General Biology

Course No: BNG2003
Credits: 3.00

6. Cellular Respiration: Harvesting Chemical Energy

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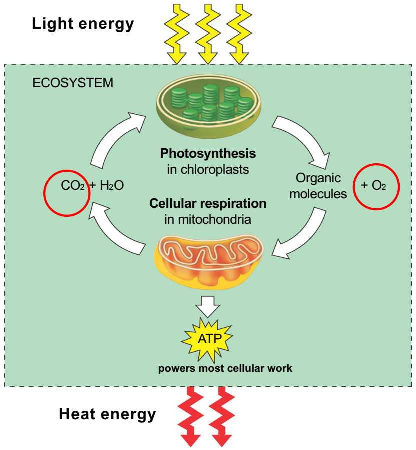
- Overview: Life is Work
- Living cells
  – require transfusions of energy from outside sources to perform their many tasks
- The giant panda
  – obtains energy for its cells by eating plants

- Energy
  – flows into an ecosystem as sunlight and leaves it as heat



- **Catabolic pathways yield energy by oxidizing organic fuels**

Catabolic Pathways and Production of ATP

- The breakdown of organic molecules is exergonic
- One catabolic process, **fermentation**
  – is a partial degradation of sugars that occurs without oxygen
- **Cellular respiration**
  – is the most prevalent and efficient catabolic pathway
  – consumes oxygen and organic molecules such as glucose
  – yields ATP

- To keep working
  - **Cells must regenerate** ATP

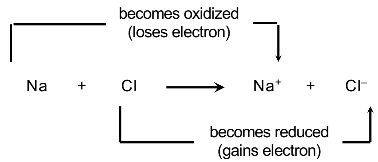
RedOx Reactions: Oxidation and Reduction

- Catabolic pathways yield energy due to the transfer of electrons

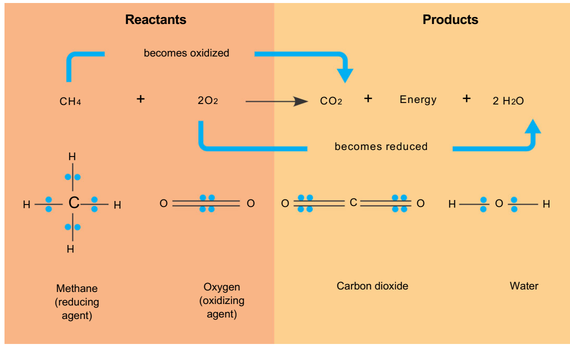
The Principle of RedOx

- RedOx reactions
  - Transfer electrons from one reactant to another by oxidation and reduction
- In oxidation – a substance loses electrons, or is oxidized
- In reduction – a substance gains electrons, or is reduced

- Examples of RedOx reactions

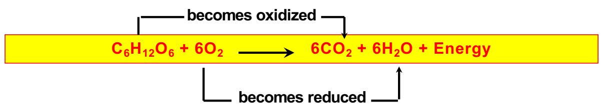


- Some RedOx reactions
  - do not completely exchange electrons
  - change the degree of electron sharing in covalent bonds



Oxidation of Organic Fuel Molecules During Cellular Respiration

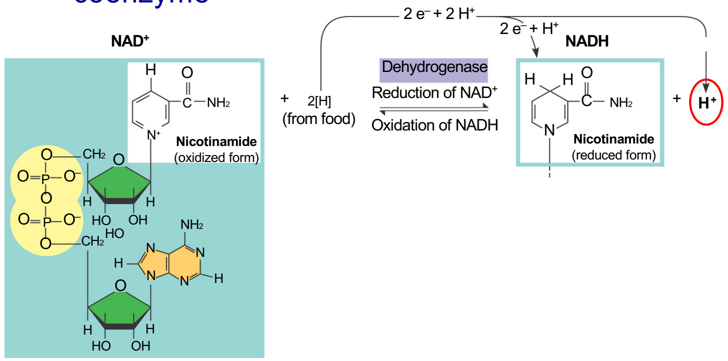
- During cellular respiration
  - **Glucose is oxidized** and **oxygen is reduced**



