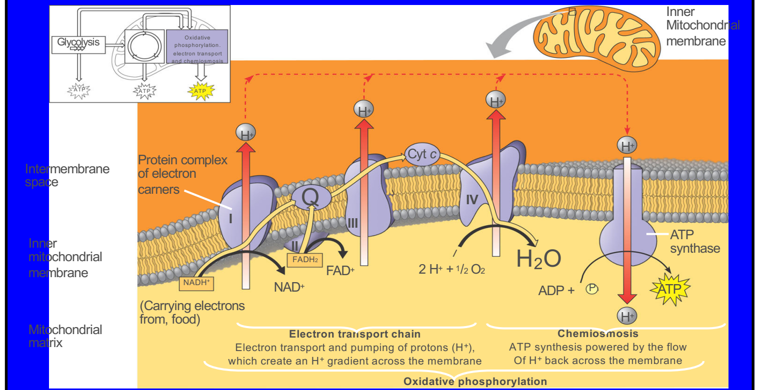
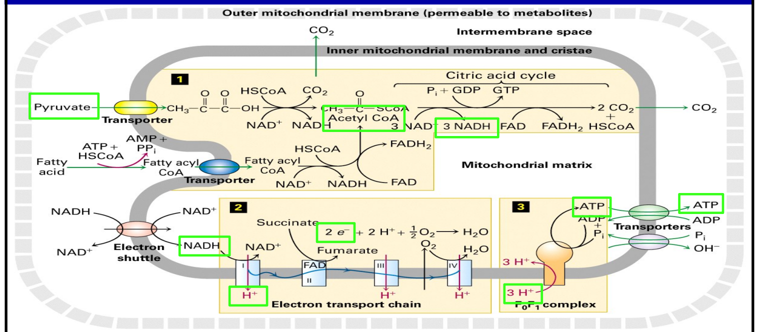
Chemiosmosis and the electron transport chain



An Accounting of ATP Production by Cellular Respiration

During respiration, most energy flows in this sequence glucose to NADH to electron transport chain to proton-motive force to ATP

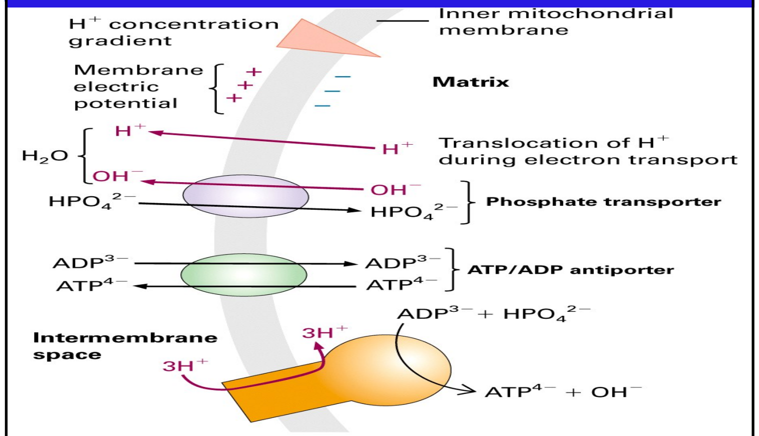
Aerobic oxidation of pyruvate and fatty acids in mitochondria



1. Pyruvate dehydrogenase, citric acid cycle, and fatty acid metabolism
2. Electron transport from NADH and $FADH_2$ to oxygen; generation of proton-motive force
3. ATP synthesis by F_0F_1 using proton-motive force

