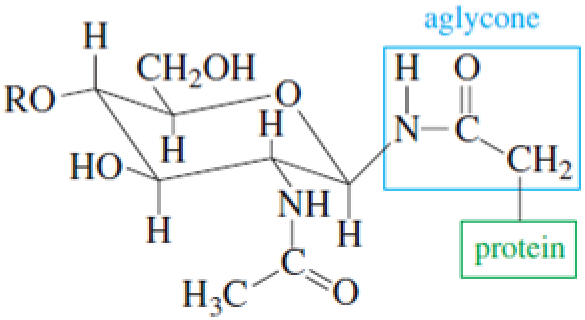


salicin, from willow bark



amygdalin

a component of laetrile, a controversial cancer drug



a glycoprotein *N*-glycoside

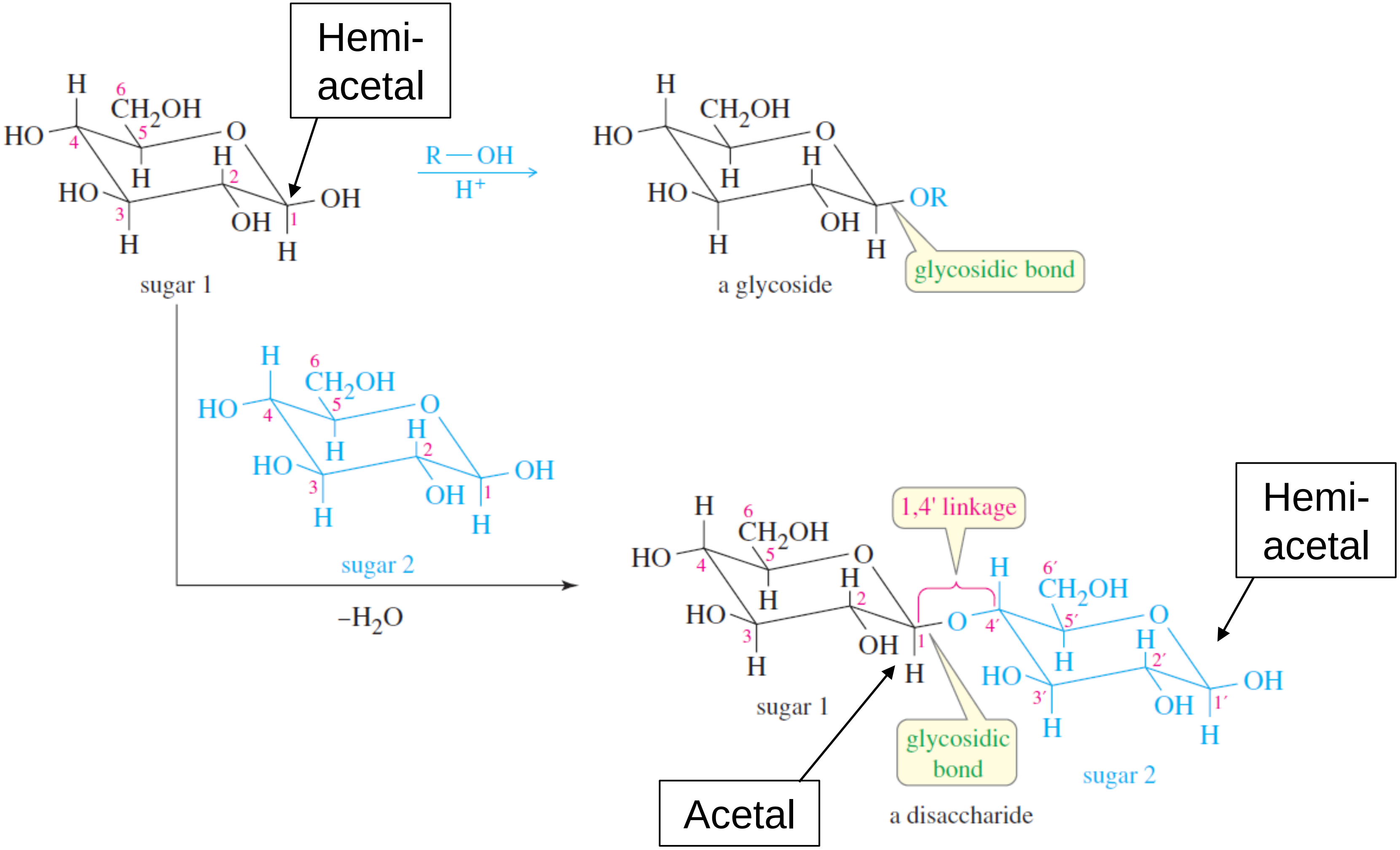
(showing the linkage from carbohydrate to protein)

Key concepts:

- What is disaccharide?
- What is glycosidic bond? What are the important types of glycosidic bond?

