

Major types of nutrients and digestion

Lecture 1+2

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- The 7 types of nutrients are
Carbohydrates, Protein, Fats, Vitamins,
Minerals, Water and Fibers

Food Guide Pyramid

A Guide to Daily Food choices

Fats, Oils, & Sweets
USE SPARINGLY

KEY

□ Fat (naturally occurring and added) ■ Sugars (added)

These symbols show that fat and added sugars come mostly from fats, oils, and sweets, but can be part of or added to foods from the other food groups as well.

Milk, Yogurt
& Cheese
Group
2-3 SERVINGS

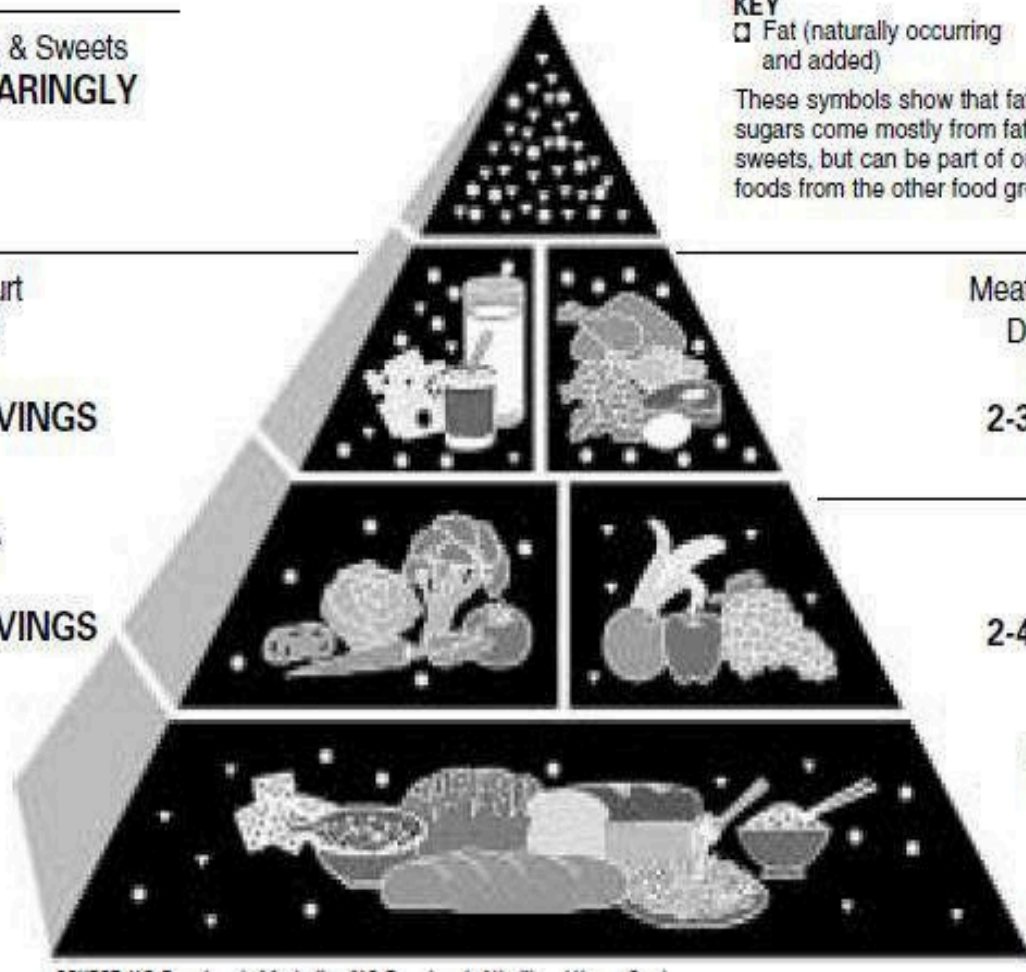
Meat, Poultry, Fish,
Dry Beans, Eggs
& Nuts Group
2-3 SERVINGS

Vegetable
Group
3-5 SERVINGS

Fruit
Group
2-4 SERVINGS

Bread, Cereal,
Rice & Pasta
Group
6-11
SERVINGS

Bread, Cereal,
Rice & Pasta
Group
6-11
SERVINGS



examples of
serving size:
* Grain products—1
slice of white bread

or ½ cup of
cooked rice;

* Vegetable
group—½ cup
cooked vegetables

* Fruit group—1
apple or banana;

* Milk Group—1
cup of milk or 60g
processed cheese;

* Meat and Beans
Group—60-80g of
cooked meat or fish
or 1 egg or 2 tbsp
peanut butter.

1. Carbohydrates

Functions

- Energy
- Fibers
- Recognition and adhesion between cells

Carbohydrate covalently attached to

proteins or lipids examples: glycoproteins, glycolipids, these classes of molecules are called glycoconjugates.

- Most foods derived from animals, such as meat or fish, contain very little carbohydrate except for small amounts of glycogen for example Liver contains 5% carbohydrates
- The major dietary carbohydrate of animal origin is lactose.
 - Although all cells require glucose for metabolic functions, neither glucose nor other sugars are specifically required in the diet.

Oxidation

- 1g carbohydrates produces about 4 kcal/g,
- 1g proteins produces 4 kcal/g
- 1g fats produces 9 kcal/g.
- Energy is also expressed in joules. One kilocalorie equals 4.18 kilojoules (kJ).

Carbohydrates are classified into three groups:

1- Monosaccharide's:

=Also called simple sugars

=Have the formula $(CH_2O)_n$

=Cannot be broken down into smaller sugars.

2- Oligosaccharides:

= Consist of from **2 to 10 monosaccharides** molecules joined by a linkage called glycosidic bonds (covalent bond).

= The most abundant are the disaccharides

= Trisaccharides also occur frequently.

= All common monosaccharides and disaccharides have names ending with the suffix “-ose.”

3- Polysaccharides: are polymers of monosaccharide's.

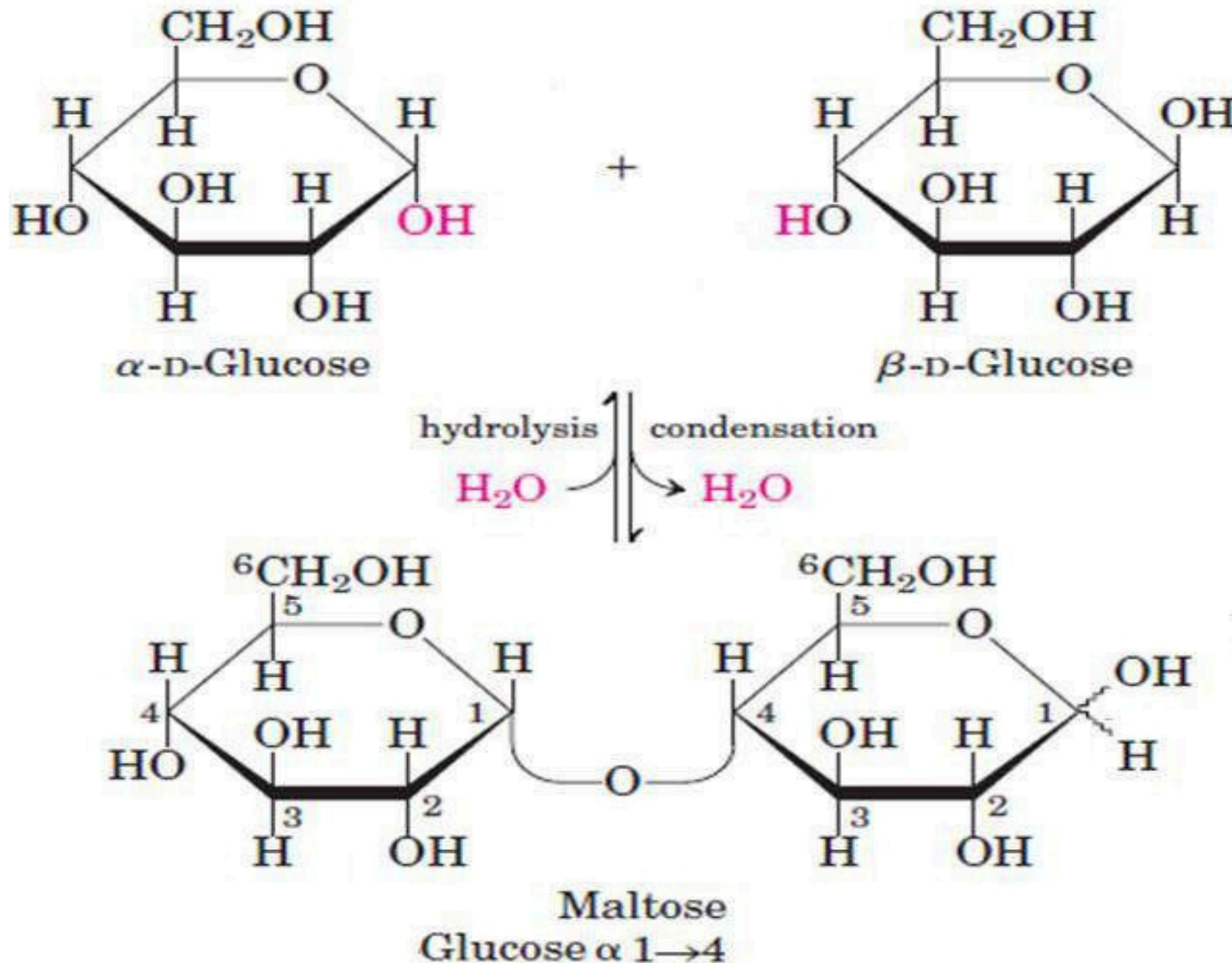
They may be either linear like cellulose or branched like glycogen. Polysaccharides may contain hundreds or even thousands of monosaccharide units.

Disaccharides

- 1- Maltose** Consist of two glucose units joined by α -1,4.
Comes from the hydrolysis of starch
- 2- Cellobiose**, is a two glucose disaccharide joined by β -1,4
obtained from the acid hydrolysis of cellulose
- 3- Isomaltose** consists of two glucose units linked by α -1,6.
obtained from the hydrolysis of some polysaccharides like dextran
- 4- Trehalose** made from two glucose units linked by α -1,1 bond
- 5- Lactose** Milk sugar, Composed of Galactose & Glucose
joined by (β -1,4) link.
- 6- Sucrose** Composed of (glucose- α -1,2-fructose)
obtained from cane or beet commonly known as table sugar

Glycosidic bond in maltose

Glycosidic bond the covalent bond between the anomeric carbon atom of a saccharide and some other group or molecule with which it forms a glycoside.

