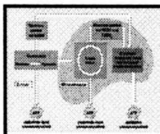
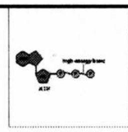
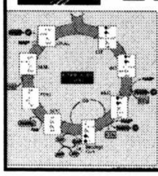
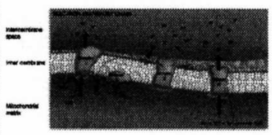
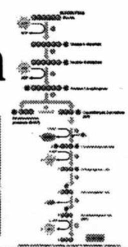



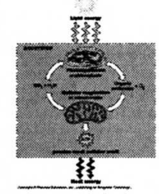
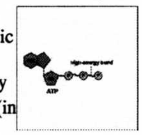
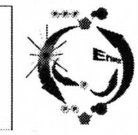
Cellular Respiration

I. Principles of Energy Harvest

A. Catabolic Pathways (Break Down)
   1. Fermentation (anaerobic)
   2. Cellular Respiration
      a. $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + energy
      b. Aerobic
      c. Exergonic (-686 kcal/mol)

B. ATP
   1. Energy storage molecule
   2. Buildup of ATP is an endergonic reaction that requires energy.
   3. ATP $\rightarrow$ ADP+ P_i creates energy
   4. 10 million recycled per second(in muscle)

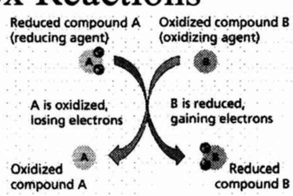




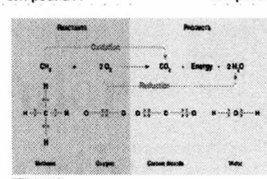
II. Redox Reactions

A. Oxidation-reduction (OIL RIG)
   1. Oxidation is e- loss
   2. Reduction is e- gain
   3. Adding e- reduces + charge

B. Reducing agent: e- donor

C. Oxidizing agent: e- acceptor

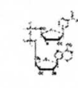
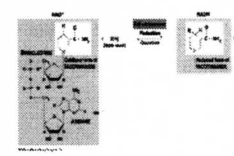
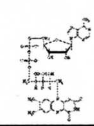




III. Oxidizing Agents in Respiration

A. Nicotinamide Adenine Dinucleotide- NAD^+ (coenzyme)
   1. NAD^+ accepts two electrons and a hydrogen ion (H^+); results in NADH + H^+
   2. NAD^+ is reduced to NADH (by dehydrogenase)
   3. NAD^+ is oxidizing agent
   4. Each NAD^+ molecule is used over and over

B. Flavin Adenine Dinucleotide-FAD (coenzyme)
   1. Can replace NAD^+
   2. FAD accepts two hydrogens, becomes $FADH_2$.

IV. Electron Transport Chains

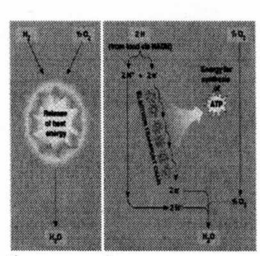
A. Electron carrier molecules (mainly membrane proteins)