Disaccharides

- Contains two monosaccharides joined together by a **glycosidic linkage**
- Anomeric carbon of a sugar can react with the hydroxyl group of an alcohol to give an acetal called a **glycoside**; If the hydroxyl group is part of **another sugar molecule**, then the glycoside product is a **disaccharide**


Hemi-acetal

Hemi-acetal

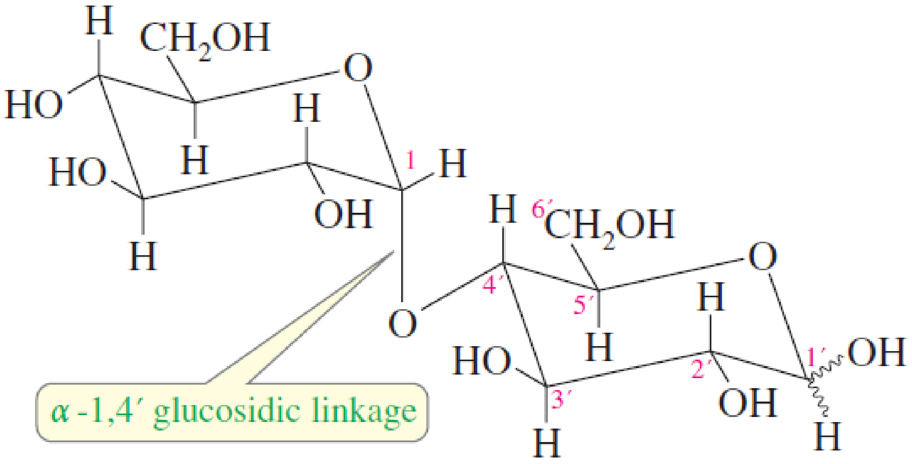
Acetal

Disaccharides

- In naturally occurring disaccharides, there are three common glycosidic bonding arrangements

