Respiration

تـــنـــفـــس

CELL RESPIRATION

Metabolism - the sum of all the chemical reactions that occur in the body. It is comprised of:

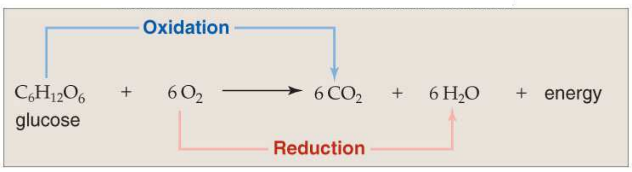
- anabolism - synthesis of molecules, requires input of energy
- catabolism - break down of molecules, releases energy..
  - aerobic - occurs in the presence of oxygen
  - anaerobic - occurs in the absence of oxygen..

METABOLIC REACTIONS

- Photosynthesis
  - Light energy converted into stored energy (glucose)
  - CO_2 + H_2O => $C_6H_{12}O_6$ (glucose) + O_2
  - Endergonic
- Cellular Respiration
  - Stored energy (glucose) converted into useable energy (ATP)
  - $C_6H_{12}O_6$ (glucose) + O_2 => CO_2 + H_2O
  - Exergonic
- NOTE—Both reactions have the same formula, but in different directions!!!

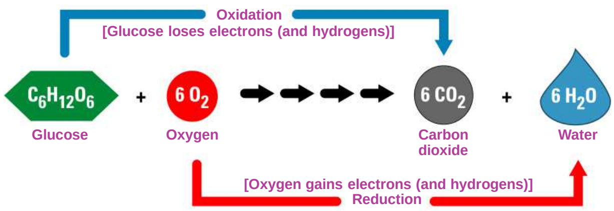
CELLULAR RESPIRATION IS A REDOX REACTION THAT REQUIRES O_2

- Oxidation of substrates, such as glucose, is a fundamental part of cellular respiration



  - **NAD^+ and FAD** coenzymes that act as electron carriers in oxidation during cellular respiration - carry high-energy electrons to the electron transport chain

- Chemical reactions that transfer electrons from one substance to another are called oxidation-reduction reactions.
  - the loss of electrons (and hydrogens) is called **oxidation**
  - the gain of electrons (and hydrogens) is called **reduction**



CELLULAR RESPIRATION

- ATP is energy currency of cells
- Aerobic Respiration
  - Requires oxygen
  - High energy (ATP) yield
  - Glycolysis—in cytoplasm
    - Common to all pathways
    - Splitting glucose forms ATP
  - Citric Acid Cycle—in mitochondrial matrix
    - Requires oxygen
    - Also called the Krebs Cycle
  - Oxidative Phosphorylation—in mitochondrial cristae
    - Requires oxygen
    - Also called Electron Transport System (ETS)

CELLULAR RESPIRATION

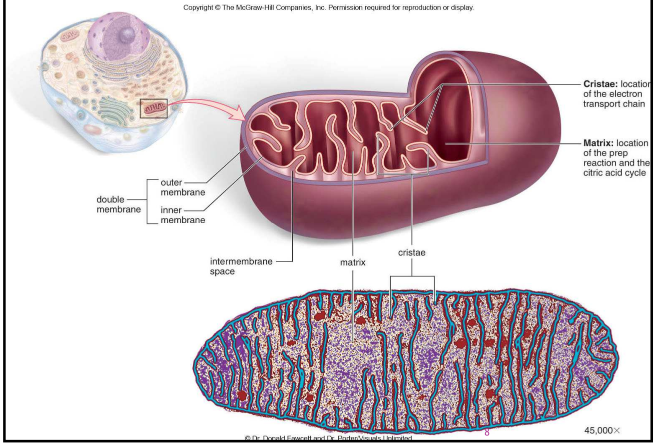
- Anaerobic Respiration
  - Doesn't require oxygen
  - Organisms without mitochondria
  - Low energy yield (small amount of ATP)

ATP Phosphorylation:

ATP is formed from ADP by two different processes:

1. Substrate-Level Phosphorylation
2. Oxidative-Level Phosphorylation

Mitochondrion Structure



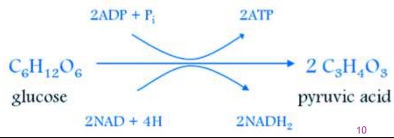
CELLULAR RESPIRATION HAS FOUR PHASES

Four phases of cellular respiration:

- **Glycolysis** - a metabolic pathway that converts glucose to pyruvate (occurs in cytoplasm)
- **Preparatory (prep) Reaction (transition reaction)**- pyruvate oxidized to a 2-carbon acetyl group (acetyl-CoA)
- **Citric Acid Cycle (Krebs Cycle)** - complete oxidation of acetyl-CoA; carriers accept electrons to make NADH and $FADH_2$ (reduced form)
- **Electron Transport Chain (ETC)** - NADH and $FADH_2$ give up electrons to ETC and energy is released to produce ATP

AEROBIC RESPIRATION STEP 1—GLYCOLYSIS

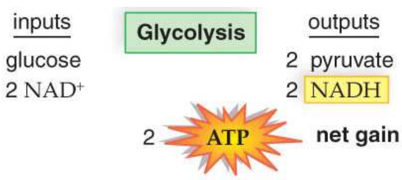
- Glycolysis— "sugar breaking" (glyco, lysis)
  - 2 ATP breaks a single glucose (6C) into two PGAL (3C each)
  - PGAL restructured into pyruvate
- Oxygen not required in this step
- 2ATP + Glucose→2 Pyruvate + 2 NADH +4 ATP
  - Net gain of 2 ATP
  - Electrons "captured" by NAD^+ to make NADH



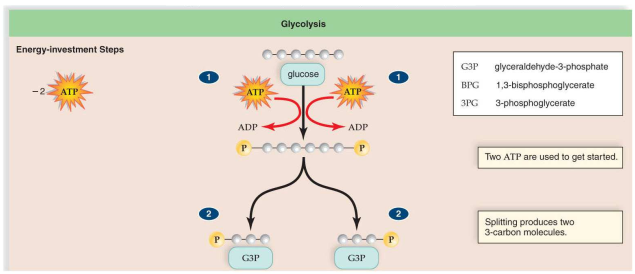
1. GLYCOLYSIS: GLUCOSE BREAKDOWN BEGINS

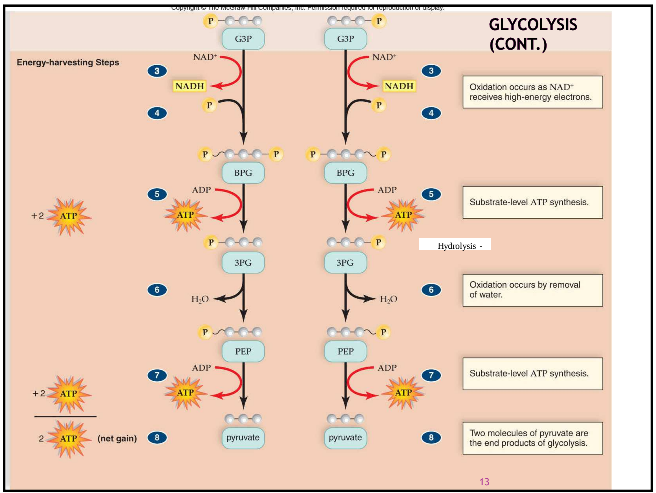
Glycolysis takes place outside the mitochondria and glucose is broken into two pyruvates

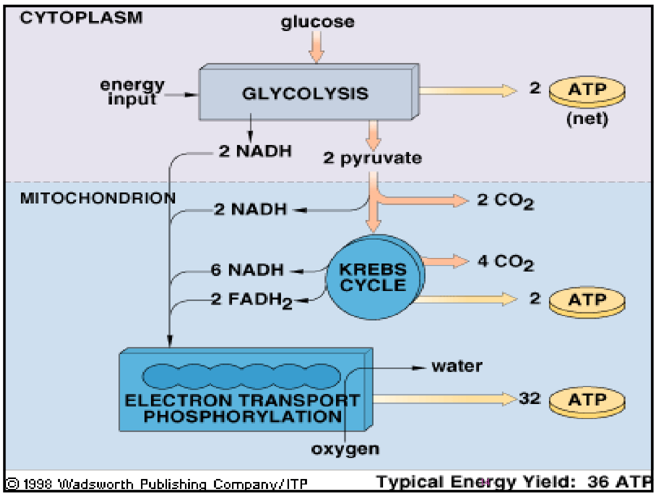
- **Inputs and outputs of Glycolysis**



GLYCOLYSIS

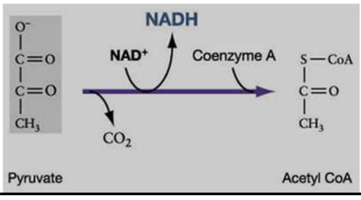






AEROBIC RESPIRATION
STEP 2— TRANSITION REACTION (ACETYL-COA)

