# SEVENTH CHAPTER: Carbohydrate metabolism

## I. Catabolism

Carbohydrates have different roles within the body: energy production or storage.

### I.1. Glycolysis

Glycolysis is the metabolic pathway that converts glucose into pyruvate and, in most organisms, occurs in the liquid part of cells (the cytosol). Glycolysis is a sequence of ten reactions catalyzed by enzymes:

1) **Transphosphorylation reaction of glucose into glucose-6-phosphate** catalyzed by glucokinase in the liver or by hexokinase in other organs. This reaction consumes one molecule of ATP.
2) **Isomerization reaction of glucose-6-phosphate to fructose-6-phosphate** catalyzed by 6-phosphofructo-kinase.
3) **Transphosphorylation reaction of fructose-6-phosphate into fructose-1,6-biphosphate** catalyzed by 6-phosphofructo-kinase. This reaction consumes one molecule of ATP.
4) **Réaction de dégradation du fructose-1,6-biphosphate en dihydroacétone-phosphate et en glycéraldéhyde-3-phosphate** catalysée par l'aldolase.
5) **Isomerization reaction of dihydroacetone-phosphate to glyceraldehyde-3-phosphate** catalyzed by triosephosphate isomerase.
6) **Phosphorylation reaction of glyceraldehyde-3-phosphate to 1,3-biphosphoglycerate** catalyzed by glyceraldehyde-3-phosphate dehydrogenase. This reaction requires a phosphate molecule; it also allows the formation of $NADH,H^+$ from $NAD^+$.
7) **Transphosphorylation reaction of 1,3-biphosphoglycerate to 3-phosphoglycerate** catalyzed by phosphoglycerate kinase. This reaction allows the formation of ATP from ADP.
8) **Mutation reaction of 3-phosphoglycerate to 2-phosphoglycerate** catalyzed by phosphoglyceromutase.
9) **Dehydrogenation reaction of 2-phosphoglycerate to phosphoenolpyruvate** catalyzed by enolase. This reaction releases a molecule of $H_2O$.

10) **Transphosphorylation reaction of phosphoenolpyruvate to pyruvate** catalyzed by pyruvate kinase. This reaction allows the formation of ATP from ADP.

