جامعـــة الـزيـتـونـــــة الأردنيـــة
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Biochemistry for Nursing

0201163

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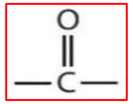
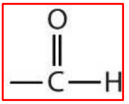
Subjects for part 3

- **Carbohydrates**
- **Lipids**
- **Digestion and Absorption of Dietary Macromolecules**
    - CHO Digestion and Absorption
    - Fat Digestion and Absorption
    - Protein Digestion and absorption

Carbohydrates

Carbohydrates (CHO) are organic compounds with a general formula: $(CH_2O)n$ (Carbon hydrates).

They are Polyhydroxy aldehydes or ketons, i.e., they have 3 characteristic functional groups:

hydroxyl group -OH , ketone group  $-\overset{O}{\overset{\|}{C}}-$, aldehyde group  $-\overset{O}{\overset{\|}{C}}-H$

Carbohydrates include sugars and the polymers of sugars

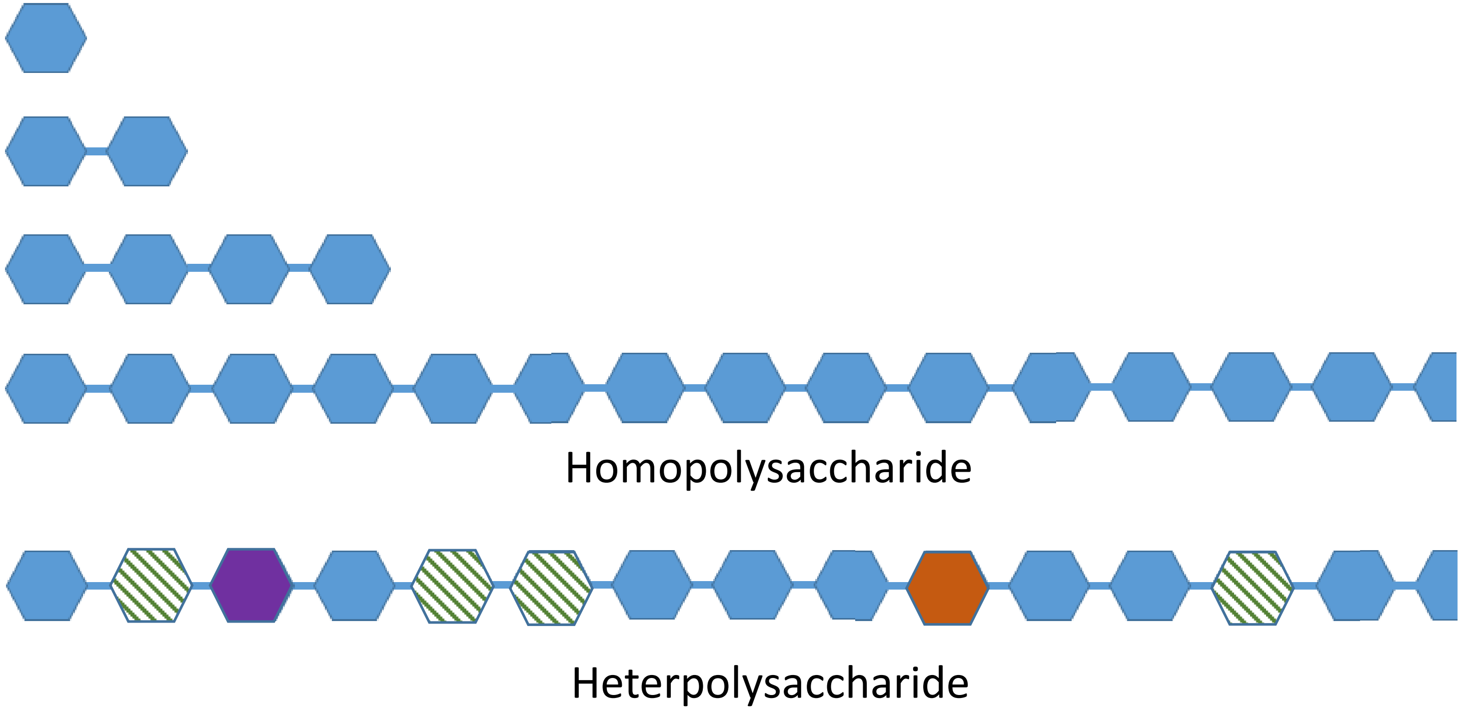
Functions:

- **Energy**: CHO are the primary source of E for the human body (a clean source as well).
- **Storage**: e.g. Starch in plants, glycogen in animals.
- **Structural**: e.g. cellulose in plant cell walls.

Classification of CHO

CHO are classified according to the **number of sugar molecules** bound together into:

a) Monosaccharides: 1 molc.
b) Disaccharides: 2 molc.
c) Oligosaccharides: 3 – 10 molc.
d) Polysaccharides: > 10 molc.



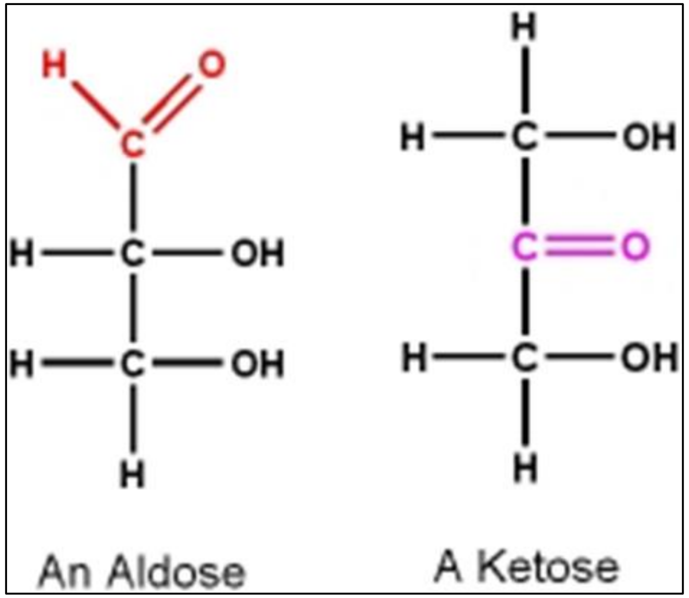
Monosaccharides

Monosaccharides are the simple sugars. Essentially they are the **building block for all complex carbohydrates** weather it by disaccharides or polysaccharides.

Monosacchrides can be **classified by the number of C atoms**:
diose (2C) triose (3C) tetrose (4C), pentose (5C), hexose (6C), heptose (7C)

Monosacchrides can be **classified based on the carbonyl group attached:**
Aldose: sugars contain an adehyde group
Ketose: sugars contain a ketone group

The carbon this group is attached to is called the anomeric carbon.

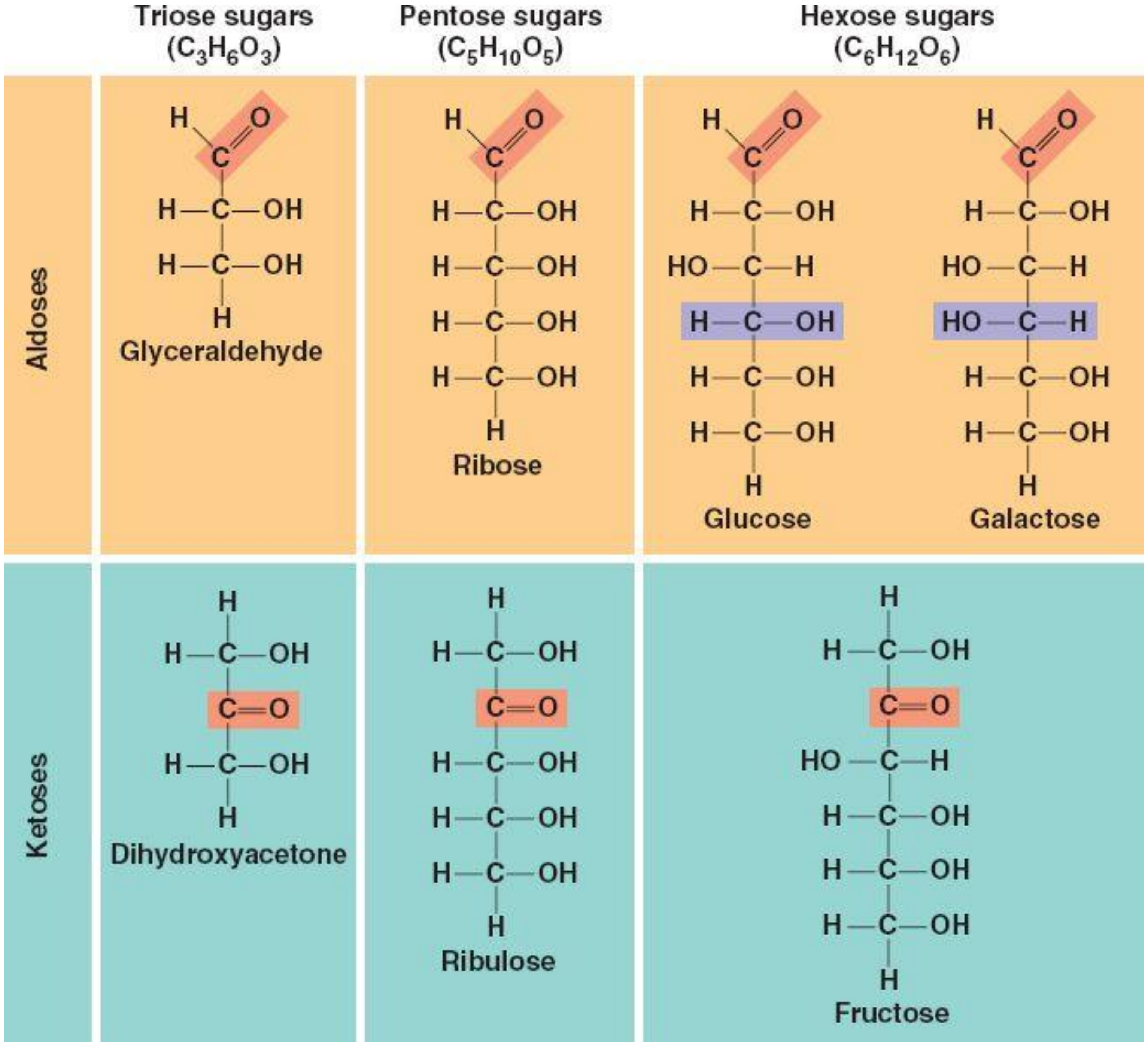


triose (3C)

Important monosaccharides

(All are isomers, have the same chemical formula: $C_6H_{12}O_6$) hexoses:

- Glucose
- Fructose
- Galactose
- Mannose



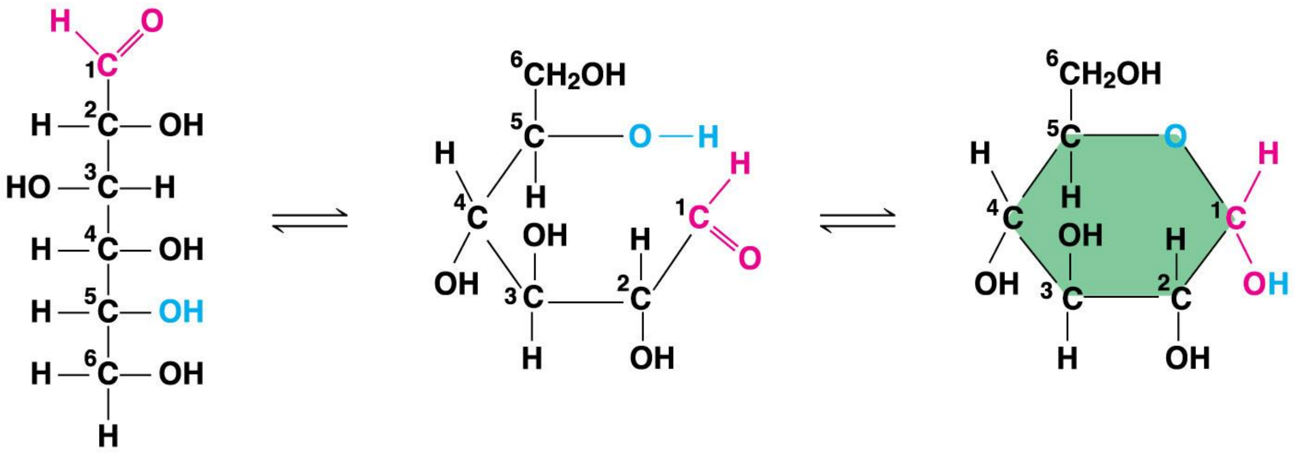
Cyclization of sugars

Monosaccharides are present in two forms:

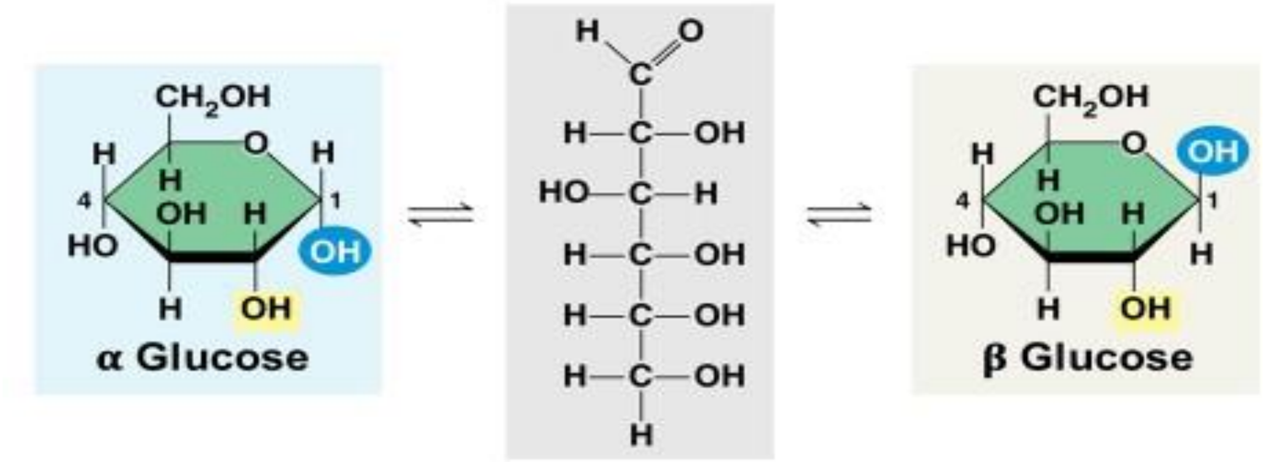
- Cyclic (ring) form.
- Acyclic (linear, open-chain) form.

