Unit 3: Cellular Energetics

Cells Need Energy

Cellular energetics focuses on how cells obtain, transfer, and use energy to maintain organization and carry out life processes. In AP Biology, this topic mainly centers on how cells generate ATP (adenosine triphosphate) through cellular respiration and photosynthesis.

In cellular respiration, energy stored in glucose is released through a series of chemical reactions that ultimately produce ATP. This ATP supplies energy for cellular work such as transport, movement, and biosynthesis.

In eukaryotic organisms, most steps of cellular respiration occur in the mitochondria, while in prokaryotes they take place in the cytoplasm and plasma membrane.

Photosynthesis is the process by which plants, algae, and some bacteria convert light energy into chemical energy stored in organic molecules like glucose. In plants, this process occurs in chloroplasts, while photosynthetic bacteria rely on specialized pigments embedded in their membranes.

Together, cellular respiration and photosynthesis form a cycle that supports life by providing a continuous supply of ATP. Understanding how energy flows through cells is essential for understanding metabolism and biological organization.

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Energy and Thermodynamics

All living organisms require a constant input of energy to maintain their highly ordered state. According to the second law of thermodynamics, entropy, or disorder, increases over time in closed systems. Living systems avoid this increase in disorder by continuously using energy.

Energy-releasing reactions are often paired with energy-requiring reactions. For example, energy released from the breakdown of molecules can be used to build new molecules or transport ions across membranes.

If energy input is disrupted or falls below what is needed to maintain organization, the system will move toward equilibrium, which for living organisms results in death.

Biological pathways often occur in a stepwise sequence, where the product of one reaction becomes the reactant for the next. This controlled process allows energy to be transferred efficiently.

The electron transport chain (ETC) is a major example of this type of energy transfer system.

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Photosynthesis

Photosynthesis allows organisms to capture energy from sunlight and convert it into stored chemical energy.

This process first evolved in prokaryotic organisms, particularly cyanobacteria, which contributed to the rise of oxygen in Earth's atmosphere. These early photosynthetic pathways later gave rise to photosynthesis in eukaryotes.

Photosynthesis occurs in two major stages:

- Light-dependent reactions capture light energy and convert it into ATP and NADPH. These reactions occur in the thylakoid membranes of chloroplasts.
- Light-independent reactions (Calvin cycle) use ATP and NADPH to fix carbon dioxide into organic molecules. This stage takes place in the stroma of the chloroplast.

Chlorophyll absorbs light energy, exciting electrons in photosystems I and II. These high-energy electrons pass through an electron transport chain, generating a proton gradient across the thylakoid membrane. This gradient powers ATP synthesis through ATP synthase.

The ATP and NADPH produced in the light reactions fuel the Calvin cycle, where carbon dioxide is converted into carbohydrates such as glucose.

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Cellular Respiration and Fermentation

Both cellular respiration and fermentation allow cells to extract energy from organic molecules to produce ATP.

Fermentation is an anaerobic process that occurs when oxygen is absent. It allows ATP production to continue by regenerating NAD^+ from NADH. Common fermentation end products include lactate and ethanol.

Cellular respiration is an aerobic process that requires oxygen and involves a series of enzyme-driven reactions that efficiently harvest energy from glucose. In eukaryotic cells, this process occurs primarily in the mitochondria and results in ATP production.

Electrons carried by NADH and $FADH_2$ move through the electron transport chain toward a final electron acceptor. In aerobic respiration, oxygen serves as this final acceptor. In photosynthesis, $NADP^+$ serves a similar role.

As electrons move through the ETC, a proton gradient forms across the membrane. The movement of protons back across the membrane through ATP synthase drives ATP production. This process is called oxidative phosphorylation in respiration and photophosphorylation in photosynthesis.

In some organisms, uncoupling electron transport from ATP synthesis releases energy as heat, which can help regulate body temperature.

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Glycolysis and the Krebs Cycle

Glycolysis is the first step in glucose breakdown and occurs in the cytosol of all cells. It produces ATP, NADH, and pyruvate and does not require oxygen.

Pyruvate is transported into the mitochondria, where it enters the Krebs cycle (citric acid cycle). This cycle releases carbon dioxide, produces ATP, and transfers high-energy electrons to NADH and $FADH_2$.

