Structure and Functions of Mitochondria

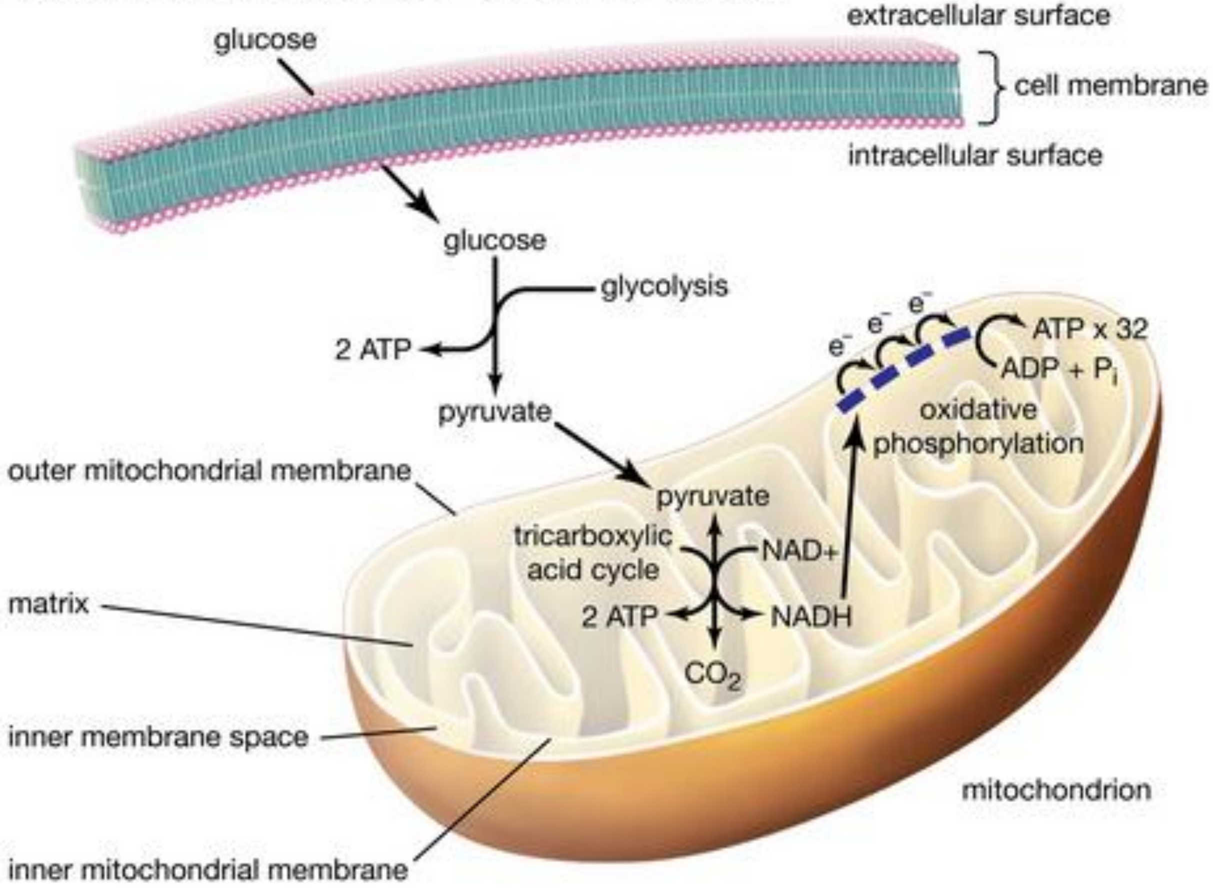
Mitochondria

- **Mitochondrion**, membrane-bound organelle found in the cytoplasm of almost all eukaryotic cells (cells with clearly defined nuclei), the primary function of which is to generate large quantities of energy in the form of adenosine triphosphate (ATP).
- Mitochondria are typically round to oval in shape and range in size from 0.5 to 10 μm. In addition to producing energy, mitochondria store calcium for cell signaling activities, generate heat, and mediate cell growth and death

