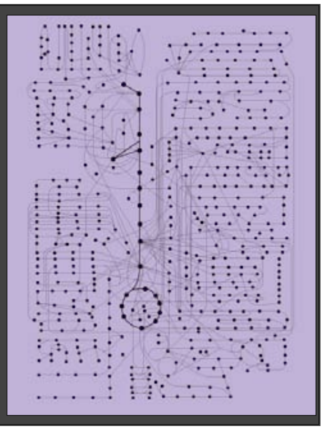
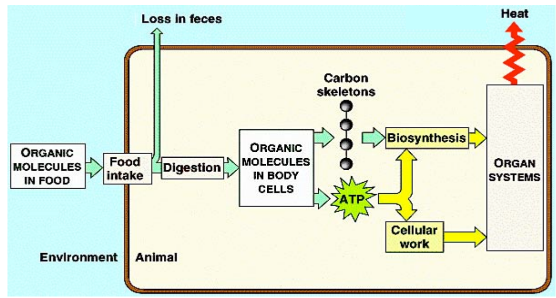
Cellular Respiration & Metabolism



Metabolism



Bioenergetics

- Flow of energy in living systems obeys:
- 1st law of thermodynamics:
  - Energy can be transformed, but it cannot be created or destroyed.
- 2nd law of thermodynamics:
  - Energy transformations increase entropy (degree of disorganization of a system).
  - Only free energy (energy in organized state) can be used to do work.
    - Systems tend to go from states of higher free energy to states of lower free energy.

Coupled Reactions: Bioenergetics

- Energy transfer from one molecule to another couples chemical reactions
- **Exergonic reaction**: reaction releases energy
- **Endergonic reaction**: reaction requires energy
- **Coupled bioenergetic reactions**: the energy released by the exergonic reaction is used to power the endergonic reaction.

Coupled Pathways: Bioenergetics

- Energy transfer from one metabolic pathway to another by means of ATP.
- **Catabolic pathway (catabolism)**: breaking down of macromolecules. Releases energy which may be used to produce ATP.
- **Anabolic pathway (anabolism)**: building up of macromolecules. Requires energy from ATP.
- **Metabolism**: the balance of catabolism and anabolism in the body.

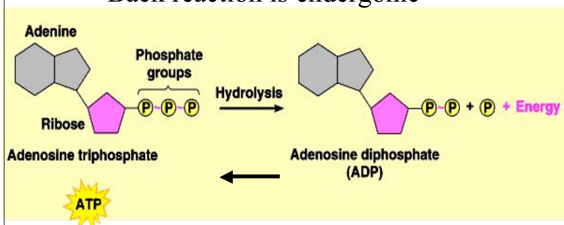
Cellular **Respiration**: ATP is the cell's rechargable battery

- Breaking down complex glucose molecule releases energy.
- That energy is used to convert ADP into ATP.

  ADP + P + ***energy*** —› ATP
- Energy is released as ATP breaks down into ADP and AMP.

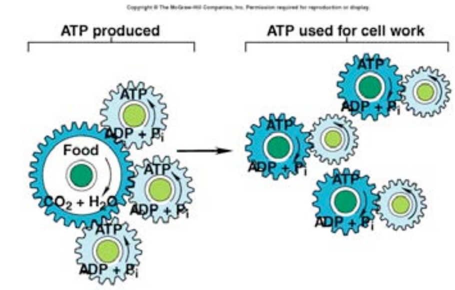
  ATP —› ***energy*** + ADP + P

Forward reaction is exergonic
Back reaction is endergonic



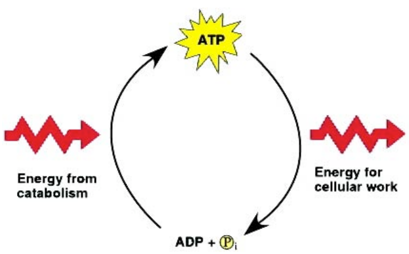
- Cells use ATP by breaking phosphate bond and transferring energy to other compounds
- Cells make ATP by transferring energy from other compounds to form phosphate bond

