

# CARBOHYDRATE METABOLISM

**Metabolism:** is the total chemical changes which takes place in the living cell

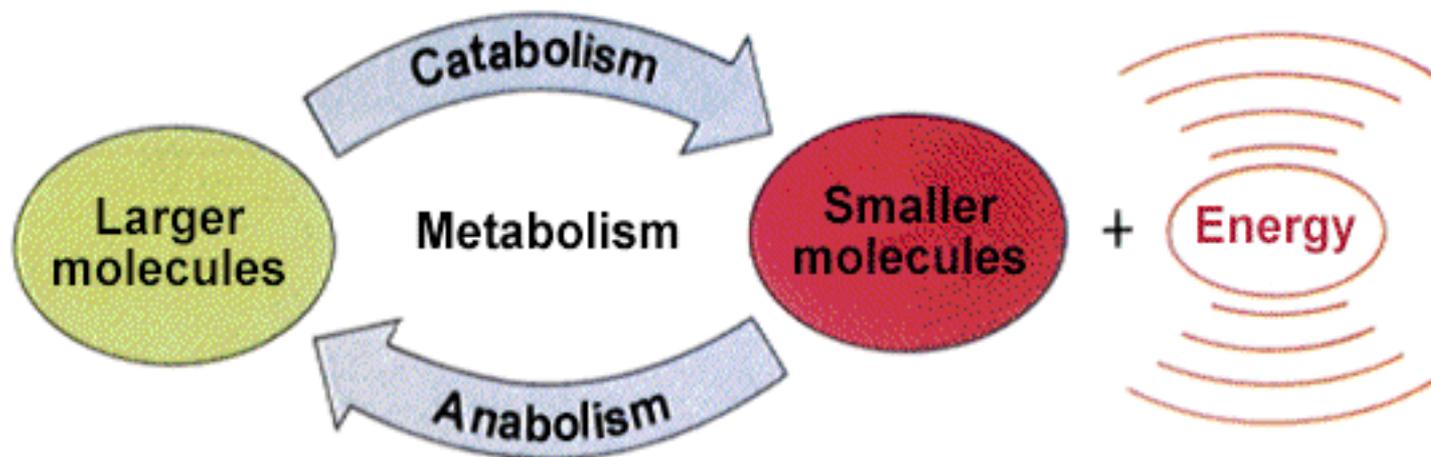
Anabolic and catabolic reaction are collectively called metabolism

metabolism

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Anabolic reaction  
(formation complex end  
Product from simple compound)

catabolic reaction  
(breakdown complex molecule  
such as polysaccharide , protein  
lipid to a few simple molecules  
like CO<sub>2</sub>, H<sub>2</sub>O, NH<sub>3</sub>)

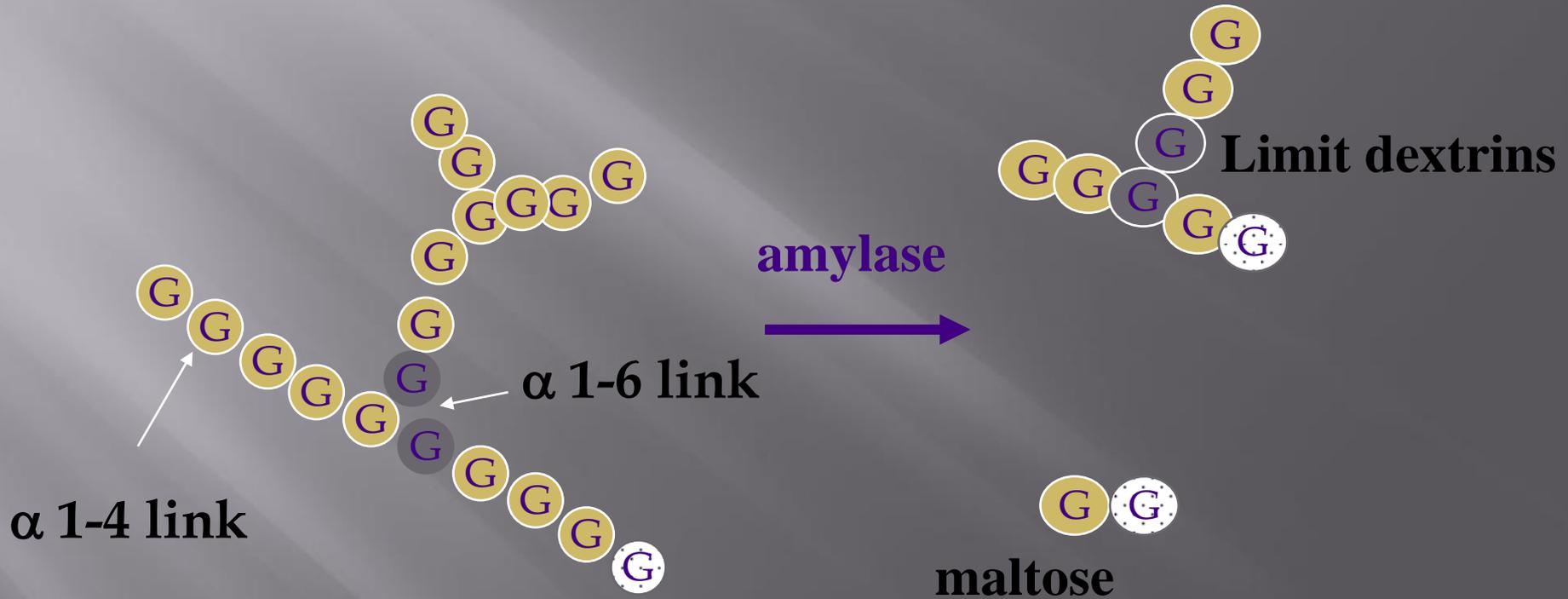


# Digestion of carbohydrate

Location of digestion	enzyme	substrate	product
Mouth	ptyalin	starch	maltose+ dextrine isomaltose
Stomach	no enzyme		
Small intestine	amylase	starch+dextrin	maltose
Intestinal mucosal	maltase	maltose	glucose +glucose
	lactase	lactose	glucose + galactose
	invertase	sucrose	glucose +fructose
	dextrinase	isomaltose	glucose +glucose

