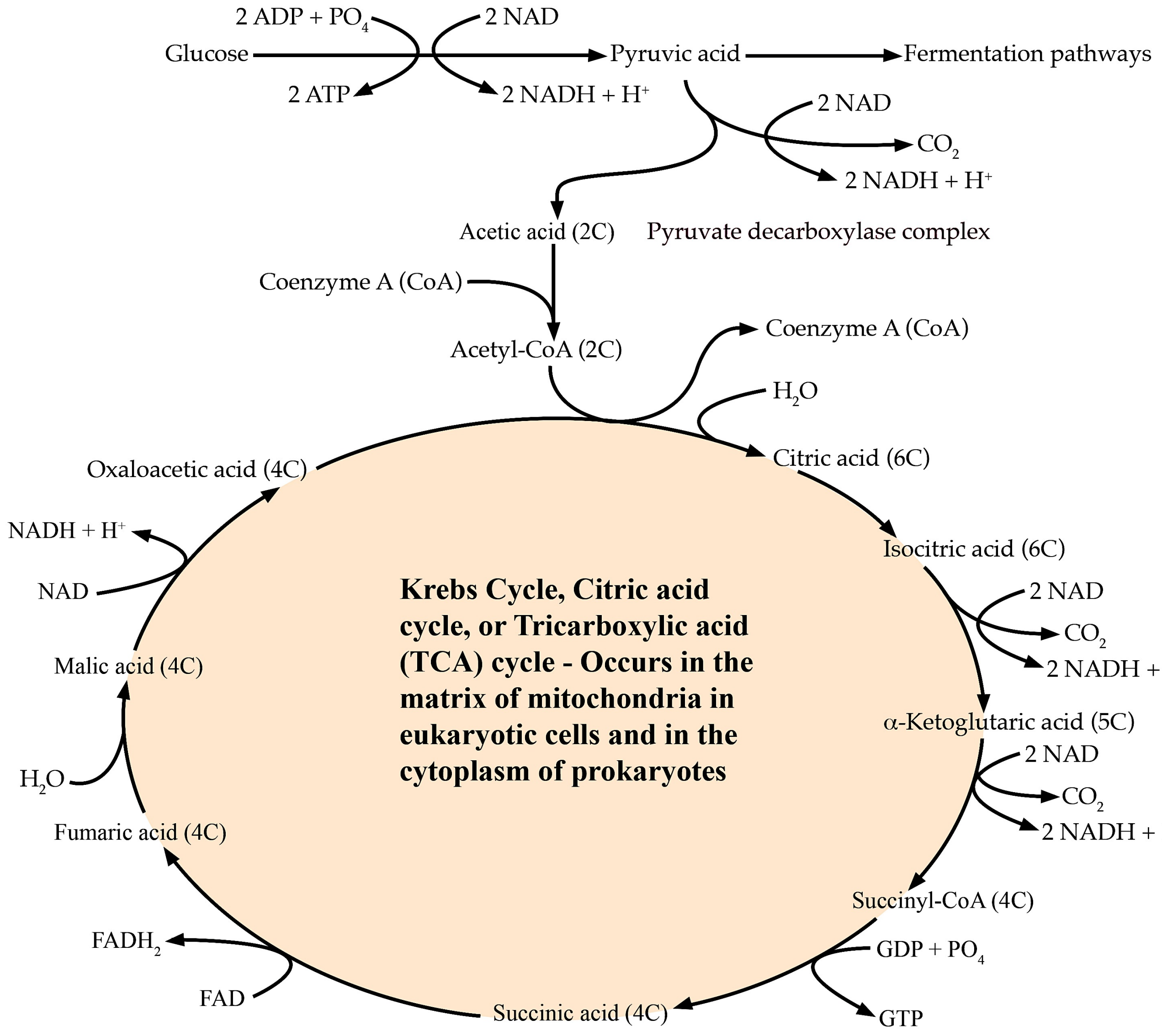
CELLULAR RESPIRATION

Cellular respiration is a metabolic process allowing cells to completely catabolize glucose forming six molecules of carbon dioxide for each sugar molecule. Respiratory organisms that use molecular oxygen as their final electron acceptor also form water in association with this process. The biochemical reactions of cellular respiration are typically divided into three pathways or steps including **glycolysis**, the **Krebs cycle** and the **electron transport chain** (respiratory chain). Cellular respiration is more efficient in terms of energy "capture" than is fermentation because much more of the energy stored in each glucose molecule is conserved in ATP. Most of the ATP formed is the result of **oxidative phosphorylation**, therefore respiratory organisms can also be described as oxidative organisms.

