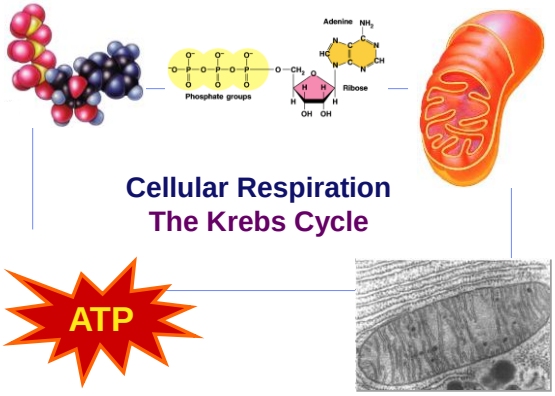
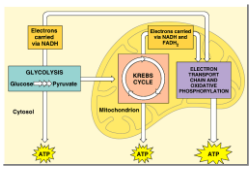


Cellular Respiration
The Krebs Cycle

ATP

Overview of cellular respiration

- 4 metabolic stages
  - Anaerobic respiration
    1. Glycolysis
       - respiration without O_2
       - in cytosol
  - Aerobic respiration
    - respiration using O_2
    - in mitochondria
    2. Link Reaction
    3. Krebs cycle
    4. Electron transport chain



$C_6H_{12}O_6 + 6O_2 \rightarrow ATP + 6H_2O + 6CO_2$ (+ heat)

Glycolysis is only the start

- Glycolysis

glucose → → → → → pyruvate
6C 2x 3C

- Pyruvate has more energy to yield
  - 3 more C to strip off (to oxidize)
  - if O_2 is available, pyruvate enters mitochondria
  - enzymes of Krebs cycle complete the full oxidation of sugar to CO_2

pyruvate → → → → → → CO_2
3C 1C

Oxidation of pyruvate

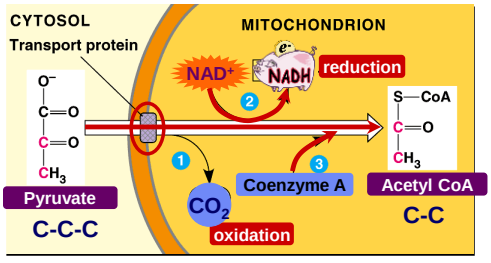
- Pyruvate enters mitochondrial matrix

2x [pyruvate → → → acetyl CoA + CO_2]
3C 2C 1C

NAD → NADH + e^-

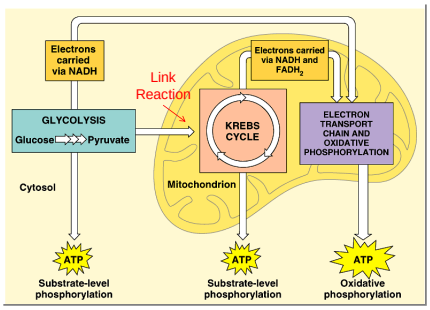
  - 3 step oxidation process
  - releases 2 CO_2 (count the carbons!)
  - reduces 2 NAD → 2 NADH (moves e^-)
  - produces 2 acetyl CoA
- Acetyl CoA enters Krebs cycle

Link Reaction: Pyruvate oxidized to Acetyl CoA



2 x [Yield = 2C sugar + NADH + CO_2]

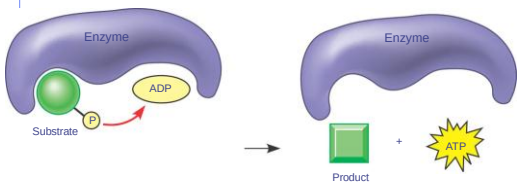
Cellular respiration



Glycolysis simulator review…

- http://www.johnkyrk.com/glycolysis.html

Both glycolysis and the Krebs cycle Can generate ATP by substrate-level phosphorylation