# Digestion

- Pre-stomach – Salivary amylase : a 1-4 endoglycosidase

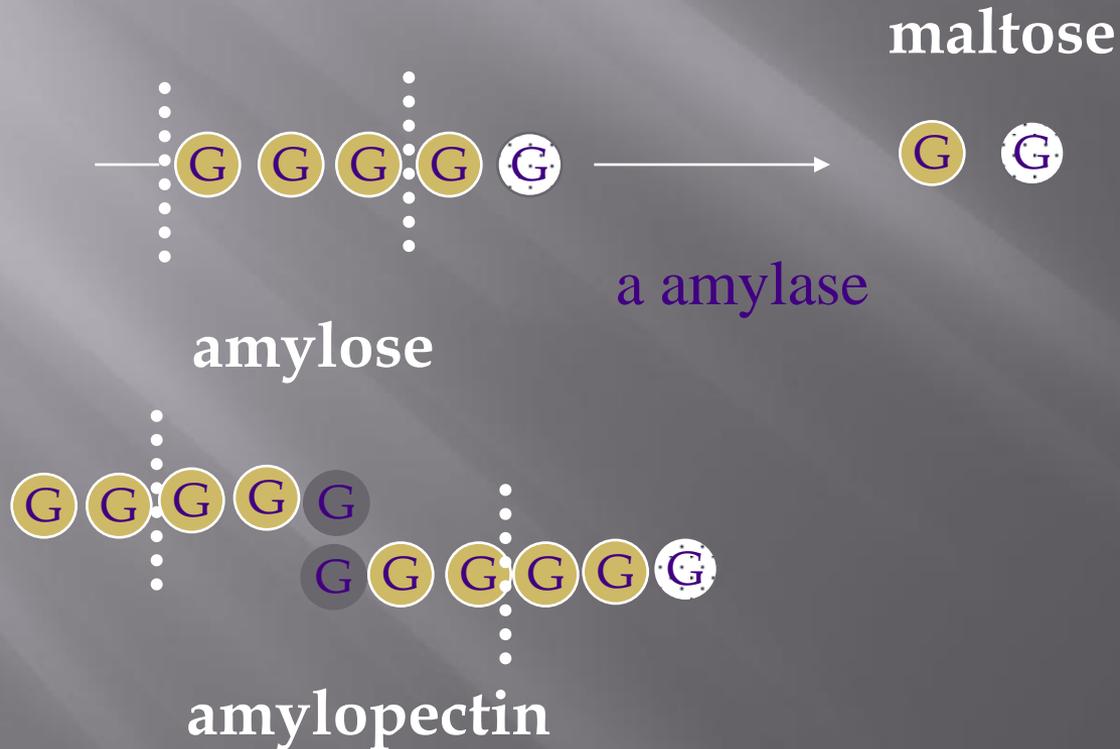


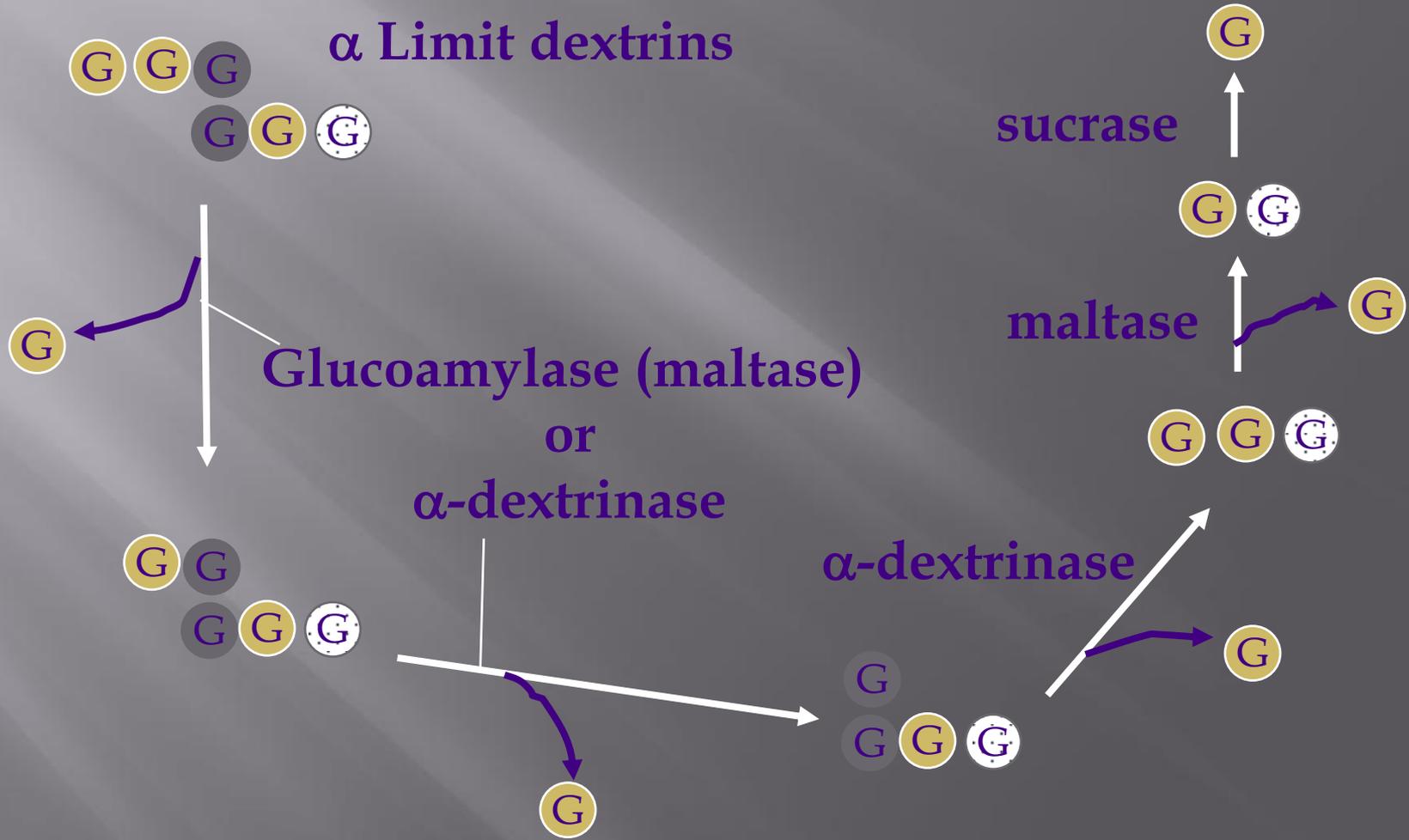
# Stomach

Not much carbohydrate digestion

# Small Intestine

- Pancreatic enzymes  
α-amylase





**A.** More than 60% of our foods are carbohydrates. Starch, glycogen, sucrose, lactose and cellulose are the chief carbohydrates in our food. Before intestinal absorption, they are hydrolysed to hexose sugars (glucose, galactose and fructose).

**B.** A family of a glycosidases that degrade carbohydrate into their monohexose components catalyzes hydrolysis of glycosidic bonds. These enzymes are usually specific to the type of bond to be broken.

## Digestion of carbohydrate by salivary $\alpha$ -amylase (ptyalin) in the mouth:

- A. This enzyme is produced by salivary glands. Its optimum pH is 6.7.
  - B. It is activated by chloride ions ( $\text{Cl}^-$ ).
  - C. It acts on cooked starch and glycogen breaking  $\alpha$  1-4 bonds, converting them into maltose [a disaccharide containing two glucose molecules attached by  $\alpha$  1-4 linkage]. This bond is not attacked by  $\beta$ -amylase.
- Because both starch and glycogen also contain 1-6 bonds, the resulting digest contains isomaltose [a disaccharide in which two glucose molecules are attached by 1-6 linkage].
- E. Because food remains for a short time in the mouth, digestion of starch and glycogen may be incomplete and gives a partial digestion products called: starch dextrans (amylodextrin, erythrodextrin and achrodextrin).
  - F. Therefore, digestion of starch and glycogen in the mouth gives maltose, isomaltose and starch dextrans.

III. In the stomach: carbohydrate digestion stops temporarily due to the high acidity which inactivates the salivary - amylase.

IV. Digestion of carbohydrate by the pancreatic - amylase small intestine in the small intestine.

A.  $\alpha$ -amylase enzyme is produced by pancreas and acts in small intestine. Its optimum pH is 7.1.

B. It is also activated by chloride ions.

C. It acts on cooked and uncooked starch, hydrolysing them into maltose and isomaltose.

Final carbohydrate digestion by intestinal enzymes:

A. The final digestive processes occur at the small intestine and include the action of several disaccharidases. These enzymes are secreted through and remain associated with the brush border of the intestinal mucosal cells.