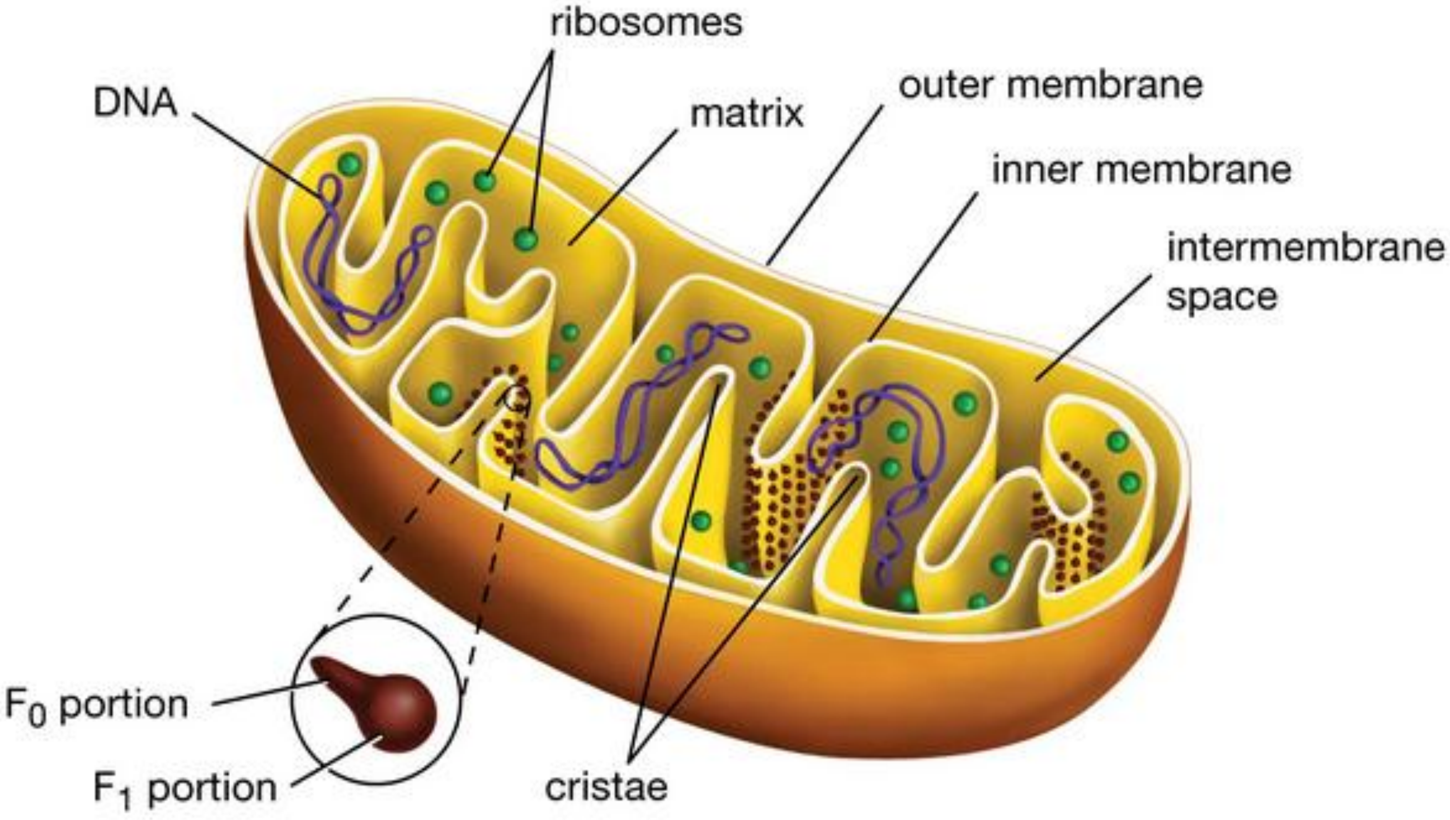
- Mitochondria have an inner and outer membrane, with an intermembrane space between them. The outer membrane contains proteins known as porins, which allow movement of ions into and out of the mitochondrion. Enzymes involved in the elongation of fatty acids and the oxidation of adrenaline can also be found on the outer membrane.
- The space within the inner membrane of the mitochondrion is known as the matrix, which contains the enzymes of the Krebs (TCA) and fatty acid cycles, alongside DNA, RNA, ribosomes and calcium granules.
- The inner membrane contains a variety of enzymes. It contains ATP synthase which generates ATP in the matrix, and transport proteins that regulate the movement of metabolites into and out of the matrix.
- The inner membrane is arranged into cristae in order to increase the surface area available for energy production via oxidative phosphorylation.

- The number of mitochondria per cell varies widely—for example, in humans, erythrocytes (red blood cells) do not contain any mitochondria, whereas liver cells and muscle cells may contain hundreds or even thousands. The only eukaryotic organism known to lack mitochondria is the oxymonad *Monocercomonoides* species. Mitochondria are unlike other cellular organelles in that they have two distinct membranes and a unique genome and reproduce by binary fission; these features indicate that mitochondria share an evolutionary past with prokaryotes (single-celled organisms)
- Most of the proteins and other molecules that make up mitochondria originate in the cell nucleus. However, 37 genes are contained in the human mitochondrial genome, 13 of which produce various components of the electron transport chain (ETC). In many organisms, the mitochondrial genome is inherited maternally. This is because the mother’s egg cell donates the majority of cytoplasm to the embryo, and mitochondria inherited from the father’s sperm are usually destroyed.