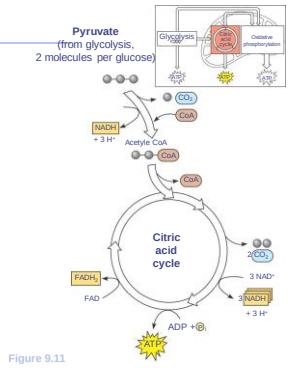
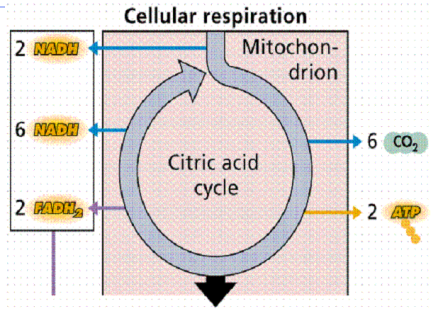
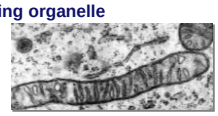


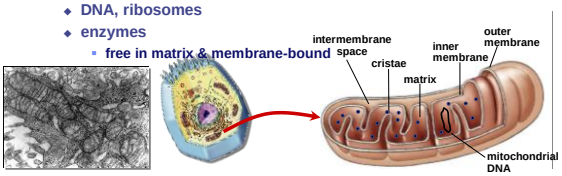
Figure 9.11



Mitochondria — Structure

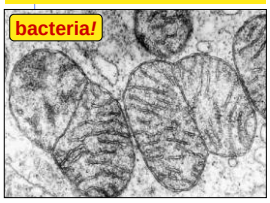
- Double membrane energy harvesting organelle
  - smooth outer membrane
  - highly folded inner membrane
    - Cristae
    - intermembrane space
    - fluid-filled space between membranes
  - matrix
    - inner fluid-filled space
  - DNA, ribosomes
  - enzymes
    - free in matrix & membrane-bound





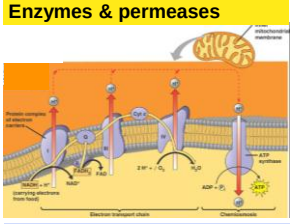
Mitochondria – Function

Dividing mitochondria
Who else divides like that?



What does this tell us about the evolution of eukaryotes?
Endosymbiosis!

Membrane-bound proteins
Enzymes & permeases



Advantage of highly folded inner membrane?
More surface area for membrane-bound enzymes & permeases

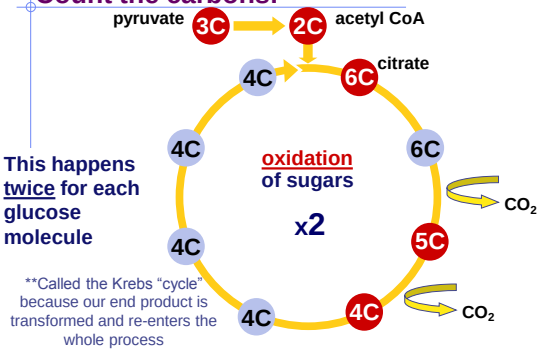
Krebs cycle

1937 | 1953

Hans Krebs
1900-1981

- aka Citric Acid Cycle
  - in mitochondrial matrix
  - 8 step pathway
    - each catalyzed by specific enzyme
    - step-wise catabolism of 6C citrate molecule
- Evolved later than glycolysis
  - does that make evolutionary sense?
    - bacteria →3.5 billion years ago (glycolysis)
    - free O_2 →2.7 billion years ago (photosynthesis)
    - eukaryotes →1.5 billion years ago (aerobic respiration = organelles → mitochondria)

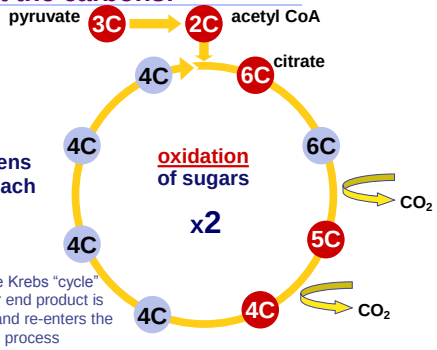
Count the carbons!