## B. The disaccharidases include:

1. Lactase ( $\beta$ -galactosidase) which hydrolyses lactose into two molecules of glucose and galactose:

Lactase



2. Maltase ( $\alpha$ -glucosidase), which hydrolyses maltose into two molecules of glucose:

Maltase



3. Sucrose ( $\alpha$ -fructofuranosidase), which hydrolyses sucrose into two molecules of glucose and fructose:

Sucrose



4.  $\alpha$  - dextrinase (oligo-1,6 glucosidase) which hydrolyze (1,6) linkage of isomaltose.

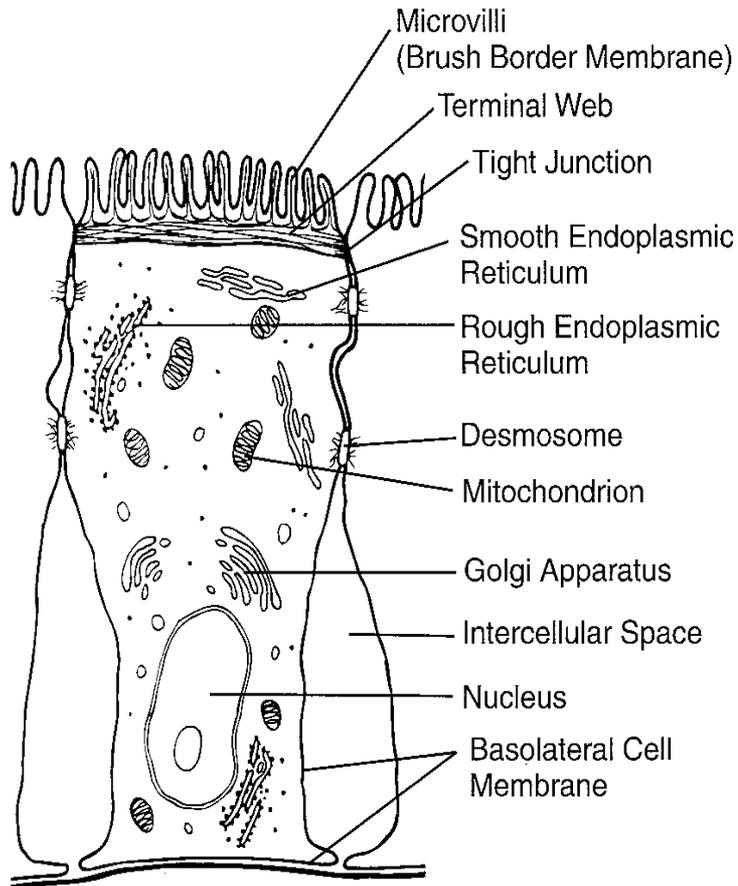
Dextrinase



## VI. Digestion of cellulose:

- A. Cellulose contains  $\beta(1-4)$  bonds between glucose molecules.
- B. In humans, there is no  $\beta(1-4)$  glucosidase that can digest such bonds. So cellulose passes as such in stool.
- C. Cellulose helps water retention during the passage of food along the intestine  $\rightarrow$  producing larger and softer feces  $\rightarrow$  preventing constipation.

# Absorption



**Figure 4-5.** Ultrastructure of a small intestinal epithelial cell (enterocyte).

Portal for transport of virtually all nutrients

# Absorption of carbohydrate

- A.** The end products of carbohydrate digestion are monosaccharides: glucose, galactose and fructose. They are absorbed from the jejunum to portal veins to the liver, where fructose and galactose are transformed into glucose.
- B.** Two mechanisms are responsible for absorption of monosaccharides: **active transport** (against concentration gradient i.e. from low to high concentration) and **passive transport** (by facilitated diffusion).
- C.** For active transport to take place, the structure of sugar should have:
1. Hexose ring.
  2. OH group at position 2 at the right side. Both of which are present in glucose and galactose. Fructose, which does not contain -OH group to the right at position 2 is absorbed more slowly than glucose and galactose by passive diffusion (slow process).

## II. Mechanisms of absorption:

### A. Active transport:

#### 1. Mechanism of active transport:

- a) In the cell membrane of the intestinal cells, there is a mobile carrier protein called sodium dependant glucose transporter (SGL T-1) It transports glucose to inside the cell using energy. The energy is derived from sodium-potassium pump. The transporter has 2 separate sites, one for sodium and the other for glucose. It transports them from the intestinal lumen across cell membrane to the cytoplasm. Then both glucose and sodium are released into the cytoplasm allowing the carrier to return for more transport of glucose and sodium.

- b) The sodium is transported from high to low concentration (with concentration gradient) and at the same time causes the carrier to transport glucose against its concentration gradient. The  $\text{Na}^+$  is expelled outside the cell by sodium pump. Which needs ATP as a source of energy. The reaction is catalyzed by an enzyme called "Adenosine triphosphatase (ATPase)". Active transport is much more faster than passive transport.
- c) Insulin increases the number of glucose transporters in tissues containing insulin receptors e.g. muscles and adipose tissue.

## 2. Inhibitors of active transport:

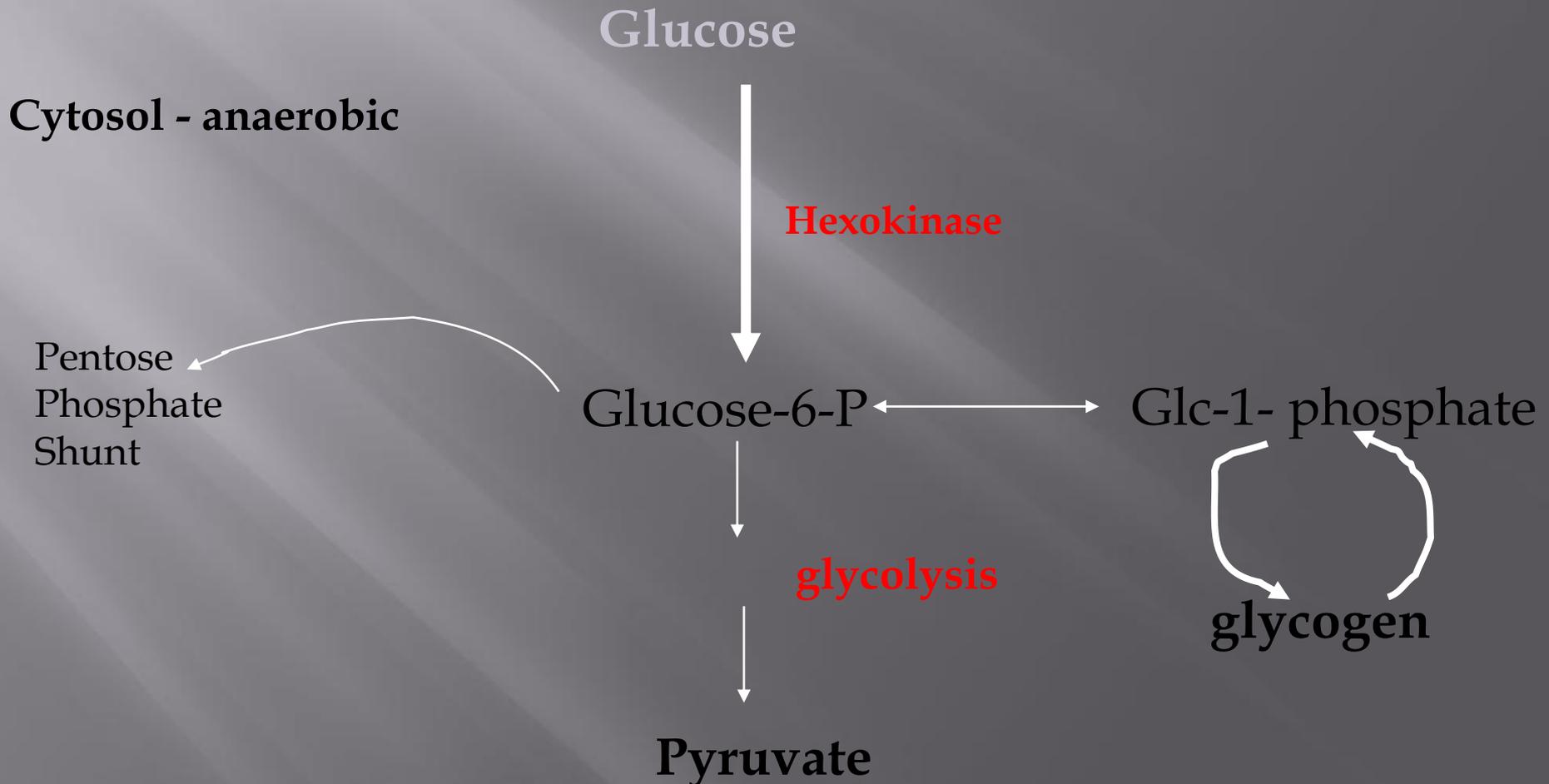
- a) Ouabin (cardiac glycoside): Inhibits adenosine triphosphatase (ATPase) necessary for hydrolysis of ATP that produces energy of sodium pump.
- b) Phlorhizin; Inhibits the binding of sodium in the carrier protein.

