GENERAL BIOCHEMISTRY - TOPICS

- Biological macromolecules:

✓ Carbohydrates

✓ Lipids

✓ Amino acids and Peptides

✓ Proteins

  - myoglobin and hemoglobin
  - enzymes and enzymology

✓ Nucleic acids

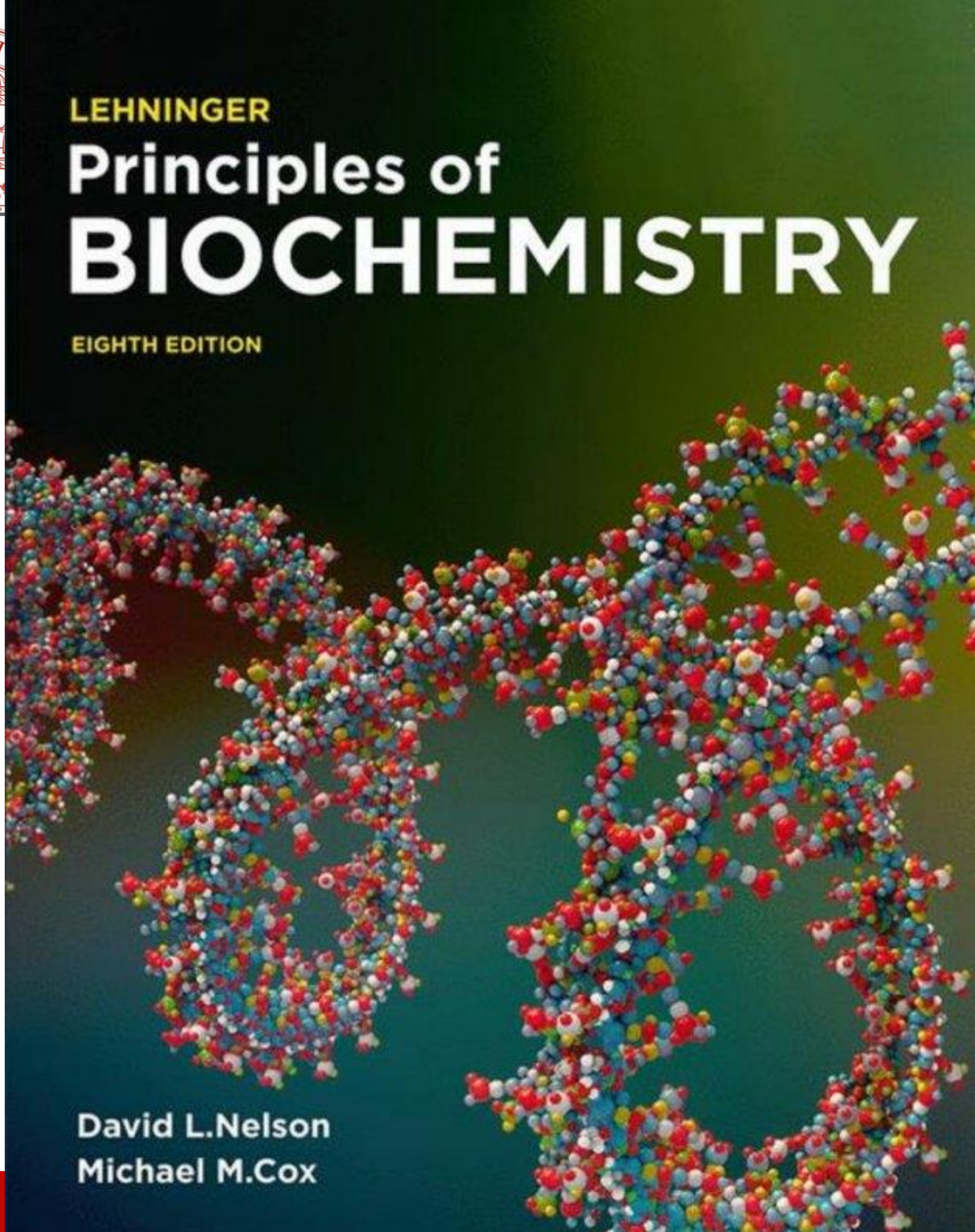
where does the term "university" come from?

Authentica Habita issued by Emperor Frederick I Barbarossa between 1154 and 1155 in Roncaglia

L'Authentica Habita was a landmark decree that protected students' rights, promoted academic freedom and mobility, and recognized students as a distinct legal group within medieval society.

- It granted legal protection and privileges to foreign students and professors, particularly those from Bologna, who sought his jurisdictional protection.
- Students traveling for study, often leaving their homeland and facing different languages and customs, were placed under imperial protection.
- The L'Authentica Habita promoted academic mobility by protecting students from reprisals and granting them rights similar to clergy.

The best and oldest known copy is the 12th-century manuscript MS. 64, which is kept at the Harvard Law School Library



Textbook

Lehninger Principles of Biochemistry
Authors: David Nelson, Michael Cox, Aaron Hoskins

w.h.freeman
Macmillan Learning
New York

7th or 8th editions are both fine!

B. Biomedica Centrale LT 572 LEHAL 2017

B. Interdip. Chimica. CHIMICA INDUSTRIALE LT 572 NELSDL /7. ed.

B. Centrale Campus di Rimini DEWEY LT 572 LEHN

B. BIMFAI di Fisica 05.01.04 Chim. Organi 0016

BIOCHEMISTRY LABORATORY

- **December 18th 2025, 11-13 AULA MAGNA OSTETRICIA E GINECOLOGIA Sant'Orsola Pad. 4 – Prof. Vadim Viviani «From Green to Near-Infrared: developing novel color tuning luciferases for Cellular Biosensing, Bioimaging and Photodynamic Therapy»**
- **January 8th 2026, 9 -11 AULA MAGNA OSTETRICIA E GINECOLOGIA Sant'Orsola - Pad. 4 - Clinical case presentations (4/5 people per group)**
- **January 12th 2026, 14-16 AULA MAGNA OSTETRICIA E GINECOLOGIA Sant'Orsola Pad. 4 - Clinical case presentations (4/5 people per group)**
- **January 13th 2026, 14-16 AULA MAGNA OSTETRICIA E GINECOLOGIA Sant'Orsola Pad. 4 - Clinical case presentations (4/5 people per group)**
- **January 26th 2026, 9-11 AULA MAGNA AULA MAGNA OSTETRICIA E GINECOLOGIA Sant'Orsola Pad. 4 - «Mock exam – Chemistry and Biochemistry (with results discussion)»**
- **January 29th 2026, 11-13 AULA MAGNA AULA MAGNA OSTETRICIA E GINECOLOGIA Sant'Orsola Pad. 4 – Prof. Antonio Pannuti «Immunoglobulins and Immunotherapy»**

BIOCHEMISTRY LABORATORY

BRING YOUR LAB COAT WITH YOU

Via San Giacomo 12, Bologna

GROUP	EXPERIENCE #1	EXPERIENCE #2
G1	December 16, 2025 14-18	January 30, 2026 14-18
G2	December 15, 2025 14-18	January 27, 2026 14-18
G3	January 19, 2026 14-18	January 21, 2026 14-18
G4	January 19, 2026 9-13	January 26, 2026 14-18
G5	January 16, 2026 14-18	January 20, 2026 14-18

"Complete Health and Safety training modules 1,2 and 3 before accessing the wet lab"

BIOCHEMISTRY LABORATORY

Tutors:

Dr. Alessia Silla
alessia.silla2@unibo.it

Dr. Greta Gozzi
greta.gozzi2@unibo.it

Important information about

ATTENDANCE REQUIREMENTS

Attendance to this learning activity is mandatory; the minimum attendance requirement to be admitted to the final exam is 60% of lessons. For Integrated Courses (IC), the 60% attendance requirement refers to the total amount of I.C. lessons. Students who fail to meet the minimum attendance requirement will not be admitted to the final exam of the course, and will have to attend relevant classes again during the next academic year.

Professors **may** authorise excused absences **upon receipt of proper justifying documentation, in case of illness or serious reasons.** Excused absences do not count against a student's attendance record to determine their minimum attendance requirement.

ATTENDANCE CONFIRMATION

1) **scan the QR code with your device**

2) **authenticate with your University credentials**

   (nome.cognome@studio.unibo.it) on the application

3) **Confirm the attendance to certify your attendance at the lesson**

EXAM PROCEDURE

- The final exam consists of a written one, including Chemistry and General Biochemistry parts.
- Maximum duration of 50 min (25 min for EACH part).
- The exam consists of true/false, single choice (3 choices), and open questions.
- The overall exam score is 33.00 points, divided into 14 points for the "Chemistry" part and 19 points for the Biochemistry module. The exam is passed by achieving at least 8 points (out of 14) for the Chemistry part and 10 (out of 19) for the Biochemistry part. The grade obtained (necessarily greater than or equal to 18) is calculated by summing the points obtained in each of the above-mentioned parts and rounding it to the nearest integer.
- The exam can be repeated at any exam session. No midterm exams will be scheduled.

EXAM CONTENT

CHEMISTRY

- **8 true/false questions:** 0.4 pts point/correct answer
- **6 single choices; 3 options with 1 correct answer,** 0.85 pts/correct answer
- **2 exercises:** 2 pts for each correct exercise
- **1 open question:** 1.7 pts

BIOCHEMISTRY

- **10 true/false questions:** 0.4 point/correct answer
- **12 single choices; 3 options with 1 correct answer,** 0.85 pts/correct answer
- **2 open questions:** 2 pts and 2.8 pts, respectively.

EXAM PROCEDURE

- If a student obtains an overall score greater than 30.5 points (from 30.51), the examining commission will confer 30 cum laude (30L)

- If a student obtains 7.5-7.9 points (out of 14) <u>in the Chemistry exam</u>, s/he will receive a final grade of 18 in the entire exam (just passing with a score ≥ 10 in the Biochemistry part,).

- If a student obtains 9.5-9.9 points (out of 19) <u>in the Biochemistry exam</u>, s/he will receive a final grade of 18 in the entire exam (just passing with a score ≥ 8 in the chemistry part).

EXAM EVALUATION

Examples:

- **Chemistry: 6 pts**
- **Biochemistry: 12.50 pts**
  ---> FAILED

- **Chemistry: 14 pts**
- **Biochemistry: 9.75 pts**
  ---> 23.75 pts ---> PASSED WITH 18/30.

- **Chemistry: 7.5 pts**
- **Biochemistry: 17.5 pts**
  ---> PASSED WITH 18/30.

- **Chemistry: 14 pts**
- **Biochemistry: 12.5 pts**
  ---> 26.5 pts ---> PASSED WITH 27/30.

Exam dates

- **February 4th, 2026 - 10:30** Just Chemistry BLOCK, intermediate exam (30 min)

AULA MAGNA NUOVE PATOLOGIE (Sant'Orsola - Pad. 5)

The Chemistry module score, once accepted, must NOT be repeated.

- **February 17th 2026 - 10:30 at AULA MAGNA NUOVE PATOLOGIE (Sant'Orsola-Pad. 5)**

- **March 4th 2026 - 10:30 at AULA MAGNA NUOVE PATOLOGIE (Sant'Orsola - Pad.5)**

- **June 23th 2026 - 10:30 at Aula magna DERMATOLOGIA**

AULA MAGNA OSTETRICIA E GINECOLOGIA (Sant'Orsola - Pad. 4)

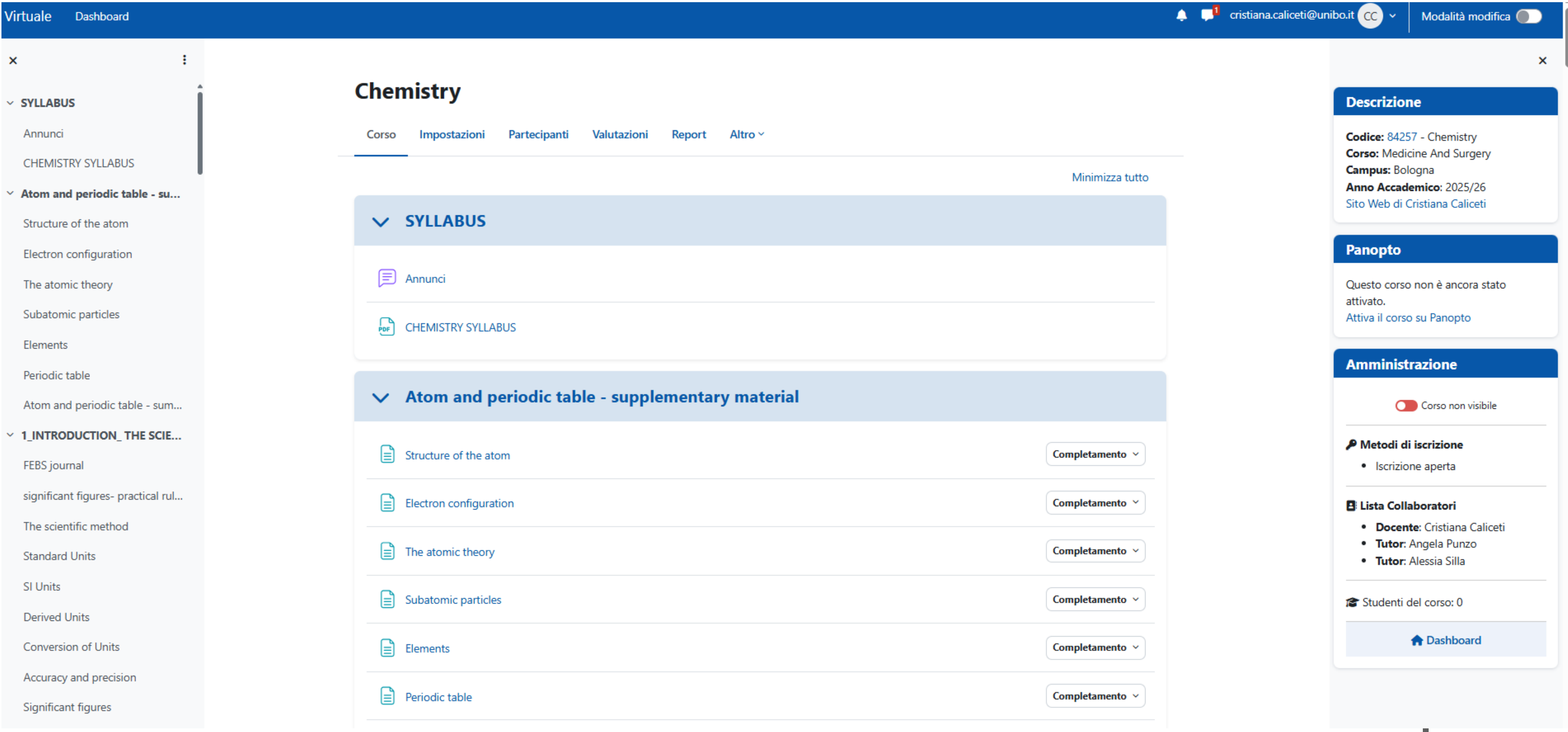
- **July 20th 2026 - 10:30 at Aula magna DERMATOLOGIA**

AULA MAGNA OSTETRICIA E GINECOLOGIA (Sant'Orsola - Pad. 4)

- **September 15th 2026 - 10:30 at Aula magna DERMATOLOGIA**

AULA MAGNA OSTETRICIA E GINECOLOGIA (Sant'Orsola - Pad. 4)

Please download the material



WOOCLAP and JOVE

https://app.wooclap.com/

https://www.jove.com/

KAHOOT FOR THE IN CLASS AUTOEVALUATION TEST

Carbohydrates

- composed by C, H, O
- The simple sugar glucose, $C_6H_{12}O_6$, is the primary energy source for the brain and nervous system and can be used by many other tissues. When “burned” by cells for energy, each gram (g) of carbohydrate releases approximately 4 kilocalories (kcal) of energy.

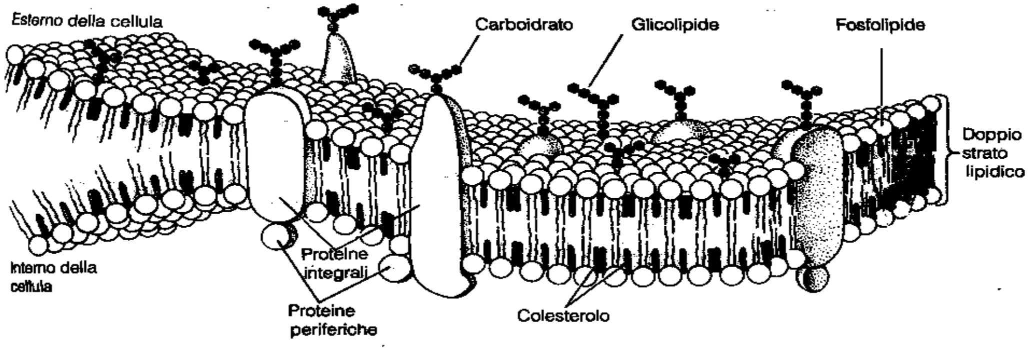
FUNCTIONS

ENERGETIC — **1 g = 4 kcal** → **Instant energy (glucose)** / **Backup energy (glycogen)**

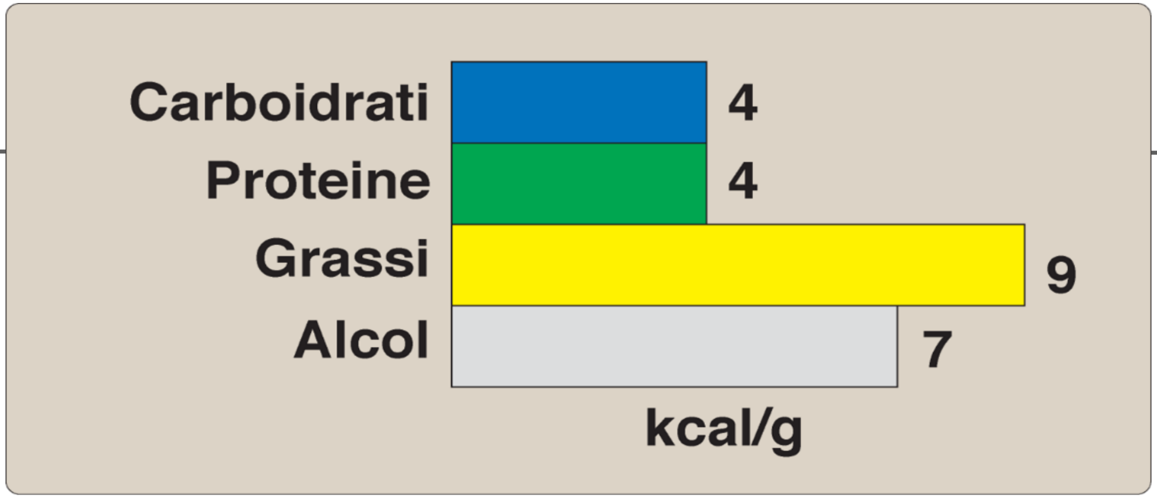
1 cal = 4.18 J

STRUCTURAL — **Constituents of nucleotides and nucleic acids (ribose and deoxyribose), proteoglycans (glycosaminoglycans), glycoproteins and glycolipids**

SIGNAL — **Communication between cells and with the external environment (oligosaccharides on the surface of cell membranes); identification of the destination of glycoproteins**



EXCRETION — **Glucuronic acid**



RISERVE ENERGETICHE
DI UN UOMO ADULTO DI 70 KG

Riserva	Tessuto	gr	kcal
Glicogeno	Muscolo	350	1400
Glicogeno	Fegato	80	320
Glucosio	Fluidi	20	80
Lipidi	Tessuto adiposo	15000	135000
Proteine	Muscolo	6000	24000

Comparison of energy sources

Glycogen

- Typically store a one day supply.
- Less energy per gram than for fat
  - about 70% by weight is water.

Fat

- Usually store a one month supply.
- May store MUCH more.
- More energy per gram - no water.
- Only released after the glycogen is gone.

Riserve energetiche	Sopravvivenza al digiuno
Lipidi:10-15 kg	35 giorni
Glicogeno muscolare: 350 g	15 ore
Glicogeno epatico: 80 g	3,5 ore
Glucosio ematico: 20 g	40 min
Proteine corporee 6-7 kg	15 giorni

Uomo adulto di 70 kg

Grasso circa 15 kg	135.000 kcal
Glicogeno (muscoli e fegato) circa 300-500 g	1.200 - 2.000 kcal
Proteine circa 6 - 12 kg	24.000 - 48.000 kcal

EQUIVALENZA FRA RISERVE ENERGETICHE

15 kg di LIPIDI → 34 kg di glicogeno

Il glicogeno lega acqua in quantità 4 volte superiore al suo peso: 4 × 34 kg = 136 kg acqua

136 kg acqua + 34 kg glicogeno = 170 kg: peso complessivo di un deposito di glicogeno equivalente a 15 kg di lipidi

15 kg di lipidi → 18 kg tessuto adiposo (ha il 15 % d'acqua)
(il muscolo ha l'80 % d'acqua)

15 kg di lipidi → 170 kg glucidi

Carbohydrates

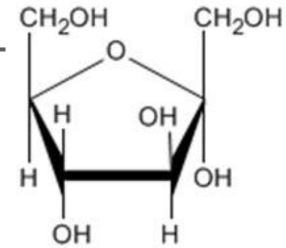
- Compounds containing C, H and O
- General formula: $C_x(H_2O)_y$
- All have the functional groups **C=O** and **-OH**
- Classification based on:
  - Number of sugar unit
  - Number of C atom in each unit
  - C=O group localization
  - Stereochemistry

Types of carbohydrates

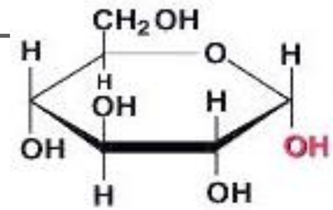
- Classification based on the number of sugar unit
  - Monosaccharides 1 unit
  - Disaccharides 2 units
  - Oligosaccharides 2-10 units
  - Polysaccharides more than 10 units

- Sugar units are linked with glycosidic bond forming an O bridge between two units

MONOSACCHARIDES



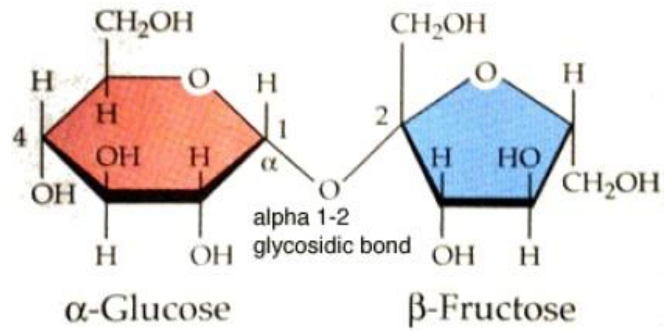
α-D-fructose



α-D-glucose

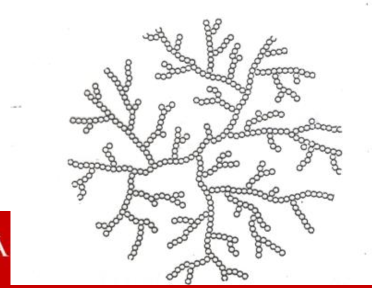
DI AND OLIGO-SACCHARIDES

constituted by a small number of molecules bound together by glycosidic bondage. An example is the **disaccharide sucrose**



POLYSACCHARIDES

polymers constituted by long chains of hundreds or thousands of monosaccharide units, such as cellulose or glycogen



MONOSACCHARIDES

- They can be classified on the basis of the **functional groups** they contain.

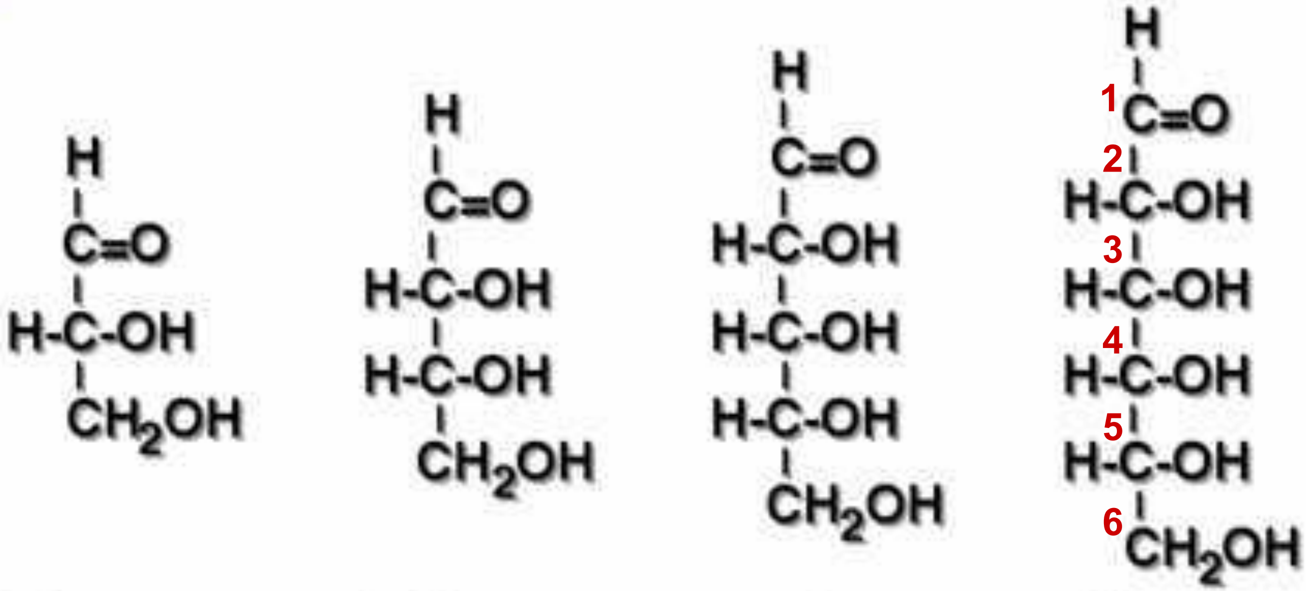
- A monosaccharide with a **ketone (carbonyl) group** is a **ketose**. In a ketose, the carbonyl group is located on <u>carbon-2</u>.

- If an **aldehyde (carbonyl) group** is present, it is called an **aldose**. In an aldose, the carbonyl group is located on <u>carbon-1</u>.

- Sometimes monosaccharides are called **polyhydroxyaldehydes** or **polyhydroxyketones** because they also contain many hydroxyl groups.

Monosaccharide classifications

- Number of carbon atoms in the chain

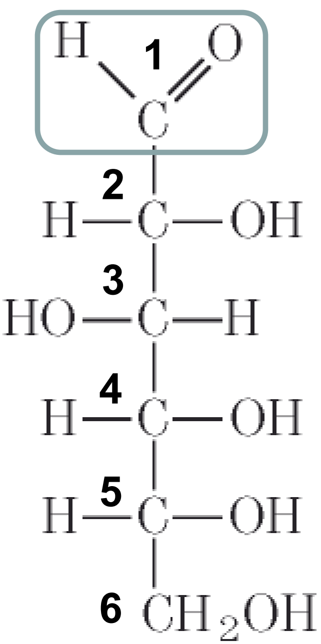


triose tetrose pentose hexose

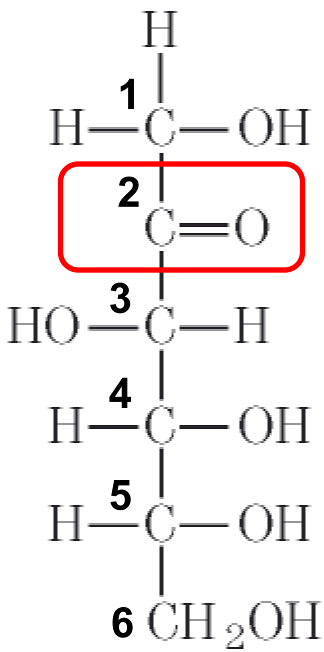
Can be either aldose or ketose sugar.

MONOSACCHARIDES

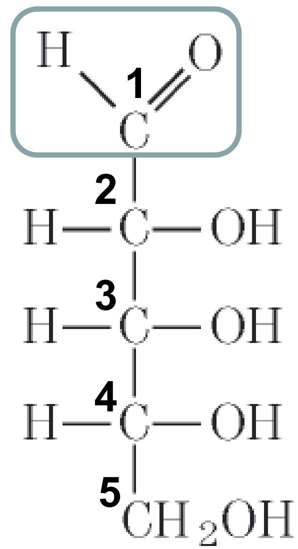
- Monosaccharides are divided into aldoses and ketoses according to their functional group.
- Depending on the number of C atoms, we can distinguish trioses (3C), tetroses (4C), pentoses (5C), hexoses (6C), heptoses (7C).



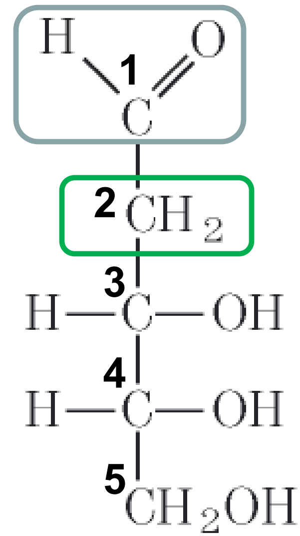
D-Glucose
an aldohexose



D-Fructose
a ketohexose



D-Ribose
an aldopentose



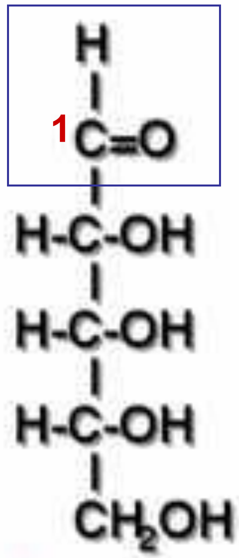
D-deoxyribose
an aldopentose

These names tell us that the structure represents one particular sugar and also identifies the sugar as one of two possible stereoisomers (D- or L-).

Monosaccharide classifications

- Based on location of C=O

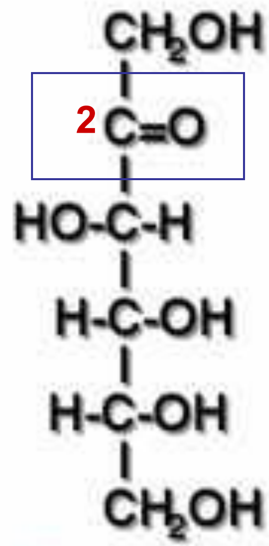
Aldehyde functional group



Aldose
- aldehyde C=O

D-Ribose

Ketone functional group



Ketose
- ketone C=O

D-Fructose

Asymmetric C atoms, chiral molecules and stereoisomers

Chiral center.

Asymmetric carbon - 4 different things are attached to it.

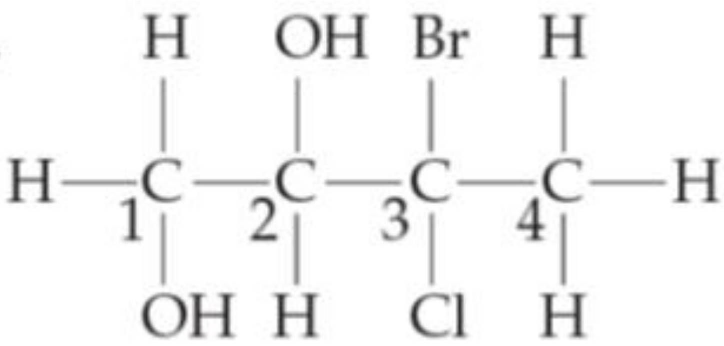
You must have at least one asymmetric carbon to have stereoisomers.

The molecule is formed from the bonding of a central carbon to four different groups. This results in two possible ways to arrange the groups, rather than one. Each isomer is bonded together through the exact *same* bonding pattern, yet the two molecules are *not* identical.

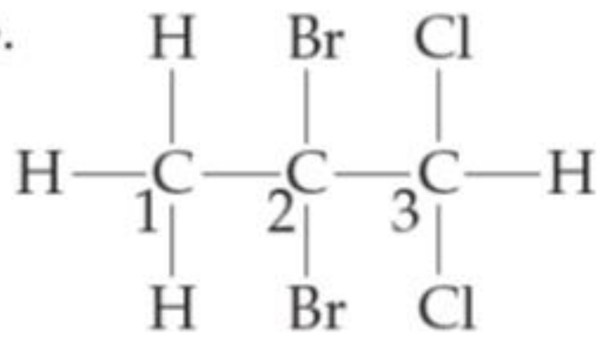
EXERCISE

Determine which of the following compounds is chiral and which is achiral (not chiral).

a.



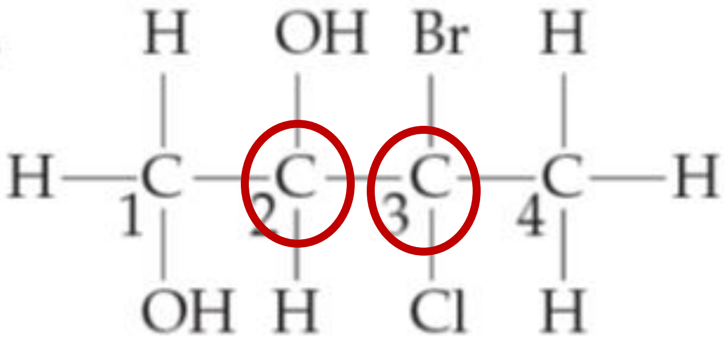
b.



