Cellular Respiration and Photosynthesis

A Meridian© Biology AP Study Guide by John Ho and Tim Qi

- **Metabolism:** Totality of an organism's chemical reactions
  - Free Energy Change : $\Delta G = \Delta H - T\Delta S$
    - Where ΔG = Gibbs free energy, ΔH = Enthalpy (i.e. Total energy), T = temperature in Kelvin's, ΔS = change in Entropy

Types of Reactions		
Endergonic	$\Delta G > 0$	Net gain of energy, energy is absorbed from surroundings. Characterized by cold around the reaction.
Exergonic	$\Delta G < 0$	Net release of energy, amount of energy in system decreases. Characterized by heat released from reaction.

- Thermodynamics Laws:
  1. First Law: Energy is constant, it is not created or destroyed
  2. Second Law: Entropy increases when energy is transferred

- **Cellular Respiration:** The breakdown of glucose to create energy
  - Oxidation of glucose for energy: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + Energy

Election Transfer	
Oxidation	Loss of electrons (e.g. $NADH \rightarrow NAD^+$), increase in charge
Reduction	Addition of electrons (e.g. $NAD^+ \rightarrow NADH$), decrease in charge

Cellular Respiration Steps			
Process	**Products**	**Location**	**Description**
1. Glycolysis	2 ATP 2 Pyruvate 2 NADH	Cytoplasm	"Splitting sugar", a process of 10 steps where a glucose molecule is split into two 3-carbon pieces known as pyruvate by different enzymes.
2. Pyruvate Oxidation	2 NADH 2 CO_2	Mitochondria	Pyruvate is transported to the mitochondria via active transport and converted into *Acetyl CoA*.
3. Citric Acid Cycle	2 ATP 4 CO_2 6 NADH 2 $FADH_2$	Mitochondria	Also known as the "Kreb's Cycle", occurs when oxygen is present. Acetyl CoA is oxidized into CO_2 in a series of steps while NAD^+ is reduced into NADH.
4. Oxidative Phosphorylation	34 ATP 6 H_2O	Mitochondria	The *Electron Transport Chain* carries proton gradients (H^+) across the mitochondria inner membrane by oxidizing NADH and FADH. ATP is synthesized by ATP synthase when the gradient is driven back into the mitochondrial matrix.

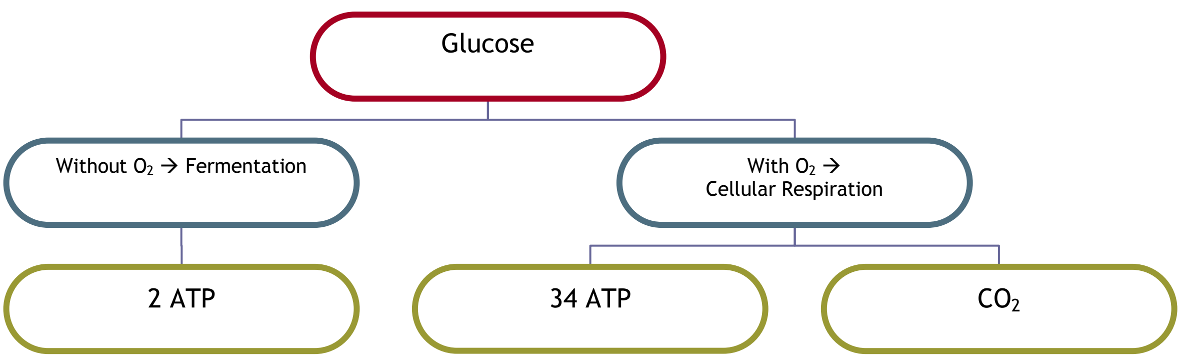
- ATP Synthase: An enzyme that synthesizes ATP when proton gradients flow back from the inter-membrane space to the mitochondria matrix.
- Chemiosmosis: Energy stored as H^+ ions, generates energy by acting a chemical gradient.