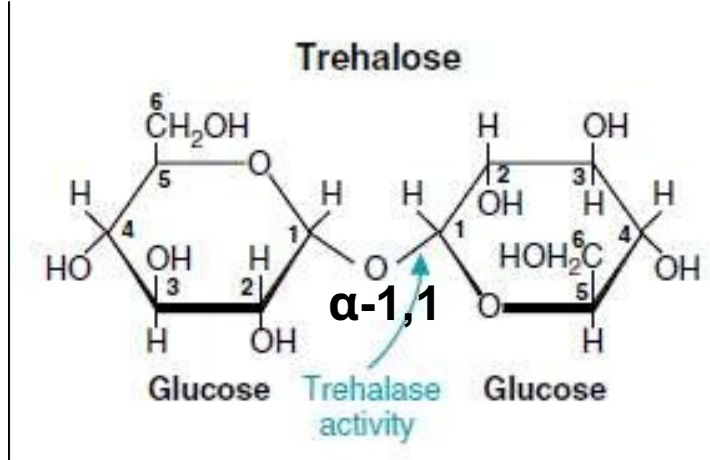


alpha 1,4glycosidic bonds are formed when the OH on the carbon-1 is below the glucosering while beta 1,4 glycosidic bonds are formed when the OH is above the plane




Reducing sugar (can donate an electron): is a sugar with free aldehyde or ketone.

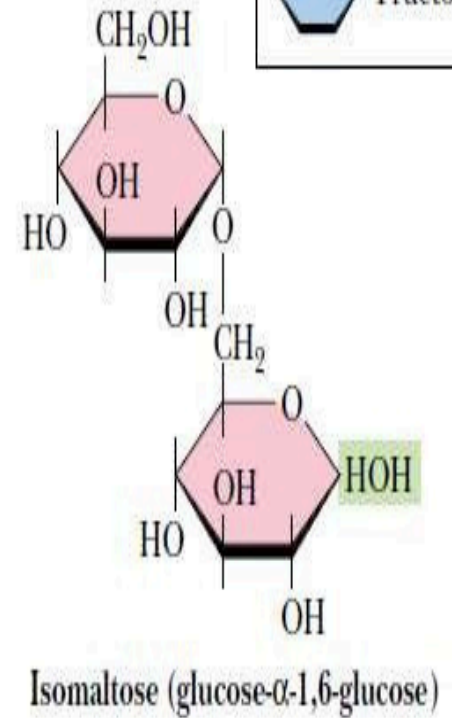
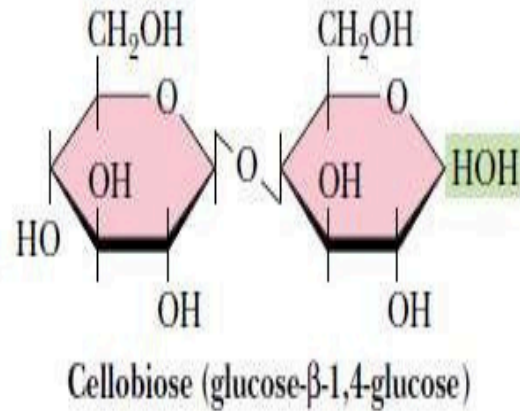
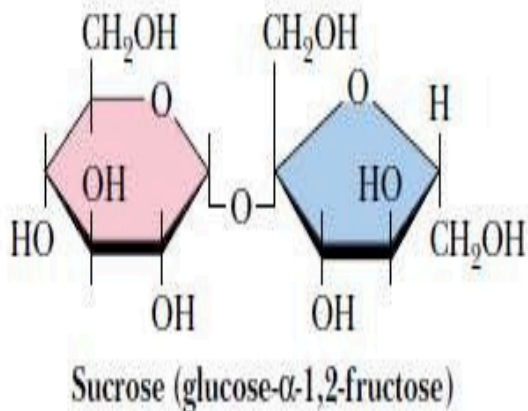
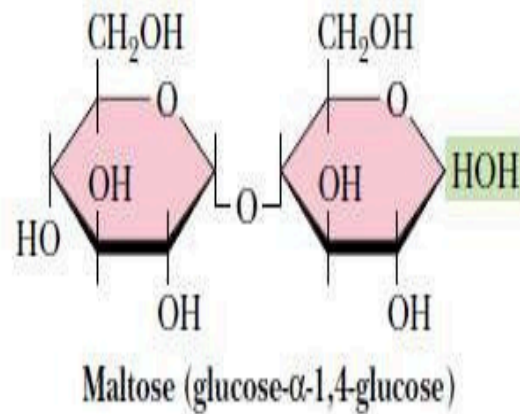
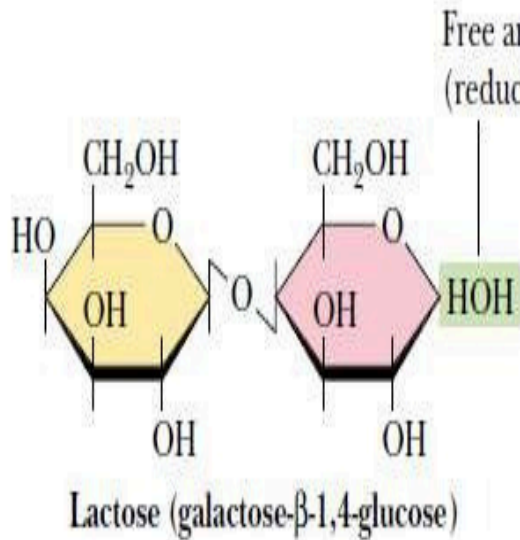
Non-reducing sugar does not have free aldehyde or ketone.

All monosaccharide are reducing sugars.



Simple sugars

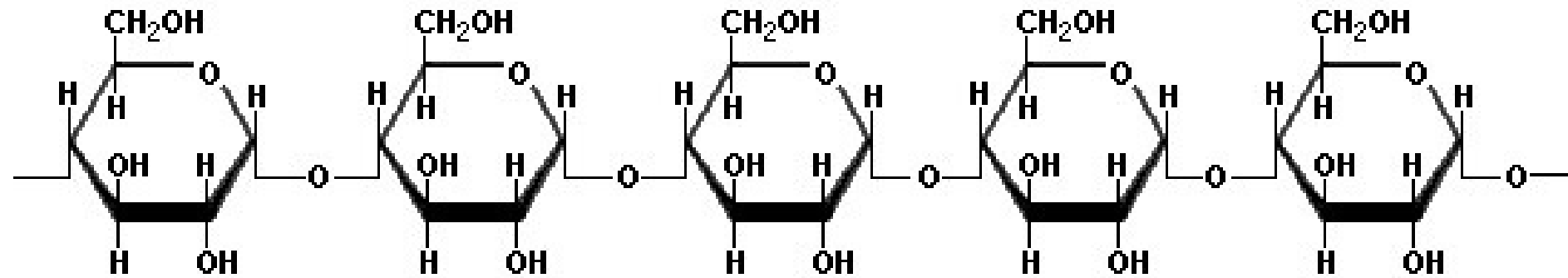
-  Glucose
-  Galactose
-  Fructose



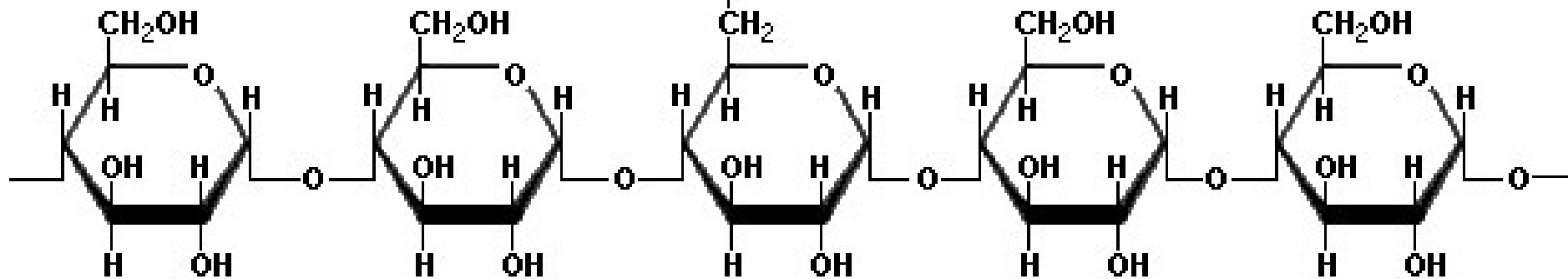
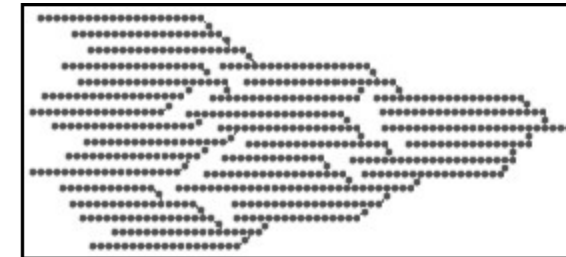
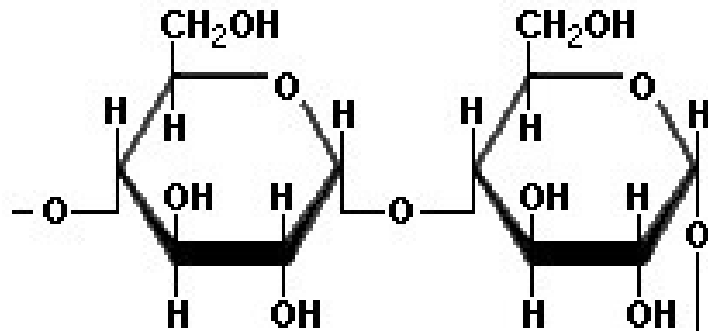
Polysaccharides

- **Starch** is made up of glucose molecules .
- Starch represents the main type of digestible polysaccharides.
- Found in grains (wheat, rice, corn, oats, and barley) and tubers such as potatoes.
- Starch exist in two structural form:-
 - 1- Amylose (about 20% of starch) strait chain of glucose which is linked by α -1,4 glycosidic bonds
 - 2- Amylopectin (about 80% of starch) (branched) the α -1,4 chains contain branches connected via α -1,6 glycosidic bonds
- **None starch polysaccharides are the main component of dietary fibers which include: Cellulose, hemicellulose, pectin's and gum.**