1) 1,4’ Linkage

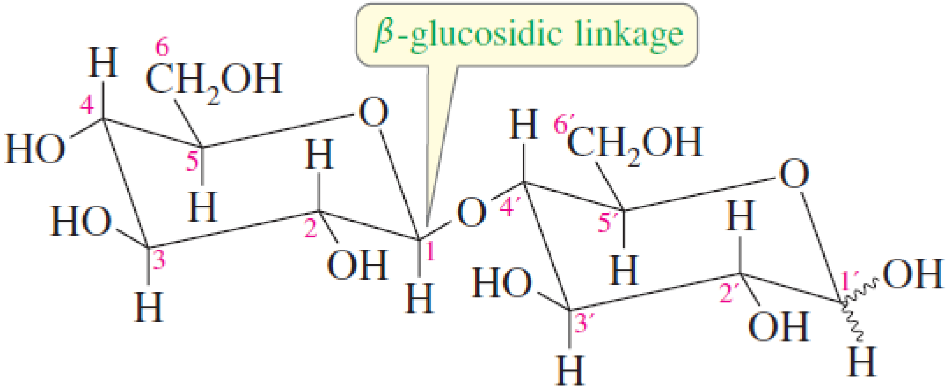
1.1) *α*-1,4’ Linkage



α -1,4′ glucosidic linkage

Maltose, 4-O-(α-D-glucopyranosyl)-D-glucopyranose

1.2) *β*-1,4’ Linkage



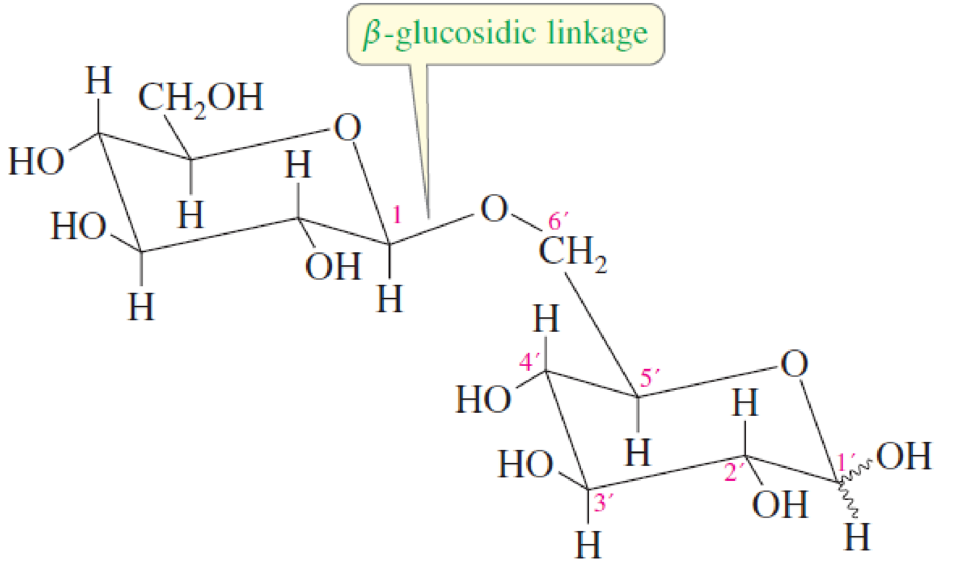
β-glucosidic linkage

Cellobiose, 4-O-(β-D-glucopyranosyl)-D-glucopyranose

Disaccharides

2) 1,6’ Linkage

The anomeric carbon of one sugar is linked to the oxygen of the terminal carbon (C6) of another

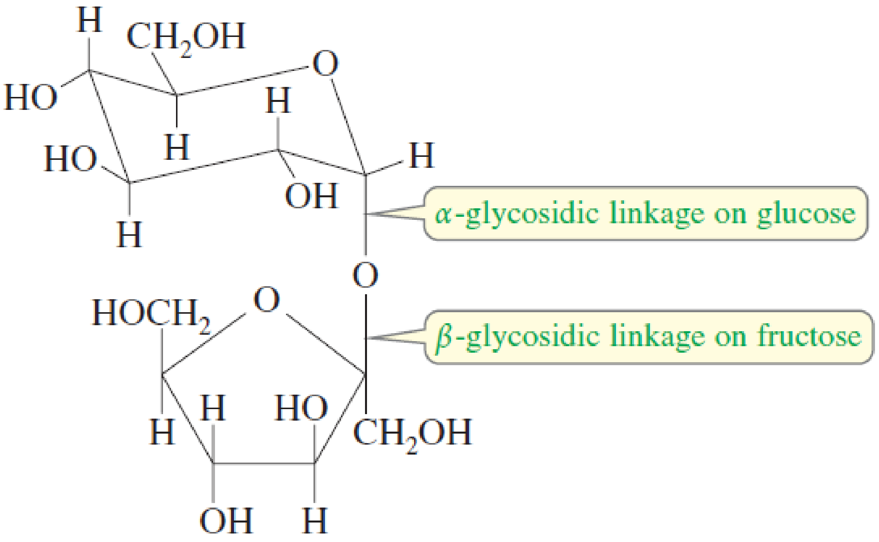


Gentiobiose, 6-O-(β-D-glucopyranosyl)-D-glucopyranose

3) 1,1’ or 1,2’ Linkage

Joined by a direct glycosidic linkage between two anomeric carbon atoms

Both monosaccharide units in sucrose are present as **acetals**, or glycosides; **sucrose does not reduce Tollens reagent; (non-reducing sugar)**