ATP Yield in Cellular Respiration (Per Glucose)			
Process	**ATP**	**Other**	**Source**
Glycolysis Preparation	-2 ATP		Phosphorylation of glucose, ATP used to split the glucose into pyruvate
Glycolysis Pay-Off	4 ATP	2 NADH	2 ATP used for transporting glucose into mitochondria. Oxidative and substrate phosphorylation generates the remaining ATP
	4 ATP		
Pyruvate Oxidation	6 ATP	2 NADH	Oxidative phosphorylation
Citric Acid Cycle	2 ATP		Oxidative phosphorylation and substrate phosphorylation.
	18 ATP	6 NADH	
	4 ATP	2 $FADH_2$	
Total Yield	36 ATP	Complete oxidation of glucose and coenzymes produced during the process.	

- Coenzyme Yields: 1 $FADH_2$ → 2 ATP, 1 NADH → 3 ATP

- Alternate Cycles:
  - Aerobic: Energy generated in the presence of oxygen
  - Anaerobic: Energy created in the absence of oxygen
  - Lactic Acid Fermentation: Anaerobic respiration which occurs in absence of oxygen.
    1. Glycolysis produces two pyruvate molecules
    2. Pyruvate undergoes fermentation (conversion of sugar to alcohol)
    3. 2 ATP, 2 NADH, and Lactic Acid produced
    4. Lactic Acid diffuses into blood and is reverted into pyruvate by the liver

  * Pyruvate is not metabolized to CO_2, Electron Transport Chain not used



- Control of Cellular Metabolism
  - Feedback Inhibition: Regulates respiration by stopping the reaction when the product is in excess.
  - Other Reactants: Proteins and fats can also be used during respiration either directly converted into pyruvate or Acetyl CoA.

Prokaryotes and Eukaryotes	
Prokaryotes	Respiration does not take place mitochondria since prokaryotes do not have them. ETC occurs instead in the plasma membrane and citric acid cycle in the cytoplasm.
Eukaryotes	The ETC occurs in the mitochondrial inner membrane and the citric acid cycle in the mitochondrial matrix.

- **Photosynthesis:** The process by which plants convert light energy and organic compounds to sugar
  - Factors Affecting Photosynthesis:
    1. Light wavelength
    2. Carbon dioxide concentration

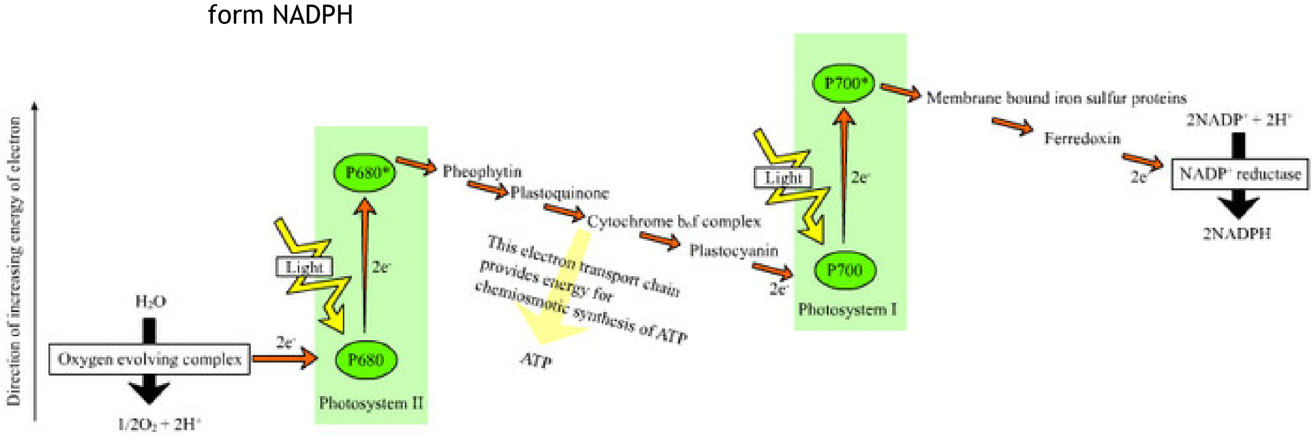
3. Temperature

- Chemical Equation: $6CO_2 + 6H_2O + \text{Energy} \rightarrow C_6H_{12}O_6 + 6O_2$
- Light Capture: Chlorophyll located in the thylakoid act as pigments that absorb light energy. In plants, $NADP^+$ instead on NAD^+ is used as an electron acceptor.