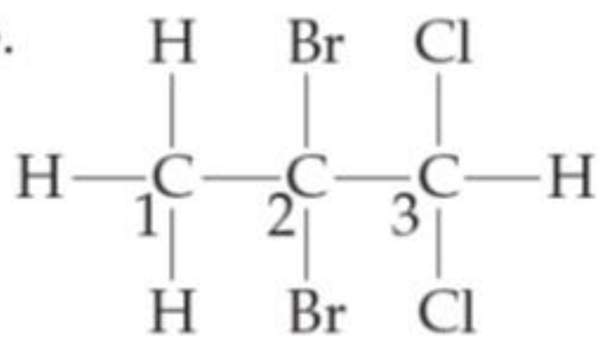
EXERCISE

Determine which of the following compounds is chiral and which is achiral (not chiral).
A carbon is chiral if it is bonded to four different groups.

a.



b.



Enantiomers

Molecules that can exist in enantiomeric forms are called chiral molecules.

Pairs of stereoisomers

Designated by D- or L- at the start of the name.

They are mirror images that can't be overlapped.

If you don't believe it,
give it a try!

D- and L-isomers differ in the spatial arrangements of atoms in the molecule. For any pair of nonsuperimposable mirror-image carbohydrates or amino acids, one is always designated D- and the other L-. Two enantiomers, which are identical to one another in all other chemical and physical properties, will rotate plane-polarized light to the same degree, but in opposite directions.

RACEMIC MIXTURES

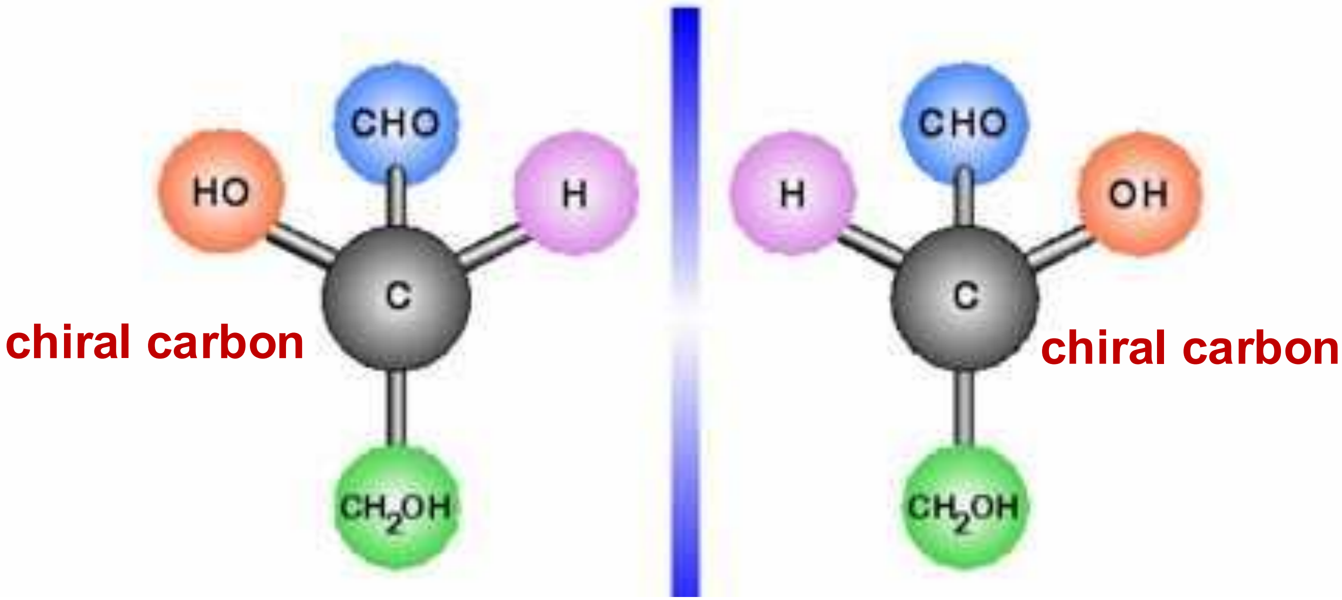
- A mixture of equal amounts of **a pair of enantiomers is called a racemic mixture** or simply a **racemate**. The prefix (±) is used to designate a racemic mixture. In this situation, the specific rotation is zero because the rotation caused by one enantiomer is canceled by the opposite rotation caused by the mirror-image enantiomer.

- **Diastereomers** are pair of stereoisomers having two or more chiral centers (not enantiomers). For a molecule of *n* chiral carbons, the maximum possible number of different configurations is 2^n. Diastereomers are different in their chemical and physical properties.

(a) (b) (c) (d)

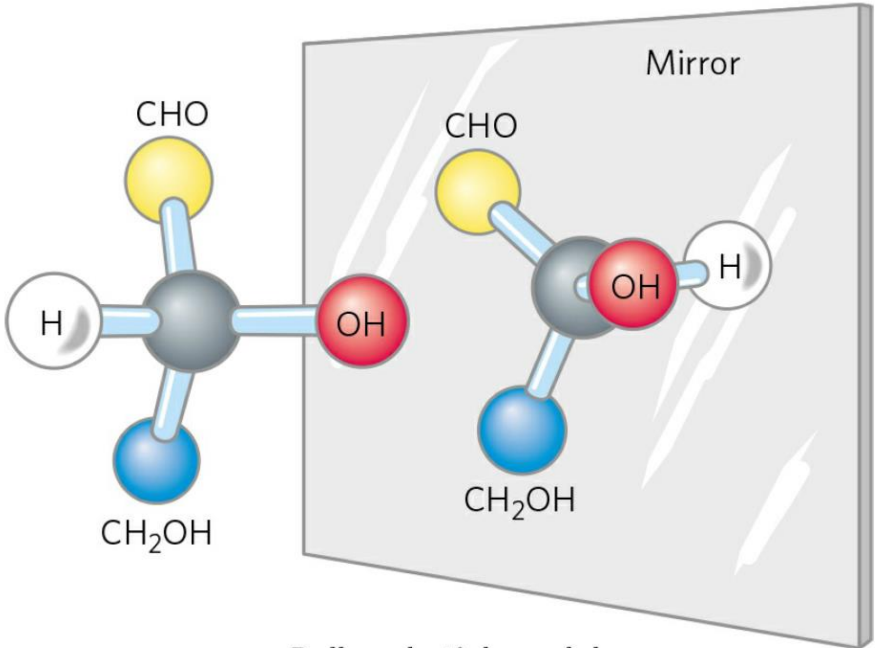
Enantiomers Enantiomers

L- and D- glyceraldehyde



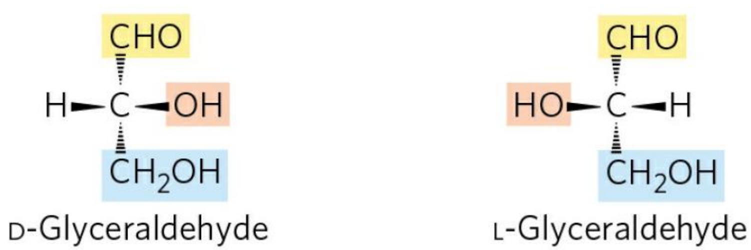
Two enantiomers of glyceraldehyde that are nonsuperimposable mirror images of one another. Larger biological molecules typically have more than one chiral carbon.

https://www.youtube.com/watch?v=GchTURvBz68



Ball-and-stick models

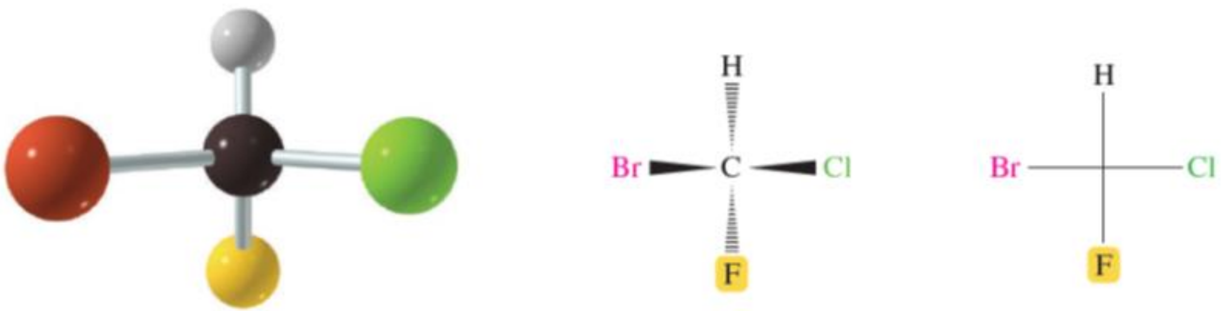
Fischer projection formulas



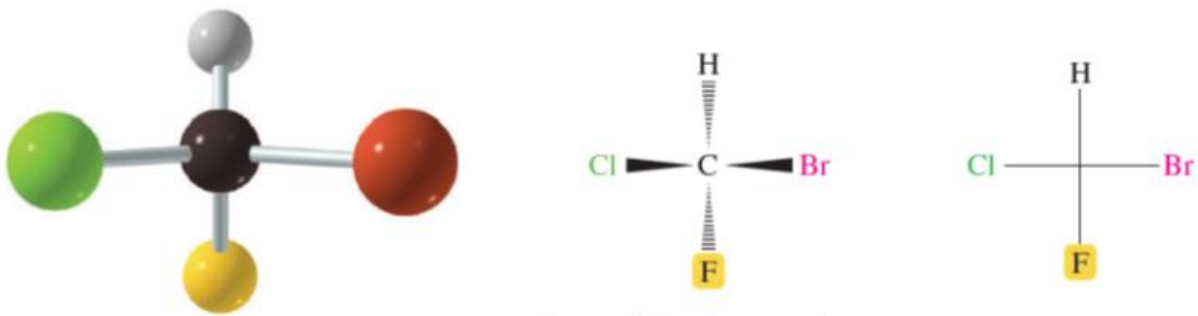
Perspective formulas

Fischer Projection Formulas

The Fischer Projection is a two-dimensional drawing of a molecule that shows a chiral carbon at the intersection of two lines.
The horizontal lines represent bonds projecting out of the plane toward the reader (corresponding to the solid wedges), and the vertical lines (dashed wedges) extend behind.



Bromochlorofluoromethane



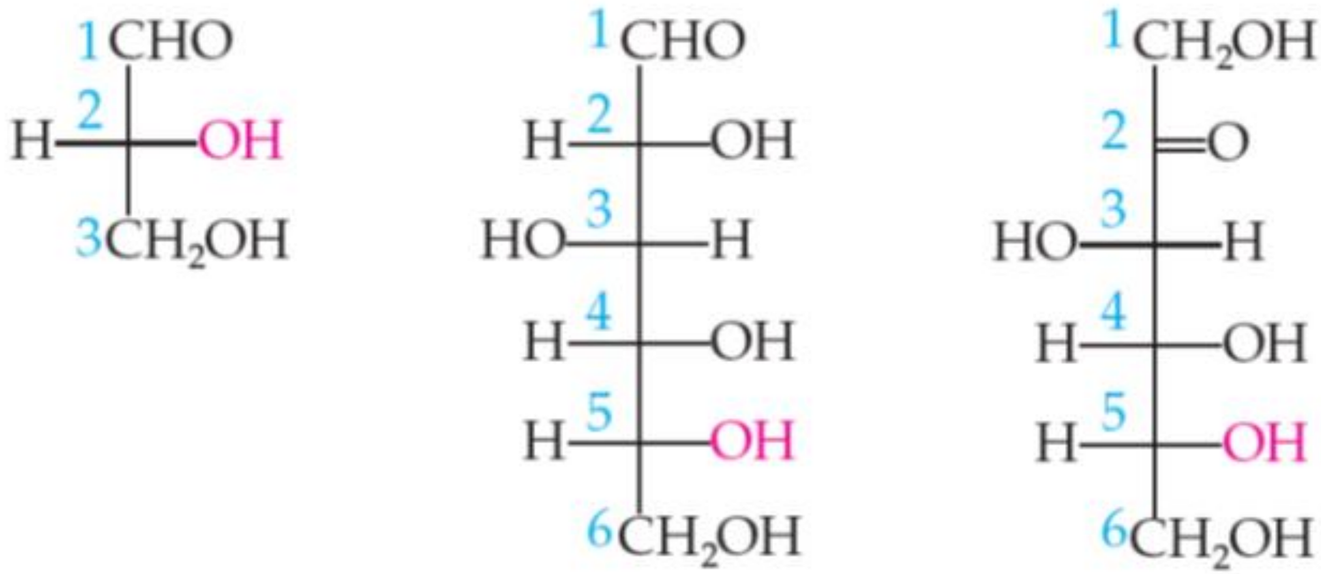
Bromochlorofluoromethane

NOMENCLATURE

Sugars with more than three carbons will have more than one chiral carbon. As for other biomolecules with chiral centers, the absolute configurations of sugars are known from x-ray crystallography.
By convention, **it is the position of the hydroxyl group (-OH) on the chiral carbon farthest from the carbonyl group (the most oxidized end of the molecule) that determines whether a monosaccharide is in the D- or L- configuration.**

- Giving the carbonyl group the lowest possible number, it is the chiral carbon with the highest number that is used to determine the D- or L- configuration.
- If the —OH group is on the right, the molecule is in the D- configuration.
- If the —OH group is on the left, the molecule is in the L- configuration.

NOTE: Almost all carbohydrates in living systems are members of the D-family.



D-Glyceraldehyde D-Glucose D-Fructose

Here are represented D-structures, i.e. the monosaccharides having the chiral C furthest from the carbonyl C with the same configuration as the chiral C of the D-glyceraldehyde.

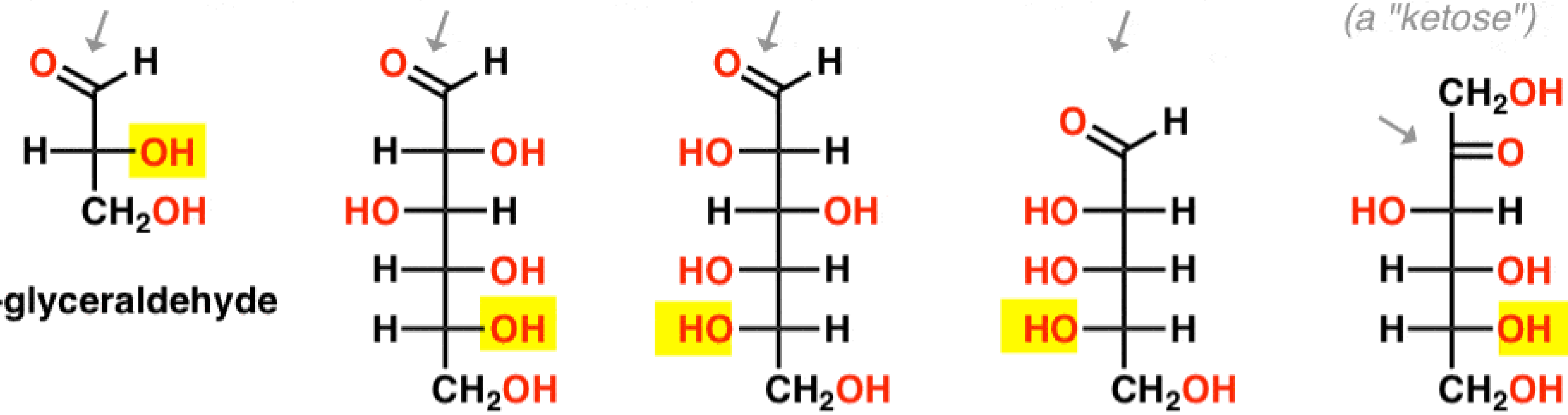
D- and L- Sugars

For a sugar drawn in the Fischer projection with the most oxidized carbon at the top:

- If the OH on the bottom chiral center points to the **right**, the sugar is **D**
- If the OH on the bottom chiral center points to the **left**, the sugar is **L**

most oxidized carbon (aldehyde) at top: these are "aldoses"

ketone (a "ketose")

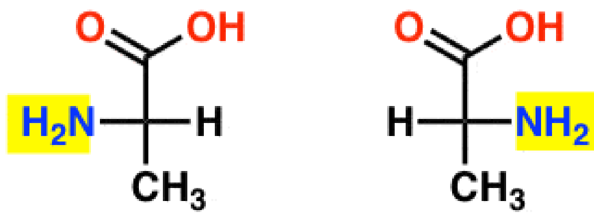


D-glyceraldehyde **D-Glucose** **L-Glucose** **L-Ribose** **D-Fructose**

enantiomers

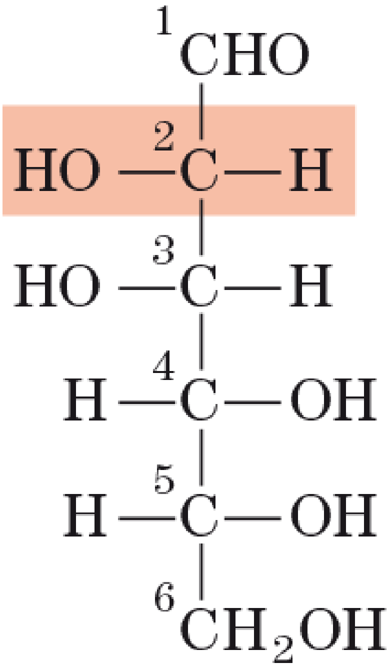
L- and D- is a means of describing the **absolute configuration** of a molecule that pre-dates *R* and *S* but is still used for some biological molecules (sugars, amino acids). It's a quick way of denoting enantiomers: e.g. L-glucose and D-glucose are enantiomers.

The D- L- system can also be applied to other chiral molecules, e.g. amino acids:

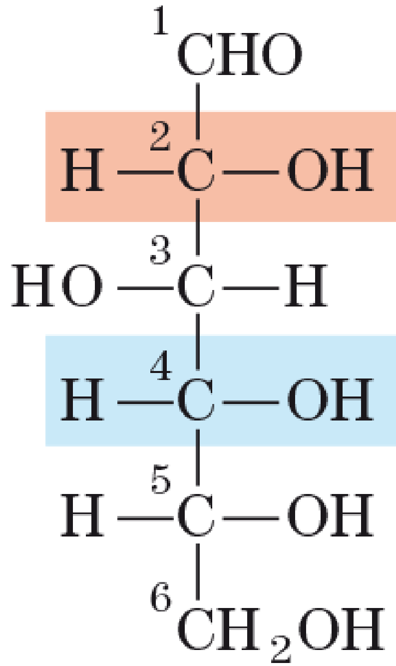


L-alanine **D-alanine**

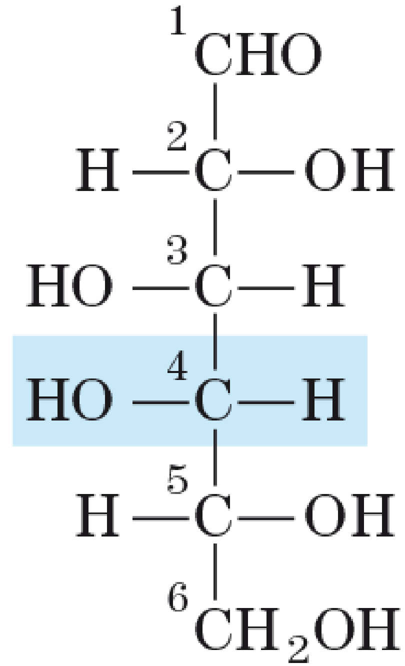
enantiomers



D-Mannnose
(epimer in C-2)



D-Glucose



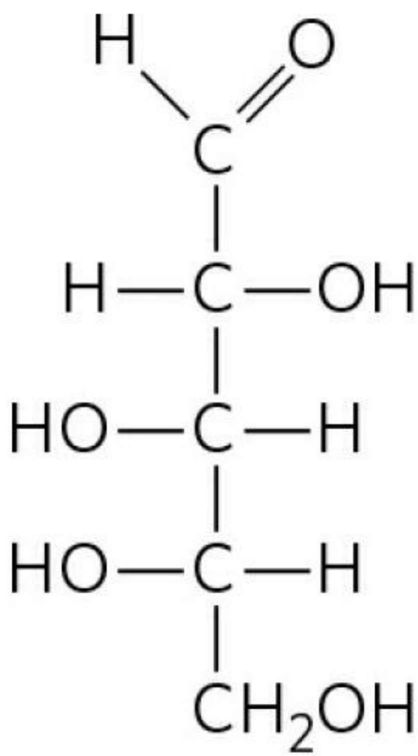
D-Galactose
(epimer in C-4)

Epimers are diastereomers that have a different configuration at one chiral C atom

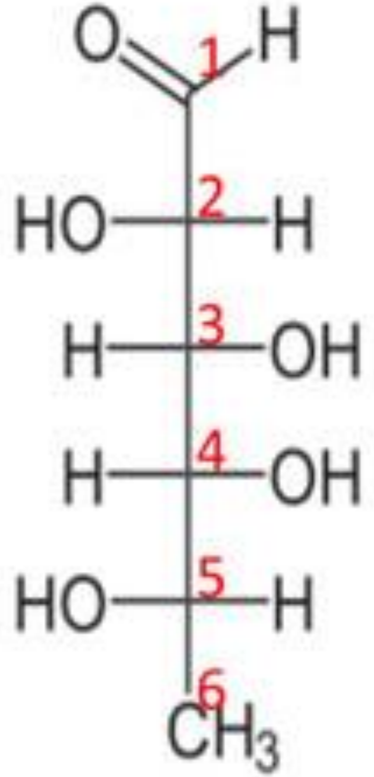
stereoisomers in Nature

Naturally, you would expect them to both be equally present in our bodies as racemic mixture, right? Wrong! In fact, all life forms only use L-amino acids and almost all D-sugars. From the smallest bacteria to elephants, only L-amino acids make up proteins and only D-sugars make up polysaccharides. Why? It is a mystery that has perplexed biologists for years. Despite the best efforts of physicists, chemists, and evolutionary biologists, we still don’t know for sure.

- Few monosaccharides occur naturally in their L form; examples are L-arabinose and L-fucose and the L isomers of some sugar derivatives that are common components of glycoconjugates
- Amino acids found in proteins are exclusively L-stereoisomers. The basis for this initial preference for one isomer during evolution is unknown; however, once one isomer had been selected, it was likely that evolving enzymes would retain their preference for that stereoisomer.

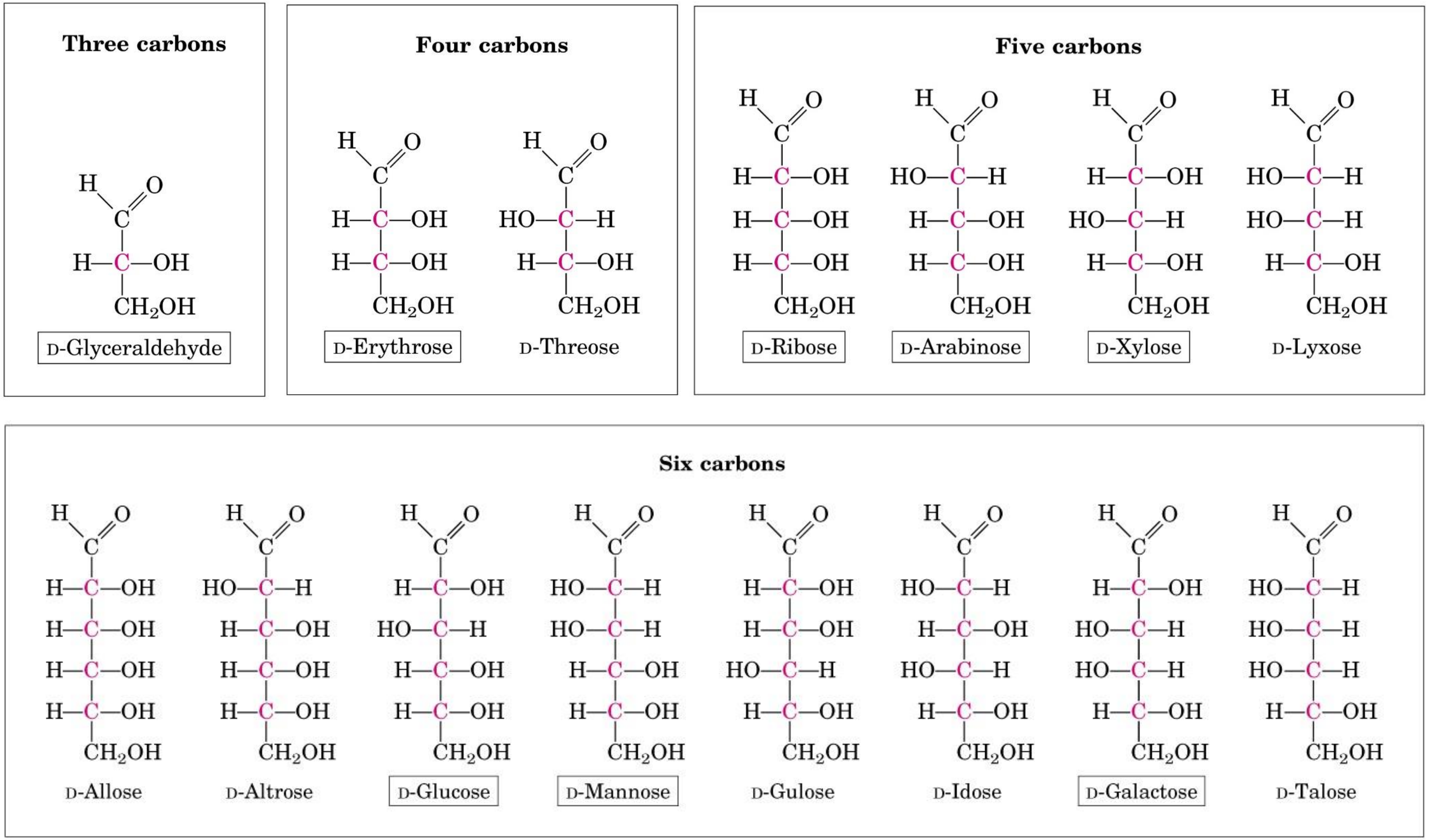


L-Arabinose



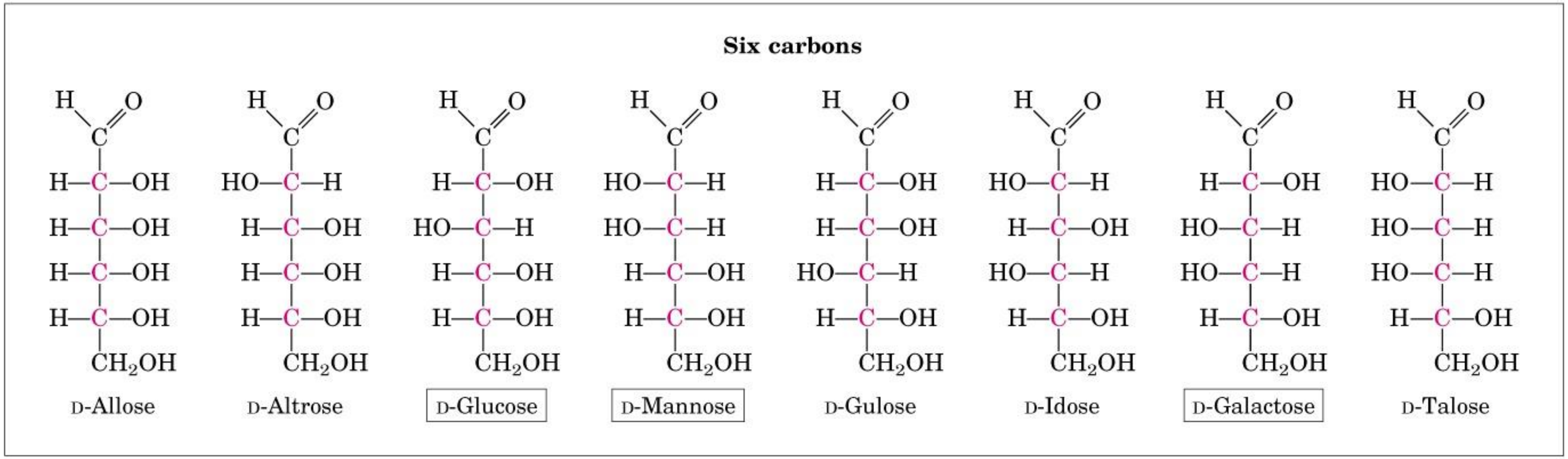
L-Fucose

Monosaccharides: ALDOSES



D-Aldoses
(a)

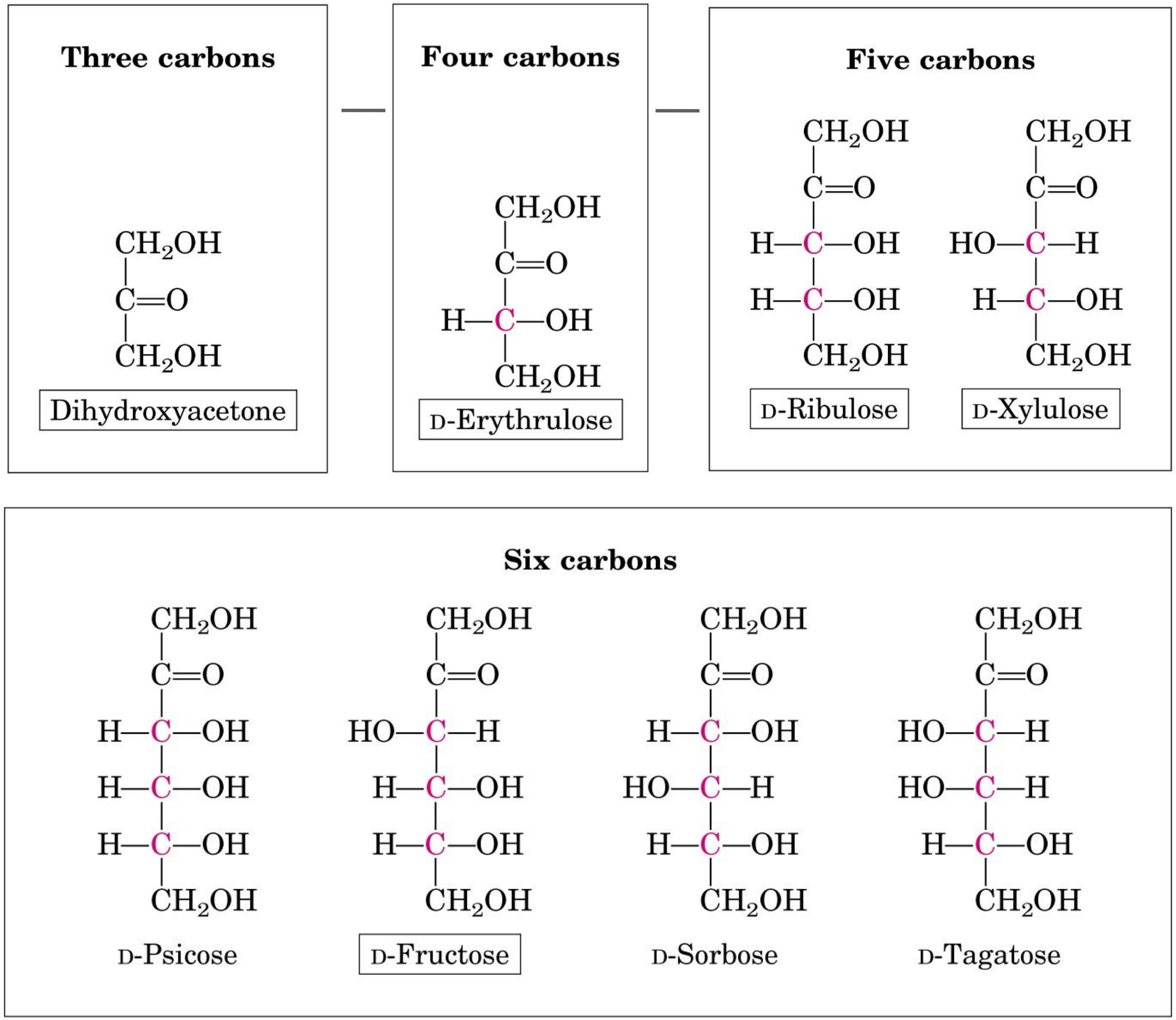
A molecule with n chiral centers may have 2^n diastereomers. Aldohexoses have 4 chiral centers and 2^4=16 stereoisomers, divided into D- and L-isomers.



D-Aldoses
(a)

A molecule with two or more chiral centers has enantiomers (pairs of stereoisomers that are mirror images) and diastereomers (pairs of stereoisomers that are not mirror images of each other).