Coupled Metabolic Pathways: via ATP



Cellular Metabolism

- Cellular Respiration provides ATP
- Cellular "Work" requires ATP



ATP drives endergonic reactions

- The three types of cellular work are powered by the hydrolysis of ATP

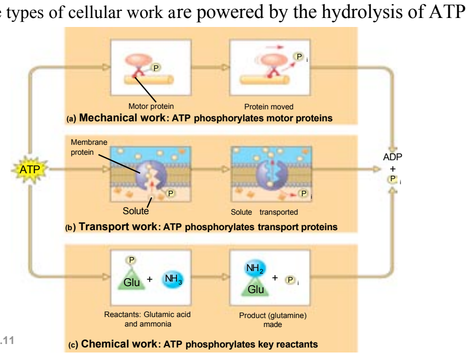
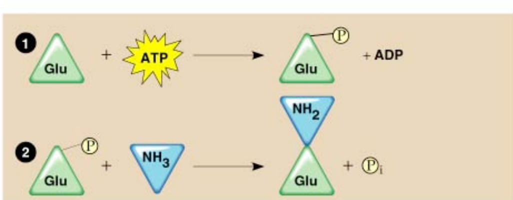


Figure 8.11

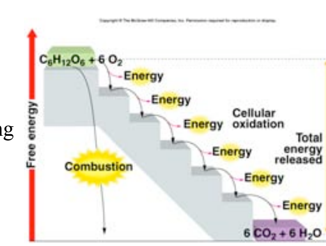


Coupled reactions using ATP.

Glu + NH_3 → Glu – NH_2		$\Delta G = +3.4$ kcal/mol
ATP → ADP + Ⓟi		$\Delta G = -7.3$ kcal/mol
		Net $\Delta G = -3.9$ kcal/mol

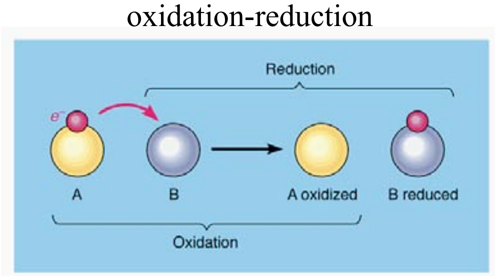
Exergonic Oxidation of Organic Fuel

- Controlled oxidation releases energy in small, usable increments
- Redox reactions regulated through reducing and oxidizing agents



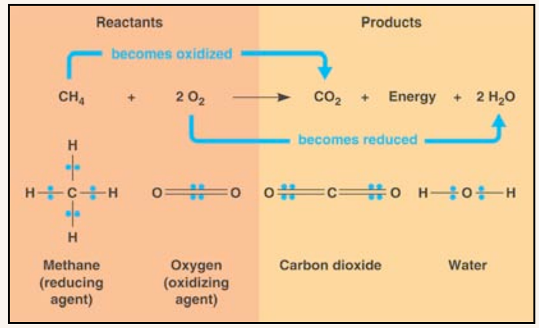
Coupled Reactions: *Redox*

Transfer of electrons is called oxidation-reduction



- AKA, Reduction–oxidation [“Redox”]

a redox process



Respiration: a redox process

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ H_2O + 6\ CO_2$$

($C_6H_{12}O_6$ is oxidized; O_2 is reduced)

$\Delta G = -686$ kcal/mol; → exergonic & spontaneous

So how does the cell prevent spontaneous combustion?

- Keep the oxidation reactions and reduction reactions separate!

But the reduction of oxygen drives the oxidation of sugar!?

- Couple them by means of electron shuttles.

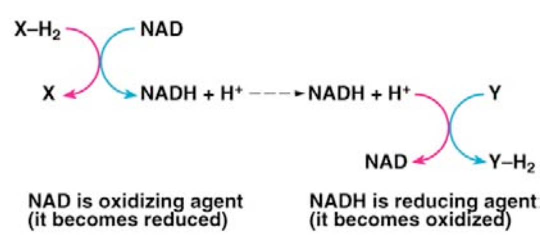
Coenzymes: Electron Carriers

- NAD^+ (nicotinamide adenine dinucleotide)
  - {Derived from vitamin B_3: **n**iacin}

    $NAD^+ + H^+ + 2e^- \rightarrow NADH$
- $FADH^+$ (flavin adenine dinucleotide)
  - {Derived from vitamin B_2: ribo**f**lavin}

    $FADH^+ + H^+ + 2e^- \rightarrow FADH_2$
- Reminder: Hydrogen = $H^+ + e^-$

Oxidation-Reduction (continued)