Stepwise Energy Harvest via NAD^+ and the Electron Transport Chain

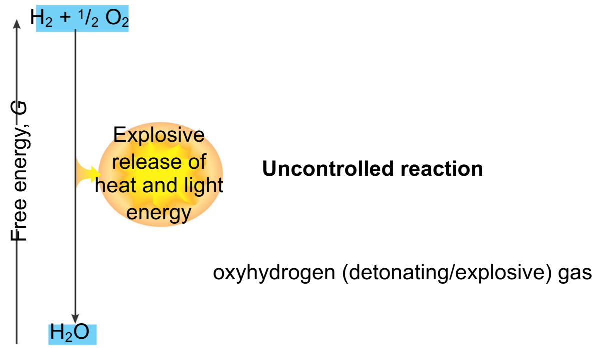
- Cellular respiration
  - Oxidizes glucose in a series of steps

- Electrons from organic compounds
  - are usually first transferred to NAD^+, a coenzyme

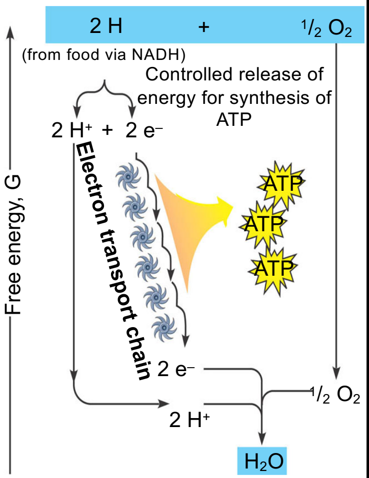


- NADH, the reduced form of NAD^+
  - passes the electrons to the electron transport chain

- If electron transfer is not stepwise
  - a large release of energy occurs
  - as in the reaction of hydrogen and oxygen to form water



- The electron transport chain
  - passes electrons in a series of steps instead of in one explosive reaction
  - uses the energy from the electron transfer to form ATP

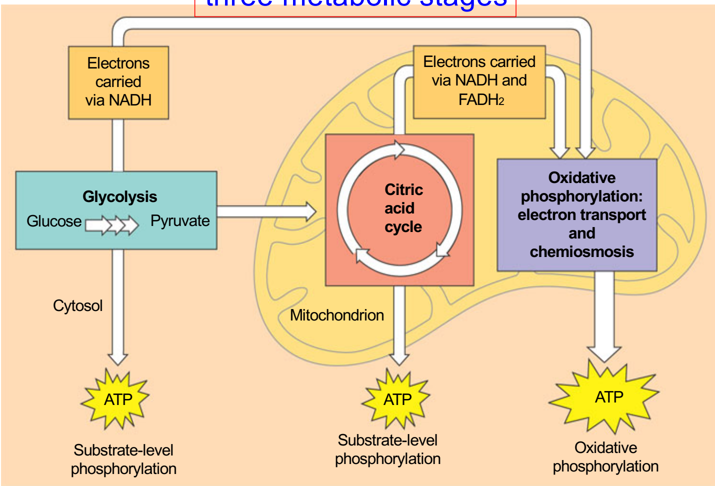


Cellular respiration

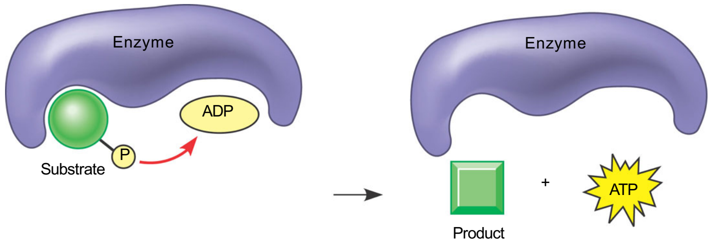
The Stages of Cellular Respiration: *A Preview*

