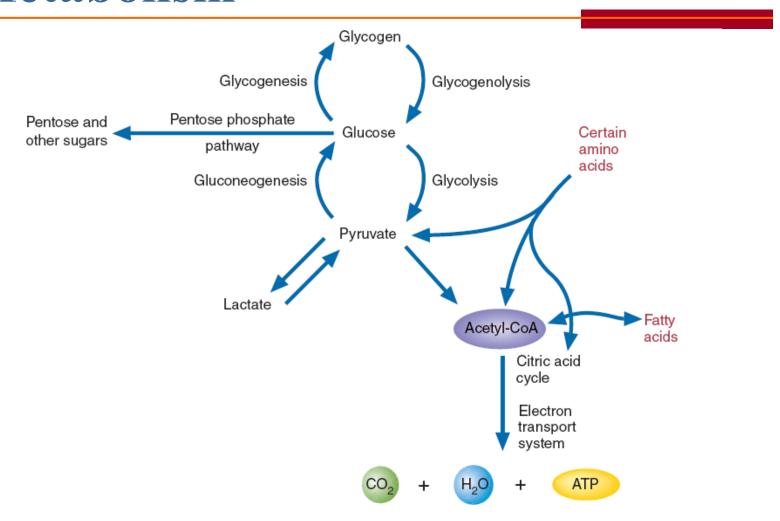
Major Pathways in Carbohydrate Metabolism

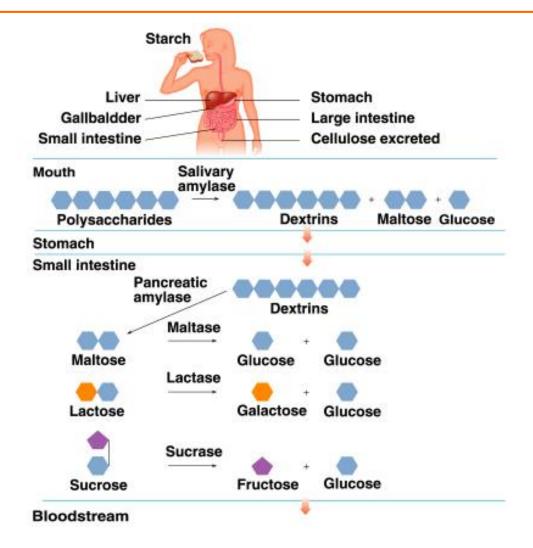


Stage 1: Digestion of Carbohydrates

In Stage 1, the digestion of carbohydrates

- Begins in the mouth where salivary amylase breaks down polysaccharides to smaller polysaccharides (dextrins), maltose, and some glucose.
- Continues in the small intestine where pancreatic amylase hydrolyzes dextrins to maltose and glucose.
- Hydrolyzes maltose, lactose, and sucrose to monosaccharides, mostly glucose, which enter the bloodstream for transport to the cells.

Digestion of Carbohydrates

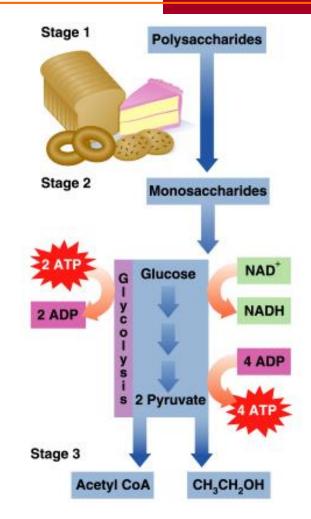


Stage 2: Glycolysis



Stage 2: Glycolysis

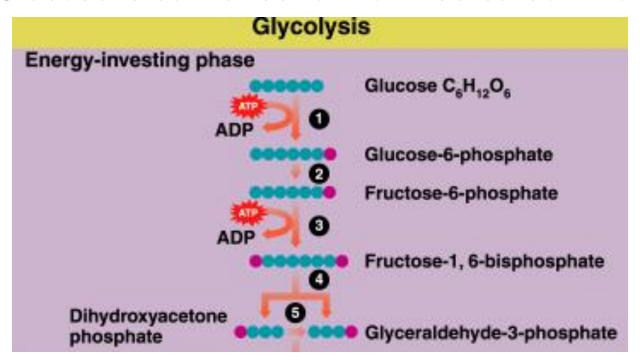
- Is a metabolic pathway that uses glucose, a digestion product.
- Degrades six-carbon glucose molecules to three-carbon. pyruvate molecules.
- Is an anaerobic (no oxygen) process.