The predominant form of sugar in **aqueous solution** is the **cyclic** form (>99%).

Sugar cyclization results in two different configurations of sugar **(α- and β-).**



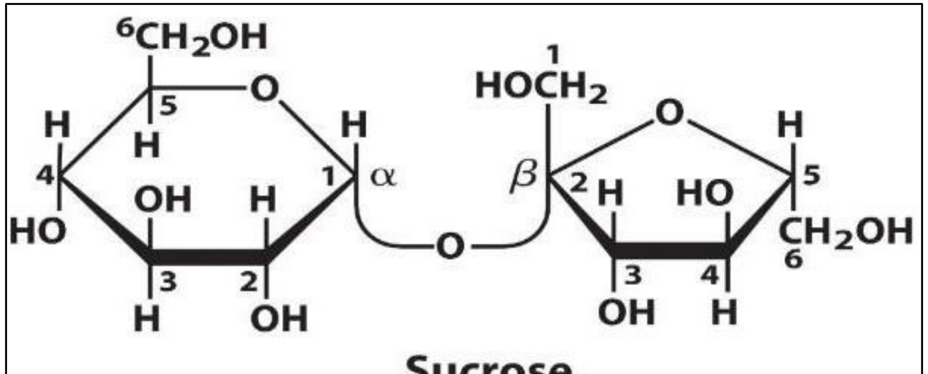
Linear and ring forms



α and β glucose ring structures

Disaccharides

A disaccharide is formed when two monosaccharides are joined together by a dehydration reaction connecting the two molecules by a covalent bond called **"the glycosidic linkage".**



Sucrose

α-D-glucopyranosyl β-D-fructofuranoside

Glc(α1↔2β)Fru

The Glycosidic linkage:

The type of the glycosidic bond depends on:

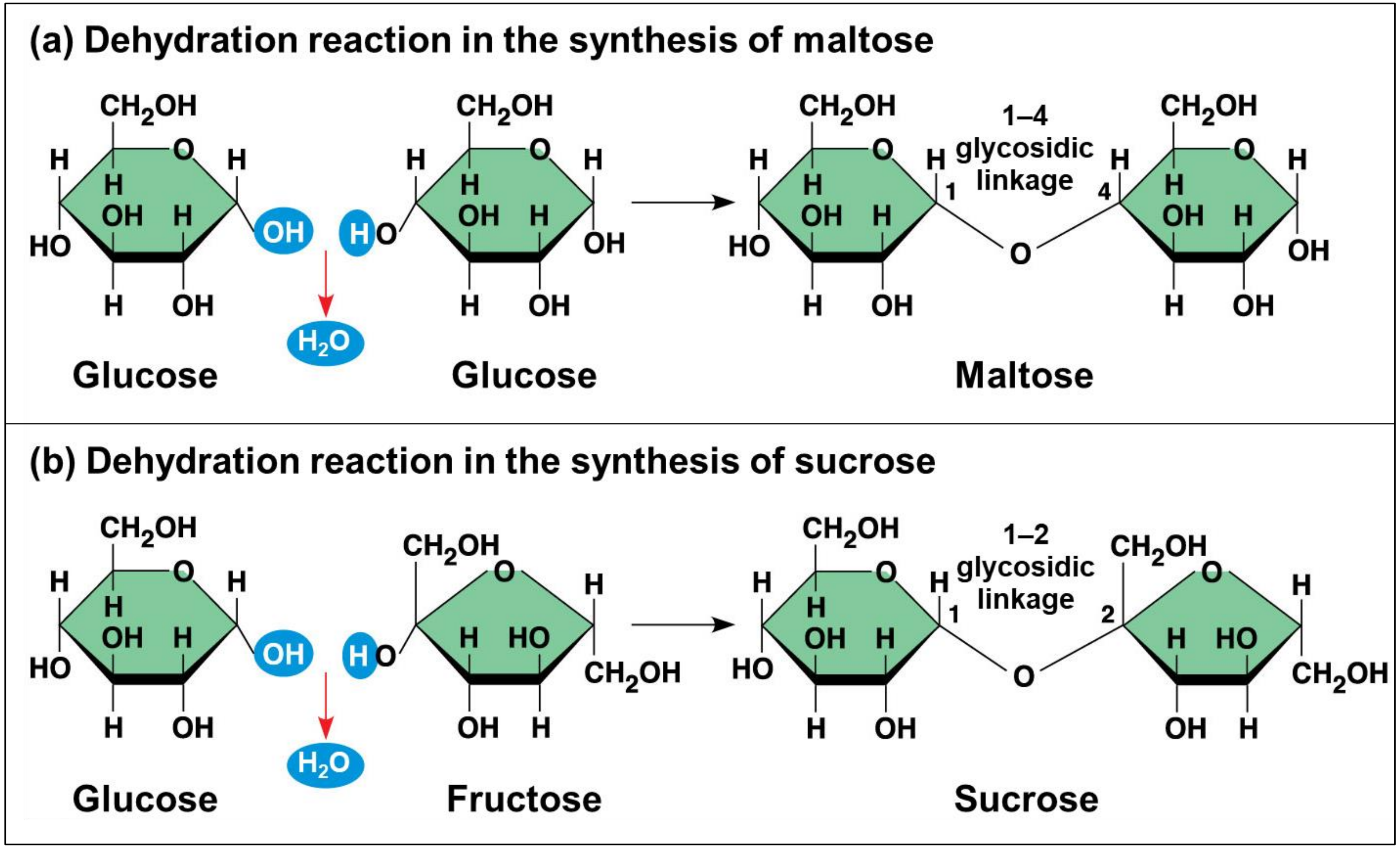
1. Sugar configuration (α- and β-).
2. Number of C atoms involved in the linkage.
   e.g. Glycogen has α 1-4, and α 1-6 linkages.

- O-glycosidic bond: when the sugar is bound to –OH.
- N- glycosidic bond: when the sugar is bound to –NH2.

in <u>di- and poly-saccharides</u>, the glycosidic linkage is of <u>O-type.</u>

Important Disaccharides

- **Sucrose (table sugar):** **$\alpha(1\rightarrow2)$**
  glucose + fructose:
- **Lactose (milk sugar):** **$\beta(1\rightarrow4)$**
  glucose + galactose:
- **Maltose (malt sugar):** **$\alpha(1\rightarrow4)$**
  glucose + glucose:

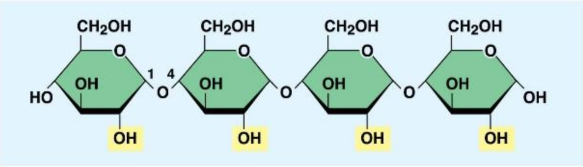


Polysaccharides

Polysaccharides are polymers of sugars. The type of a polysaccharide is determined by its sugar monomers and the positions of its glycosidic linkages.

Important Polysaccharides (all are glucose polysaccharides):

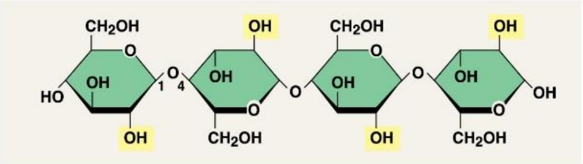
1. Starch: storage form of CHO in plants, especially starchy vegetables s.a. potato, sugar beet, carrots…
Composed of two types of polymers:
<u>Amylose</u>: linear α(1→4).
<u>Amylopectin</u>: branched, α(1→4) in the linear chains, α(1→6) at the branching points.

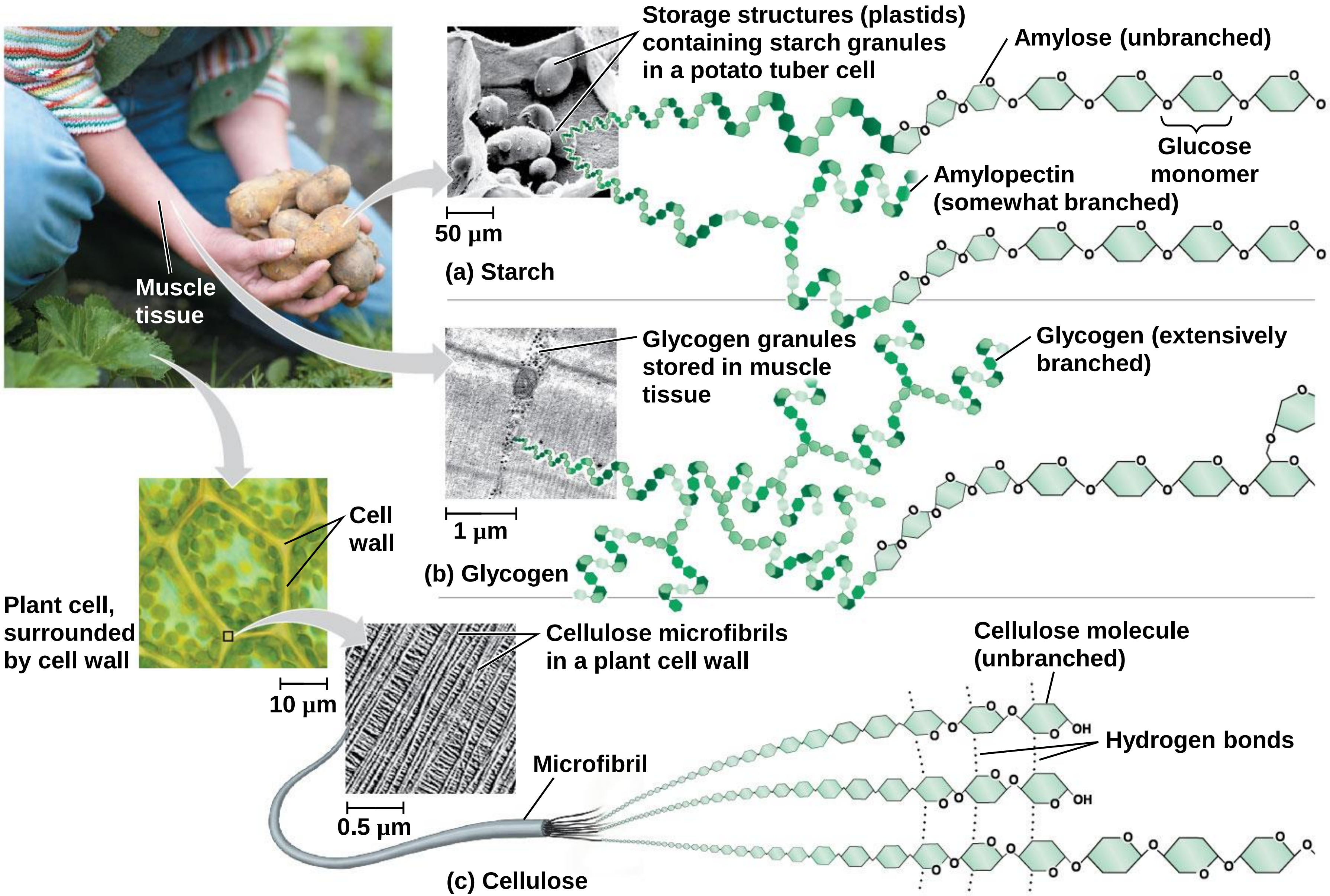


2. Glycogen: more branched than amylopectin, the same glycosidic linkages: α(1→4) in the linear chains, α(1→6) at the branching points. Storage form of CHO in animals. In humans: in liver and muscles.

3. Dextrins: a mixture of partially hydrolyzed amylopectin fragments.

4. Cellulose β(1→4): main component in plant cell walls. Linear but differs from amylose in that it is composed of "strands of fibers" →rigidity.
Non-digestable by humans because human lack β-amylaes → dietary fibers.