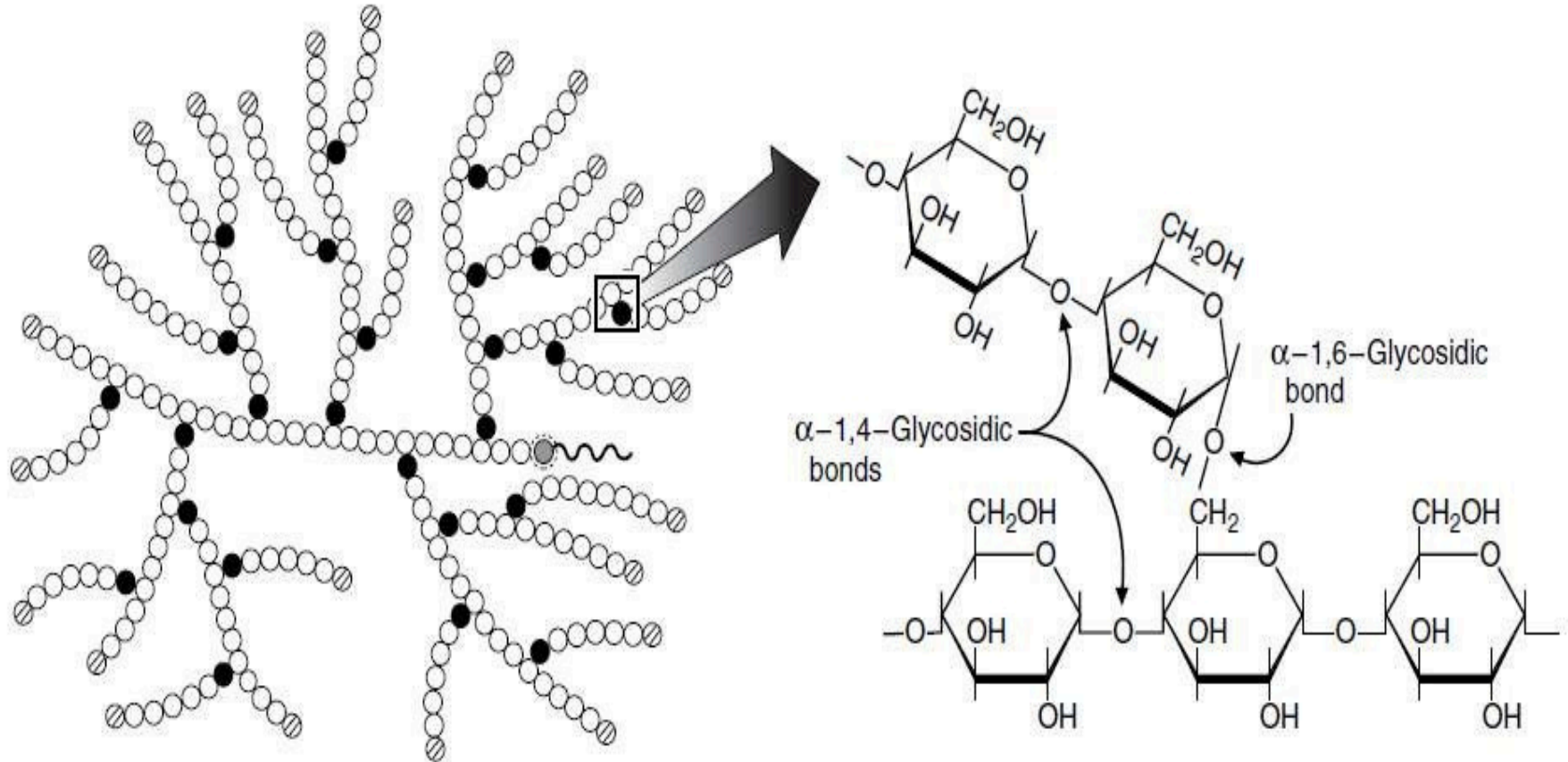
Amylose



Amylopectin



Glycogen structure



- Glucose residue linked α -1,4
- Glucose residue linked α -1,6
- ⊙ Reducing end attached to glycogenin
- ⊘ Nonreducing ends

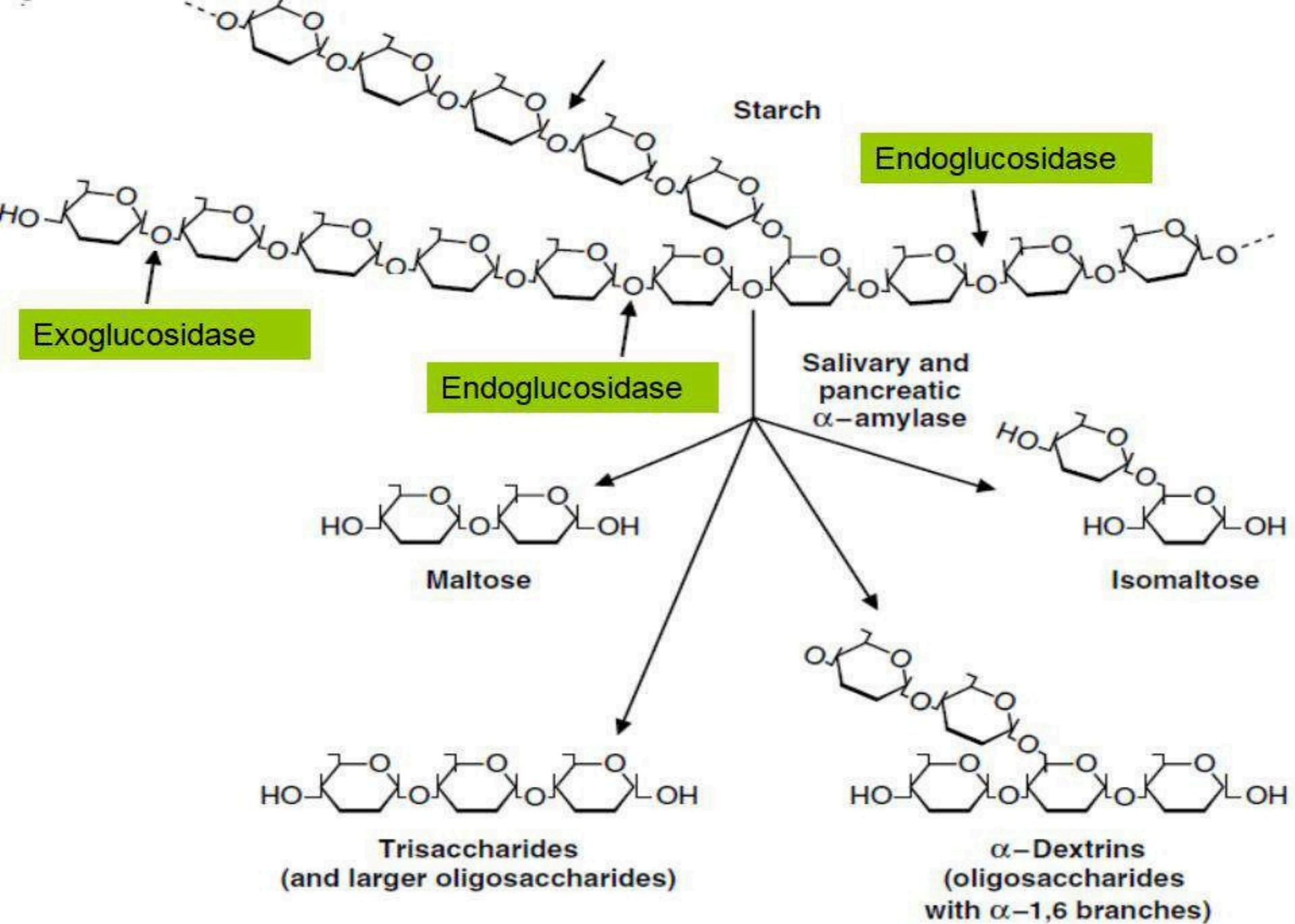
Digestion of dietary carbohydrates

- Glycosidases: enzymes that hydrolyze the glycosidic bonds between the sugars
- Glycosidases convert polysaccharides and disaccharides to monosaccharides
- Our body does not have enzymes to break down the glucose-glucose β 1-4 linkage in Cellulose
- Undigested carbohydrates enter the colon, where they may be fermented by bacteria

Digestion of dietary carbohydrates

•A. Salivary α -amylase

- The digestion of starch begins in the mouth.
- The salivary glands secrete approximately 1 liter of liquid per day into the mouth containing salivary α -amylase.
- α -Amylase is an endoglucosidase (cleaves internal glycosidic bond), which means that it hydrolyzes internal α -1,4 bonds between glucose residues at random intervals in the polysaccharide chains.
- Requires Cl^- ion for activation with an optimum pH of about 7.
- Digestion of starch and glycogen in the mouth gives maltose, isomaltose and α -dextrins



Digestion of carbohydrates in the Stomach

- In the stomach: Carbohydrate digestion stops temporarily, the acidity of the stomach inactivate salivary α -amylase.
- Gastric juice does not contain enzyme for carbohydrate digestion.
- Hydrochloric acid in the stomach may hydrolyze sucrose into glucose and fructose.

Digestion of carbohydrates in Small Intestine

A. Pancreatic Secretions

- Secretions from the exocrine pancreas (approximately 1 L/day) enter the duodenum which contain:
 - 1- Bicarbonate (HCO_3^-), which neutralizes the acidic pH of stomach contents
 - 2- Pancreatic α -amylase.

Pancreatic α -amylase (optimum pH about 7) endoglucosidase also activated by chloride ions, continues to hydrolyze the starches and glycogen, forming the disaccharide maltose, isomaltose, the trisaccharide maltotriose (three glucose molecules linked with α -1,4 glycosidic bonds), and oligosaccharides.

- These oligosaccharides, are usually 4-9 glucose units long polymers other than glucose linked by α -1,4 bonds
- α -Amylase has no activity toward sugar containing linked by α 1-4 and contain one or more α -1,6

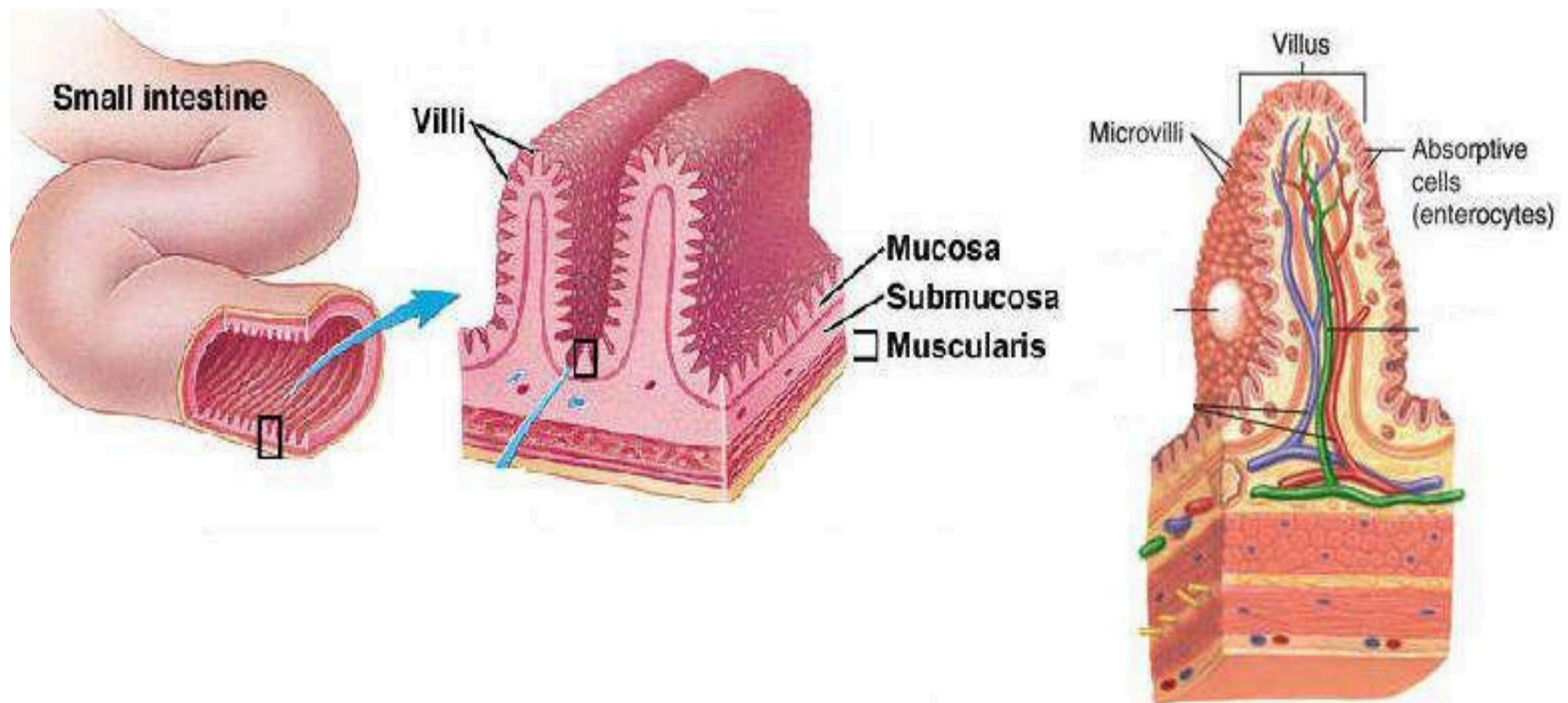
B. Intestinal brush-border membrane Disaccharidases

