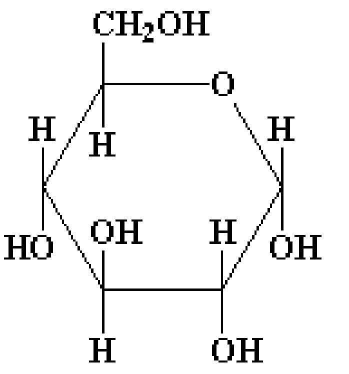
# Carbohydrate metabolism

The name carbohydrate arises from the basic molecular formula
(CH2O)n
(C  H2O)n hydrates of carbon
n=3 or more.




glucose

Energy from the sun captured by green plants during photosynthesis is stored in the form of **carbohydrates**.

C**arbohydrates are the metabolic precursors of virtually all other biomolecules.**

## Source of energy

Phototroph: an organism that obtains energy from sunlight for the synthesis of organic compounds (they convert the solar energy to chemical one)

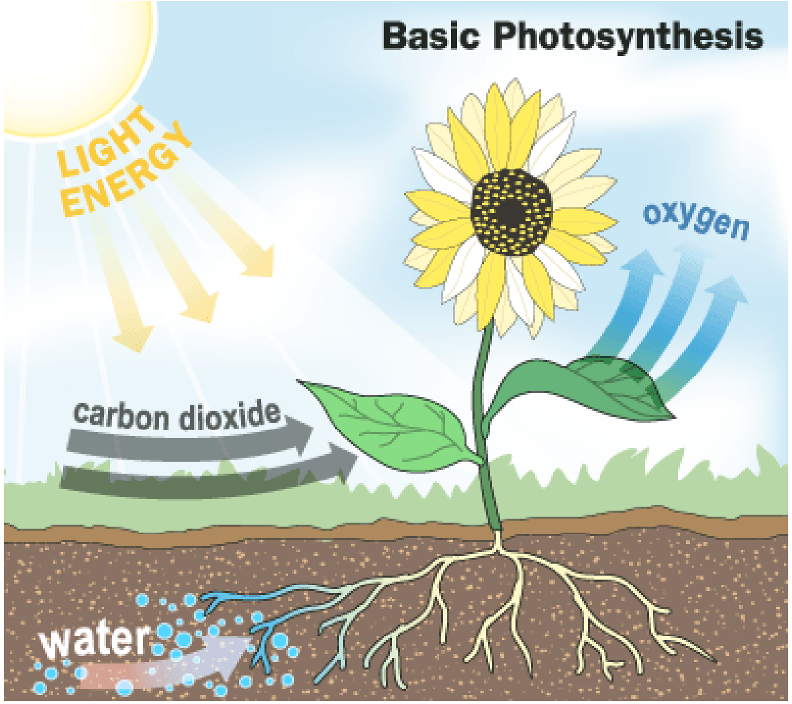
Chemotroph: an organism that cannot harvest and convert the solar energy, instead of it take up organic compounds and oxydize them to gain energy.

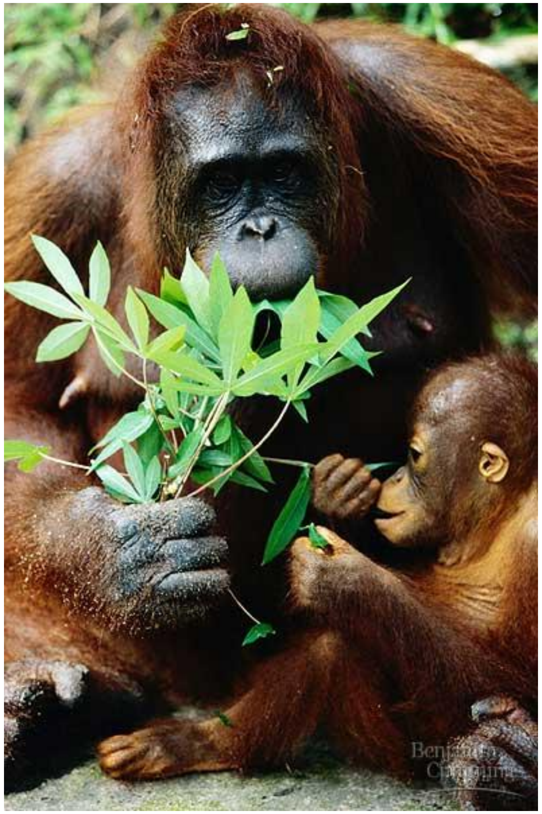

## Source of carbon

Autotroph: An organism capable of synthesizing its own food from inorganic substances, using light or chemical energy. Green plants, algae, and certain bacteria are autotrophs.

Heterotroph: An organism that cannot synthesize its own food and is dependent on complex organic substances for nutrition.

Solar energy → **Photosynthesis** → Chemical energy → Contraction / Transport / Biosynthesis

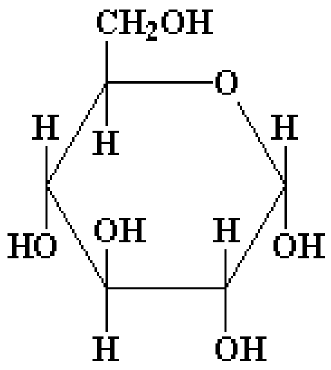


**Breakdown of carbohydrates provides the energy that sustains animal life.**

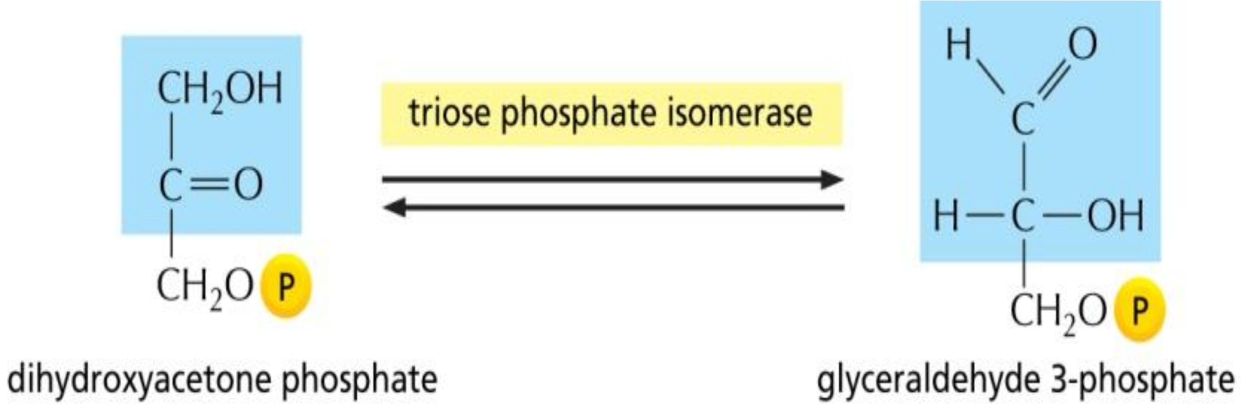
**Monosaccharides:** cannot be broken down into smaller sugars under mild conditions

Consist typically of three to seven carbon atoms



glucose

**Aldoses**: aldehyde function group or a
**Ketoses**: ketone function group

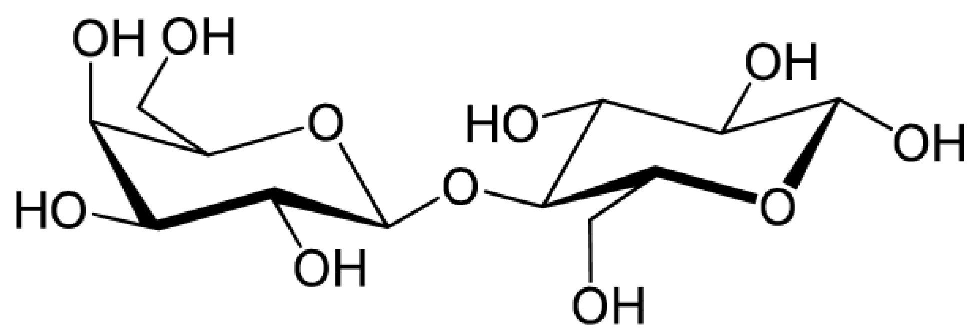



The simplest monosaccharides are water-soluble, and most taste sweet.