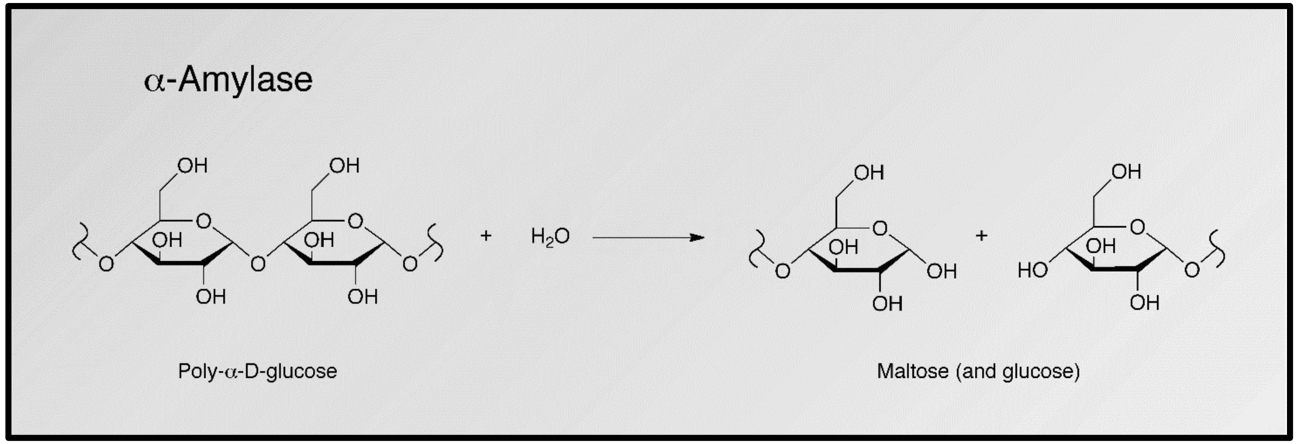




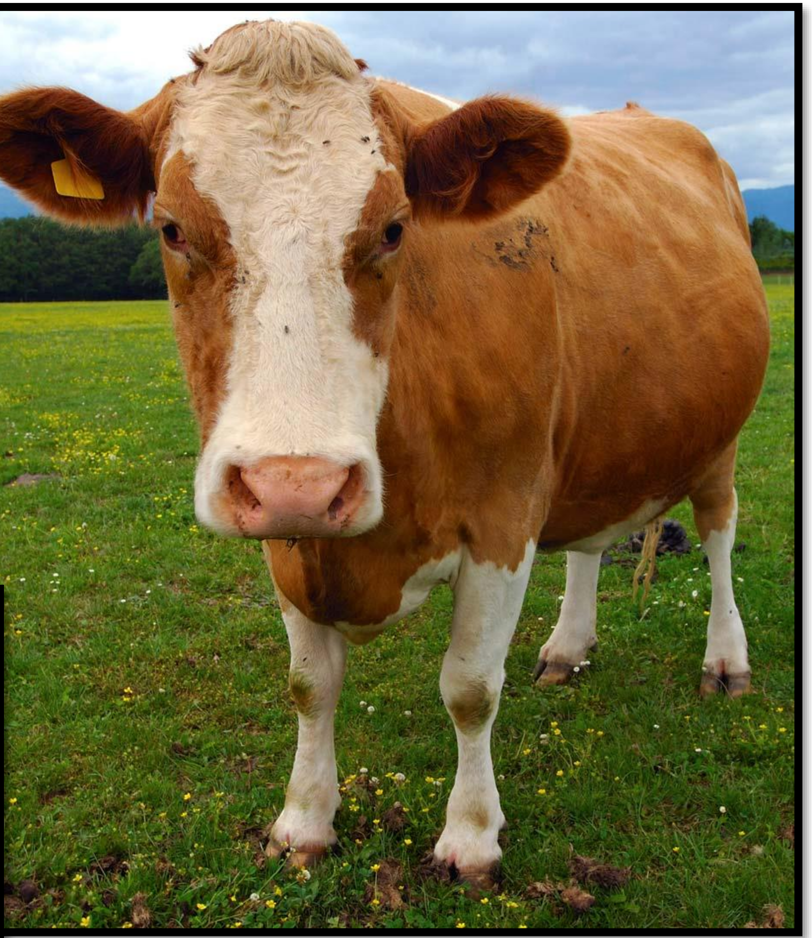
In starch and glycogen, the polymer chains tend to form helices in unbranched regions because of the angle of the linkages between glucose molecules

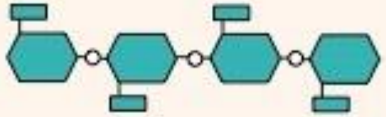
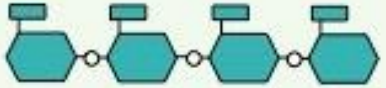
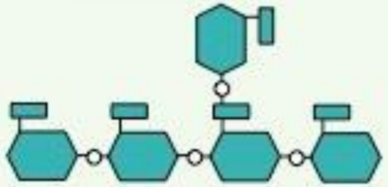
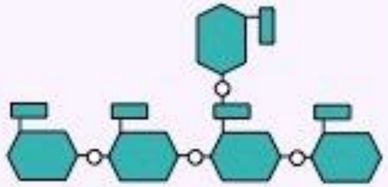
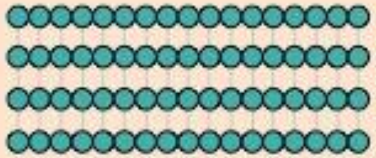
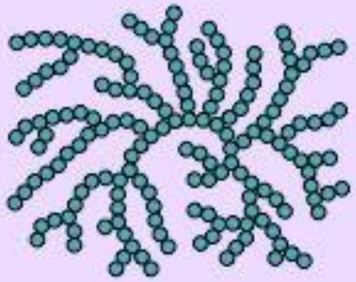
Cellulose, with a different kind of glucose linkage, is always unbranched

Enzymes that digest starch by hydrolyzing α linkages cannot hydrolyze β linkages in cellulose. The human body has the enzymes that can digest α- but NOT β- glycosidic linkage, that's why the cellulose in human food passes through the digestive tract as "*insoluble fiber*". Some microbes have the enzymes that can digest cellulose.

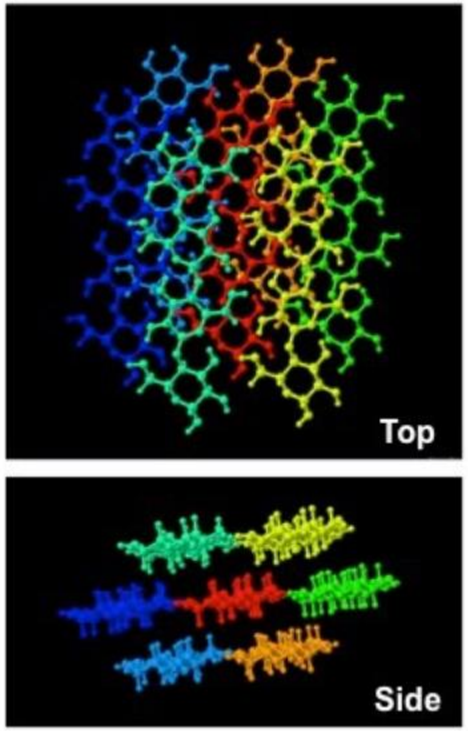


Many herbivores, from cows to termites, have symbiotic relationships with these microbes



	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				

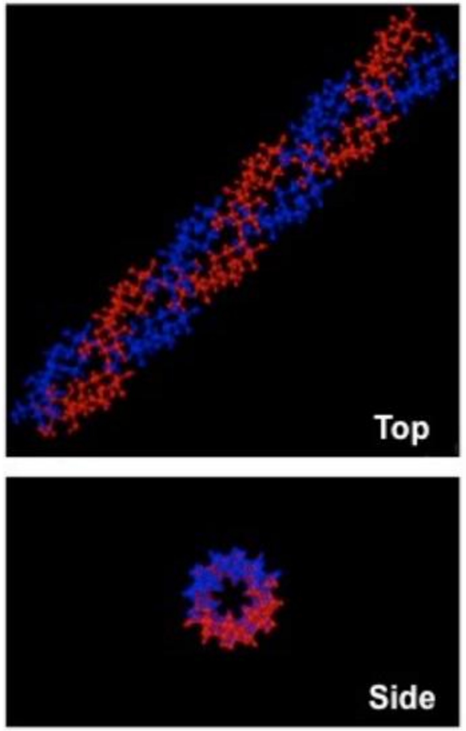
Molecular Images of Glucose Polymers



Cellulose

Linear chains (β-glucose)

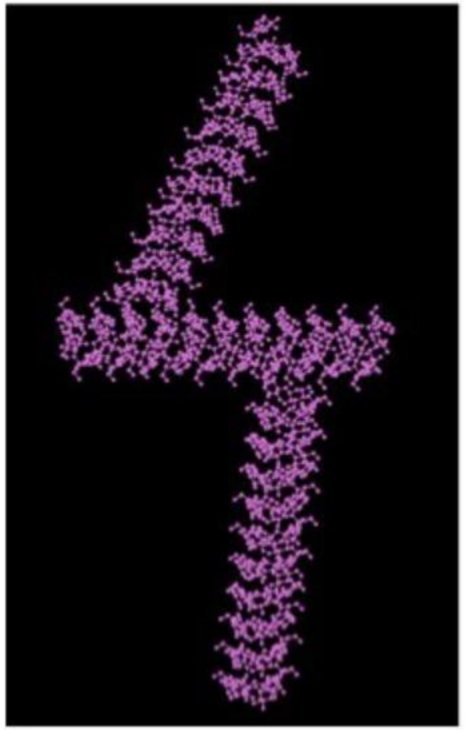
Cell wall structure (plants)



Amylose

Helical chains (α-glucose)

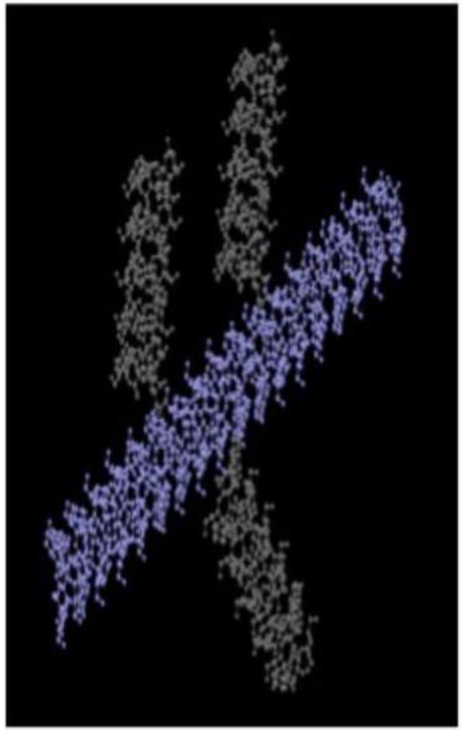
Energy storage (plants)



Amylopectin

Branched chains (α-glucose)

Energy storage (plants)

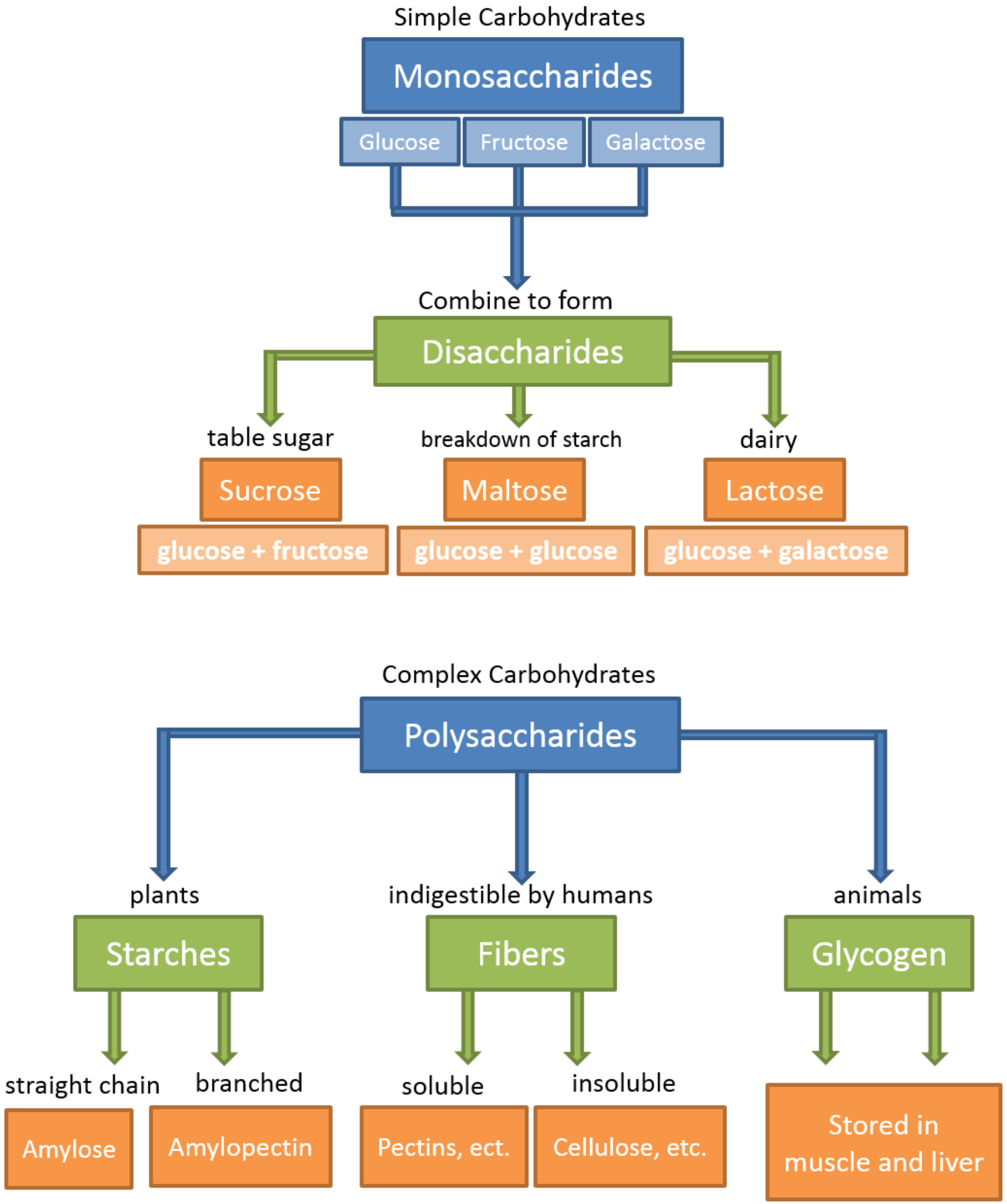


Glycogen

Branched chains (α-glucose)

Energy storage (animals)

Summary



Simple Carbohydrates

Monosaccharides

Glucose

Fructose

Galactose

Combine to form

Disaccharides

table sugar

Sucrose

glucose + fructose

breakdown of starch

Maltose

glucose + glucose

dairy

Lactose

glucose + galactose

Complex Carbohydrates

Polysaccharides

plants

Starches

straight chain

Amylose

branched

Amylopectin

indigestible by humans

Fibers

soluble

Pectins, ect.

insoluble

Cellulose, etc.

animals

Glycogen

Stored in muscle and liver

LIPIDS

Lipids are a diverse group of **hydrophobic** molecules

Lipids are the one class of large biological molecules that does **not include true polymers**

The unifying feature of lipids is that they are "**hydrophobic**", i.e., they mix poorly, if at all, with water

Lipids are hydrophobic because they consist mostly of hydrocarbons, which form nonpolar covalent bonds

The most biologically important lipids are **fats, phospholipids, and steroids**

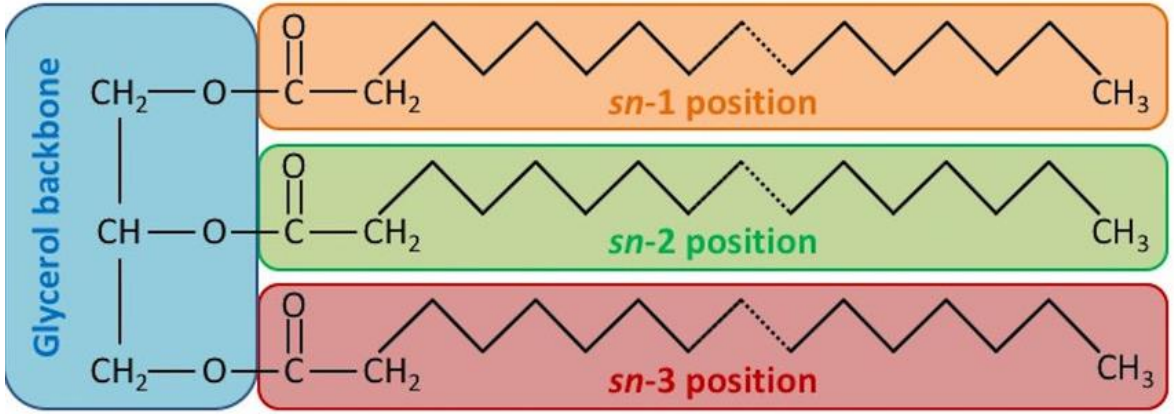
Fats

Fats (triacylglycerols) are formed by binding of one glycerol molecule to three molecules of fatty acids by an "ester bond".