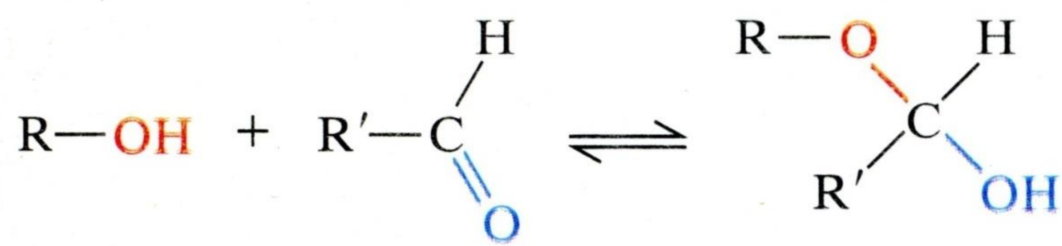
Monosaccharides: KETOSES



D-Ketoses
(b)

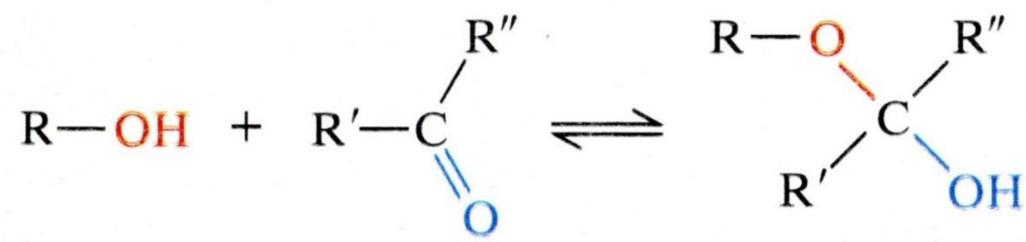
HEMIACETAL AND HEMIKETAL FORMATION

An aldehyde can react with an alcohol to form an hemiacetal



alcohol **aldehyde** **hemiacetal**

A ketone can react with an alcohol to form an hemiketal



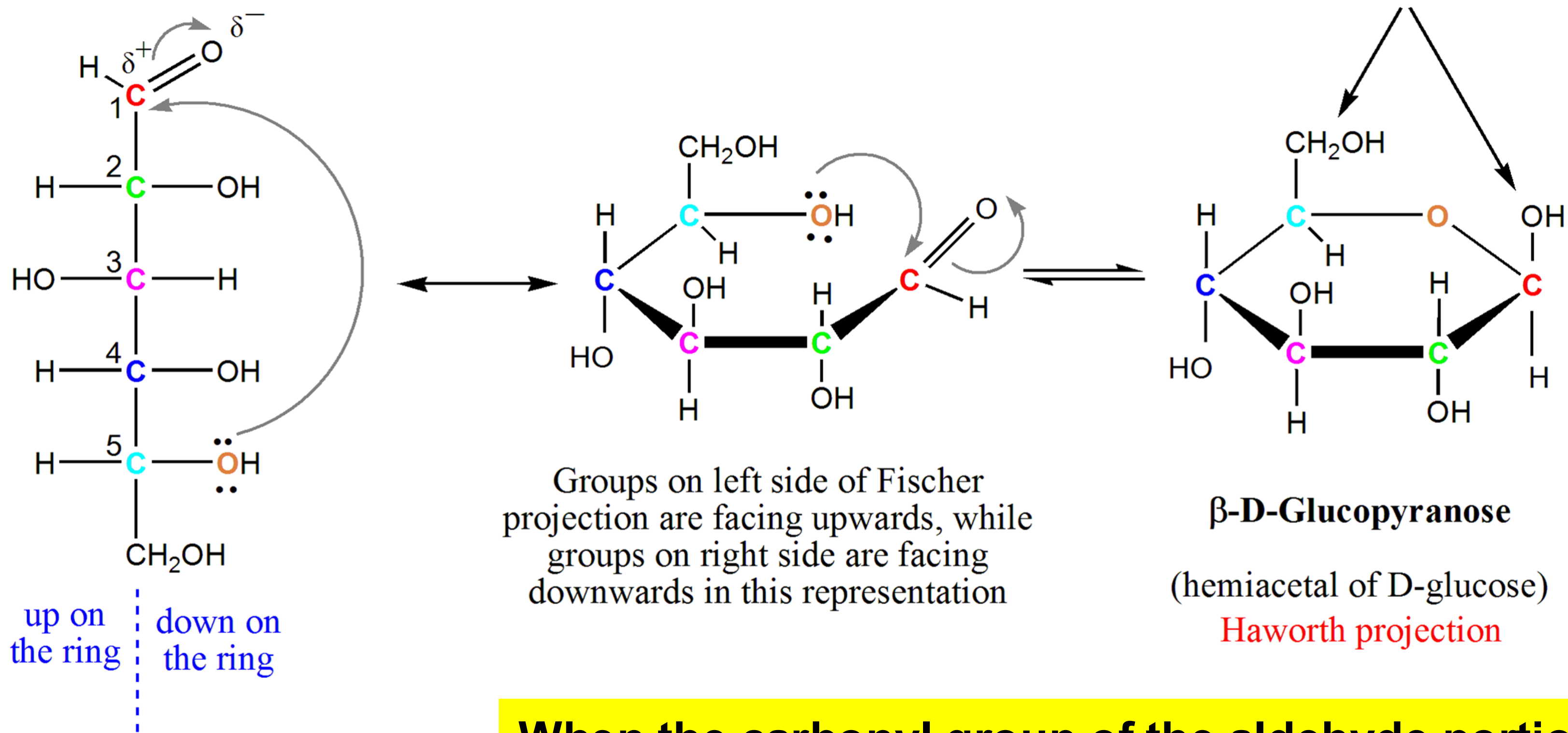
alcohol **ketone** **hemiketal**

Carbonyl C of aldehydes or ketones reacts with a **nucleophile (alcohol) by an addition reaction** forming hemiacetals or hemiketals.
Hemiacetals (or hemiketals) undergo spontaneous hydrolysis in the presence of H_2O, and in solution are in equilibrium with the starting aldehyde or ketone.

MONOSACCHARIDES

In water, monosaccharides may switch from the acyclic to cyclic form and also the cyclic forms (**mutarotation).**

It's **beta-anomer** when CH_2OH and OH are on the same side



Groups on left side of Fischer projection are facing upwards, while groups on right side are facing downwards in this representation

β-D-Glucopyranose

(hemiacetal of D-glucose)

Haworth projection

D-Glucose

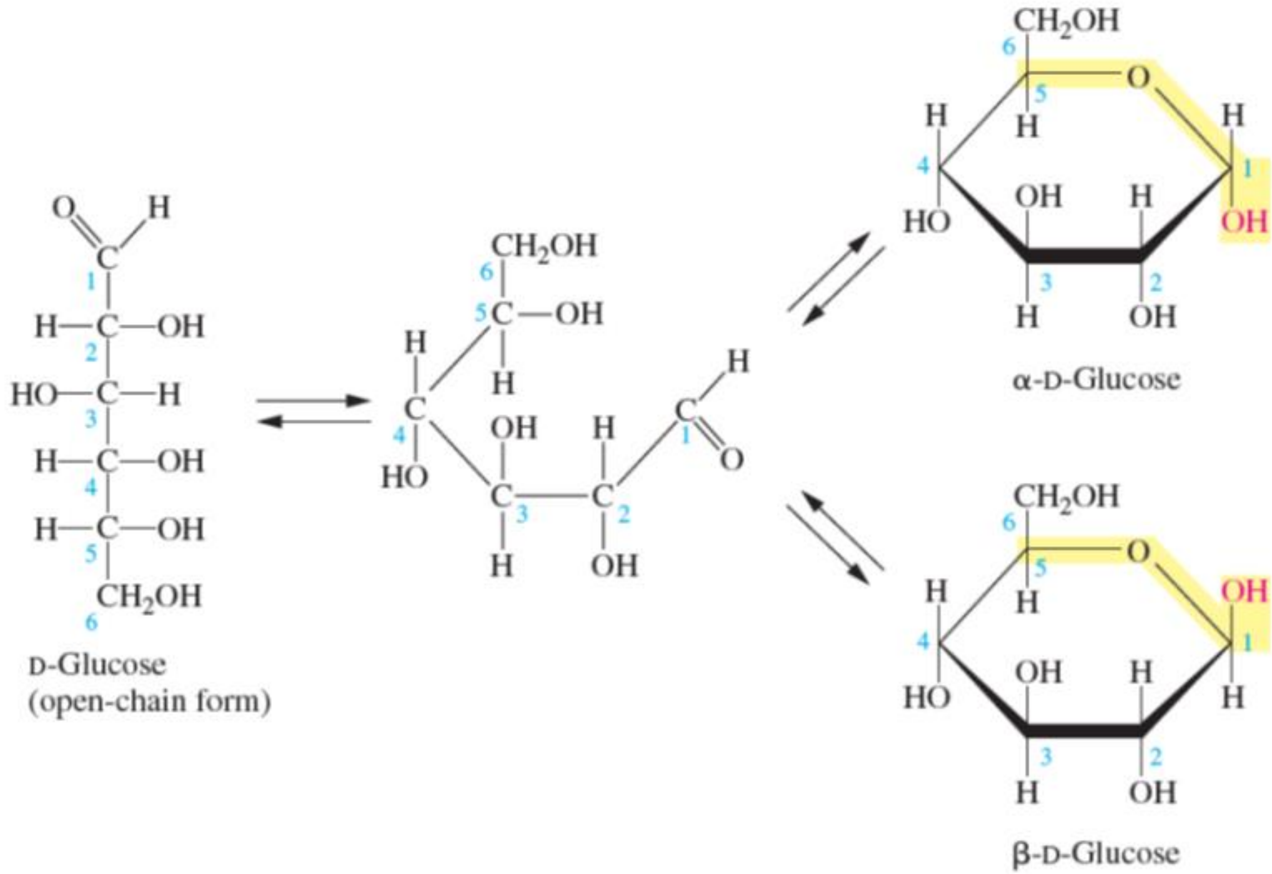
Fischer projection

When the carbonyl group of the aldehyde portion of the glucose molecule reacts with the C-5 hydroxyl group, the product is a cyclic intramolecular hemiacetal.

MONOSACCHARIDES

For D-glucose, two isomers can be formed in this reaction, called **α- and β-D-glucose**. The two isomers, called **anomers**, differ in the location of the -OH attached to the hemiacetal carbon, C-1.
In the **α-anomers**, the C-1 (anomeric carbon) hydroxyl group is below the ring, and in the **β-anomers**, the C-1 hydroxyl group is above the ring. Like stereoisomers, the α- and β forms can be distinguished from one another because they rotate plane-polarized light differently.

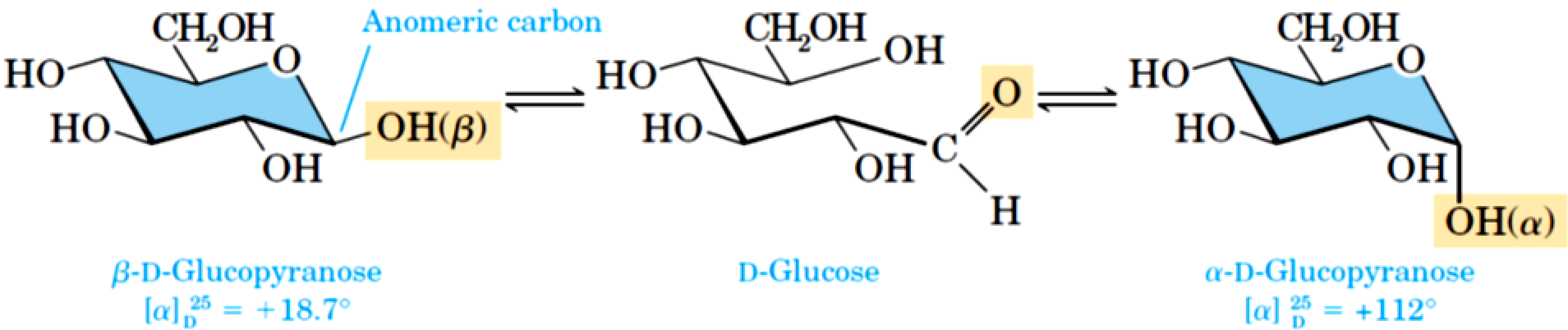
At equilibrium, D-glucose is a mixture of β-anomers (66%, more stable) and α-anomers (34%), while the linear form (open aldehyde) is present in small quantities.



The α and β anomers of D-glucose interconvert in aqueous solution by a process called mutarotation, in which one ring form (the α anomer) opens briefly into the linear form, then closes again to produce the β anomer

CONFORMATIONS OF PYRANOSES

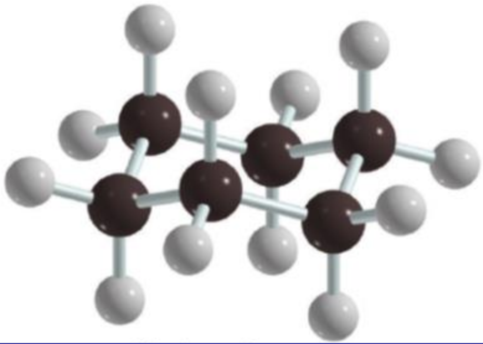
The open-chain or free aldehyde form with which the cyclic hemiacetal forms are in equilibrium in aqueous solution. Notice that each group, including the anomeric –OH group, on the chair conformation of β-D-glucopyranose is equatorial.
Notice also that the -OH group on the anomeric carbon is axial in α-D-glucopyranose.
Because the -OH on the anomeric carbon of β-D-glucopyranose is in the more stable equatorial position, the β anomer predominates in aqueous solution.



CONFORMATIONS OF PYRANOSES

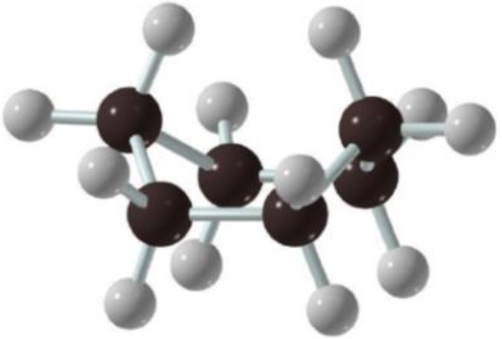
Cycloalkanes with at least 6 C atoms exist in different conformations.
The conformations of six-member rings have been the most thoroughly studied.
Important and abundant biological molecules have six-member ring structures, for example the simple **sugar glucose**.

CHAIR



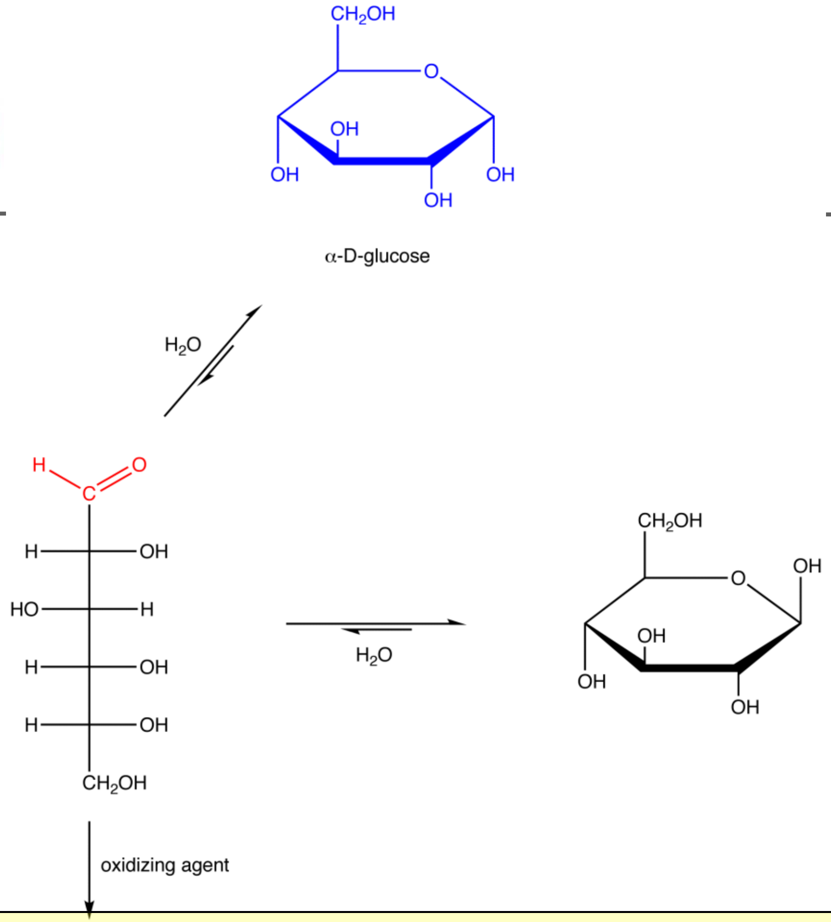
The most stable (energetically favorable) conformation because the atoms are as far from one another as possible, so the repulsion between the bonding electrons is minimized. In addition, the bond angle between carbons is 109.5°, exactly the angle expected for tetrahedral carbon atoms.

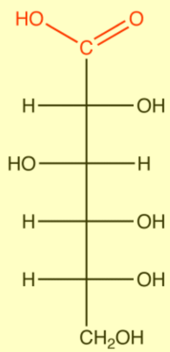
BOAT



This form is much less stable than the chair conformation because the atoms are much more crowded, creating much more repulsion between the electrons.

ALDOSES AS REDUCING AGENTS

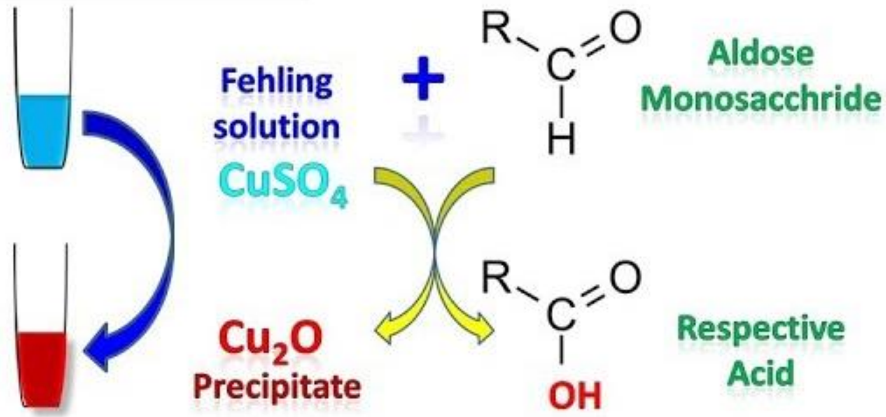


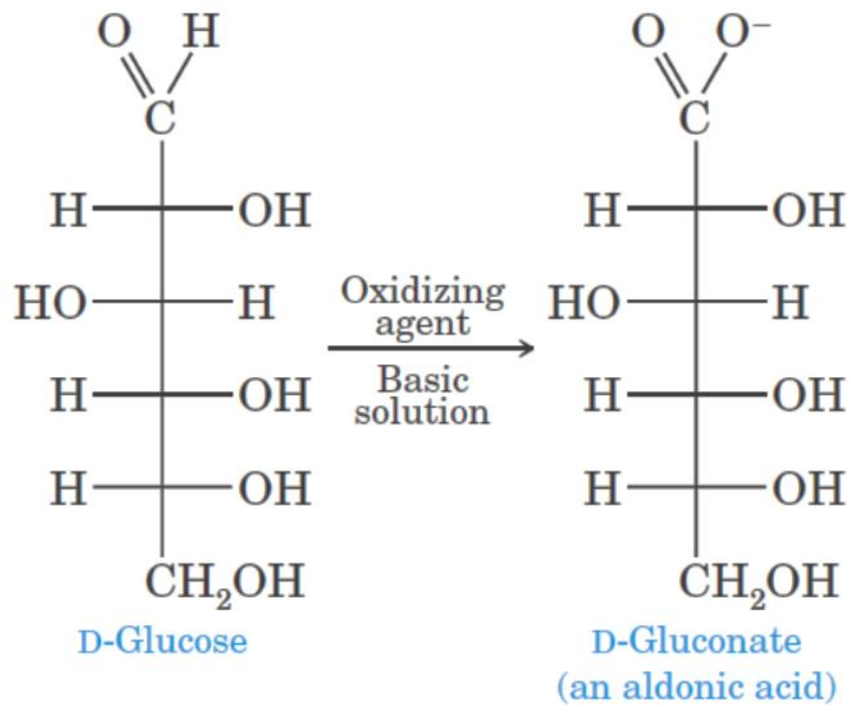


- The aldehyde is oxidized to a carboxylic acid;
- the oxidant is reduced by the aldehyde, therefore the aldehyde is the reducing agent.

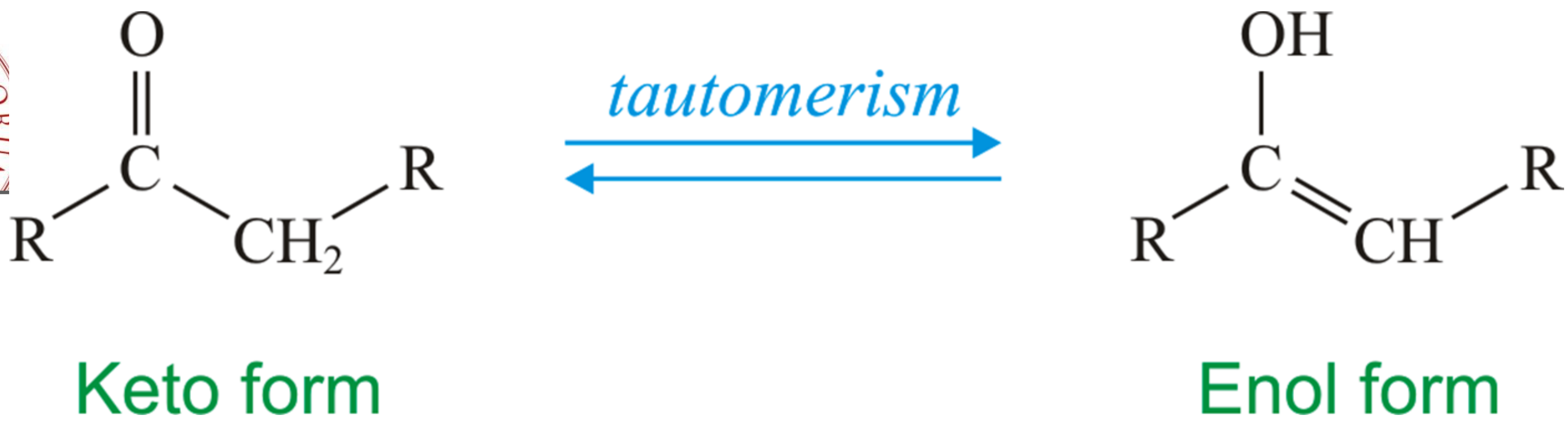
Quickly understand

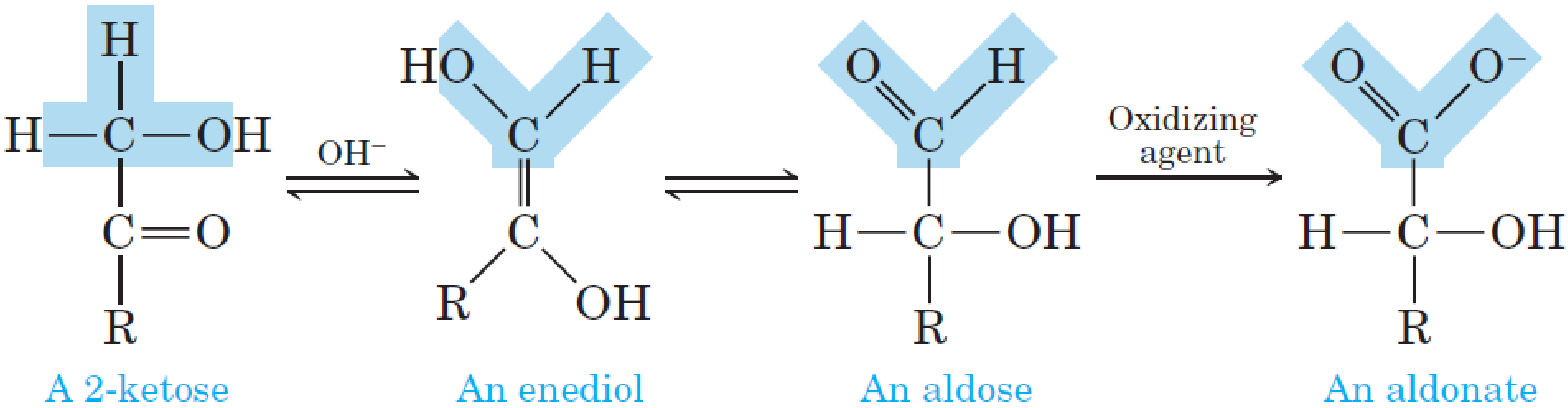
Fehling's test





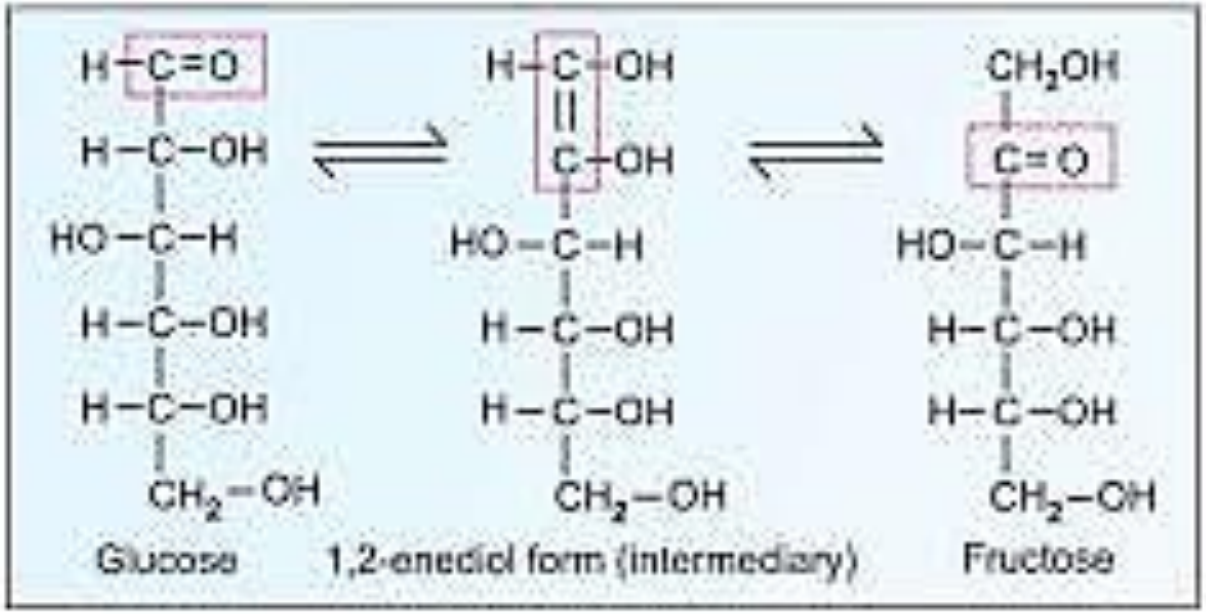
The cyclic form of the aldose is in equilibrium with the open-chain form, which is then oxidized by the mild oxidizing agent. D-Glucose, is oxidized to D-gluconate (the anion of D-gluconic acid, an aldonic acid).





Carbon 1 (a CH_2OH group) of a ketose is not oxidized directly. Instead, under the basic conditions of this oxidation, a 2-ketose exists in equilibrium with an aldose by way of an enediol intermediate. The aldose is then oxidized by the mild oxidizing agent.

ENEDIOL FORMATION

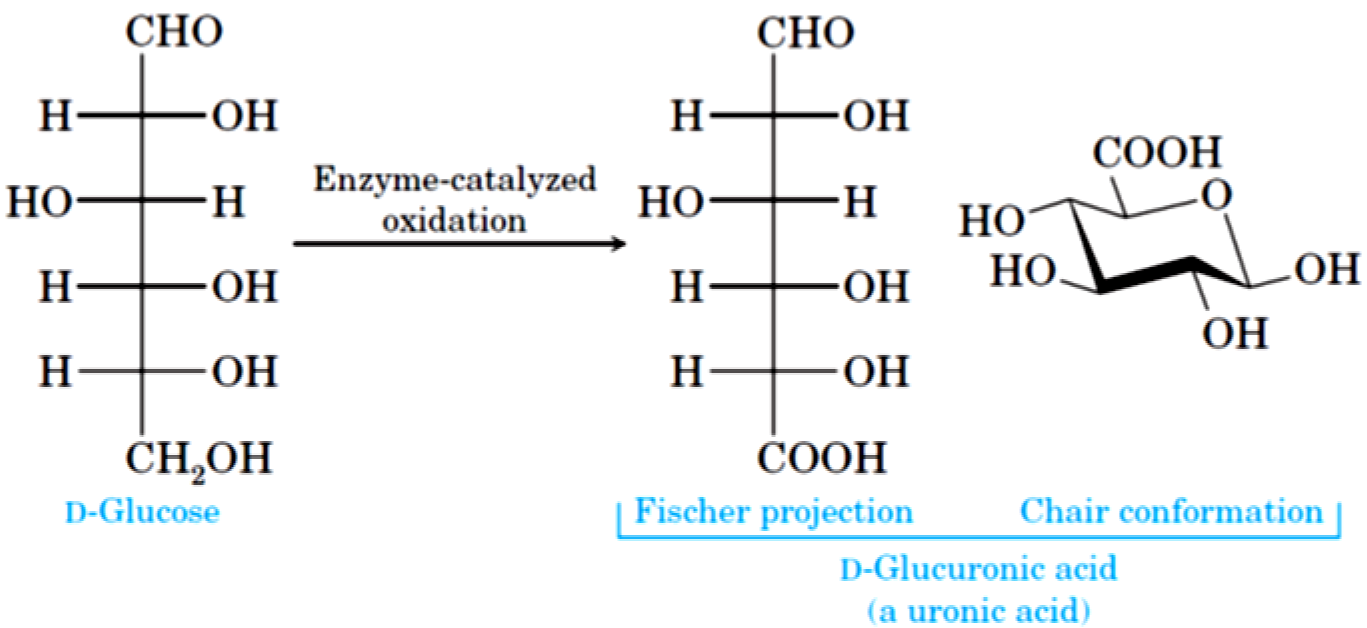


Fructose is an α-hydroxyketone

Keto form

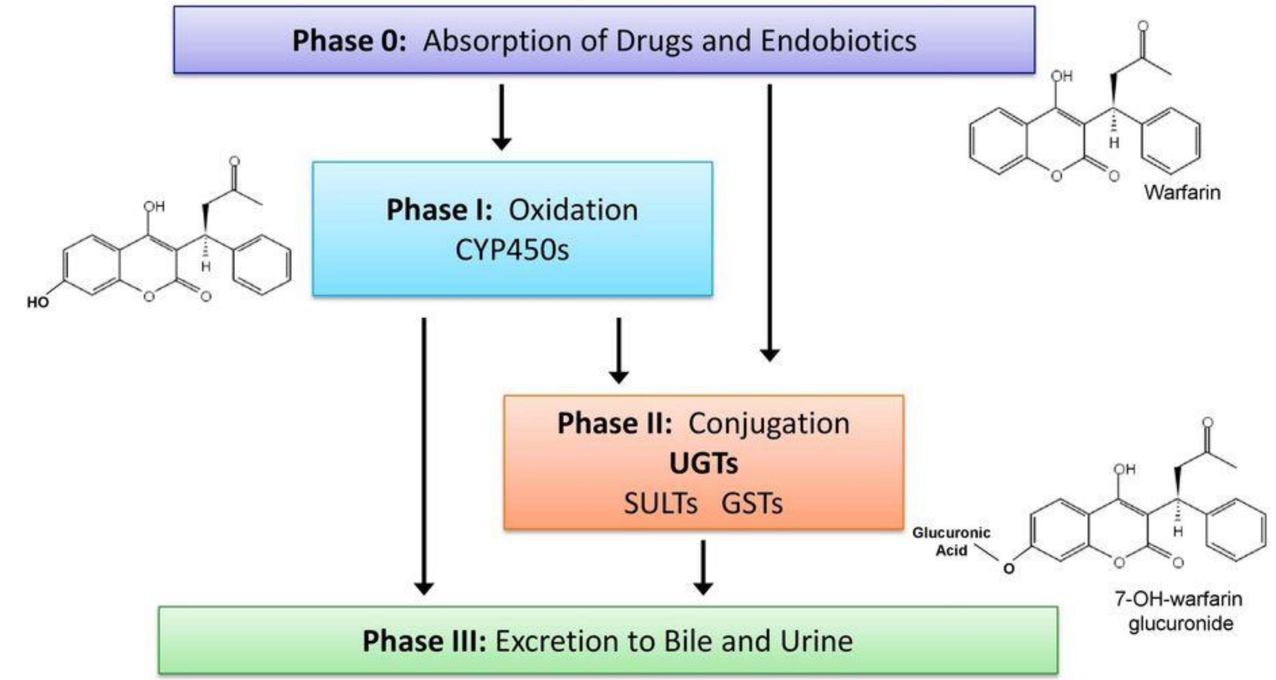
Enol form

OXIDATION TO URONIC ACIDS

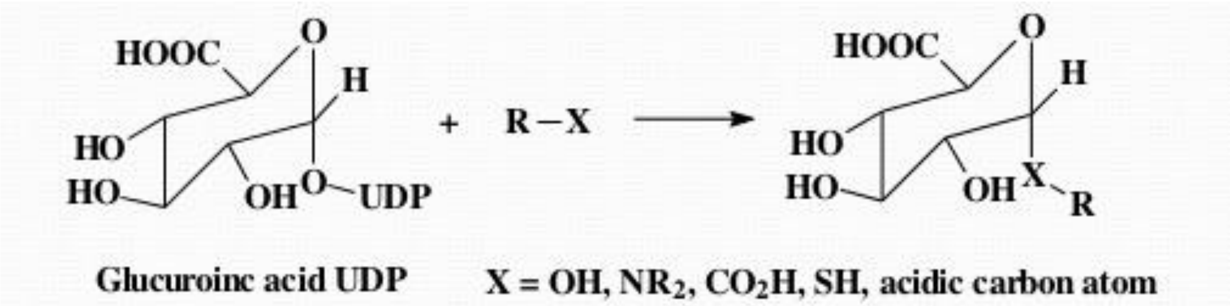


In humans, it serves as an important component of the acidic polysaccharides of connective tissues. The body also uses UDP-D-glucuronic acid to detoxify endo- and xenobiotics. In the liver, these compounds are converted to glycosides of glucuronic acid (glucuronides) through glucuronidation and excreted in the urine.

