Chapter 8

Topics

–**Metabolism**

–**Energy**

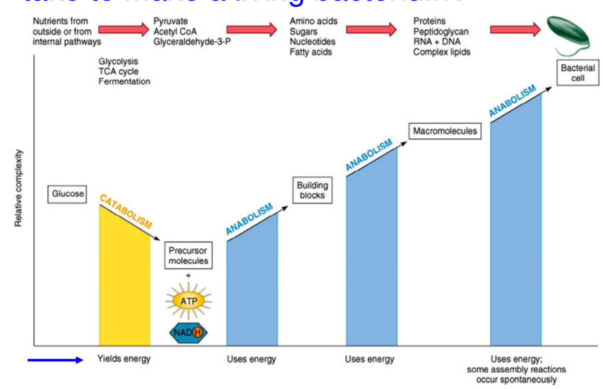
–**Pathways**

Metabolism

- **Metabolism = Catabolism + Anabolism**
- **Enzymes**

- **Catabolism** - Enzymes are involved in the **breakdown** of complex organic molecules in order to extract energy and form simpler end products
- **Anabolism -** Enzymes are involved in the use of energy from catabolism in order to **synthesize** macromolecules and cell structures from precursors (simpler products)

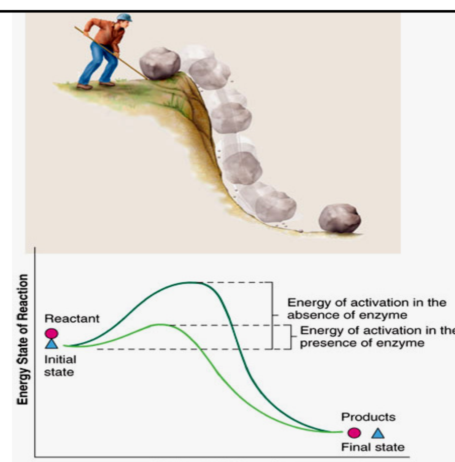
Catabolism and Anabolism - what does it take to make a living bacterium?



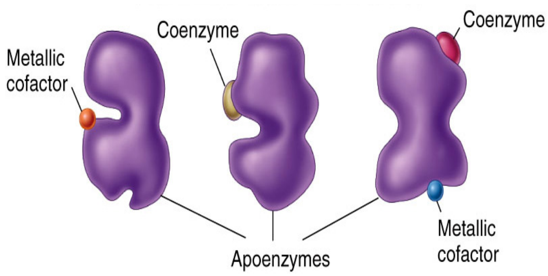
Enzymes

Function

- **Catalysts for chemical reactions**
  - **EX. - RedOx reactions**
- **Lower the energy of activation**
- **Two other properties!!!**



Enzyme Structure
(Simple vs Conjugated)



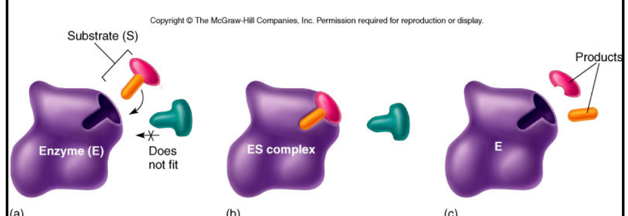
Enzyme Structure

Two components in conjugated:
1) Apoenzyme – protein component
2) Cofactors
   - Coenzymes – Organic molecules (vitamins)
   - Inorganic elements – Metal ions
3) Active site or Catalytic site – interacts with substrate

Enzyme-substrate interactions

- Substrates specifically bind to the active sites on the enzyme
  - Catalase → Hydrogen peroxide
  - Urease → Urea
- Once the reaction is complete, the product is released and the enzyme reused - over and over again!