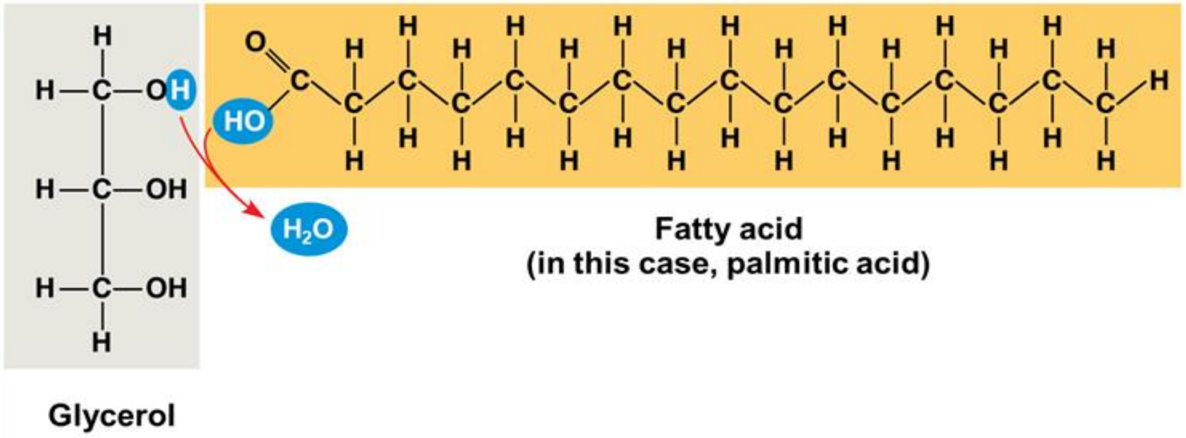
Thus their chemical name is "triacylglycerols", and the process/ reaction that binds glycerol to the 3 fatty acids is called "esterification“.

The fatty acids in a fat can be all the same or of two or three different kinds.

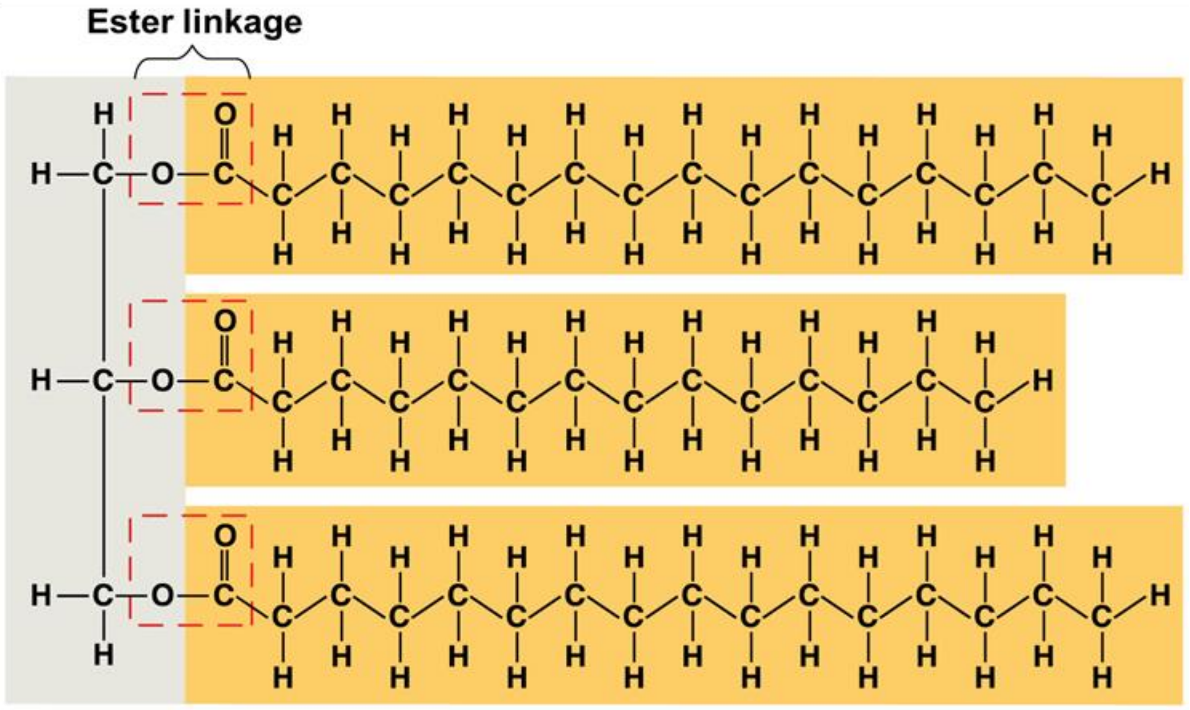
Glycerol is a three-carbon alcohol with a hydroxyl group attached to each carbon



A **fatty acid** consists of a carboxyl group attached to a long carbon skeleton



(a) One of three dehydration reactions in the synthesis of a fat



(b) Fat molecule (triacylglycerol)

Ester linkage Is a bond formed by a **dehydration** reaction between a hydroxyl group and a carboxyl group

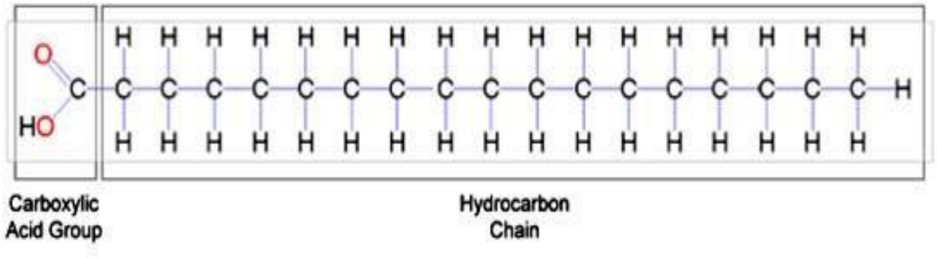
The resulting fat, also called a **triacylglycerol or triglyceride**, thus consists of three fatty acids linked to one glycerol molecule.

The fatty acids in a fat can be all the same or of two or three different kinds

Fatty acids vary in length (number of carbons) and in the number and locations of double bonds

Fatty acids

Composed of a hydrocaron tail and a carboxylic group



Fatty Acids Classification

Length of the hydrocarbon tail

1. Short chian F.As: < 6 carbons.
2. Medium chain F.As: 6-12 carbons.
3. Long chian F.As: >12 carbons.

Saturation

1. Saturated F.As: hydrocarbon tail with no double bond
2. Unsaturated F.As: some C atoms in the hydrocarbon tail are linked together by double bonds

Location of the double bond

ω- designation for unsaturated fatty acids:

Nutrition

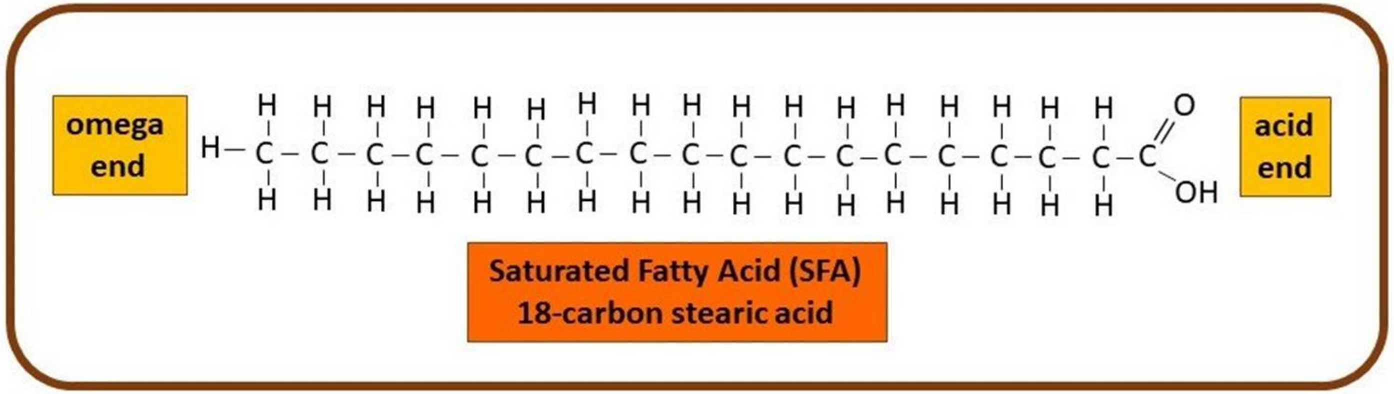
1. Essential FA (not synthesized in body)
2. Non- essential FA
3. Semi-essential FA

F.As Saturation:

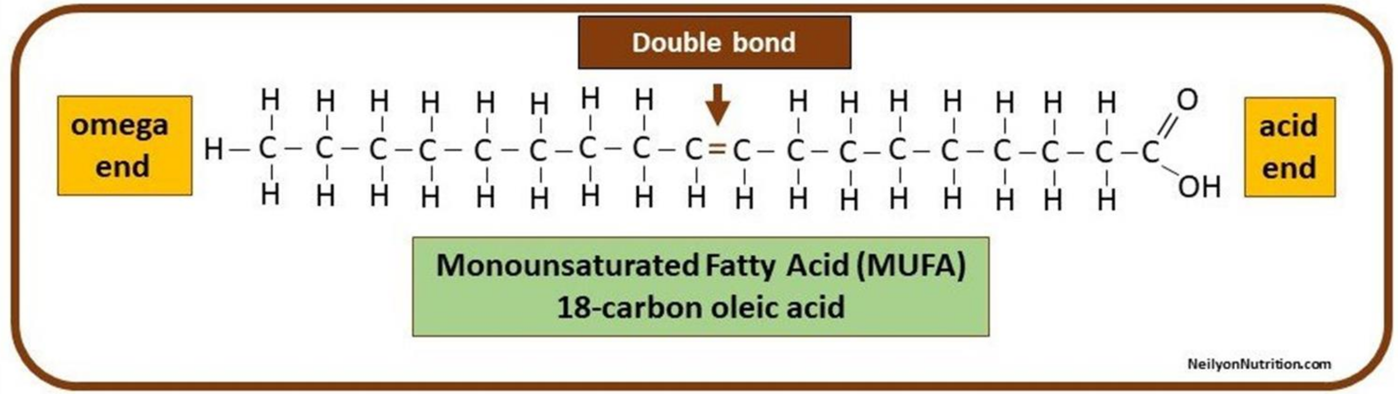
1) Saturated F.As: all carbon atoms in the hydrocarbon tail are linked together by single bonds and to the maximum no. of H atoms.
2) Unsaturated F.As: some C atoms in the hydrocarbon tail are linked together by double bonds and to the less than the maximum no. of H atoms:
    - MUFA: Mono-unsaturated F.As (1 double bond).
    - PUFA: Poly-unsaturated F.As (>1 double bond).

Location of the double bond:

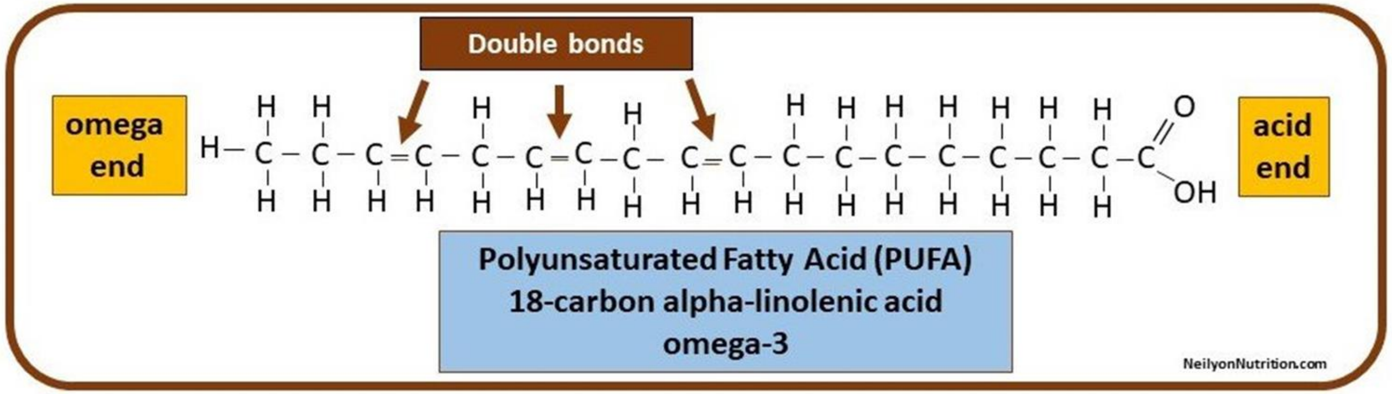
Unsaturated fatty acids are assigned using the ω- designation according to the number of the first double bond starting counting form the methyl end. Most importantly are ω-3, ω-6, ω-9 F.As.