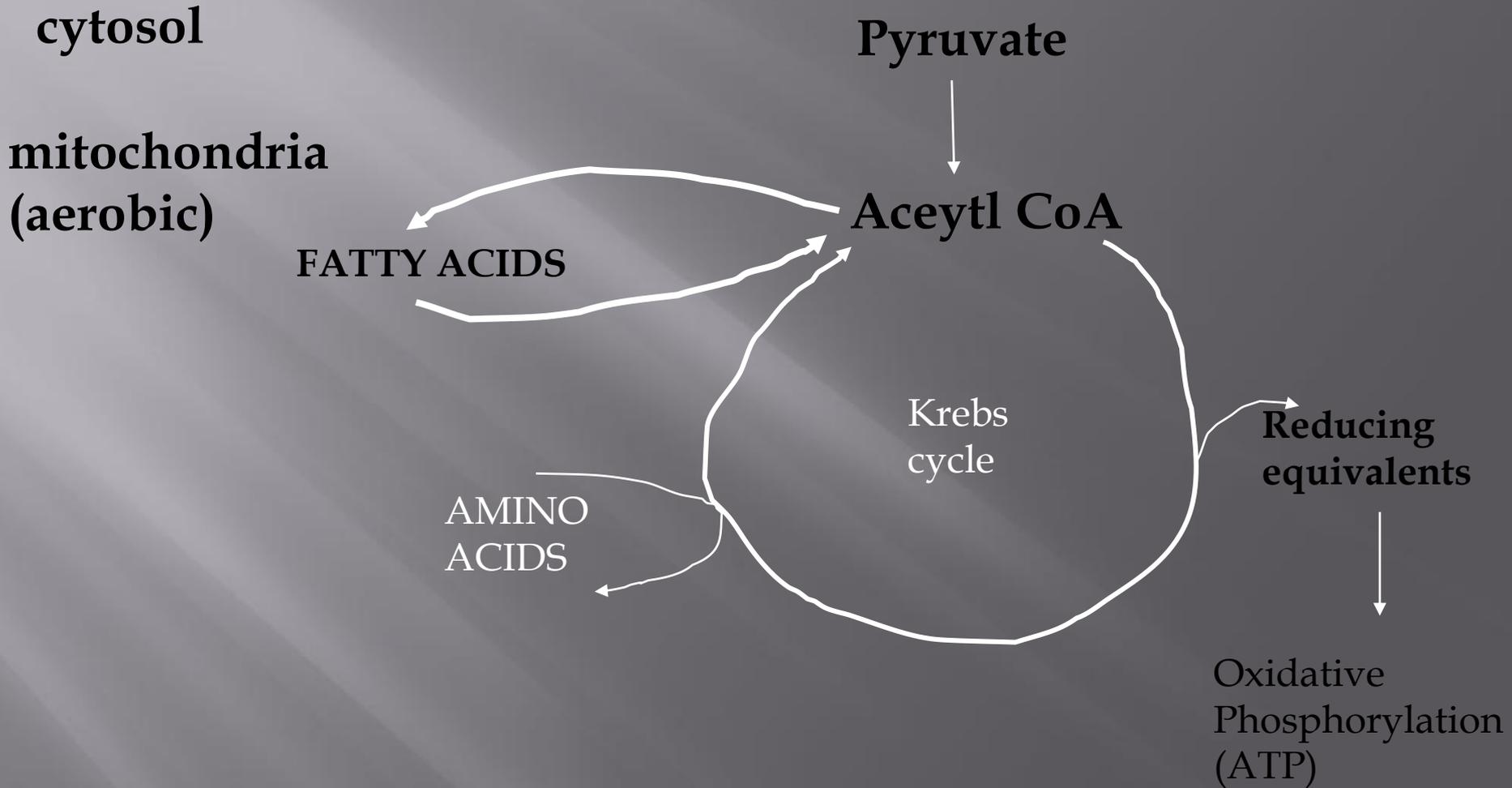
## B. Passive transport (facilitated diffusion):

Sugars pass with concentration gradient i.e. from high to low concentration. It needs no energy. It occurs by means of a sodium independent facilitative transporter (GLUT -5). Fructose and pentoses are absorbed by this mechanism. Glucose and galactose can also use the same transporter if the concentration gradient is favorable.

# Carbohydrates

- Serve as primary source of energy in the cell
- Central to all metabolic processes





## IV. Fate of absorbed sugars:

Monosaccharides (glucose, galactose and fructose) resulting from carbohydrate digestion are absorbed and undergo the following:

A. Uptake by tissues (liver):

After absorption the liver takes up sugars, where galactose and fructose are converted into glucose.

B. Glucose utilization by tissues:

Glucose may undergo one of the following fate:

1. **Oxidation:** through

a) Major pathways (glycolysis and Krebs' cycle) for production of energy.

b) Hexose monophosphate pathway: for production of ribose, deoxyribose

and  $\text{NADPH} + \text{H}^+$

c) Uronic acid pathway, for production of glucuronic acid, which is used in

detoxication and enters in the formation of mucopolysaccharide.

2. **Storage:** in the form of:

a) Glycogen: glycogenesis.

b) Fat: lipogenesis.

3. **Conversion:** to substances of biological importance:

a) Ribose, deoxyribose → RNA and DNA.

b) Lactose → milk.

c) Glucosamine, galactosamine → mucopolysaccharides.

d) Glucuronic acid → mucopolysaccharides.

e) Fructose → in semen.