1. Glucoamylase

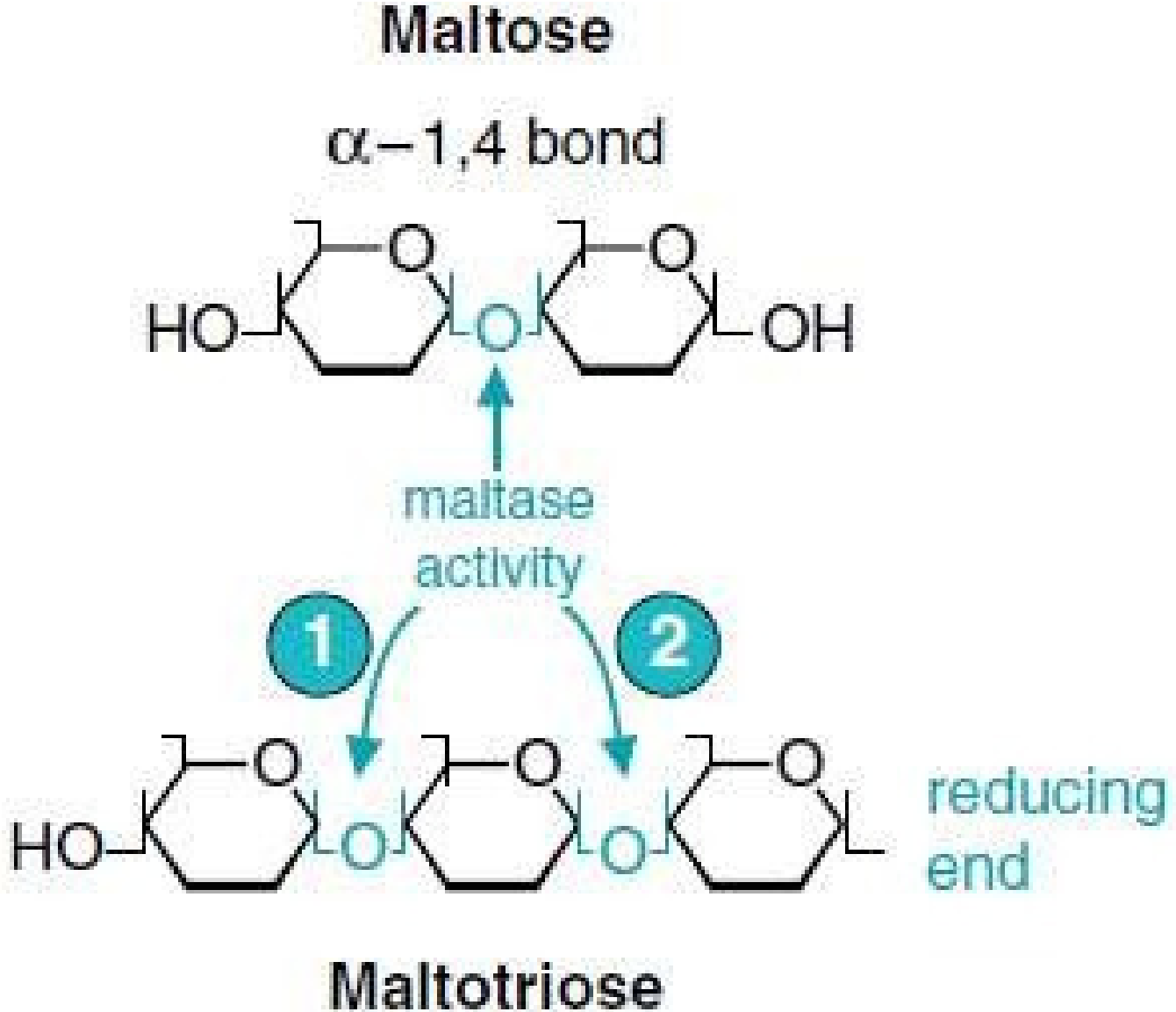
- It has two catalytic sites with similar activities.
- Glucoamylase is an exoglucosidase (release monosaccharide from non-reducing) that is specific for the α -1,4 bonds between glucose residues.
- Exoglucosidase begins at the non-reducing end of saccharic
- The glucoamylase is heavily glycosylated with oligosaccharides that protect it from digestive proteases.
- α -amylase split of large polysaccharides molecule and thus supplying new substrate molecules for glucoamylase

Location of disaccharide complexes in intestinal villi

- The **villi** are finger like projections of the mucosa into the lumen of the small intestine.
- A villus has thousands of **microvilli**.
- Collectively, microvilli known as a “brush border”.
- Function: increase intestinal absorptive surface area



Glucoamylase activity Glucoamylase is an α -1,4 exoglycosidase, which initiates cleavage at the nonreducing end of the sugar.



2. Sucrase–isomaltase complex

- Sucrase–isomaltase has two catalytic sites that differs in substrate specificity from the other (Intestinal protease clips it into two separate subunits)

The two catalytic sites are:

A- The sucrase–maltase site

= Hydrolyze all sucrose (glucose- α -1,2-fructose)

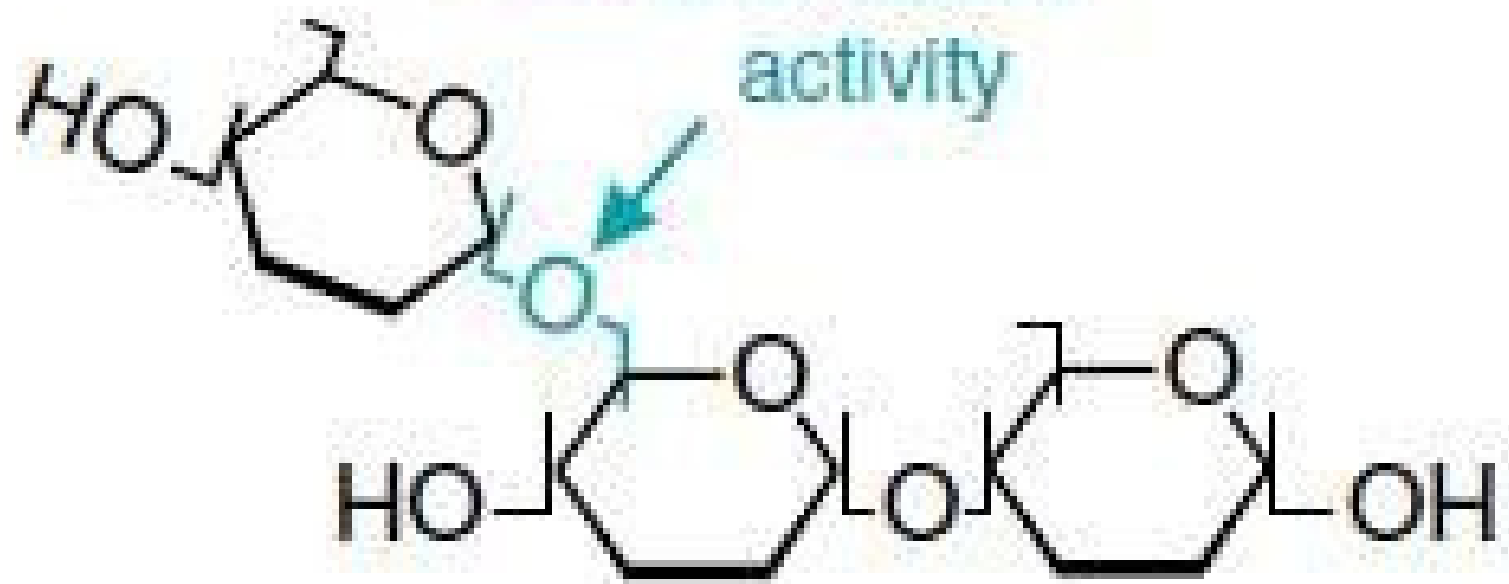
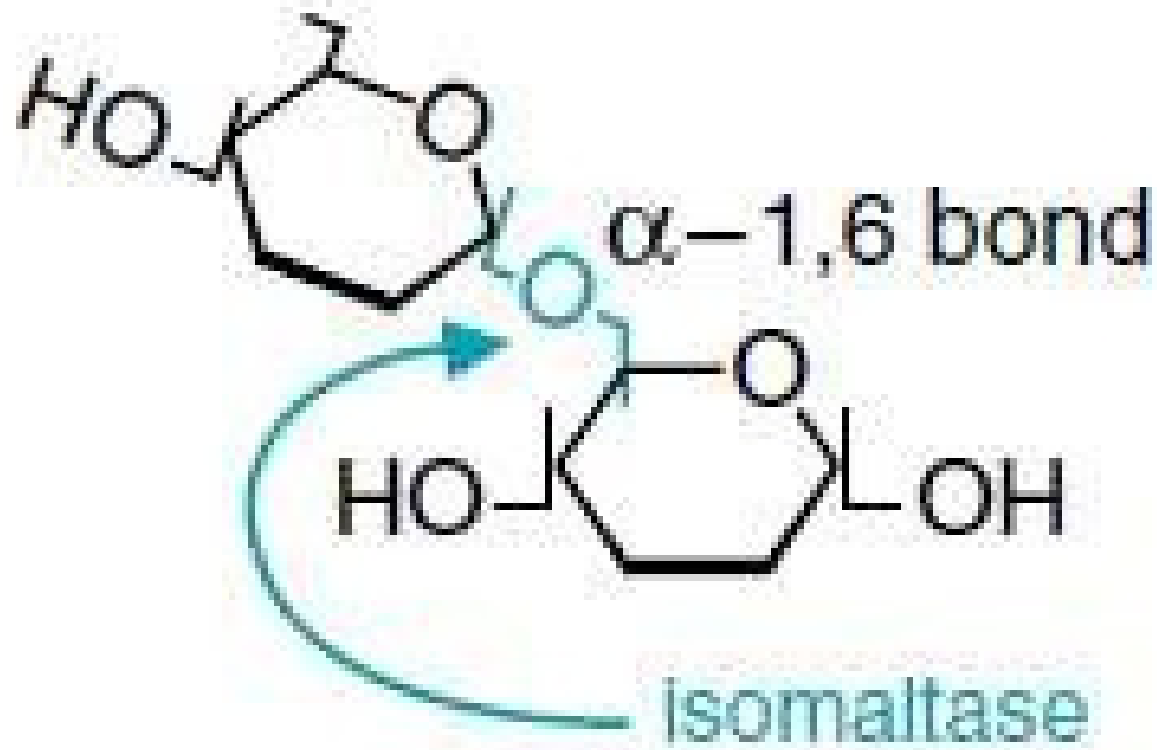
= Maltase activity.