Saturated Fatty Acid (SFA)
18-carbon stearic acid

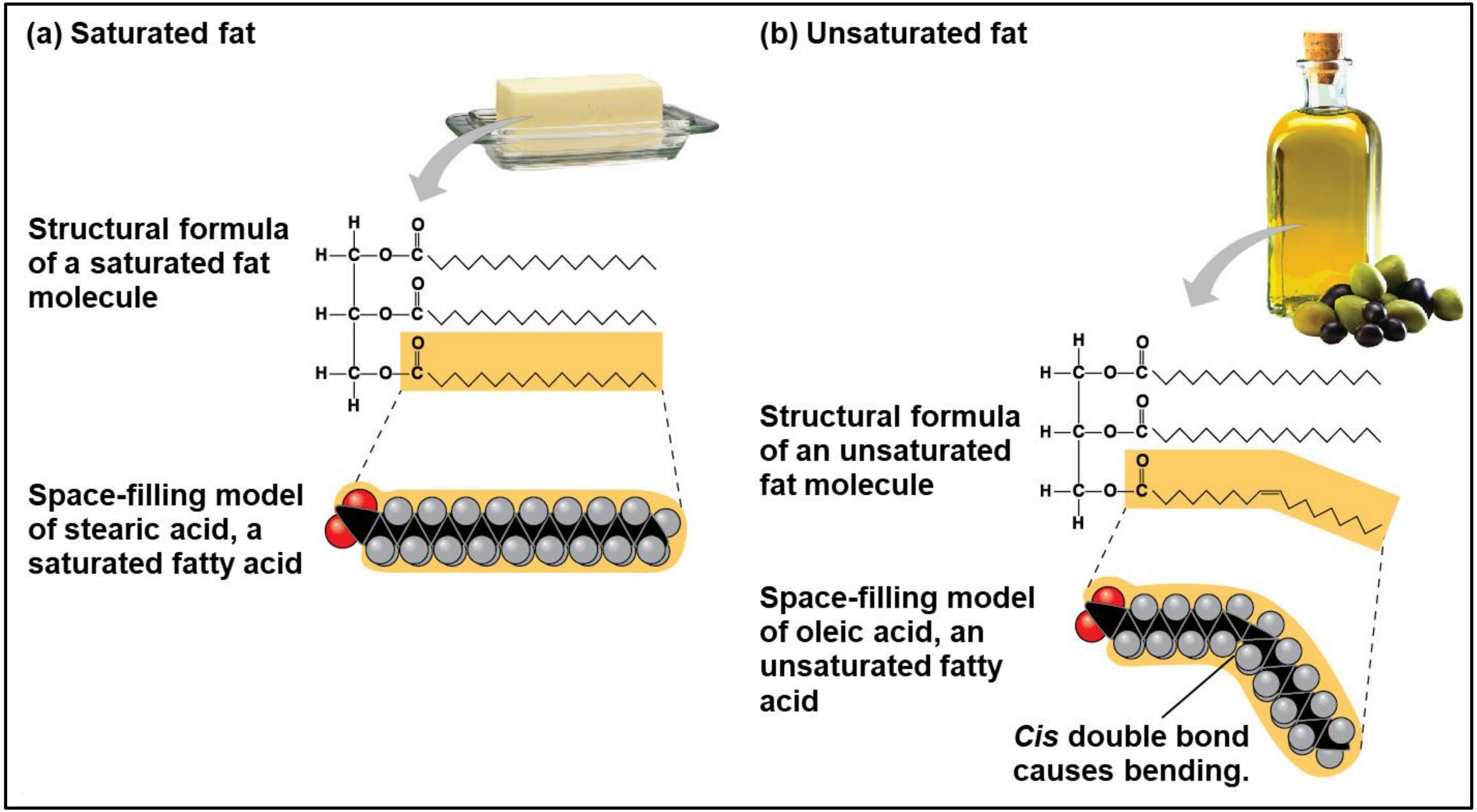


Monounsaturated Fatty Acid (MUFA)
18-carbon oleic acid



Polyunsaturated Fatty Acid (PUFA)
18-carbon alpha-linolenic acid
omega-3

Fats made from saturated fatty acids are called saturated fats and are solid at room temperature. Most animal fats are saturated. Fats made from unsaturated fatty acids are called unsaturated fats or oils and are liquid at room temperature. Plant fats and fish fats are usually unsaturated.



SFA are found in animal sources (butter, ghee, milk…) → **Examples of SFAs (*Memorize the highlighted*!)::**

Acetic acid (ethanoic acid)	2-C
Propionic acid	3-C
Butyric acid	4-C
Pentaoic acid	5-C
Hexanoic acid	6-C
Lauric acid	12-C
Myristic acid	14-C
Palmitic acid	16-C
Stearic acid	18-C
Arachidic acid	20-C

MUFA are relatively abundantly found in olive oil.

Examples of MUFAs: Oleic acid (18:1), ω-9.

PUFA are found in plant oils (corn oil, sunflower oil…).

Examples of PUFAs:

1) ω-6 F.As: Linoleic acid (LA), Arachidonic acid (AA).
2) ω-3 F.As: α- Linolenic acid (ALA), Eicosapentanoic acid (EPA), Docosahexanoic acid (DHA).

Physiologically important F.As:

1. Linoleic acid (LA): 18:2, ω-6.
2. α-Linolenic acid (ALA): 18:3, ω-3.
3. Arachidonic acids (AA): 20:4, ω-6.
4. Eicosapentanoic acid (EPA): 20:5, ω-3.
5. Docosahexanoic acid (DHA): 22:6, ω-3.

Essential F.As

Essential fatty acids are those fatty acids that are not synthesized in the human body and must be supplied in the diet.

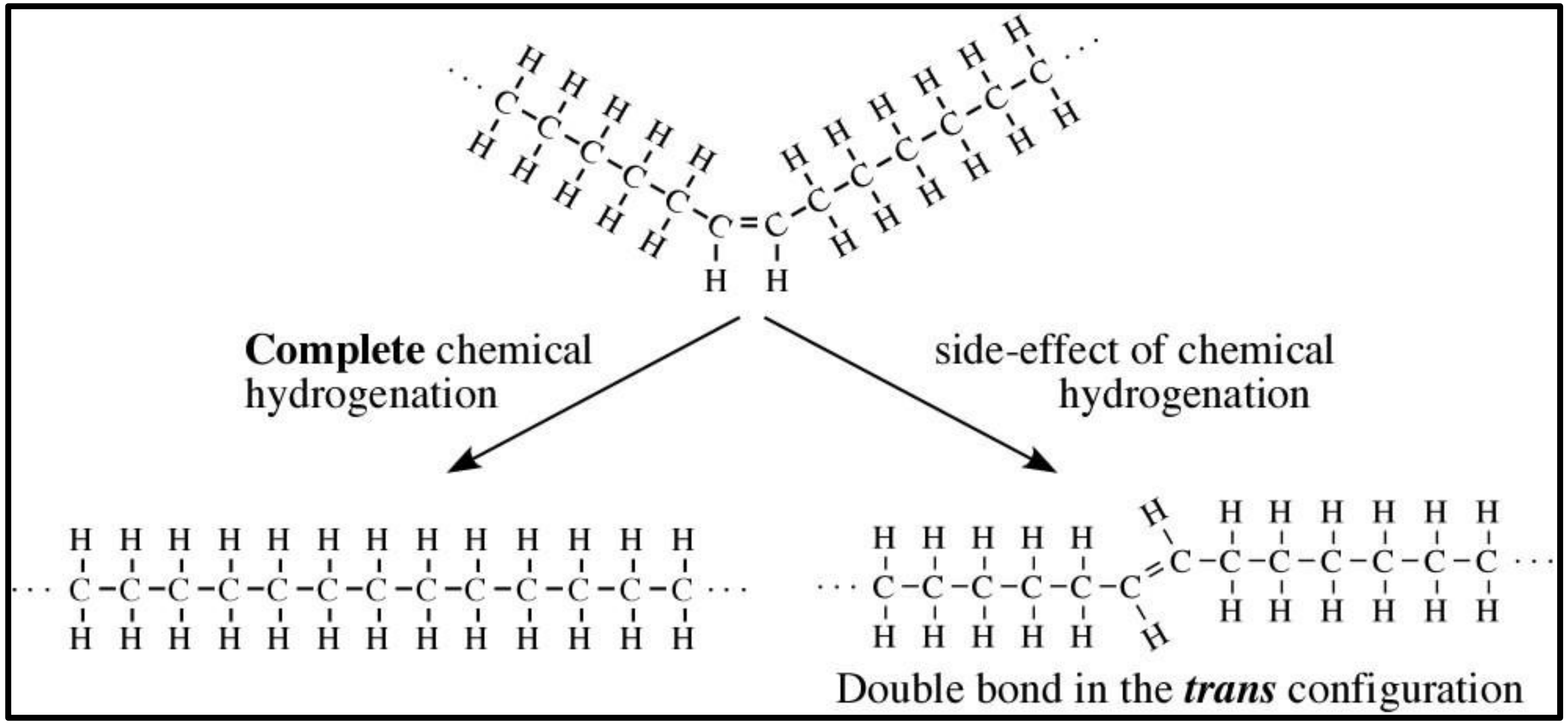
The essential fatty acids are: linoleic acid: 18:2, ω6 and α-linolenic acid (ALA): 18:3, ω3.

Hydrogenation

Hydrogenation is adding hydrogen (H) to USFA to convert them to SFA.

Hydrogenation of F.As results in converting their configuration from cis- to trans-. (*cis is the natural configuration of F.As*).

SFA and trans- F.As are correlated with hyperlipidemia, atherosclerosis and cancer.



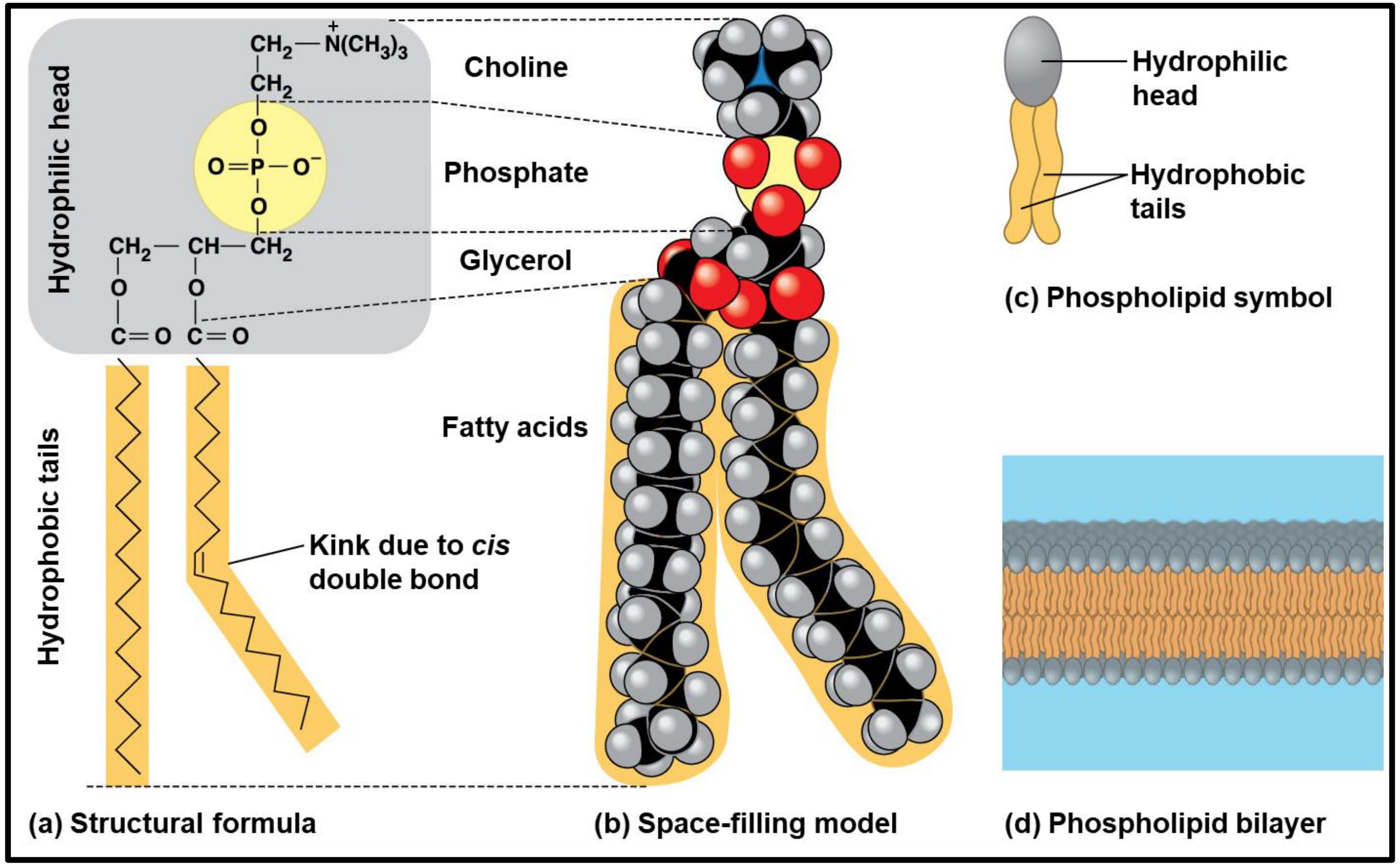
Hydrogenating vegetable oils also creates unsaturated fats with *trans* double bonds

Phospholipids

- **A phospholipid is formed by binding two fatty acids and a phosphate group to glycerol.**
- The two fatty acid tails are hydrophobic, but the phosphate group and its attachments form a hydrophilic head → **amphipathic** molecules (hydrophilic head and hydrophobic tail)

- Thus, when phospholipids are added to water, they **self-assemble** into double-layered structures called **bilayers.** Phospholipid bilayers compose the main structure of the cell membrane.

- At the surface of a cell, phospholipids are also arranged in a bilayer, with the hydrophobic tails pointing toward the interior. Cells die if their phospholipid bilayers are damaged.