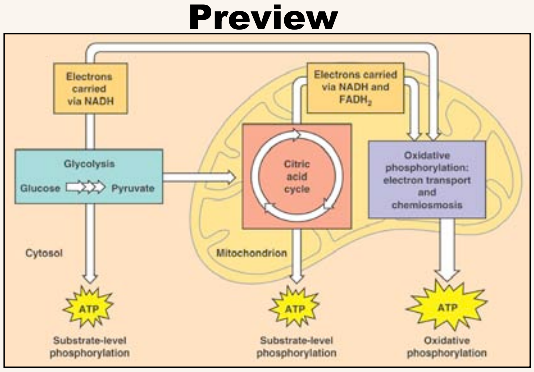
Cellular Respiration

- Controlled oxidation of organic fuel (exergonic)
  - coupled with
- Phosphorylation of **ADP to ATP** (endergonic)

Respiration

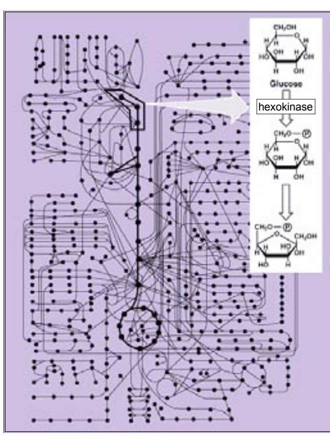
- ❖ **Respiration is a redox process.**
- ❖ **Respiration uses a proton gradient to power ATP synthesis.**
- ❖ **An electron transport chain links the oxidation of food molecules to the production of the proton gradient.**

Preview



Respiration mechanisms

- ❖ **Harvesting electrons from food:** ***glycolysis & the Krebs cycle.***
- ❖ **Making a proton gradient:** ***electron transport chain.***
- ❖ **Using the proton gradient to power ATP synthesis:** **chemiosmosis &** ***oxidative phosphorylation.***

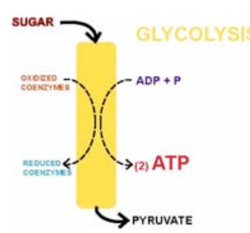


Respiration

Getting started

- ❑ "Light the match"
  - ▪ Spend an ATP to phorhorylate glucose
  - ▪ "activated glucose"
- ❑ Glucose gate is not permeable to glucose-6-phosphate
  - ▪ Glucose trapped in cell

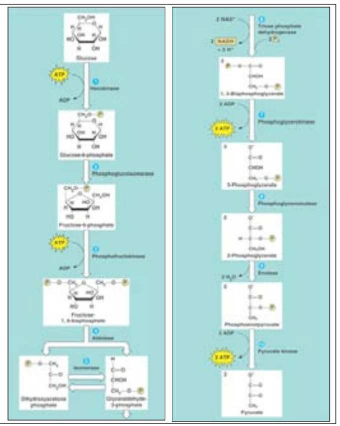
Cellular Respiration (making ATP)



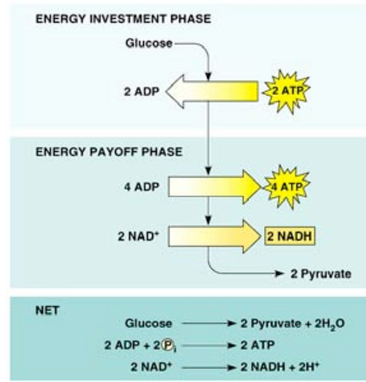
"sugar splitting"
1 C_6 glucose
□
2 C_3 pyruvates

Glycolysis

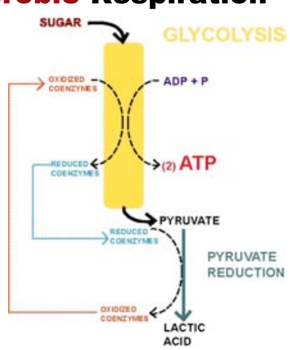
- "Light two matches" to get started
- Glucose partially ozixidized.
- Electrons harvested, ATP made.
- Pyruvate is end product.