B- The isomaltase–maltase site

= Hydrolyze all α -1,6-glucose-glucose bonds

= Maltase activity.

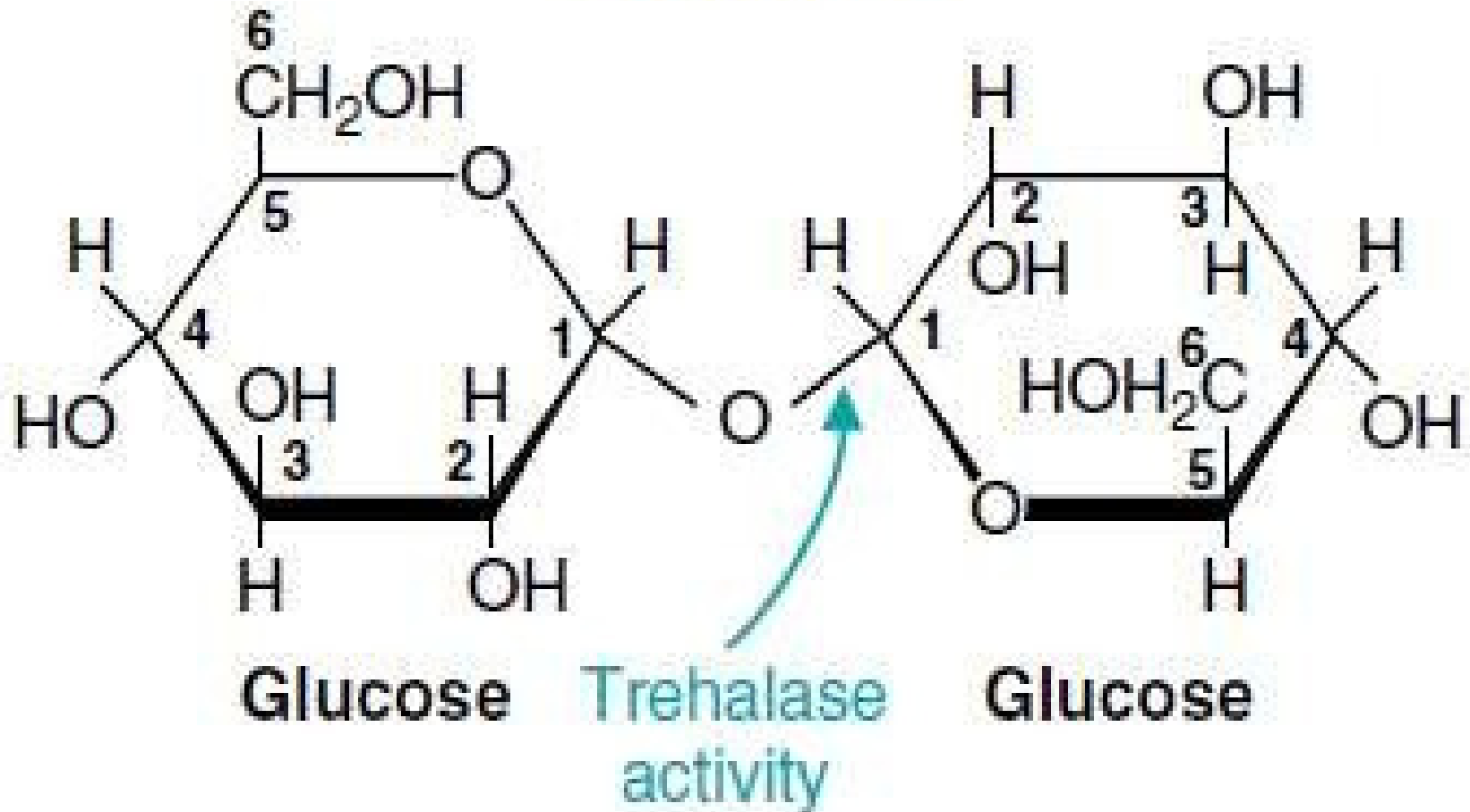
80% of the maltose are hydrolyzed by Sucrase–isomaltase complex (maltose: glucose α -1,4 glucose) and the remainder of the maltose hydrolyzed by glucoamylase complex.



3. Trehalase

- Trehalase has only one catalytic site.
- Trehalose is disaccharide made up of two glucose units linked by an α -bond between their anomeric carbons (α -1,1).
- Trehalose is found in algae, mushrooms, and other fungi
- Trehalase is only half as long as the other disaccharidases

Trehalose



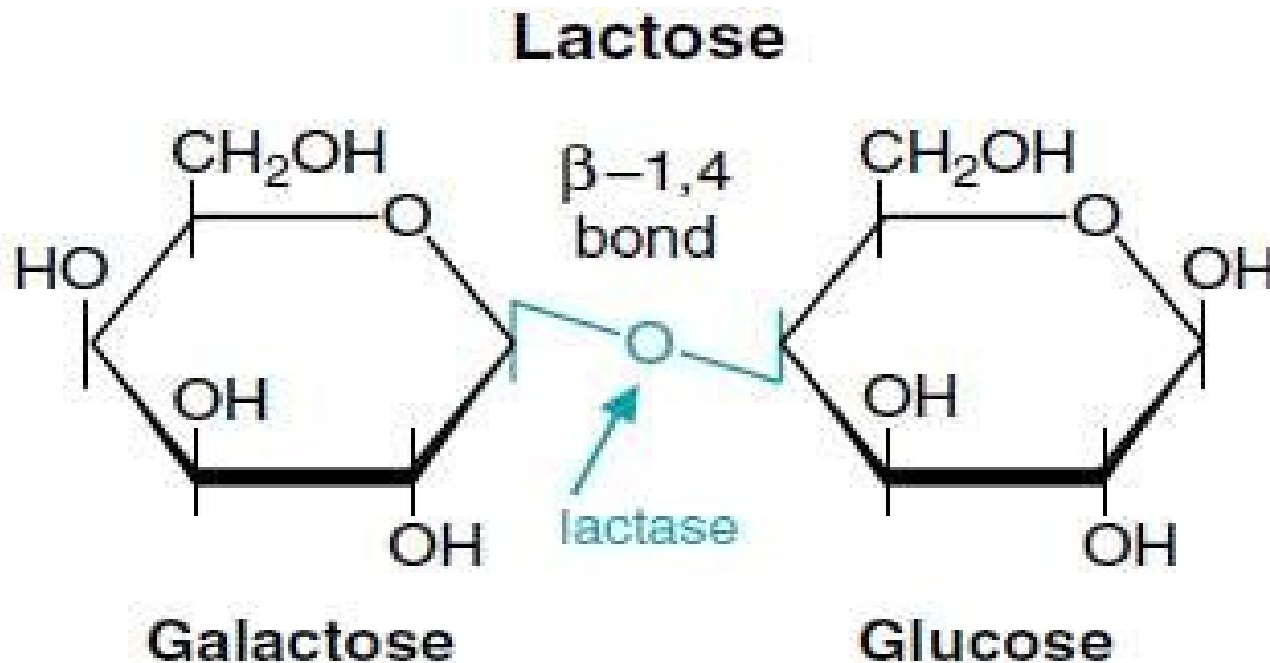
4. β -glycosidase complex (lactase-glucosylceramidase)

- Has two catalytic sites

1- The lactase catalytic site hydrolyzes the β -bond connecting glucose and galactose in lactose (also splits the β -1,4 bond between some cellulose disaccharides).

2- The β -bond between glucose or galactose and hydrophobic residues ceramide in glycolipids.

- Ceramide is the fundamental structural unit to all sphingolipids which is found in cell membrane.



Location of disaccharidases within the intestine

- A- Sucrase–isomaltase activity is highest in the jejunum,
- B- β -Glycosidase activity is also highest in the jejunum.
- C- Glucoamylase activity increases along the length of the small intestine and is highest in the ileum.

•Metabolism of Sugars by Colonic Bacteria

- Starches high in amylose, or less well hydrated (e.g.,

starch in dried beans), are resistant to digestion and enter the colon.

- Colonic bacteria rapidly metabolize the saccharides, forming gases, short-chain fatty acids, and lactate.

-

The short-chain fatty acids are absorbed by the colonic mucosal cells and can provide a substantial source of energy for these cells.

Lactose Intolerance

- The small intestine of lactose intolerance patients does not make enough of the enzyme lactase.
- The lactose that is not absorbed is converted by colonic bacteria to lactic acid, methane gas (CH₄), and H₂ gas that result in: abdominal pain, gases, and diarrhea.

Causes of lactase deficiency may be

(1) Congenital complete deficiency of lactase enzyme since birth (rare).

(2) Acquired: which occurs later on in life. which include:

a. Primary lactase deficiency develops over time and begins after about age 2 when the body begins to produce less lactase with a possible genetic link

b. Secondary lactase deficiency results from injury to the small intestine, gastrointestinal diseases, including exposure to intestinal parasites.

How is lactose intolerance diagnosed?

1. Hydrogen Breath Test .

The person drinks a lactose-loaded beverage and then the breath

is analysed at regular intervals to measure the amount of hydrogen. Normally, very little hydrogen is detectable in the breath, but undigested lactose produces high levels of hydrogen.

2. Stool Acidity Test

Undigested lactose creates lactic acid and other fatty acids that can be detected in a stool sample. Glucose may also be present in the stool as a result of undigested lactose.

Management:

- 1- Most people with lactose intolerance can tolerate some amount of lactose in their diet know your limit and stick to
2. Decreasing or removing lactose from milk and milk products

Glycemic Index (GI)

- Glycemic index is a measure of how quickly a food can raise your blood sugar.
- Glucose has the highest glycemic indices (142) with white bread defined as an index of 100.
- The glycemic response to ingested foods depends not only on the glycemic index of the foods, but also on the fiber and fat content of the food, as well as its method of preparation.
- Foods with high glycemic index values tend to raise blood sugar higher, faster and for a longer time than do foods with lower values.
- Research shows that eating a lot of foods that are high on the glycemic index is linked to an increased risk of diabetes, high blood pressure and heart disease.