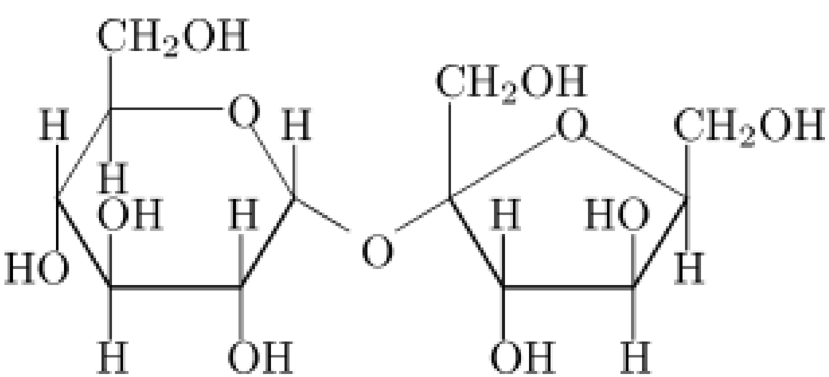
**Oligosaccharides:** consist of from two to ten simple sugar molecules

**Oligo**: Greek word meaning "few"

Disaccharides are common in nature consist of two monosaccharide units linked by a **glycosidic bond**.




lactose

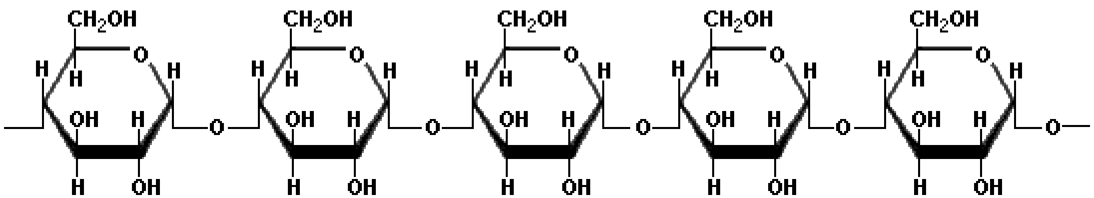



sucrose

**Polysaccharides:** are polymers of the simple sugars and their derivatives

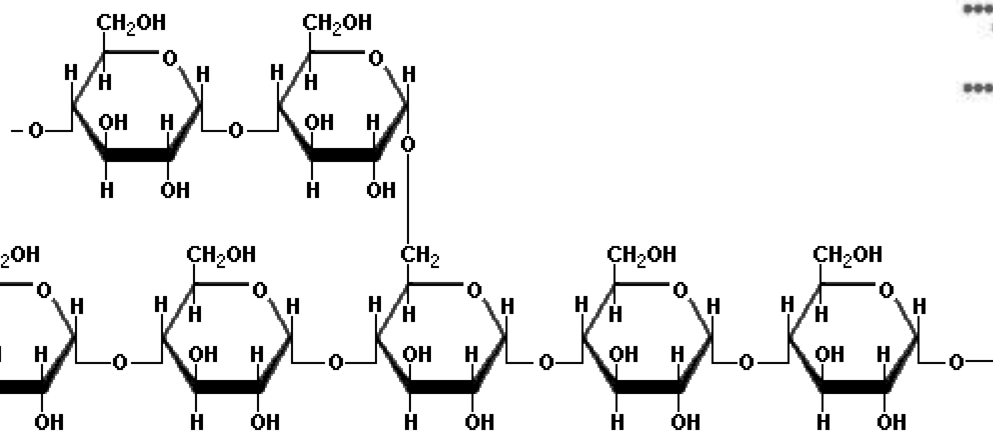
They may contain **hundreds or even thousands of monosaccharide units.** Their molecular weights range up to 1 million or more.

**linear or branched** polymers



amylose

Complex amylopectin structure



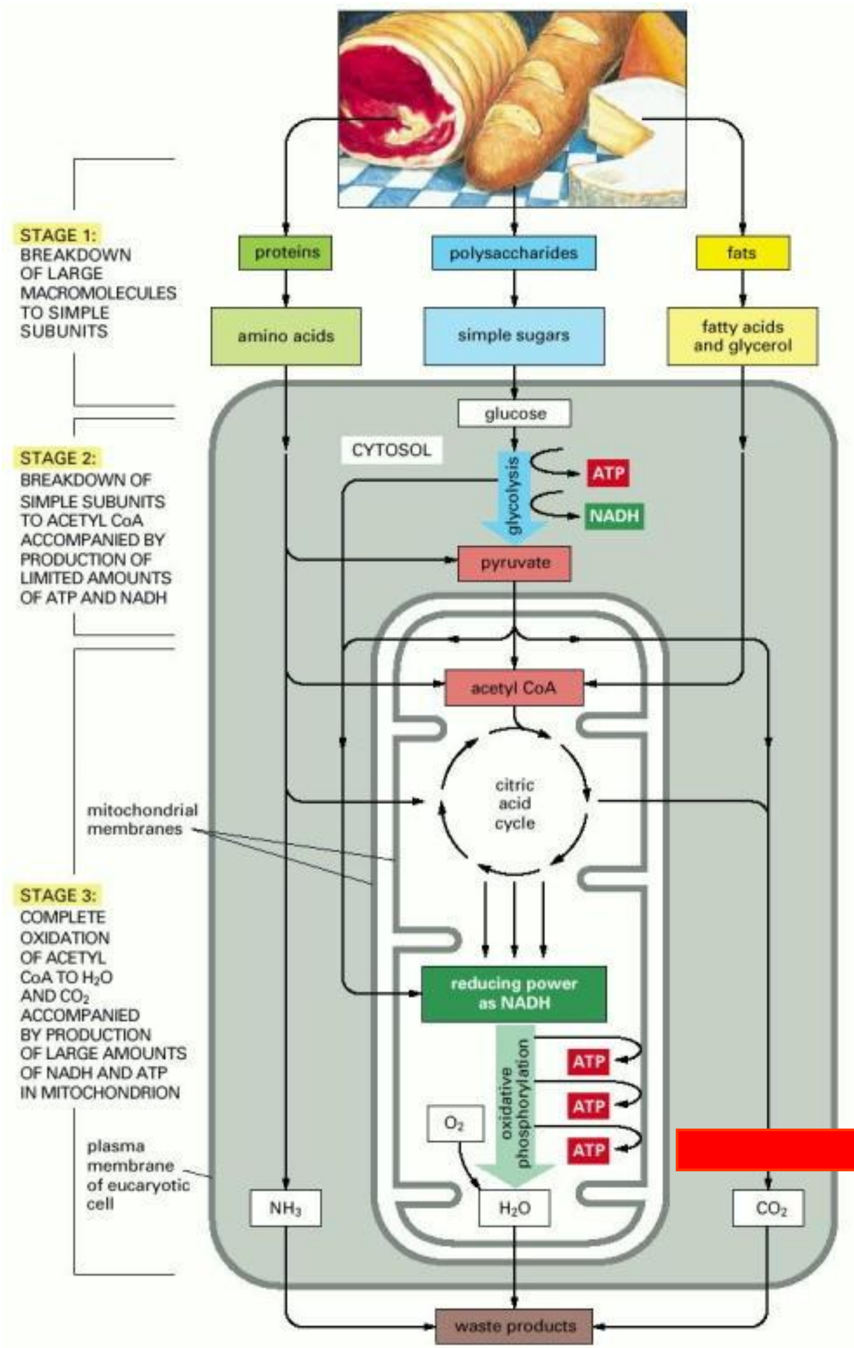
amylopectin

**Polysaccharides are storage materials, structural components, or protective substances.**

**Starch, glycogen:** provide energy reserves for cells
organisms store carbohydrates in the form of polysaccharides rather than as monosaccharides to lower the osmotic pressure of the sugar reserves

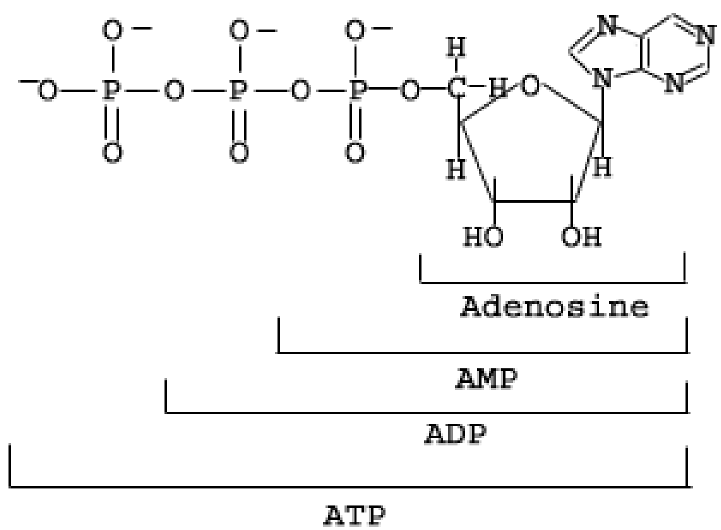
**Mucopolysaccharides**: eg. the hyaluronic acids, form protective coats on animal cells.