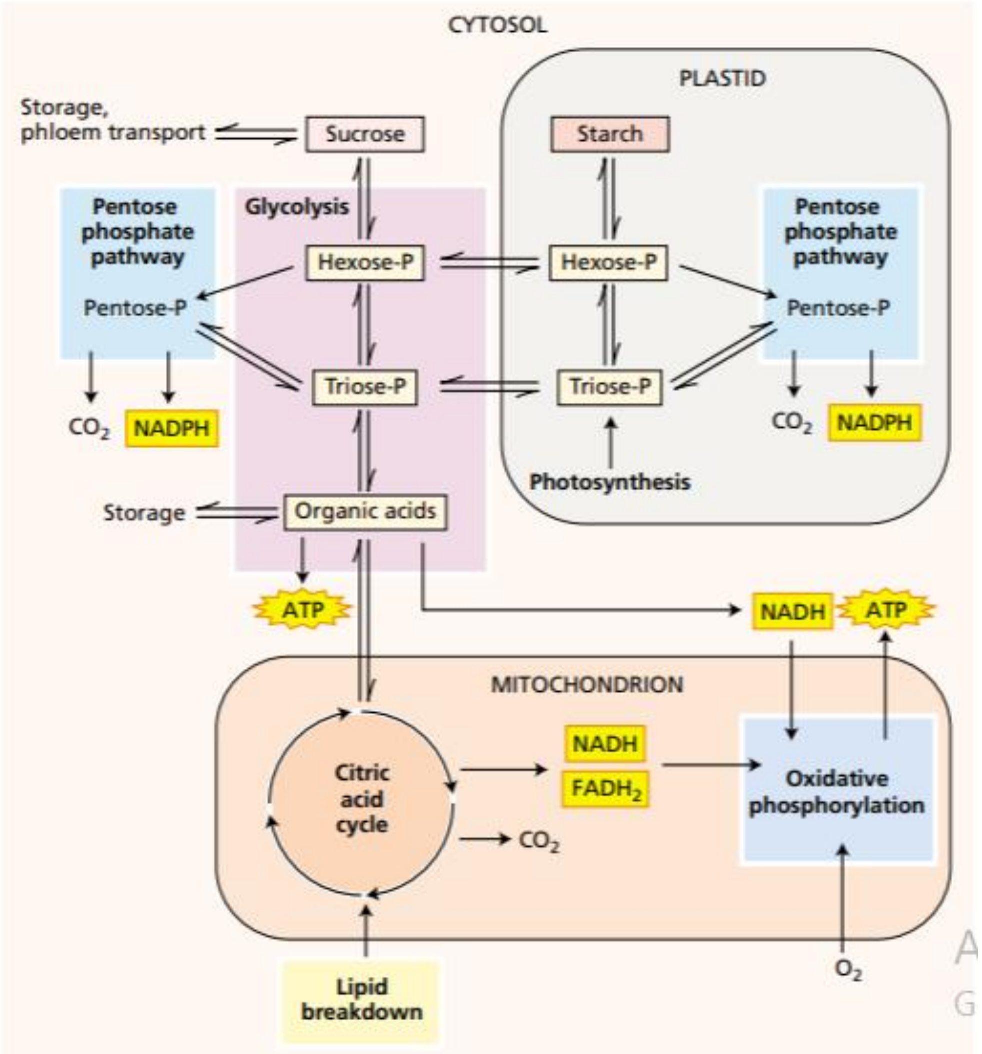
Basic overview of processes of ATP production



Mitochondria structure



Overview of respiration



Overview of respiration. Substrates for respiration are generated by other cellular processes and enter the respiratory pathways. Glycolysis and the pentose phosphate pathways in the cytosol and plastid convert sugars to organic acids, via hexose phosphates and triose phosphates, generating NADH or NADPH and ATP. The organic acids are oxidized in the mitochondrial citric acid cycle, and the NADH and FADH2 produced provide the energy for ATP synthesis by the electron transport chain and ATP synthase in oxidative phosphorylation. In gluconeogenesis, carbon from lipid breakdown is broken down in the glyoxysomes, metabolized in the citric acid cycle, and then used to synthesize sugars in the cytosol by reverse glycolysis.

Cellular respiration

- Depending on the availability of oxygen, the pyruvate may be subjected to one of two alternative processes:
- Aerobic respiration occurs in the presence of oxygen and results in the further production of ATP (~ 34 molecules).
- Anaerobic respiration (fermentation) occurs in the absence of oxygen and no further ATP is produced.

Aerobic Respiration

- If oxygen is present, the pyruvate is transported to the mitochondria for further breakdown (complete oxidation).
- This further oxidation generates large numbers of reduced hydrogen carriers (NADH + H+ and FADH2).
- In the presence of oxygen, the reduced hydrogen carriers can release their stored energy to synthesise more ATP.
- Aerobic respiration involves three additional processes – the link reaction, krebs cycle and the electron transport chain.