B. Electronegativity shuttles electrons

C. Prevents energy released in one explosive step

D. Released energy used to make ATP

E. Electron route:
   food---> NADH ---> electron transport chain ---> oxygen



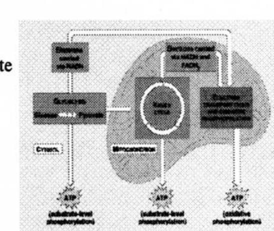
V. Cellular Respiration Overview

A. Glycolysis
   1. In cytosol
   2. Degrades glucose into pyruvate

B. Transition Reaction
   1. Shuttles pyruvate into Mitochondia
   2. Makes Acetyl CoA

C. Kreb's Cycle
   1. In mitochondrial matrix
   2. Acetyl CoA used to produce NADH and $FADH_2$

D. Electron Transport Chain
   1. Inner mitochondrial membrane
   2. Electrons passed to oxygen



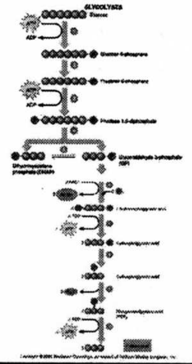
VI. Glycolysis

A. The breakdown of glucose to two molecules of pyruvate.

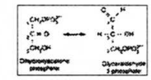
B. Occurs in the cytosol

C. Doesn't require oxygen

D. Universal in organisms (most likely evolved before Krebs cycle and electron transport system)

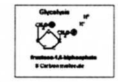


VI. Glycolysis



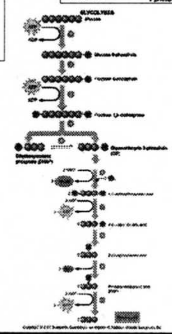
E. Energy Investment Steps

1. Two ATP molecules phosphorylate Glucose
2. Glucose splits into two C3 molecules (PGAL), each with a phosphate group.



F. Energy Harvesting Steps

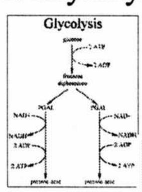
1. Reduction of $2NAD^+$ produces 2 NADH.
2. Further steps generate 4 ATP molecules by substrate-level phosphorylation
3. Two H_2O molecules are produced
4. There is a net gain of two ATP from glycolysis.

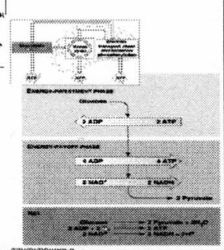


VI. Glycolysis

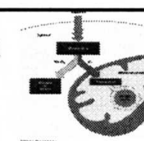
G. Summary

1. Two Pyruvate molecules are the final products
2. No CO_2 is released
3. If O_2 is present, pyruvate enters mitochondria.
4. If no O_2, fermentation follows
5. Net energy yield per glucose molecule = 2 ATP plus 2 NADH





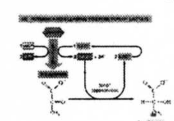
VII. Fermentation



A. Consists of glycolysis plus reduction of pyruvate to either lactate or alcohol and CO_2.

B. NADH passes its electrons to pyruvate

C. Regenerates NAD^+ for glycolysis

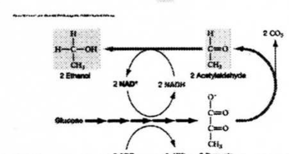


D. Two Types

1. Lactic Acid Fermentation
2. Alcohol Fermentation

E. Fermentation results in a net gain of only two ATP per glucose molecule

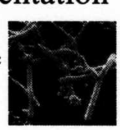
F. Lactic acid and alcohol are toxic to cells.

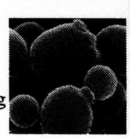


VII. Fermentation

G. Examples

1. Anaerobic bacteria produce lactic acid when we manufacture some cheeses.
2. Anaerobic bacteria produce industrial chemicals: isopropanol, butyric acid, propionic acid, and acetic acid.
3. Yeasts use CO_2 to make bread rise, produce alcohol in winemaking
4. Animals reduce pyruvate to lactate when it is produced faster than it can be oxidized by Krebs cycle.



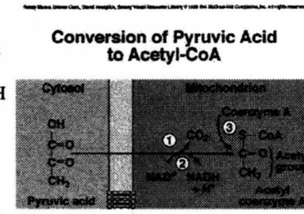


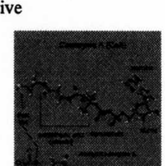
VIII. Transition Reaction

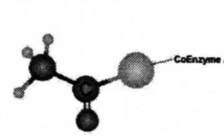
A. Each pyruvate loses a CO_2 (becoming acetate)

B. NAD^+ is reduced to NADH

C. Coenzyme A(B vitamin derivative) attaches to acetate making it very reactive







IX. Kreb's Cycle

A. Sir Hans Krebs (1930's)

B. Also called Citric Acid Cycle

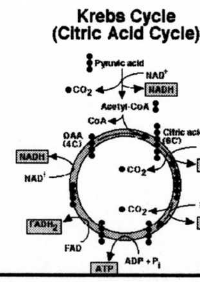
C. Occurs in mitochondrial matrix if O_2 is present

D. Acetyl CoA combines with Oxaloacetate (forming citric acid)

E. For each turn of cycle

1. Two CO_2 are released
2. Three 3 NADH produce
3. One FAD is reduced to $FADH_2$
4. GTP accepts a phosphate group and passes it on to convert ADP to ATP.