**Chitin, cellulose**: provide strong support for the skeletons of arthropods and green plants

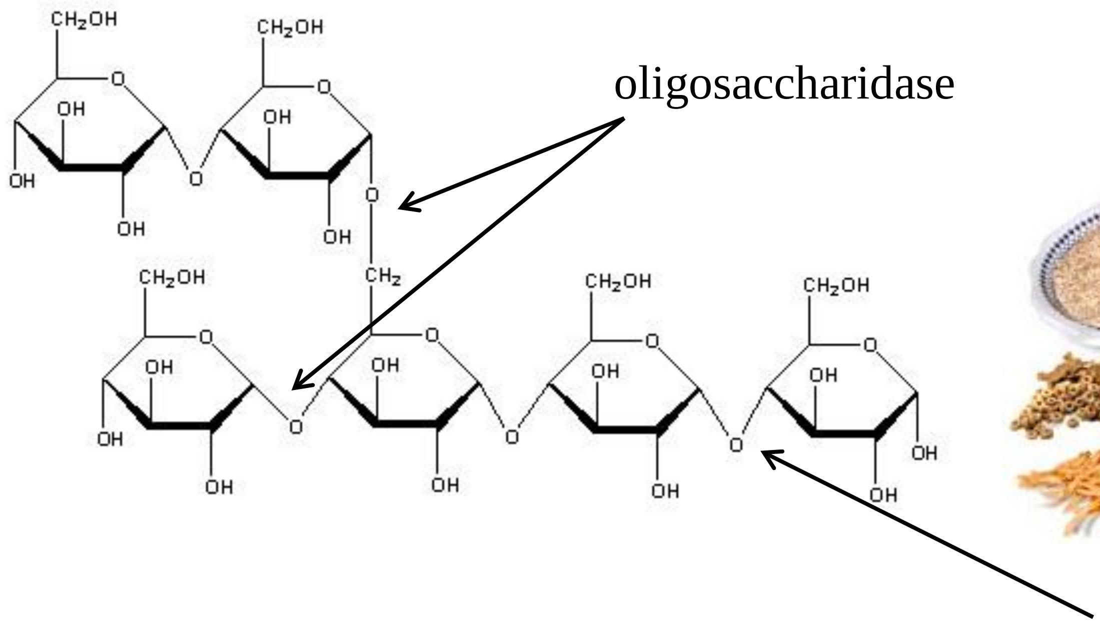


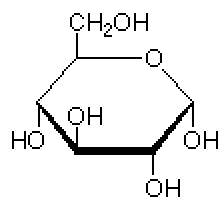

The polysaccharides (together with proteins, lipids) must be **broken down into smaller molecules (monomers)** before our cells can use them either as a source of energy or as building blocks for other molecules.

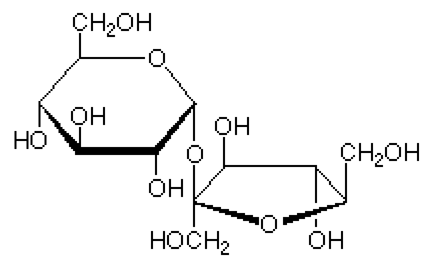
**Energy currency: ATP**

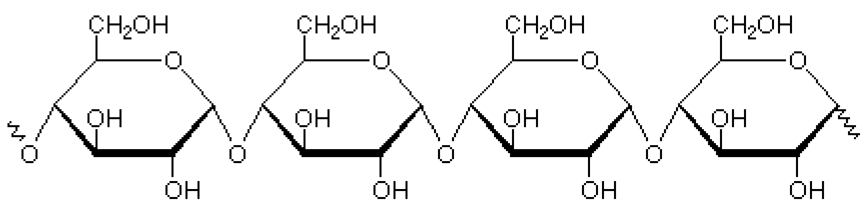


# starch

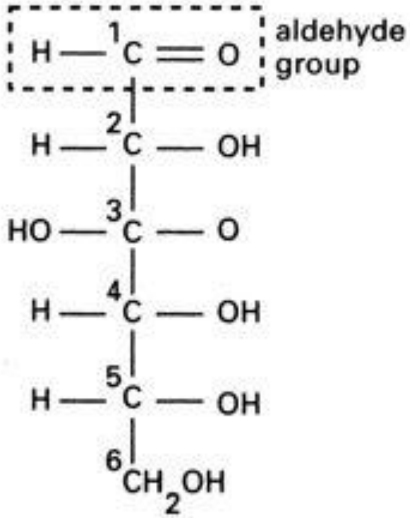




monosaccharide (glucose)

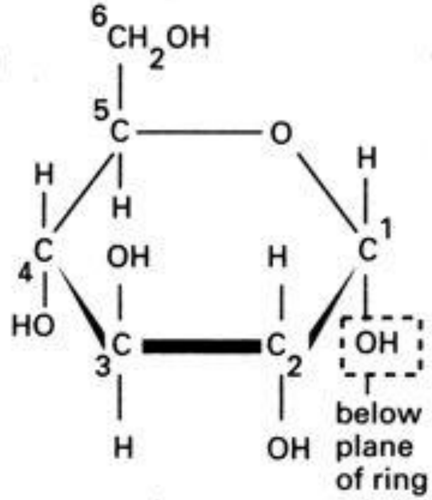

disaccharide (sucrose)


polysaccharide (amylose starch)

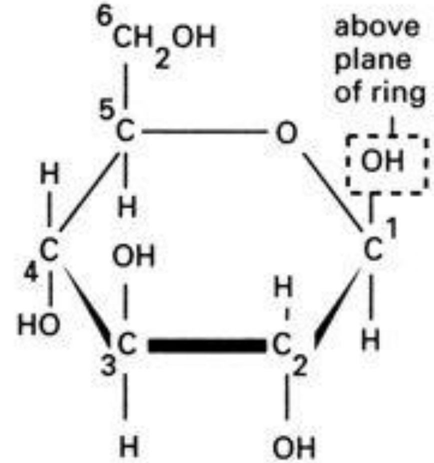
Glucose (an aldohexose)




straight-chain form



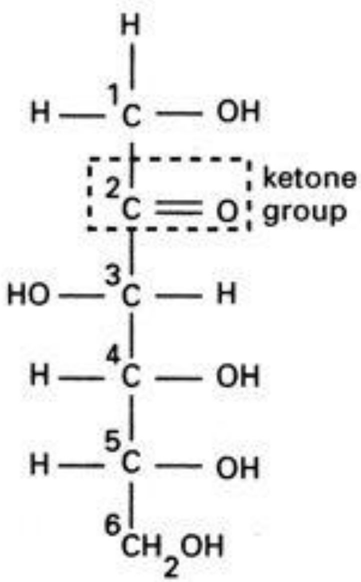

α-glucose



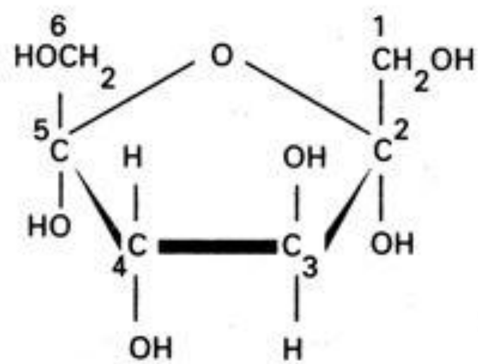

β-glucose

ring forms

Fructose (a ketohexose)

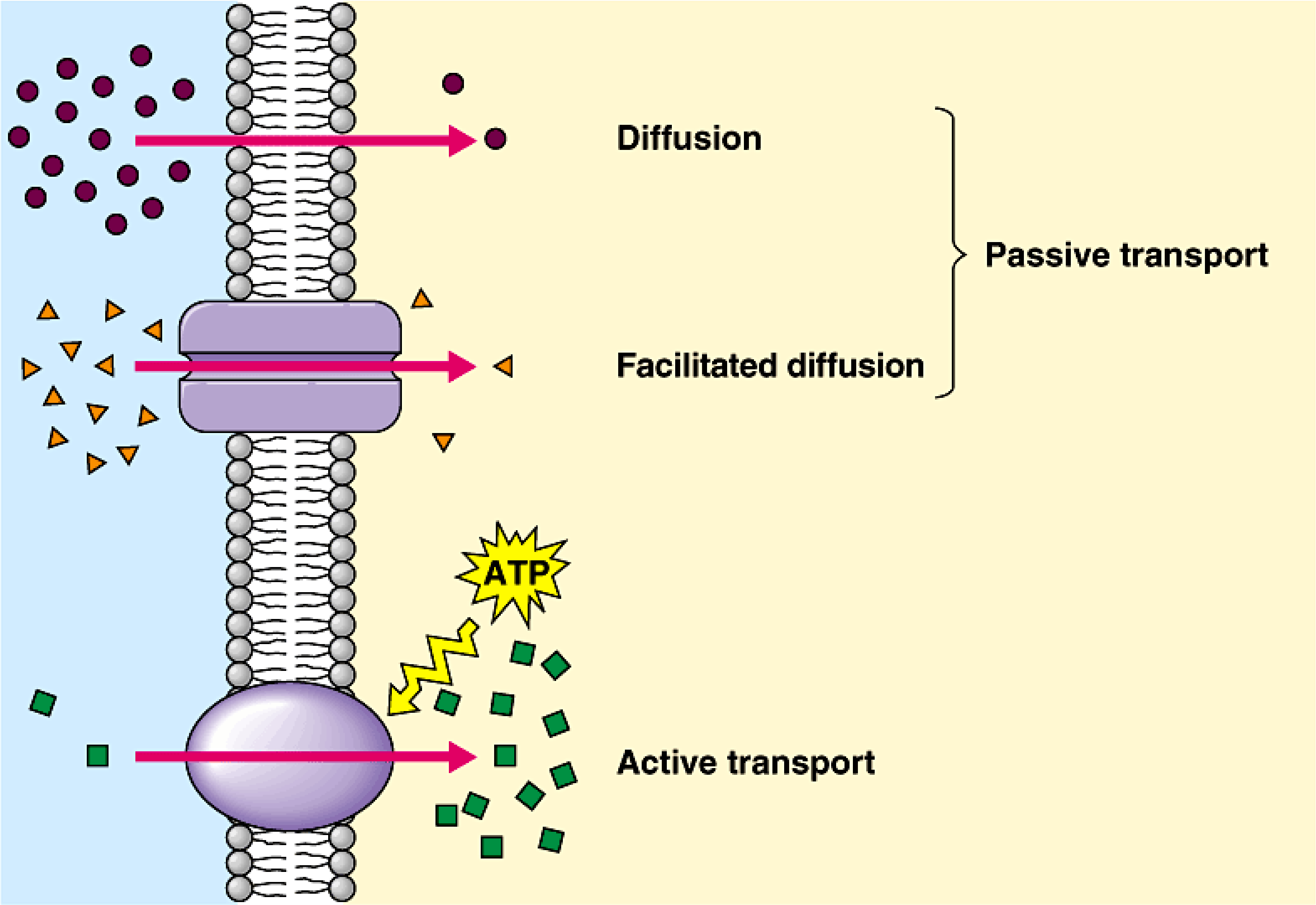



straight-chain form



ring form

Simple diffusion: the compouns permeate freely through the membrane to the direction of concentration gradient. Quite rare.