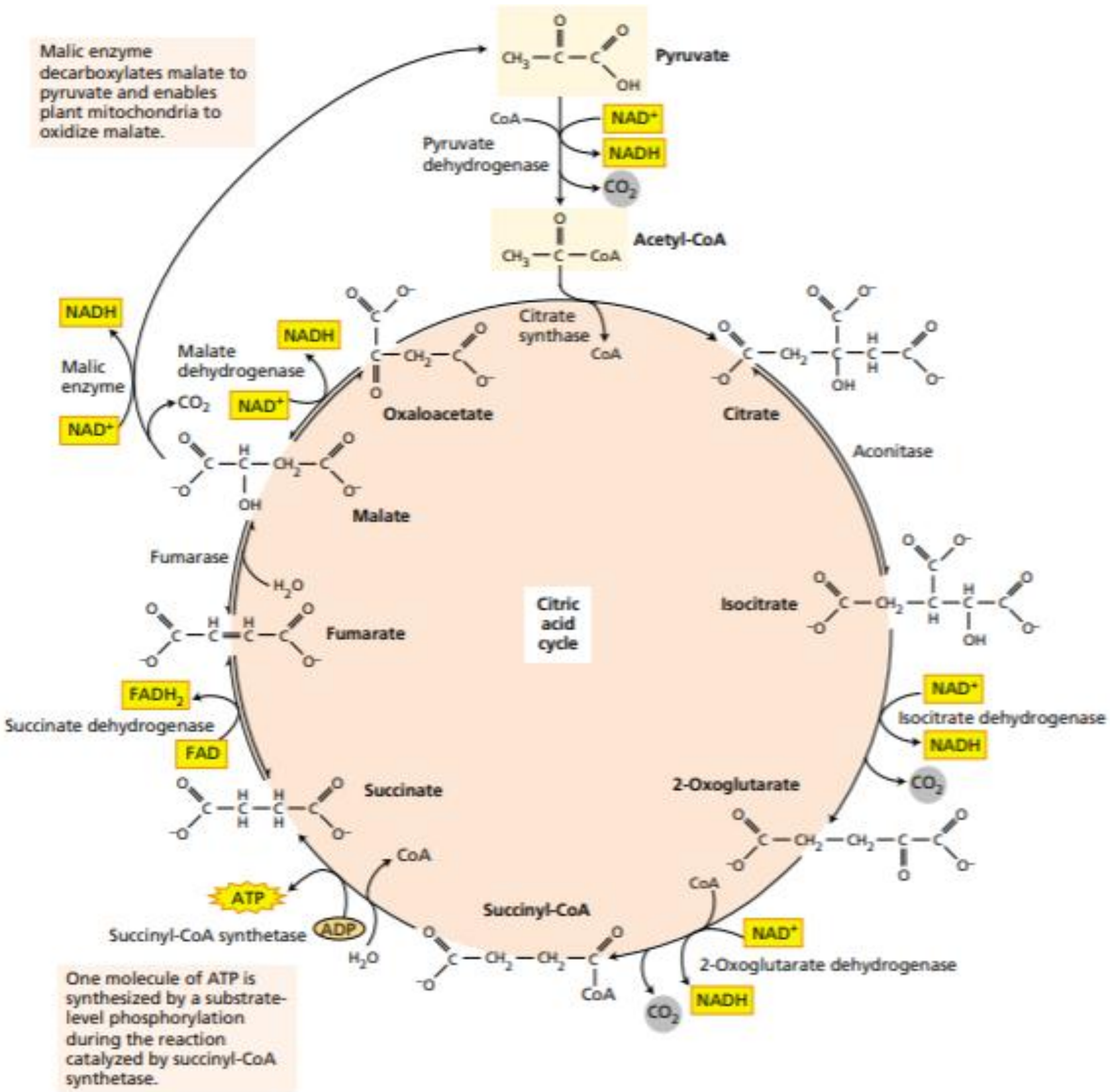
Anaerobic Respiration (Fermentation)

- If oxygen is not present, pyruvate is not broken down further and no more ATP is produced (incomplete oxidation)
- The pyruvate remains in the cytosol and is converted into lactic acid (animals) or ethanol and CO_2 (plants and yeast)
- This conversion is reversible and is necessary to ensure that glycolysis can continue to produce small quantities of ATP
- Glycolysis involves oxidation reactions that cause hydrogen carriers (NAD^+) to be reduced (becomes $NADH + H^+$)
- Typically, the reduced hydrogen carriers are oxidised via aerobic respiration to restore available stocks of NAD^+
- In the absence of oxygen, glycolysis will quickly deplete available stocks of NAD^+, preventing further glycolysis
- Fermentation of pyruvate involves a reduction reaction that oxidises NADH (releasing NAD^+ to restore available stocks)
- Hence, anaerobic respiration allows small amounts of ATP to be produced (via glycolysis) in the absence of oxygen