- Conversion of pyruvate to acetyl-CoA
  - Pyruvate (3C) converted to acetyl-CoA (2C)
  - Releases CO_2
  - $NAD^+ \rightarrow NADH$
    - Electrons captured
  - 2 Pyruvate => 2 CO_2 + 2 NADH



15

- Transition reaction =
  - pyruvic acid moves into the matrix of the mitochondrion.
  - CO_2 is cleaved off and at the same time Coenzyme A is added.Coenzyme A is derived from the vitamin pantotenic acid.

$$\underset{\text{pyruvic acid}}{2C_3H_4O_3} + \underset{\text{coenzyme A}}{2CoA} \xrightarrow{NAD+2H \quad NADH_2} \underset{\text{acetyl-CoA}}{2C_2H_3O\text{-}CoA} + \underset{\text{carbon dioxide}}{2CO_2}$$

16

AEROBIC RESPIRATION
STEP 3— CITRIC ACID CYCLE

- Citric Acid Cycle (a.k.a. Krebs Cycle)
  - 2 Acetyl-CoA enter
  - Oxygen breaks Carbon-Carbon bonds
  - Broken bonds release energy & electrons
  - Energy used to form ATP
  - Electrons captured by NAD^+ and FAD^+

$$2C_2H_3O\text{-}CoA \xrightarrow[FAD+2H \;\; FADH_2 \;\; 2ADP+P \;\; 2ATP]{3NAD+6H \;\; 3NADH_2} 4CO_2$$

17

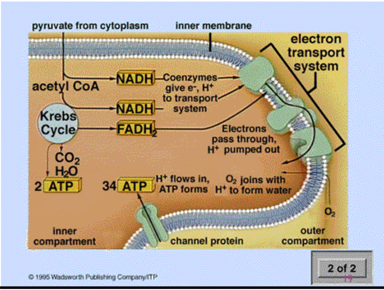
AEROBIC RESPIRATION
STEP 3— CITRIC ACID CYCLE

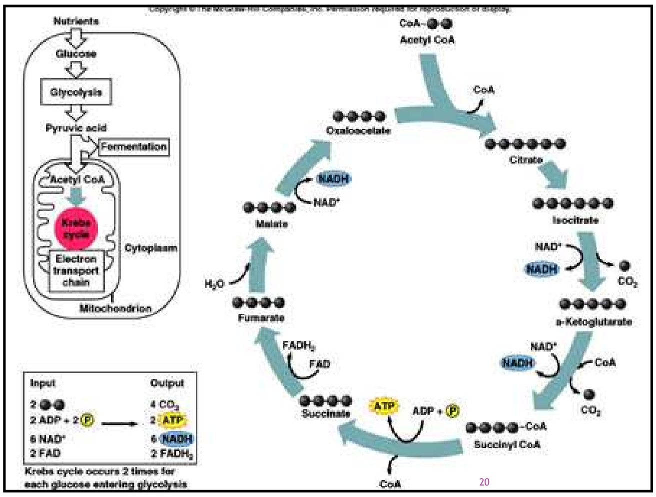
- Citric Acid Cycle (cont.)
  - Carbon leaves as CO_2
  - Intermediate products recycled, cycle starts again
  - 1 Glucose = 2 Pyruvate
    - Two complete “cycles” per glucose molecule
  - Net gain (per glucose) of 4 CO_2, 6 NADH, 2 $FADH_2$, 2 ATP