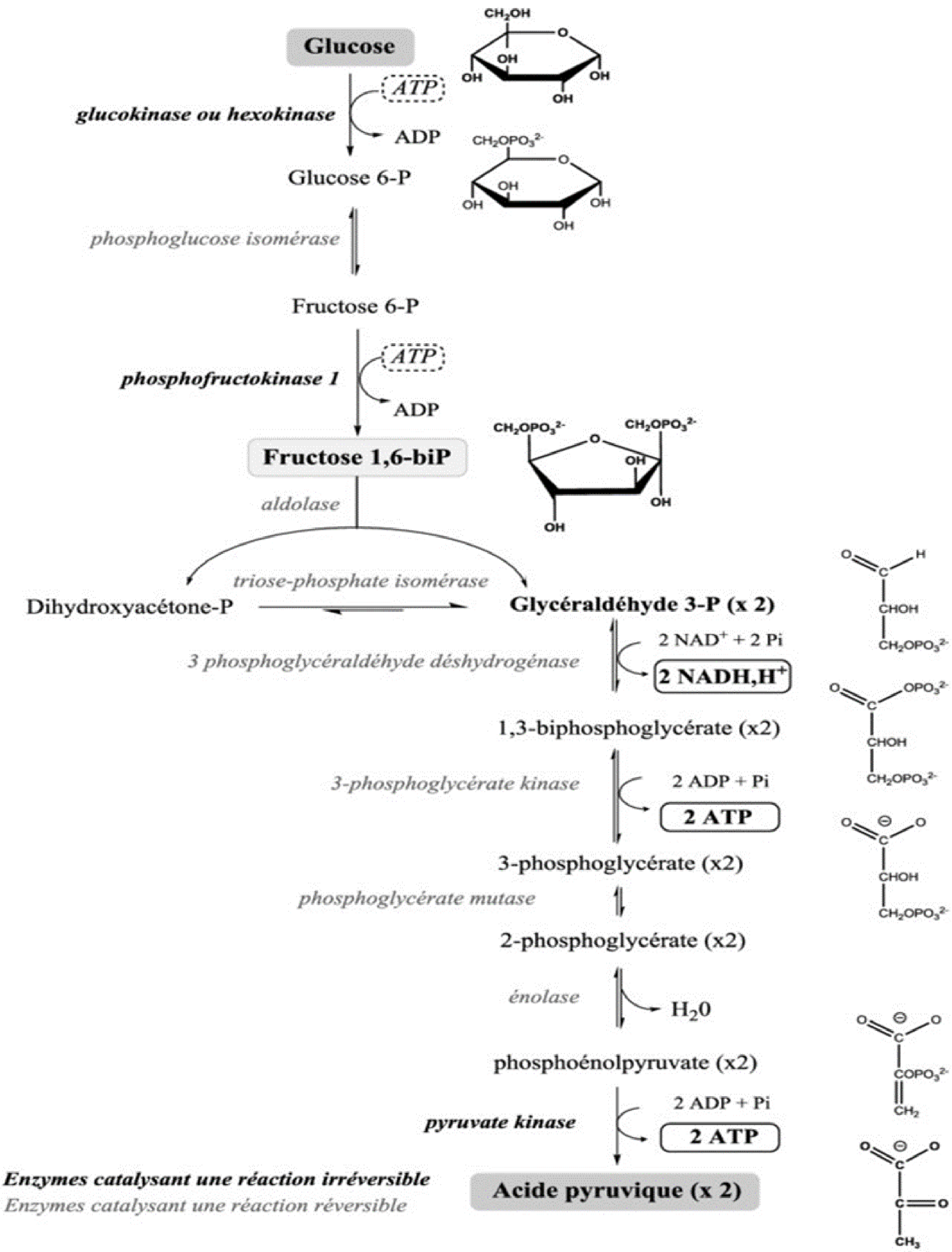


**Fig 1.** Glycolysis.

The energy balance of the degradation of a glucose molecule in glycolysis is the synthesis of 2ATP and the formation of 2 $NADH,H^+$ and 2 pyruvates:

$$Glucose + 2ADP + 2Pi + 2\ NAD^+ \longrightarrow 2\ Pyruvate + 2\ ATP + 2\ NADH,H^+ + 2H_2O$$

## I.2. Krebs cycle

Krebs cycle, also known as the citric acid or tricarboxylic acid cycle, is a cyclic pathway of enzymatic reactions which oxidizes the compounds derived from glucose, fatty acids and amino acids in the matrix of mitochondria. The Krebs cycle involves eight steps which produce in different steps $CO_2$ and $NADH,H^+$ and $FADH_2$.