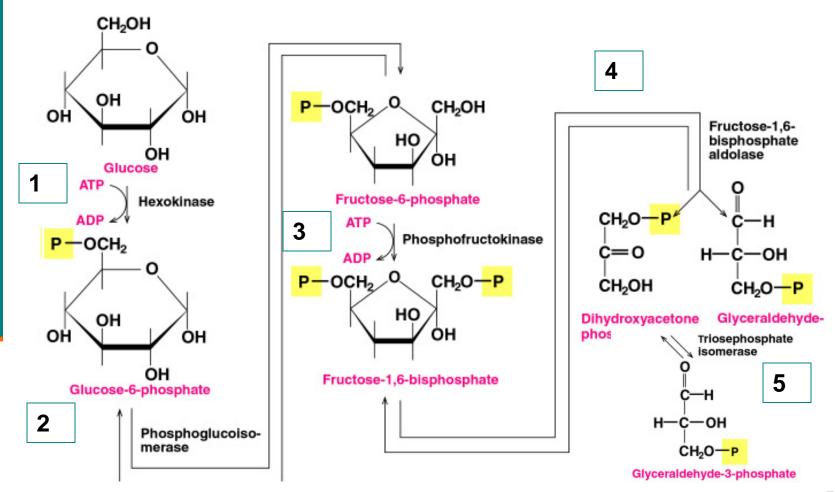
Glycolysis: Energy-Investment

In reactions 1-5 of glycolysis,

- Energy is required to add phosphate groups to glucose.
- Glucose is converted to two three-carbon molecules.



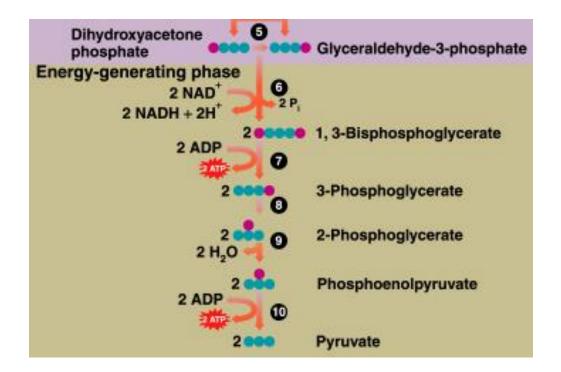
Glycolysis: Energy Investment



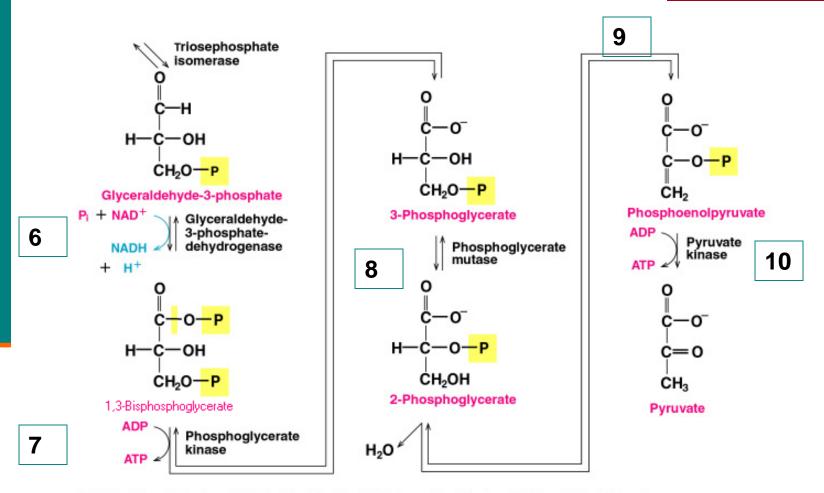
Glycolysis: Energy-Production

In reactions 6-10 of glycolysis, energy is generated as

- Sugar phosphates are cleaved to triose phosphates.
- Four ATP molecules are produced.