- Respiration is a cumulative function of three metabolic stages
  - Glycolysis
  - The citric acid cycle
  - Oxidative phosphorylation
- Glycolysis
  - Breaks down glucose into two molecules of pyruvate
- The citric acid cycle
  - Completes the breakdown of glucose
- Oxidative phosphorylation
  - is driven by the electron transport chain
  - generates ATP

- An overview of cellular respiration – the principle three metabolic stages

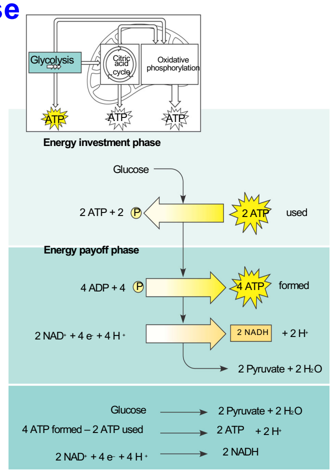


- Both glycolysis and the citric acid cycle
  - can generate ATP by substrate-level phosphorylation

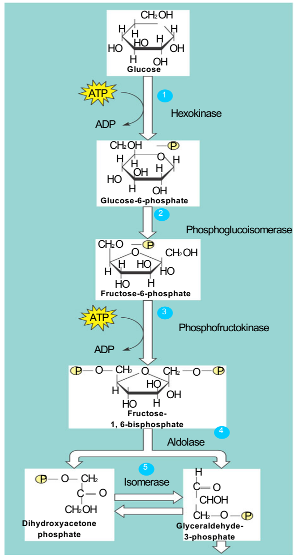


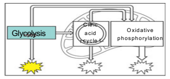
- **Glycolysis harvests energy by oxidizing glucose to pyruvate**
- Glycolysis
  - means “splitting of sugar”
  - breaks down glucose into pyruvate
  - occurs in the cytoplasm of the cell

- **Glycolysis** consists of **two major phases**
  - **Energy investment phase**
  - **Energy payoff phase**