E + Substrate → ES Complex → E + Products



Role of Enzymes in Disease

Exoenzymes and Endoenzymes
- **Exoenzymes – role in virulence (toxins)**
- **Endoenzymes – role in metabolic pathways**

Examples of exoenzymes:

Streptococcus pyogenes **(Strept Throat)**
Produces Streptokinase - digests clots
Pseudomonas aeruginosa **(many diseases)**
Produces Elastase and Collagenase - digest elastin and collagen - ↑ Disease
Clostridium perfringens **(gas gangrene)**
Lecithinase C - destroys tissue in wounds

Factors that Affect Enzyme

- **Temperature**
- **pH**
- **Osmotic pressure**

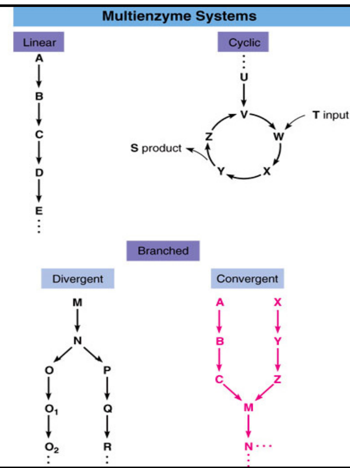
Denaturation!!!!

Regulation

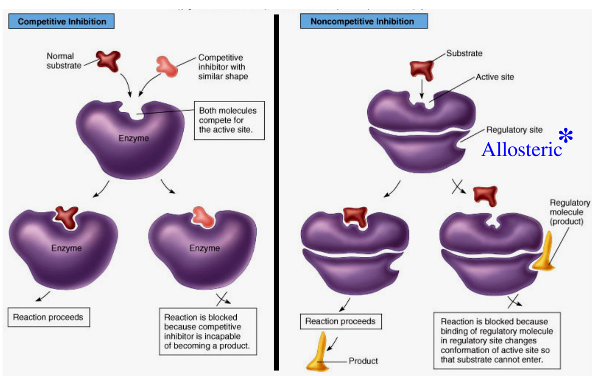
- Metabolic pathways
- Direct control - Quickest way to regulate
  - Competitive - bind active site
  - Non-competitive - DO NOT bind active site
- Genetic control - Slower because 'switch' is mediated by accumulation or production of product
  - Induction
  - Repression

Conserved Patterns in Metabolism

- Linear
- Cyclic
- Branched
  - Divergent
  - Convergent



Competitive vs. Noncompetitive Inhibition

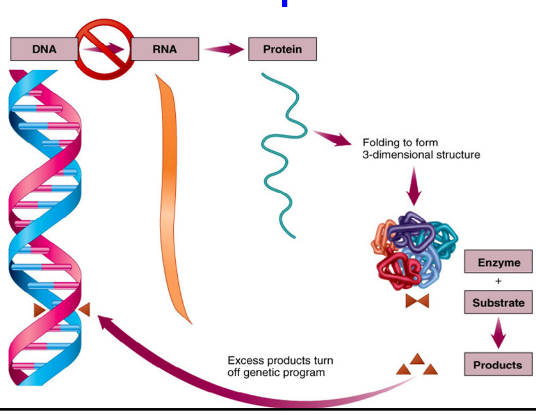


Genetic control -

more long term effects

- Repression
  - Excess of end product binds to the genetic component and turns if 'OFF'
- Induction
  - Induced by presence of substrate (i.e LACTOSE) binds to the genetic component and turns it 'ON'
  - Make enzymes necessary for action

Genetic Repression



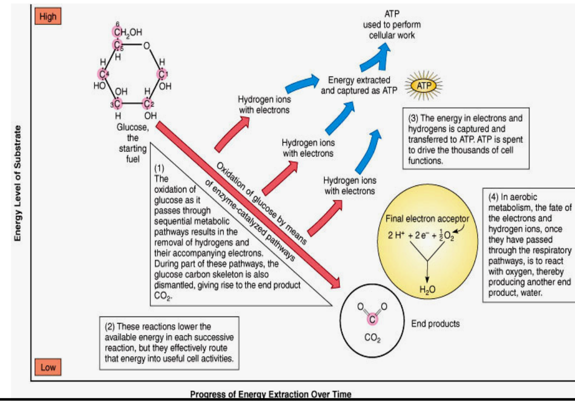
Lactose Operon

- If *E. coli* into medium containing **LACTOSE**
- *E. coli* will synthesize the enzyme **LACTASE**
- This enzyme will allow the organism to break down **LACTOSE** into **GLUCOSE** and **GALACTOSE**
- If **LACTOSE** is gone, **LACTASE** synthesis stops