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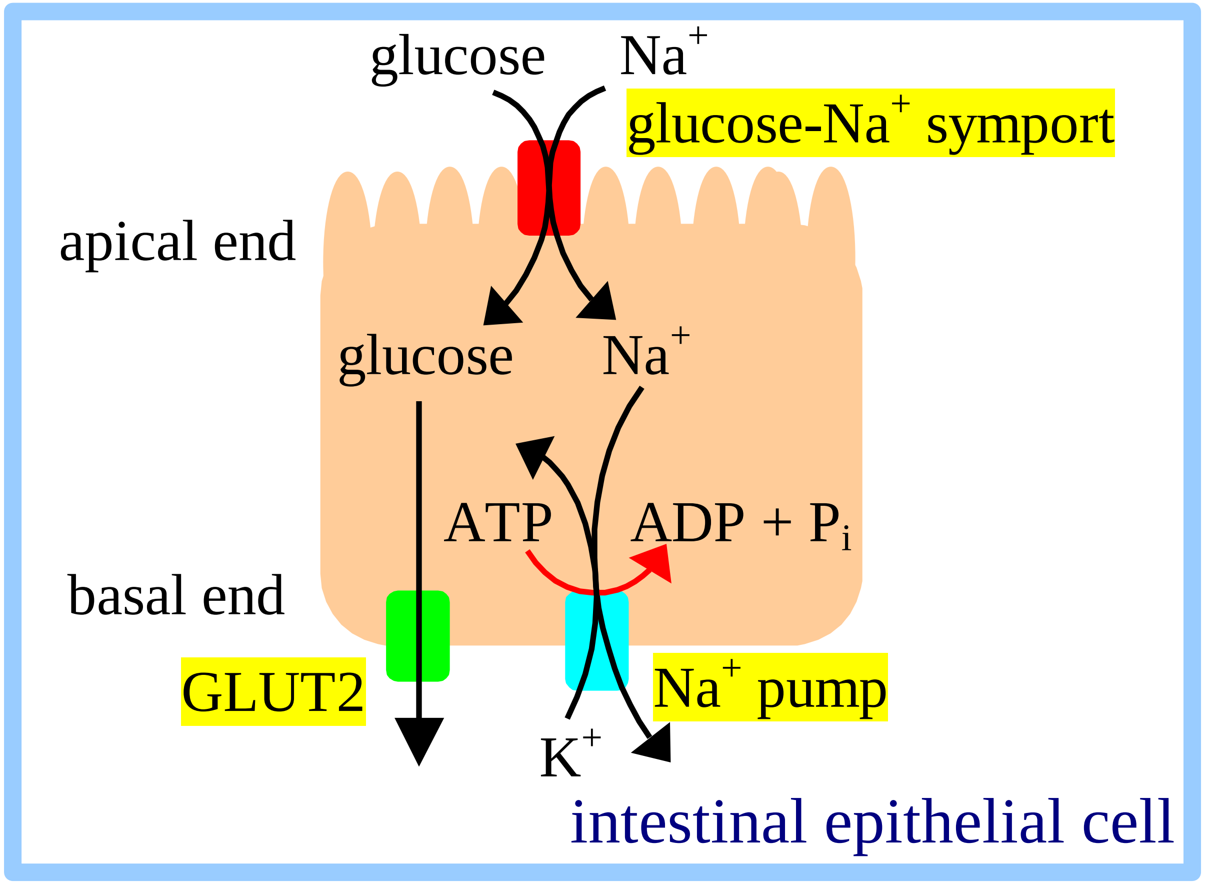
# Transport of glucose

The uptake of glucose from the lumen of intestine is coupled to the uptake of $Na^+$. The driving force is the electrochemical gradient of $Na^+$.

The electrochemical gradient of $Na^+$ has been biult up by the $Na^+/K^+$ pump on the expense of ATP hydrolysis.



# Glucose transporters (GLUT family)

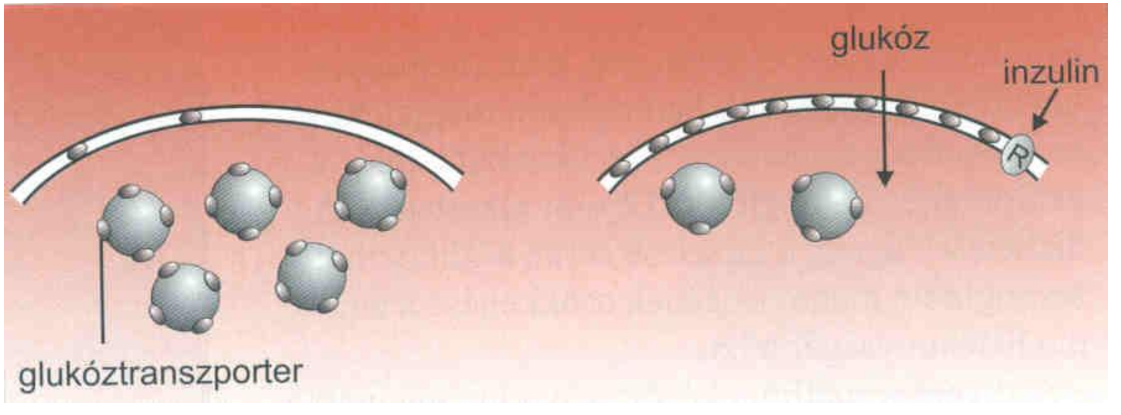
•GLUT 1: red blood cell, brain, muscle adipose tissue, insulin independent

•GLUT 2: liver cells, pancreatic b-cell, kidney cells, intestinal epithelium, high $K_m$ value

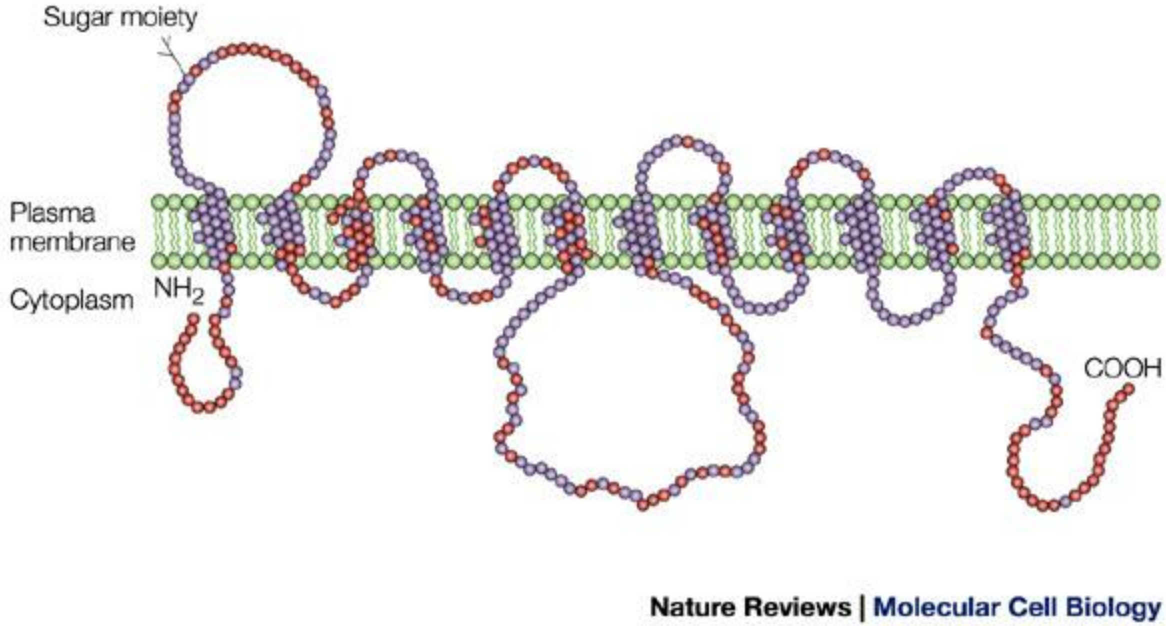
•GLUT 3: nerve cells, low $K_m$ value

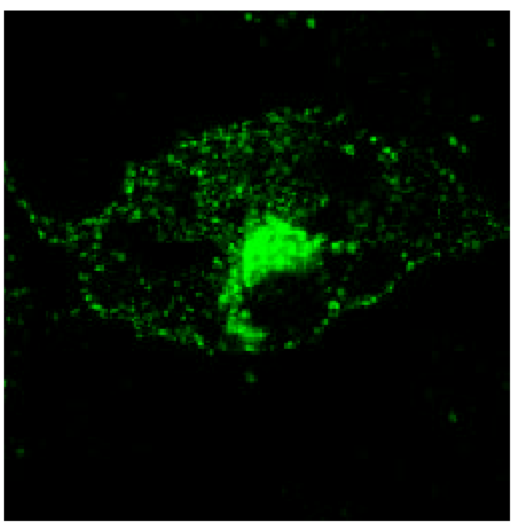
•GLUT 4: muscle, adipose tissue, insulindependent