Glycolysis: Reactions 6-10



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Glycolysis: Overall Reaction



In glycolysis,

- Two ATP add phosphate to glucose and fructose-6phosphate.
- Four ATP are formed in energy-generation by direct transfers of phosphate groups to four ADP.
- There is a net gain of 2 ATP and 2 NADH.

$$C_6H_{12}O_6 + 2ADP + 2Pi + 2NAD^+$$
Glucose
$$2C_3H_3O_3^- + 2ATP + 2NADH + 4H^+$$
Pyruvate

محصلة الطاقة الناتجة من تحلل جزيء من الجلوكوز إلى جزيئيين من البيروفيت:

- إستهلاك ATP 1 في الخطوة رقم 1.
- إستهلاك 1 ATP في الخطوة رقم 3.
- إنتاج جزيئيين من الـ NADH (باعتبار أن الجلوكوز إنشطر إلى جزئيين) في الخطوة رقم 6. كل جزيء من الـ NADH عند أكسدته يعطي ATP 3.
- إنتاج 2 ATP في الخطوة رقم 7 (باعتبار أن الجلوكوز إنشطر إلى جزئيين من الجليسر ألدهيد 3-فوسفات وكل جزء يعطى ATP 1).
- إنتاج 2 ATP في الخطوة رقم 10 (باعتبار وجود جزئيين من 3-فوسفو إنول بيروفيت ليعطى كلاً منهما ATP 1).

وبالتالي يكون الناتج: ATP = 8+2+2+1-1

Regulation of Glycolysis

Glycolysis is regulated by three enzymes,

- Reaction 1 Hexokinase is inhibited by high levels of glucose-6-phosphate, which prevents the phosphorylation of glucose.
- Reaction 3 Phosphofructokinase, an allosteric enzyme, is inhibited by high levels of ATP and activated by high levels of ADP and AMP.
- Reaction 10 Pyruvate kinase, another allosteric enzyme is inhibited by high levels of ATP or acetyl CoA.





In glycolysis, what compounds provide phosphate groups for the production of ATP?

Solution



In glycolysis, what compounds provide phosphate groups for the production of ATP?

In reaction 7, phosphate groups from two

1,3-bisphosphoglycerate molecules are transferred to ADP to form two ATP.

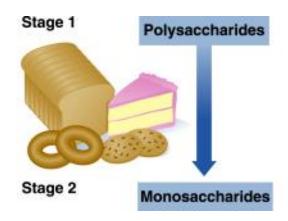
In reaction 10, phosphate groups from two phosphoenolpyruvate molecules are used to form two more ATP.