Energy

- Cell energetics
  - Exergonic - RXN produces energy
  - Endergonic - RXN uses energy
- Redox reaction
- Electron carriers
- Adenosine Triphosphate (ATP)

Simplified Model of Energy Machine of Cell



Redox reaction

- Reduction and oxidation reaction
- Electron carriers transfer electrons and hydrogens
  - Electron donor (REDUCED) → NADH
  - Electron acceptor (OXIDIZED) → NAD
- Energy is also transferred and captured by the phosphate in form of ATP

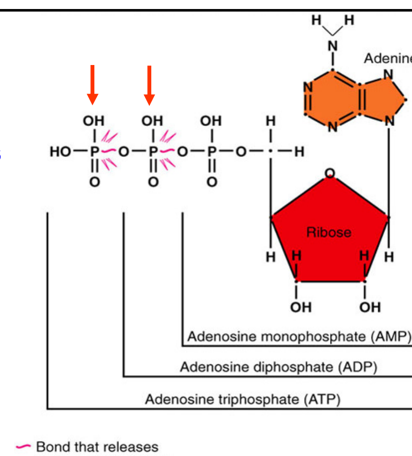
Electron carriers – shuttle electrons and hydrogens

- Coenzymes
  - Nicotinamide adenine dinucleotide (NADH)
  - Flavin adenin dinucleotide (FADH)
- Respiratory chain carriers
  - Cytochromes (protein)

Adenosine Triphosphate (ATP)

- Temporary energy repository
- Breaking of phosphates bonds will release energy
- Three part molecule
  - Nitrogen base
  - 5-carbon sugar (ribose)
  - Chain of phosphates

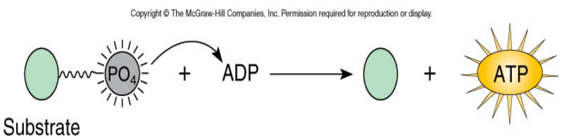
The phosphates capture the energy and becomes part of the ATP molecule



How ATP is made? Remember, there is a determined number of ATP molecules in the cell!!

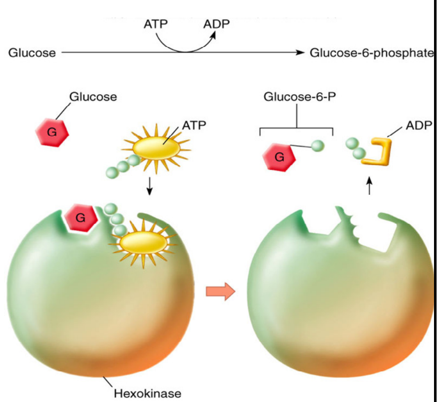
- **ATP is made either by SUBSTRATE LEVEL PHOSPHORYLATION – transfer of a (P) group from a (P)– compound <u>substrate</u> directly to ADP**
- **or by OXIDATIVE PHOSPHORYLATION – ATPs are formed in <u>respiration/electron transport system</u>**