•GLUT 5: fructose transporter

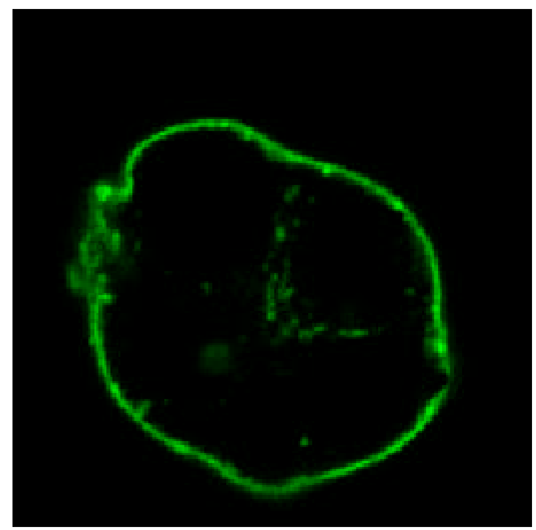


# The structure of GLUT4



**insulin**



# Glycolysis

Glycolysis is occured in all human cells. Glusose is the central fuel of metabolism. All cells can utilize it.

glykys = sweet, lysis = cleavage

Daily glucose demand of the human body: ca. 160 g

central nerve system, brain: 120 g

ATP- synthesis: 40 g

ATP is generated in anaerobic conditions

# The reactions of glycolysis

The first discovered metabolic pathway

All reactions are locelized to the cytosol

The enzymes are organized into **multienzyme complexes**

↓

The intermediers are channeled from one enzyme to the other

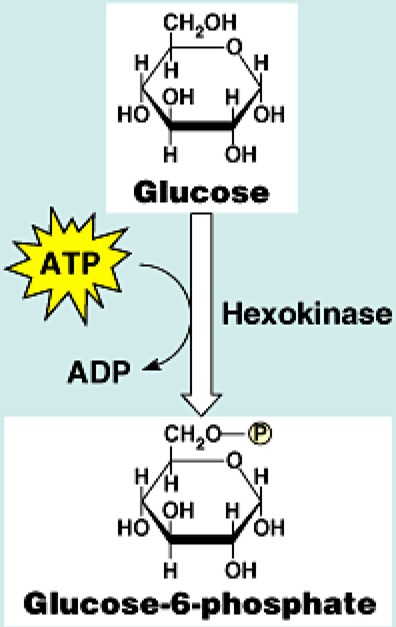
All intermediates are phosphorylated

↓

The cell membrane is **not permeable** for them

Reversible and irreversible reactions

# The first six C phase




1. glucose + ATP → glucose-6-phosphate + ADP

**enzymes**: glucokinase, hexokinase

**irreversible**

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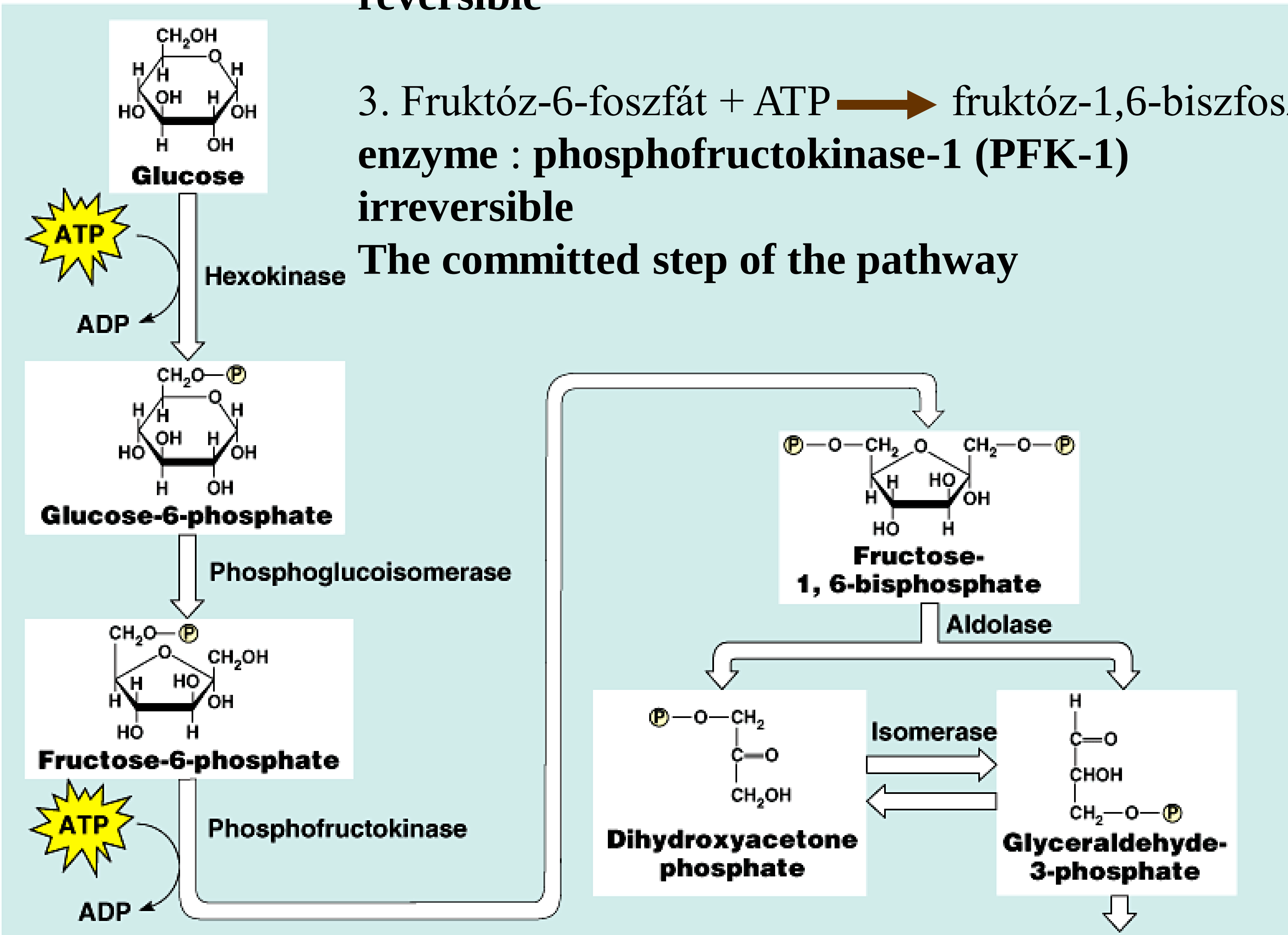
glucose-6-P cannot be transported back across the plasma membrane

2. glucose-6-phospate → fructose-6-phosphate
**enzyme**: phosphoglucoisomerase
**reversible**

3. Fruktóz-6-foszfát + ATP → fruktóz-1,6-biszfoszfát + ADP
**enzyme : phosphofructokinase-1 (PFK-1)**
**irreversible**
**The committed step of the pathway**

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4. fructose-1,6-bisphosphate

