

22.3: Glycolysis

Learning Objectives

- Objective 1
- Objective 2

Glycolysis is the **catabolic** process in which **glucose** is converted into pyruvate via ten enzymatic steps. There are three regulatory steps, each of which is highly regulated.

Introduction

There are two phases of Glycolysis:

1. the "priming phase" because it requires an input of energy in the form of 2 **ATP**s per glucose molecule and
2. the "pay off phase" because energy is released in the form of 4 **ATP**s, 2 per glyceraldehyde molecule.

The end result of Glycolysis is two new pyruvate molecules which can then be fed into the Citric Acid cycle (also known as the **Kreb's Cycle**) if oxygen is present, or can be reduced to lactate or ethanol in the absence of oxygen using a process known as **Fermentation**. Glycolysis occurs within almost all living cells and is the primary source of Acetyl-CoA, which is the molecule responsible for the majority of energy output under **aerobic** conditions. The structures of Glycolysis intermediates can be found in the following diagram:

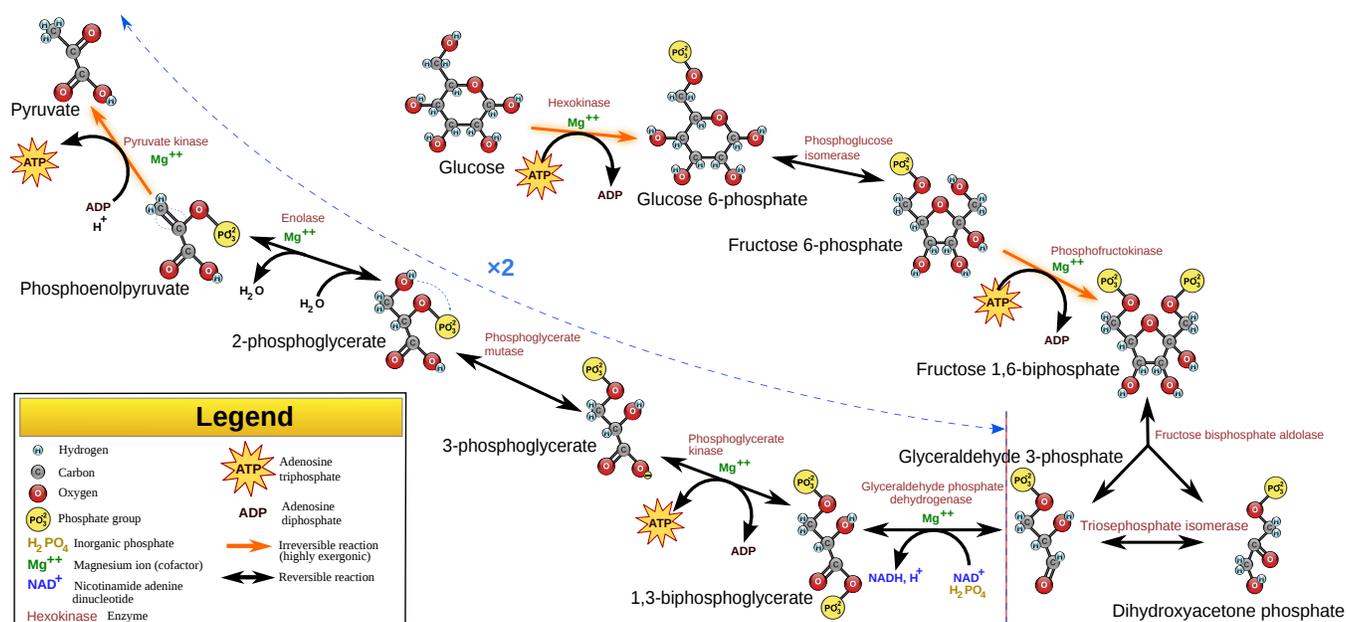


Figure 1: Glycolysis pathway. from Wikipedia (CCBY-SA 3.0; YassineMrabet).

Phase 1: The "Priming Step"

The first phase of Glycolysis requires an input of energy in the form of ATP (adenosine triphosphate).

1. alpha-D-Glucose is phosphorylated at the 6 carbon by ATP via the enzyme Hexokinase (Class: Transferase) to yield alpha-D-Glucose-6-phosphate (G-6-P). This is a regulatory step which is negatively regulated by the presence of glucose-6-phosphate.
2. alpha-D-Glucose-6-phosphate is then converted into D-Fructose-6-phosphate (F-6-P) by Phosphoglucosomerase (Class: Isomerase)
3. D-Fructose-6-phosphate is once again phosphorylated this time at the 1 carbon position by ATP via the enzyme Phosphofruktokinase (Class: Transferase) to yield D-Fructose-1,6-bisphosphate (FBP). This is the committed step of glycolysis because of its large ΔG value.
4. D-Fructose-1,6-bisphosphate is then cleaved into two, three carbon molecules; Dihydroxyacetone phosphate (DHAP) and D-Glyceraldehyde-3-phosphate (G-3-P) by the enzyme Fructose biphosphate aldolase (Class: Lyase)

5. Because the next portion of Glycolysis requires the molecule D-Glyceraldehyde-3-phosphate to continue Dihydroxyacetone phosphate is converted into D-Glyceraldehyde-3-phosphate by the enzyme Triose phosphate isomerase (Class: Isomerase)

Phase 2: The "Pay Off Step"

The second phase of Glycolysis where 4 molecules of ATP are produced per molecule of glucose. Enzymes appear in red:

1. D-Glyceraldehyde-3-phosphate is phosphorylated at the 1 carbon by the enzyme Glyceraldehyde-3-phosphate dehydrogenase to yield the high energy molecule 1,3-Bisphosphoglycerate (BPG)
2. ADP is then phosphorylated at the expense of 1,3-Bisphosphoglycerate by the enzyme Phosphoglycerate kinase (Class: Transferase) to yield ATP and 3-Phosphoglycerate (3-PG)
3. 3-Phosphoglycerate is then converted into 2-Phosphoglycerate by Phosphoglycerate mutase in preparation to yield another high energy molecule
4. 2-Phosphoglycerate is then converted to phosphoenolpyruvate (PEP) by Enolase. H₂O, potassium, and magnesium are all released as a result.
5. ADP is once again phosphorylated, this time at the expense of PEP by the enzyme pyruvate kinase to yield another molecule of ATP and and pyruvate. This step is regulated by the energy in the cell. The higher the energy of the cell the more inhibited pyruvate kinase becomes. Indicators of high energy levels within the cell are high concentrations of ATP, Acetyl-CoA, Alanine, and cAMP.

Because Glucose is split to yield two molecules of D-Glyceraldehyde-3-phosphate, each step in the "Pay Off" phase occurs twice per molecule of glucose.

References

1. Garrett, H., Reginald and Charles Grisham. Biochemistry. Boston: Twayne Publishers, 2008.
2. Raven, Peter. Biology. Boston: Twayne Publishers, 2005.

Problems

1. What is the net yield of Glycolysis as far as ATP?
2. Name the enzymes that are key regulatory sites in Glycolysis.
3. Why are the enzymes in the previous question targets for regulation?
4. Why is the priming phase necessary?
5. Draw the entire pathway for glycolysis including enzymes, reactants and products for each step.

Contributors and Attributions

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