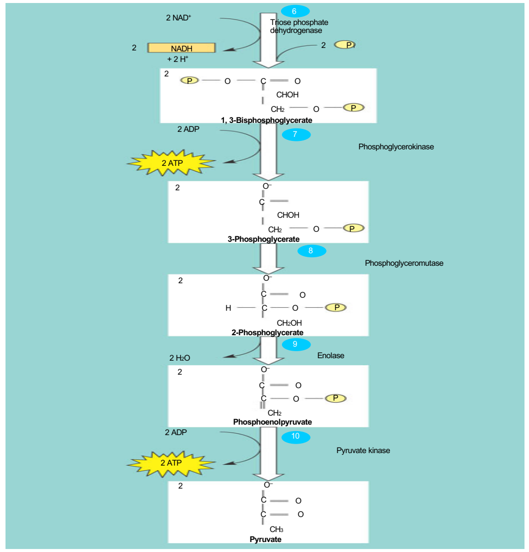


- A closer look at the energy investment phase

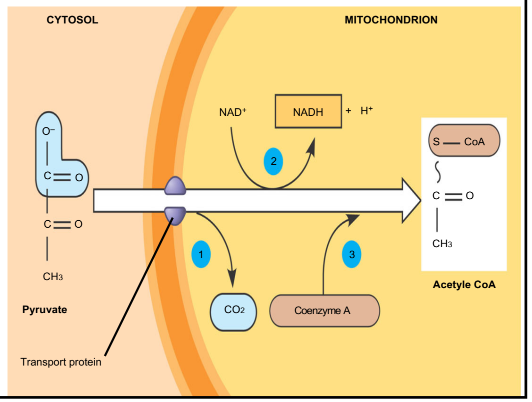




- A closer look at the energy payoff phase

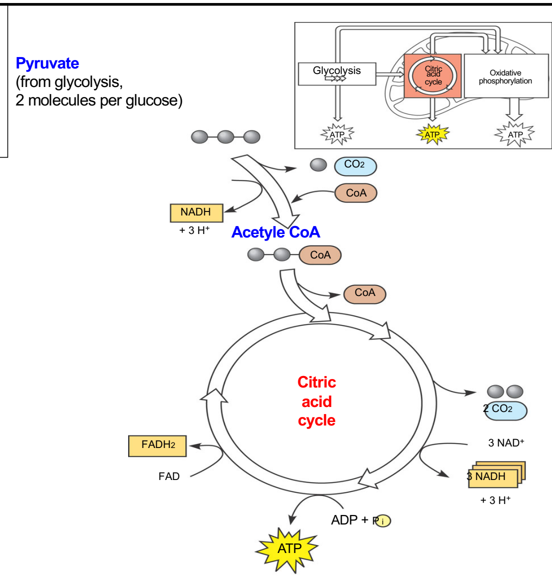


- **The citric acid cycle** completes the energy-yielding oxidation of organic molecules
- The citric acid cycle
  - **takes place in the matrix of the mitochondrion**
- Before the citric acid cycle can begin
  - Pyruvate must first be converted to acetyl CoA, which links the cycle to glycolysis

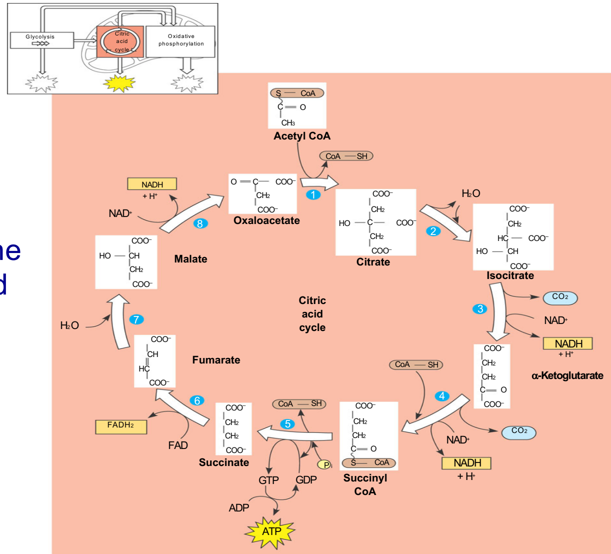


- An overview of the citric acid cycle

(Krebs Cycle)



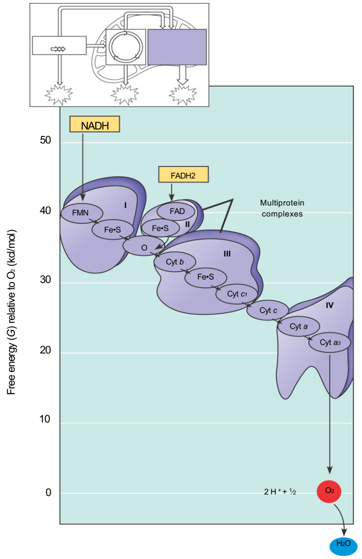
A closer look at the citric acid cycle



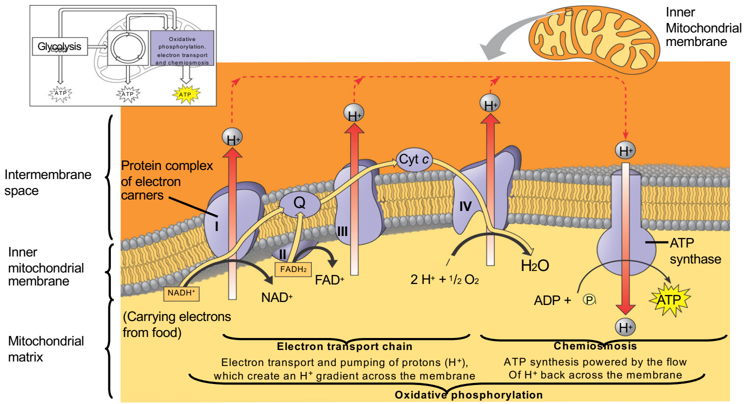
- During **oxidative phosphorylation**, chemiosmosis couples electron transport to ATP synthesis
- NADH and $FADH_2$ donate electrons to the electron transport chain, which powers ATP synthesis via oxidative phosphorylation