Photosynthesis Pigments	
Chlorophyll α	The primary pigment in photosynthesis; absorbs light wavelengths that yield the color red and violet-blue. The pigment appears blue-green on the leaf.
Chlorophyll β	Absorbs light, found in land plants and appears yellow-green on leaves.
Carotenoids	Absorbs violet and blue-green light, prevents damage from ultraviolet rays.

- Stages of Photosynthesis
  1. Light Reactions: Captures light energy to produce ATP and NADPH
  2. Calvin Cycle: ATP and NADPH used to “fix” carbon into carbohydrate.

- Light Reaction Process:
  - Cyclic Flow
    1. Light enters the thylakoid in Photosystem II splits an H_2O molecule. The H molecule enters a chain of electrons (ETC) while the O_2 is given off as a waste product.
    2. The electrons enter Photosystem I dropping to a lower state of energy. The energy difference is used to generate ATP through ATP synthase.
    3. Light again raises the energy level of the electrons. The H^+ ion is bound with $NADP^+$ to form NADPH

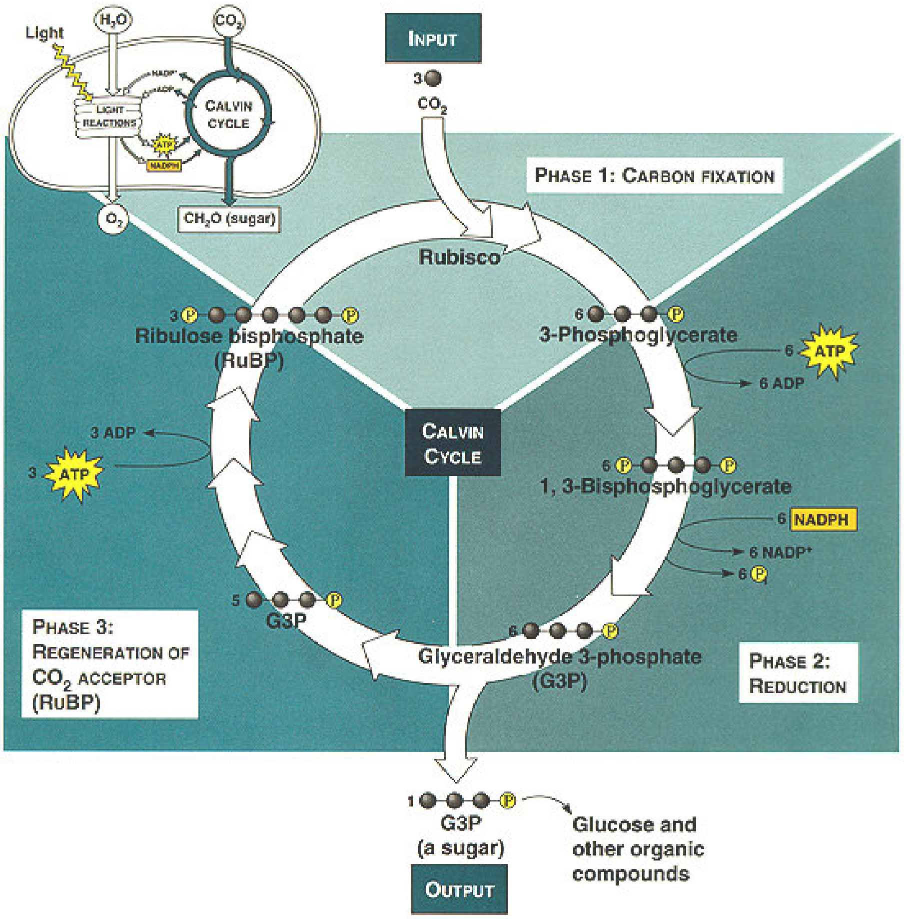


  - Non Cyclic Flow
    1. Light excites electrons in Photosystem I, which enter the ETC
    2. The electrons drive ATP synthase to generate ATP
    3. Electrons reenter Photosystem I and continue process.

Cyclic and Non-cyclic Flow				
Flow	**Products**	**Location**	**Electron Source**	**Reactants**
Cyclic	ATP only	Photosystem I	No electrons lost	Light, electrons
Non-cyclic	ATP, NADPH, O_2	Photosystem I & Photosystem II	$H_2O \rightarrow 2H + O_2$	H_2O, light, $NADP^+$

- The Calvin Cycle: Also “Light Independent Reaction”. Energy is used to synthesize sugar from CO_2, which is then stored and used through cellular respiration.
  - Calvin Cycle Process (Most Common C_3):
    1. The enzyme Rubisco incorporates Carbon Dioxide into a five carbon sugar (*RuBP*) which creates a 6-carbon intermediate.
    2. The 6-carbon intermediate splits into two 3-carbon molecules which are used to create glucose and other sugars.