Sucrose, α-D-glucopyranosyl-β-D-fructofuranoside

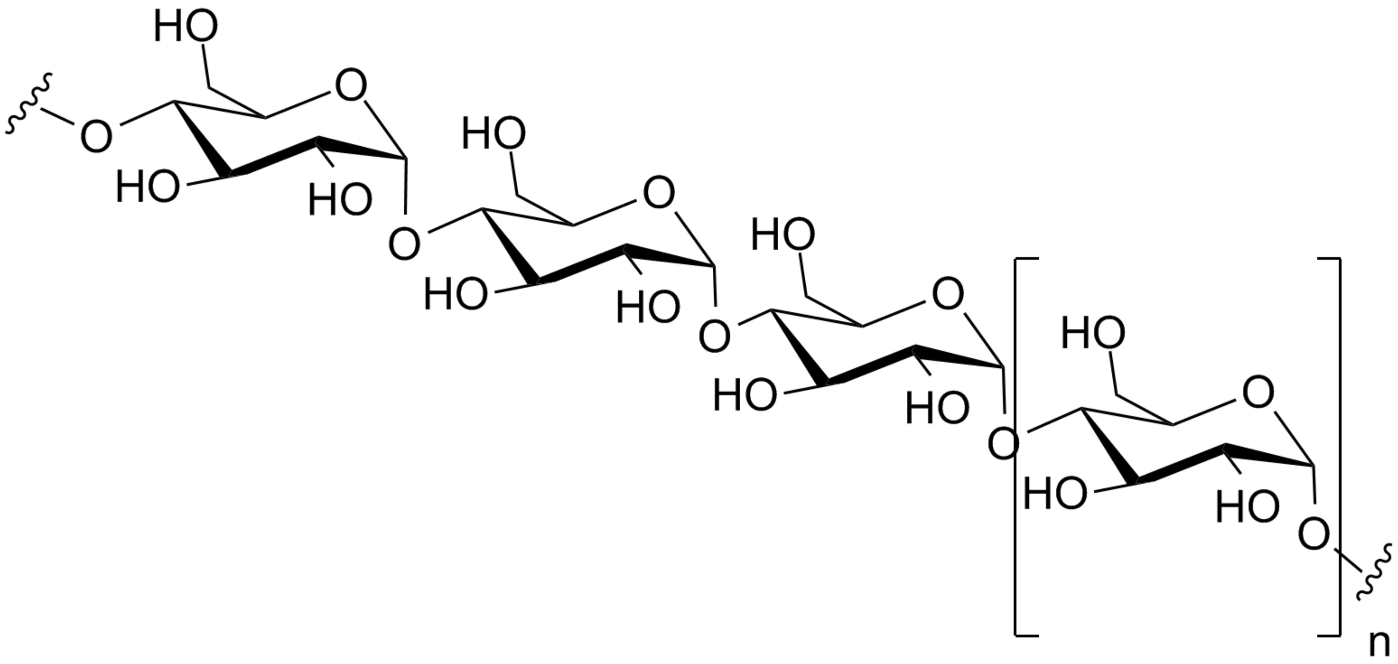
Key concepts:

- What is polysaccharide?
- What are the important types of polysaccharide?

Polysaccharides

- Contain **many** (usually hundreds or thousands) monosaccharide units joined by glycosidic bonds to form a **polymer chain**

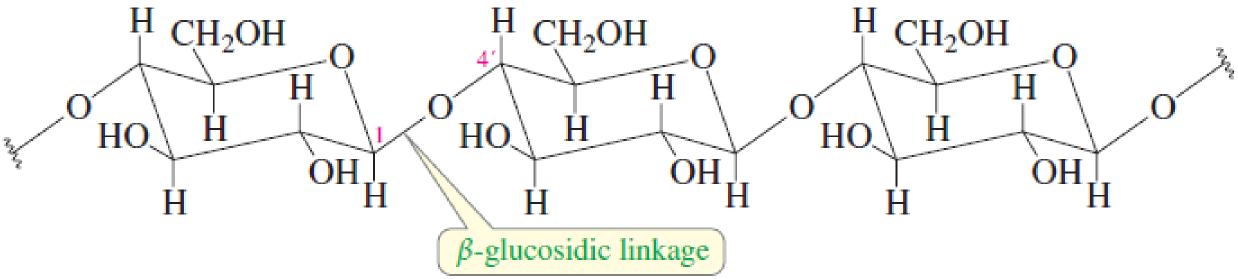
- Smaller polysaccharides, containing about **three to ten** monosaccharide units, are sometimes called **oligosaccharides**



- Except for units at the ends of chains, **all the anomeric carbon** atoms of polysaccharides are involved in **acetal glycosidic links**. Therefore, polysaccharides give **no noticeable reaction with Tollens reagent**