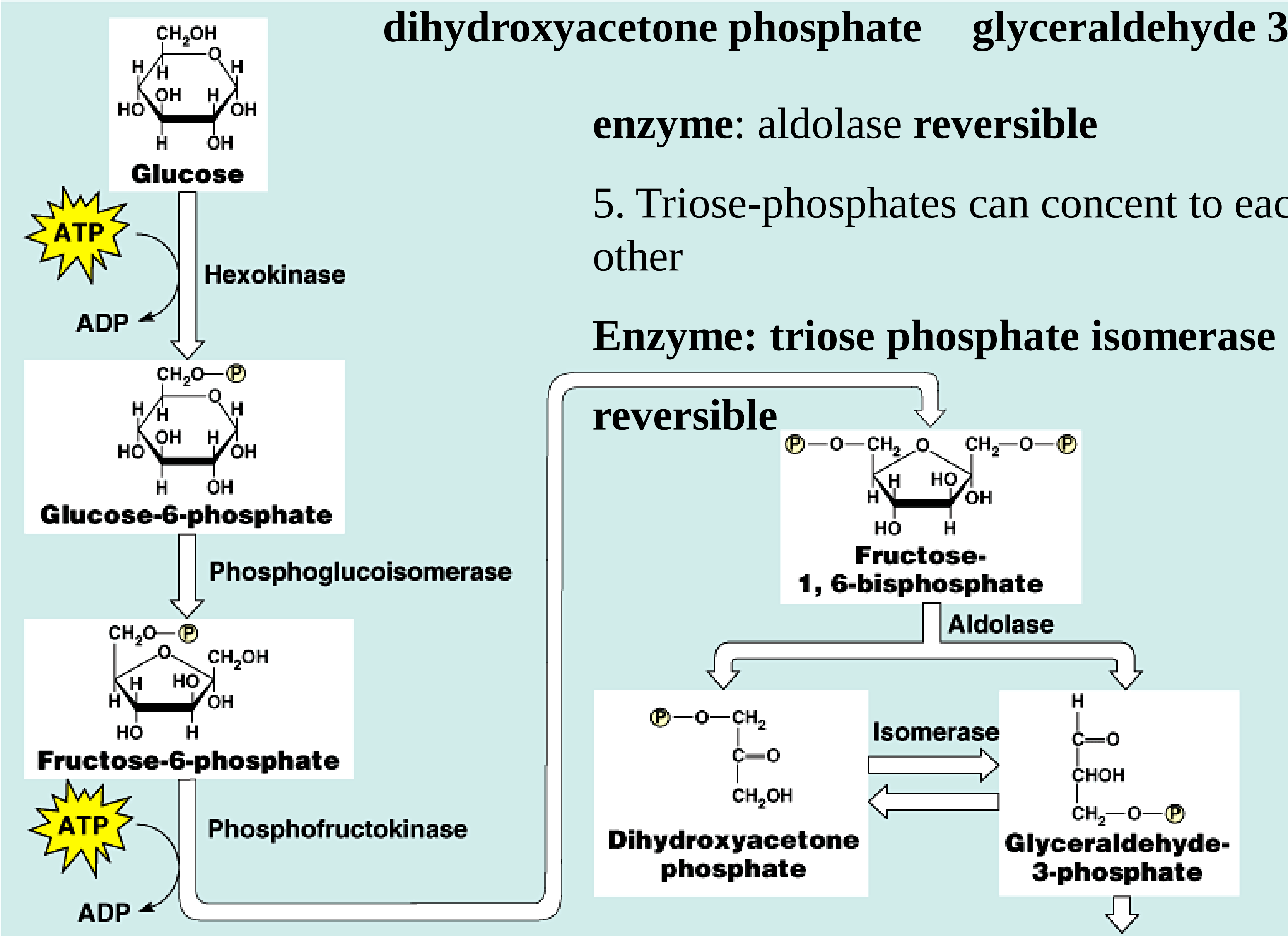
**dihydroxyacetone phosphate** **glyceraldehyde 3-phosphate**

**enzyme**: aldolase **reversible**

5. Triose-phosphates can concent to each other

**Enzyme: triose phosphate isomerase**

**reversible**

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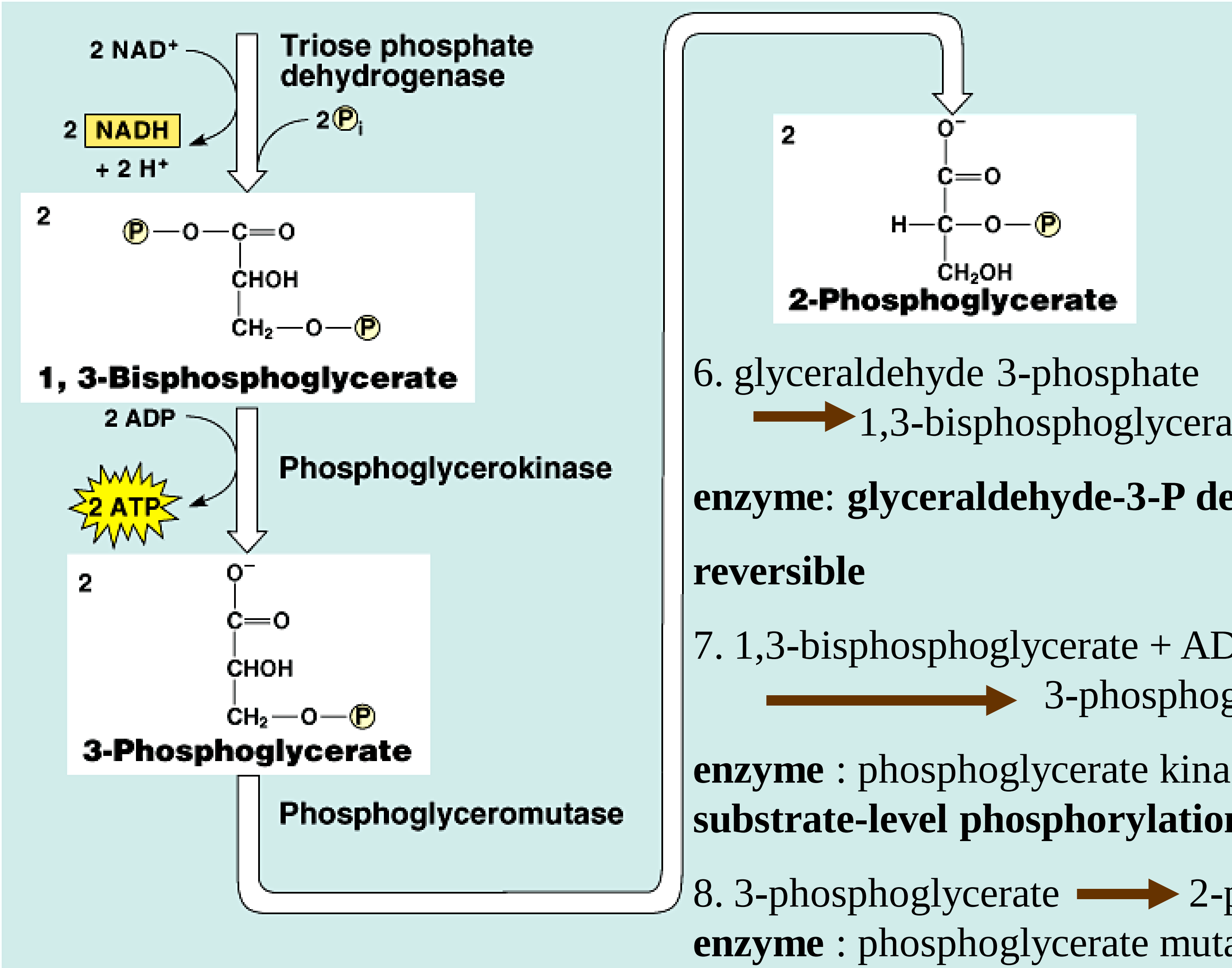
# The second 3 C phase




6. glyceraldehyde 3-phosphate → 1,3-bisphosphoglycerate

**enzyme**: **glyceraldehyde-3-P dehydrogenase**

**reversible**

7. 1,3-bisphosphoglycerate + ADP → 3-phosphoglycerate + ATP

**enzyme** : phosphoglycerate kinase, **reverzibilis**
**substrate-level phosphorylation**

8. 3-phosphoglycerate → 2-phoglycerate
**enzyme** : phosphoglycerate mutase, **reversible**

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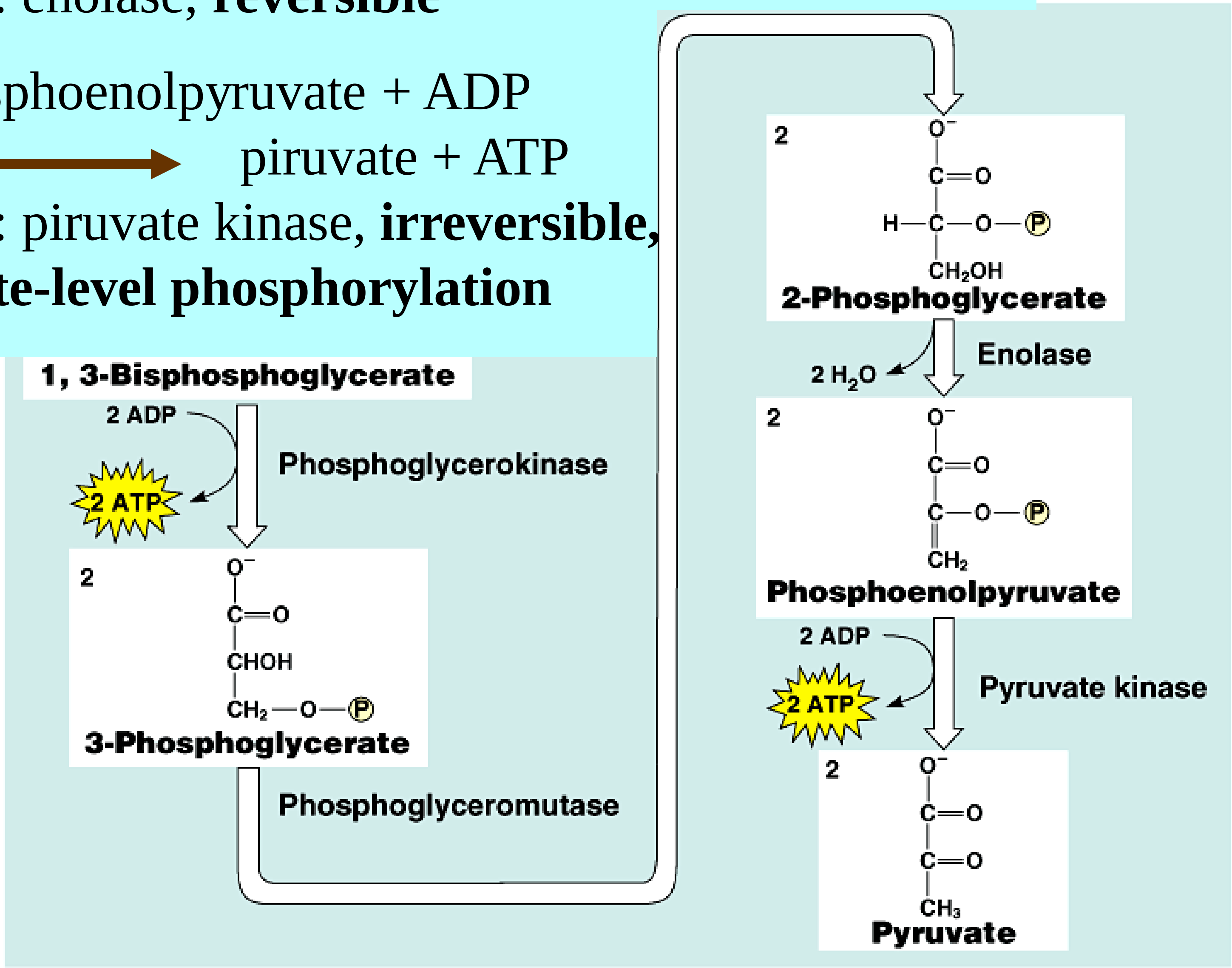
9. 2-phosphoglycerate ⟶ phosphoenolpyruvate