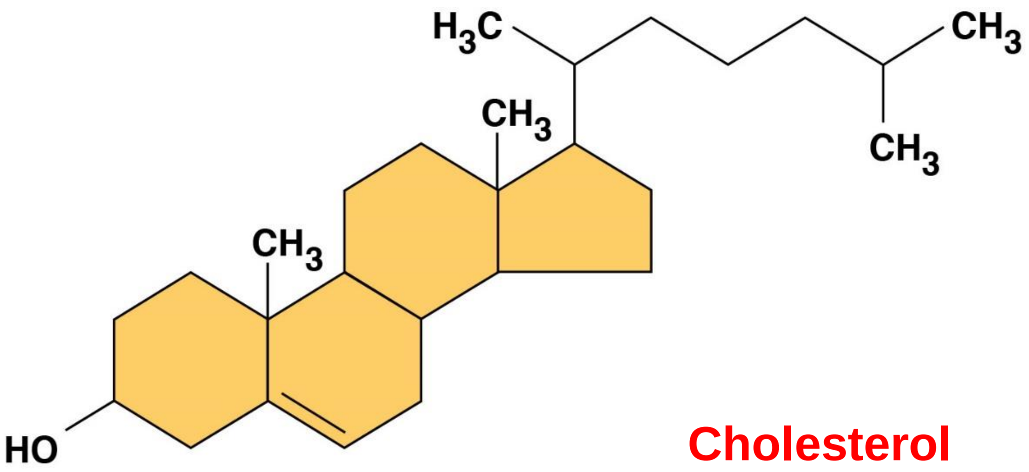


Steroids

- Steroids are lipids characterized by a carbon skeleton consisting of four fused rings.
- Cholesterol, steroidal sex hormones (e.g. testosterone and estrogen) and cortisol are examples of important and physiologically active steroids.

- **Cholesterol**, is a component in animal cell membranes and a precursor from which other steroids (sex hormones, bitamin D, bile acids…) are synthesized.

- **Hypercholesterolemia**, a high level of cholesterol in the blood, is a risk factor to cardiovascular diseases.



Cholesterol

Note the four fused rings characteristic to steroid

Digestion and Absorption of Dietary Macromolecules

Digestion: the breakdown of food into smaller and smaller components, until they can be absorbed and assimilated into the body.

Macromolecules → smaller molecules (monomers) by **HYDROLOSIS** reaction.

Absorption:

Intestinal lumen → mucosa → blood.

Digestion is achieved by mechanical and chemical processes. Mechanical processes include mastication, peristalsis.. whereas chemical processes are mainly enzymatic (bile, HCl, bicarbonate also contribute to chemical digestion).

Digestion is controlled by different *hormones* including secretin, cholecystokinin, and gastrin.

CHO Digestion and Absorption

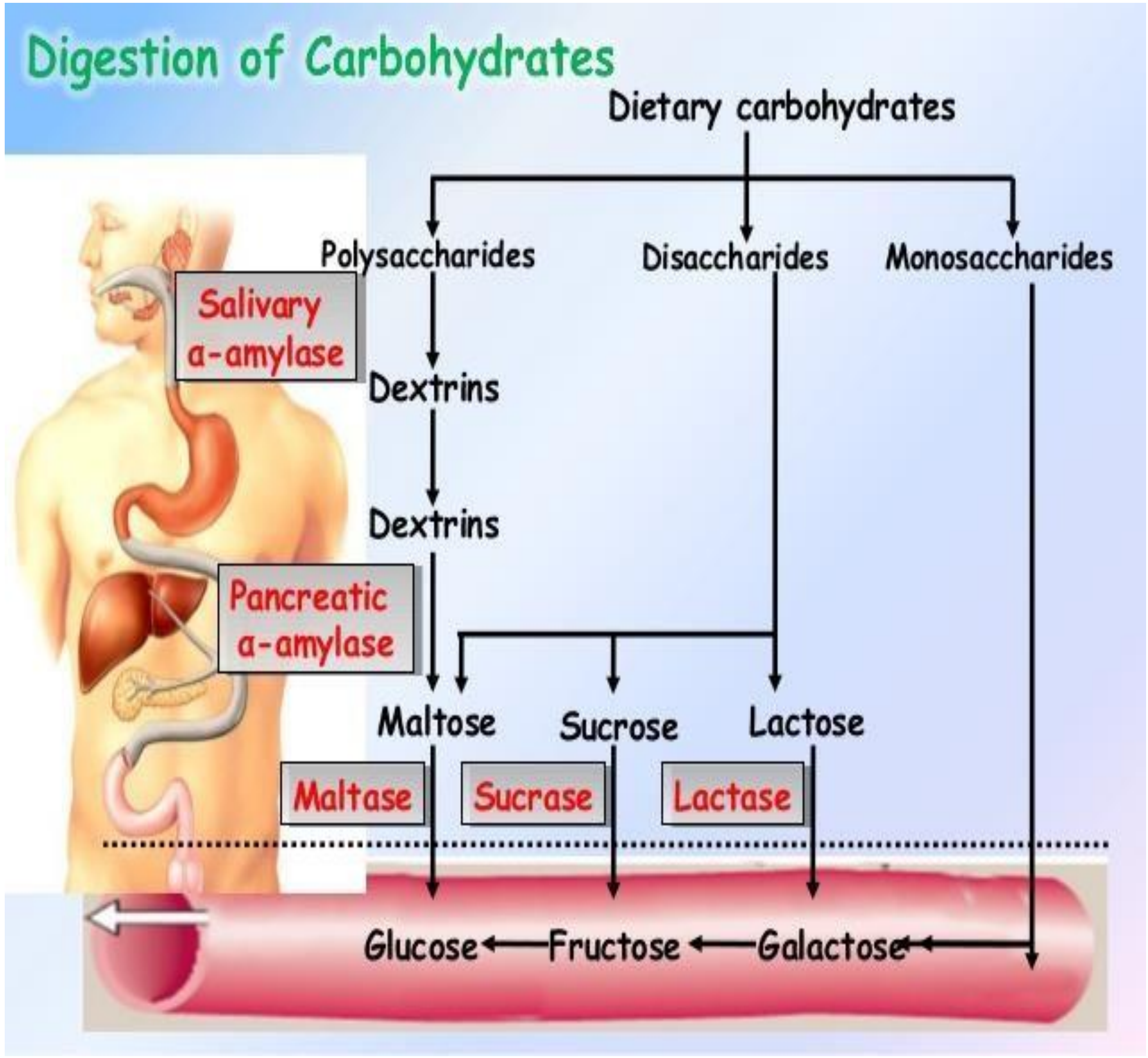
CHO Digestion (fig.4):

- **Mouth**: salivary α- amylase, breaks down α (1-4) glycosidic bonds.
- **Stomach**: CHO digestion is halted, due to high acidity.
- **Small intestine** (S.I):
  - Pancreatic secretions: bicarbonate: to neutralize pH in S.I + pancreatic α-amylase: breaks down α (1-4) glycosidic bonds.
  - Intestinal enzymes: isomaltase: breaks down α (1-6) bonds + disaccahridases (e.g. sucrase, lactase, maltase).

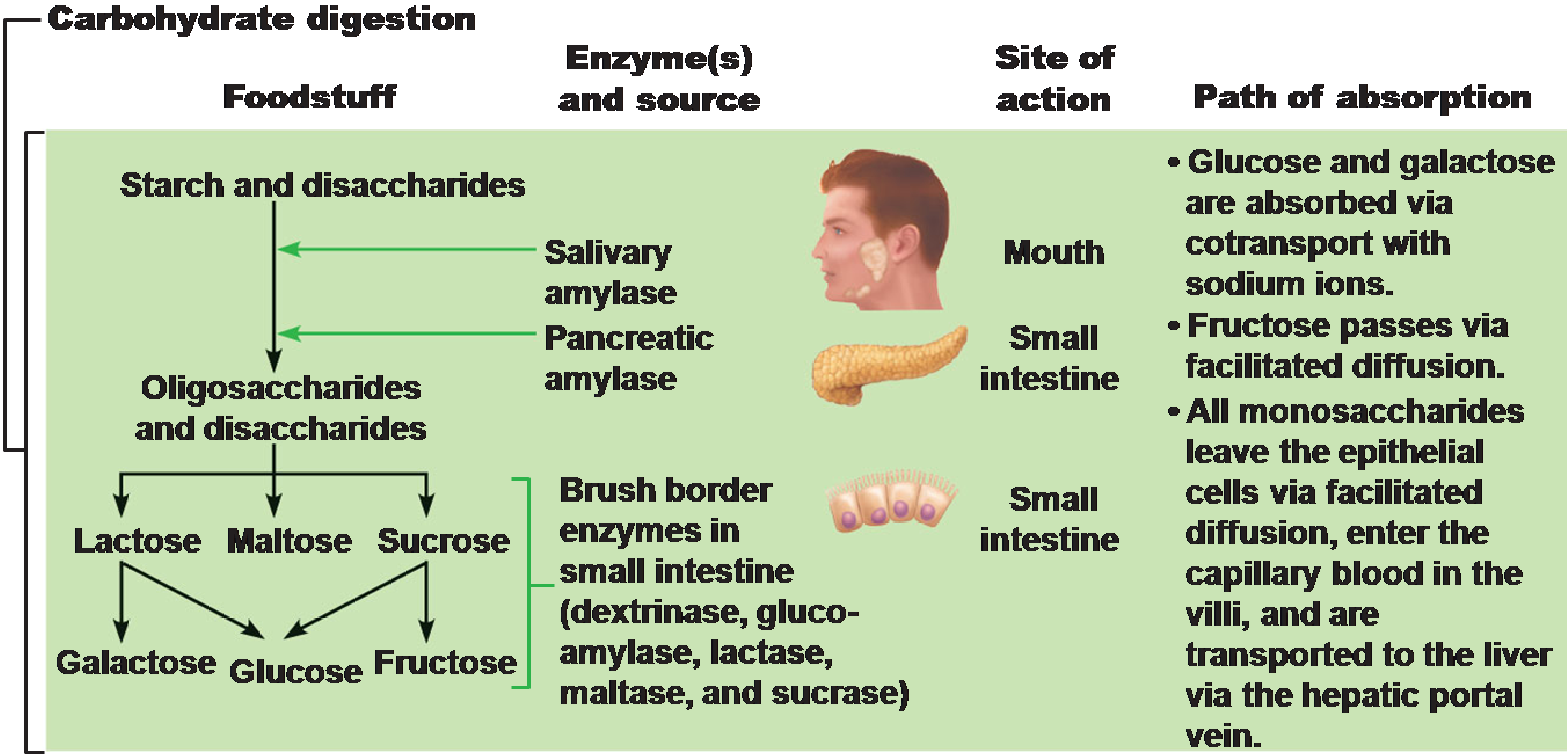
CHO Absorption:

All CHO → glucose + galactose + fructose.

Glucose, galactose, fructose are actively transported through "glucose transporters "**GLUT**"".



Carbohydrate digestion



Foodstuff

Enzyme(s) and source

Site of action

Path of absorption

Starch and disaccharides

Salivary amylase

Mouth

Pancreatic amylase

Small intestine

Oligosaccharides and disaccharides

Lactose Maltose Sucrose

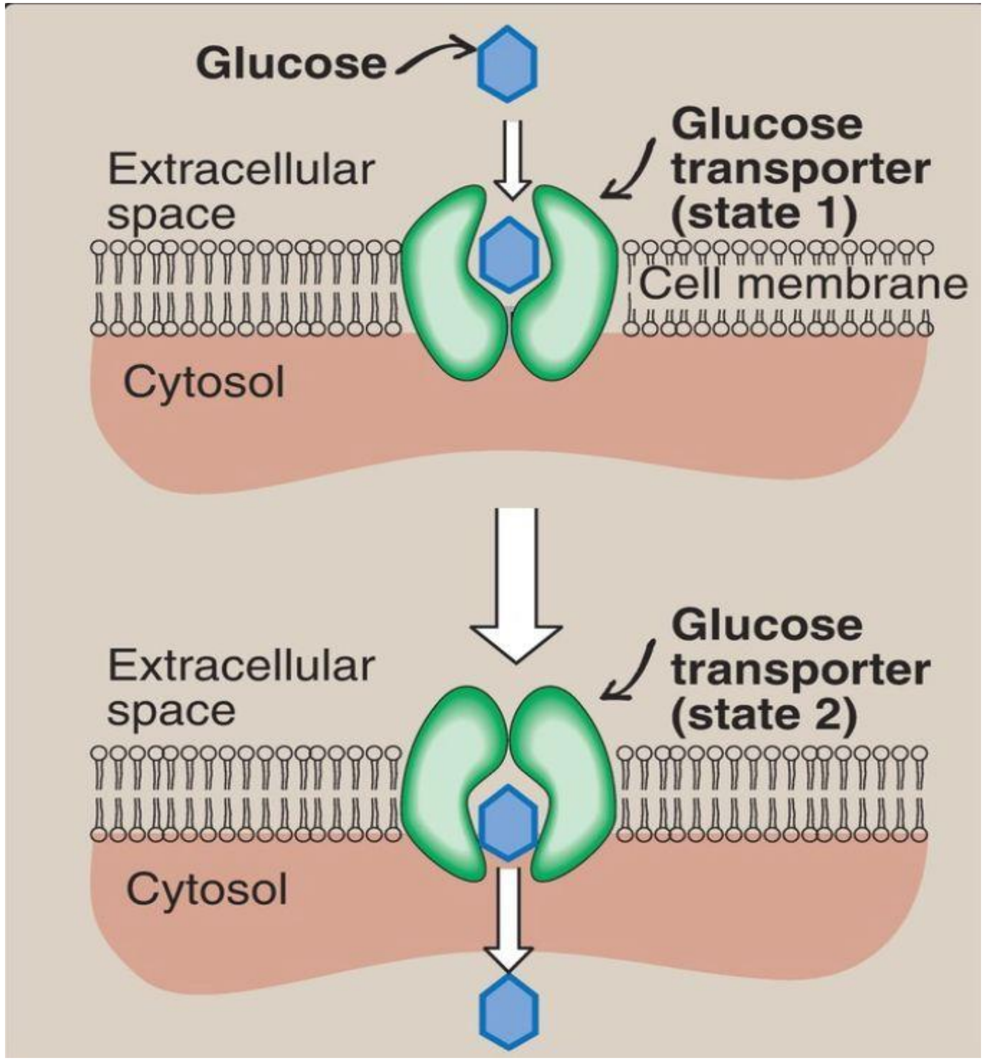
Galactose Glucose Fructose

Brush border enzymes in small intestine (dextrinase, glucoamylase, lactase, maltase, and sucrase)