Asst. Prof. Dr. Mustafa Taha Mohammed

Metabolic Pathways for Carbohydrates

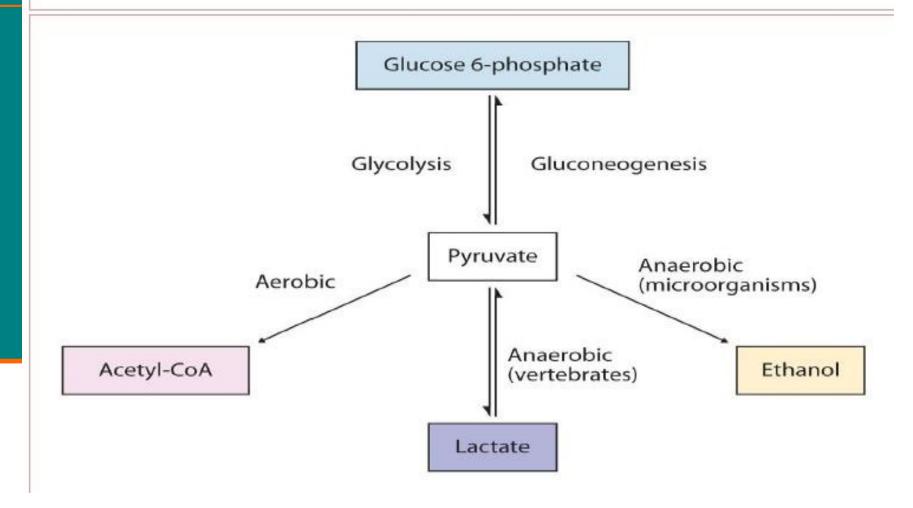


1.6
Pathways for Pyruvate

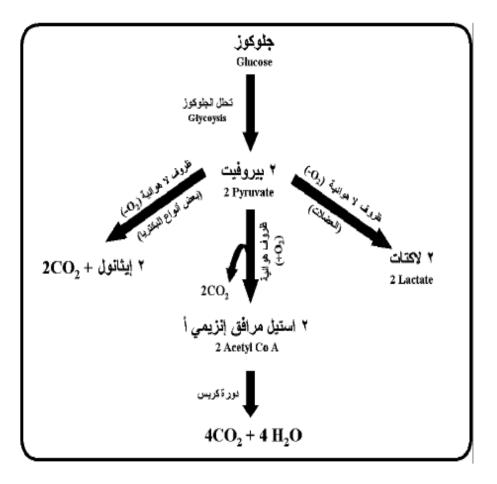


Asst. Prof. Dr. Mustafa Taha Mohammed

مصير البيروفيت الناتج من تحلل الجلوكوز



مصير البيروفيت الناتج من تحلل الجلوكوز Fate of pyruvate produced from glycolysis



التفاعلات اللاهوائية للبيروفيت وتحويله إلى لاكتات في العضلات

 في غياب الأكسجين في العضلات أو في بكتريا حمض اللاكتيك يتحول البيروفيت إلى لاكتات بواسطة إنزيم لاكتات ديهيدروجينيز LDH

Pyruvate

Lactate

Pyruvate: Aerobic Conditions

Under aerobic conditions (oxygen present),

- Three-carbon pyruvate is decarboxylated.
- Two-carbon acetyl CoA and CO₂ are produced.

Pyruvate: Anaerobic Conditions

Under anaerobic conditions (without oxygen),

- Pyruvate is reduced to lactate.
- NADH oxidizes to NAD+ allowing glycolysis to continue.

O O lactate

$$|| \quad ||$$
 CH_3 — C — C — O^- + NADH + H+

pyruvate

OH O

 $| \quad | \quad |$
 CH_3 — CH — C — O^- + NAD+

lactate

Lactate in Muscles



During strenuous exercise,

- Oxygen in the muscles is depleted.
- Anaerobic conditions are produced.

Muscles tire and become painful.

After exercise, a person breathes heavily to repay the oxygen debt and reform pyruvate in the liver.

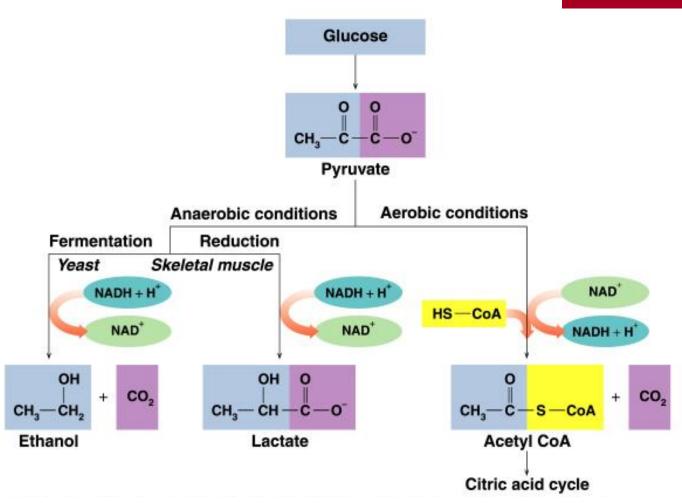
Fermentation



Fermentation

- Occurs in anaerobic microorganisms such as yeast.
- Decarboxylates pyruvate to acetaldehyde, which is reduced to ethanol.
- Regenerates NAD+ to continue glycolysis.

Pathways for Pyruvate



Learning Check



Match the following terms with the descriptions

1) Catabolic reactions

2) Coenzymes

3) Glycolysis

- 4) Lactate
- A. Produced during anaerobic conditions.
- B. Reaction series that converts glucose to pyruvate.
- C. Metabolic reactions that break down large molecules to smaller molecules + energy.
- D. Substances that remove or add H atoms in oxidation and reduction reactions.

Solution

Match the following terms with the descriptions:

1) Catabolic reactions

2) Coenzymes

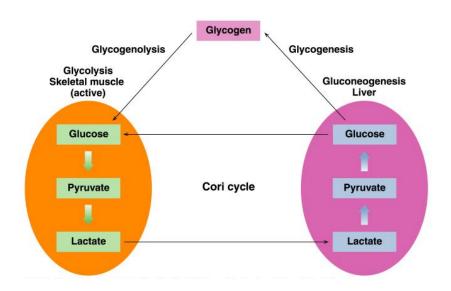
3) Glycolysis

- 4) Lactate
- A. 4 Produced during anaerobic conditions.
- B. 3 Reaction series that converts glucose to pyruvate.
- C. 1 Metabolic reactions that break down large molecules to smaller molecules + energy.
- D. 2 Substances that remove or add H atoms in oxidation and reduction reactions.