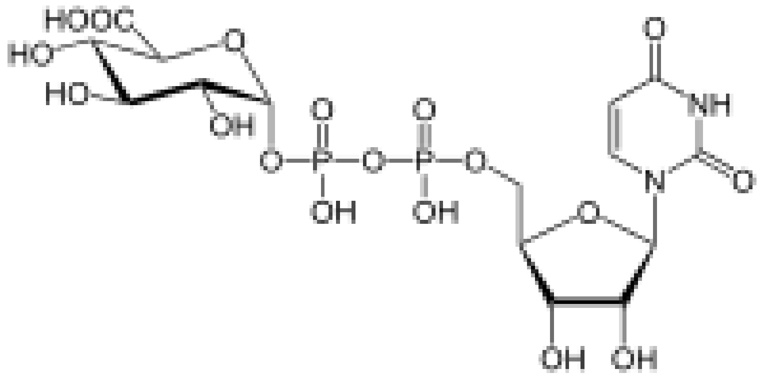
Biotransformation of Drugs and Endobiotics via Oxidation and Conjugation Pathways



Abbreviations: CYP450 (Cytochrome P450); UGT (UDP-Glucuronosyltransferase); SULT (Sulfotransferase); GST (Glutathione Sulfatransferase)

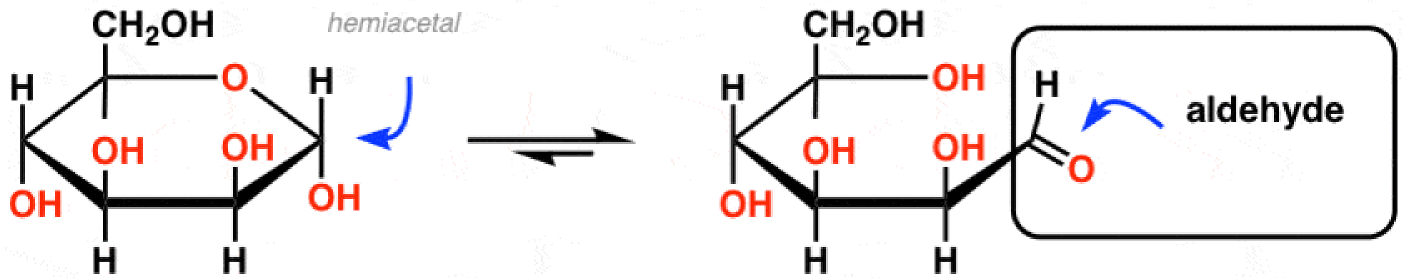


Glucuronyl Transferease catalyses this conjugation reaction



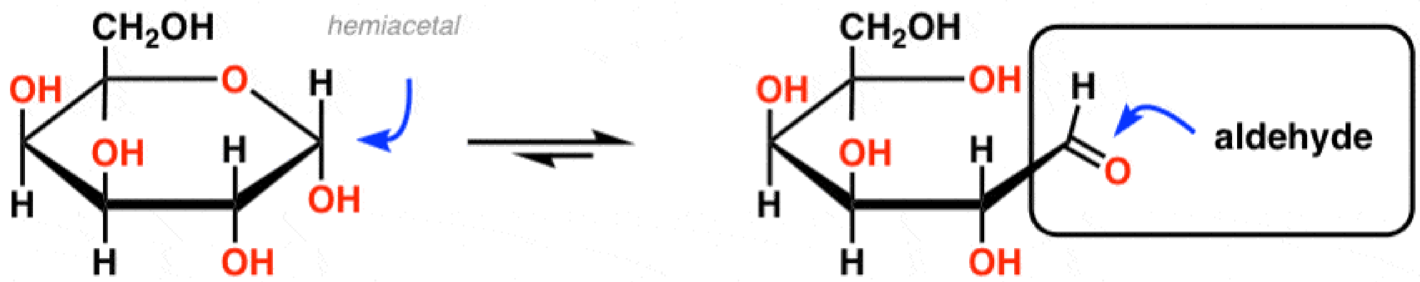
GLUCURONIC ACID IS LINKED VIA A GLYCOSIDIC BOND TO URIDINE DIPHOSPHATE

Monosaccharides with a hemiacetal are also "reducing sugars" since their open-chain form contains an aldehyde



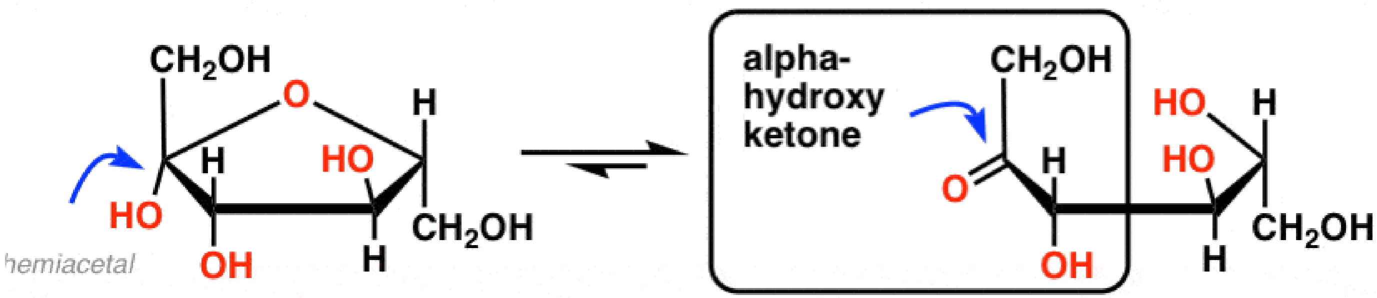
D-Mannose

D-Mannose (open-chain aldehyde)



D-Galactose

D-Galactose (open-chain aldehyde)

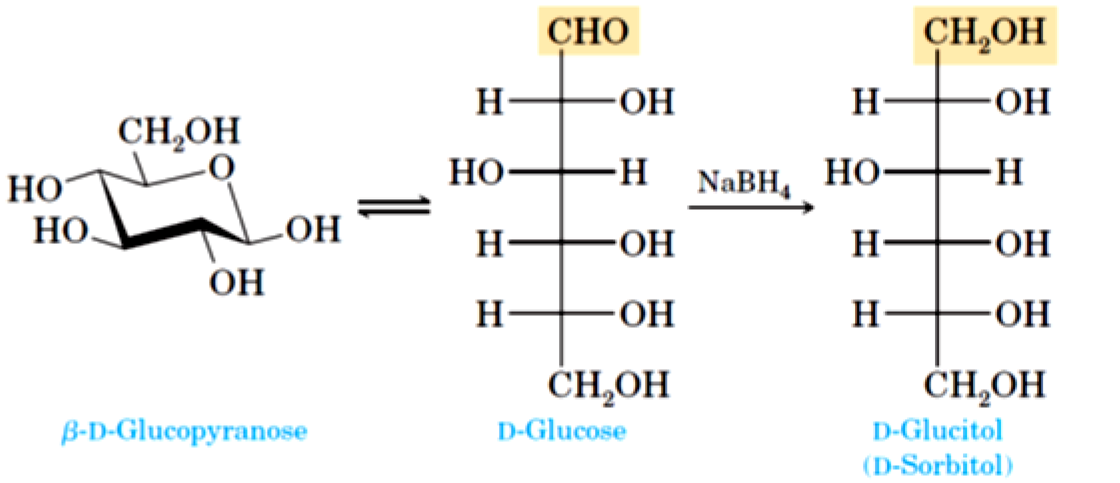


D-Fructose

D-Fructose (keto form)

REDUCTION TO ALDITOLS

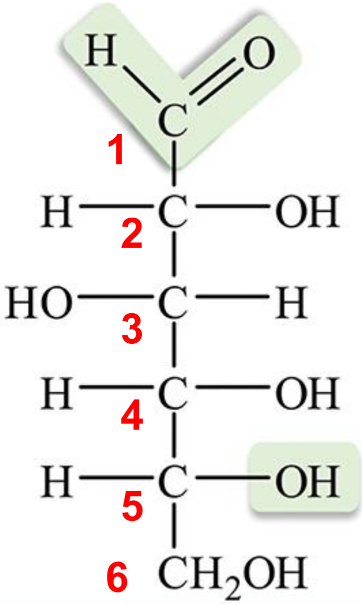
The carbonyl group of a monosaccharide can be reduced to a hydroxyl (alcoholic) group by a variety of reducing agents, including hydrogen in the presence of a transition metal catalyst and sodium. The reduction products are known as alditols.



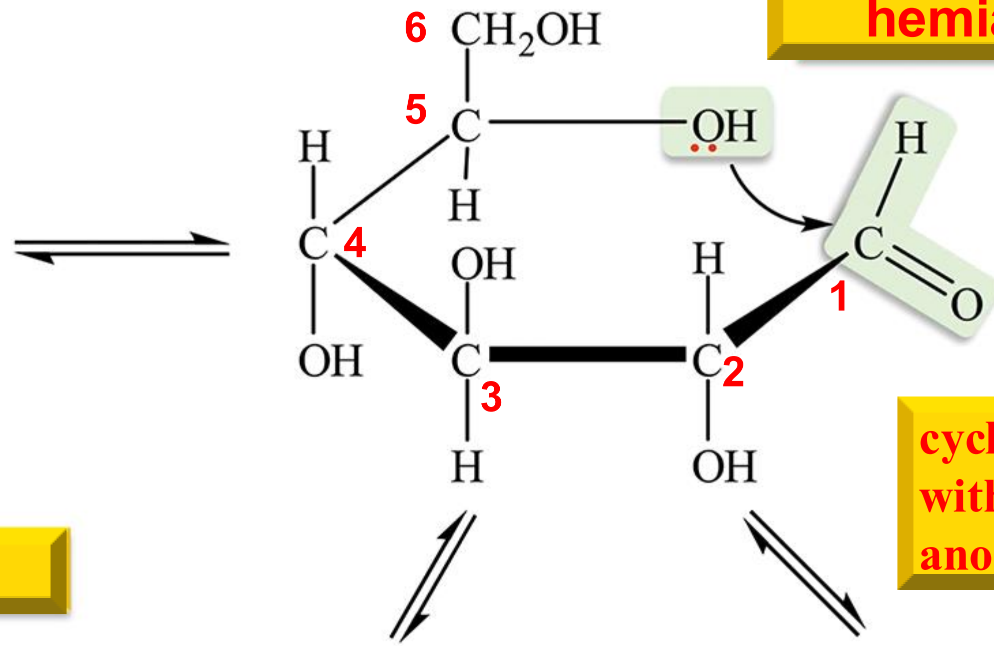
Sorbitol is found in the plant world in many berries and in cherries, plums, pears, apples, seaweed, and algae. It is about 60% as sweet as sucrose (table sugar) and is used in the manufacture of candies and as a sugar substitute for diabetics. Other alditols commonly found in the biological world include erythritol, D-mannitol, and xylitol (used as a sweetening agent in "sugarless" gum, candy, and sweet cereals).

GLUCOSE

formation of the hemiacetal bond

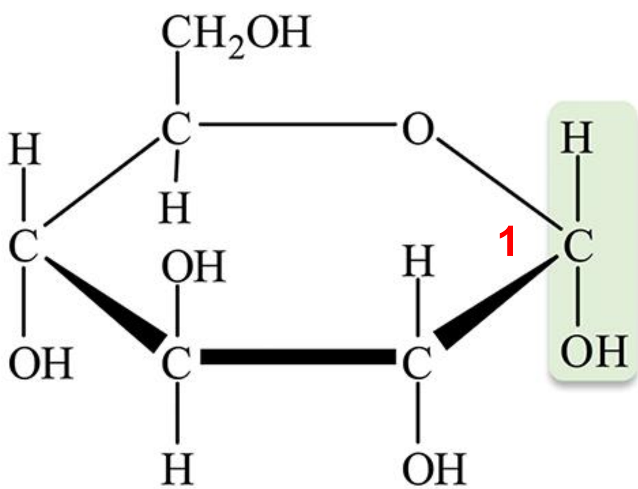


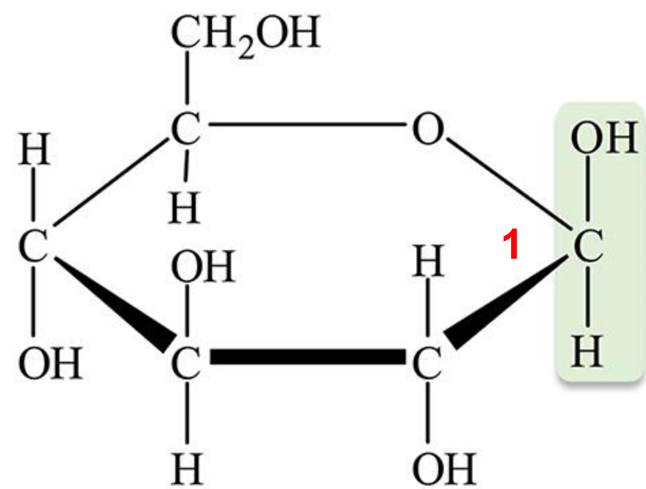
open - acyclic form



cyclization of D-glucose with formation of 2 anomers (hemiacetals)

Intramolecular reaction: the aldehyde function on C1 of glucose reacts with the hydroxyl function on C5 to give a cyclic Hemiacetal





Cyclic form of 6 atoms: pyranose structure

α-D-glucose

β-D-glucose

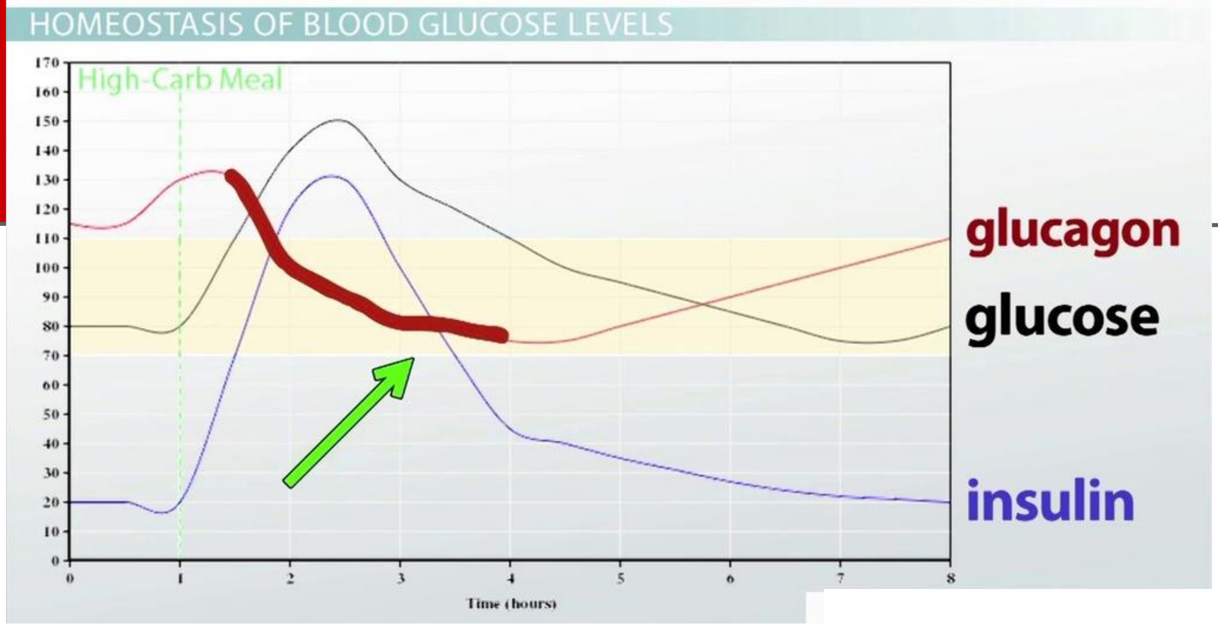
D-Glucose, an aldohexose

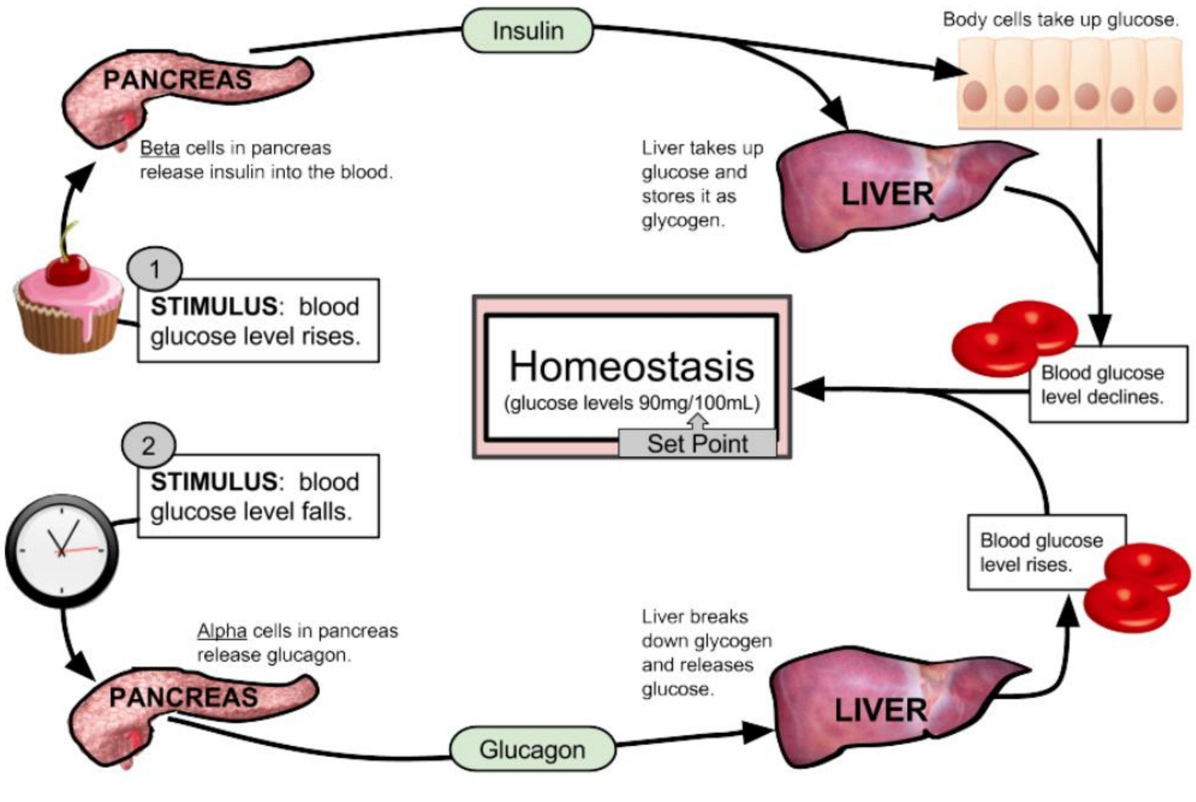
- Glucose is the most important sugar in the human body, and it is found in numerous foods. It has several common names, including grape sugar, and blood sugar.

- Glucose is “burnt” in **glycolysis** and other pathways to release energy for body functions.

- The concentration of glucose in the blood is critical to normal body function.

As a result, it is carefully controlled by the hormones **insulin** and **glucagon**. Normal blood glucose levels are **100–120 mg glucose/100 mL blood**, with the highest concentrations appearing after a meal. Insulin stimulates the uptake of the excess glucose by most cells of the body, and after 1 to 2 hours (h), levels return to normal. If blood glucose concentrations drop too low, the individual feels lightheaded and shaky. When this happens, glucagon stimulates the liver to release glucose into the blood, reestablishing normal levels.


HOMEOSTASIS OF BLOOD GLUCOSE LEVELS
High-Carb Meal
glucagon
glucose
insulin
Time (hours)

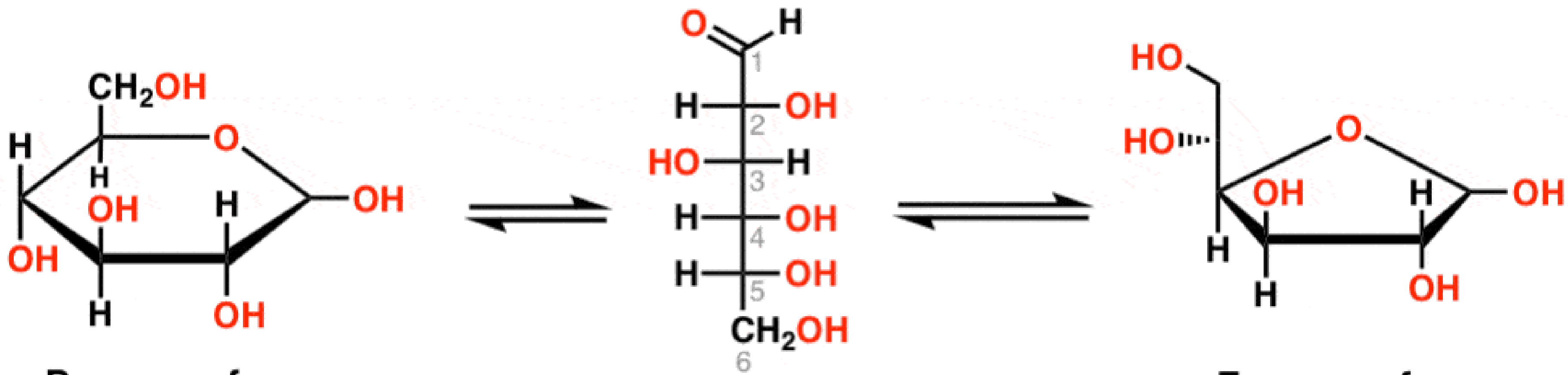

Insulin
Body cells take up glucose.
PANCREAS
Beta cells in pancreas release insulin into the blood.
Liver takes up glucose and stores it as glycogen.
LIVER
1
STIMULUS: blood glucose level rises.
Homeostasis
(glucose levels 90mg/100mL)
Set Point
Blood glucose level declines.
2
STIMULUS: blood glucose level falls.
Blood glucose level rises.
Alpha cells in pancreas release glucagon.
Liver breaks down glycogen and releases glucose.
PANCREAS
LIVER
Glucagon

Summary: Pyranoses, Furanoses, and Ring-Chain Tautomerism

Sugars exist in equilibrium between their open-chain and various closed-chain forms. (This is called "ring-chain tautomerism")

Particularly important for hexoses (e.g. glucose) and pentoses (e.g. ribose)

e.g. D-glucose (below)



Pyranose forms (α + β) — Open-chain form — Furanose forms (α + β)

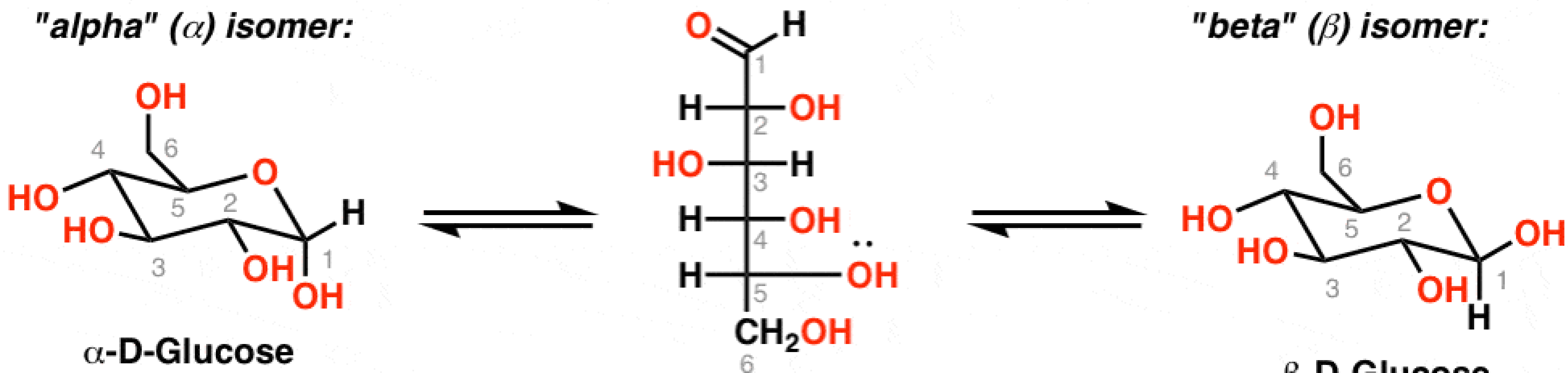
99% — 0.25% — < 1%

The six-membered cyclic form is generally referred to as the "pyranose" form, and the five-membered cyclic form is called the "furanose" form

Closure of the ring creates a chiral center at C-1, resulting in two diastereomers (sometimes called "anomers") - the alpha (α) and beta (β) forms

Why the change in specific rotation?

The alpha and beta anomers are each in equilibrium with the "linear" form, and therefore with each other.



α-D-Glucose

36%
(at equilibrium)

D-Glucose

("linear" form)

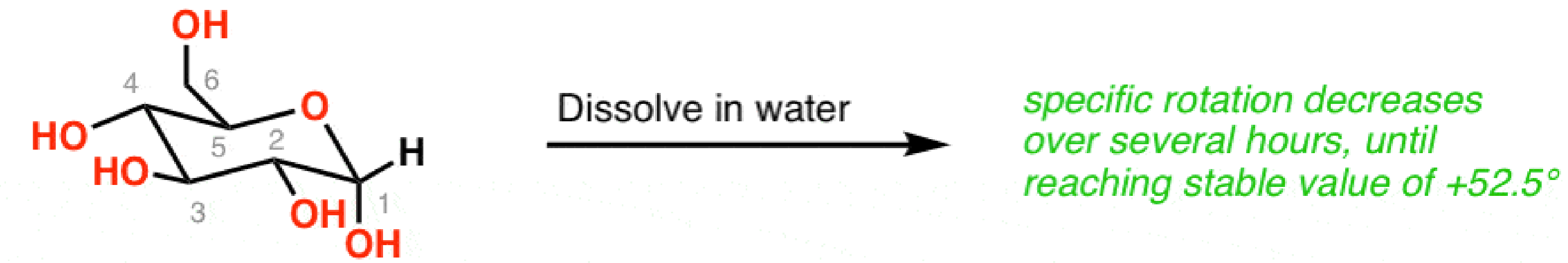
β-D-Glucose

64%
(at equilibrium)

At equilibrium the mixture consists of 36% α-D-Glucose, 64% β-D-Glucose, and traces of the linear and furanose forms.

Mutarotation

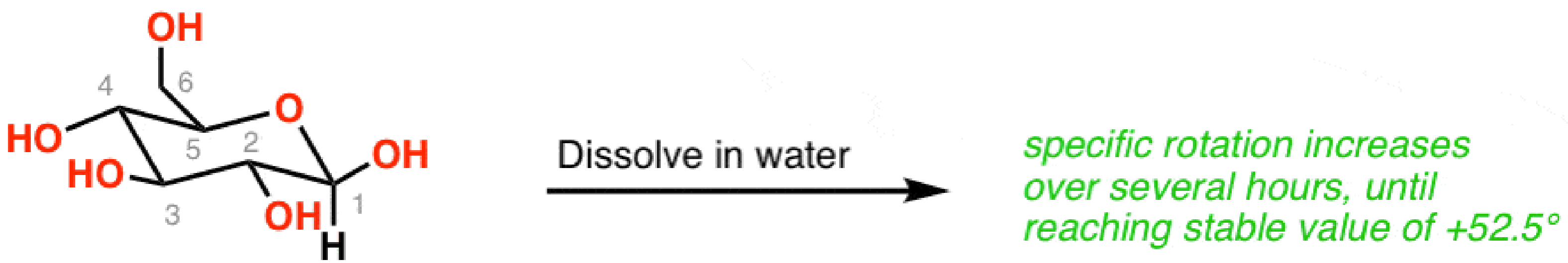
When 100% pure α-D-glucopyranose is dissolved in water, the specific rotation slowly changes from +112° to + 52.5° over a few hours.



α-D-Glucose (pyranose form)

Specific rotation: $[\alpha]_D^{20}$ + 112°

Similarly, when 100% pure β-D-glucopyranose is dissolved in water, the specific rotation slowly changes from + 18.7° to + 52.5°.

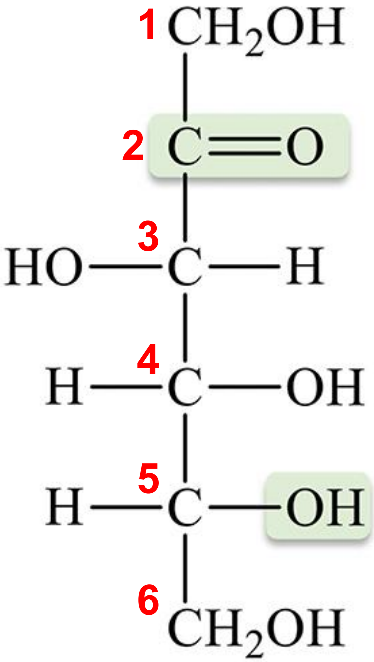


β-D-Glucose (pyranose form)

Specific rotation: $[\alpha]_D^{20}$ + 18.7°

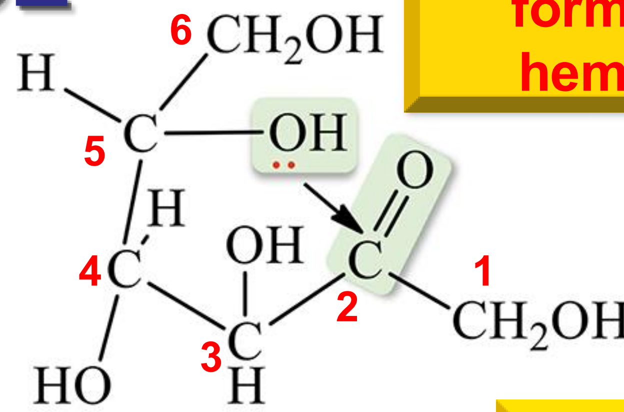
This is called "mutarotation" (*"muta" = change, so "change of rotation"*)

FRUCTOSE



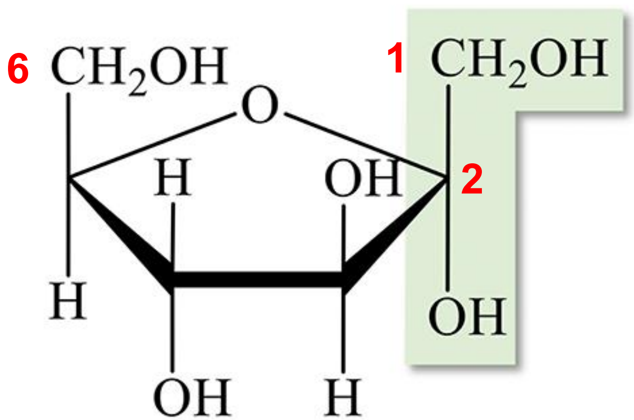
Open- acyclic form

Intramolecular reaction: the ketone function on C2 of fructose reacts with the hydroxyl function on C5 to give an hemiketal

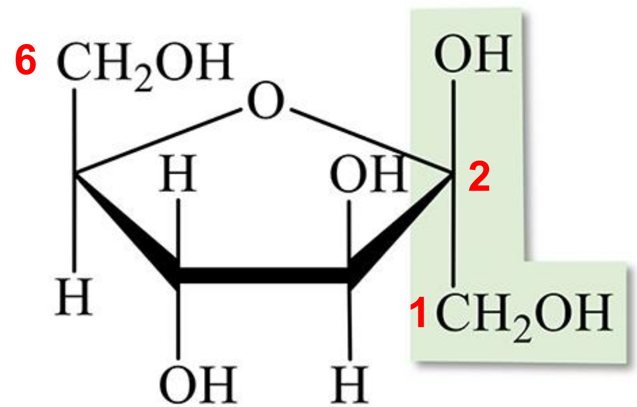


formation of the hemiketal bond

cyclization of D-fructose with formation of anomers (hemiketals)