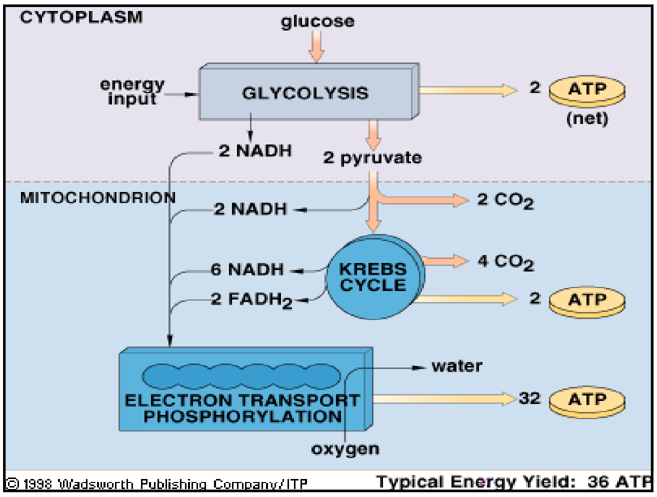
18

AEROBIC RESPIRATION
STEP 3— CITRIC ACID CYCLE

Inputs	Outputs (per glucose)
Pyruvate	4 CO_2
NAD^+, FAD^+	6 NADH, 2 $FADH_2$
ADP	*2 ATP*
O_2	







AEROBIC RESPIRATION
STEP 4—OXIDATIVE PHOSPHORYLATION

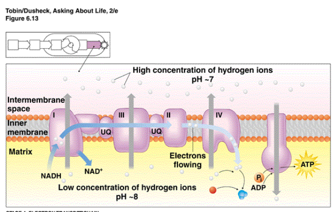
- Electron Transfer System (ETS)
  - Starts with NADH & $FADH_2$ from previous steps
  - Electrons flow through “chain” of membrane proteins
  - Each protein then takes H+ from above molecules and pumps them into intermembrane space
  - This sets up concentration gradient
  - H^+ moves down gradient through ATP synthase
  - Movement forms ATP from ADP & P (32 net gain per glucose)
    - **Chemiosmosis**
  - Ends with electrons passed to O_2, combines with H^+ to form H_2O

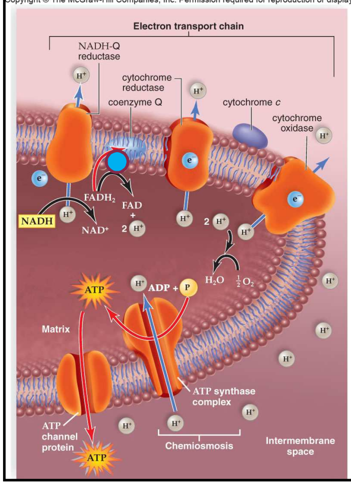
AEROBIC RESPIRATION
STEP 4—OXIDATIVE PHOSPHORYLATION

- If no oxygen, electrons can’t pass on
- This backs up to NADPH, so no H^+ gradients
- No ATP forms, starving cells

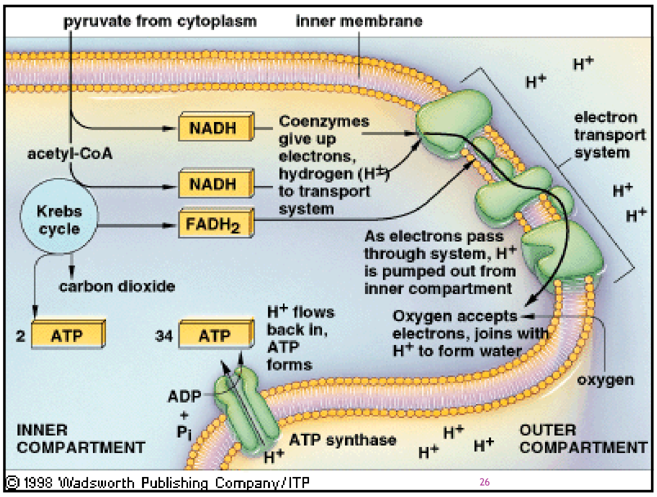
AEROBIC RESPIRATION
STEP 4—OXIDATIVE PHOSPHORYLATION