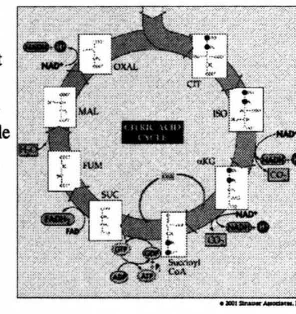
F. Oxaloacetate is regenerated



IX. Kreb's Cycle

G. Summary

1. NADH and $FADH_2$ carry electrons to electron transport system
2. Krebs cycle turns twice for each original glucose molecule
3. Products of the Krebs cycle per glucose molecule include $4CO_2$, 2ATP, 6NADH and $2FADH_2$



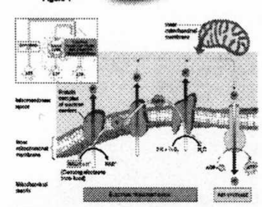
X. Electron Transport Chain

A. Series of electron carrier molecules in mitochondrial cristae

B. Cristae are the inner folds of membrane that jut out into matrix

C. Carrier Molecules

1. Most are proteins (heme and cytochromes)
2. Ubiquinone is a lipid
3. Electrons pass from higher to lower energy states

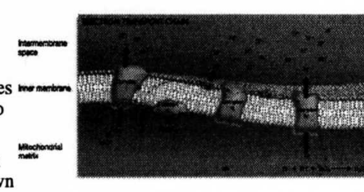


X. Electron Transport Chain

D. NADH and $FADH_2$ give electrons to carriers

E. Oxygen is final acceptor and combines with hydrogen ions to form H_2O

F. Energy released from flow of electrons down electron transport chain is used to pump H^+ ions into the mitochondrial intermembrane space.

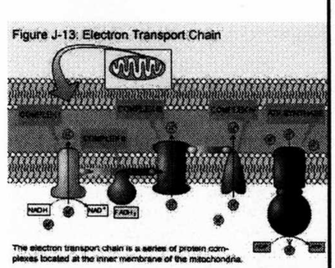


X. Electron Transport Chain

G. Electrons from NADH pump 3 H^+ into intermembrane space.

H. Electrons from $FADH_2$ pump 2 H^+ into intermembrane space

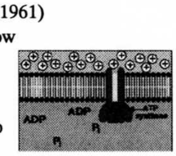
I. H^+ ions in this intermembrane space creates an electrochemical gradient. (proton-motive force)



XI. Chemiosmosis

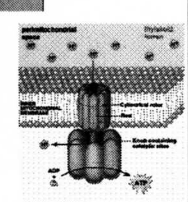
A. Proposed by Peter Mitchell(1961)

B. H^+ ions flow from high to low concentration through ATP synthase



C. ATP Synthase Complexes

1. Channel proteins that also serve as enzymes for ATP synthesis
2. Found in mitochondrial and chloroplast membranes.
3. Found in Prokaryote cell membranes



D. Because O_2 must be present for system to work, it is also called oxidative phosphorylation.

XII. Energy Review

- Glycolysis: 2ATP (substrate-level phosphorylation)
- Kreb's Cycle: 2ATP (substrate-level phosphorylation)
- Electron transport & oxidative phosphorylation:
  2 NADH (glycolysis) = 6ATP
  2 NADH (acetyl CoA) = 6ATP
  6 NADH (Kreb's) = 18 ATP
  2 FADH2 (Kreb's) = 4 ATP

  38 TOTAL ATP/glucose

XIII. Cellular Respiration Review

A. The metabolic pathways that break down carbohydrates and other metabolites and build up ATP.
B. Aerobic respiration begins with glucose and ends with CO_2 and H_2O.
C. Glucose is high-energy molecule; CO_2 and H_2O are low-energy molecules; process is exergonic and releases energy.
D. Electrons are removed from substrates and received by oxygen, combines with H^+ to become water.
E. Glucose is oxidized and O_2 is reduced.
F. Pathways of aerobic respiration allow energy in glucose to be released slowly; ATP is produced gradually.

XIII. Cellular Respiration Review

G. Rapid breakdown of glucose would lose most energy as nonusable heat.
H. Breakdown of glucose yields synthesis of 38(36) ATP; this preserves 40% of energy available in glucose.
I. Prokaryotes lack mitochondria; each NADH produces three ATP for total of 38 ATP.
J. Electrons received by NAD^+ and FAD are carried to the electron transport system.
K. If O_2 is not available to the cell, fermentation, an anaerobic process, occurs.
L. Coenzymes and ATP recycle
M. Most ATP is produced by the electron transport system.
N. Glycolysis is the most widespread metabolic process