Glycemic Index of Selected Foods, with Values Adjusted to White Bread of 100

Breads		Legumes	
Whole wheat	100	Baked beans (canned)	70
Pumpernickel (whole grain rye)	88	Butter beans	46
Pasta		Garden peas (frozen)	85
Spaghetti, white, boiled	67		
Cereal grains		Kidney beans (dried)	43
Barley (pearled)	36	Kidney beans (canned)	74
Rice (instant, boiled 1 min)	65	Peanuts	15
Rice, polished (boiled 10–25 min)	81	Fruit	
Sweet corn	80	Apple	52
Breakfast cereals		Apple juice	45
All bran	74	Orange	59
Cornflakes	121	Raisins	93
Muesli	96	Sugars	
Cookies		Fructose	27
Oatmeal	78	Glucose	142
Plain water crackers	100	Lactose	57
Root vegetables		Sucrose	83
Potatoes (instant)	120	Dairy Products	
Potato (new, white, boiled)	80	Ice cream	69
Potato chips	77	Whole milk	44
Yam	74	Skim milk	46
		Yogurt	52

Absorption of sugars

Two mechanisms are responsible for absorption of monosaccharides: 1. Active transport; 2. Facilitated diffusion.

Features	<u>Facilitated diffusion</u>	<u>Active transport</u>
Concentration gradient	Down the concentration gradient from high to low.	Against a concentration gradient from low to high
Energy expenditure	none	Require energy in the form of ATP
Carrier protein/transporter	required	required
Speed	Fast	Fastest mode
Monosaccharides	Fructose and mannose	Glucose and Galactose

Note: Glucose and other monosaccharide's are polar and large in size thus cannot pass to cell through passive diffusion.

- Only monosaccharide form of carbohydrates is absorbed from lumen of the small intestine.
- Once in the liver galactose and fructose are converted to glucose.
- Glucose and Galactose are absorbed by Na⁺ active transport through (GLUT1) also known as Sodium-Glucose Linked Transporter (SGLT)
- Fructose is absorbed by Facilitated diffusion through (GLUT5)
- Sodium – independent transporter (GLUT-2) facilitates transport of absorbed sugars out of the intestinal mucosal cell into portal circulation.
- Glucose transporters (GLUT) are the membrane-bound protein molecules. They help in transport of glucose across the plasma membrane of cells.

•Absorption by the Intestinal Epithelium

•1. Sodium-Glucose Linked Transporter (SGLT)

•These are GLUT1 Na⁺-dependent glucose transporters, which are located on the luminal side of the absorptive cells, enable these cells to concentrate glucose from the intestinal lumen.

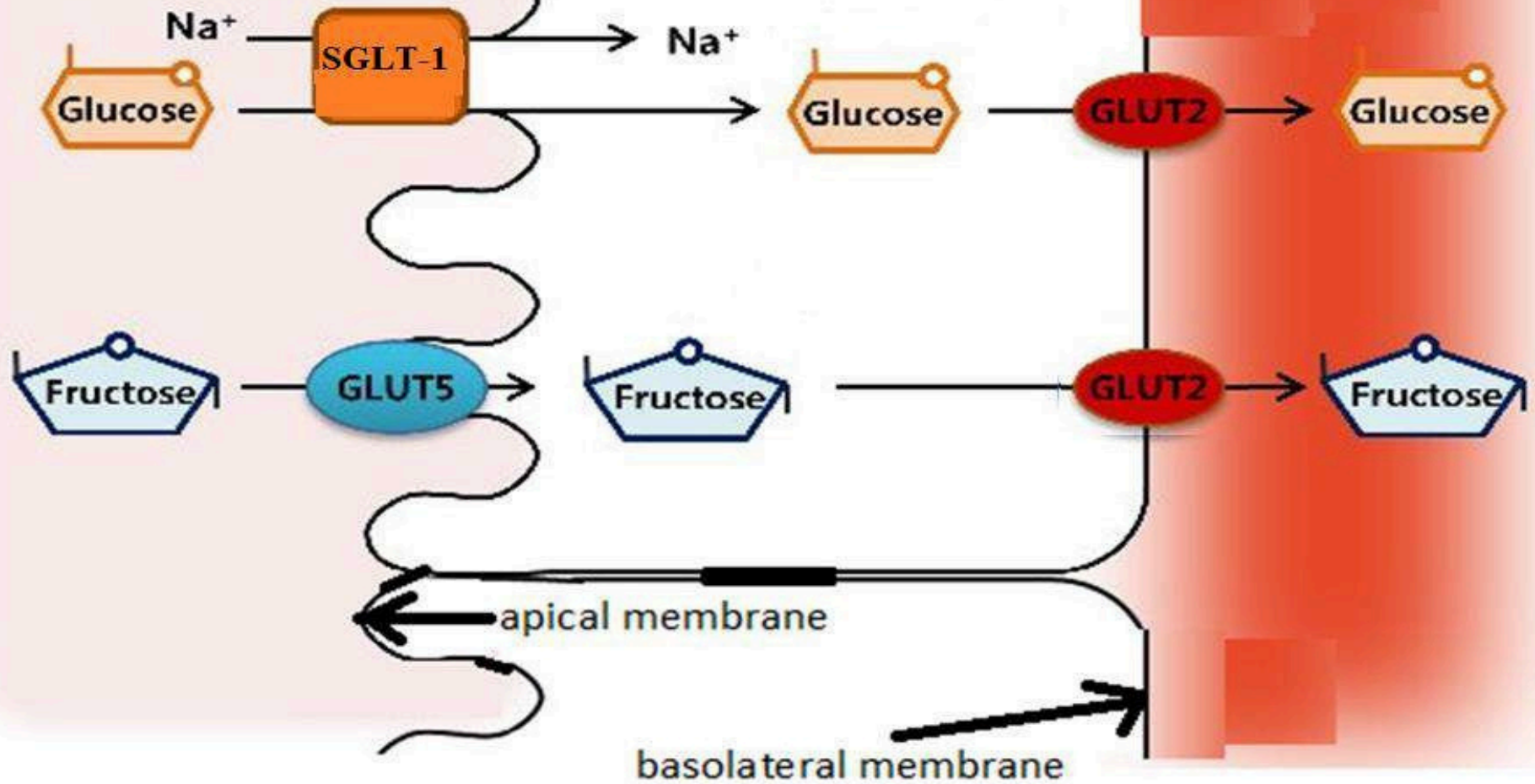
•A low intracellular Na⁺ concentration is maintained by a Na⁺-K⁺-ATPase that uses the energy from ATP cleavage to pump Na⁺ out of the cell into the blood.

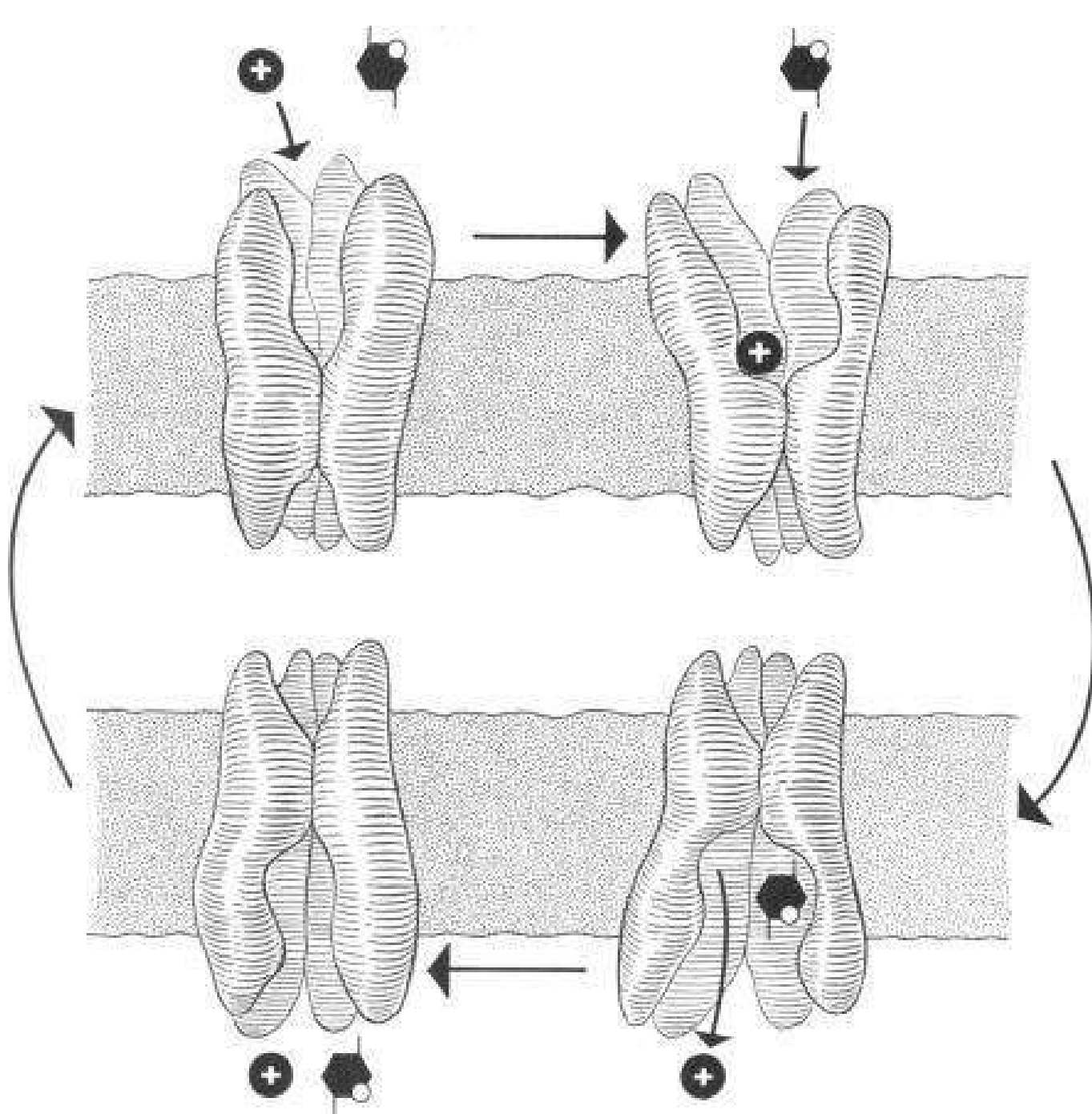
•Thus, the transport of glucose from a low concentration in the lumen to a high concentration in the cell is promoted by the cotransport of Na⁺ from a high concentration in the lumen to a low concentration in the cell.

Intestinal lumen

Epithelial Cell

Portal Blood





Na⁺ binds to the cotransporter, which results in a conformational change that permits glucose to bind to the glucose-binding site.

The cotransporter undergoes a new conformational shift, placing Na⁺ and glucose near the inner surface of the membrane.

- 2. Facilitative glucose transporters (Na⁺ independent transporter)
- Glucose moves via the facilitative transporters from the high concentration inside the epithelial cell to the lower concentration in the blood without the need of energy through

GLUT-2.

- The various types of facilitative glucose transporters found in the plasma membranes of cells referred to as GLUT 1 to GLUT 14.
- One common structural theme to these proteins is that they contain 12 membrane-spanning domains. Because glucose leaves the intestine via the hepatic portal
- the liver is the first tissue it passes through.