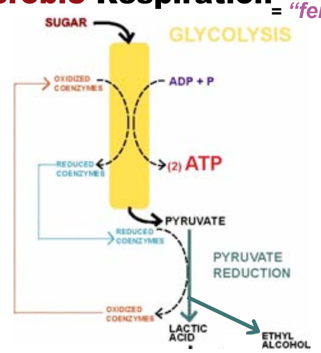
Glycolysis summary



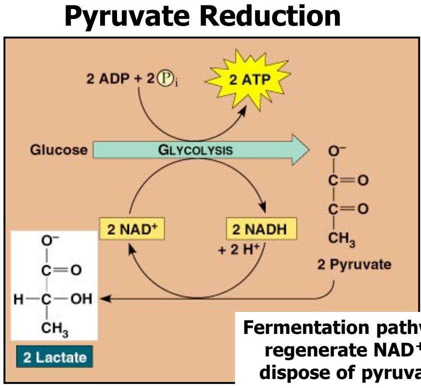
Anaerobic Respiration



Anaerobic Respiration = *"fermentation"*



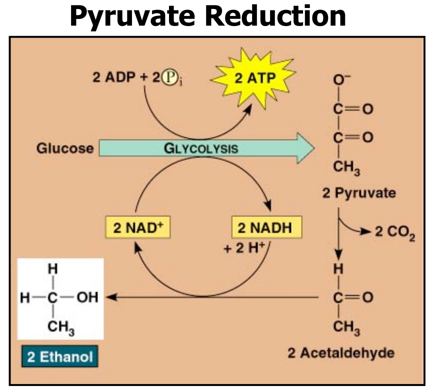
Pyruvate Reduction



Fermentation pathways regenerate NAD^+ & dispose of pyruvate.

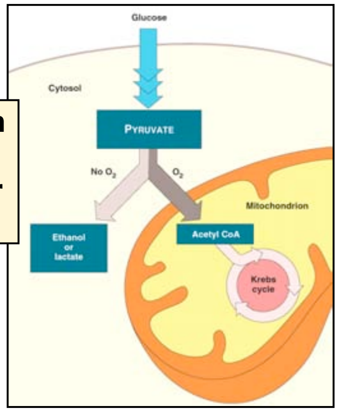
lactate fermentation

Pyruvate Reduction

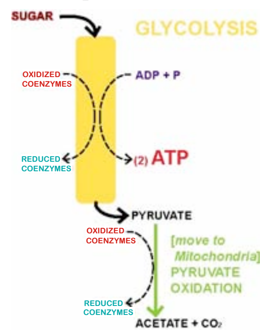


alcohol fermentation

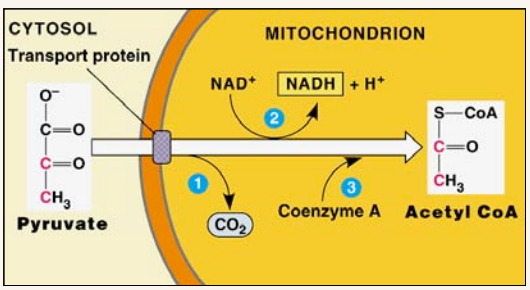
Glycolysis can lead to respiration or fermentation



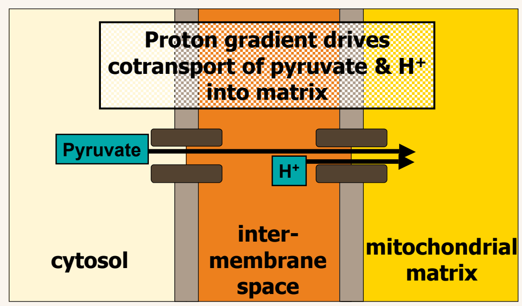
Aerobic Respiration



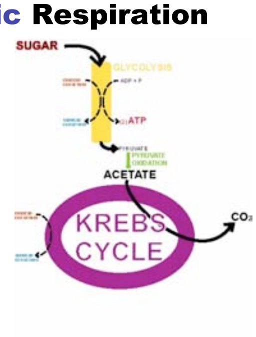
Pyruvate transport & oxidation to acetate



Pyruvate / H^+ symporter

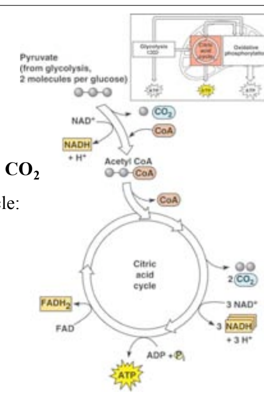


Aerobic Respiration



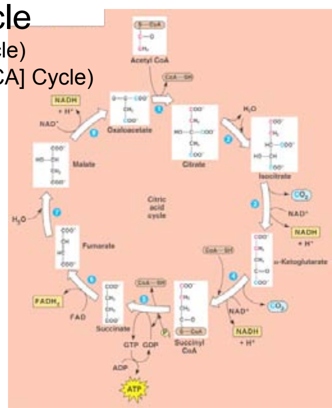
Krebs Cycle

- **Acetate completely oxidized to CO_2**
- For *each* acetate through the cycle:
  - 3 (NAD^+) → 3 ($NADH+H^+$)
  - 1 FAD → 1 $FADH_2$
  - 1 ADP → 1ATP
- (Remember, 1 glucose produced **2** acetates)