# Glucose Oxidation

*major Pathway*

## oxidation of glucose

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- 1- anaerobic oxidation (glycolysis)
- 2- aerobic oxidation (Krebs cycle)

## I. Glycolysis (Embden Meyerhof Pathway):

### A. Definition:

1. Glycolysis means oxidation of glucose to give pyruvate (in the presence of oxygen) or lactate (in the absence of oxygen).

## B. Steps:

### Stages of glycolysis

#### 1. Stage one (the energy requiring stage):

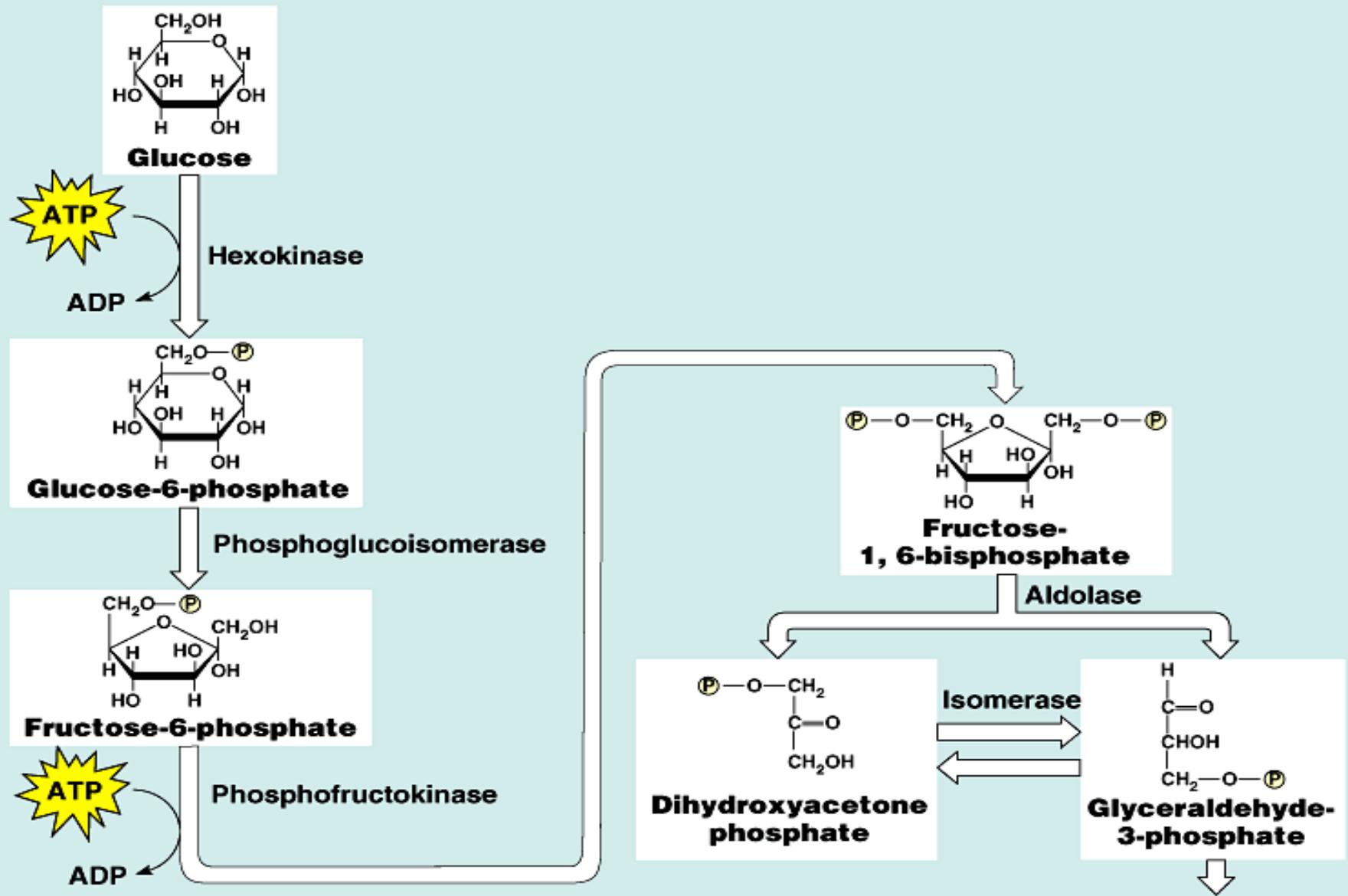
- a) One molecule of glucose is converted into two molecules of glyceraldehyde-3-phosphate.
- b) These steps requires 2 molecules of ATP (energy loss)

#### 2. Stage two (the energy producing stage):

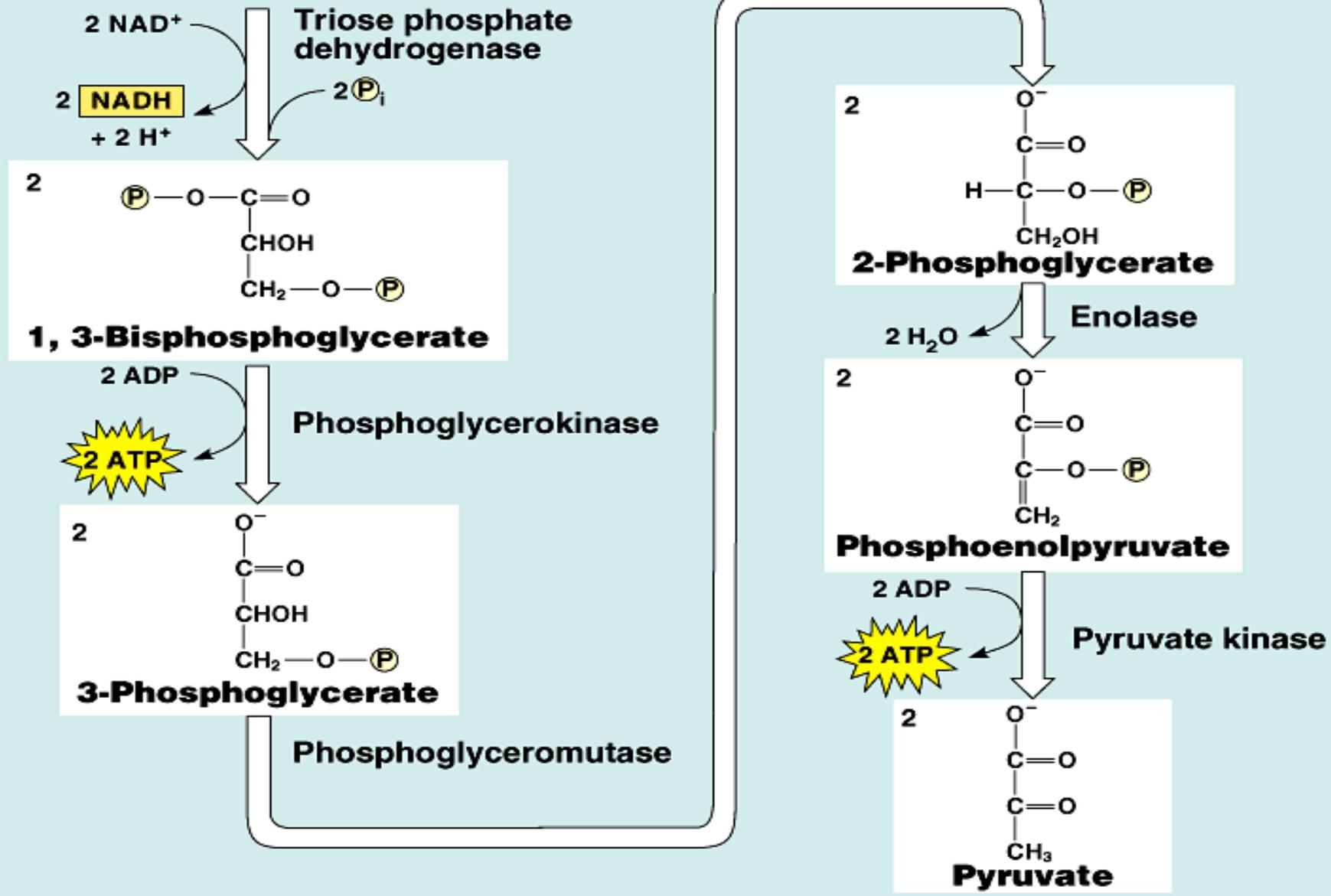
- a) The 2 molecules of glyceraldehyde-3-phosphate are converted into pyruvate (aerobic glycolysis) or lactate (anaerobic glycolysis).
- b) These steps produce ATP molecules (energy production).