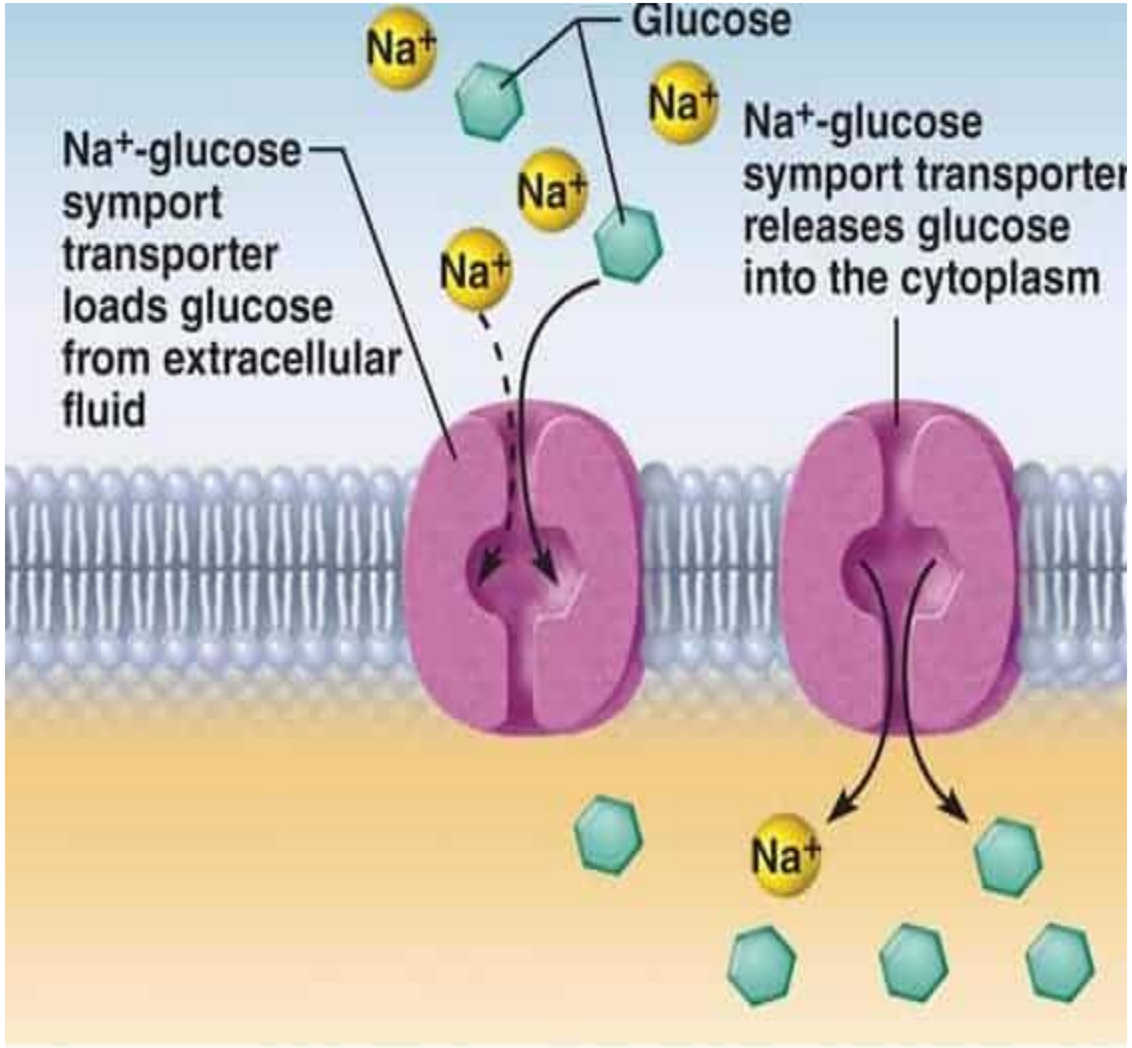
Small intestine

- Glucose and galactose are absorbed via cotransport with sodium ions.
- Fructose passes via facilitated diffusion.
- All monosaccharides leave the epithelial cells via facilitated diffusion, enter the capillary blood in the villi, and are transported to the liver via the hepatic portal vein.

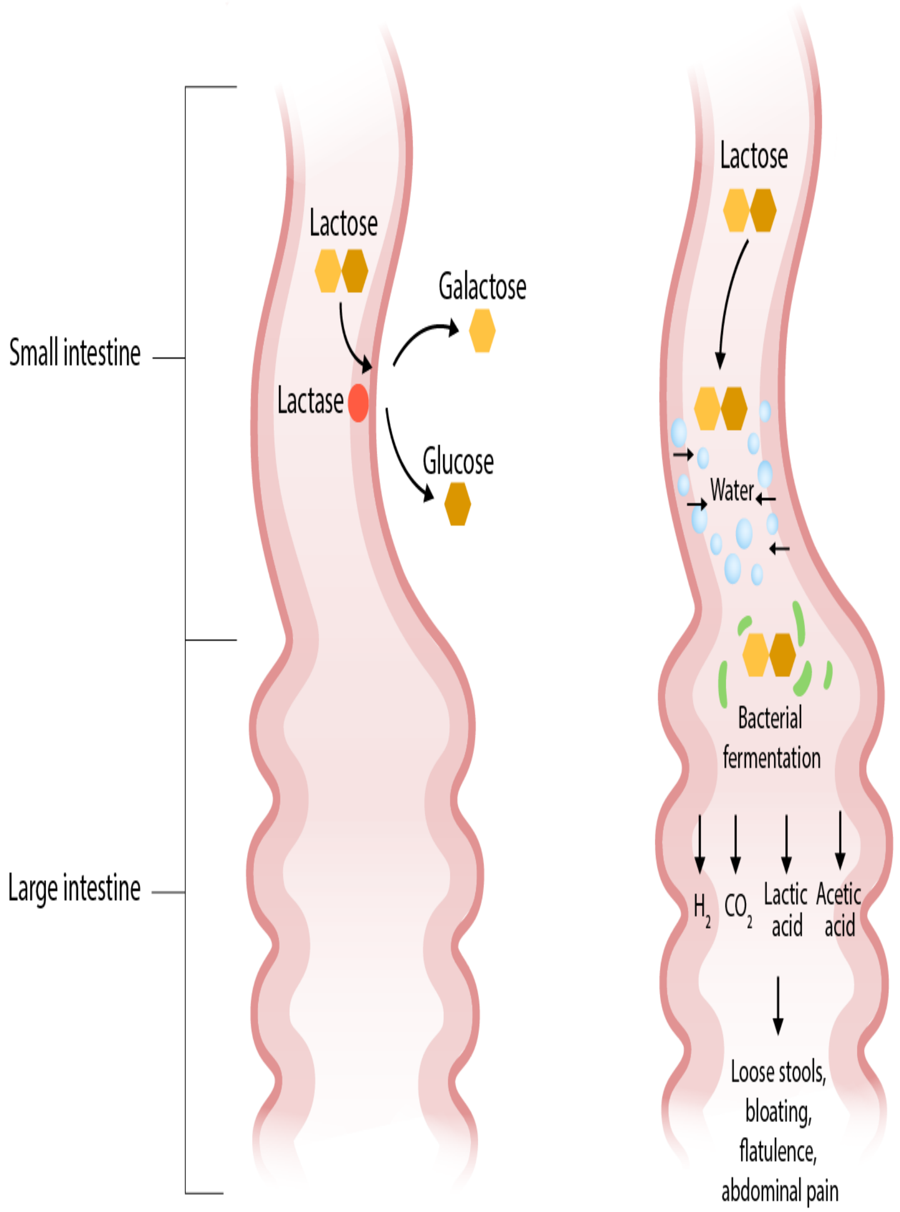
A. Na^+ independent, facilitated diffusion transport system



B. Na^+ monosaccharide cotransporter system



Clinical Correlation: Deficiency of digestive enzymes



Undigested carbohydrates, caused by a deficiency in a particular disaccharidase activity, can move from the small intestine to the large intestine, causing:

1- Osmotic diarrhea

2- Over-fermentation by intestinal microflora

Produce large volumes of CO_2 and H_2 gas→ Causing abdominal cramps, diarrhea, and flatulence.

Example of digestive enzyme deficiency: "**Lactase deficiency**"→ improper digestion of lactose → **Lactose intolerance**.

Protein Digestion and Absorption

Stomach:

1)HCL:

-Secreted by "Parietal cells" in the stomach wall.

-Role in digestion:

- Denatures proteins.
- Helps in cutting them down into polypeptides.
- activates pepsinogen & converting it into pepsin (Pepsinogen
- Kills germs.

2) Pepsin:

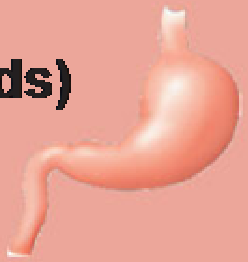
- Proteins → Polypeptides.

Small Intestine:

Pancreas: Pancreatic peptidases + Trypsin & chymotrypsin.

Aminopeptidases: Polypeptides → amino acids.

Protein digestion

Foodstuff	Enzyme(s) and source	Site of action	Path of absorption
Protein → Large polypeptides	Pepsin (stomach glands) in presence of HCl 	Stomach	• Amino acids are absorbed by cotransport with sodium ions. • Some dipeptides and tripeptides are absorbed via cotransport with H^+ and hydrolyzed to amino acids within the cells. • Amino acids leave the epithelial cells by facilitated diffusion, enter the capillary blood in the villi, and are transported to the liver via the hepatic portal vein.
Large polypeptides → Small polypeptides, small peptides	Pancreatic enzymes (trypsin, chymotrypsin, carboxypeptidase) 	Small intestine	
Small polypeptides, small peptides → Amino acids (some dipeptides and tripeptides)	Brush border enzymes (aminopeptidase, carboxypeptidase, and dipeptidase) 	Small intestine	

Lipid Digestion and Absorption

Important terms:

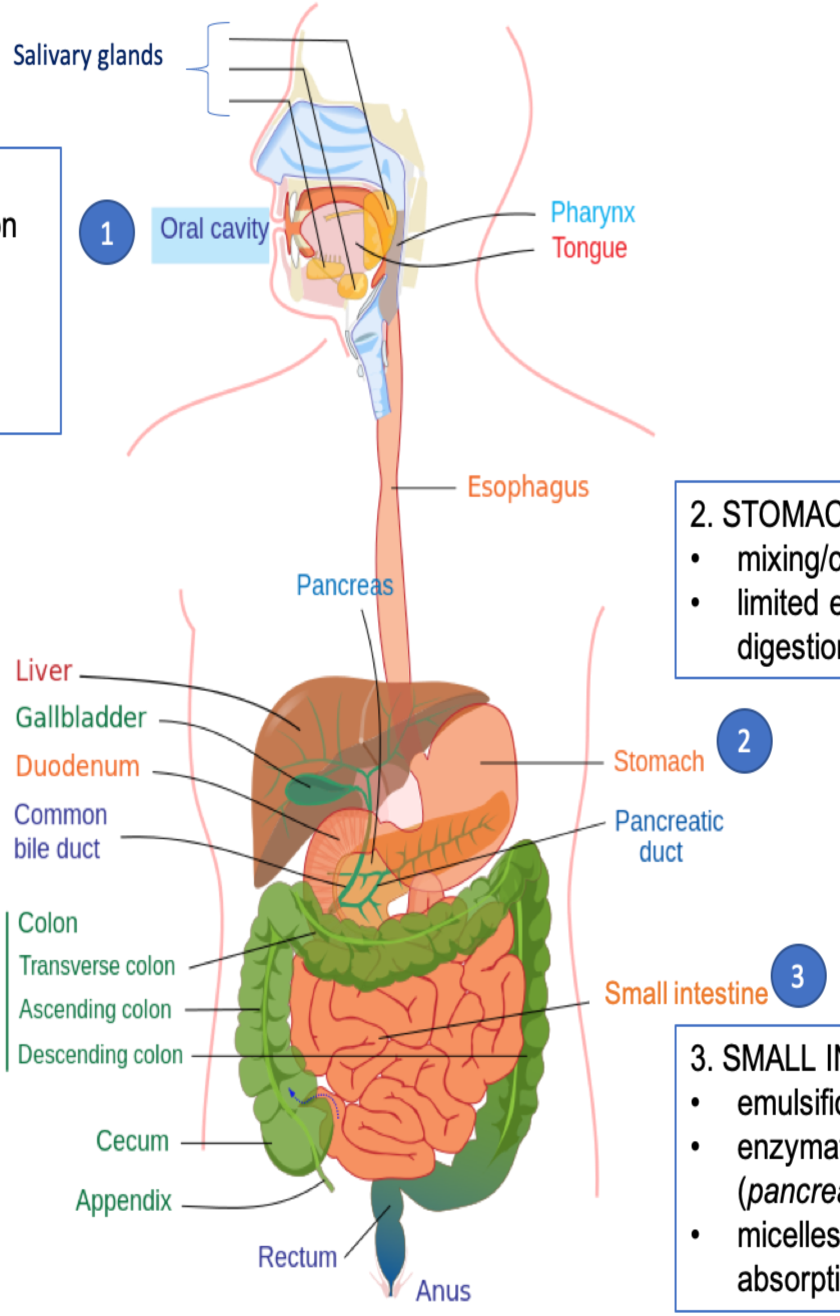
- **Emulsification:** the breakdown of fat globules in the duodenum into tiny droplets, which provides a *larger surface area* on which the enzyme pancreatic lipase can act to digest the fats into fatty acids and glycerol.

- **Bile:** dark green to yellowish brown fluid, secreted by the liver, and stored in the gall bladder. After eating, bile is discharged into the duodenum.

Fat Digestion and Absorption Steps

- **Limited processing of lipids by acid stable enzymes in:**
  - **Mouth (lingual lipase)**
  - **Stomach (gastric lipase)**
- **Small intestine:**
  - **1.Emulsification of the dietary lipids**
  - **2.Degradation of dietary lipids by pancreatic enzymes into small droplets of fats**
  - **3. Formation of micelles**
  - **4.Absorption** of lipids by intestinal mucosal cells (enterocytes)
  - **5.Resynthesis of TAG**
  - **6.Chylomicrons formed.**
  - **7.Chylomicrons move** from intestinal mucosa into the lymphatic system by **lacteals** (lymphatic capillaries) →then enter blood.
  - **8.Chylomicrons are recognized by receptors** on surface of muscle and adipose tissue mainly (also other tissues) where they are degraded.