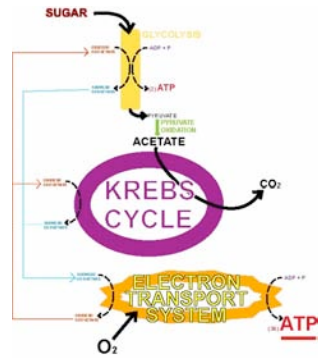


Krebs Cycle
(Citric Acid Cycle)
(Tricarboxylic Acid [TCA] Cycle)

Carboxylic acid and keto acid intermediates

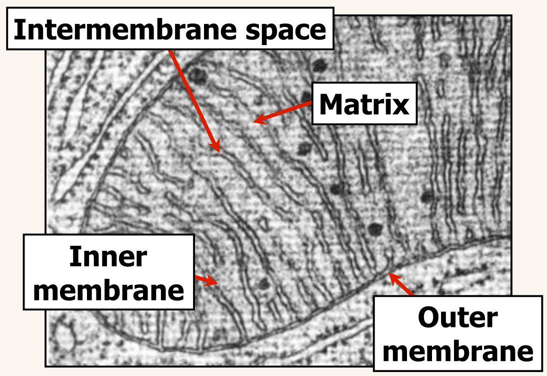


Aerobic Respiration

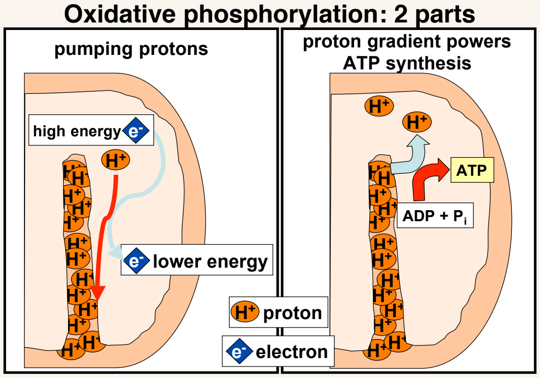


Respiration mechanisms

- Harvesting electrons from food: glycolysis & the Krebs cycle.
- Making a proton gradient: electron transport chain.
- Using the proton gradient to power ATP synthesis: chemiosmosis & *oxidative phosphorylation*.

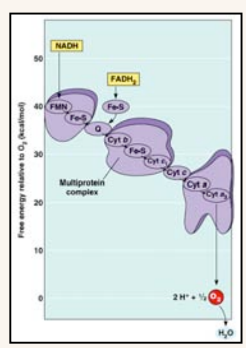


Oxidative phosphorylation: 2 parts



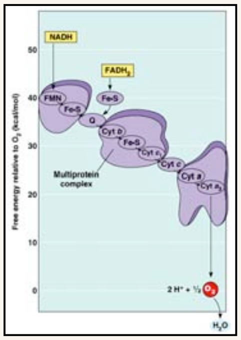
Electron Transport Chain

- Series of increasingly electronegative e⁻ carriers in 3 membrane-bound complexes.
- NADH starts at high energy level, $FADH_2$ slightly lower.
- O_2 is the final e⁻ acceptor.

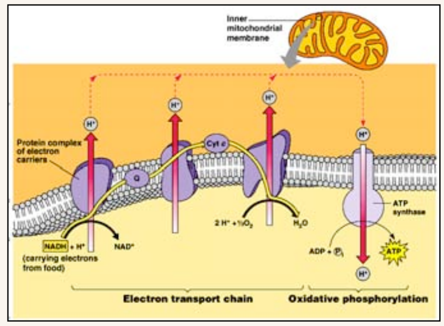


Electron Transport Chain

- Each complex transports 3–4 protons for each pair of e^-.
- $2e^-$ from NADH pumps 10 H^+;
  $2e^-$ from $FADH_2$ pumps only 6–7.