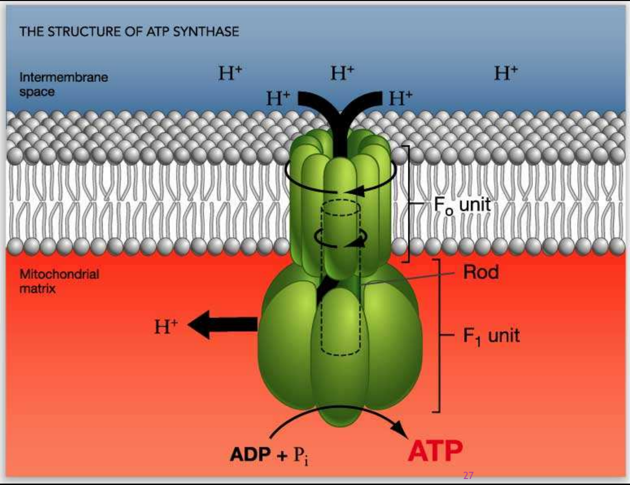
Inputs	Outputs (per glucose)
10 NADH, 2 $FADH_2$	6 H_2O
ADP	NAD^+, FAD^+
O_2	***32 ATP*** (net)





Electron Transport Chain in Mitochondria

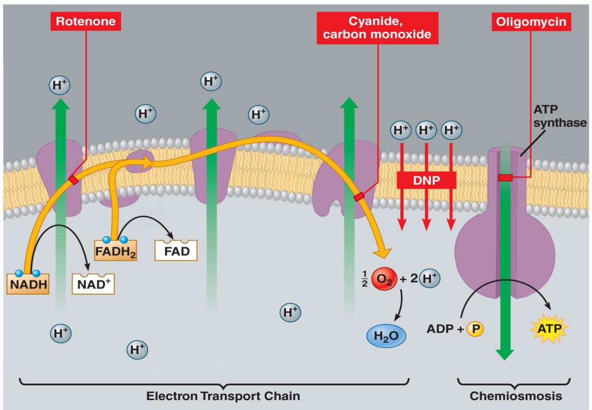




POISONS & ETS

- Rotenone
  - Used to kill insects & fish
  - Blocks ETS near its start
  - Prevents ATP synthesis, starving organisms of energy
- Cyanide, Carbon Monoxide
  - Blocks passage of electrons to oxygen
  - Stops flow of electrons before chemiosmosis
  - Like rotenone, prevents ATP synthesis
- Oligomycin
  - Topical, kills skin fungal infections
  - Blocks H^+ moving through ATP Synthase, preventing ATP synthesis

POISONS & ETS

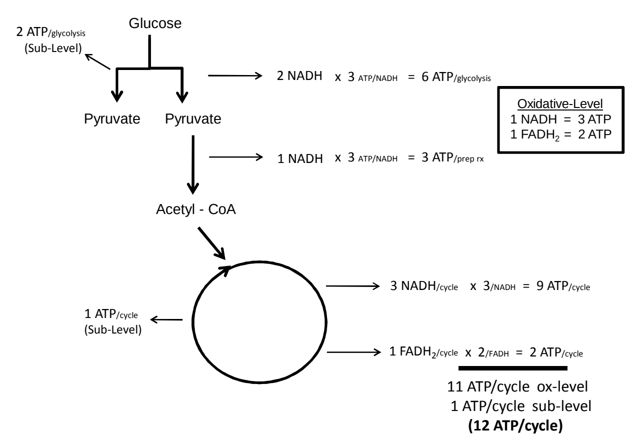


AEROBIC RESPIRATION

- Energy Harvest (net ATP per glucose)
  - Glycolysis—2 ATP
  - Citric Acid Cycle—2 ATP
  - ETS—32 ATP
- Total yield varies from 32-38 ATP depending on the type of cell

AEROBIC RESPIRATION

- Glycolysis
  - Glucose + 2ATP → 4ATP + 2NADH + 2 Pyruvate
- Intermediate
  - 2 Pyruvate → $2CO_2$ + 2NADH + 2 Acetyl-CoA
- Citric Acid Cycle
  - 2 Acetyl-CoA → 6NADH + 2ATP + $2FADH_2$
- Electron Transfer
  - 10NADH + $2FADH_2$ → 32ATP + $4CO_2$ + $6H_2O$
- $C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2$ + 36 ATP + heat



Metabolic Disorders

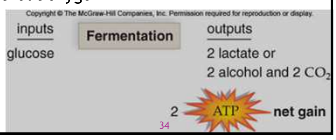
Glycogen Storage Disease (von Gierke's disease): Makes glycogen in liver, but unable to break glycogen down. So liver swells as more glycogen is made.