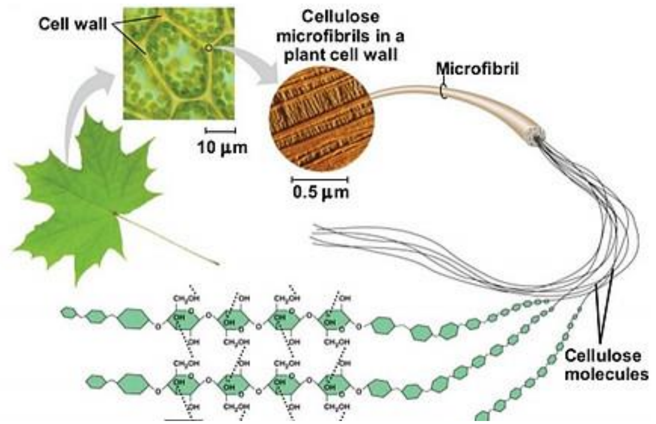
Polysaccharides

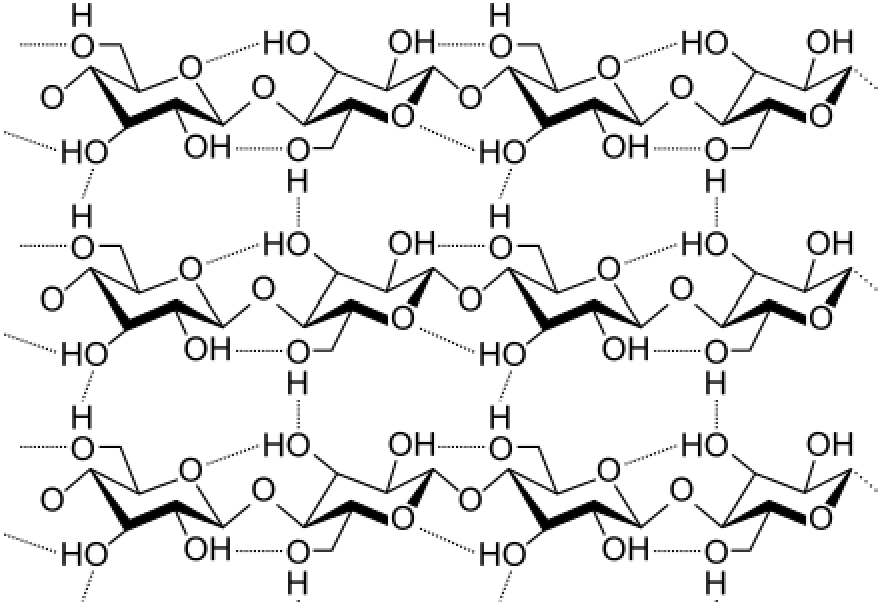
1) Cellulose



β-glucosidic linkage

- a polymer of **D-glucose**, is the **most abundant** organic material. Cellulose is synthesised by plants as a structural material to support the weight of the plant



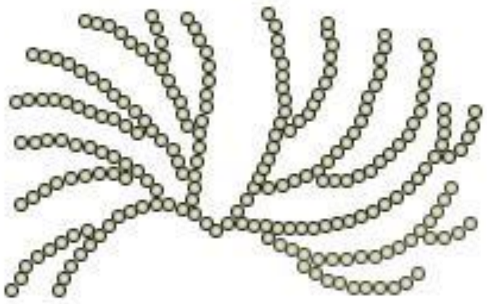


- Cellulose is composed of D-glucose units linked by ***β*-1,4’ glycosidic bonds**.
- This bonding arrangement is rather rigid and very stable, giving cellulose desirable properties for a structural material