**enzyme**: enolase, **reversible**

10. phosphoenolpyruvate + ADP ⟶ piruvate + ATP

**enzyme**: piruvate kinase, **irreversible**, **substrate-level phosphorylation**

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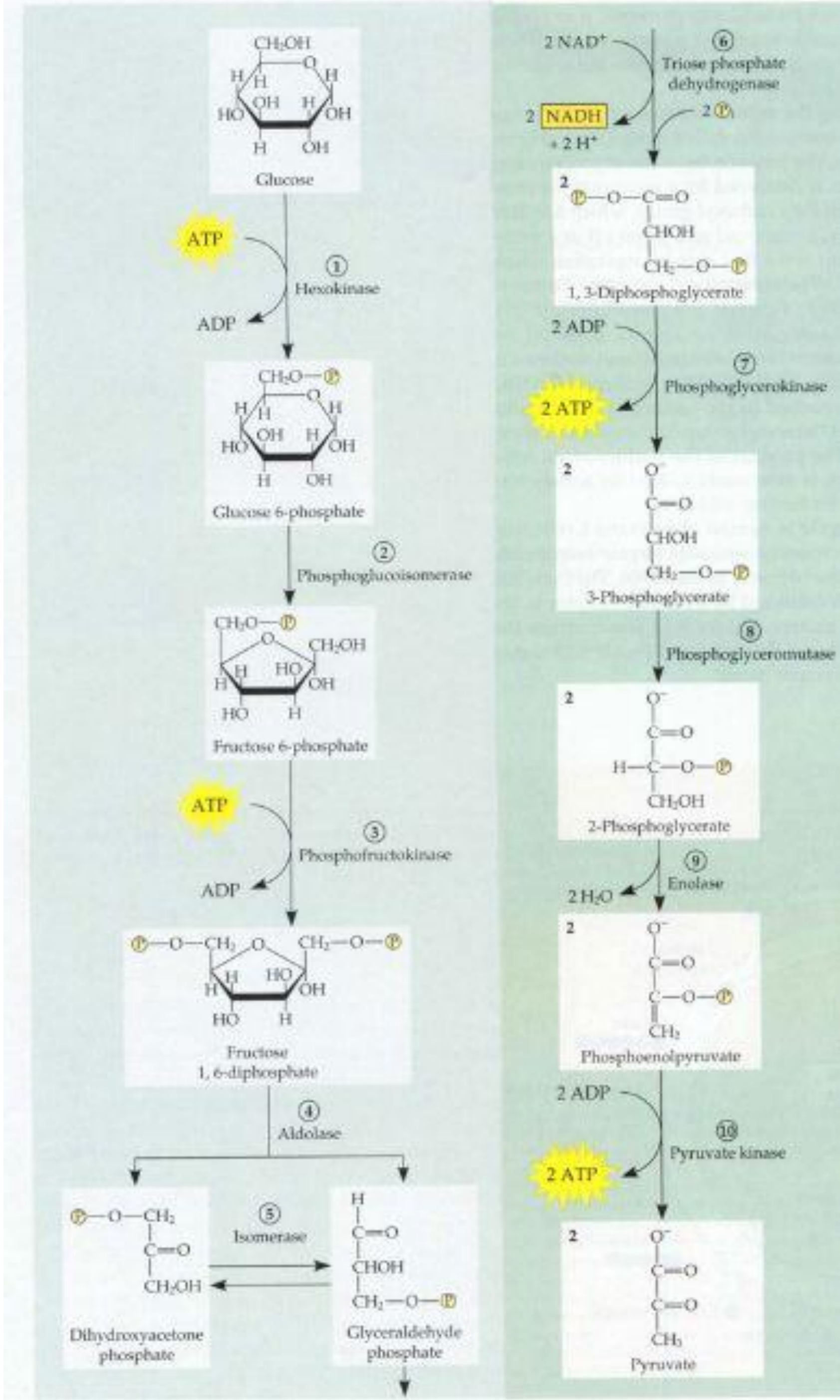
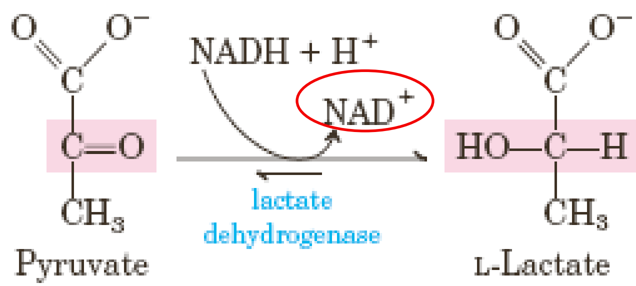


Glucose
ATP
① Hexokinase
ADP
Glucose 6-phosphate
② Phosphoglucoisomerase
Fructose 6-phosphate
ATP
③ Phosphofructokinase
ADP
Fructose 1, 6-diphosphate
④ Aldolase
Dihydroxyacetone phosphate
⑤ Isomerase
Glyceraldehyde phosphate
2 NAD+
⑥ Triose phosphate dehydrogenase
2 NADH + 2 H+
2 Pi
1, 3-Diphosphoglycerate
2 ADP
⑦ Phosphoglycerokinase
2 ATP
3-Phosphoglycerate
⑧ Phosphoglyceromutase
2-Phosphoglycerate
⑨ Enolase
2 H2O
Phosphoenolpyruvate
2 ADP
⑩ Pyruvate kinase
2 ATP
Pyruvate

The fate of pyruvate is depends on the type of the cell and on the ability to oxgen.