Lactic Acidosis: Excess buildup of lactic acid in blood. Causes – excess exercise, cancer, anemia, alcohol, liver failure.

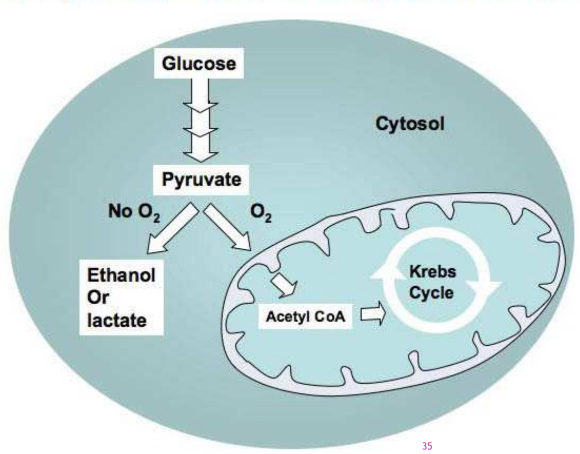
Phenylketonuria (PKU): Cannot metabolize or convert amino acid, phenylalanine. Excess levels build in body – effect nervous system. Phenylalanine needed for color pigment, melanin.

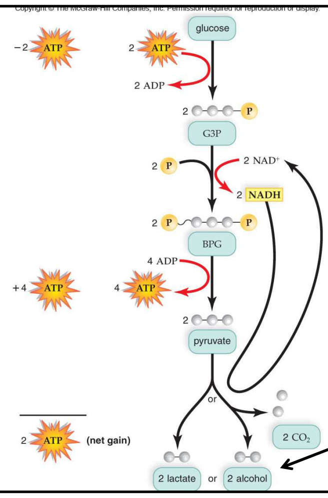
ANAEROBIC RESPIRATION

- Oxygen-poor or unoxygenated environments
- After glycolysis, pyruvate converted to compounds other than acetyl-CoA
- Fermenters
  - Protists, bacteria
  - Marshes, bogs, deep sea, animal gut, sewage, canned food
- **Fermentation** produces a limited amount of ATP using organic molecules instead of oxygen as the final electron acceptor
  - Benefit of Fermentation
    - Provide a rapid burst of ATP without oxygen
  - Drawback of Fermentation
    - Creates **oxygen debt**
    - Yields 2 ATP, cellular (respiration yields ≥36ATP)



Fate of Pyruvate in catabolism: cellular respiration or fermentation





FERMENTATION

Final Electron Acceptors

FERMENTATION HELPS PRODUCE NUMEROUS FOOD PRODUCTS

- Fermenting yeasts leaven bread and produce alcohol (beer and wine)
- Fermenting bacteria produce acids used to make yogurt, sour cream, and cheese
- Soy sauce is made by adding a mold and a combination of yeasts and fermenting bacteria to soybeans and wheat

37

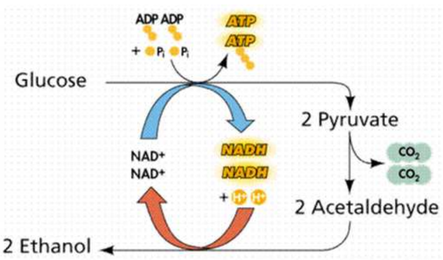
ANAEROBIC RESPIRATION

- Glycolysis happens normally
- 2 Pyruvate, 2 NADH, 2 Net ATP form
- Enough energy for many single-celled species
- Not enough energy for large organisms

38

ALCOHOL FERMENTATION

- Glucose → 2 Pyruvate → 2 Acetaldehyde + 2 CO_2
- NADH + Acetaldehyde → Ethanol
- Yeasts
  - Bread
  - Beer
  - Wine