Dietary fiber

- Are components of food cannot be digested by human digestive enzymes they are mainly polysaccharide derivatives and lignan (Noncarbohydrate, polymeric derivatives of phenylpropane).
- According to their solubility fibers are divided into:
 - 1. Water insoluble fiber:** include Cellulose, lignin and hemicellulose.
 - Function: stimulate regular function of the colon.
 - 2. Water-soluble fiber** include Pectins and gums which form viscous gel-like suspensions in the digestive system.
 - Function: slowing the rate of absorption of many nutrients, including carbohydrates, and lowering serum cholesterol in many cases.

Benefits of fibers

1- Soluble fibers are fermented by bacteria and produce small chain of fatty acids. 10% of our total calories we get from compounds produced by bacterial digestion of substances in our digestive tract.

2- Fiber is thought to “soften” the stool, thereby reducing pressure on the colonic wall and enhancing expulsion of feces. This specifically beneficial effect to diverticular disease, in which sacs or pouches may develop in the colon because of a weakening of the muscle and submucosal structures.

3- Disease prevention for example (water soluble fibers):

- Pectins: may lower blood cholesterol levels by obstructing the diffusion of bile acid and bile salts thus obstructing the absorption of cholesterol and also slow or inhibit amylase activity.

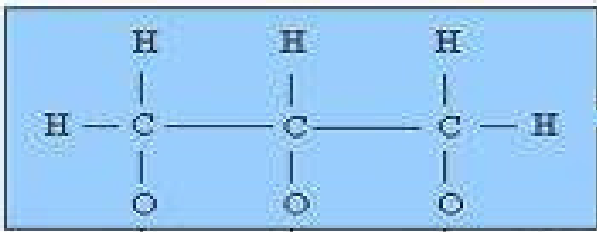
- β -glucan (water soluble that is found in the cell wall of plants) stimulate the growth and activity of the desired natural intestinal microbes, while inhibiting the growth of pathogens. It also prevents the body from absorbing cholesterol from food.

2. Fats

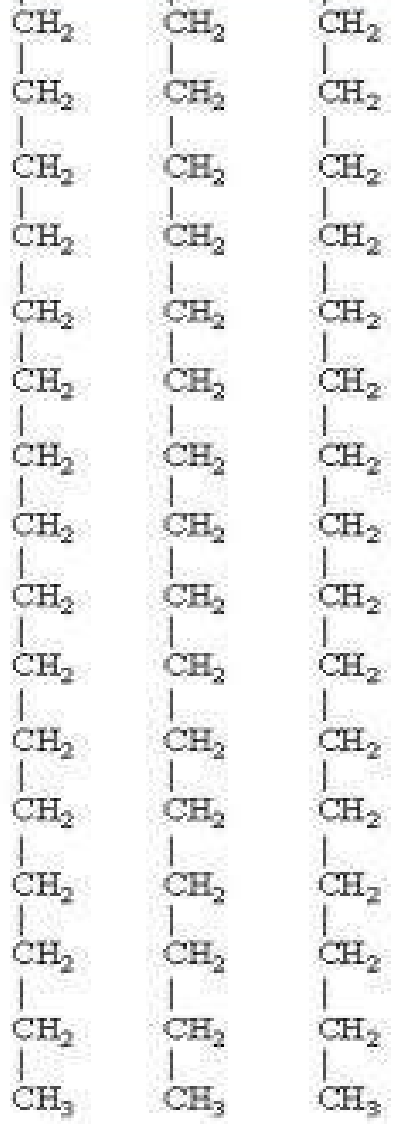
- Functions: 1- Cell structure, 2- fuel storage, 3- hormone
- Nonessential fatty acids can be synthesized in our body while essential fatty acids we have to get them from food.
- There are two essential fatty acids to humans linoleic acid and α -linolenic acid which we get from dietary plant oils.
- More than 300 different **fatty acids** are known however only 20–25 of them are widely distributed in **nature**

Triacylglycerols

- Triacylglycerols are the major fat in the human diet because they are the major storage lipid in the plants and animals that constitute our food supply.
- The remainder of the dietary lipids consists primarily of cholesterol, phospholipids, and free fatty acids.
- Triacylglycerols contain a glycerol backbone to which three fatty acids are esterified.
- The main route for digestion of triacylglycerols involves hydrolysis to fatty acids and 2-monoacylglycerols in the lumen of the intestine. However, the route depends to some extent on the chain length of the fatty acids.

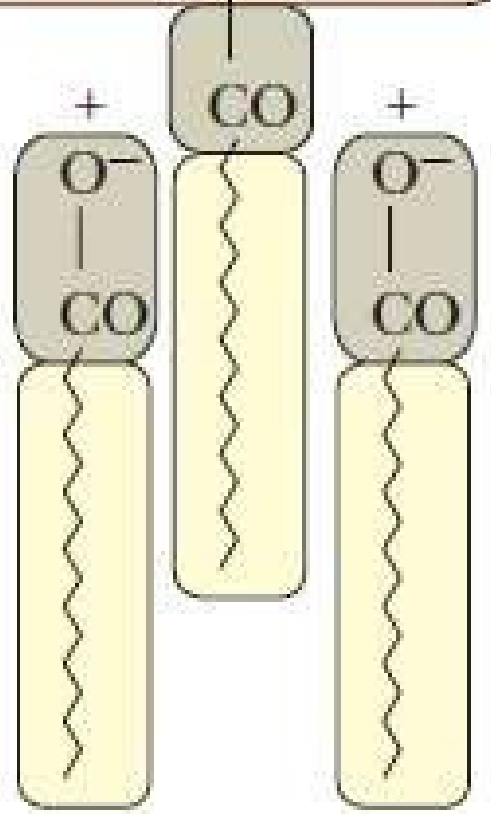
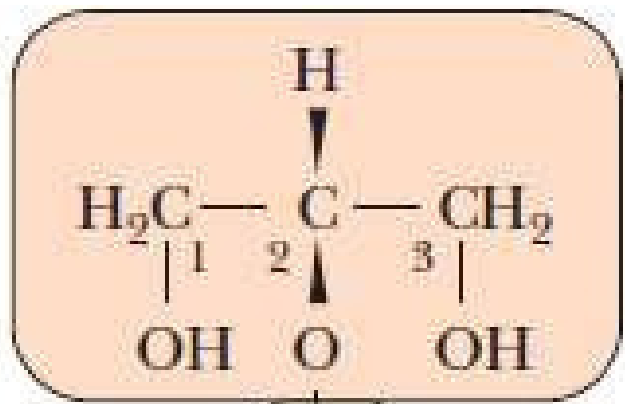


Glycerol



Triacylglycerol

Fatty acid chains



2-monoacylglycerols

Digestion of fat

A. **Digestion of fats in Mouth and stomach**

Limited digestion of lipids occurs in the mouth and stomach because of the low solubility.

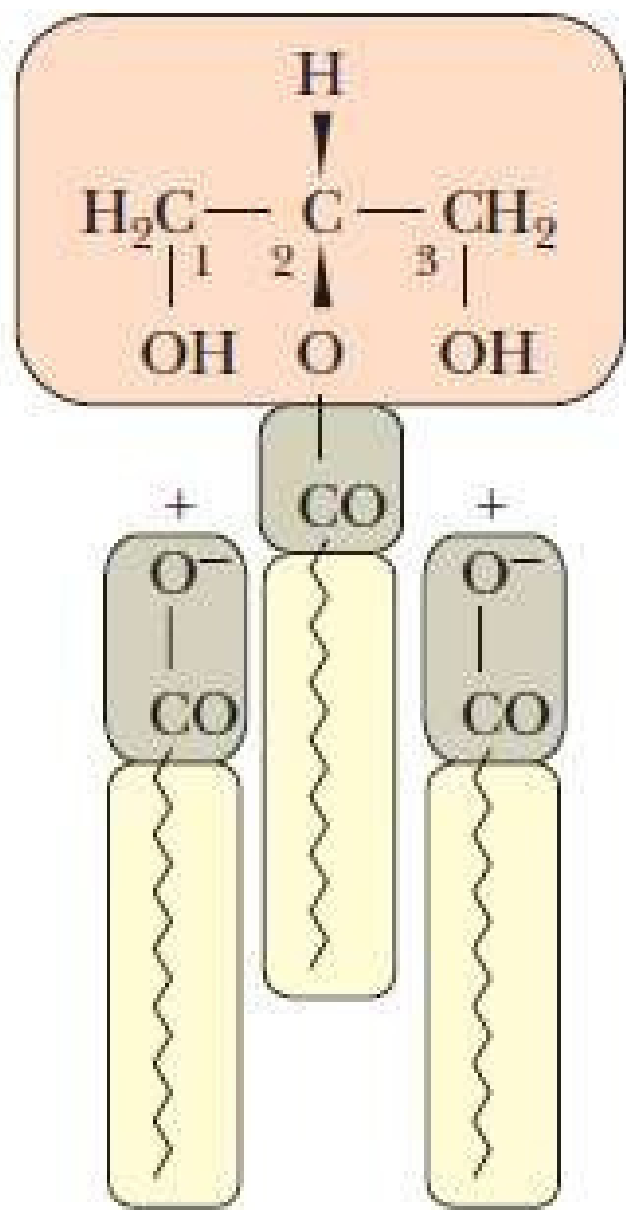
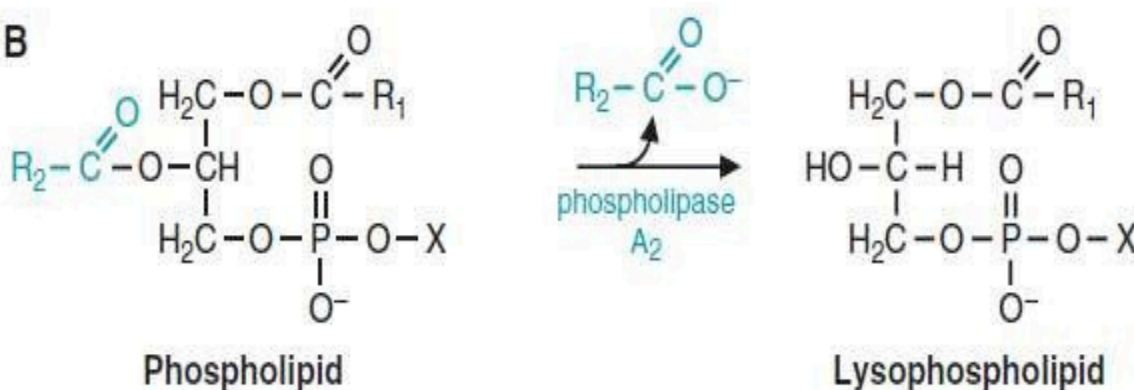
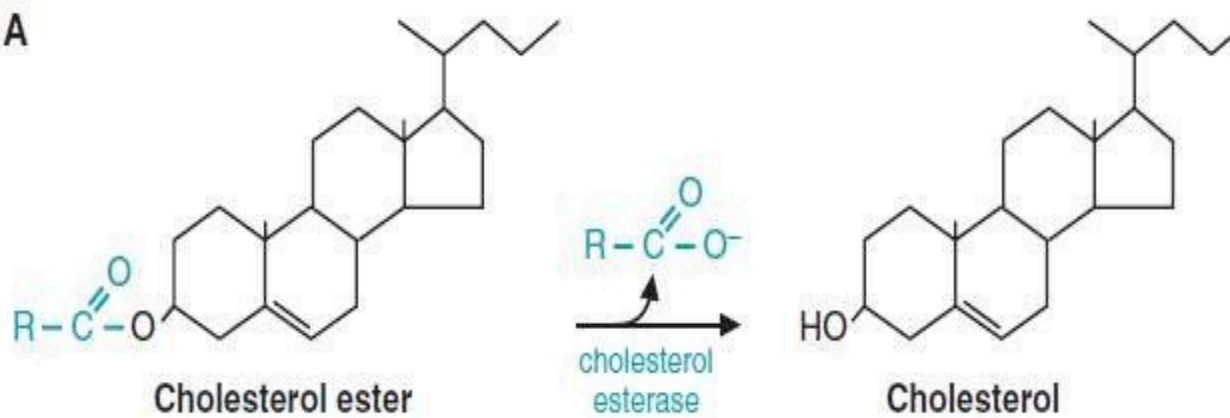
1. Lingual lipase produced by cells at the back of the tongue
2. Gastric lipase produced by stomach
 - Same function for both enzymes: they hydrolyze short- and medium-chain fatty acids triacylglycerols (containing 12 or fewer carbon atoms).
 - Lingual and gastric lipases hydrolyse 10–30% of ingested triglycerides.