The Pathway of Electron Transport

- In the electron transport chain **electrons from NADH and $FADH_2$ lose energy in several steps**
- At the end of the chain electrons are passed to oxygen, forming water



- Chemiosmosis and the electron transport chain



An Accounting of ATP Production by Cellular Respiration

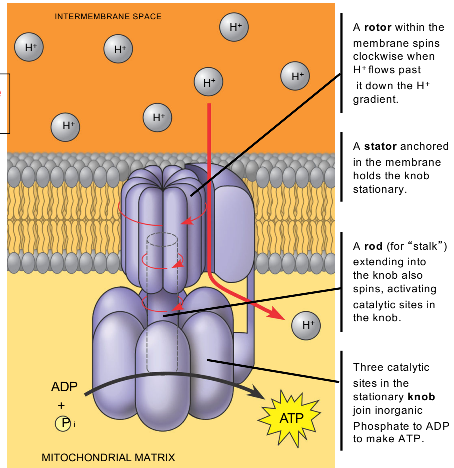
During respiration, most energy flows in this sequence glucose to NADH to electron transport chain to proton-motive force to ATP

- At certain steps along the electron transport chain
  - Electron transfer causes protein complexes to pump H^+ from the mitochondrial matrix to the intermembrane space
- The resulting H^+ gradient
  - stores energy
  - drives chemiosmosis in ATP synthase
  - is referred to as a proton-motive force (pmf)
- **Chemiosmosis**
  - Is an energy-coupling mechanism that uses energy in the form of a H^+ gradient across a membrane to drive cellular work

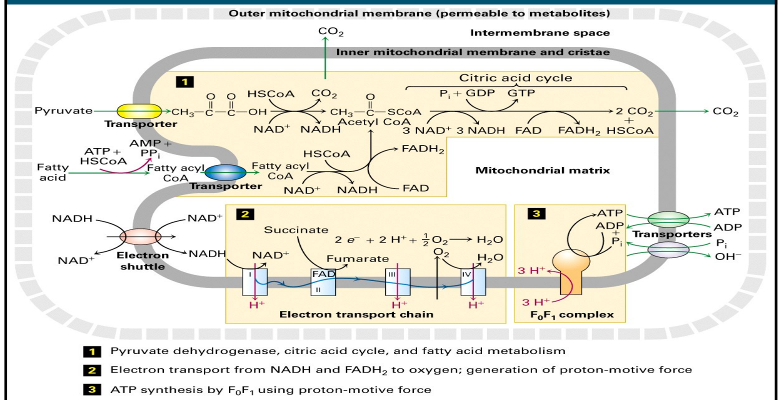
Chemiosmosis: The Energy-Coupling Mechanism

- ATP synthase – is the enzyme that actually makes ATP

The proton motive force (pmf)