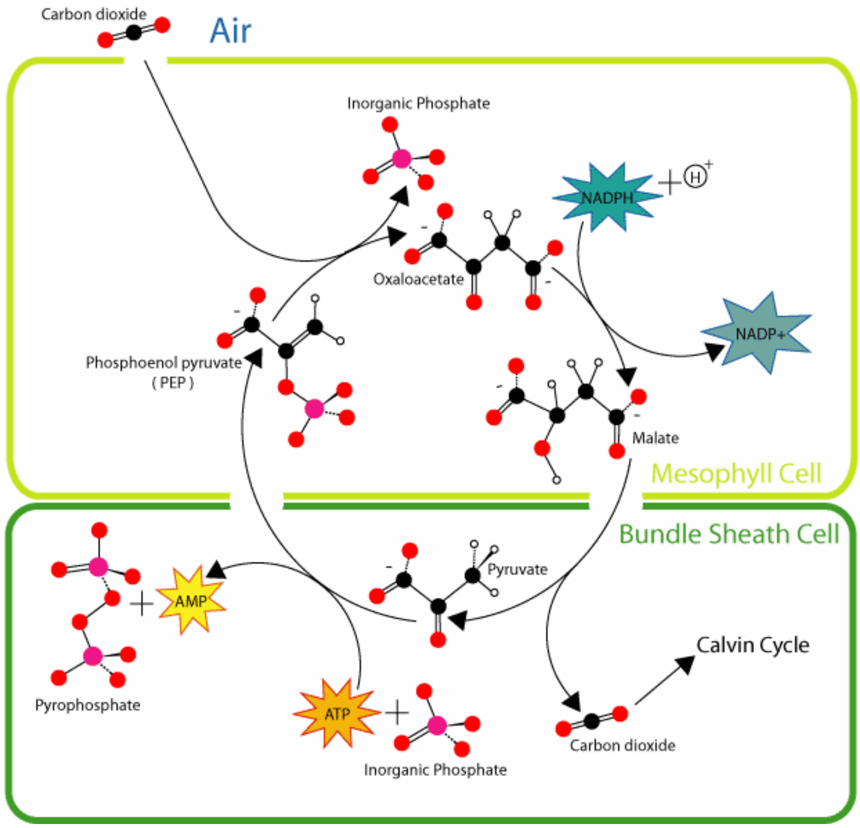
3. Pools of used 3-carbon sugars are used to create the five carbon CO_2 acceptor RuBP. The process consumes 18 ATP.



- Other Calvin Cycle Pathways: Photorespiration
  - Photorespiration: Occurs under conditions of high O_2 concentration and high temperatures when Rubisco reacts with O_2 instead of CO_2. The process is wasteful since it consumes organic material without producing sugars.

C_4 and CAM Pathways		
Cycle	**Separation**	**Description**
C_4 Pathway	Spatial: Mesophyll and Bundle-Sheath cell	CO_2 is trapped by *PEP Carbonxylase* instead of Rubisco and is fixed into a 4-carbon intermediate instead of 6-carbon. The process is separated physically in the mesophyll and the bundle-sheath cell (not CO_2 permeable) so that Rubisco does not come in contact with O_2. 30 ATP is consumed.
CAM Pathway	Time: Day and night	CO_2 is stored as maltic acid by the enzyme *maltase* during the night and broken down during the day into pyruvate to continue the Calvin Cycle. The stomata is opened only in night for CO_2 intake and closed in the day to prevent water loss. The *4-carbon* intermediate is also used in the cycle.

  - Pathway Advantages: C_3 is more efficient that the C_4 up to a certain point of light intensity. C_3 becomes energy inefficient when Rubisco reacts with O_2 excessively, reducing efficiency up to 25%.



- Rubisco is used only in the lower reaction (Bundle-Sheath Cell) where there is a low concentration of O_2. PEP takes its place in the mesophyll.