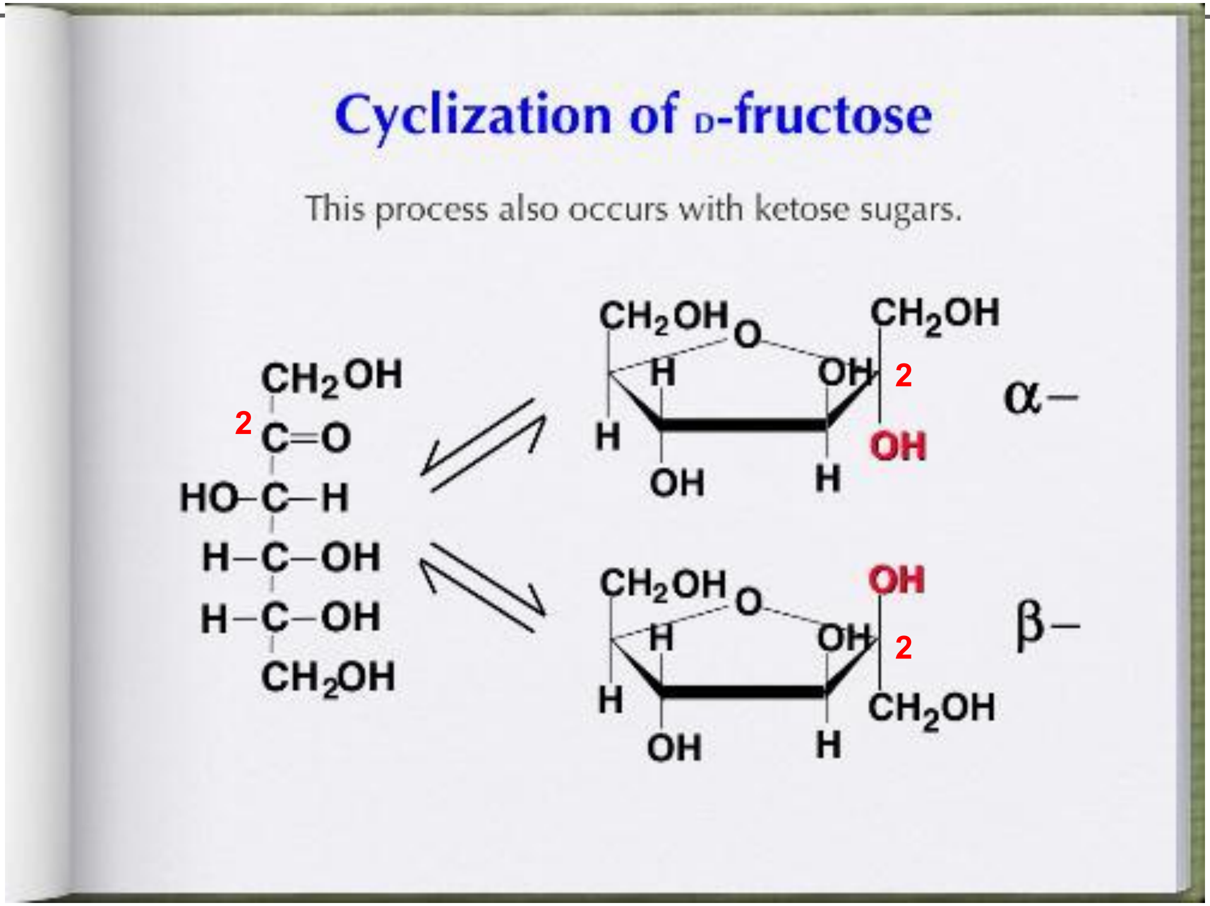


α-D-fructose



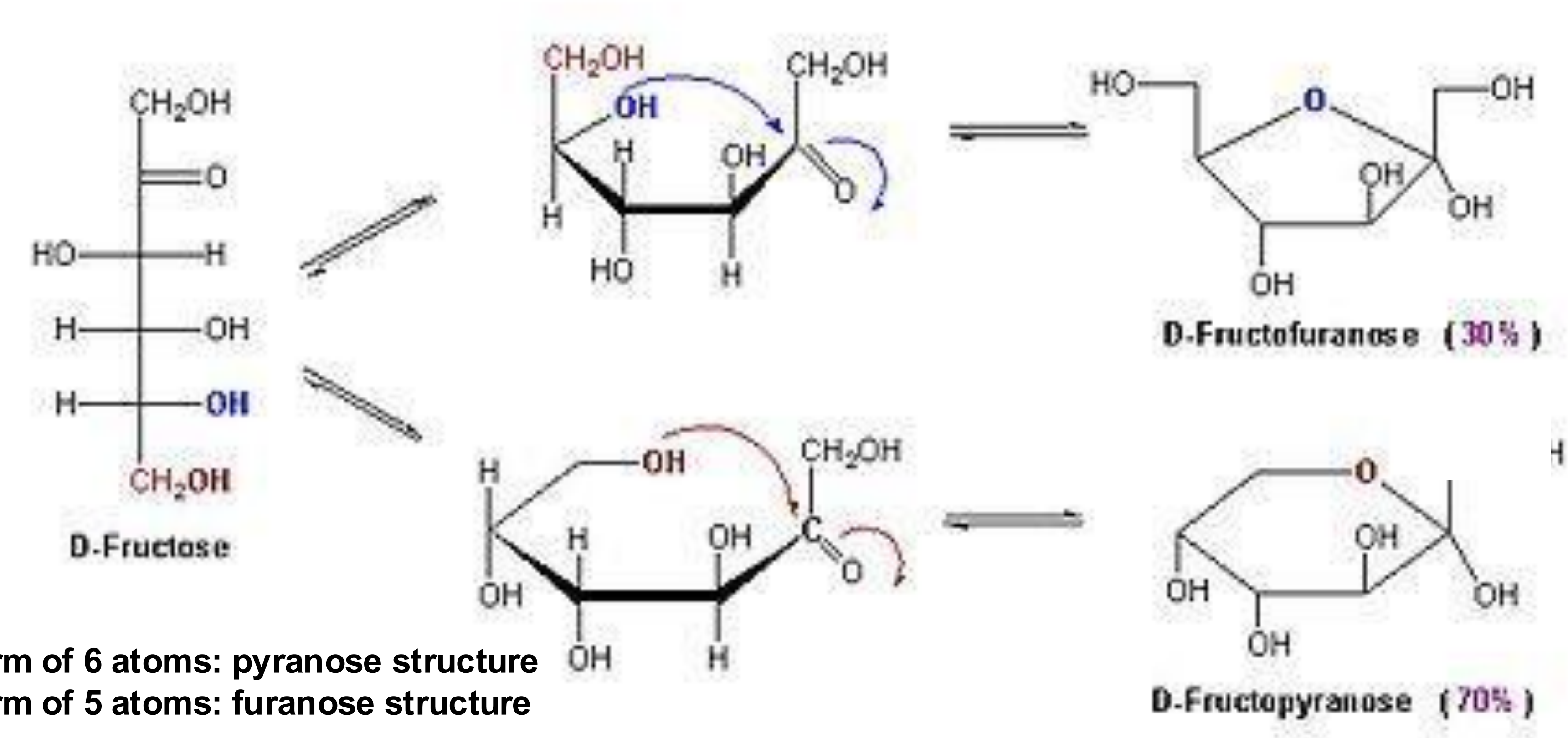
β-D-fructose

D-Fructose, a ketohexose



Fructose, also called fruit sugar, is the sweetest of all sugars. It is found in large amounts in honey, corn syrup, and sweet fruits. The structure of fructose is similar to that of glucose, they are isomers.

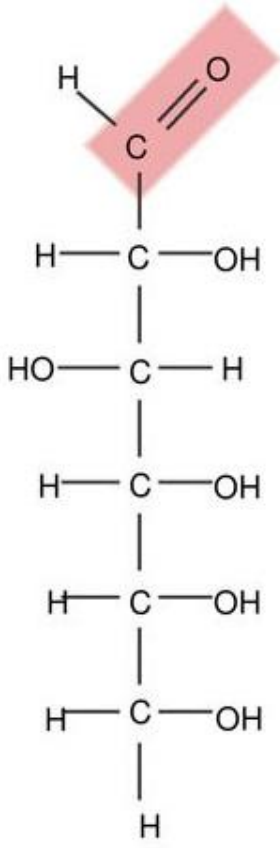
Isomeric Forms of Fructose



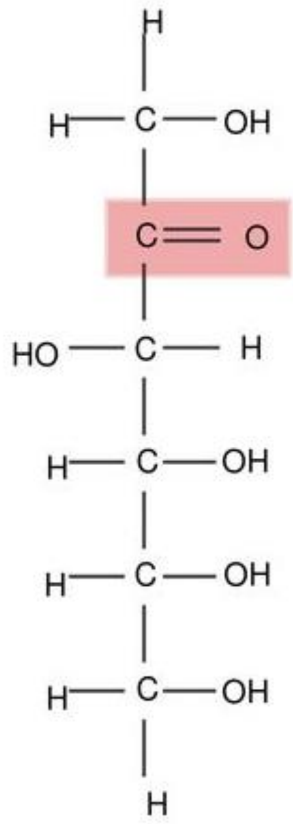
Cyclic form of 6 atoms: pyranose structure
Cyclic form of 5 atoms: furanose structure

Fructopyranose is the free form of fructose. When fructose is attached to another glucose forming sucrose or attached to other fructose making fructans, it does so in its furanose form. When invertase breaks down sucrose into glucose and fructose, the furanose form of fructose that occurs in sucrose, is now a pyranose form that can be metabolized in the liver by fructolysis.

D-glucose and D-fructose are isomers because they contain the same atoms but in different positions

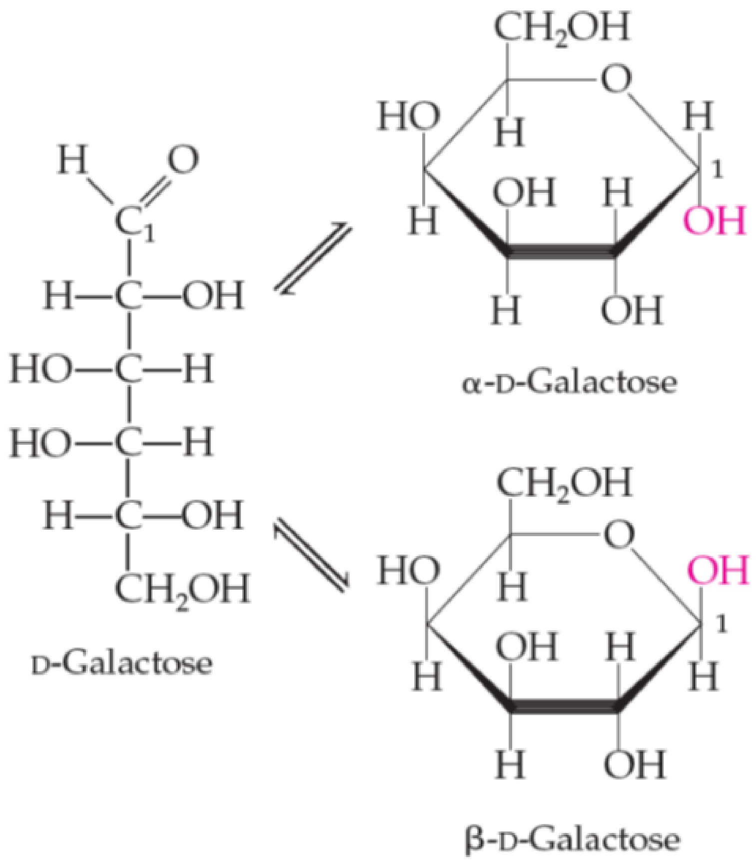


D-Glucose



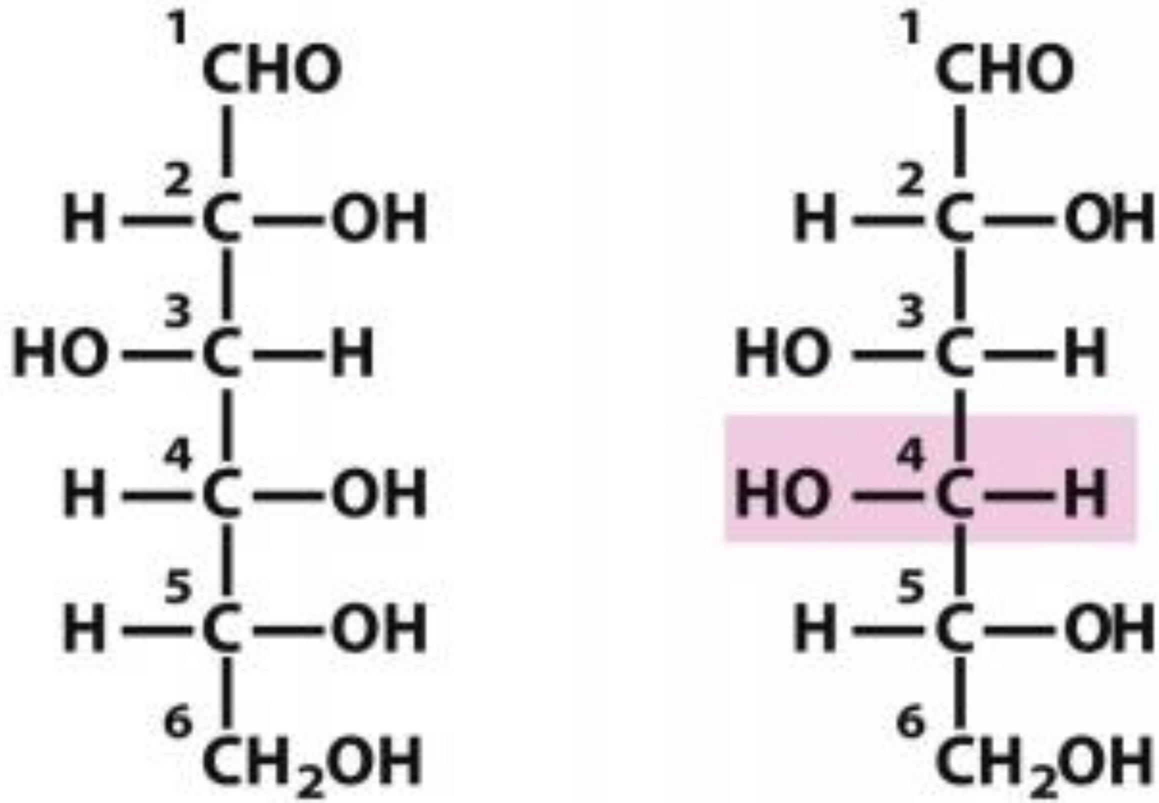
D-Fructose

D-Galactose, an aldohexose



Galactose is found in biological systems as a component of the disaccharide lactose, or milk sugar. This is the principal sugar found in the milk of most mammals. β-D-Galactose and its modified form, β-D-N-acetylgalactosamine, are also components of the blood group antigens.

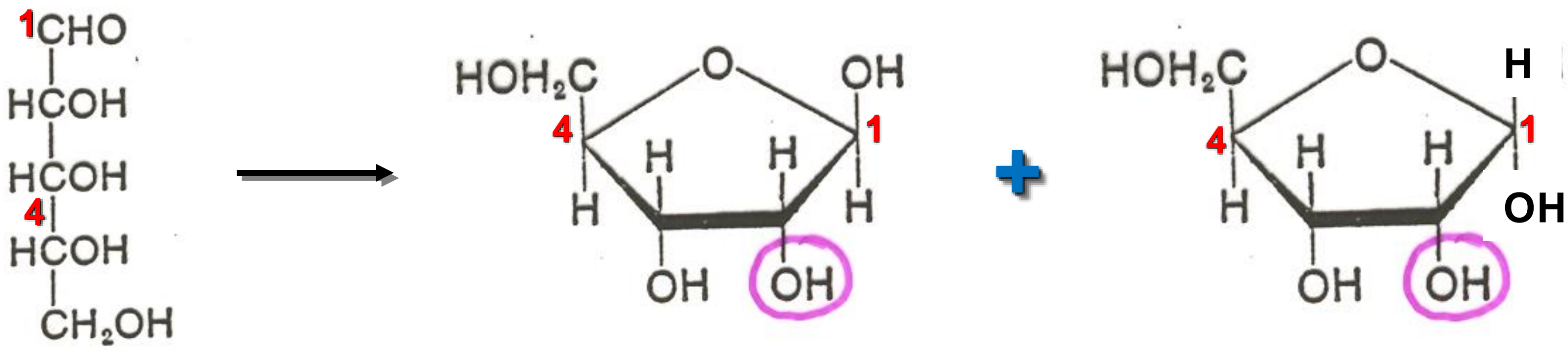
D-glucose and D-galactose are epimers because they have a different configuration at one chiral C atom



D-Glucose

D-Galactose (epimer at C-4)

Ribose and Deoxyribose, aldopentoses

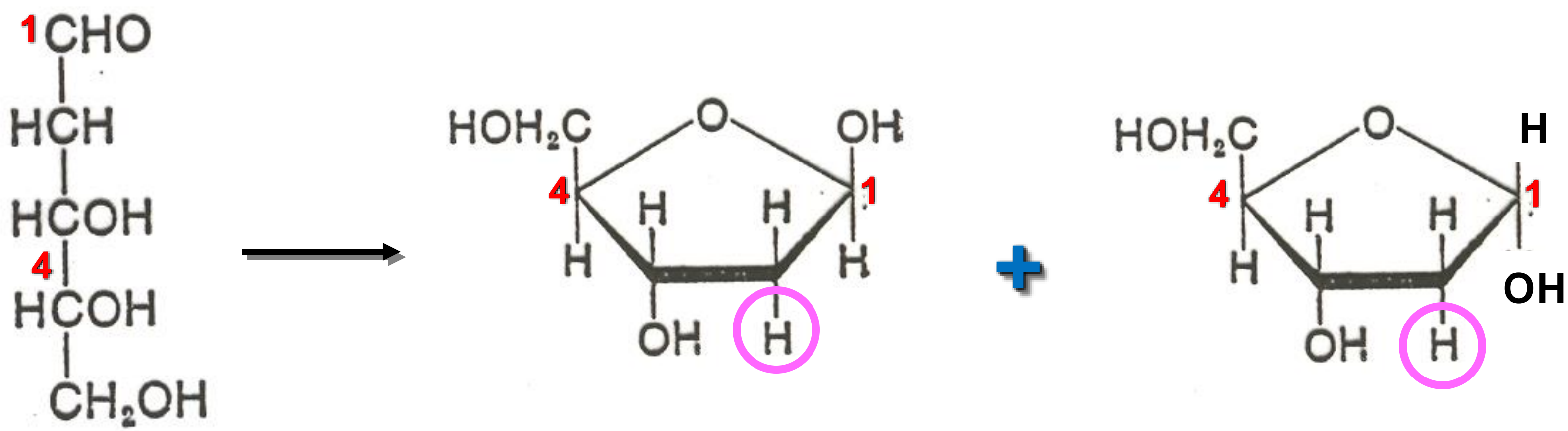


D-ribose, an aldopentose (acyclic form)

β-D-ribose

FURANOSIC FORM

α-D-ribose



2-deoxy- D-ribose, an aldopentose (acyclic form)

β-D- 2- deoxyribose

α-D-2-deoxyribose

Ribose and Deoxyribose, aldopentoses

- ✓ **Ribose,** an aldopentose, is a component of many biologically important molecules, including **RNA and various coenzymes** that are required by many of the enzymes that carry out biochemical reactions in the body.

- ✓ **DNA**, the molecule that carries the genetic information of the cell, contains the aldopentose **β-D-2-deoxyribose**. In this molecule, the -OH group found in ribose at C-2 has been replaced by a hydrogen.

- ✓ **ATP** is classified as a nucleoside triphosphate, which indicates that it consists of three components: a nitrogenous base (adenine), the sugar ribose, and the three phosphate groups. It is an organic compound that provides energy to drive many processes in living cells, *e.g.* muscle contraction, nerve impulse propagation, condensate dissolution, and chemical synthesis.

Reactions Involving Aldehydes and Ketones

Addition Reaction

When the hemiacetal of one monosaccharide reacts with the hydroxyl group of another monosaccharide, the product is an acetal. A sugar molecule made up of two monosaccharides is called a disaccharide. The C—O—C or acetal bond between the two monosaccharides is called a glycosidic bond (oxygen bridge).

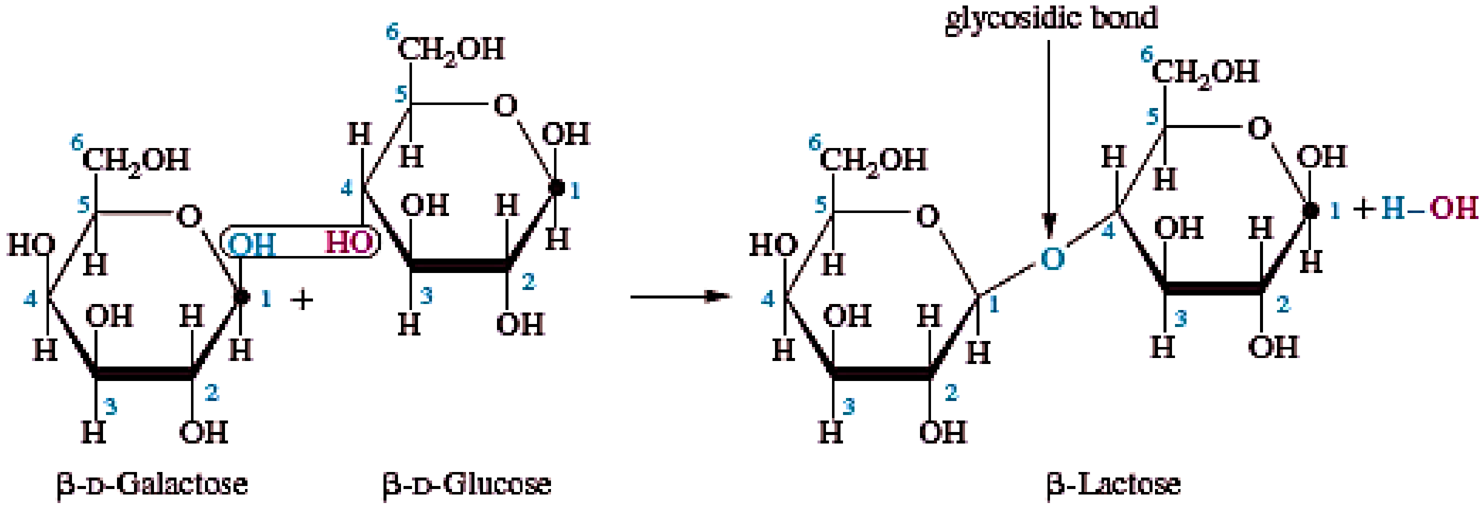
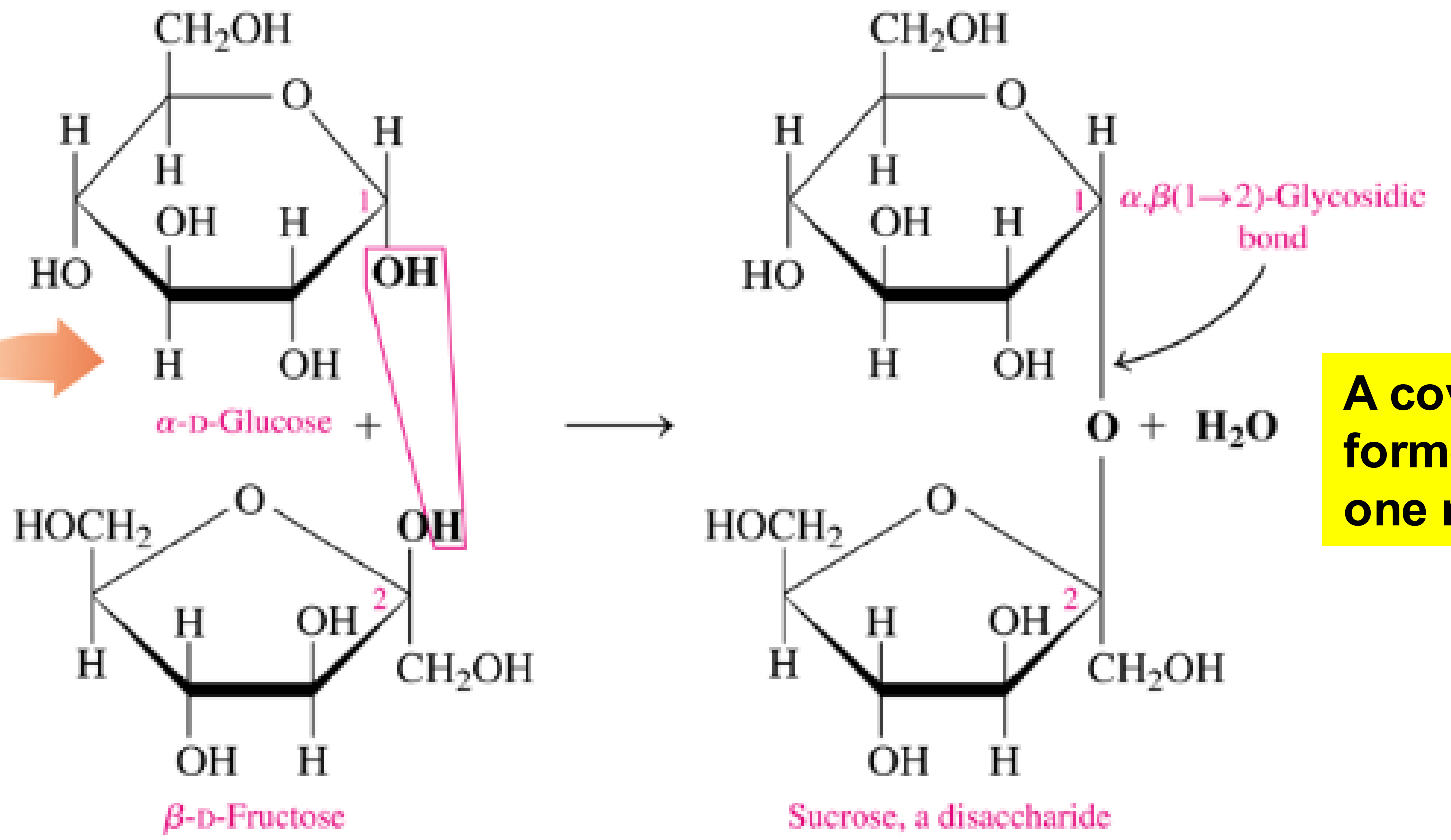


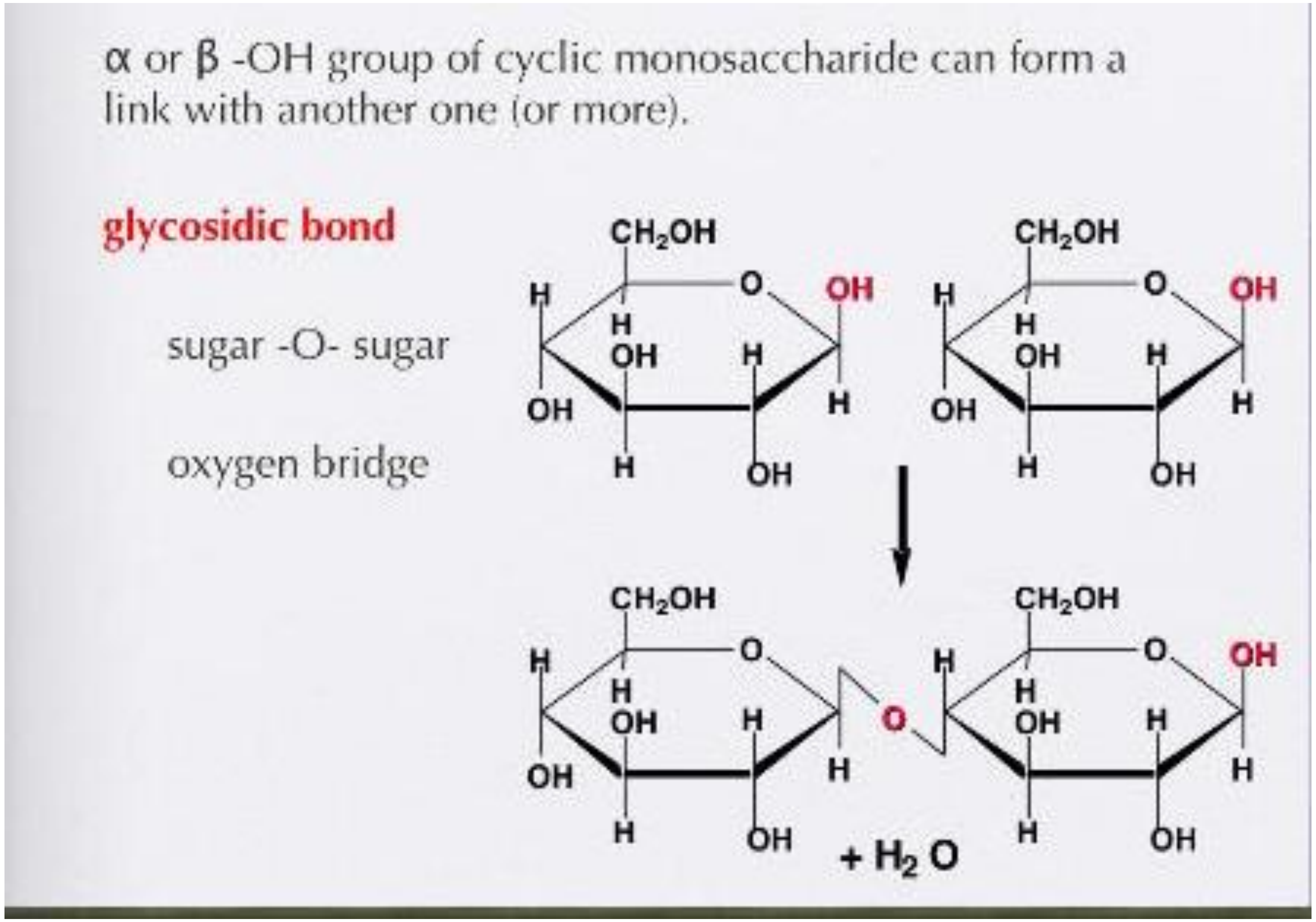
Figure 13.7 Acetal formation, demonstrated in the formation of the disaccharide lactose, milk sugar. The reaction between the hemiacetal hydroxyl group of the monosaccharide galactose (blue) and an alcohol hydroxyl group of the monosaccharide glucose (red) produces the acetal lactose. The bond between the two sugars is a glycosidic bond.

DISACCHARIDES



A covalent bond is formed with the loss of one molecule of water.

Monosaccharides may be joined together (through an "oxygen bridge") by O-glycosidic bonds to form polymers.



The bond can be either α-glycosidic or β-glycosidic depending on the configuration of the anomeric C engaged in the bond

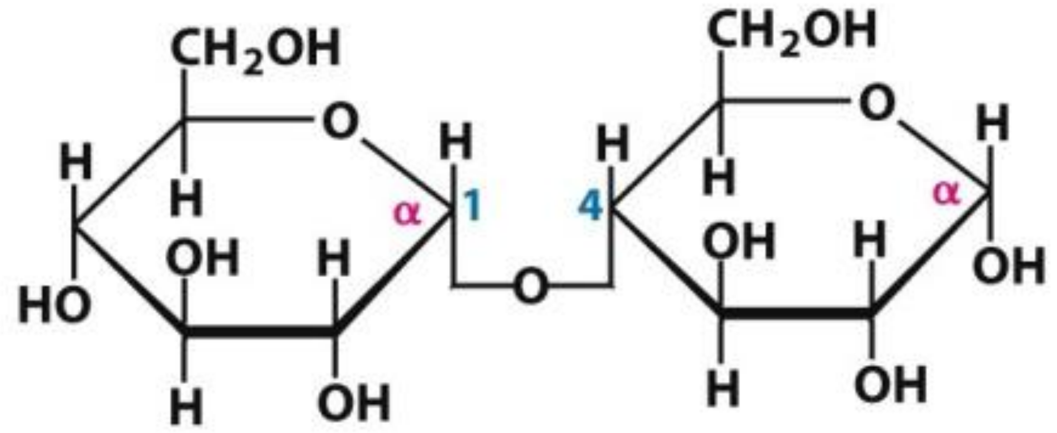
DISACCHARIDES

- **Glycosidic bond formation is nonspecific**; it can occur between a hemiacetal and any of the hydroxyl groups on the second monosaccharide.

- However, in biological systems, we commonly see only particular disaccharides, such as maltose, lactose, or sucrose. These specific disaccharides are produced in cells because **the reactions are catalyzed by enzymes.**

- **Each enzyme catalyzes the synthesis of one specific disaccharide, ensuring that one particular pair of hydroxyl groups on the reacting monosaccharides participates in glycosidic bond formation.**

Disaccharides
Maltose



Maltose
(α-D-Glucopyranosyl-(1→ 4)-α-D-glucopyranose

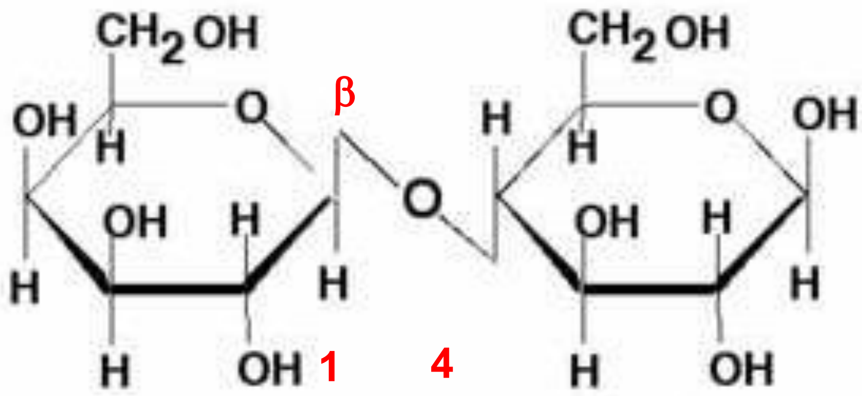
α (1,4) glycosidic bond

- Not common in nature except in germinating grains; it is one of the intermediates in the hydrolysis of starch.
- To break the glycosidic bond and release the monosaccharides of maltose the **enzyme MALTASE**, present in our body, is needed.
- Maltose is a **reducing sugar**. Any disaccharide that has a hemiacetal hydroxyl group (a free —OH group at C-1) is a reducing sugar. This is because the cyclic structure can open at this position to form a free aldehyde. Disaccharides that do not contain a hemiacetal group on C-1 are called nonreducing sugars.

Disaccharides
Lactose

Milk sugar - dimer of β-D-galactose and either the α or β -D-glucose.