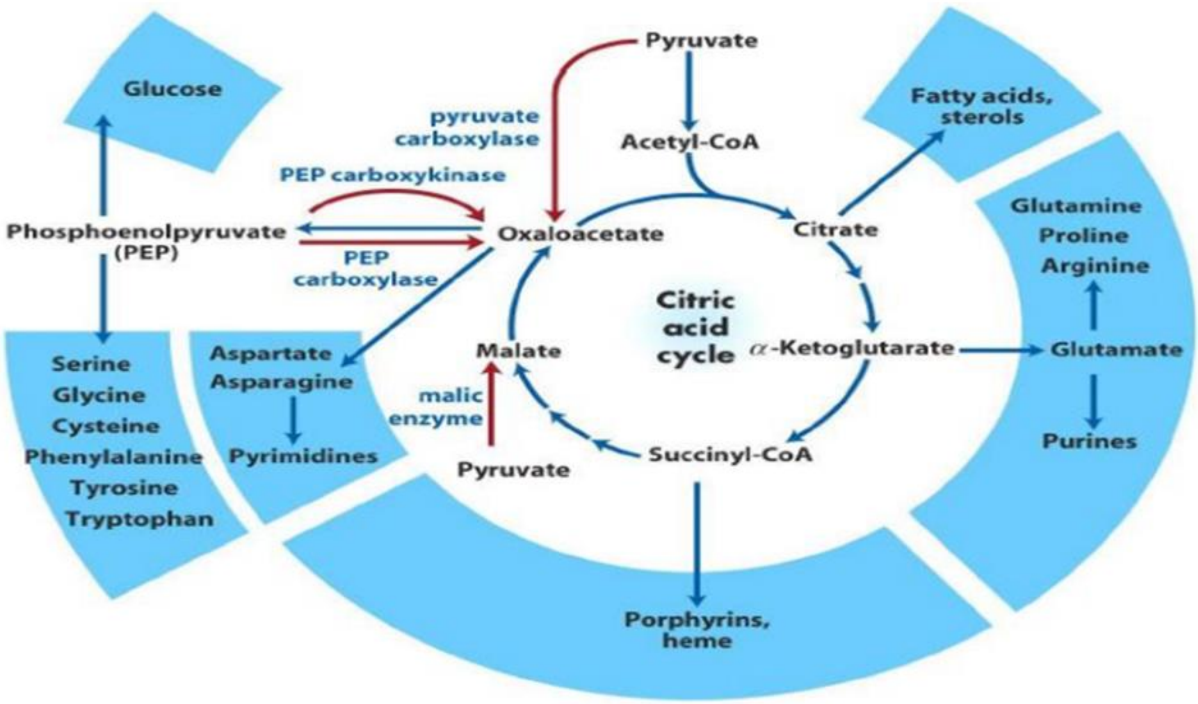


**Fig 2.** Krebs cycle.

1) **Condensation reaction of acetylcoenzyme A (ACoA) and oxaloacetate to citrate** catalyzed by citrate synthase. This reaction requires an $H_2O$ and releases a molecule of CoA-SH.
2) **Isomerization reaction of citrate to isocitrate** catalyzed by aconitase.
3) **Dehydrogenation reaction of isocitrate to oxalosuccinate** catalyzed by isocitrate dehydrogenase. This reaction allows the formation of $NADH,H^+$ from $NAD^+$, and non-

oxidative β-decarboxylation reaction of oxalosuccinate to α-ketoglutarate. This reaction results in the release of $CO_2$.

4) **Oxidative α-decarboxylation reaction of α-ketoglutarate to succinyl-CoA** catalyzed by α-ketoglutarate dehydrogenase. This reaction requires a CoA-SH molecule and results in the release of $CO_2$; it also allows the formation of NADH,$H^+$ from $NAD^+$.
5) **Transphosphorylation reaction of succinyl-CoA to succinate** catalyzed by succinate thiokinase. This reaction requires a phosphate molecule and releases a CoA-SH molecule; it also allows the formation of GTP from GDP.
6) **Dehydrogenation reaction of succinate to fumarate** catalyzed by succinate dehydrogenase. This reaction allows the formation of $FADH_2$ from FAD.
7) **Hydration reaction of fumarate to malate** catalyzed by fumarase. This reaction requires an $H_2O$.
8) **Dehydrogenation reaction of malate to oxaloacetate** catalyzed by malate dehydrogenase. This reaction allows the formation of NADH,$H^+$ from $NAD^+$.