Metabolic Pathways for Carbohydrates

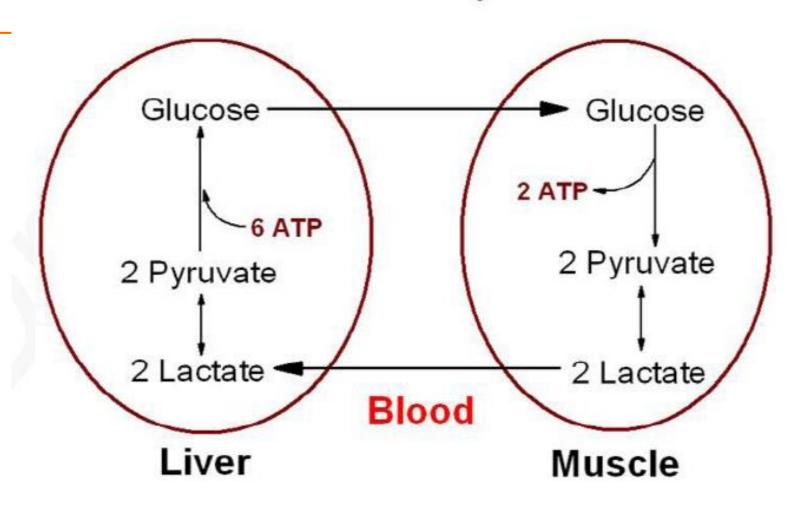
1.7 Glycogen Metabolism





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The Cori Cycle

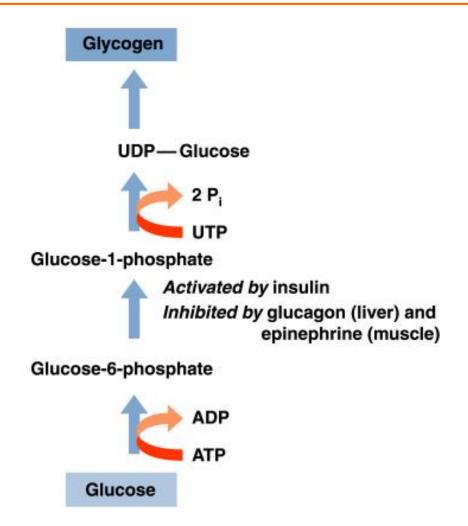


Glycogenesis

Glycogenesis

- Stores glucose by converting glucose to glycogen.
- Operates when high levels of glucose-6-phosphate are formed in the first reaction of glycolysis.
- Does not operate when energy stores (glycogen) are full, which means that additional glucose is converted to body fat.

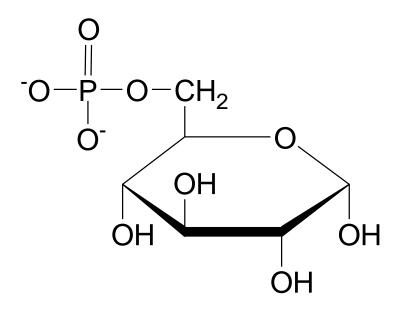
Diagram of Glycogenesis

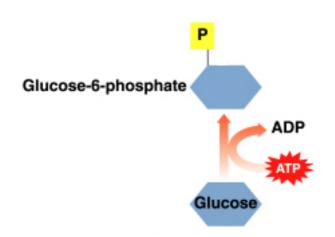


Formation of Glucose-6-Phosphate

In glycogenesis

 Glucose is initially converted to glucose-6-phosphate using ATP.