This happens twice for each glucose molecule

**Called the Krebs "cycle" because our end product is transformed and re-enters the whole process

Count the carbons!



This happens twice for each glucose molecule

**Called the Krebs "cycle" because our end product is transformed and re-enters the whole process

So what happened?

We fully oxidized glucose

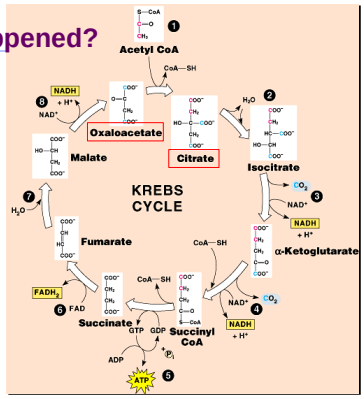
$C_6H_{12}O_6$

↓

CO_2

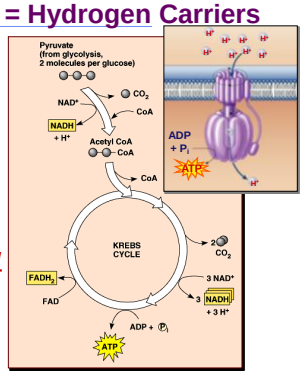
& ended up with 4 ATP!

But what's the point?

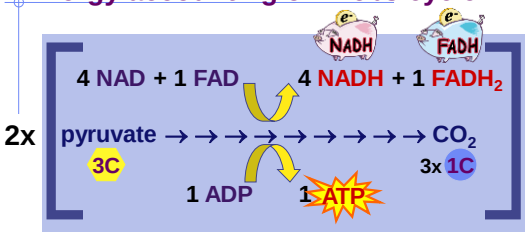


Electron Carriers = Hydrogen Carriers

- Krebs cycle produces large quantities of electron carriers
  - NADH
  - $FADH_2$
  - go to Electron Transport Chain!



Energy accounting of Krebs cycle

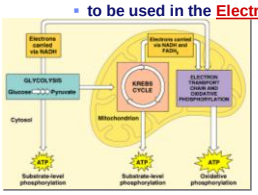


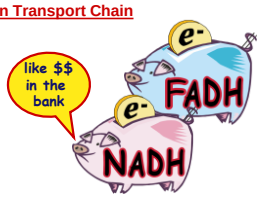
Net gain = 2 ATP

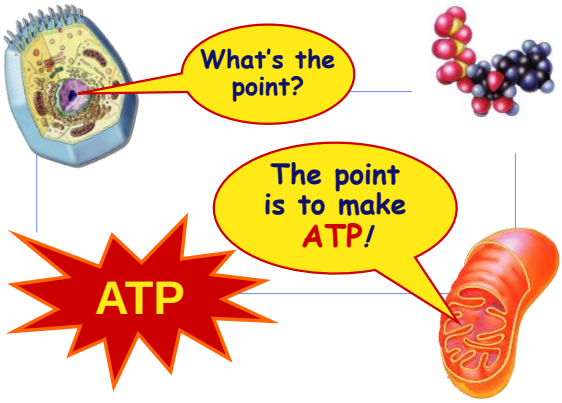
= 8 NADH + 2 $FADH_2$

Value of Krebs cycle?

- If the yield is only 2 ATP then how was the Krebs cycle an adaptation?
  - value of NADH & $FADH_2$
    - electron carriers & H carriers
      - reduced molecules move electrons
      - reduced molecules move H^+ ions
    - to be used in the Electron Transport Chain

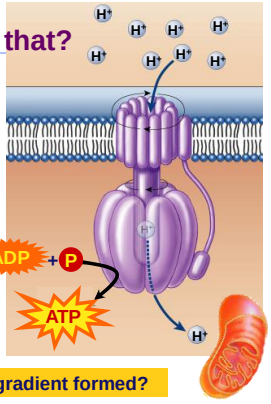






And how do we do that?