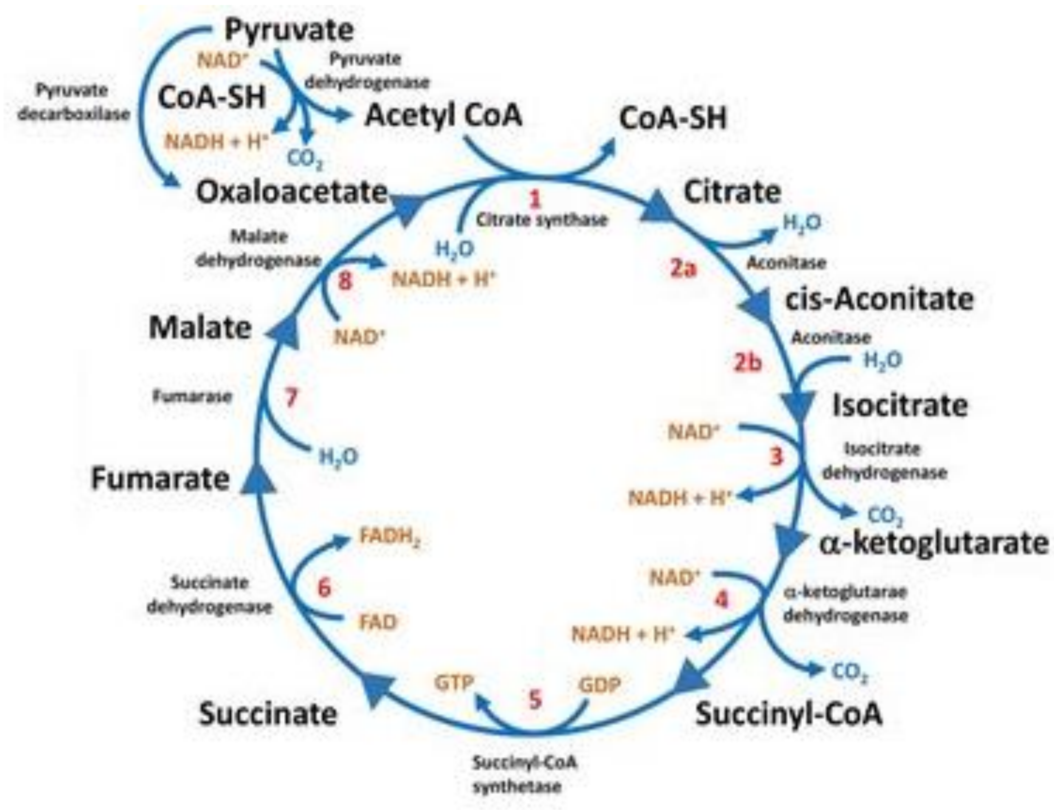


**Fig 3.** Enzymatic reactions of the Krebs cycle.

The results of the Krebs cycle can be written as follows:

Acetyl CoA + 3 NAD+ 1 FAD + GDP + Pi+ 2 $H_2O$ ⟶ 2 $CO_2$ + 3 $NADH_2$ + 1 $FADH_2$ + GTP + 2 $H^+$ + CoA

### I.3. Glycogenolysis

Glycogenolysis is the process of glycogen degradation. Glycogenolysis happens in the liver and kidney to produce glucose for balancing the blood sugar; however, it produces G6P in muscle cells to be used as the energy supplier of myocytes. Glycogenolysis is a sequence of three reactions catalyzed by enzymes:

1) Phosphorolysis of glycogen by glycogen phosphorylase. This enzyme cuts the α (1-4) bond and fixes a phosphate group on carbon 1 of the released glucose, giving glucose-1-phosphate.
2) Isomerization of glucose-1-phosphate to glucose-6-phosphate by phosphoglucomutase. Glucose-6-phosphate can enter into glycolysis in the liver and muscle.
3) Hydrolysis of glucose-6-phosphate to glucose by glucose-6-phosphatase.

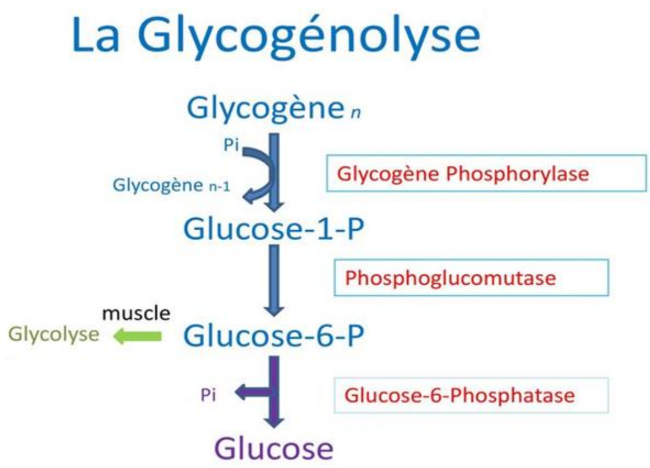


**Fig 4.** Glycogenolysis.

## II. Anabolism

### II.1. Gluconeogenesis

Gluconeogenesis is a metabolic pathway that results in the biosynthesis of glucose from certain non-carbohydrate carbon substrates. It used by humans and many other animals to maintain blood sugar levels, avoiding low levels (hypoglycemia).