Citric acid cycle

- In the citric acid cycle, pyruvate is oxidized completely to CO_2, and a considerable amount of reducing power (16 NADH + 4 $FADH_2$ equivalents per sucrose) is generated in the process.
- With one exception (succinate dehydrogenase), these reactions involve a series of enzymes located in the internal aqueous compartment, or matrix, of the mitochondrion (see Figure).
- Succinate dehydrogenase is localized in the inner of the two mitochondrial membranes.

Citric acid cycle

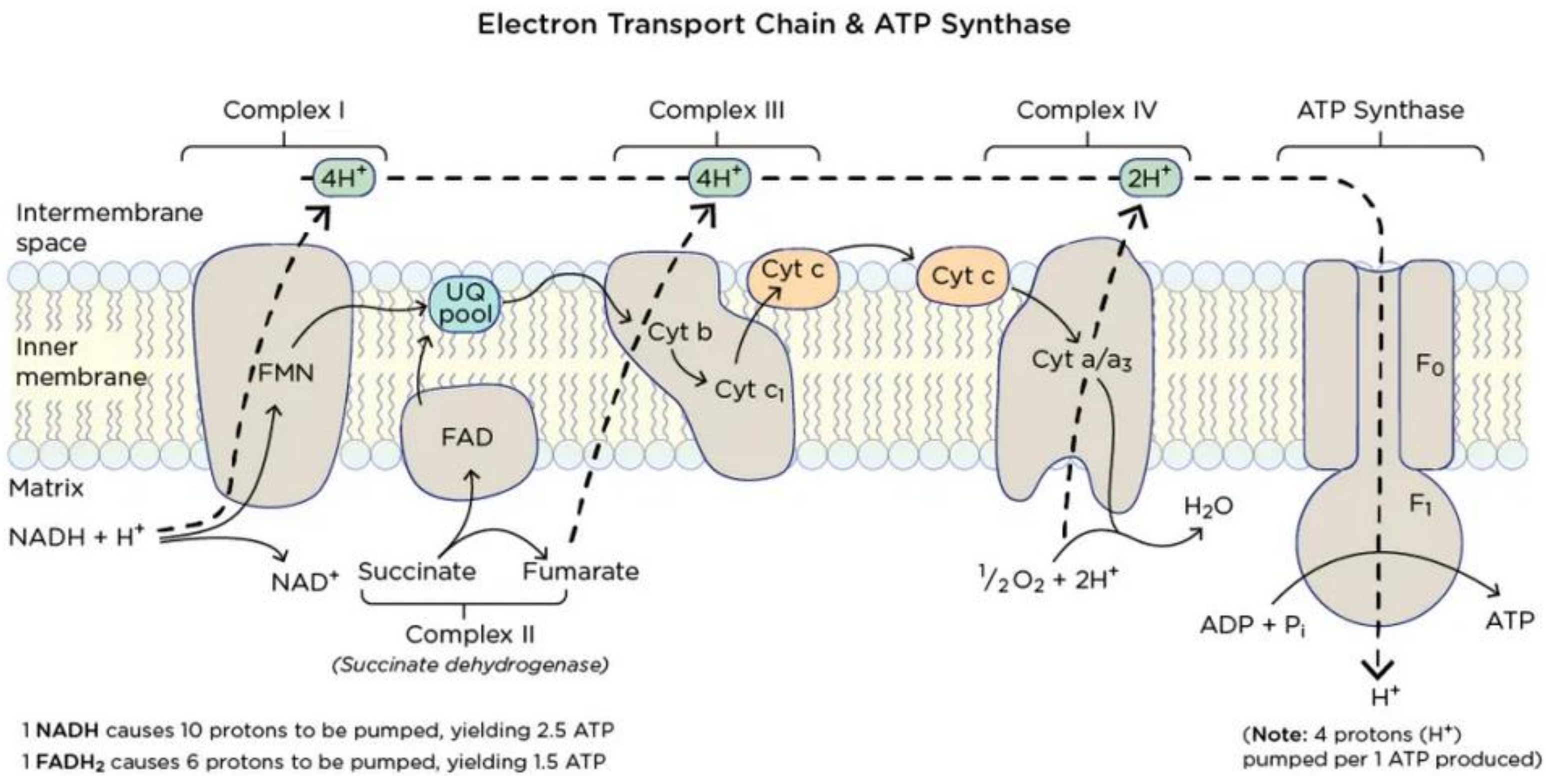


Reactions and enzymes of the plant citric acid cycle. Pyruvate is completely oxidized to three molecules of CO2. The electrons released during these oxidations are used to reduce four molecules of NAD+ to NADH and one molecule of FAD to FADH2.