- ATP synthase enzyme
  - H^+ flows through it
    - conformational changes
    - bond P_i to ADP to make ATP
  - set up a H^+ gradient
    - allow the H^+ to flow down concentration gradient through ATP synthase
    - ADP + P_i → ATP



But… How is the proton (H^+) gradient formed?

Forming a Proton Gradient

- To generate large amounts of ATP, we first need large amounts of hydrogens for an electron transport chain
- We get these hydrogens primarily from the Krebs cycle!

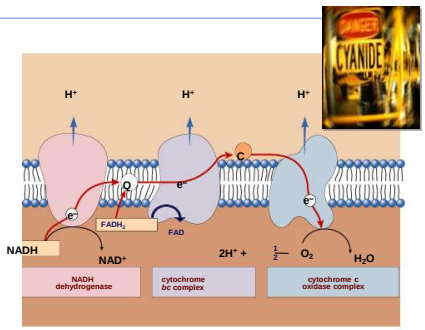
Krebs Cycle

- http://www.johnkyrk.com/krebs.html

Taking it beyond Aerobic Resp.

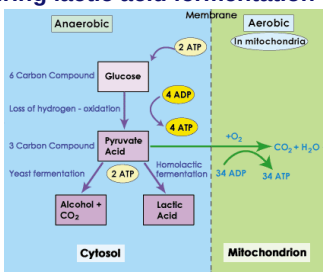
O_2

- Oxygen is really important for several reasons–
  - It's the final electron acceptor in ETC
  - Important for transporting pyruvate into mitochondria
- So what happens if O_2 unavailable?
  - ETC backs up
    - nothing to pull electrons down chain
    - NADH & $FADH_2$ can't unload H
  - ATP production ceases
  - cells run out of energy
  - and you die*!*



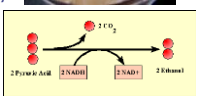
Fermentation– No Oxygen!

- In alcohol fermentation
- During lactic acid fermentation



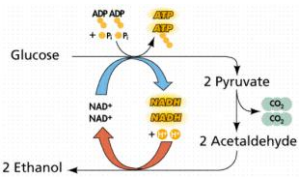
Anaerobic Resp. & Fermentation:

- Anaerobic Respiration
- Inorganics; nitrates & sulfates are final e- acceptors
- Yields 2 ATP from glycolysis
- Occurs in anaerobic environments
  - waterlogged soil, intestines, stagnant ponds, N cycle



Alcoholic & Lactate Fermentation

- Both are inefficient = 2ATP produced
- Alcoholic Ferm. produces Ethanol
  - pyruvate converted to ethanol to regenerate NAD+ → Gives us a new e- acceptor!
- Ethanol is toxic waste to cells



Alcoholic Fermentation

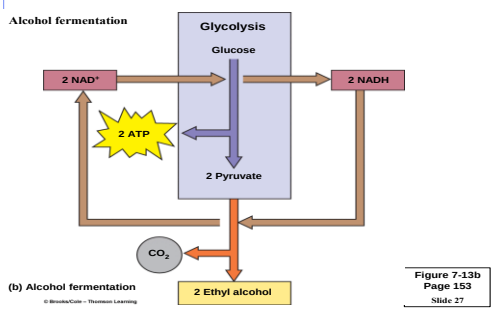


Figure 7-13b
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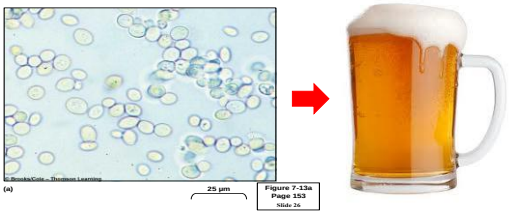
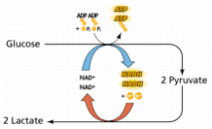
Slide 27

Brewer's Yeast



Lactate Fermentation

- Bacteria & some fungi carry out lactate fermentation
  - pyruvate converted to lactate to regenerate NAD+
- Strenuous activity results in lactate fermentation
  - Lactate → liver → converted to glycogen
- Yields 2 ATP from glycolysis



Lactate Fermentation