The electrons carried by these molecules are delivered to the electron transport chain in the inner mitochondrial membrane. As electrons move through the ETC, a proton gradient is created, which is used to generate ATP.

Fitness and Molecular Variation

Variation at the molecular level allows organisms to respond to changing environments. Differences in molecular structure, enzyme efficiency, or metabolic pathways can affect survival and reproductive success. This variation is a key component of evolutionary fitness and adaptability.

Key Equations and Components

Major Equations:

Cellular Respiration:

- $C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O$ + ATP

Photosynthesis:

- $CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$

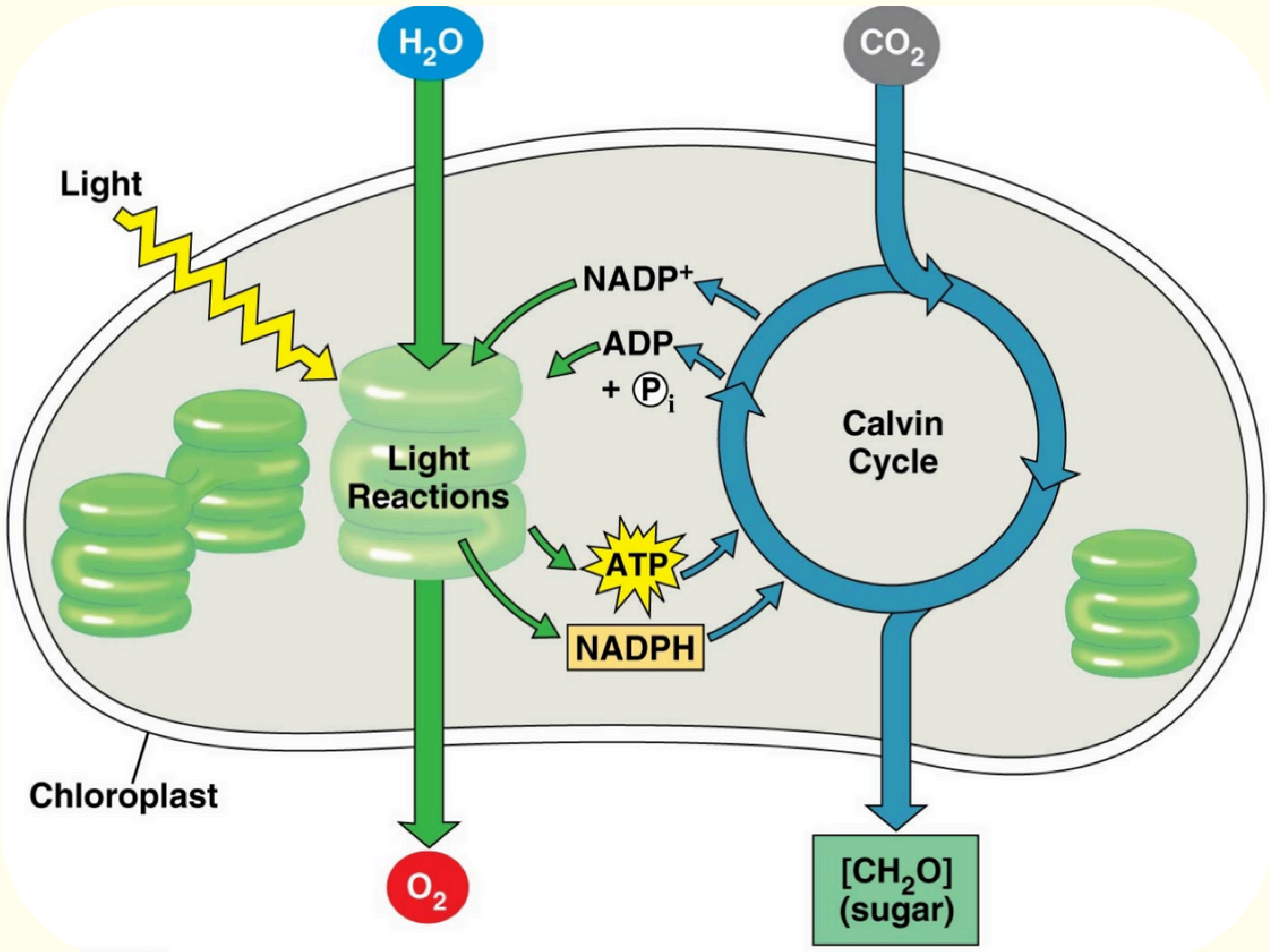
Key Equations and Components

Electron carriers (NADH, $FADH_2$, NADPH)

- These molecules transport high-energy electrons to the electron transport chain or the Calvin cycle.