**aerobe**: pyruvate → acetyl-CoA → TCA cycle

**anaerobe**: pyruvate → lactate (enzyme: lactate-dehydrogenase)

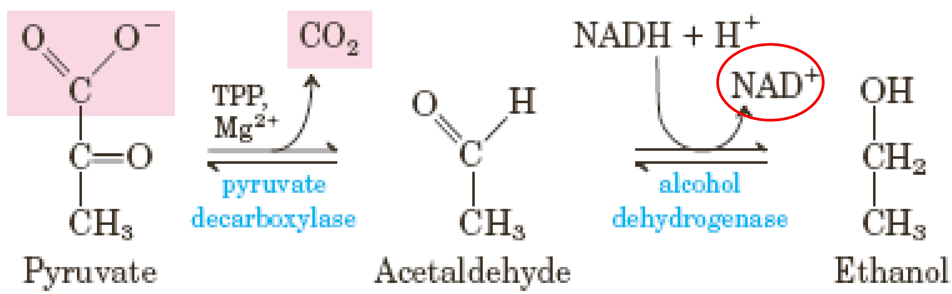



↓

acetaldehyde

↓

ethanol




Alcoholic fermentation

# The energy balance of glycolysis

**anaerobe**: glucose + 2$P_i$ + 2 ADP ⟶ 2 lactate + **2 ATP** + 2 $H_2O$

**aerobe**: glucose + 2$P_i$ + 2 ADP + 2 $NAD^+$ ⟶

⟶ 2 piruvate + 2 ATP + 2 $H_2O$ + 2 NADH + 2 $H^+$

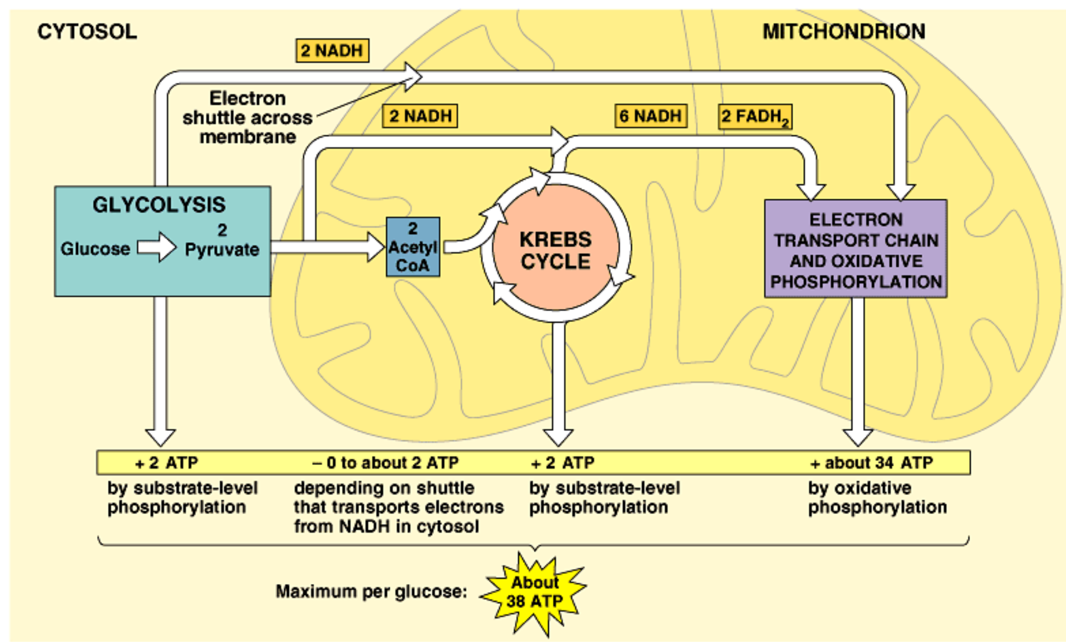
Σ: **36-38 ATP**

2 NADH - - → 4-6 ATP

2 piruvate → 2*4 NADH - - → 24 ATP

2 piruvate - - → 2 GTP

2 piruvate → 2*1 $FADH_2$ - - → 4 ATP

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# Gluconeogenesis

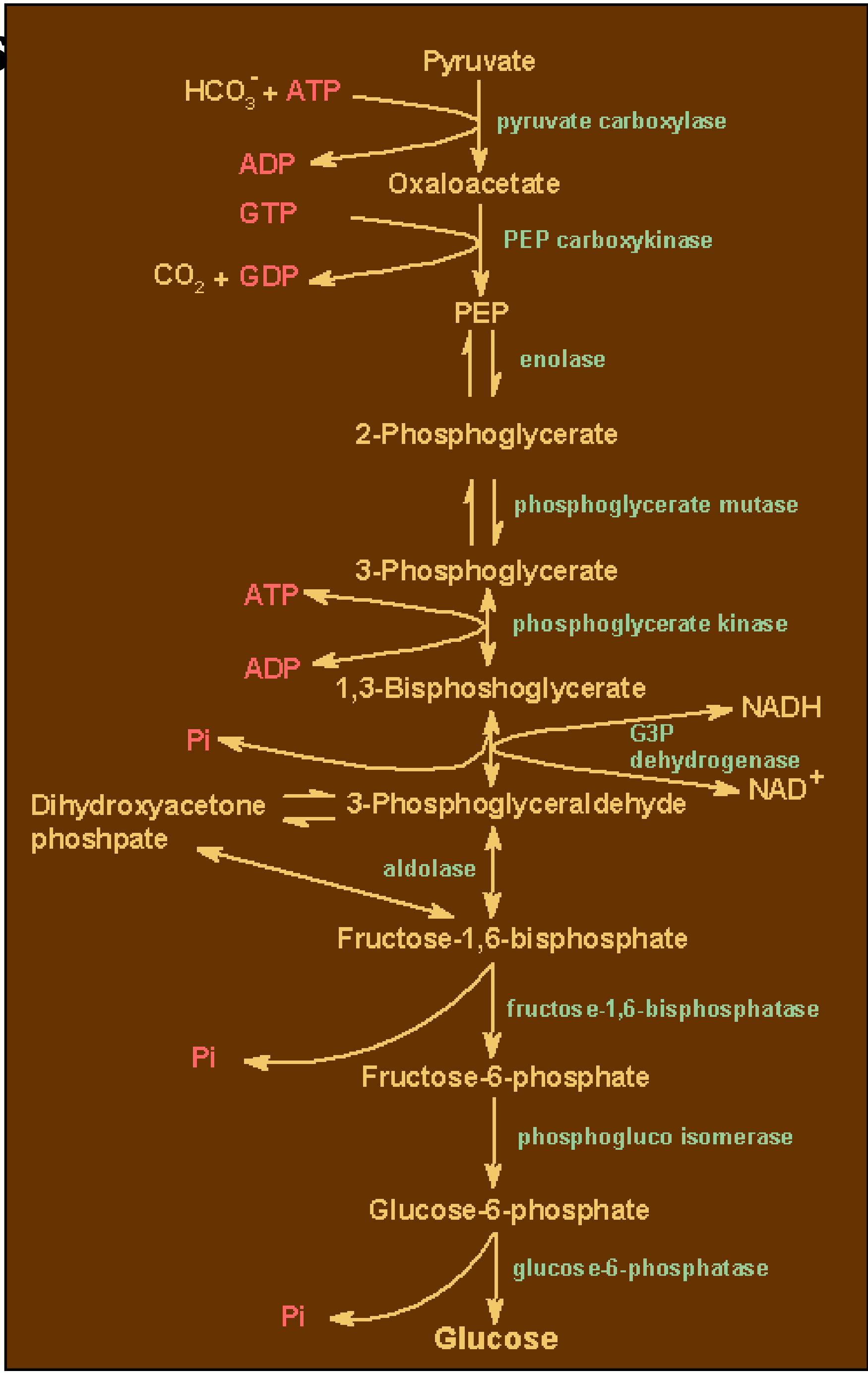
**The process by which glucose is synthesized from noncarbohydrate precursors (eg. lactate), occurs mainly in the liver under fasting conditions.**

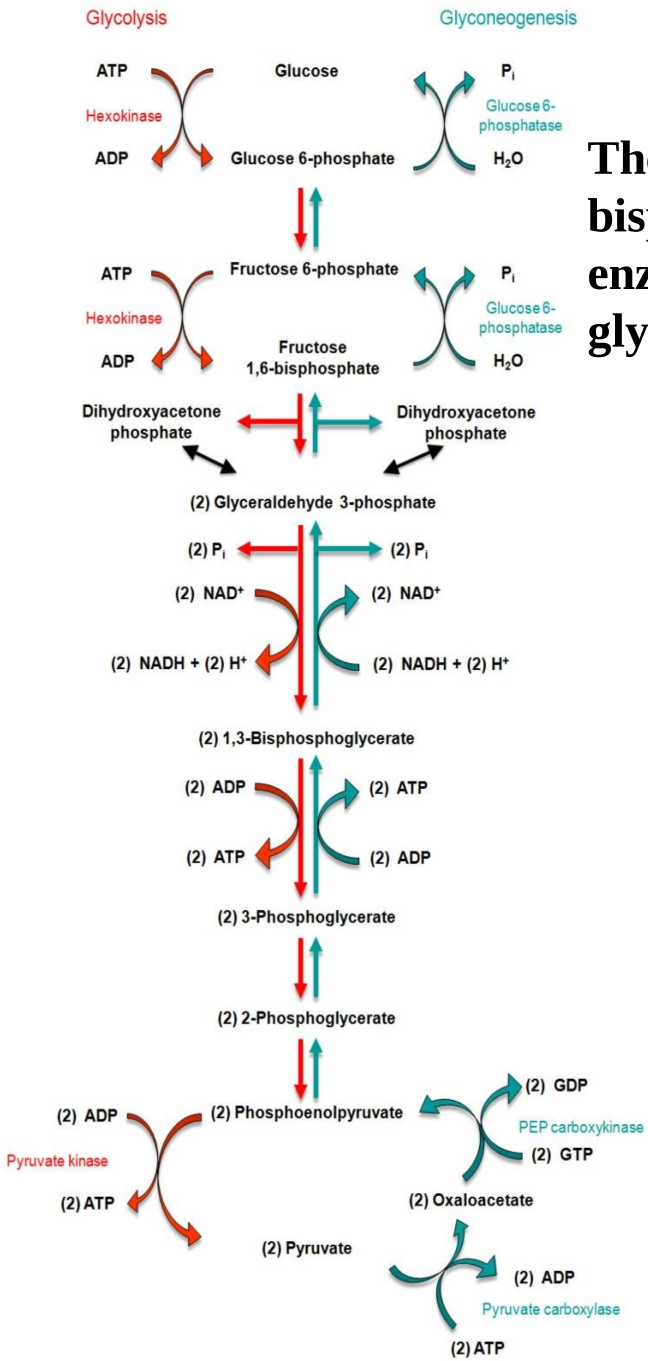
The reverse of the glycolysis except 3 steps. The exceptions are the irreversible steps (and enzymes catalyze them :

**1. Hexokinase**

**2. Phosphofructokinase-1**

**3. Pyruvate kinase**






**The reactions that remove phosphate from fructose 1,6-bisphosphate and from glucose 6-phosphate each use single enzymes that differ from the corresponding enzymes of glycolysis.**

**Pyruvate is carboxylated by pyruvate carboxylase to form oxaloacetate.**
**Oxaloacetate is transported across the mitochondrial membrane as malate or aspartate**
**Oxaloacetate, produced from malate or aspartate in the cytosol, is converted to PEP by the cytosolic PEP carboxykinase**

Energy requirement of gluconeogenesis:

2 lactate + 6 ATP ⟶ 1 glucose + 6 ADP + 6 $P_i$

Gluconeogenesis is occured in the liver and kidney, main organ: liver.

**Cori-cycle**