SUBSTRATE LEVEL PHOSPHORYLATION



Glucose to Glucose-6-phosphate

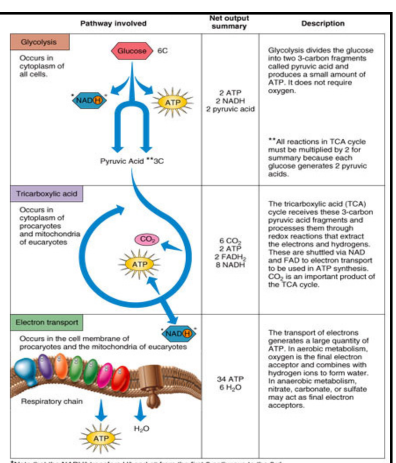
Phosphate comes from ATP



Pathways

- **Catabolism**
  - –Glycolysis
  - –Tricarboxylic acid cycle (TCA)
  - –Respiratory chain - Electron Transport
    - •Aerobic
    - •Anaerobic
  - –Fermentation
- **Anabolism - building blocks**

A summary of the metabolism (<u>catabolism</u>) of glucose and the synthesis of energy



Aerobic respiration

- **Glycolysis**
- **Tricarboxylic acid (TCA)**
- **Electron transport**

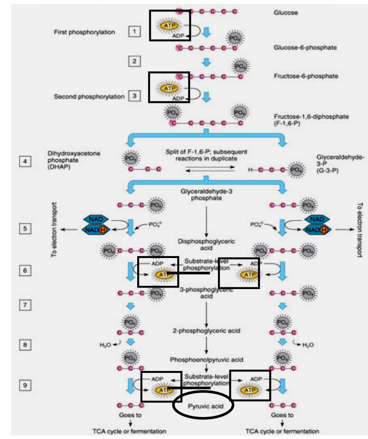
*** Oxygen final electron acceptor**

*** ATP per glucose molecule = 38 ATP**

Glycolysis

- Oxidation of glucose
- Phosphorylation of some intermediates (Uses 2 ATPs)
- 1) Where does it take place?
- Splits a 6 carbon sugar into **two** 3 carbon molecules (pyruvic acid)
- Coenzyme NAD is reduced to NADH
- Substrate-level-phosphorylation (4 ATPs are synthesized but 2 are used!!!)
- NET YIELD = 2 ATP + 2 NADH + 2 pyruvic acid

Summary of Glycolysis

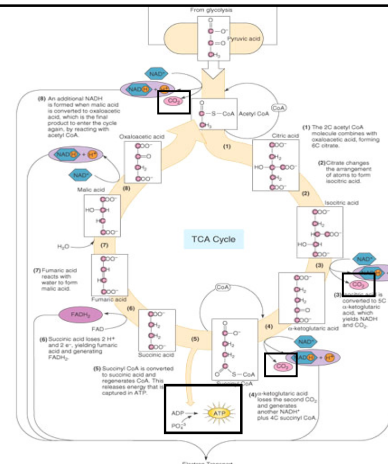


TCA cycle

- Each pyruvic acid is processed to Acetyl-CoA (2C) that enters the TCA cycle (two complete cycles)
- Where does it take place?
- CO_2 is generated
- Coenzymes NAD and FAD are reduced to NADH and $FADH_2$
- Net yield of **2** ATPs
- Critical intermediates (8 NADH and 2 $FADH_2$) are synthesized

1 TCA cycle - remember - this happens twice - once for each pyruvic acid

Production of 8 NADH and 2 $FADH_2$ important - electron transport system



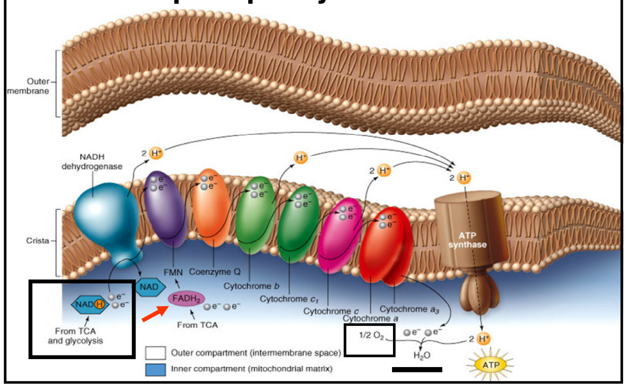
Electron Transport Chain

- NADH and $FADH_2$ donate electrons to the electron carriers
- NADH generates 3 ATP, $FADH_2$ = 2 ATP
- Membrane bound carriers transfer electrons (redox reactions)
- The final electron acceptor completes the terminal step (ex. Oxygen)
- Chemiosmosis
- Proton motive force (PMF)