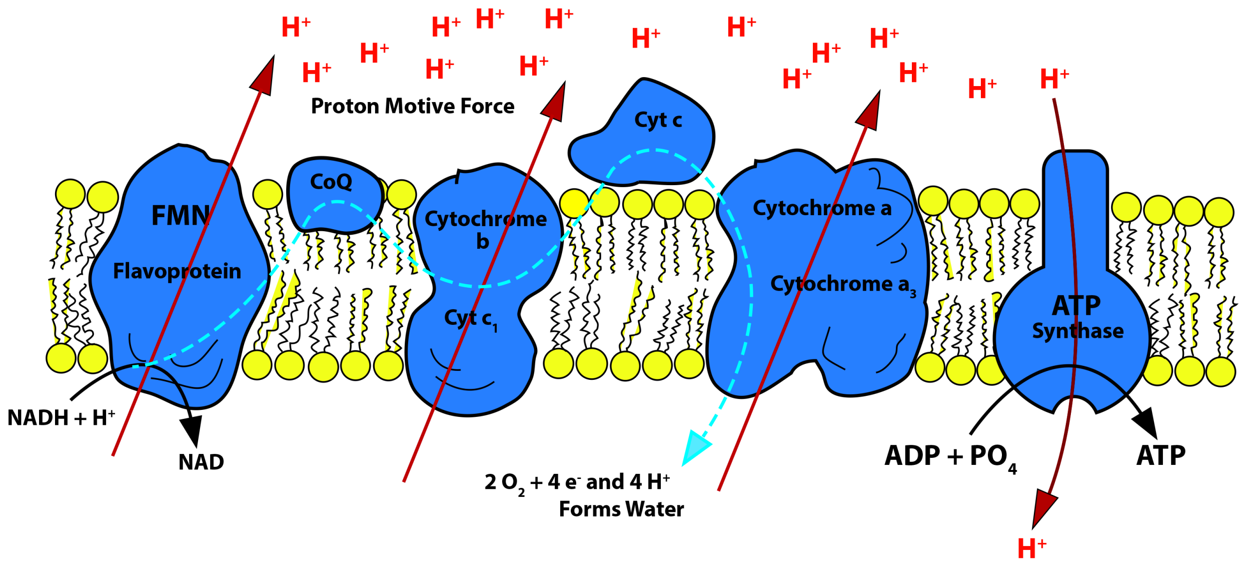
Glycolysis - Occurs in the cytoplasm



The coenzymes (NAD and FAD) reduced during the Krebs cycle store considerable potential energy that can be transferred when they pass their extra electrons to the **electron transport chain** or **respiratory chain**. These involve electron carriers associated with membranes (the cristae of mitochondria or the cell membranes of prokaryotic cells). As the electron carriers are alternately reduced and oxidized, they transport hydrogen protons across the membrane generating a **proton motive force**.

The proton motive force is an electrical and concentration gradient formed due to the accumulation of hydrogen protons (in the intermembrane space of mitochondria or within the periplasmic space of prokaryotic cells). The protons (given the opportunity) will move back across the membrane (diffuse down their gradients), and they can do this when their movement is facilitated by **ATP-synthase**, an integral protein complex. The enzyme uses the energy provided by the proton flow (potential energy), to convert ADP + PO_4 into ATP. One ATP molecule can be made for every three hydrogen protons passing through ATP-synthase, and this ATP is the result of **oxidative phosphorylation**. As mentioned earlier, the last cytochrome complex in the electron transport chain, **cytochrome c oxidase** (which contains cytochrome a and cytochrome a_3), picks up four electrons from cytochrome c molecules and transfers them to two oxygen molecules (O_2), these electrons, along with hydrogen protons (from hydronium ions), convert the molecular oxygen into water.

A Diagrammatic Representation of the Electron Transport Chain



For each NADH + H^+ oxidized (by passing electrons to the electron transport chain), there are nine protons "pumped" across the membrane, and for each $FADH_2$ oxidized there are around seven protons "pumped" across the membrane (these numbers are approximations and vary depending on organism type). Because ATP-synthase requires the passage of three protons in order to make one ATP, there are three ATP produced for each NADH + H^+ oxidized, and two ATP produced for each $FADH_2$ oxidized. A few of the ATP produced during cellular respiration are the result of substrate-level phosphorylation, but most are produced by means of oxidative phosphorylation. Below is a summary of ATP formation.

Maximum energy yield = 38 ATP per glucose (prokaryotes)
(Eukaryotic cells yield only 36)

Glycolysis	2 ATP	= 2 ATP	2 X Krebs Cycle	2 GTP	= 2 ATP
	2 NADH + H^+	= 6 ATP		8 NADH + H^+	= 24 ATP
		8 ATP		2 $FADH_2$	= 4 ATP
					30 ATP

Note – The NADH + H^+ reduced in association with the glycolysis pathway must be oxidized by passing electrons to the electron transport chain in order to yield the 6 ATP as shown above.