Polysaccharides

2) Starches

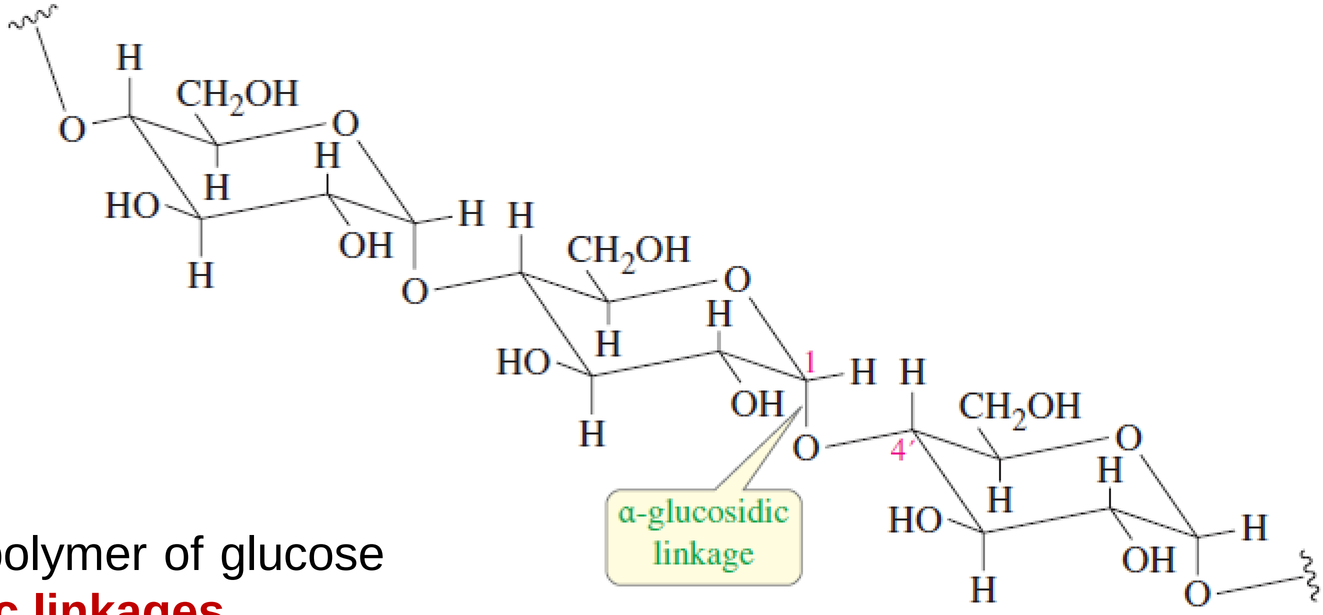
Amylose



Amylopectin

- Plants use starch granules for storing energy
- About 20% of the starch is water-soluble ***amylose***, and the remaining 80% is water-insoluble ***amylopectin***

2.1) Amylose

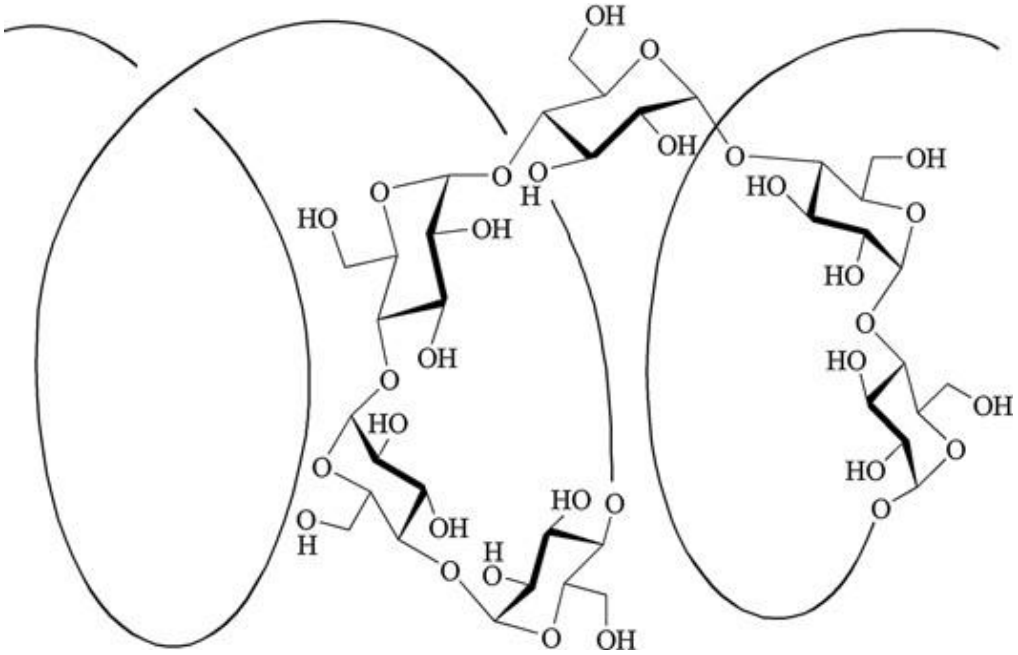


- Amylose is a linear polymer of glucose with **α-1,4’ glycosidic linkages**

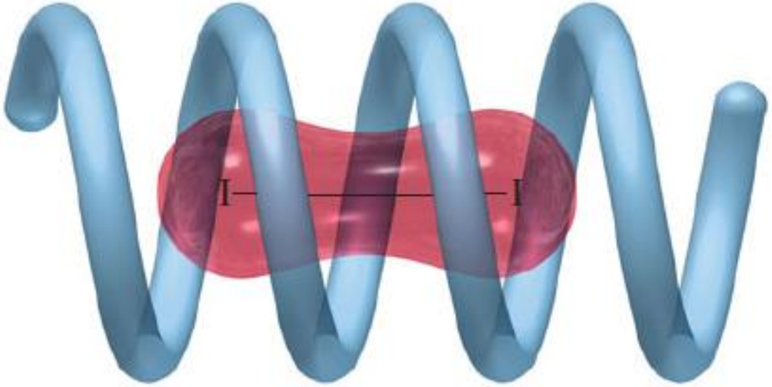
Polysaccharides

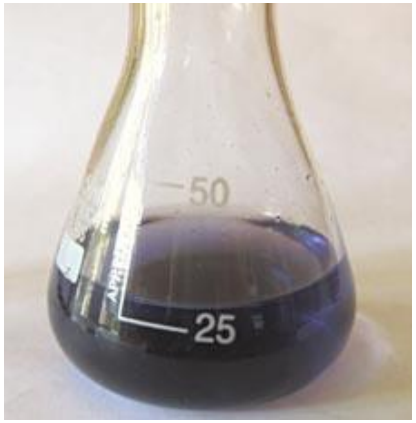
2) Starches

2.1) Amylose – Helical Structure



- The linkage in amylose kinks the polymer chain into a **helical structure**. This kinking increases **hydrogen bonding** with water and lends additional **solubility** (compared with cellulose)
- The inside of the helix is just the right size and polarity to accept an **iodine molecule**. When iodine is lodged within this helix, a **deep blue starch-iodine complex** results. This is the basis of the **starch-iodide test** for oxidizers