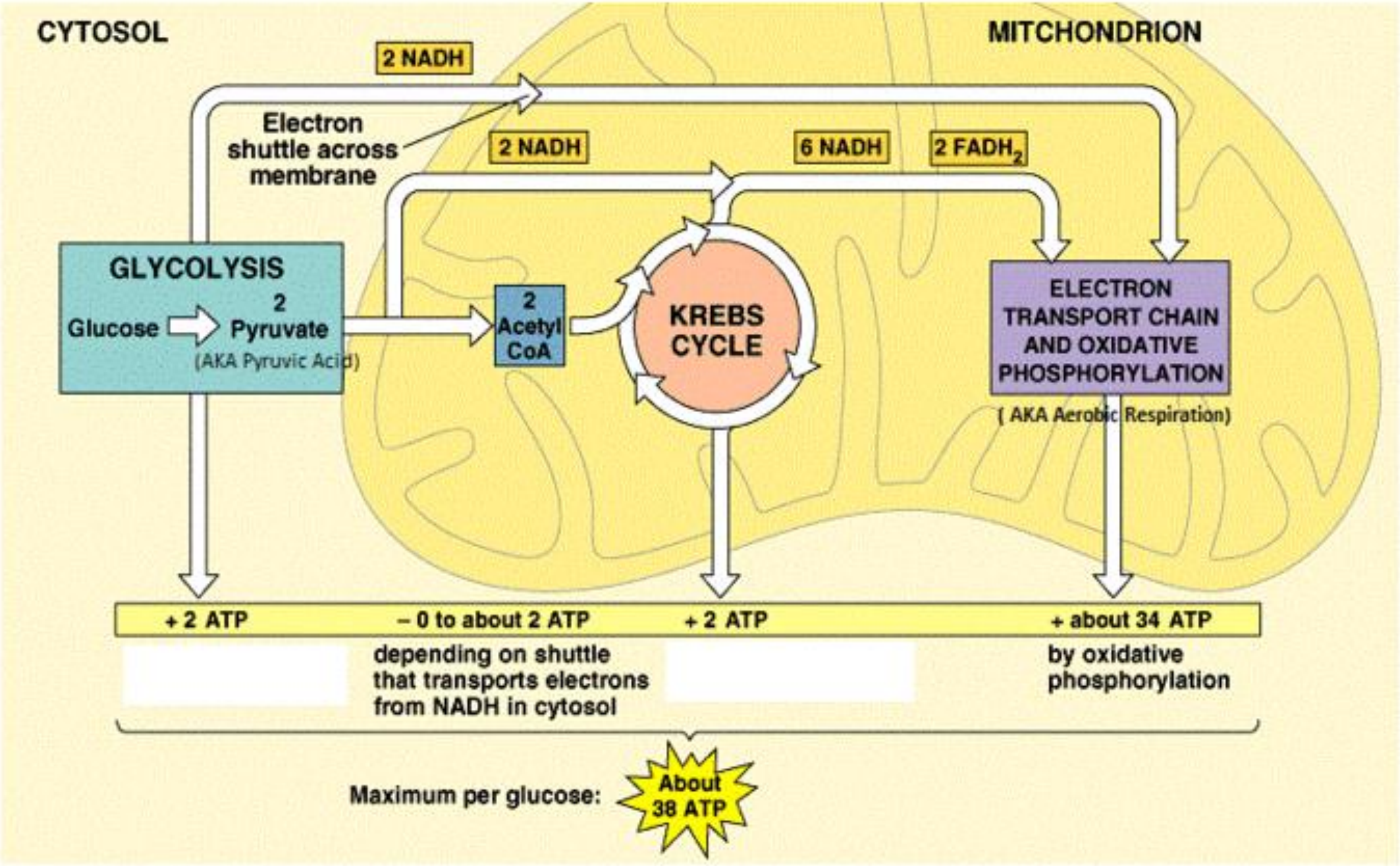
Oxidative phosphorylation

- In oxidative phosphorylation, electrons are transferred along an electron transport chain, consisting of a collection of electron transport proteins bound to the inner of the two mitochondrial membranes.
- This system transfers electrons from NADH (and related species)—produced during glycolysis, the pentose phosphate pathway, and the citric acid cycle—to oxygen.
- This electron transfer releases a large amount of free energy, much of which is conserved through the synthesis of ATP from ADP and Pi (inorganic phosphate) catalyzed by the enzyme ATP synthase.
- Collectively the redox reactions of the electron transport chain and the synthesis of ATP are called oxidative phosphorylation. This final stage completes the oxidation of sucrose.