Gluconeogenesis is a pathway consisting of a series reactions. The pathway occurs in the liver, with a minor contribution from the kidney, the intestine, and muscle, in the mitochondria or cytoplasm of those cells. Many of the reactions are the reverse of steps found in glycolysis.

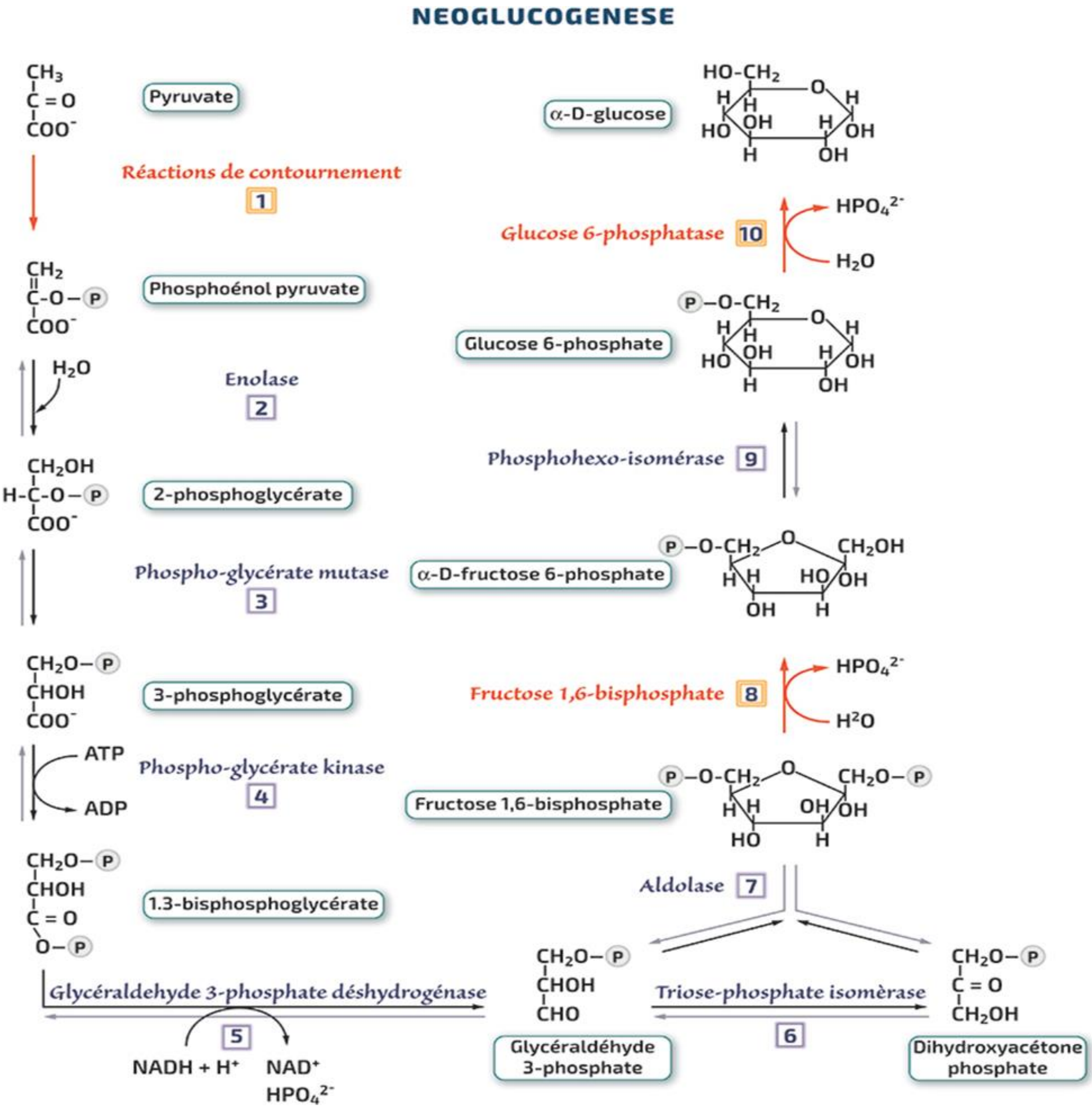


**Fig 5.** Gluconeogenesis.

The results of the formation of glucose from 2 pyruvates are as follows:

$$2\ \text{pyruvate} + 4\ ATP + 2\ GTP + 2\ NADH,H^+ \longrightarrow \text{Glucose} + 4\ ADP + 2\ GDP + 6\ Pi + 2\ NAD^+$$

## II.2. Glycogenesis

Glycogenesis is the process of glycogen synthesis or the process of converting glucose into glycogen in which glucose molecules are added to chains of glycogen for storage. Glycogenesis primarily occurring in the liver and muscle tissues. It is a sequence of fous reactions:

1) Glucose is converted into glucose 6-phosphate by the action of glucokinase or hexokinase with conversion of ATP to ADP.
2) Glucose-6-phosphate is converted into glucose-1-phosphate by the action of phosphoglucomutase, passing through the glucose-1,6-bisphosphate.
3) Glucose-1-phosphate is converted into UDP-glucose by the action of the enzyme UDP-glucose pyrophosphorylase. Pyrophosphate is formed, which is later hydrolysed by pyrophosphatase into two phosphate molecules.
4) The enzyme glycogenin is needed to create initial short glycogen chains forming α(1→4) bonds, which are then lengthened and branched by the other enzymes of glycogenesis. glycogen synthase binds to the growing glycogen chain and adds UDP-glucose.

Branches are made by glycogen branching enzyme (also known as amylo-α(1:4)→α(1:6)transglycosylase).

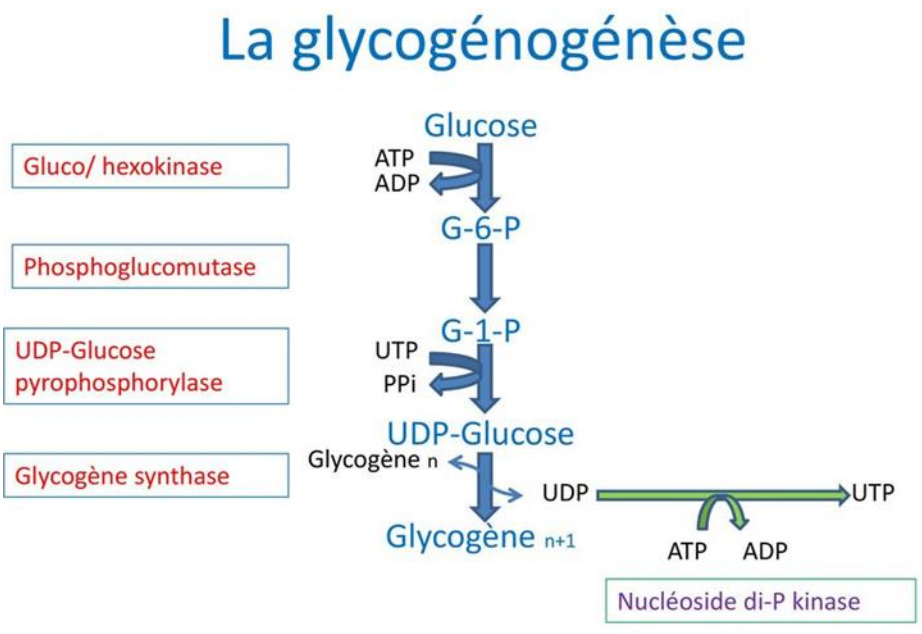


**Fig 5.** Glycogenesis.