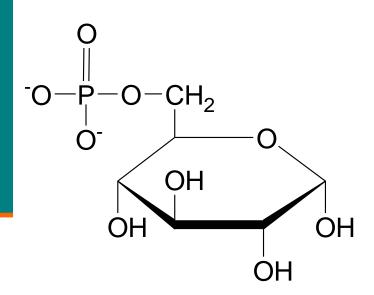




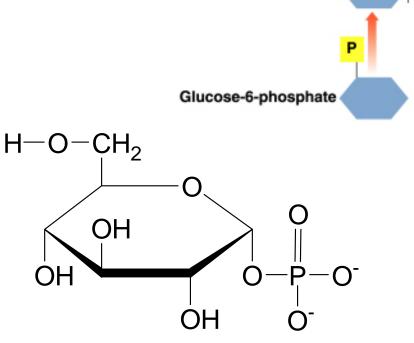
glucose-6-phosphate

Formation of Glucose-1-Phosphate

Glucose-6-phosphate is converted to glucose-1-phosphate.



glucose-6-phosphate



Glucose-1-phosphate

glucose-1-phosphate

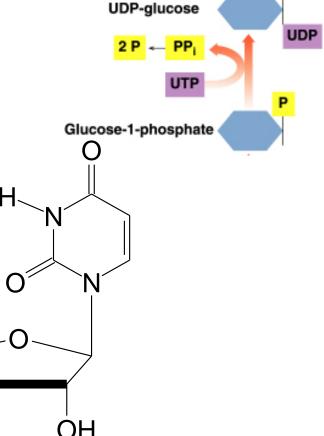
UDP-Glucose

CH₂OH

OH



UTP activates glucose-1-phosphate to form UDP-glucose and pyrophosphate (PP_i).



UDP-glucose

 OH

CH₂

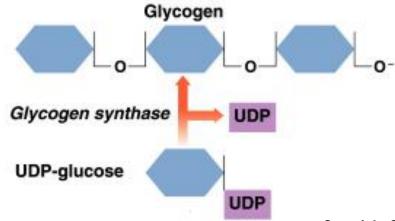
OH

Glycogenesis: Glycogen

The glucose in UDP-glucose adds to glycogen.
 UDP-Glucose + glycogen → glycogen-glucose + UDP

The UDP reacts with ATP to regenerate UTP.

$$UDP + ATP \rightarrow UTP + ADP$$

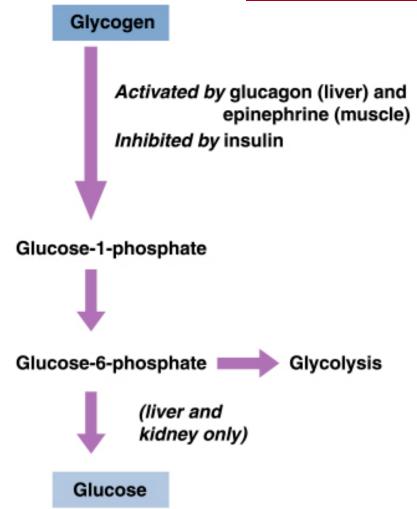


Glycogenolysis



In glycogenolysis

- Glycogen is broken down to glucose.
- Glucose molecules are removed one by one from the end of the glycogen chain to yield glucose-1phosphate.

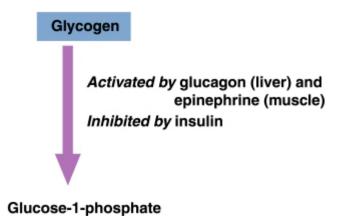


Glycogenolysis



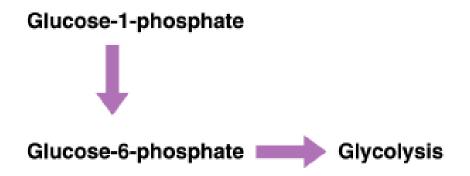
Glycogenolysis

- Is activated by glucagon (low blood glucose).
- Bonds glucose to phosphate to form glucose-1phosphate.



Isomerization of Glucose-1-phosphate

 The glucose-1-phosphate isomerizes to glucose-6-phosphate, which enters glycolysis for energy production.

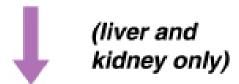


Glucose-6-phosphate

Glucose-6-phosphate

- Is not utilized by brain and skeletal muscle because they lack glucose-6-phosphatase.
- Hydrolyzes to glucose in the liver and kidney, where glucose-6-phosphatase is available providing free glucose for the brain and skeletal muscle.