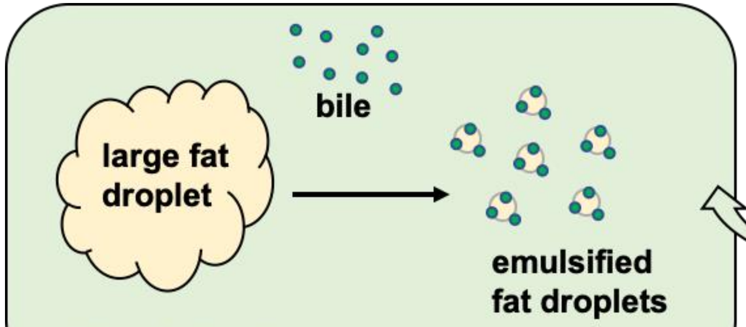
1. MOUTH
- mechanical digestion
- mixing with saliva
- limited enzymatic digestion (*lingual lipase*)



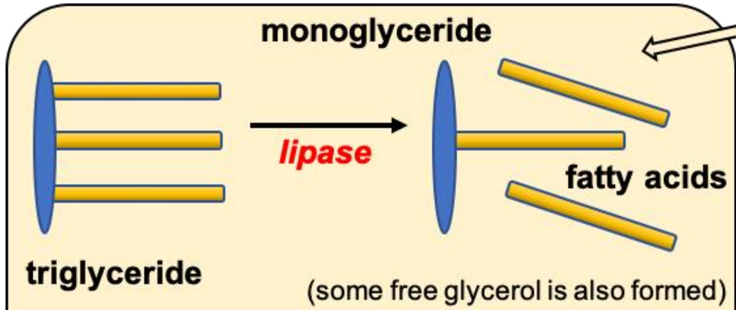
2. STOMACH
- mixing/churning
- limited enzymatic digestion (*gastric lipase*)

3. SMALL INTESTINE
- emulsification (bile)
- enzymatic digestion (*pancreatic lipases*)
- micelles help with absorption

Overall Fat digestion in small intestine



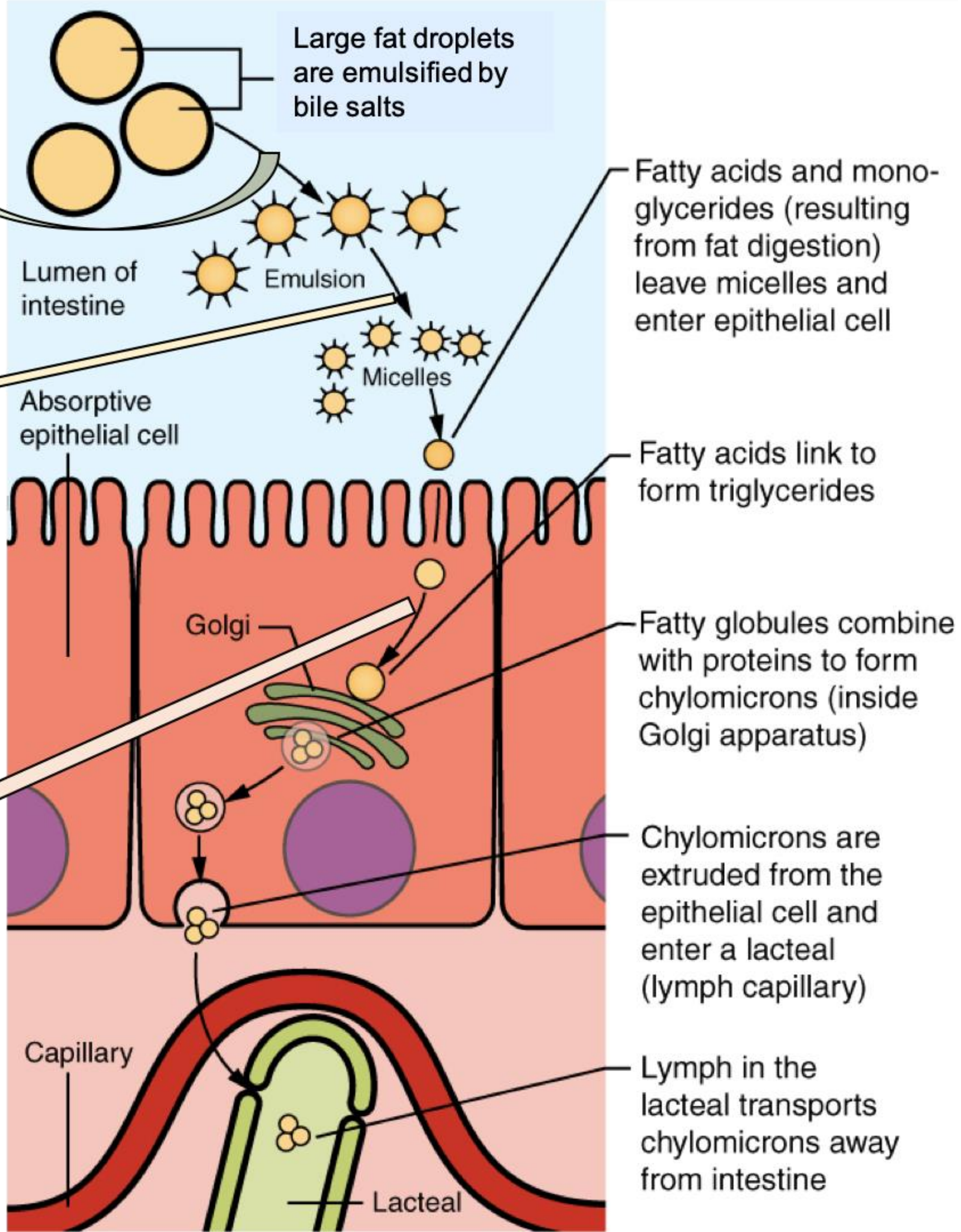
1) Emulsification by bile



2) Enzymatic digestion by pancreatic lipase

3) Absorption of products of fat digestion depends on size

- Short and medium-chain fatty acids and glycerol (small products) → absorbed into blood via capillary (*not shown in figure*)
- Long-chain fatty acids and monoglycerides (large products) → form into triglycerides and are transported in chylomicrons into lymph vessels

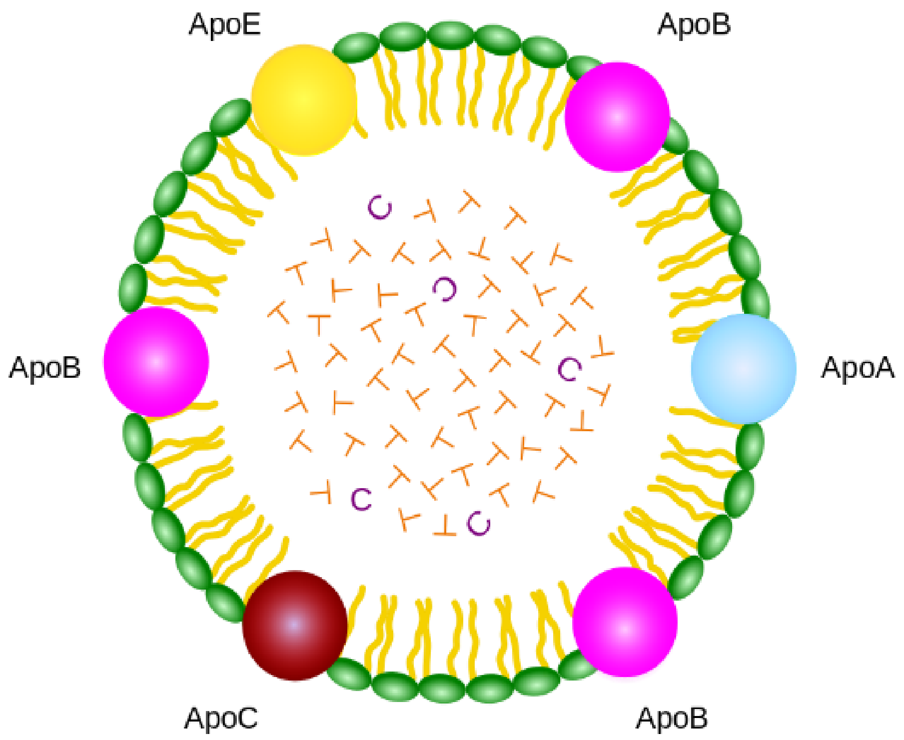


There are five classes of lipoproteins:

1. Chylomicrons (ultra low-density lipoprotein ULDL)
2. Very Low-Density Lipoprotein (VLDL)
3. Intermediate-Density Lipoprotein (IDL)
4. Low-Density Lipoprotein (LDL)
5. High-Density Lipoprotein (HDL)

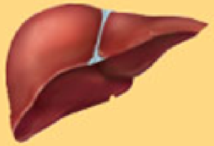
- **Chylomicrons** are lipoprotein particles that consist of triglycerides (85–92%), phospholipids (6– 12%), cholesterol (1–3%), and proteins (1–2%). They transport dietary lipids from the intestines to other locations in the body.

- **Lacteals:** lymphatic capillaries that absorb dietary fats (Chylomicrons) in the villi of the small intestine.



Lipoprotein molecule. Note the proteins and the phosphate groups "the hydrophilic part" coating the sphere, whereas the TAGs (T) and cholesterol (C) "the hydrophobic part" are embedded in the interior of the sphere.

Fat digestion

Foodstuff	Enzyme(s) and source	Site of action	Path of absorption
Unemulsified fats	Emulsification by the detergent action of bile salts ducted in from the liver 	Small intestine	• Fatty acids and monoglycerides enter the intestinal cells via diffusion. • Fatty acids and monoglycerides are recombined to form triglycerides and then combined with other lipids and proteins within the cells, and the resulting chylomicrons are extruded by exocytosis. • The chylomicrons enter the lacteals of the villi and are transported to the systemic circulation via the lymph in the thoracic duct. • Some short-chain fatty acids are absorbed, move into the capillary blood in the villi by diffusion, and are transported to the liver via the hepatic portal vein.
	Pancreatic lipases 	Small intestine	
Monoglycerides and fatty acids Glycerol and fatty acids			

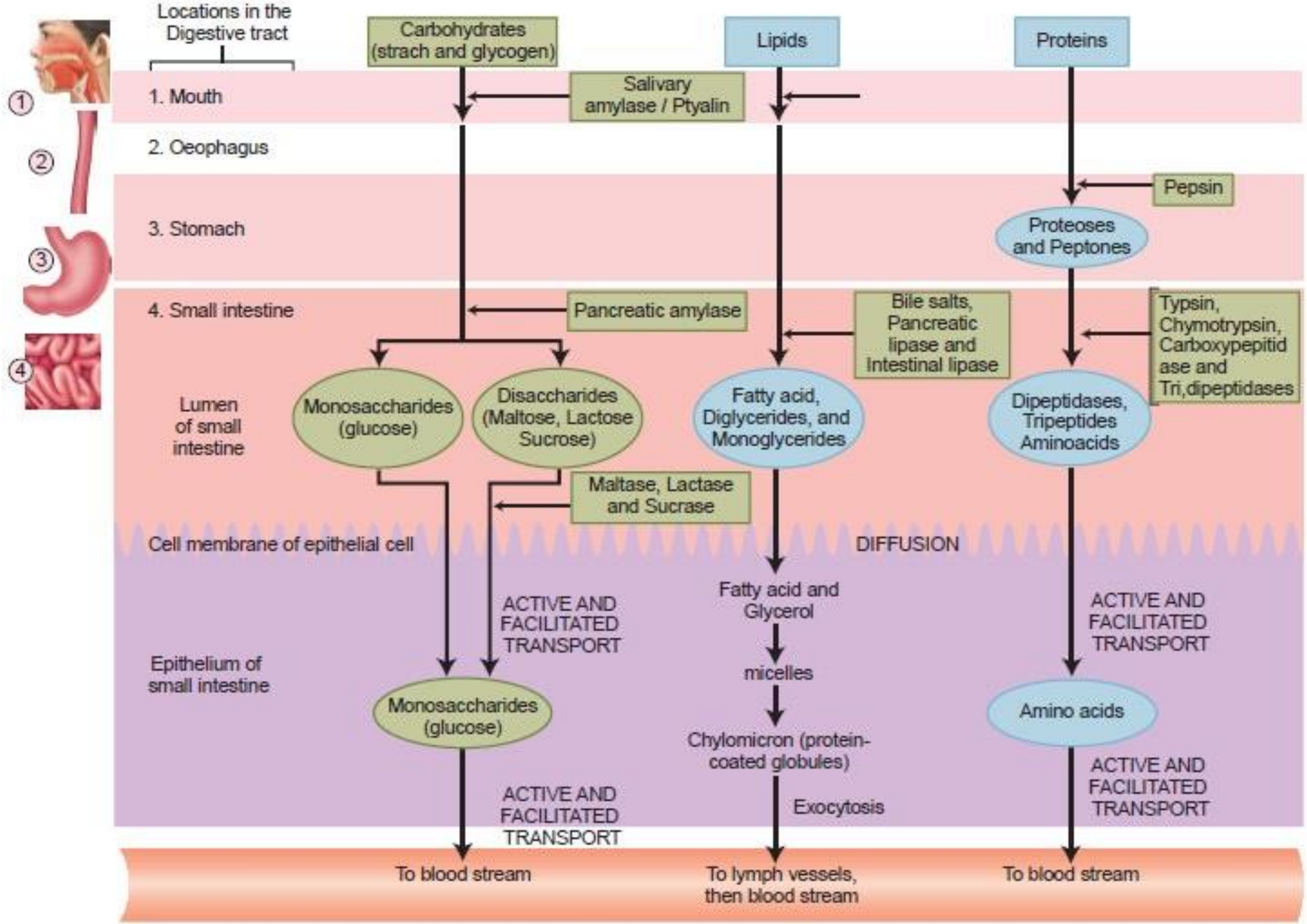


Figure 5.9 Process of Digestion and absorption