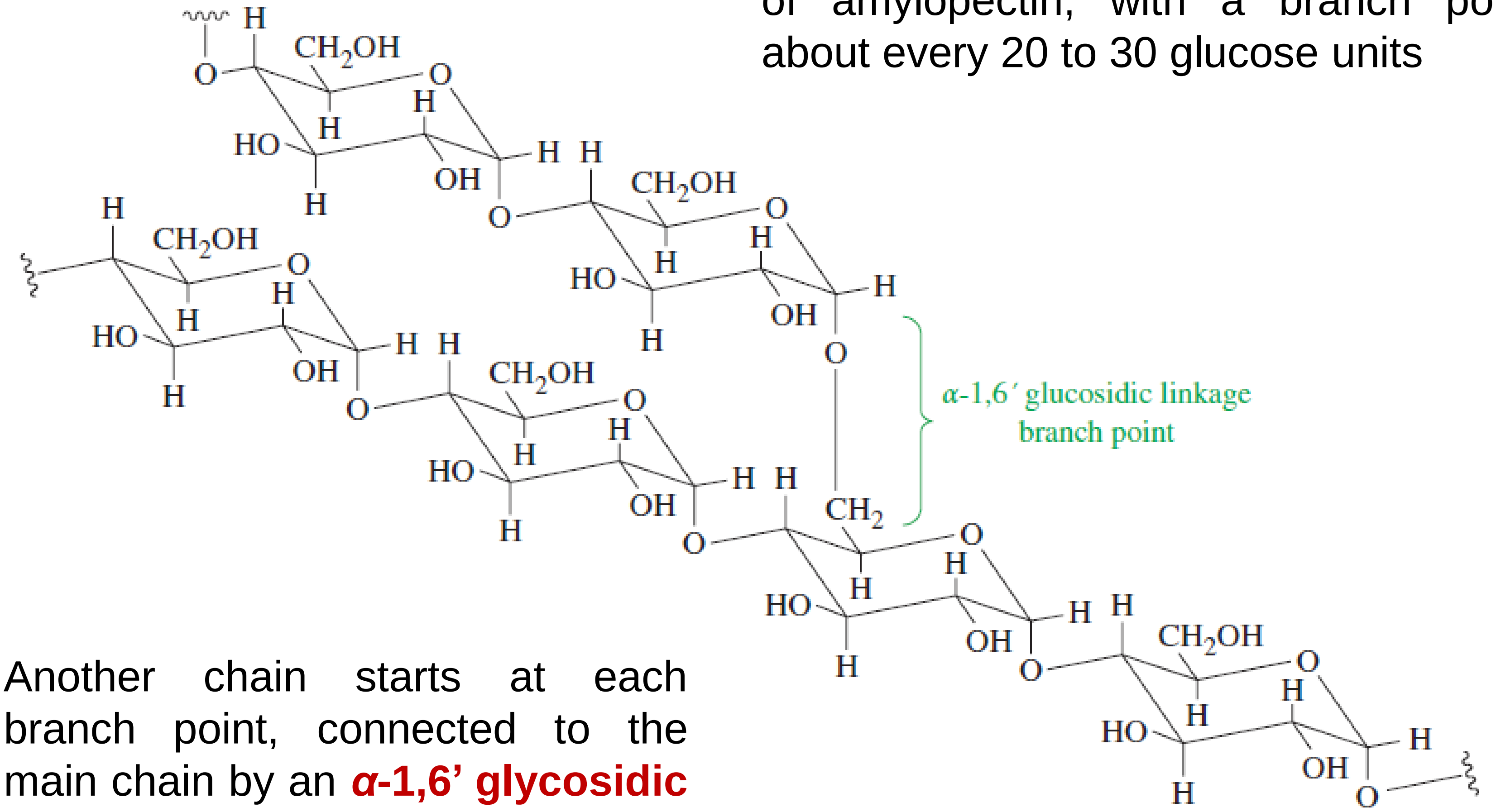


Polysaccharides

2) Starches

2.2) Amylopectin

- The insoluble fraction of starch, is also primarily an **α-1,4’** polymer of glucose
- The difference between amylose and amylopectin lies in the **branched** nature of amylopectin, with a branch point about every 20 to 30 glucose units