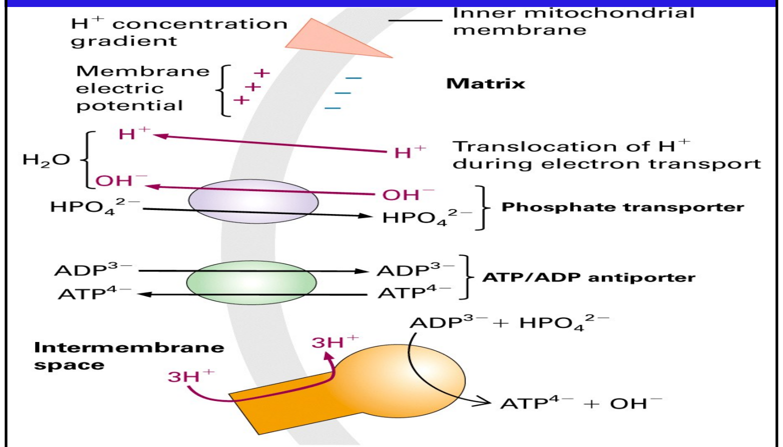


Aerobic oxidation of pyruvate and fatty acids in mitochondria



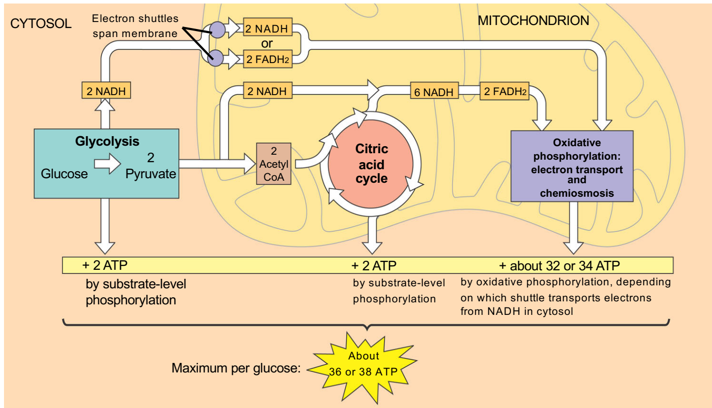
The outer membrane is freely permeable to all metabolites, but specific transport proteins (colored ovals) in the inner membrane are required to import pyruvate (yellow), ADP (green), and P_i (purple) into the matrix and to export ATP (green). NADH generated in the cytosol is not transported directly 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 (orange), 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



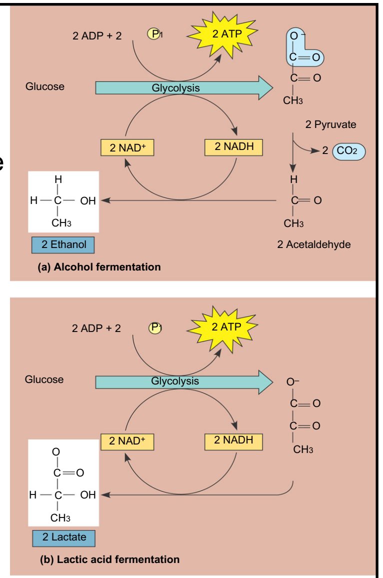
- About 40% of the energy in a glucose molecule is transferred to ATP during cellular respiration, making approximately 38 ATP

- **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

(ATP without the use of oxygen)

- 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

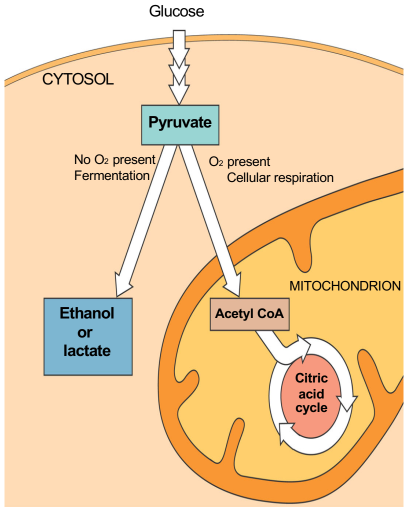


Fermentation and Cellular Respiration Compared

- Both fermentation and cellular respiration

  use glycolysis to oxidize glucose and other organic fuels to pyruvate
- Fermentation and cellular respiration

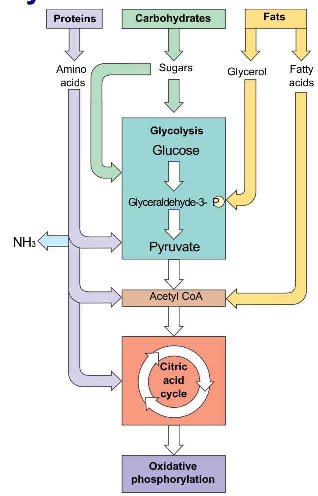
  differ in their final electron acceptor
- Cellular respiration produces more ATP
- pyruvate is a key juncture in catabolism



- **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



Biosynthesis (Anabolic Pathways)

- The body uses small molecules to build other substances
- These small molecules may come directly from food or through glycolysis or the citric acid cycle

Regulation of Cellular Respiration via Feedback Mechanisms

- Cellular respiration
  - is controlled by allosteric enzymes at key points in glycolysis and the citric acid cycle