Glucose-6-phosphate





Learning Check

Match each description with

1) Glycogenesis

- 2) Glycogenolysis
- A. Activated by low levels of blood glucose.
- B. Converts glucose-1-phosphate to glucose-6-phosphate.
- C. Activated by high levels of glucose-6-phosphate.
- D. Glucose + UTP \longrightarrow UDP-glucose + PP_i

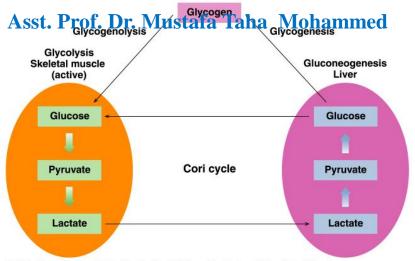
Solution

Match each description with:

- 1) Glycogenesis
- 2) Glycogenolysis
- A. 2 Activated by low levels of blood glucose.
- B. 2 Converts glucose-1-phosphate to glucose-6-phosphate.
- C. 1 Activated by high levels of glucose-6-phosphate.

Metabolic Pathways for Carbohydrates

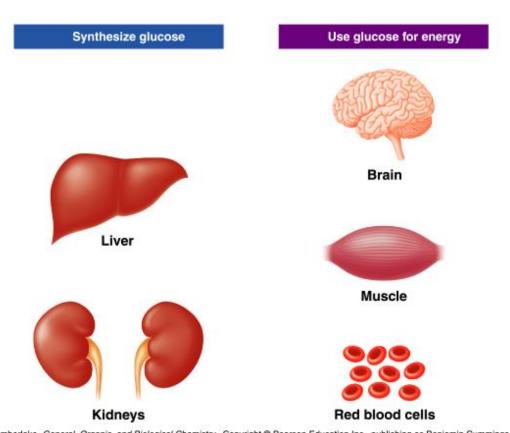
1.8 Gluconeogenesis: Glucose Synthesis



Utilization of Glucose

Glucose

- Is the primary energy source for the brain, skeletal muscle, and red blood cells.
- Deficiency can impair the brain and nervous system.



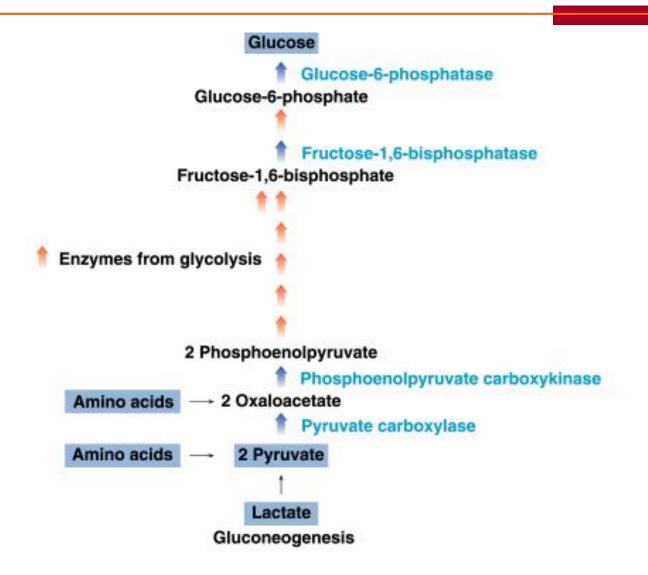
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Gluconeogenesis: Glucose Synthesis

Gluconeogenesis is

- The synthesis of glucose from carbon atoms of noncarbohydrate compounds.
- Required when glycogen stores are depleted.

Gluconeogenesis: Glucose Synthesis



Gluconeogenesis: Glucose Synthesis

In gluconeogenesis,

- Glucose is synthesized from noncarbohydrates such as lactate, some amino acids, and glycerol after they are converted to pyruvate or other intermediates.
- Seven reactions are the reverse of glycolysis and use the same enzymes.
- Three reactions are not reversible.

Reaction 1 Hexokinase

Reaction 3 Phosphofructokinase

Reaction 10 Pyruvate kinase

Gluconeogenesis: Pyruvate to Phosphoenolpyruvate

- Pyruvate adds a carbon to form oxaloacetate by two reactions that replace the reverse of reaction 10 of glycolysis.
- Then a carbon is removed and a phosphate added to form phosphoenolpyruvate.