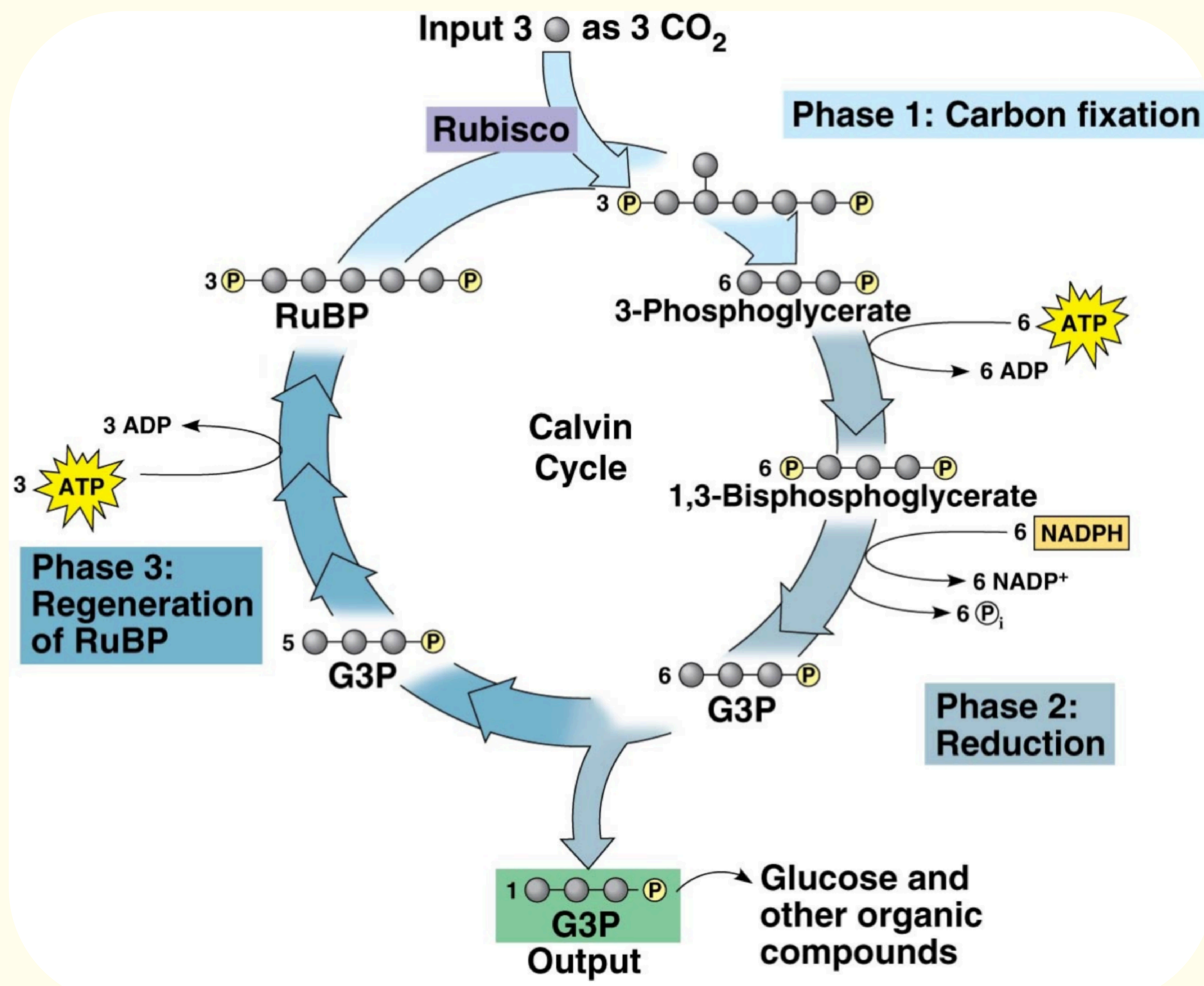
ATP Synthase

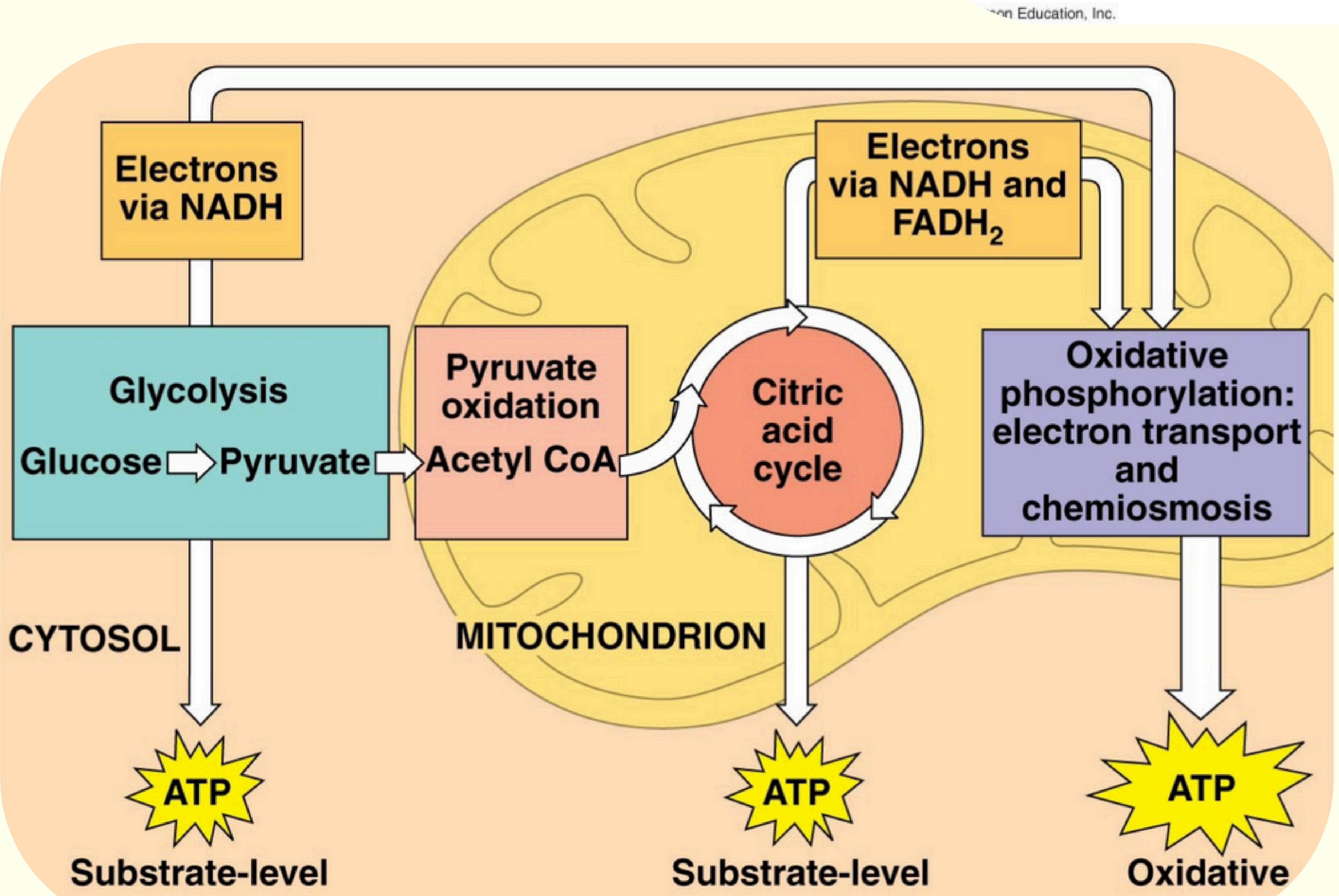
- This enzyme uses the energy stored in proton gradients to convert ADP into ATP through chemiosmosis.



Light - Dependent Reactions

Light - Independent Reactions





Cellular Respiration