39

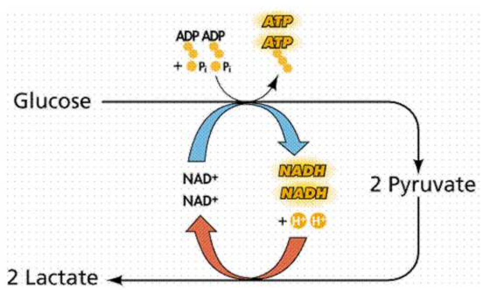
LACTATE FERMENTATION

- Can spoil food
- Some bacteria create food
  - Cheese, yogurt, buttermilk
  - Cure meats
  - Pickle some fruits & vegetables
- Muscle cells
  - When doing anaerobic exercise
  - Lactic acid builds up in cells, causing "the burn" felt during extensive exercise

40

LACTATE FERMENTATION

- Glucose → Pyruvate → Lactate

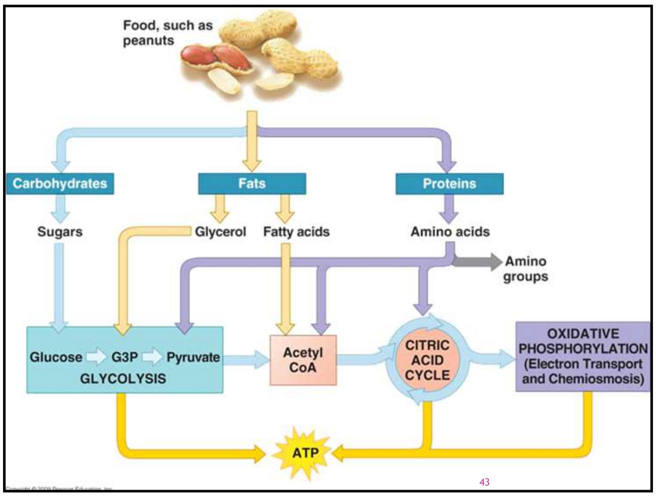


41

FOOD BREAKDOWN

- Different foods are broken down in different ways to be used as energy
- Carbohydrates
  - Starts with glycolysis and proceeds through respiration
- Fats
  - Broken down to glycerol and fatty acids
  - Glycerol converted to pyruvate, enters respiration there
  - Fatty acids converted into acetyl-CoA
  - Very energy dense
- Proteins
  - Broken down into amino acids
  - Amino acids converted into intermediates used in glycolysis, acetyl-CoA conversion, and the citric acid cycle

42

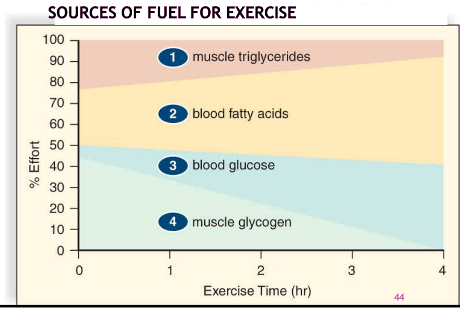


43

EXERCISE BURNS FAT

Prolonged aerobic exercise burns fat

- Breathing and heart rate increase during exercise in order to supply the muscles with adequate oxygen

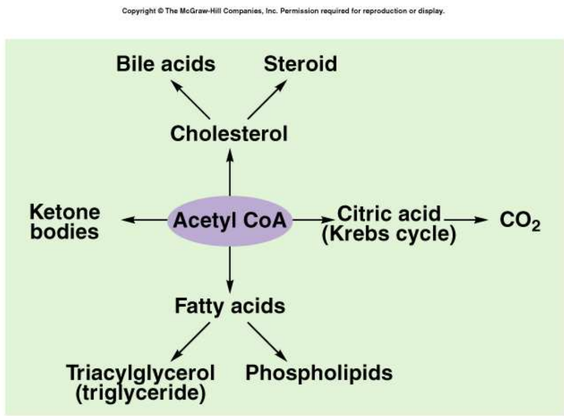


44

LIPOGENESIS

- Excess glucose does not complete respiration but instead is converted into glycerol and fatty acids. The acetyl-CoA subunits from the transition reaction are added together to produce fatty acids. This occurs primarily in adipose tissue and the liver..

45



46

LIPOLYSIS

- Triglycerides are hydrolyzed into glycerol and free fatty acids (FFA) by lipolysis.
- In some tissues glycerol can be converted into phosphoglyceraldehyde.
- FFAs are a major energy source and are metabolized by β-oxidation..

47