Oxidative phosphorylation



Biological oxidation



Photorespiration

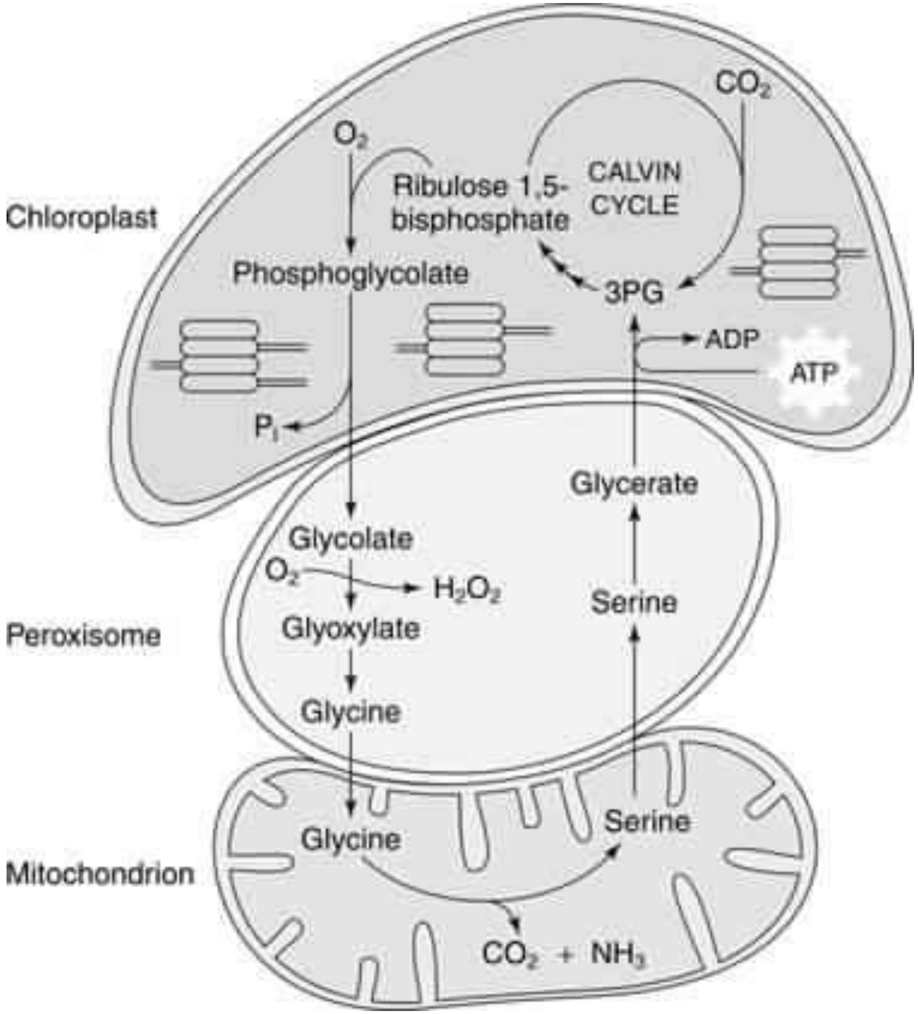
- Photorespiration (Also Called Photosynthesis C2)
- The fundamental basis of photorespiration was found in the dual nature of the enzymatic activity of Rubisco, because it has the ability to catalyze both the carboxylation (Calvin–Benson cycle) and oxygenation of ribulose 1,5-biphosphate. That is, when molecular oxygen is the substrate for Rubisco in the Calvin–Benson cycle, the products are one molecule of 3-phosphoglycerate and another of 2-phosphoglycerate, whereas the carboxylase activity yields two molecules of 3-PGA.
- In other words, photorespiration is the result of Rubisco oxygenase activity that implies O2 consumption, spent photosynthetic ATP, and converts phosphoglycolate to 3-PGA, releasing CO2.
- There are some common environmental conditions that promote Rubisco to react as oxygenase, such as elevated internal temperatures (32° C), or low CO2 concentrations inside photosynthetic cells in relation to higher levels of O2 accumulated in the stroma.

- This can happen when the stomata are closed or not fully open, and even more, oxygen accumulation is accelerated by high irradiation levels that maintain a high water photolysis by PSII. This results in a decrease of up to 25% of the carbon that is normally fixed during photosynthetic carbon assimilation, because a molecule of ribulose 1,5-bisphosphate is lost for the Calvin–Benson cycle, as well as part of the ATP generated by photosystems. Therefore, photorespiration strongly reduces the photosynthetic capacity of plants, affecting also the normal functions of subcellular organelles, since it induces a complex series of reactions that take place across three separate subcellular compartments: chloroplasts, peroxisomes, and mitochondria