β-Lactose



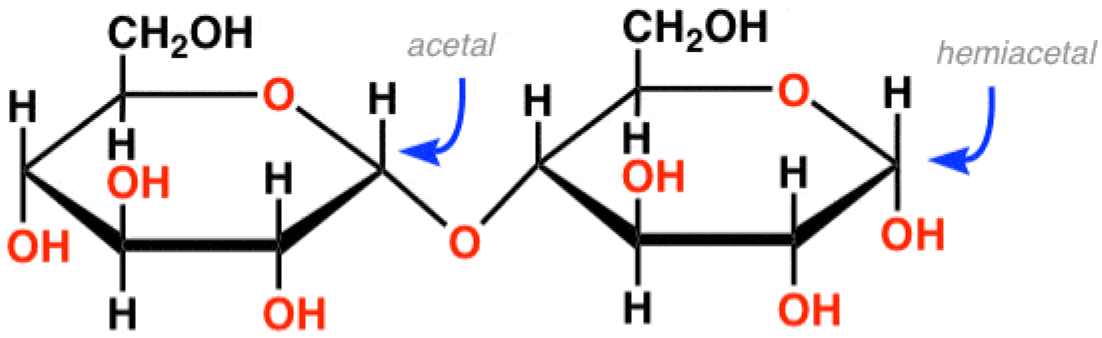
β-D-galactose β-D-glucose

β (1 ⟶ 4) linkage, β disaccharide.

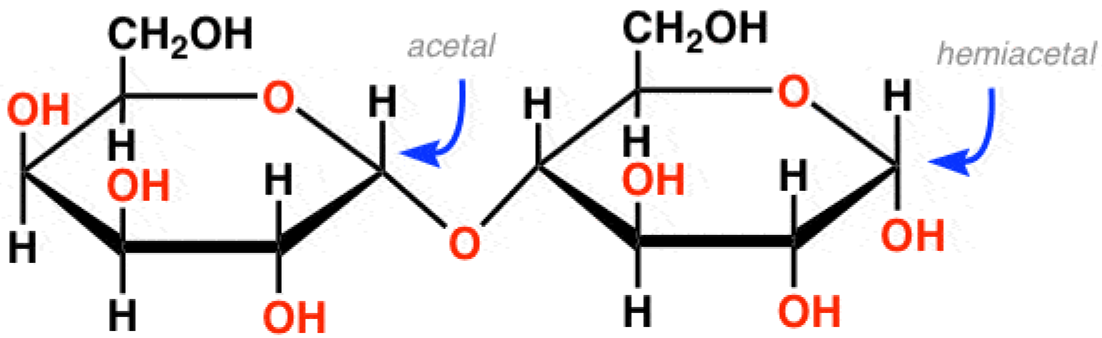
Many adults, and some children, are unable to hydrolyze lactose because they do not make the **enzyme *lactase*.** This condition, which affects 20% of the population of the United States and about 95% in Japan, is known as **lactose intolerance.**

Lactose and Maltose are also reducing sugars and give a positive Fehling test

Maltose:



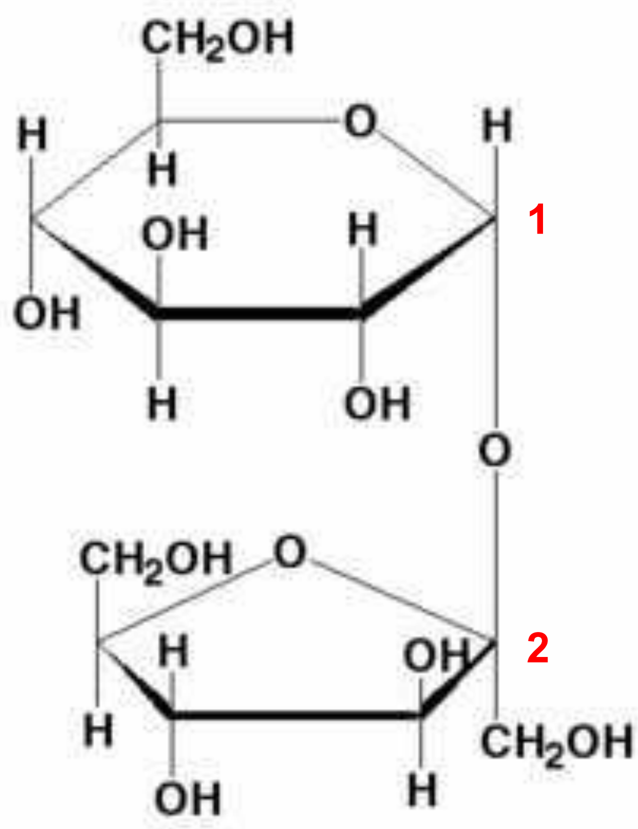
Lactose:



Disaccharides
Sucrose

- Table sugar - most common sugar in all plants.
- Sugar cane and beet, are up to 20% by mass sucrose.
- Disaccharide of α-glucose and β-fructose.

α β (1,2) glycosidic bond



Disaccharides
Sucrose

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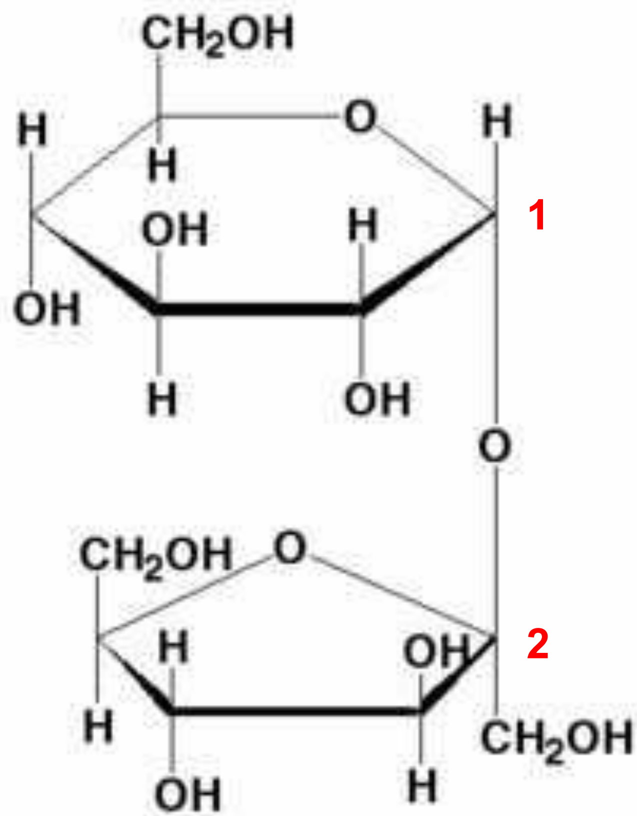


IS IT A REDUCING AGENT?

Disaccharides
Sucrose

- **Sucrose** is water-soluble and can easily be transported through the circulatory system of the plant. It cannot be synthesized by animals.

- High concentrations of sucrose produce a high osmotic pressure, which inhibits the growth of microorganisms, so it is used as a preservative.

- It is widely used as a sweetener even it has been suggested that sucrose in the diet is undesirable because it represents a source of empty calories; that is, it contains no vitamins or minerals.

- Recent studies have determined that there is a significant relationship between excess sugar consumption and an increased risk for cardiovascular disease–related mortality. In addition, the link between sucrose in the diet and dental cavities has been scientifically proved.

Polysaccharides

- They are the most abundant carbohydrates in nature
- **Abundant in plants, where they make up 50 to 90% of the dry weight**
- **Unlike monosaccharides and disaccharides, they are almost insoluble in water, due to the size of the molecules, which only be hydrated on the surface.**

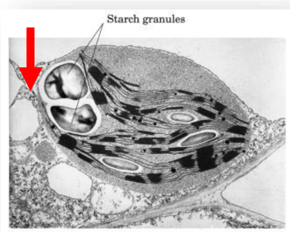
POLYSACCHARIDES

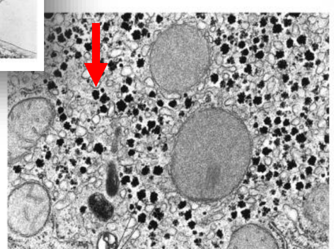
Homopolysaccharides

Polymers composed of a single monosaccharide

Storage

starch (plants)
glycogen (animals)





Structural

cellulose

Heteropolysaccharides

Polymers made up of two or more different monosaccharides

other functions

Glucosaminoglycans

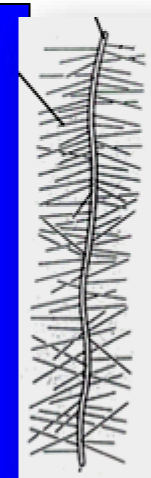
in the extracellular matrix with lubricant functions

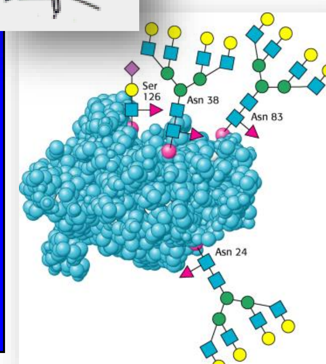
proteoglycans

in the cartilage, in the joints

glycoproteins

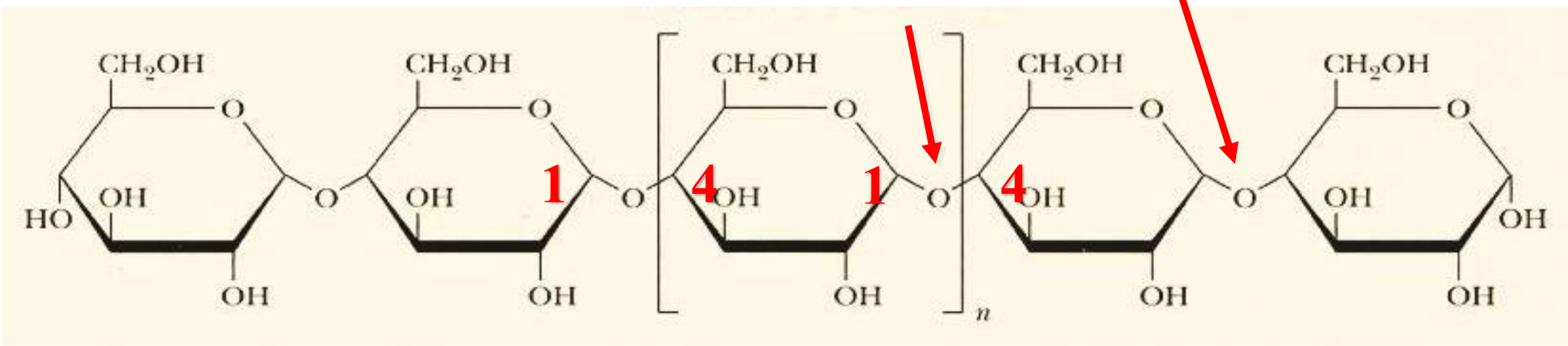
in cell plasma membranes

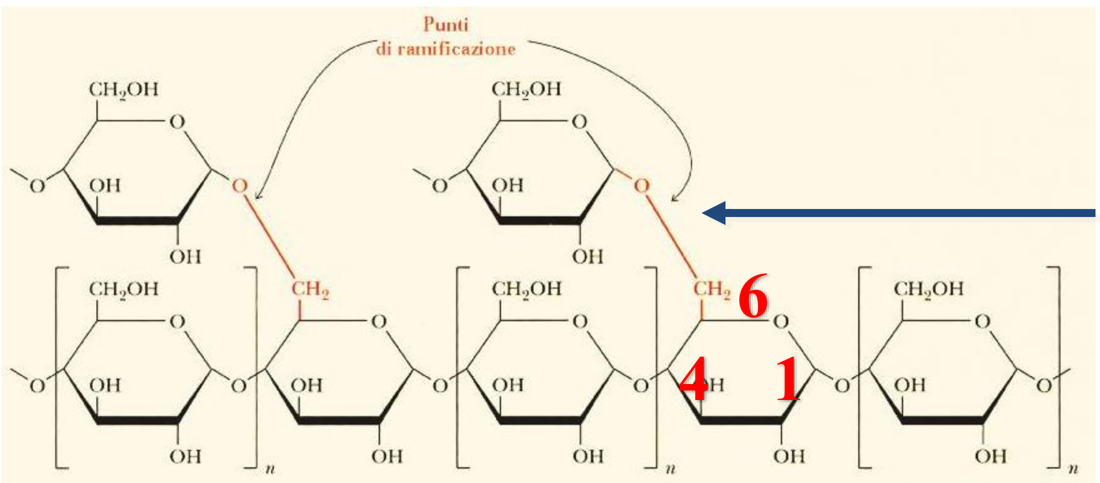




GLYCOSIDIC BONDS

In the formation of polysaccharides, the monosaccharides can be joined together by one type of glycosidic bond, in which case there will be a linear polymer (α 1,4)



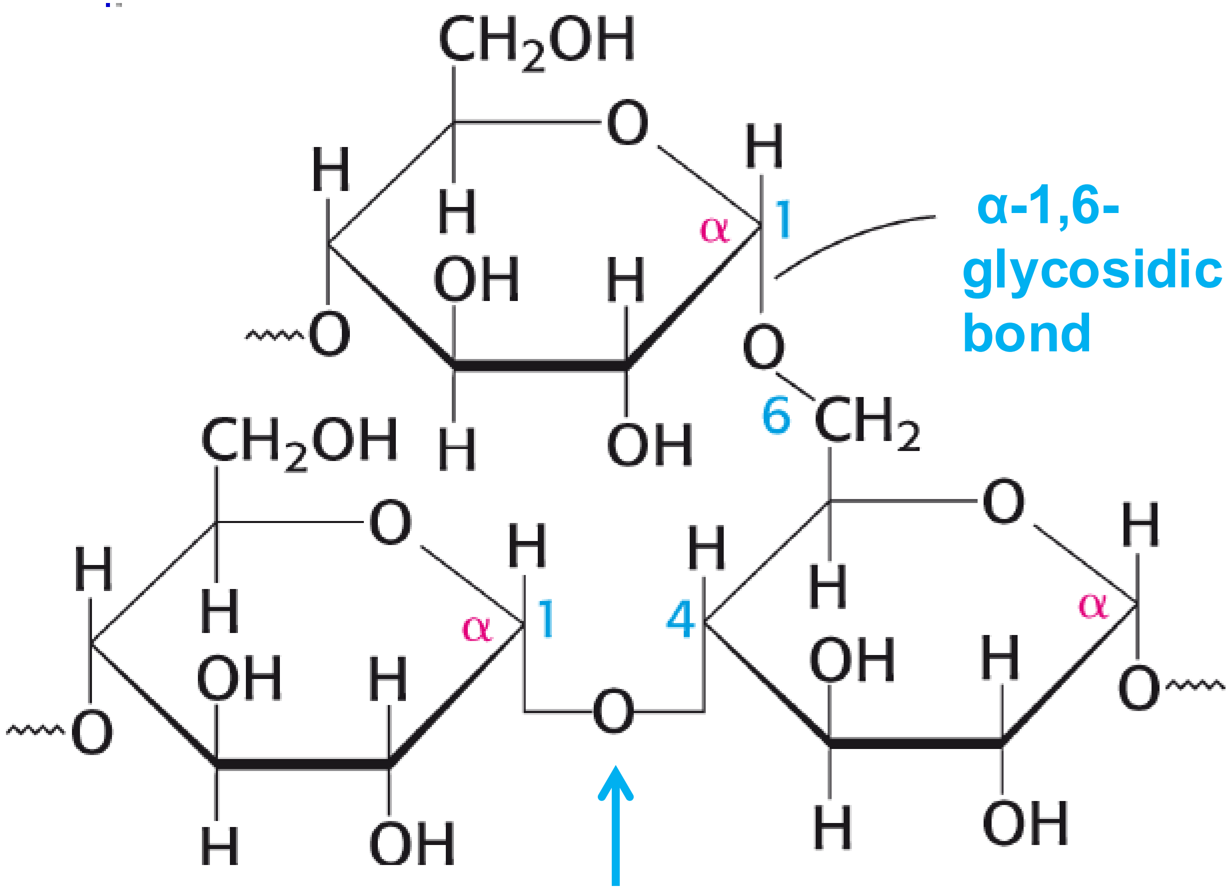


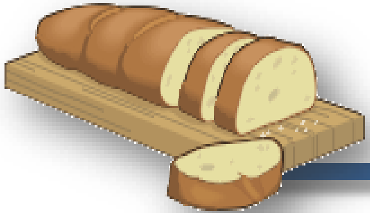
If some internal residues form other glycosidic bonds, there will be a branched polymer (α 1,6)

α-1,4 and α-1,6-GLYCOSIDIC BOND

- When the anomeric carbon forms the glycosidic bond with the C6-bonded hydroxyl group of another monosaccharide, a α-1,6-glycosidic bond is formed.

- This bond creates ramifications in the chains of monosaccharides linked together by glycosidic bonds.

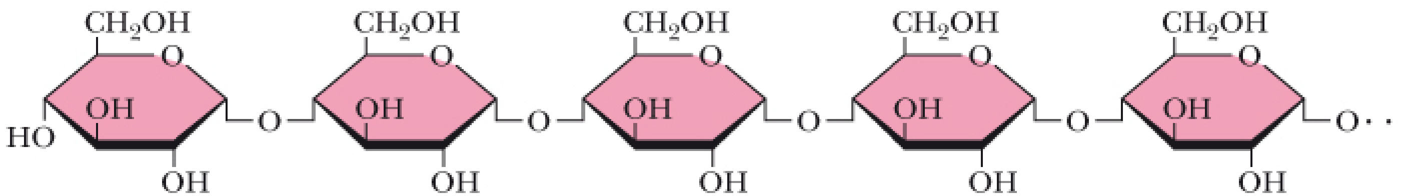




STARCH

Starch is composed of the glucose polymers **amylose** and **amylopectin**.

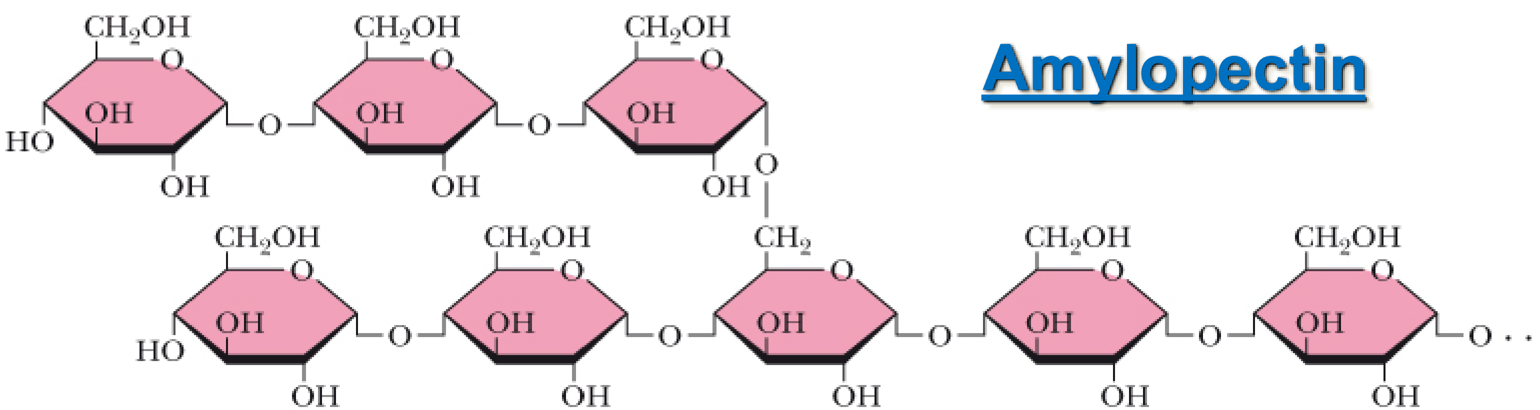
Amylose



amylose

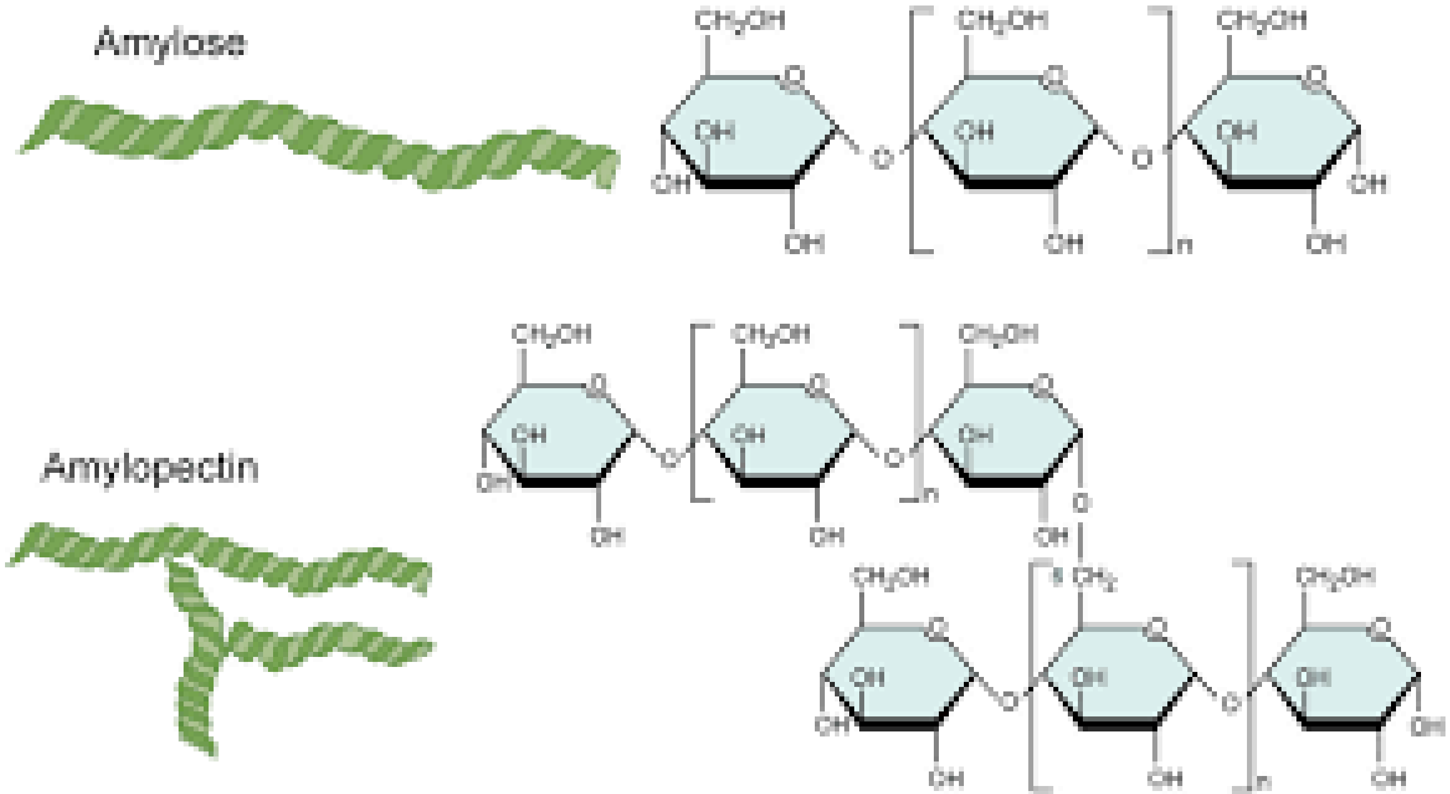
Amylose, which accounts for about 20% of the starch of a plant cell, is a linear polymer of **α-D-glucose** with α(1,4) glycosidic bonds, soluble in hot H_2O.

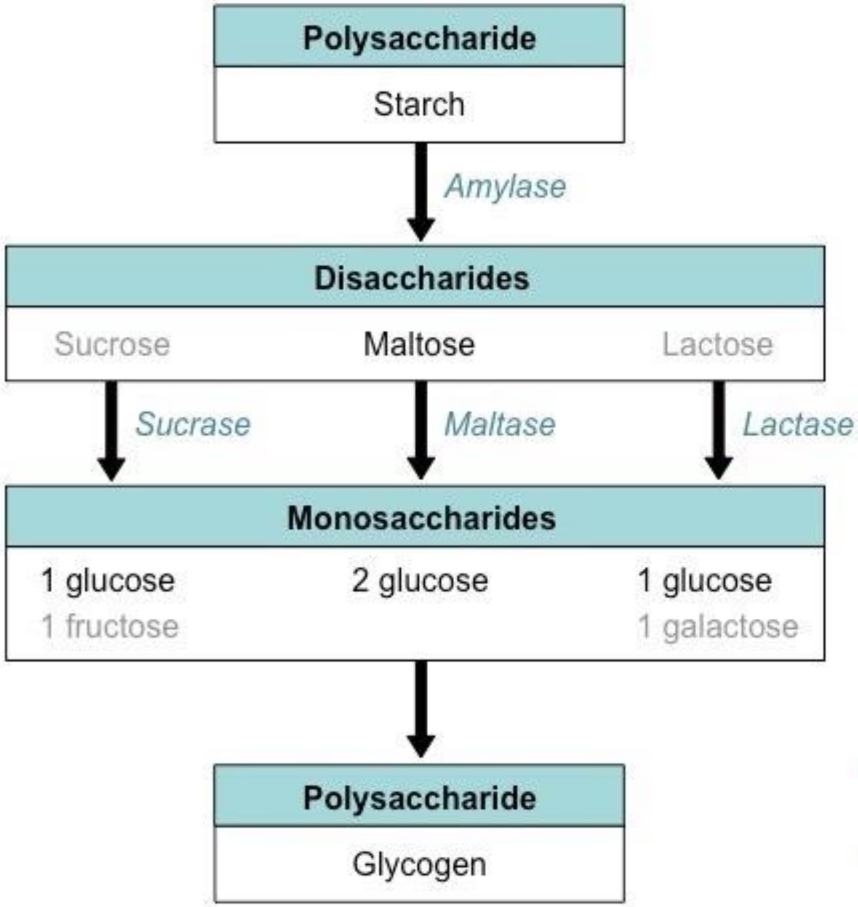
Amylopectin

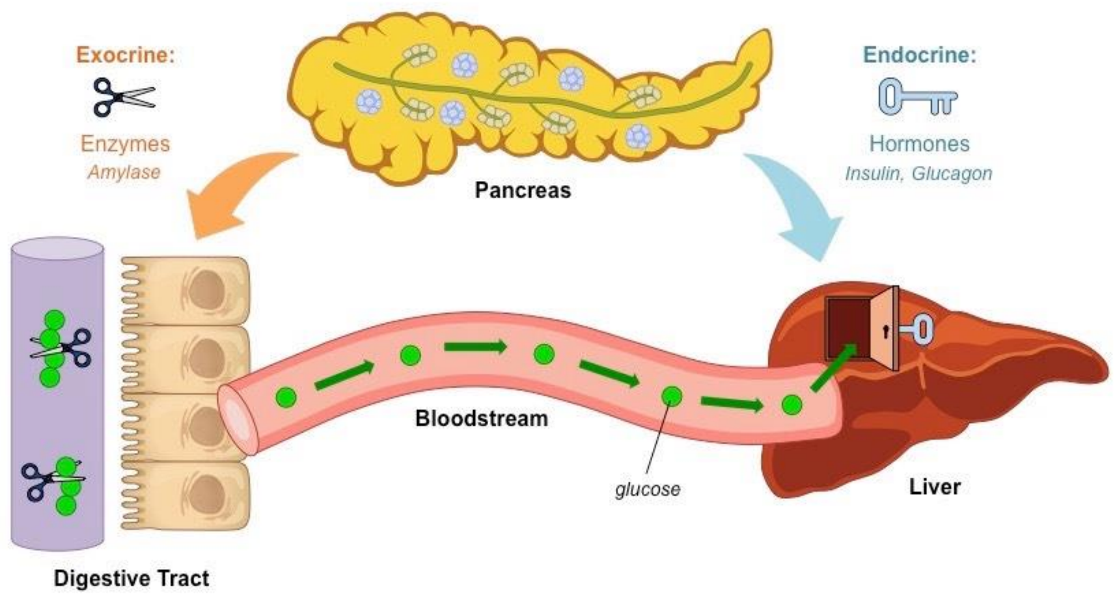


amylopectin

Amylopectin, which accounts for about 70-90% of the starch of a plant cell is a highly branched amylose in which the branches are attached to the C-6 hydroxyl groups by α(1, 6) glycosidic bonds. The main chains consist of α (1, 4) glycosidic bonds.

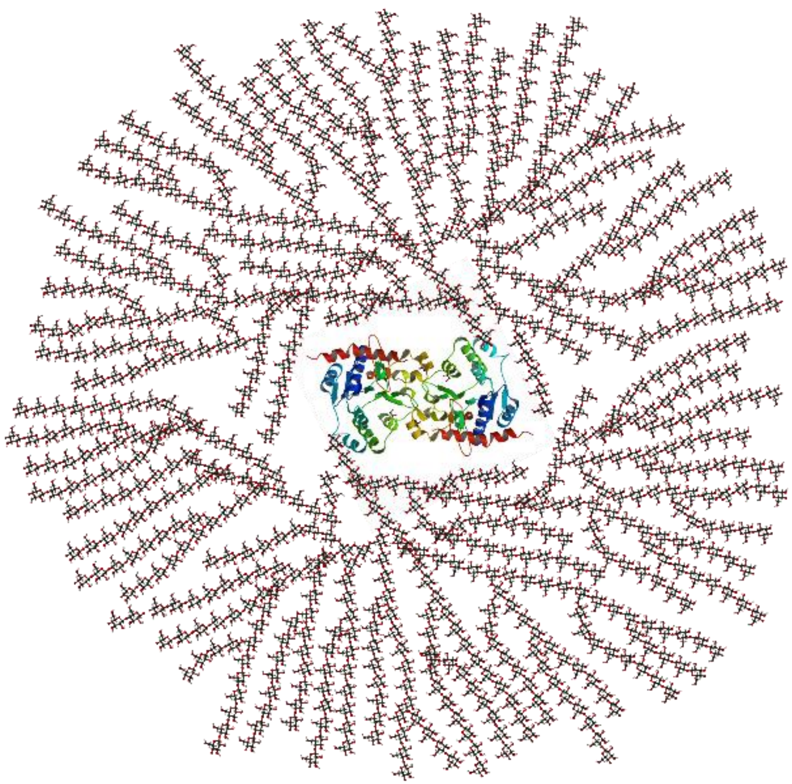

Amylose
Amylopectin
CH_2OH
OH
O
n


Polysaccharide
Starch
Amylase
Disaccharides
Sucrose
Maltose
Lactose
Sucrase
Maltase
Lactase
Monosaccharides
1 glucose
1 fructose
2 glucose
1 glucose
1 galactose
Polysaccharide
Glycogen


Exocrine:
Enzymes
Amylase
Pancreas
Endocrine:
Hormones
Insulin, Glucagon
Bloodstream
glucose
Liver
Digestive Tract

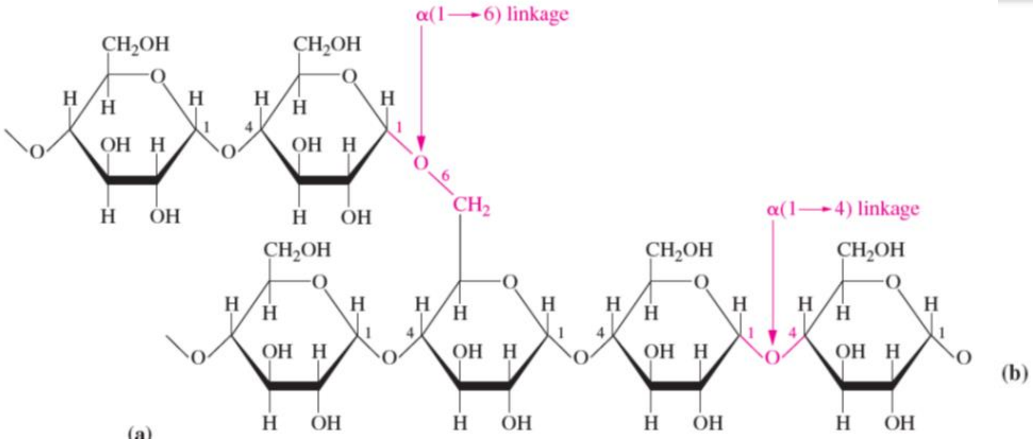
GLYCOGEN

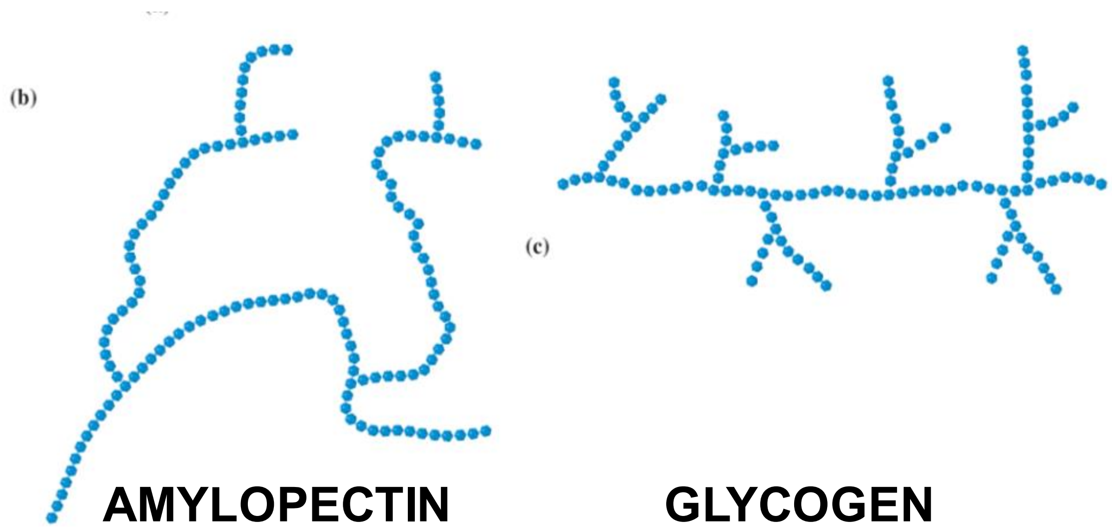
- **Glycogen** is a polysaccharide in which the "main chain" is linked by α(1, 4) glycosidic bonds, and it has numerous α(1, 6) glycosidic bonds, which provide many branch points along the chain.