2 Phosphoenolpyruvate

Phosphoenolpyruvate carboxykinase

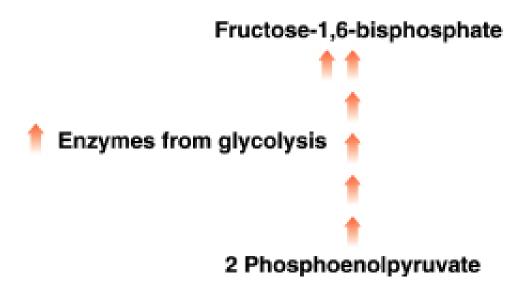
2 Oxaloacetate



2 Pyruvate

Phosphoenolpyruvate to Fructose-1,6-bisphosphate

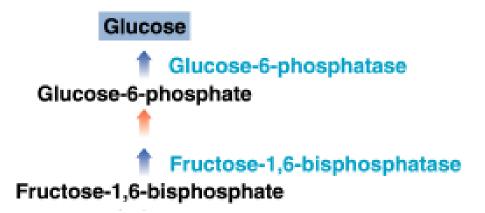
 Phosphoenolpyruvate is converted to fructose-1,6bisphosphate using the same enzymes in glycolysis.



Glucose Formation

Glucose forms when

- A loss of a phosphate from fructose-1,6-bisphosphate forms fructose-6-phosphate and P_i.
- A reversible reaction converts fructose-6-phosphate to glucose-6-phosphate.
- A phosphate is removed from glucose-6-phosphate.



Cori Cycle

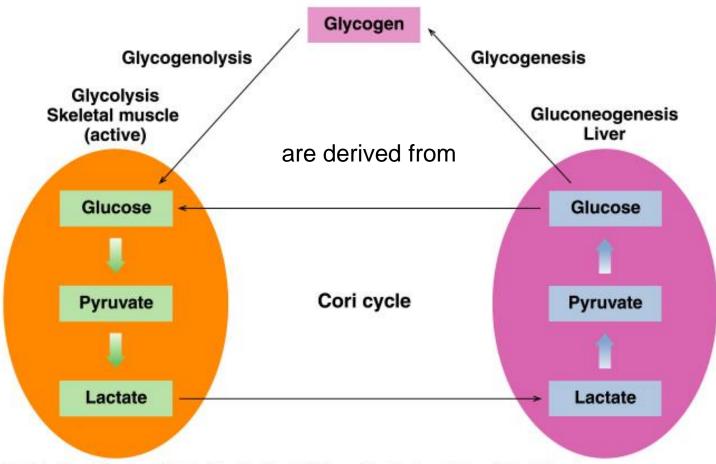


The Cori cycle

- Is the flow of lactate and glucose between the muscles and the liver.
- Occurs when anaerobic conditions occur in active muscle and glycolysis produces lactate.
- Operates when lactate moves through the blood stream to the liver, where it is oxidized back to pyruvate.
- Converts pyruvate to glucose, which is carried back to the muscles.







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Regulation of Glycolysis and Gluconeogenesis

Regulation occurs as

- High glucose levels and insulin promote glycolysis.
- Low glucose levels and glucagon promote gluconeogenesis.

Regulation of Glycolysis and Gluconeogenesis

TABLE 22.2	Regulation of Glycolysis and Gluconeogenesis	
	Glycolysis	Gluconeogenesis
Enzyme	Hexokinase	Glucose-6-phosphatase
Activated by	High glucose levels Insulin, epinephrine	Low glucose levels Glucose-6-phosphate
Inhibited by	Glucose-6-phosphate	
Enzyme	Phosphofructokinase	Fructose-1,6-bisphosphatase
Activated by	AMP	Low glucose levels, glucagon
Inhibited by	ATP	AMP, insulin
Enzyme	Pyruvate kinase	Pyruvate carboxylase
Activated by	Fructose-1,6-bisphosphate	Low glucose level, glucagon
Inhibited by	ATP Acetyl CoA	Insulin

Learning Check



Identify each process as:

1) glycolysis

2) glycogenesis

3) glycogenolysis

- 4) gluconeogenesis
- A. The synthesis of glucose from noncarbohydrates.
- B. The breakdown of glycogen into glucose.
- C. The oxidation of glucose to two pyruvate.
- D. The synthesis of glycogen from glucose.

Solution



Identify each process as:

- 1) glycolysis 2) glycogenesis
- 3) glycogenolysis 4) gluconeogenesis
- A. 4 The synthesis of glucose from noncarbohydrates.
- B. 3 The breakdown of glycogen into glucose.
- C. 1 The oxidation of glucose to two pyruvate.
- D. 2 The synthesis of glycogen from glucose.



The Citric Acid Cycle

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