Electron transport chain

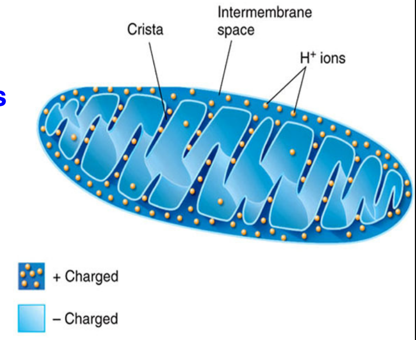
- Mitochondria
  - eukaryotes
- Cytoplasmic membrane
  - prokaryotes

The electron transport system and oxidative phosphorylation



Chemiosmosis - pump hydrogen ions out

Proton Motive Force - concentration gradient of differing charge

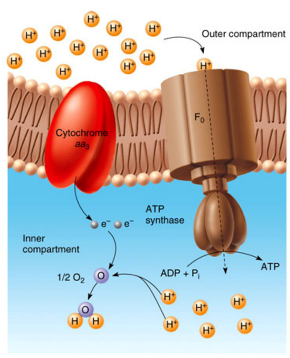


(a) As the carriers in the mitochondrial cristae transport electrons, they also actively pump H^+ ions (protons) to the intermembrane space, producing a chemical and charge gradient between the outer and inner mitochondrial compartments.

Final Step - production of ATP and H_2O

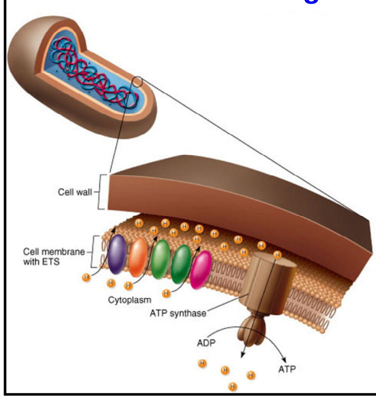
- ATP Synthase

- 2nd way to make ATP!!!



(b) The distribution of electric potential and the concentration gradient of protons across the membrane drive the synthesis of ATP by ATP synthase. The rotation of this enzyme couples diffusion of H^+ to the inner compartment with the bonding of ADP and P_i. The final event of electron transport is the reaction of the electrons with the H^+ and O_2 to form metabolic H_2O. This step is catalyzed by cytochrome oxidase (cytochrome aa_3)

ETS in a bacterial cell - Gram positive or negative?



(c) Enlarged view of bacterial cell envelope to show the relationship of electron transport and ATP synthesis. Bacteria have the ETS and ATP synthase stationed in the cell membrane. ETS carriers transport H^+ and electrons from the cytoplasm to the exterior of the membrane. Here, it is collected to create a gradient just as it occurs in mitochondria.

TABLE 8.4 Summary of Aerobic Respiration for One Glucose Molecule

	Glycolysis*	Net Output	TCA Cycle*	Net Output	Respiratory Chain	Net Output	Total Net Output per Glucose
ATP produced	2 X 2 =	2	1 X 2 =	2	17 X 2 =	34	40 – 2 (used) = 38**
ATP used	2		0		0		
NADH produced	1 X 2 =	2	4 X 2 =	8	0		10
FADH produced	0		1 X 2 =	2	0		2
CO_2 produced	0		3 X 2 =	6	0		6
O_2 used	0		0		3 X 2 =	6	
H_2O produced	2		0		3 X 2 =	6	8 – 2 (used) = 6
H_2O used	0		2		0		

*Products are multiplied by 2 because the first figure represents the amount for only one trip through the pathway, and two molecules make this trip for each glucose.
**This amount can vary among microbes.