- Another chain starts at each branch point, connected to the main chain by an **α-1,6’ glycosidic linkage**

Polysaccharides

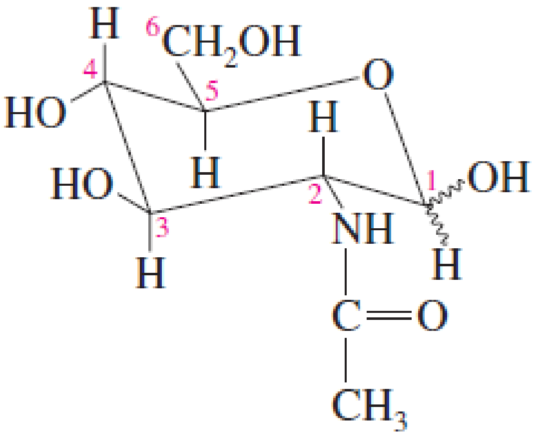
3) Chitin:

- Chitin forms the exoskeletons of insects. In crustaceans, chitin forms a matrix that binds calcium carbonate crystals into the exoskeleton.

- It is a polymer of ***N*-acetylglucosamine**, an amino sugar (actually an amide) that is common in living organisms.

- In *N*-acetylglucosamine, the hydroxyl group on C2 of glucose is replaced by an amino group (forming glucosamine), and that amino group is acetylated.

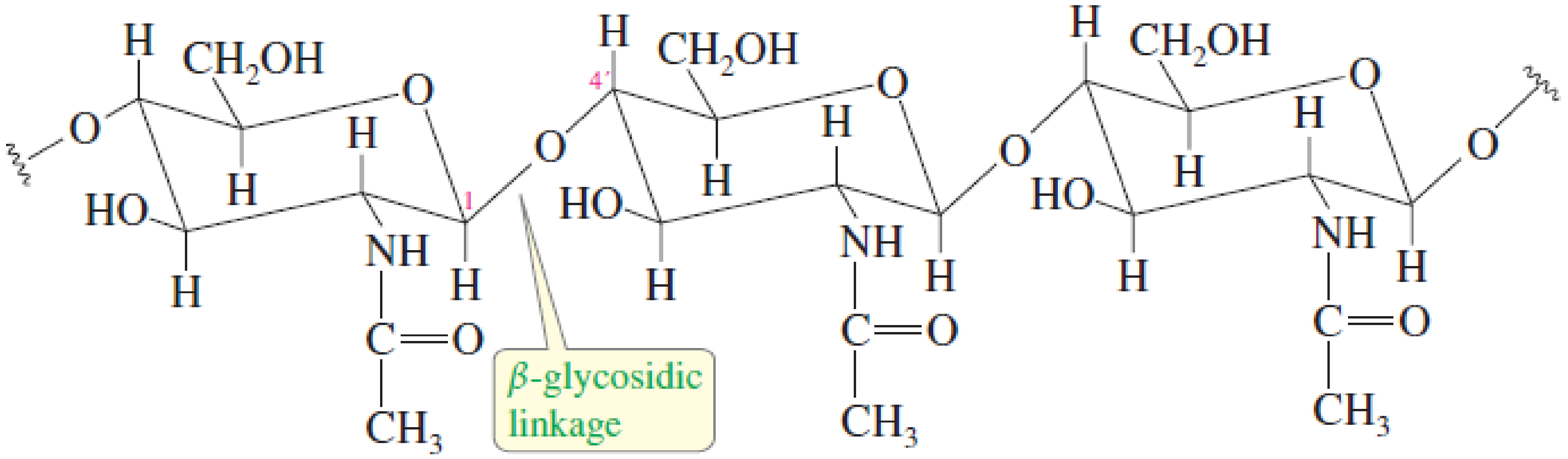
N-Acetylglucosamine, or 2-acetamido-2-deoxy-D-glucose



Polysaccharides

3) Chitin:

- Chitin is bonded like cellulose (***β*-1,4' glycosidic bonds**) giving chitin structural rigidity, strength, and stability that exceed even that of cellulose.
- Like other amides, *N*-acetylglucosamine forms exceptionally strong hydrogen bonds between the amide carbonyl groups and N-H protons.



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