Electron transport chain & oxidative phosphorylation

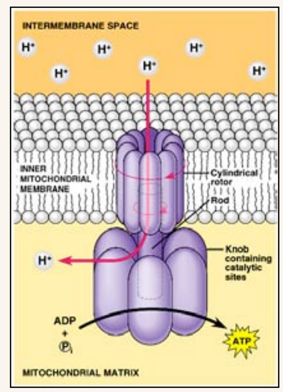


Respiration mechanisms

- **Harvesting electrons from food:** glycolysis & the Krebs cycle.
- **Making a proton gradient:** electron transport chain.
- **Using the proton gradient to power ATP synthesis:** chemiosmosis & ***oxidative phosphorylation***.

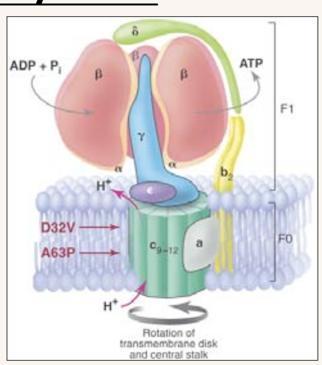
ATP Synthase:

Facilitated diffusion powers ADP phosphorylation



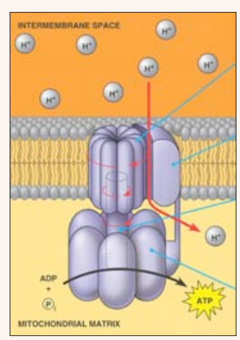
ATP Synthase

- ATP synthase couples facilitated diffusion of H^+ with ATP formation.



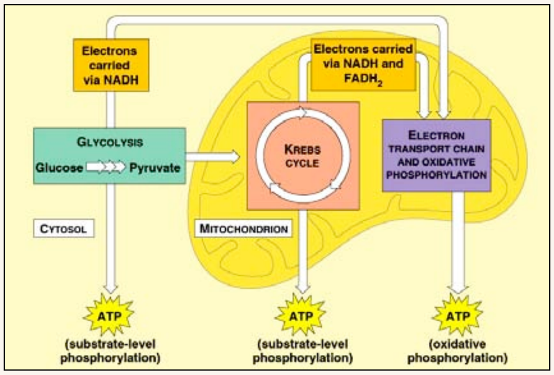
ATP Synthase

- Proton gradient is electrochemical.
- As protons move through ATP synthase, they turn the rotor.
- Active sites on knob change shape, causing ADP phosphorylation.



1 ATP for 3–4 H^+

Review



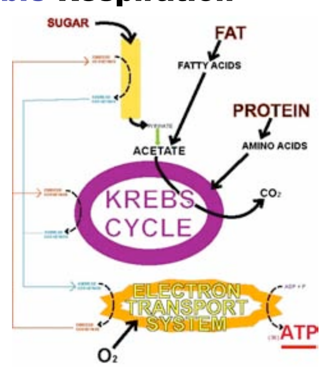
Yield from the electron transport chain

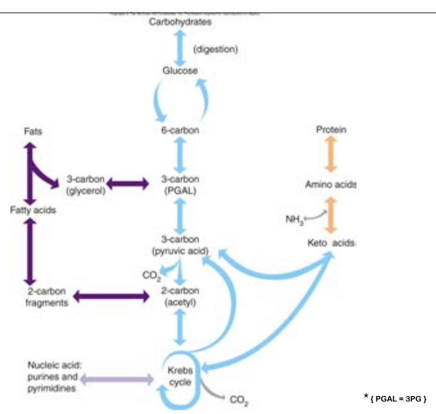
- Each NADH (2 e^-) pumps 10 H^+.
- Each $FADH_2$ pumps 6-7 H^+.
- 3-4 H^+ → 1 ATP.
- 1 glucose: 10 NADH → 25-33 ATP.
  2 $FADH_2$ → 3-4 ATP.
  about 32-34 ATP
- Plus the 4 ATP from glycolysis & TCA cycle = 34–38 ATP/glucose

How much ATP would you have to eat?

- 1 mole glucose → 32 moles ATP.
- Glucose: 180 g/mole
- ATP: 507 g/mole
- 25 g glucose = 2.3 kg ATP

Aerobic Respiration





* (PGAL = 3PG)

Cellular Respiration

- **Anaerobic** Respiration "without air"
  - = glycolysis + pyruvate reduction
  - Produce ATP in absence of O_2
- **Aerobic** Respiration "with air"
  - = glycolysis
    + pyruvate oxidation
    + Krebs cycle
    + electron transport system
  - Produces much more ATP per sugar molecule
  - Non-toxic waste product (CO_2)
  - Allows use of fats and protein for fuel