#### C). Energy (ATP) production of glycolysis:

ATP production = ATP produced - ATP utilized



**Energy Investment Phase (steps 1-5)**



## Energy-Payoff Phase (Steps 6-10)

## Energy production of glycolysis:

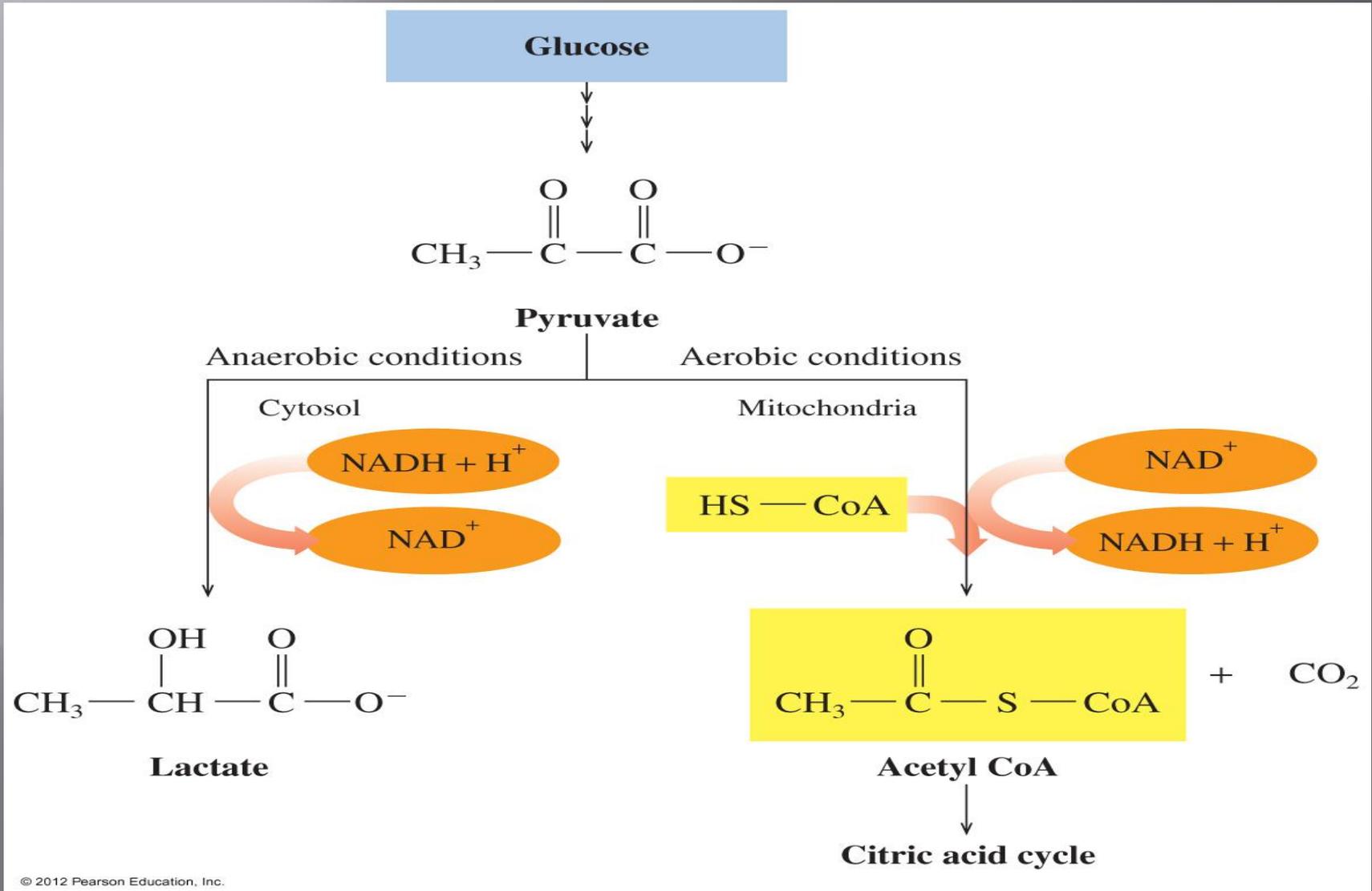
	ATP produced	ATP utilized	Net energy
In absence of oxygen (anaerobic glycolysis)	4 ATP (Substrate level phosphorylation) 2ATP from 1,3 DPG. 2ATP from phosphoenol pyruvate	2ATP From glucose to glucose -6-p. From fructose -6-p to fructose 1,6 p.	2 ATP
In presence of oxygen (aerobic glycolysis)	4 ATP (substrate level phosphorylation) 2ATP from 1,3 BPG. 2ATP from phosphoenol pyruvate.	2ATP -From glucose to glucose -6-p. From fructose -6-p to fructose 1,6 p.	6 ATP Or 8 ATP
	+ 4ATP or 6ATP (from oxidation of 2 NADH + H in mitochondria).		

## D. oxidation of extramitochondrial $\text{NADH} + \text{H}^+$ :

1. cytoplasmic  $\text{NADH} + \text{H}^+$  cannot penetrate mitochondrial membrane, however, it can be used to produce energy (4 or 6 ATP) by respiratory chain phosphorylation in the mitochondria.
2. This can be done by using special carriers for hydrogen of  $\text{NADH} + \text{H}^+$ . These carriers are either dihydroxyacetone phosphate (Glycerophosphate shuttle) or oxaloacetate (aspartate malate shuttle).
  - a) Glycerophosphate shuttle:
    - 1) It is important in certain muscle and nerve cells.
    - 2) The final energy produced is 4 ATP.
    - 3) Mechanism:
      - The coenzyme of cytoplasmic glycerol-3-phosphate dehydrogenase is  $\text{NAD}^+$ .
      - The coenzyme of mitochondrial glycerol-3-phosphate dehydrogenase is FAD.
      - Oxidation of FADH, in respiratory chain gives 2 ATP. As glycolysis gives 2 cytoplasmic  $\text{NADH} + \text{H}^+ \rightarrow 2$  mitochondrial FADH,  $2 \times 2 \text{ ATP} \rightarrow = 4 \text{ ATP}$ .
  - b) Malate – aspartate shuttle:
    - 1) It is important in other tissues particularly liver and heart.
    - 2) The final energy produced is 6 ATP.