B. Digestion of fats in small intestine

- **1. Action of Bile:**
- **Emulsification** (suspended in small particles in the aqueous environment) by bile salts.
- The biles are amphipathic compounds
- The contraction of the gallbladder and secretion of pancreatic enzymes are stimulated by the gut hormone cholecystokinin, which is secreted by the intestinal cells when stomach contents enter the intestine.
- Bile act as detergents, binding to dietary fat as they are broken up by the action of the intestinal muscle. This emulsified fat, which has an increased surface area as compared with unemulsified fat, is attacked by digestive enzymes from the pancreas.

2. Action of Pancreatic secretion

- A- Bicarbonate (hormone secretin released from the intestine when acid enters the duodenum) raises the pH of the contents of the intestinal lumen into a range (pH ~ 6.5).
- B-Lipase digests dietary triacylglycerols producing 2 free fatty acids and 2-monoacylglycerol
- Pancreatic lipase is the enzyme responsible for hydrolysis of approximately 75% of dietary triglycerides
- C- Colipase it binds to the dietary fat and to the lipase, thereby increasing lipase activity.
- D- Esterases remove fatty acids from compounds such as **cholesterol esters** (The ester bond is formed between the carboxylate group of a fatty acid and the hydroxyl group of cholesterol.)
- E- phospholipase A₂ digests phospholipids to a free fatty acid and a lysophospholipid



Action of pancreatic esterases (A) and phospholipase A2 (B).

- **Absorption of digested fats**

- Short- and medium-chain fatty acids (C4 to C12) are absorbed directly into intestinal epithelial cells, they enter the portal blood and are transported to the liver where they are bound to serum albumin. Fatty acids (FA) with chain lengths of 14 or greater are more highly lymphatically transported.
- Enterocytes (intestinal absorptive cells) use diffusion and protein-mediated transport mechanisms to take up 2-monoacylglycerols and FFAs.
- (Diffusion across these epithelial cells occurs when FFA concentrations in the lumen exceed those inside the cell. When extracellular concentrations are lower than intracellular concentrations then protein-mediated uptake mechanisms might become more important in the uptake of monoacylglycerols and FFAs).
- The digested fatty acids and 2-monoacylglycerols are resynthesized into triacylglycerols in endoplasmic reticulum in the intestinal epithelial cells, then packaged in lipoprotein particles chylomicrons because they are insoluble in water and secreted by way of the lymph into the blood. The lymphatic vascular system has the capacity to take up and transport particulate that is too large to enter the blood circulation.
- Chylomicrons transport lipids to adipose tissue, heart, and skeletal muscle.

3. Protein

- Function:

- Cytoskeleton, movement (actin and myosin), transport (Hb), immune protection (antibodies), receptors and as catalysts enzymes

- Proteins that come from animals source are known as High quality protein because they contain all essential amino acids.

- Low quality protein don't contain all essential aa and are plants origin.

- The sequence of amino acids in a protein is determined by the genetic code. Four levels of protein structure are commonly defined: Primary structure, Secondary structure, Tertiary structure, and Quaternary structure

- There are 20 different amino acids 8 essential and 12 nonessential amino acids that form human proteins.

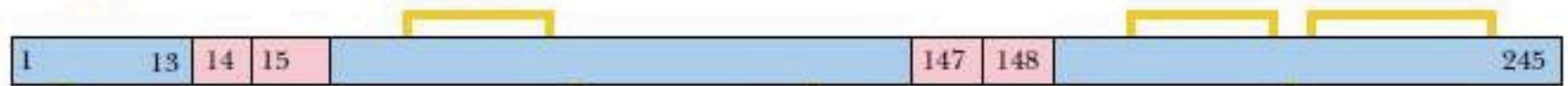
- **Zymogens**

- Inactive proteases enzymes are called **zymogens** or **proenzymes**.
- Zymogen activation by specific proteolysis is an irreversible process.
- Important to switch on processes at the appropriate time and place
- The synthesis of zymogens as inactive precursors prevents them from cleaving proteins prematurely at their sites of synthesis or secretion.

Origin	Zymogen/ proe nzy mes	Activator	Active Protease
Pancreas	Trypsinogen	E n ter op ep tid ase (brush border enzyme)	Tr yp si n
Pancreas	Chymotrypsinogen	Tr yp si n	Chymotrypsin
Pancreas	Procarboxypeptidase	Tr yp si n	Carboxypeptidase
Pancreas	Pr o elast ase	Tr yp si n	Elastase
St o ma ch	Pep si no g en	H ⁺ (pH drop)	Pep si n

- Activation of chymotrypsinogen
 - Chymotrypsinogen is a 245-aa cross-linked by five disulfide bonds.
 - Chymotrypsinogen is converted to an enzymatically active form called π -chymotrypsin when trypsin cleaves the peptide bond joining Arginine 15 and Isoleucine 16.
- The enzymatically active π -chymotrypsin acts upon other π -chymotrypsin molecules, removing two dipeptides, Serine14-Arginine15 and Threonine147-Asparagine148.
 - The end product of this processing pathway is the mature protease α -chymotrypsin, in which the three peptide chains.
 - A (residues 1 through 13), B (residues 16 through 146), and C (residues 149 through 245), remain together because they are linked by two disulfide bonds, one from A to B, and one from B to C.

Chymotrypsinogen (inactive zymogen)



Cleavage at Arg¹⁵
by trypsin

π -Chymotrypsin (active enzyme)

Arginine 15 and Isoleucine 16

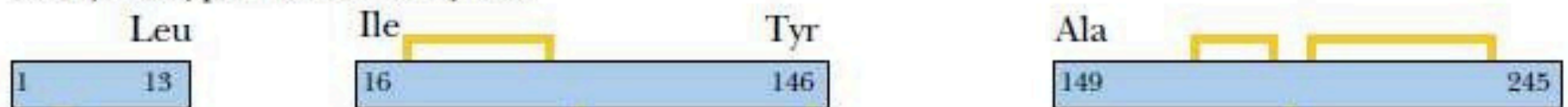


Self digestion at Leu¹³,
Tyr¹⁴⁶, and Asn¹⁴⁸ by
 π -chymotrypsin

14 15
Ser Arg
Serine14-Arginine15

147 148
Thr Asn
Threonine147- Asparagine148

α -Chymotrypsin (active enzyme)



A **disulfide bond** is a covalent bond between two sulfur containing amino acids like two cysteine molecules

Digestion of Proteins

1. Digestion of Proteins in the Stomach

A- **Pepsinogen** is activated to its active form **pepsin** by acidic gastric juice (pH 1.0 to 2.5) that alters the conformation of so that it can cleave itself, producing the active pepsin.

- **Pepsin** acts as an endopeptidase, cleaving peptide bonds at various points within the protein chain.

B- **Stomach acidity**: causes dietary proteins denaturation, this serves to inactivate the proteins and partially unfolds them

such that they are better substrates for proteases.

- Smaller peptides and some free amino acids are produced.

2. Digestion of Proteins by Pancreas Enzymes

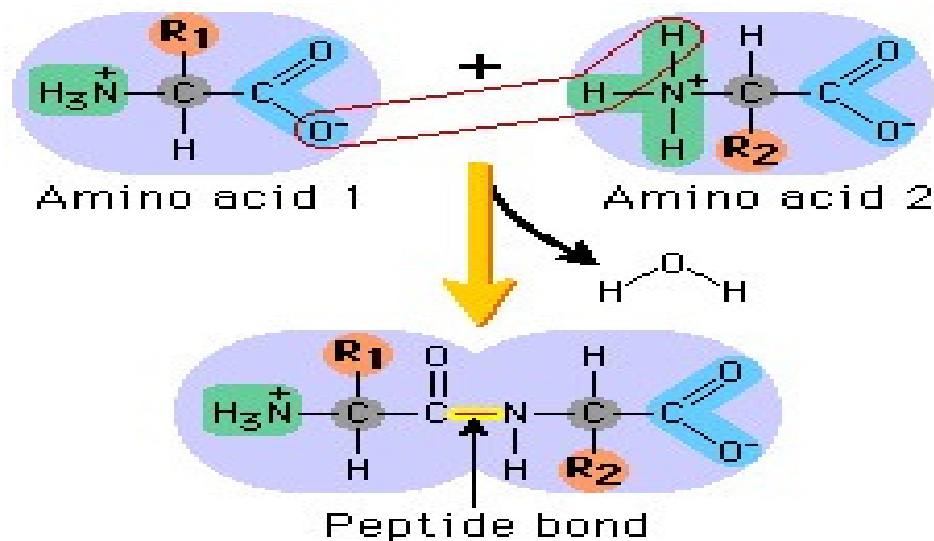
Bicarbonate causes raises the pH such that the pancreatic proteases can be active.

1. Trypsinogen is activated to trypsin by enteropeptidase (protease) secreted by the brush-border cells of the small intestine.

Trypsin catalyzes conversion of:

2. Chymotrypsinogen to chymotrypsin: that favors residues that contain hydrophobic or acidic amino acids.
3. Proelastase to elastase: that cleaves elastin and proteins with small side chains (alanine, glycine, or serine).
4. Procarboxypeptidases to carboxypeptidases.

- Carboxypeptidase A preferentially releases hydrophobic amino acids.
- Carboxypeptidase B releases basic amino acids (arginine and lysine).
- **These enzymes are exopeptidases remove amino acids from the carboxyl ends of peptide chains.**
- Sequences of amino acids in a peptide are read from the amino terminal end to the carboxy-terminal end.



3. Digestion of Proteins by Enzymes from Intestinal Cells

- Aminopeptidases, located on the brush border, cleave one amino acid at a time from the amino end of peptides.
- Amino acids are absorbed from the intestinal lumen through Na⁺-dependent transport systems and through facilitated diffusion.