Anaerobic respiration

- Similar to aerobic respiration, except that oxygen containing ions such as **nitrate or nitrite** are the final electron acceptor

Fermentation

- <u>Glycolysis only</u>
- Incomplete oxidation of glucose in the absence of oxygen
- NADH from glycolysis is used to reduce the organic products
- Organic compounds as the final electron acceptors
- ATP yields are small (2 per glucose molecule), compared to respiration
- Must metabolize large amounts of glucose to produce equivalent respiratory ATPs

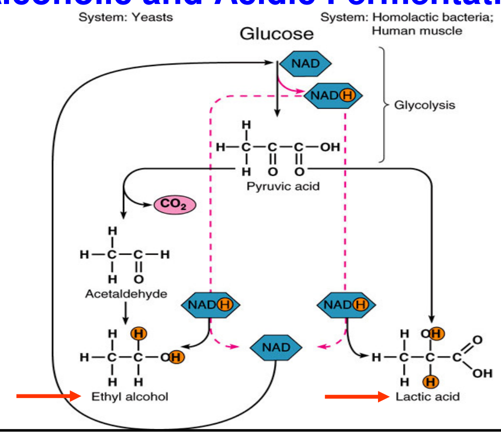
Types of Fermenters

- Facultative anaerobes
  - Fermentation in the absence of oxygen
  - Respiration in the presence of oxygen
  - Ex. *Escherichia coli*
- Strict fermenters
  - No respiration
  - Ex. yeast

Products of fermentation

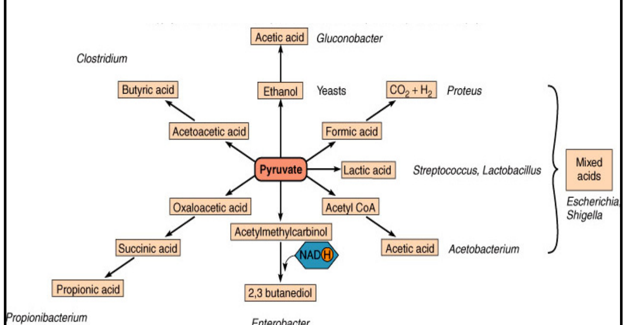
- Alcoholic fermentation
- Acidic fermentation
- Mixed acid fermentation

Alcoholic and Acidic Fermentation

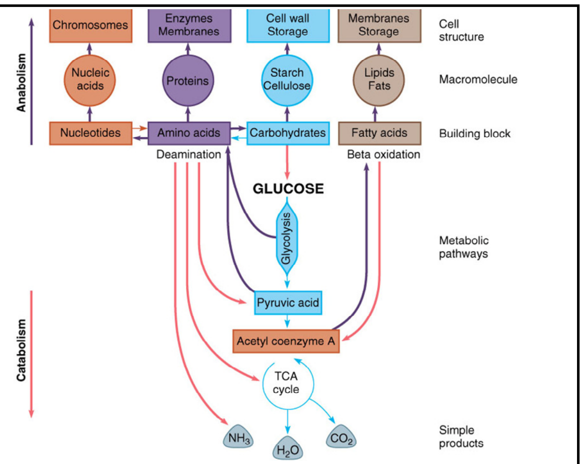


Miscellaneous products of pyruvate

Mixed Acid Fermentation



Biosynthesis - Crossing pathways of Metabolism


Anabolism
Catabolism
Chromosomes
Enzymes Membranes
Cell wall Storage
Membranes Storage
Cell structure
Nucleic acids
Proteins
Starch Cellulose
Lipids Fats
Macromolecule
Nucleotides
Amino acids
Carbohydrates
Fatty acids
Building block
Deamination
Beta oxidation
GLUCOSE
Glycolysis
Metabolic pathways
Pyruvic acid
Acetyl coenzyme A
TCA cycle
NH_3
H_2O
CO_2
Simple products

The End