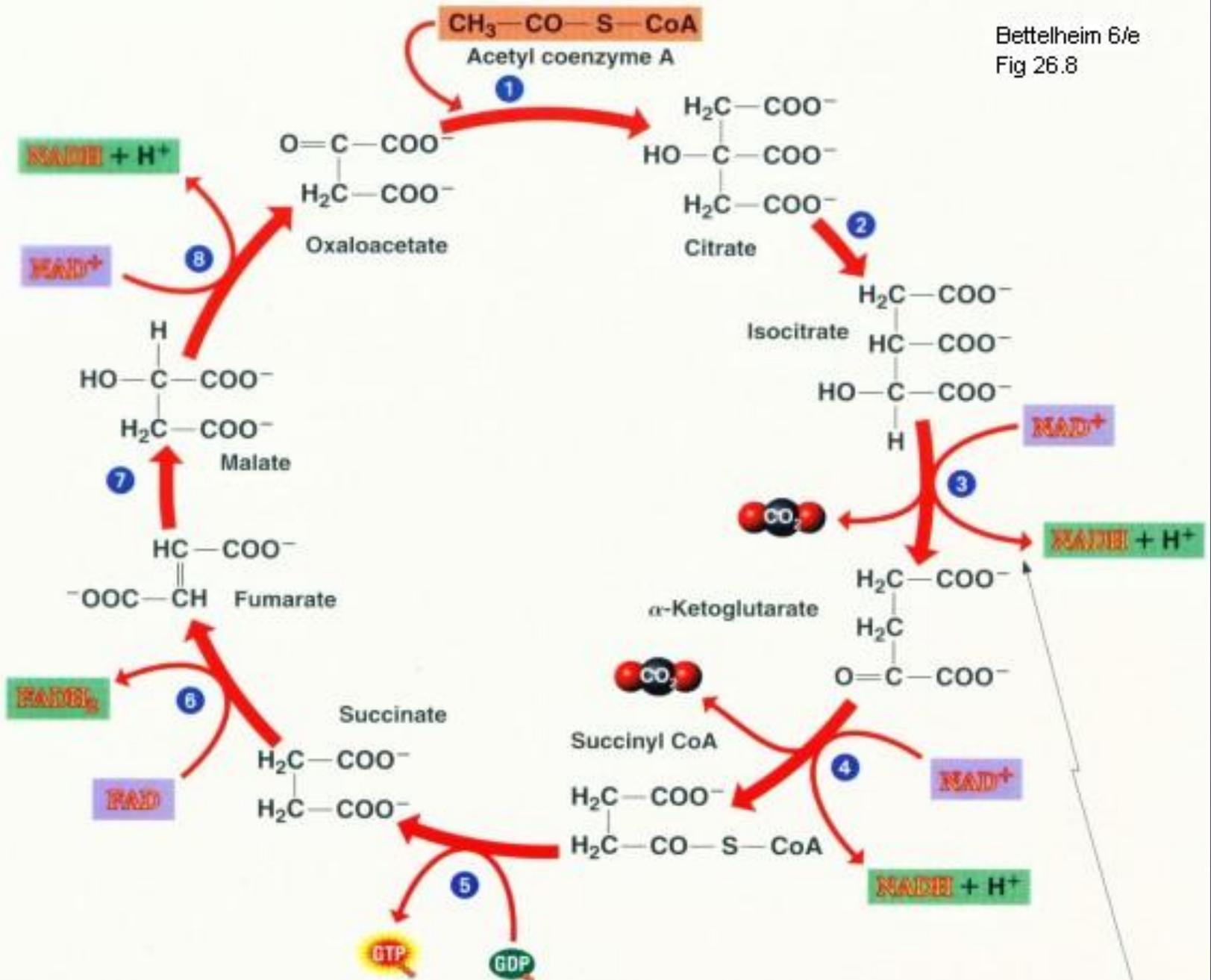
# Pyruvate Pathways, Aerobic and Anaerobic

Pyruvate is converted to acetyl CoA under aerobic conditions and to lactate under anaerobic conditions.



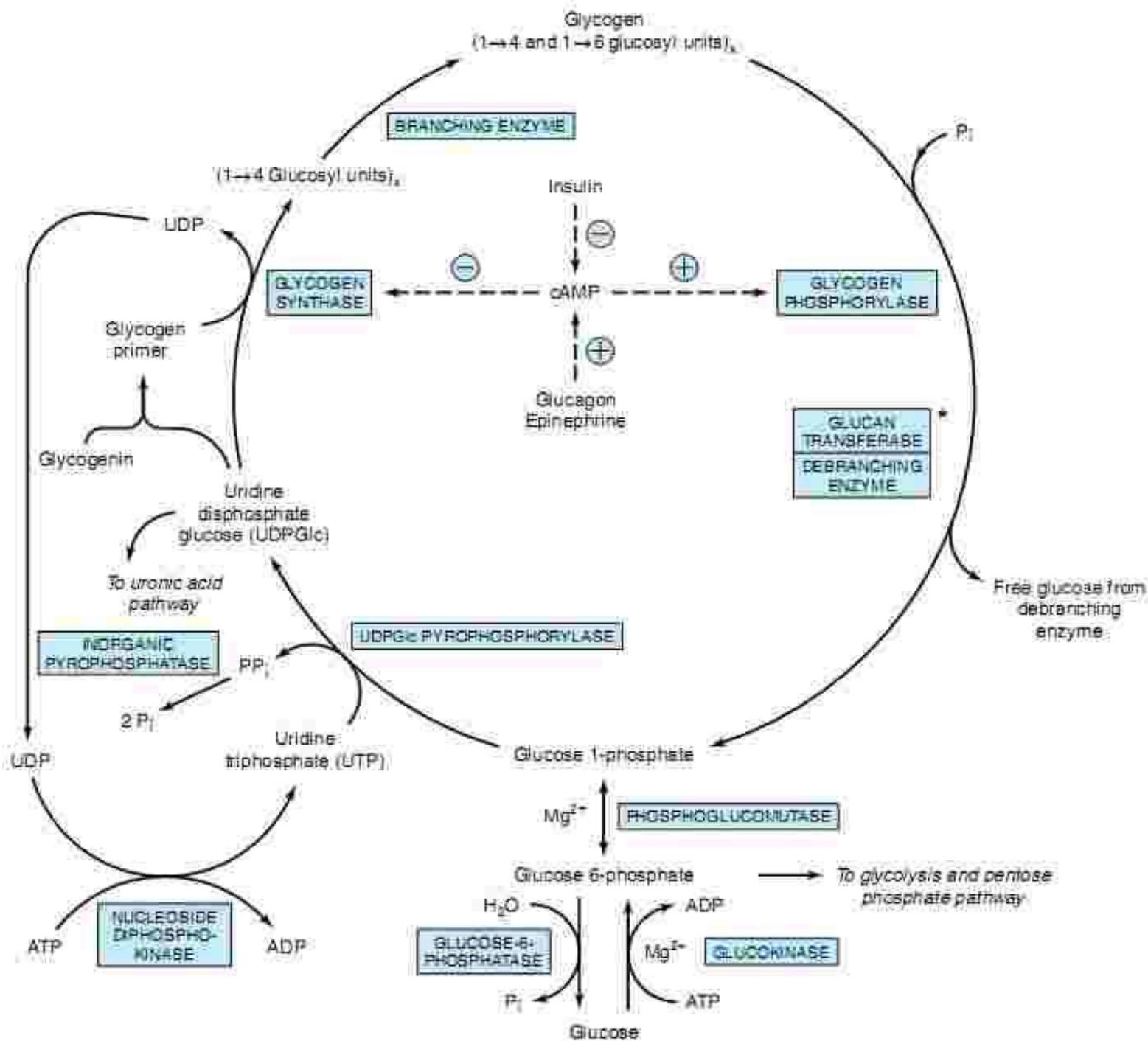
# Aerobic oxidation

Bettelheim 6/e  
Fig 26.8



# Glycogenesis & glycogenolysis

In the liver and muscles, most of the glucose is changed into glycogen by the process of **glycogenesis (anabolism)**. Glycogen is stored in the liver and muscles until needed at some later time when glucose levels are low. If blood glucose levels are low, then epinephrine and glucagon hormones are secreted to stimulate the conversion of glycogen to glucose. This process is called **glycogenolysis (catabolism)**.