- Within the globules of glycogen there is the protein **glycogenin**, linked to residues of glucose, which acts as a "trigger" for its reconstitution.
- Glycogen is the major glucose storage molecule in animals.
- Glycogen is stored in the liver and skeletal muscle. Glycogen synthesis and degradation in the liver are carefully regulated (by insulin/glucagon) to keep blood glucose levels constant.

AMYLOPECTIN VS GLYCOGEN





- Glycogen differs from amylopectin only by having more and shorter branches.
- The highly branched structure allows the rapid mobilization of glucose in times of metabolic need and glycogenin guarantees the possibility of its reconstitution.

DEGRADATION

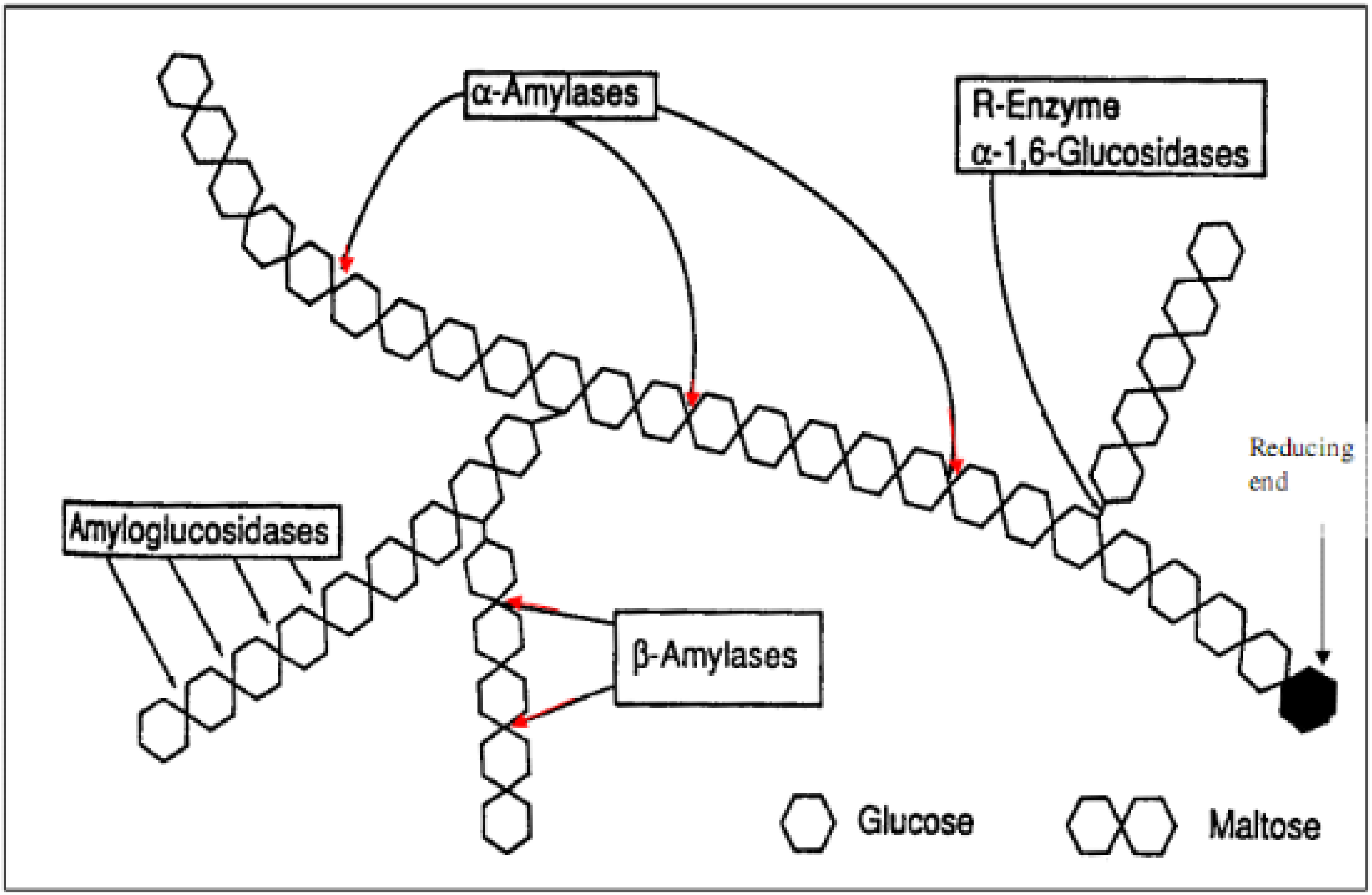
Amylose, amylopectin taken from food and glycogen are hydrolyzed **by α-amylases and glucosidases**, enzymes in saliva, pancreas and small intestine that break (α 1→4) glycosidic bonds between glucose units.

α- amylase enzyme cleaves glycosidic bonds at random points in the main starch chain, producing shorter polysaccharide chains.

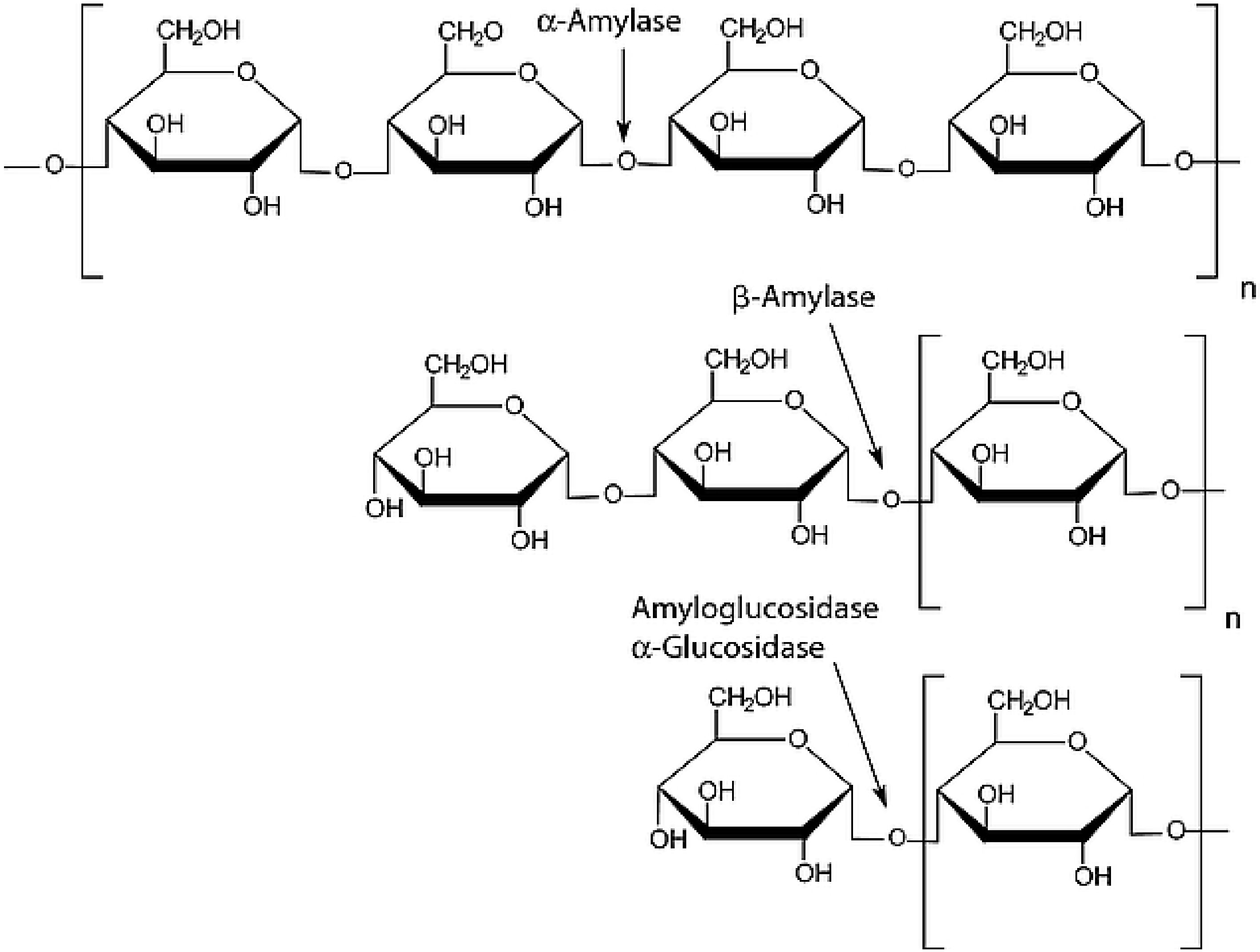
β-amylase sequentially acts on the bond between the last 2 and 3 glucose residues in the starch chain, releasing the disaccharide maltose from the reducing end of the starch chain.

The maltose is hydrolyzed into glucose by the enzyme **maltase**. The glucose is quickly absorbed by intestinal cells and used by the cells of the body as a source of energy.

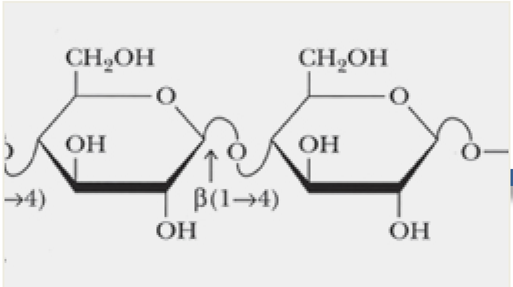
Amylo-glucosidases, present in the mucosa of the small intestine hydrolyses specifically at the level of the 1,4 and 1,6-glucosidic bond, releasing also glucose.



α-Amylases
R-Enzyme
α-1,6-Glucosidases
Reducing
end
Amyloglucosidases
β-Amylases
Glucose
Maltose

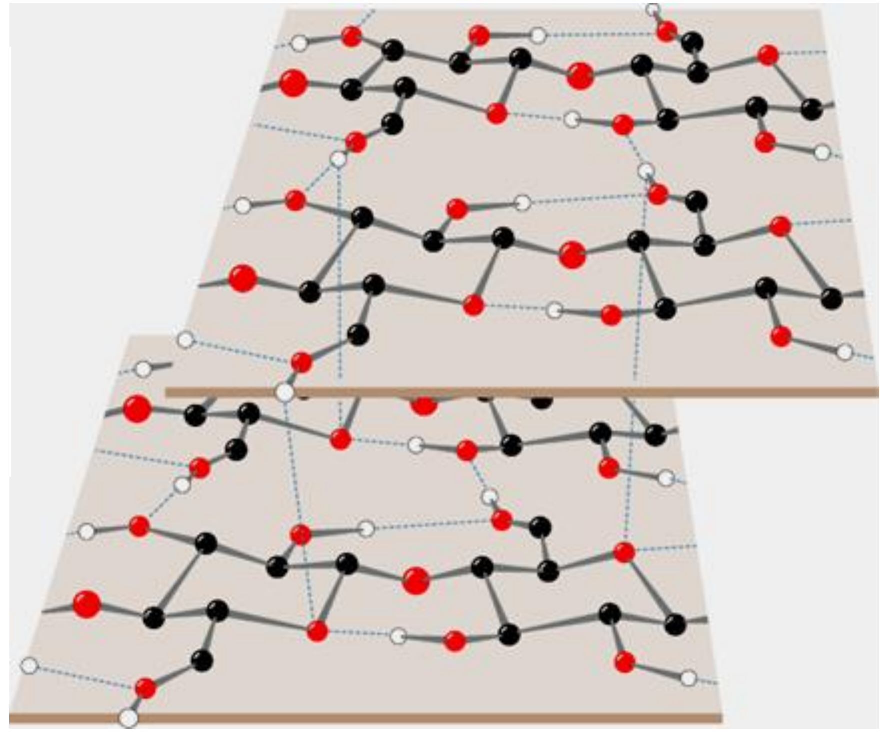


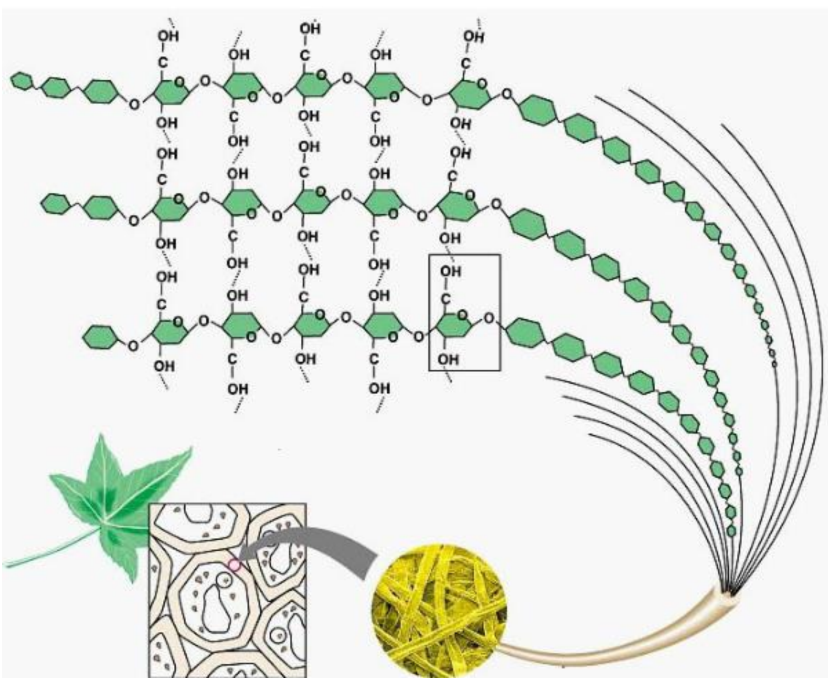
α-Amylase
β-Amylase
Amyloglucosidase
α-Glucosidase



CELLULOSE

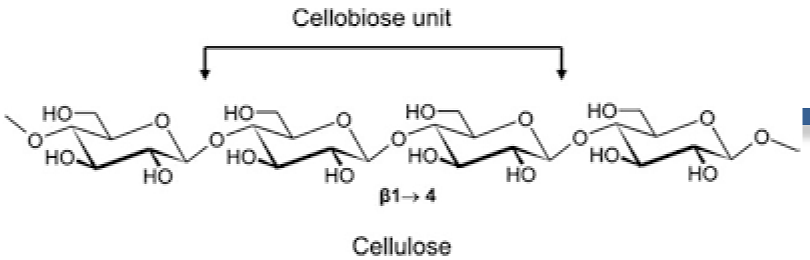
- **The most abundant polysaccharide in nature consisting of β-D-glucose molecules**
- **Cellulose is a structural component of the plant cell wall**
- **β (1,4) glycosidic bonds cause the cellulose molecules to be stable in a linear form**

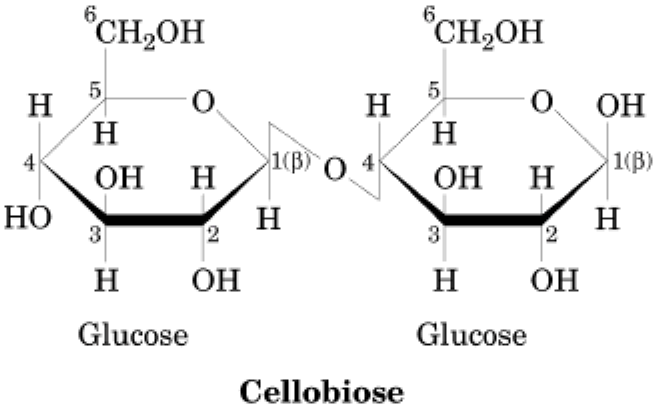




The unbranched structure of the cellulose polymer and the β(1, 4) glycosidic bonds allow cellulose molecules to form long, straight chains of parallel cellulose molecules called *fibrils.* These fibrils are rigid and tightly held together by hydrogen bonds; thus, it is not surprising that cellulose is a cell wall structural element.

CELLOBIOSE

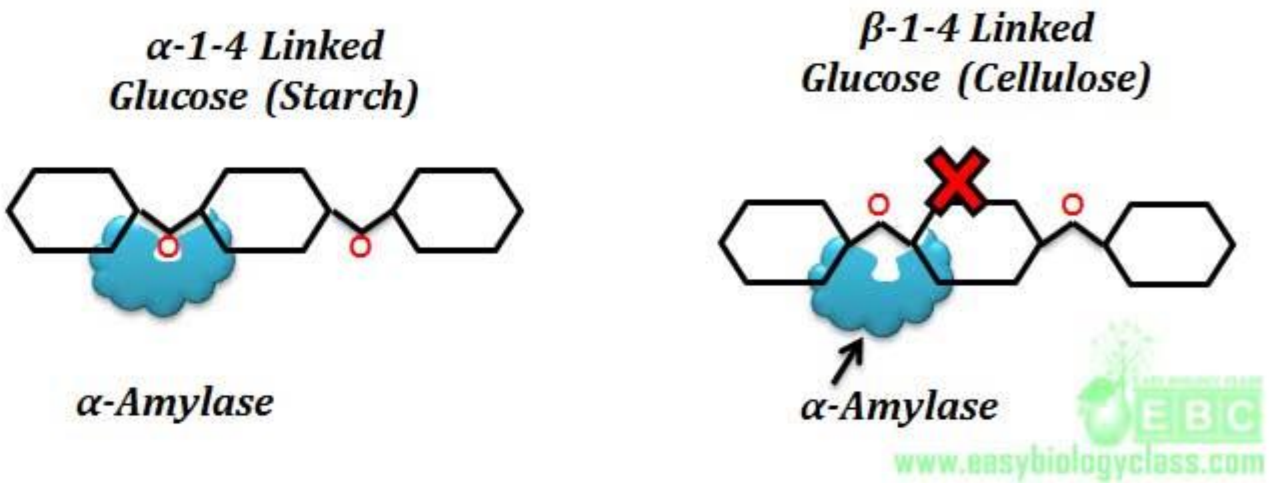




Common disaccharide: β-cellobiose

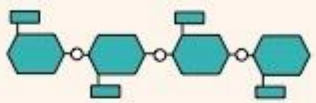
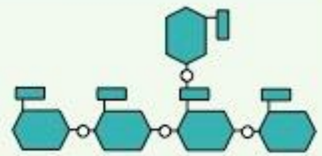
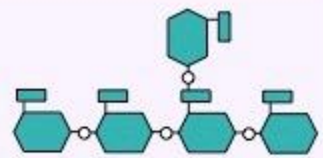
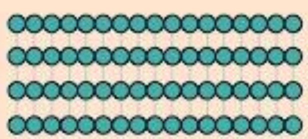
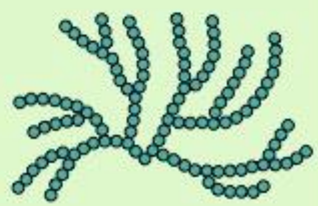
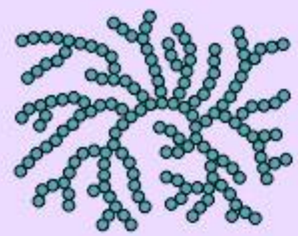
- 1 β-D-glucose + 1 β-D-glucose
- C involved in glycosidic bond is β configuration, so it is **β (1,4)** glycosidic bond
- the enzyme **cellulase** can catalyze the hydrolysis of the β(1, 4) glycosidic bond of cellulose, but humans don't synthesize this enzyme.
- Cellobiose derives from cellulose hydrolysis.

Stereo specificity of Enzymes



- Most vertebrates cannot use cellulose as an energy source, because they lack an enzyme to hydrolyze the (β1→4) linkages. Termites readily digest cellulose (and therefore wood), but only because their intestinal tract harbors a symbiotic microorganism, *Trichonympha*, that secretes **cellulase, which hydrolyzes the (β1→4) linkages.**

- **Ruminant animals** such as cows, sheeps, and goats have symbiotic microorganisms in the rumen (the first of their four stomach compartments) that can hydrolyze cellulose, allowing the animal to degrade dietary cellulose from soft grasses, but not from woody plants.

	Cellulose	Starch		Glycogen
		Amylose	Amylopectin	
Source	Plant	Plant	Plant	Animal
Subunit	β-glucose	α-glucose	α-glucose	α-glucose
Bonds	1-4	1-4	1-4 *and* 1-6	1-4 *and* 1-6
Branches	No	No	Yes (~per 20 subunits)	Yes (~per 10 subunits)
Diagram				
Shape				

ORGANISMS CONTAIN A VARIETY OF HEXOSE DERIVATIVES

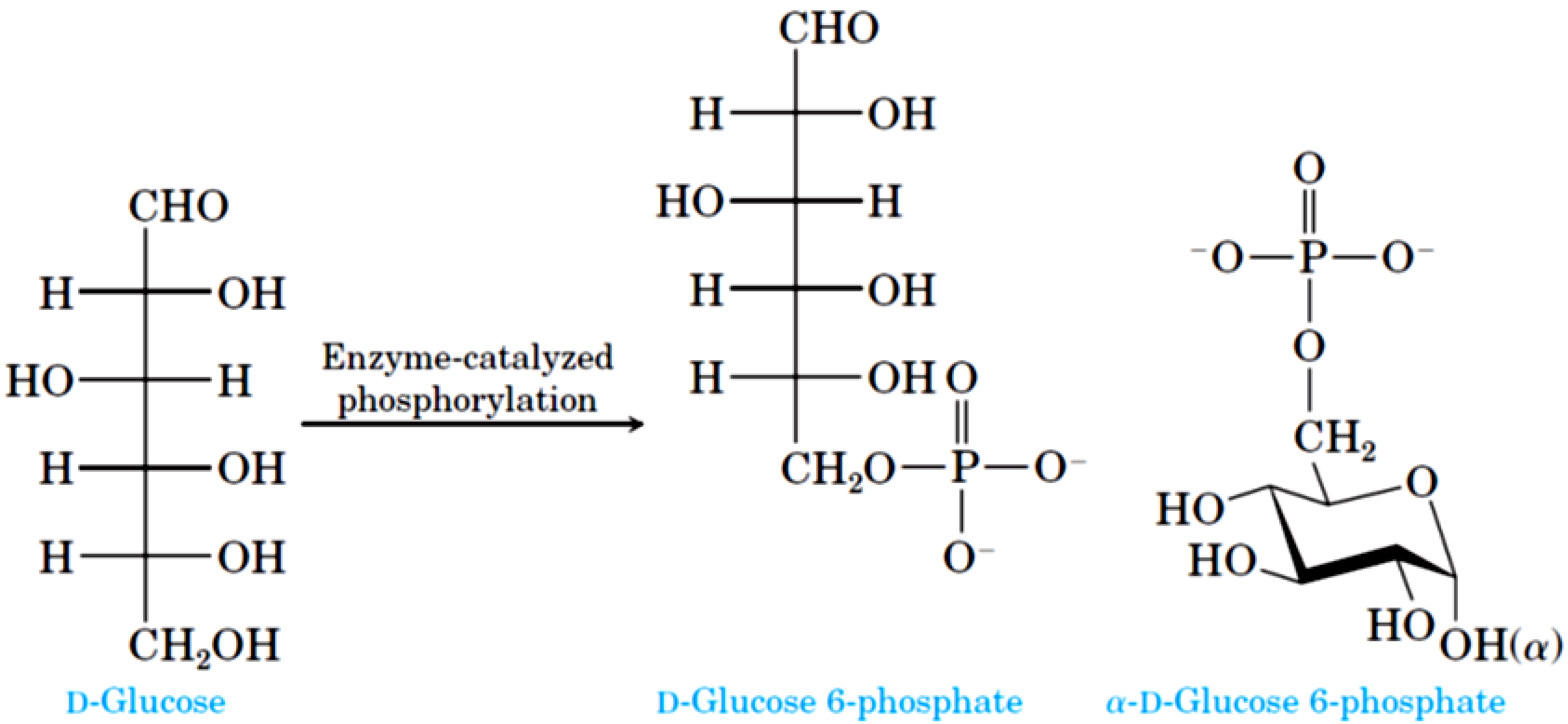
- Oxidation of the carbon at C-6 of UDP- D-glucose forms the corresponding uronic acid called **UDP-D-glucuronic acid**. Glucuronic acid is a common building block of proteoglycans and glycolipids (heparin, an inhibitor of blood coagulation; chondroitin sulfate is found in large quantities in cartilage, aorta, connective tissue, bone, and skin; hyaluronic acid occurs in large quantities in connective tissues, skin, cartilage, and synovial fluid)

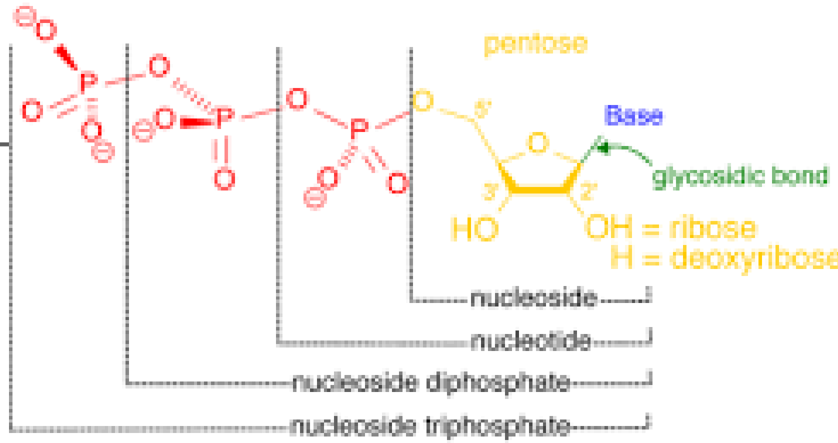
- Condensation of phosphoric acid with one of the hydroxyl groups of a sugar forms a **phosphate ester, as in glucose 6-phosphate**, the first metabolite in the pathway by which most organisms oxidize glucose for energy.

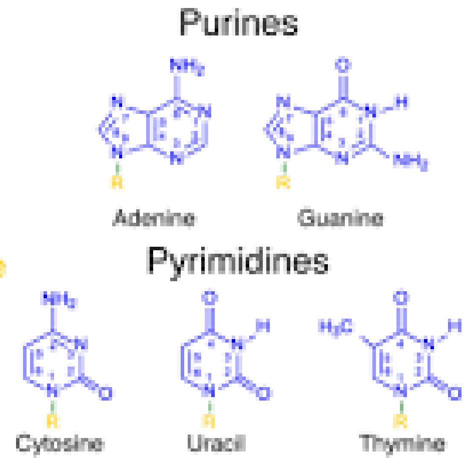
- In glucosamine, galactosamine, and mannosamine, the hydroxyl group at C-2 of the parent compound is replaced with an amino group. The amino group can be condensed with acetic acid, as **in *N*-acetylglucosamine**.

- Substitution of a hydrogen with the hydroxyl group at C-6 of L-galactose or L-mannose produces L-fucose or L-rhamnose, respectively. **L-Fucose** is found in the complex oligosaccharide components of **glycoproteins and glycolipids**.

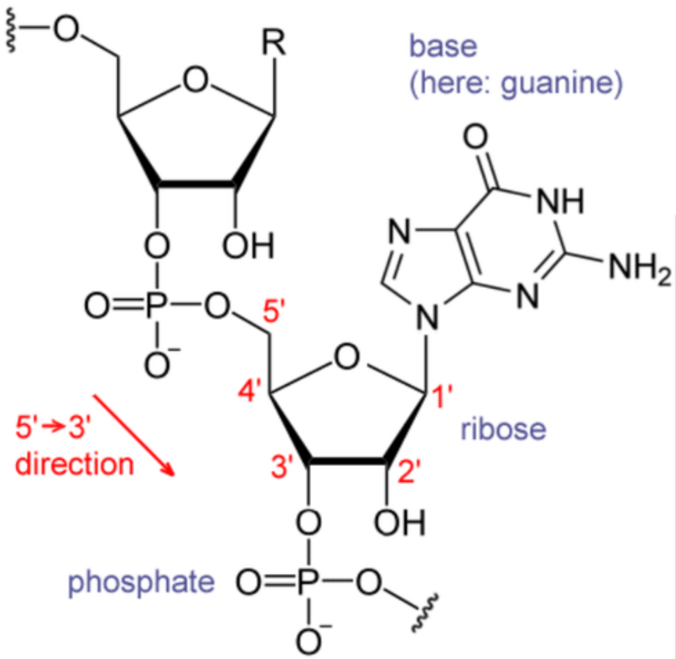
THE FIRST STEP IN GLYCOLYSIS INVOLVES CONVERSION OF GLUCOSE TO GLUCOSE 6-PHOSPHATE

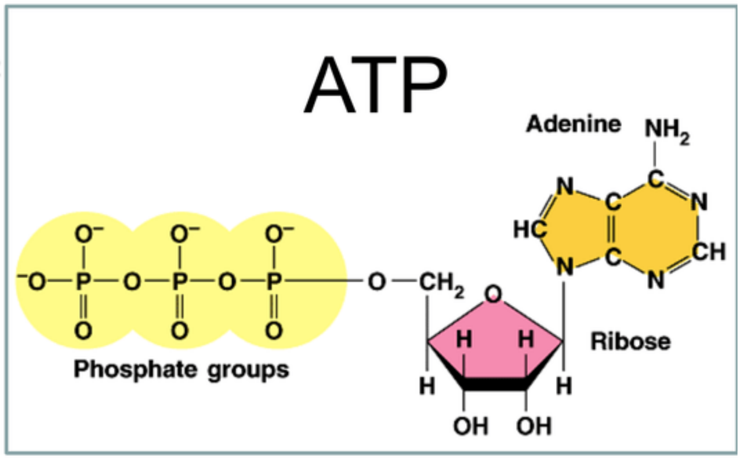


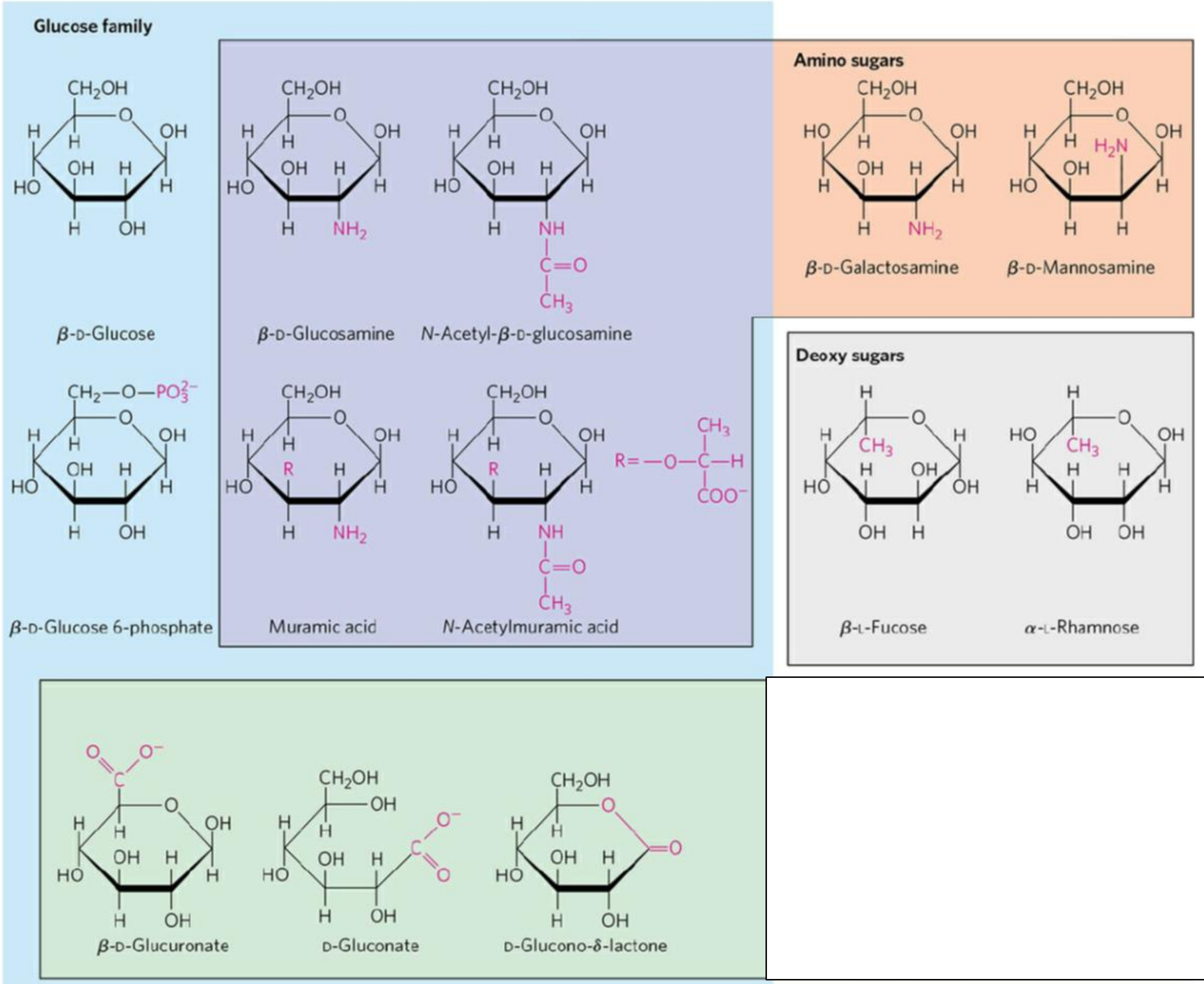

pentose
Base
glycosidic bond
5'
3'
2'
HO
OH = ribose
H = deoxyribose
nucleoside
nucleotide
nucleoside diphosphate
nucleoside triphosphate

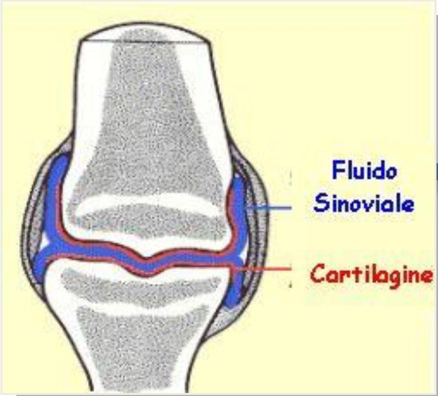

Purines
Adenine
Guanine
Pyrimidines
Cytosine
Uracil
Thymine

DNA-RNA unit


base
(here: guanine)
5'→3'
direction
ribose
phosphate
5'
4'
3'
2'
1'

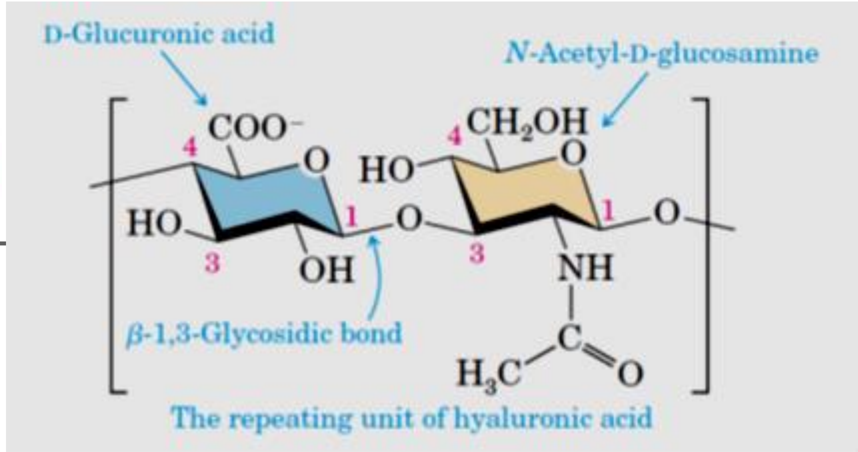

ATP
Adenine
Ribose
Phosphate groups


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



HETEROPOLYSACCHARIDES

- Heteropolysaccharides are long-chain polymers that contain more than one type of monosaccharide, many of which are amino sugars. With many negative charges, they attract water to their surface, giving viscous and gelatinous solutions (also known as mucopolysaccharide).
- **Glycosaminoglycans** include **chondroitin sulfate**, **hyaluronic acid**, and **heparin**. Hyaluronic acid is abundant in the fluid of joints and in the vitreous humor of the eye. Chondroitin sulfate is an important component of cartilage, and heparin has an anticoagulant function.
- Most connective tissues (cartilage, synovial fluid, skin, tendons, blood vessels, intervertebral disks, cornea…) consist of collagen, a structural protein, combined with a variety glycosaminoglycans to form tight or loose networks.