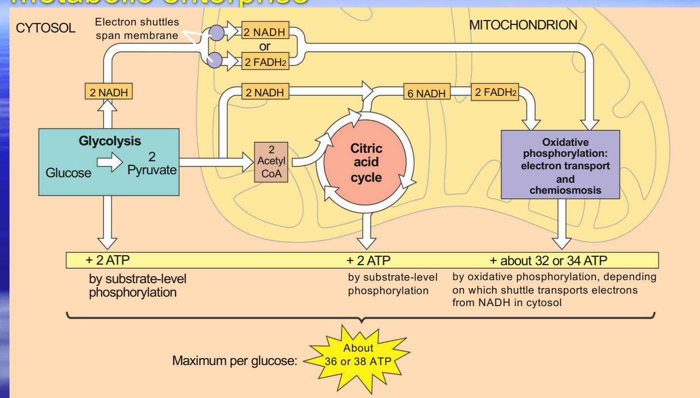
The outer membrane is freely permeable to all metabolites, but specific transport proteins (colored ovals) in the inner membrane are required to import pyruvate (yellow), ADP (green), and P_i (purple) into the matrix and to export ATP (green). NADH generated in the cytosol is not transported directly to the matrix because the inner membrane is impermeable to NAD^+ and NADH; instead, a shuttle system (red) transports electrons from cytosolic NADH to NAD^+ in the matrix. O_2 diffuses into the matrix and CO_2 diffuses out. Stage-1: fatty acyl groups are transferred from fatty acyl CoA and transported across the inner membrane via a special carrier (blue oval) and then reattached to CoA on the matrix side. Pyruvate is converted to acetyl CoA with the formation of NADH, and fatty acids (attached to CoA) are also converted to acetyl CoA with formation of NADH and $FADH_2$. Oxidation of acetyl CoA in the citric acid cycle generates NADH and $FADH_2$. Stage-2: electrons from these reduced coenzymes are transferred via electron transport complexes (blue boxes) to O_2 concomitant with transport of H^+ ions from the matrix to the intramembrane space, generating the proton-motive force. Electrons from NADH flow directly from complex I to complex III, bypassing complex II. Stage 3: ATP synthase, the F_0F_1 complex (ornage), harnesses the proton-motive force to synthesize ATP. Blue arrows indicate electron flow; red arrows transmembrane movement of protons; and green arrows indicate transport of metabolites.

The phosphate and ATP/ADP transport system in the inner mitochondrial membrane



The coordinated action of two antiporters (purple and green) results in the uptake of one ADP^{3-} and one HPO_4^{2-} in exchange for one H^+ during e^- transport. The outer membrane is not shown here because it is permeable to molecules smaller than 5kDa.

There are three main processes in this metabolic enterprise



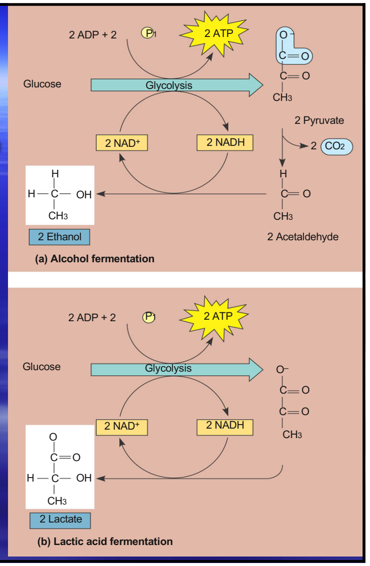
- About 40% of the energy in a glucose molecule is transferred to ATP during cellular respiration, making approximately 38 ATP

- **Fermentation** enables some cells to produce **ATP without the use of oxygen**
- **Cellular respiration**
  - relies on oxygen to produce ATP
- In the absence of oxygen
  - cells can still produce ATP through fermentation

- **Glycolysis**
  - can produce ATP with or without oxygen, in aerobic or anaerobic conditions
  - couples with fermentation to produce ATP

Types of Fermentation

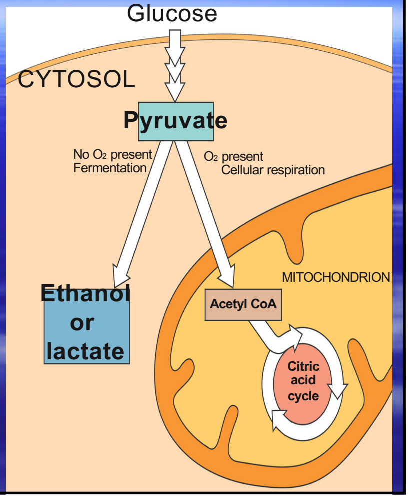
- Fermentation consists of
- - glycolysis plus reactions that regenerate NAD^+, which can be reused by glyocolysis



- In alcohol fermentation
  - pyruvate is converted to ethanol in two steps, one of which releases CO_2
- During lactic acid fermentation
  - pyruvate is reduced directly to NADH to form lactate as a waste product

Fermentation and Cellular Respiration Compared

- Both fermentation and cellular respiration
  - use glycolysis to oxidize glucose and other organic fuels to pyruvate
- Fermentation and cellular respiration
  - differ in their final electron acceptor
- Cellular respiration produces more ATP
- pyruvate is a key juncture in catabolism



- **Glycolysis and the citric acid cycle connect to many other metabolic pathways**

The Versatility of Catabolism

- Catabolic pathways
  - Funnel electrons from many kinds of organic molecules into cellular respiration
- The catabolism of various molecules from food