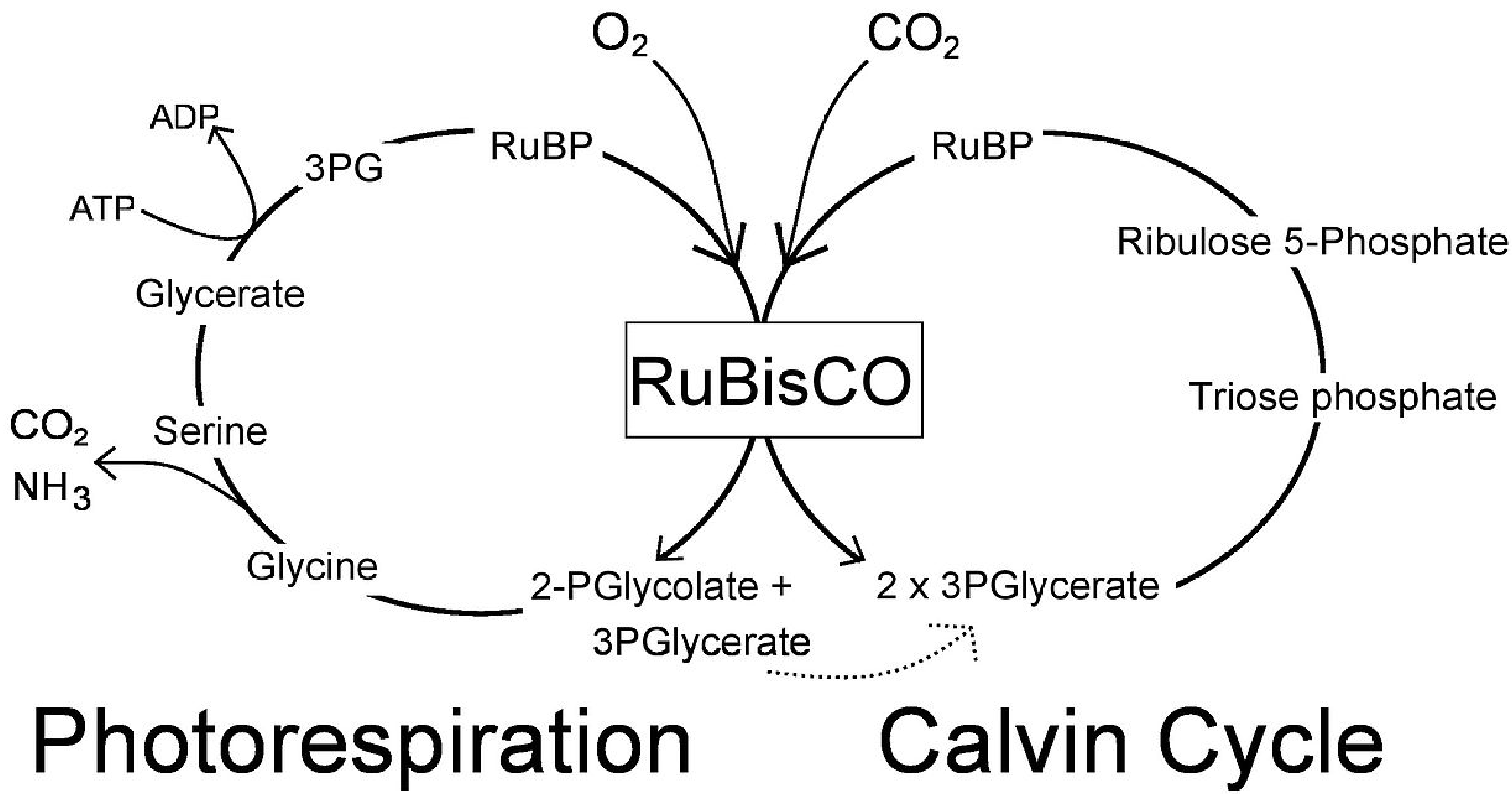
- It is known that high irradiation levels can saturate the photosystems, leading to the generation of reactive oxygen species (ROS) which cause oxidative damage to the chloroplast and the cell; and recent studies have demonstrated that photorespiration helps in some way to regulate such situations, because during photorespiration, O2 and ATP are consumed, and this minimizes the formation of ROS. In addition, if photorespiration consumes ATP, the saturation of electron acceptors in photosystems is avoided, since the electronic flow can continue because of the increase in ATP demand.

- Even when plants are growing under generally favorable conditions, photorespiration often occurs during the hottest hours of the day, when stomata tend to close, avoiding high evapotranspiration rates; therefore, plants experience a reduction in their photosynthetic efficiency on a daily basis, and that is why some species have overcome these limitations by developing different strategies to increase the concentration of carbon dioxide around Rubisco. These include the C4 pathway of carbon fixation and the crassulacean acid metabolism (CAM).

Photorespiration



Functions of RuBisCo



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