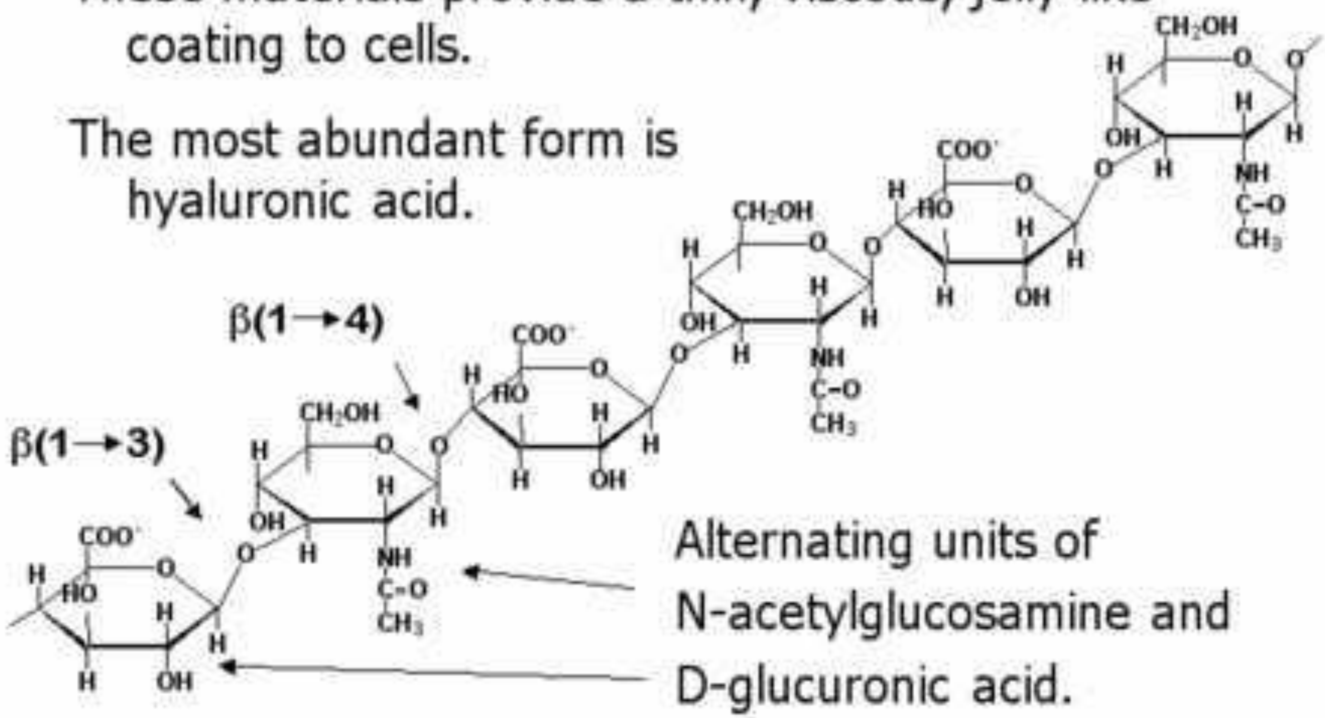
Mucopolysaccharides

Hyaluronic acid is a major component of:

- the synovial fluid and was found to increase the viscosity of the fluid;
- articular cartilage, where it is present as a coat around each cell (chondrocyte);
- muscular connective tissues to enhance the sliding between adjacent tissue layers;
- skin, where it is involved in tissue repair.

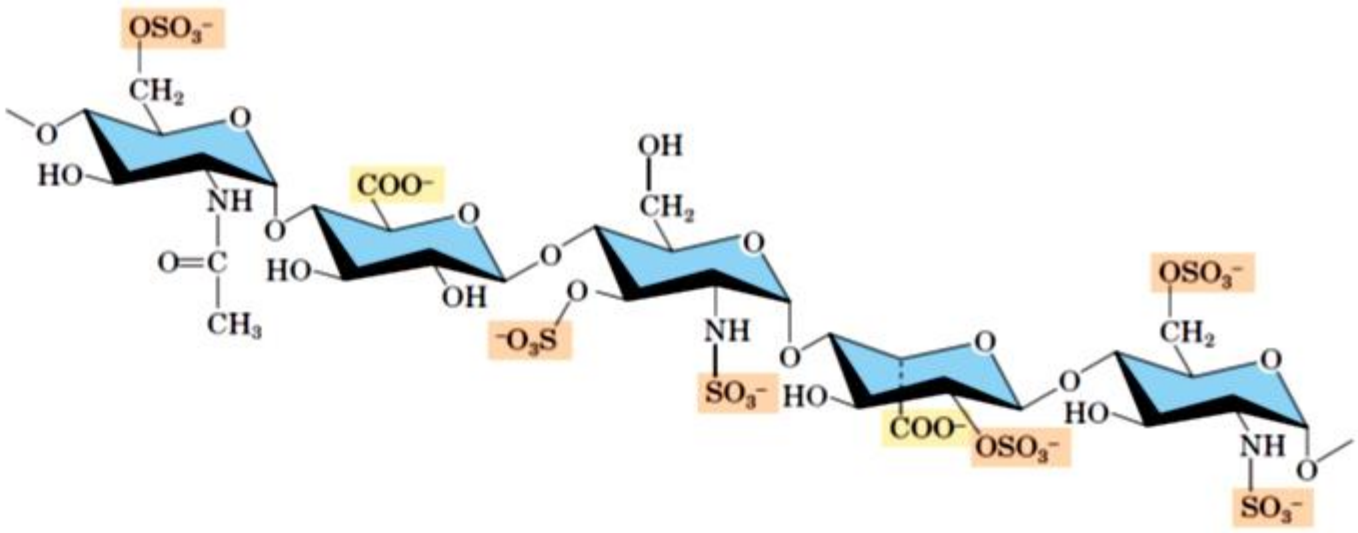
These materials provide a thin, viscous, jelly-like coating to cells.

The most abundant form is hyaluronic acid.



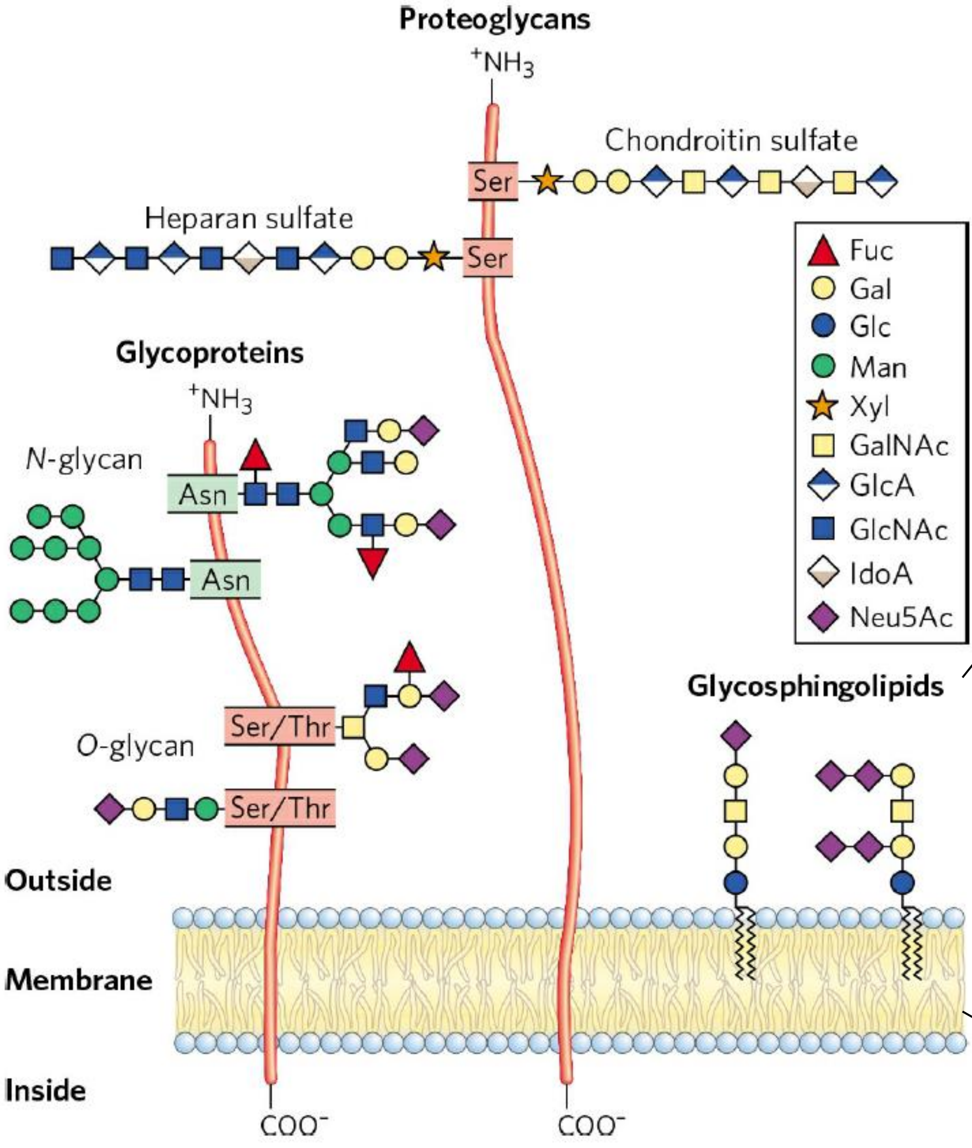
Alternating units of N-acetylglucosamine and D-glucuronic acid.

HEPARIN



- Heparin is a heterogeneous mixture of **variably sulfonated polysaccharide** chains, ranging in molecular weight from 6000 to 30,000 g/mol.
- This polysaccharide is synthesized and stored in mast cells (cells that are part of the immune system and that occur in several types of tissues) of various tissues—particularly the liver, lungs, and gut.
- Heparin has many biological functions, the best known of which is its anticoagulant activity. It binds strongly to antithrombin III, a plasma protein involved in terminating the clotting process. Because of this anticoagulant activity, it is widely used in medicine.

GLYCOCONJUGATES



Also glycoproteins

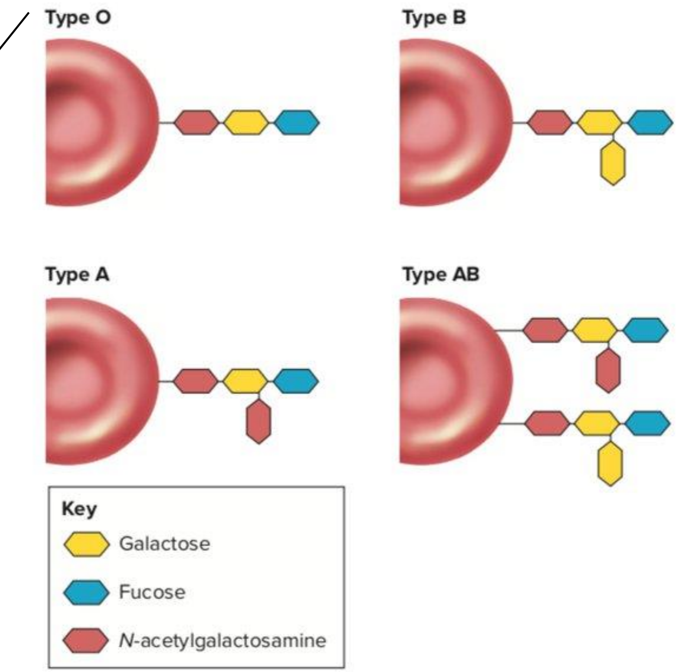
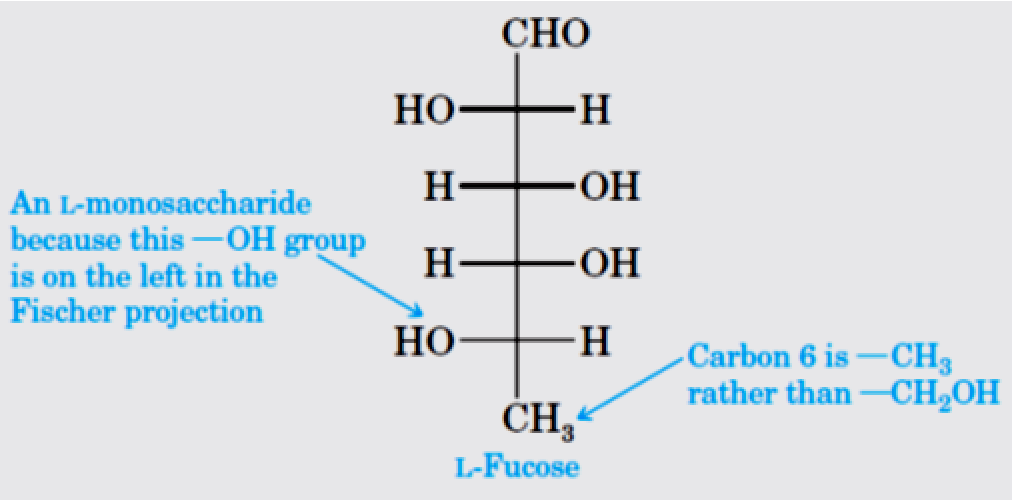


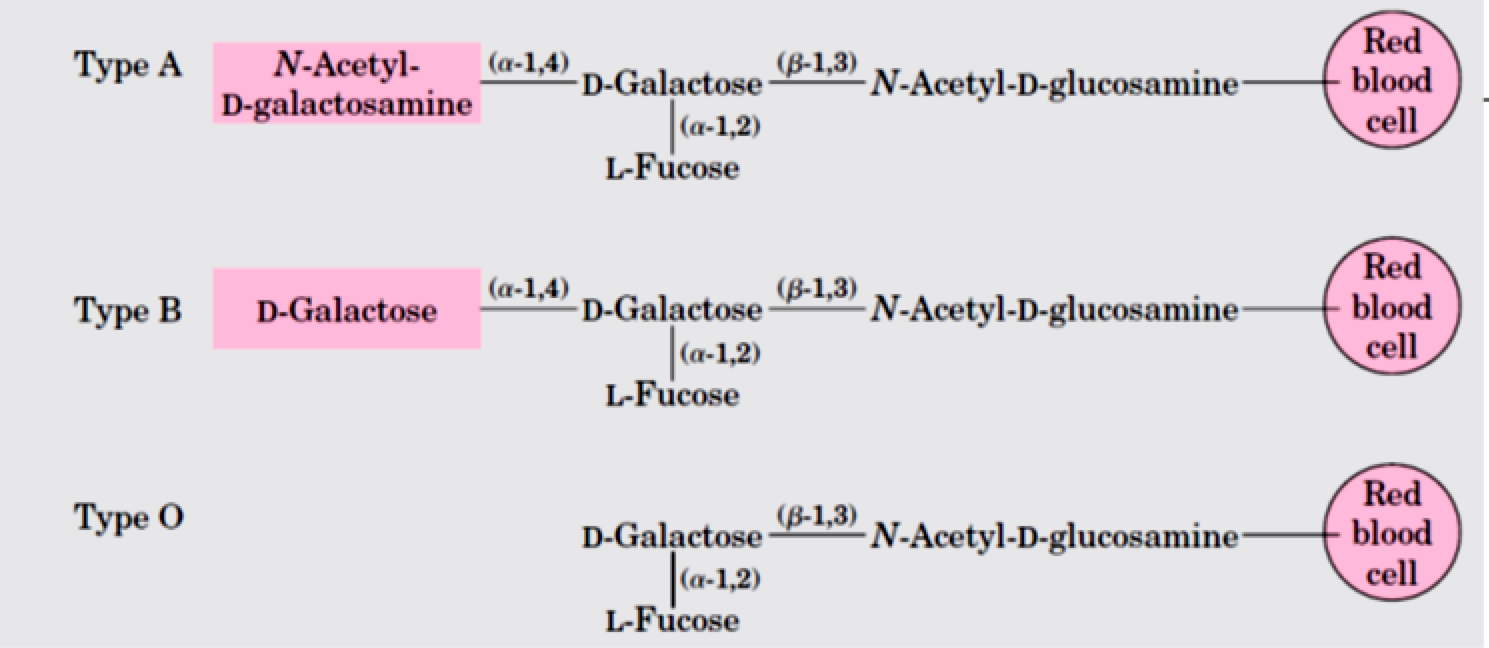
FIGURE 18.12 Chemical Basis of the ABO Blood Types. The terminal carbohydrates of the antigenic glycolipids are shown. All of them end with galactose and fucose (not to be confused with fructose). In type A, the galactose also has *N*-acetylgalactosamine added to it; in type B, it has another galactose; and in type AB, both of these chain types are present.

A, B, AB, and 0 blood types

- ✓ The outsides of most plasma cell membranes are literally “sugar-coated.” These membrane-bound carbohydrates are part of the mechanism by which cell types recognize one another and, in effect, act as biochemical markers.
- ✓ Typically, they contain from 4 to 17 monosaccharide units consisting primarily of relatively few monosaccharides (D-galactose, D-mannose, L-fucose, N-acetyl-D-glucosamine, and N-acetyl-D-galactosamine).
- ✓ Whether an individual belongs to blood type A, B, AB, or O is genetically determined and depends on the type of saccharide bound to the surface of the red blood cells.

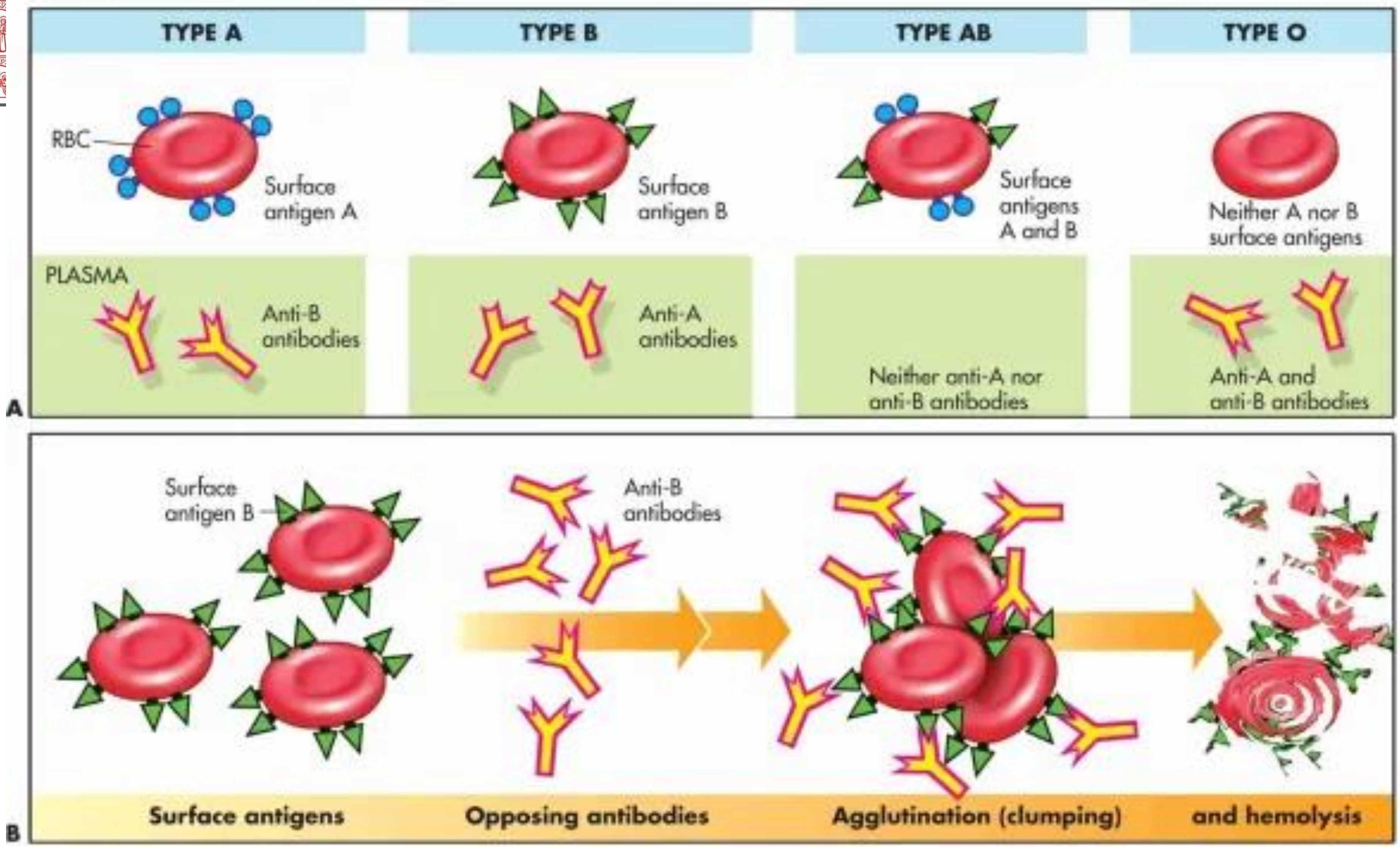


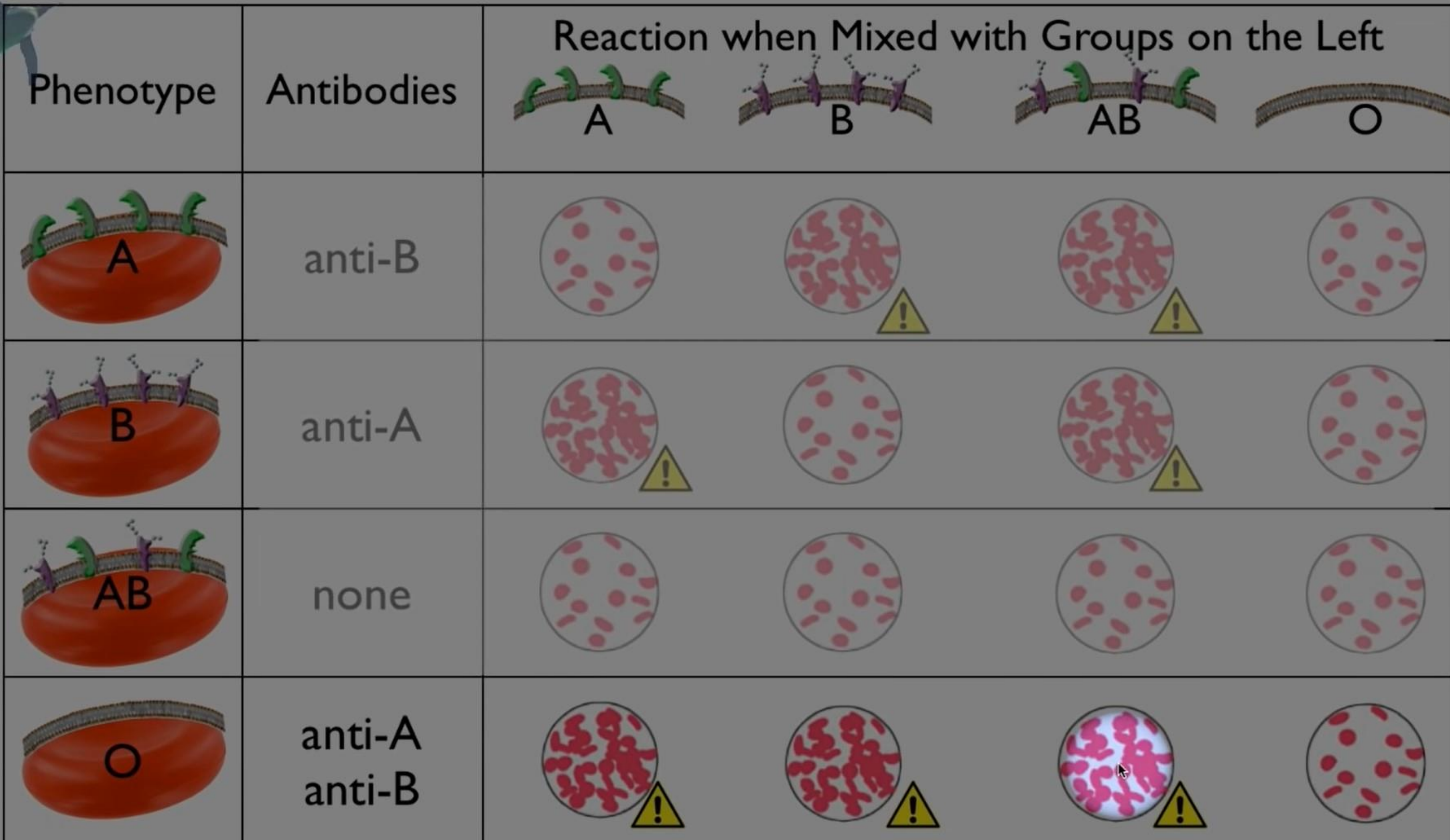
A, B, AB, and 0 blood types

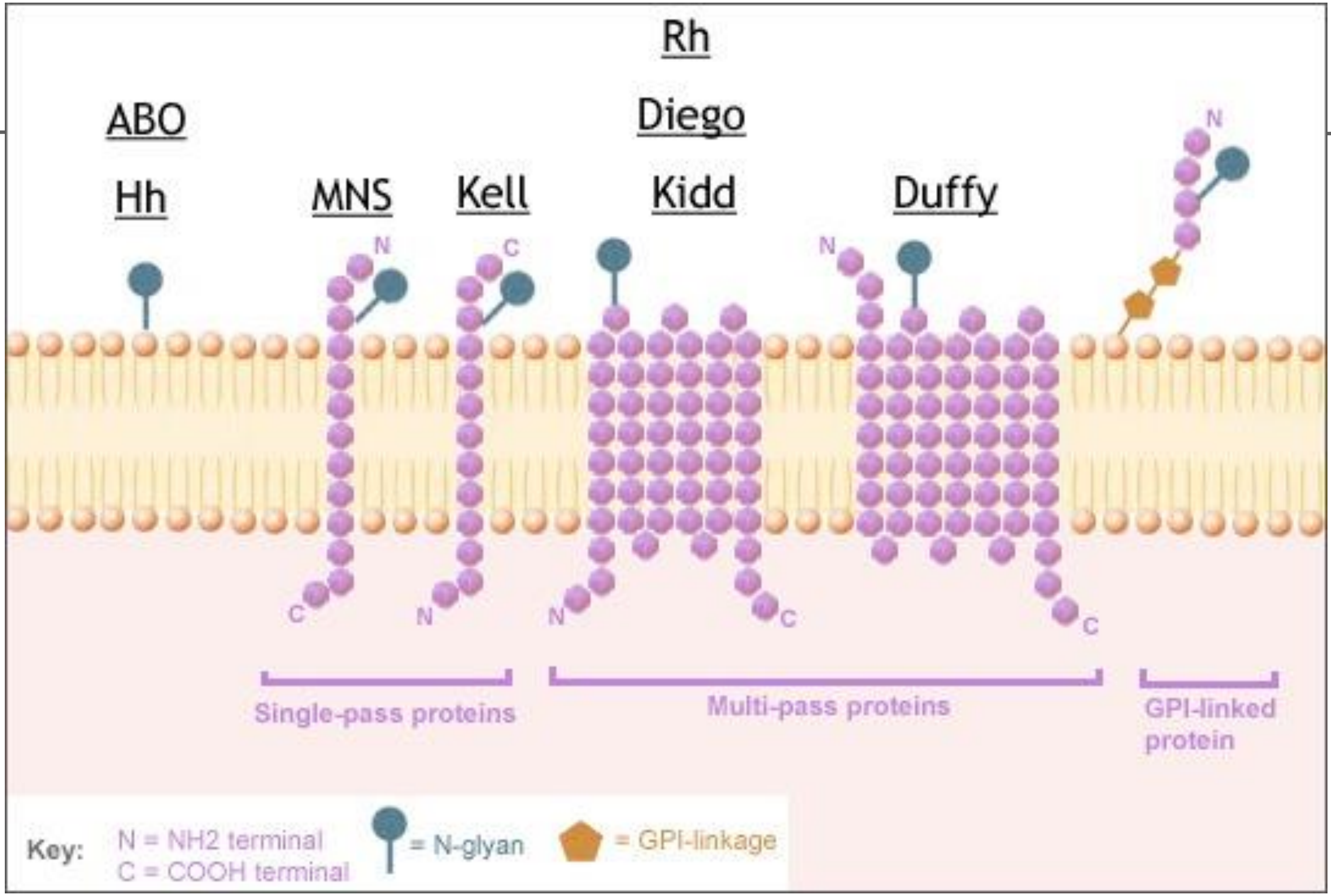


The blood carries antibodies against foreign substances. When a person receives a blood transfusion, the antibodies clump together (aggregate) the foreign blood cells.

- ✓ Type A blood has A antigens (N-acetyl-D- galactosamine) on the surfaces of its red blood cells and carries anti-B antibodies (against B antigen).
- ✓ B-type blood carries B antigen (D-galactose) and has anti-A antibodies (against A antigens).
- ✓ Transfusion of type A blood into a person with type B blood can be fatal, and vice versa.


TYPE A
TYPE B
TYPE AB
TYPE O
RBC
Surface antigen A
Surface antigen B
Surface antigens A and B
Neither A nor B surface antigens
PLASMA
Anti-B antibodies
Anti-A antibodies
Neither anti-A nor anti-B antibodies
Anti-A and anti-B antibodies
A
Surface antigen B
Anti-B antibodies
Surface antigens
Opposing antibodies
Agglutination (clumping)
and hemolysis
B


Phenotype
Antibodies
Reaction when Mixed with Groups on the Left
A
B
AB
O
A
anti-B
B
anti-A
AB
none
O
anti-A
anti-B



https://www.ncbi.nlm.nih.gov/books/NBK2264/

TO REMEMBER

OPEN CHAINS AND CYCLIC STRUCTURES OF:

- Glyceraldheyde (just open chain)
- Glucose
- Fructose
- Ribose
- Deoxyribose
- Galactose
- Mannose
- Sucrose
- Lactose
- Maltose

L- fucose
Beta D- Glucuronate
Beta D- Galactosamine
Beta-D- glucose 6 phosphate