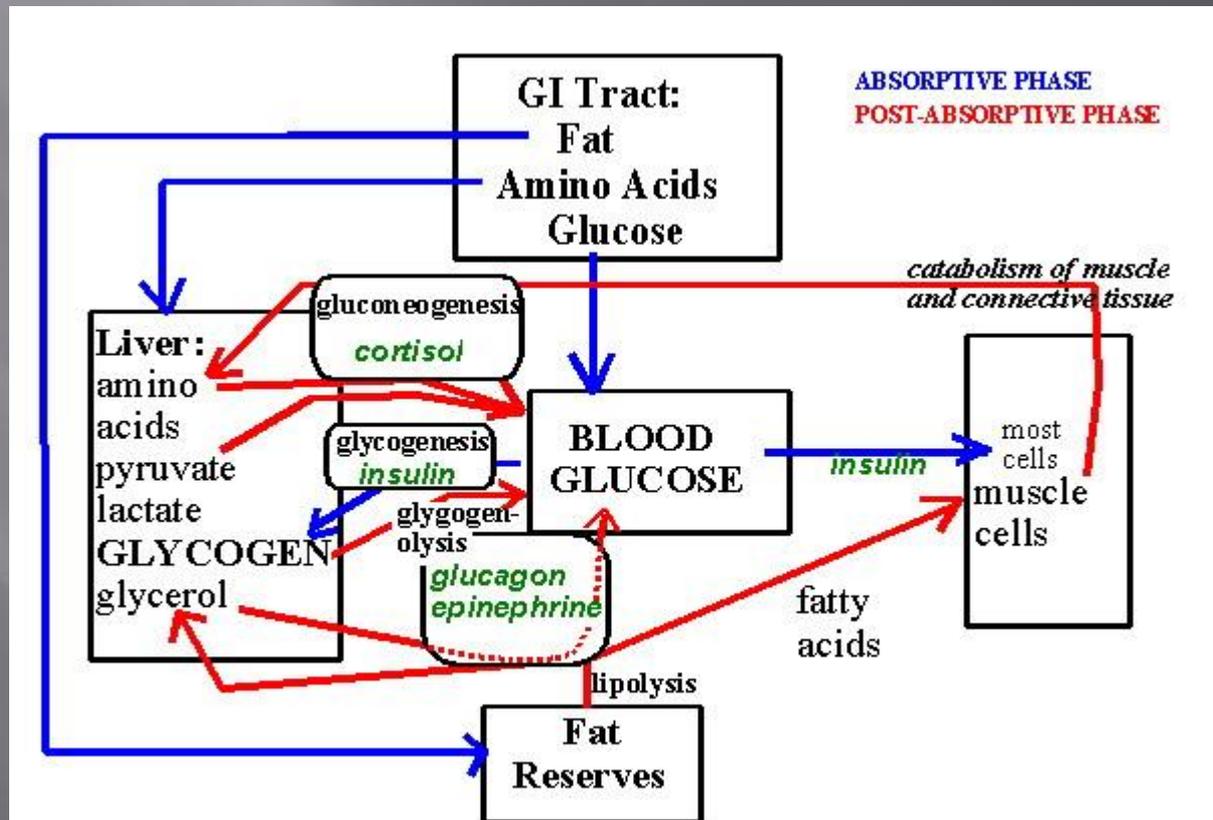


# Blood glucose

## Sources of blood glucose

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- 1- diet (carbohydrate)
  - 2- breakdown of glycogen (glycogenolysis )
  - 3- non carbohydrate sources (gluconeogenesis )
- A- amino acid  
B- glycerol



**Q- what are the benefits of blood glucose?**

# Abnormalities in blood glucose level

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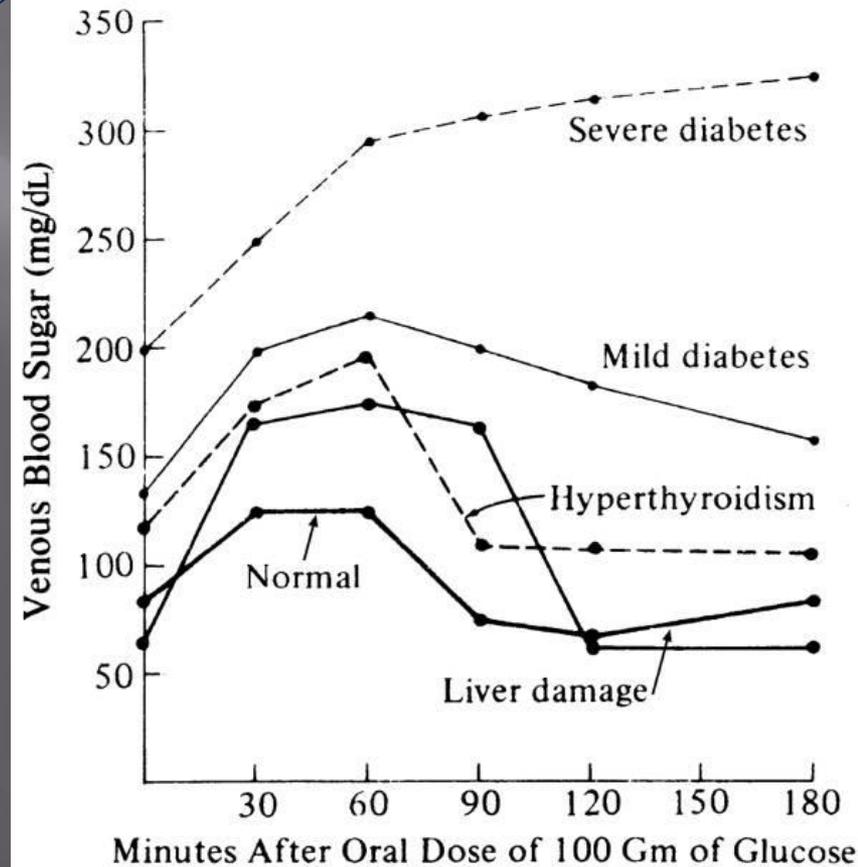
- 1- hyperglycemia
- 2- diabetes mellitus
- 3- hypoglycemia

**Q-what are the causes of hypoglycemia , hyperglycemia ?**

# Determination of blood glucose level

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- 1- fasting blood sugar (F.B.S )
- 2- random blood sugar (R.B.S)
- 3- post prandial test (p.p.t)
- 4- oral glucose tolerance test (O.G.T.T)



**Thank you**