Metabolism

• Functions of food
  – source of energy
  – essential nutrients

• Metabolism is all the chemical reactions of the body
  – some reactions produce the energy stored in ATP that other reactions consume
  – all molecules will eventually be broken down and recycled or excreted from the body
Catabolism and Anabolism

• Catabolic reactions breakdown complex organic compounds
  – providing energy
  – glycolysis, Krebs cycle and electron transport
• Anabolic reactions synthesize complex molecules from small molecules
  – requiring energy
• Exchange of energy requires use of ATP (adenosine triphosphate) molecule.
ATP Molecule & Energy

- Each cell has about 1 billion ATP molecules that last for less than one minute
- Over half of the energy released from ATP is converted to heat
Energy Transfer

• Energy is found in the bonds between atoms
• Oxidation is a decrease in the energy content of a molecule
• Reduction is the increase in the energy content of a molecule
• Oxidation-reduction reactions are always coupled within the body
  – whenever a substance is oxidized, another is almost simultaneously reduced.
Oxidation and Reduction

• Biological oxidation involves the loss of (electrons) hydrogen atoms
  – dehydrogenation reactions require coenzymes to transfer hydrogen atoms to another compound
  – common coenzymes of living cells that carry H+
    • NAD (nicotinamide adenine dinucleotide )
    • NADP (nicotinamide adenine dinucleotide phosphate )
    • FAD (flavin adenine dinucleotide )
• Biological reduction is the addition of electrons (hydrogen atoms) to a molecule
  – increase in potential energy of the molecule
Mechanisms of ATP Generation

- Phosphorylation is
  - bond attaching 3rd phosphate group contains stored energy
- Mechanisms of phosphorylation
  - within animals
    - substrate-level phosphorylation in cytosol
    - oxidative phosphorylation in mitochondria
      - electron transport chain
Phosphorylation in Animal Cells

- In cytoplasm (1)
- In mitochondria (2, 3 & 4)
Carbohydrate Metabolism--In Review

- In GI tract
  - polysaccharides broken down into simple sugars
  - absorption of simple sugars (glucose, fructose & galactose)

- In liver
  - fructose & galactose transformed into glucose
  - storage of glycogen (also in muscle)

- In body cells --functions of glucose
  - oxidized to produce energy (ATP)
  - conversion into amino acids, glycogen, glycerol and fatty acids (triglycerides)
Triglycerides

- 3 fatty acids & one glycerol molecule
- Most common lipid in body and diet

Lipogenesis
Fate of Glucose

• ATP production during cell respiration
  – uses glucose preferentially
• Converted to one of several amino acids in many different cells throughout the body
• Glycogenesis
  – hundreds of glucose molecules combined to form glycogen for storage in liver & skeletal muscles
• Lipogenesis (triglyceride synthesis)
  – converted to glycerol & fatty acids within liver & sent to fat cells
Glucose Catabolism

- **Cellular respiration**
  - 4 steps are involved
  - glucose + O₂ produces H₂O + energy + CO₂
- **Anaerobic respiration**
  - Does not require O₂
  - called glycolysis (1)
  - formation of acetyl CoA (2)
    - is transitional step to Krebs cycle
- **Aerobic respiration**
  - Requires O₂
  - Krebs cycle (3) and electron transport chain (4)
Glycolysis of Glucose & Fate of Pyruvic Acid

- Breakdown of six-carbon glucose molecule into 2 three-carbon molecules of pyruvic acid
  - 10 step process occurring in cell cytosol
  - produces 4 molecules of ATP after input of 2 ATP

- If O2 shortage in a cell
  - pyruvic acid is reduced to lactic acid
  - rapidly diffuses out of cell to blood
  - liver cells remove it from blood & convert it back to pyruvic acid
Formation of Acetyl Coenzyme A

- Pyruvic acid enters the mitochondria
- PA is converted to Acetyl coenzyme A which enter Krebs cycle
Krebs Cycle (Citric Acid Cycle)

- Series of oxidation-reduction reactions occurring in matrix of mitochondria
Krebs Cycle

- Energy stored in bonds is released step by step to form several reduced coenzymes (NADH & FADH2) that store the energy.

- In summary: each Acetyl CoA molecule that enters the Krebs cycle produces
  - 2 molecules of CO2
    - Diffuses into blood and exhaled
  - 3 molecules of NADH + H+
  - one molecule of ATP
  - one molecule of FADH₂

- Remember, each glucose produced 2 acetyl CoA molecules.
The Electron Transport Chain

- Series of integral membrane proteins in the inner mitochondrial membrane capable of oxidation/reduction
- Each electron carrier is reduced as it picks up electrons and is oxidized as it gives up electrons
- Small amounts of energy released in small steps
- Energy used to form ATP by chemiosmosis
Chemiosmosis

- Small amounts of energy released as substances are passed along inner membrane
- Energy used to pump H+ ions from matrix into space between inner & outer membrane
- High concentration of H+ is maintained outside of inner membrane
- ATP synthesis occurs as H+ diffuses through a special H+ channel in inner membrane
Steps in Electron Transport

- Carriers of electron transport chain are clustered into 3 complexes that each act as proton pump (expel H+).
- Mobile shuttles pass electrons between complexes.
- Last complex passes its electrons (2H+) to a half of O2 molecule to form a water molecule (H2O).
Proton Motive Force & Chemiosmosis

• Buildup of H+ outside the inner membrane creates + charge
  – electrochemical gradient potential energy is called proton motive force

• ATP synthase enzyme within H+ channel uses proton motive force to synthesize ATP from ADP and P
Summary of Cellular Respiration

• Glucose + O2 is broken down into CO2 + H2O + energy used to form 36 to 38 ATPs
  – 2 ATP are formed during glycolysis
  – 2 ATP are formed by phosphorylation during Krebs cycle
  – electron transfers in transport chain generate 32 or 34 ATPs from one glucose molecule
Glycogenesis & Glycogenolysis

• Glycogenesis
  – glucose storage as glycogen
  – Glycogen is formed in liver and skeletal muscle
  – stimulated by insulin

• Glycogenolysis
  – glucose release
  – Requires phosphatase enzyme
  – enzyme only in hepatocytes so muscle can’t release glucose
  – enzyme activated by glucagon (pancreas) & epinephrine (adrenal)
Transport of Lipids by Lipoproteins

• Most lipids are nonpolar and must be combined with protein to be transported in blood

• Lipoproteins are spheres containing hundreds of molecules
  – outer shell polar proteins (apoproteins) & phospholipids
  – inner core of triglyceride & cholesterol esters

• 4 major classes of lipoproteins
  – chylomicrons, very low-density, low-density & high-density lipoproteins
Classes of Lipoproteins

- **Chylomicrons (2 % protein)**
  - form in intestinal epithelial cells to transport dietary fat
- **VLDLs (10% protein)**
  - transport triglycerides formed in liver to fat cells
- **LDLs (25% protein) --- “bad cholesterol”**
  - carry 75% of blood cholesterol to body cells
  - if cells have insufficient receptor for LDLs, remains in blood and more likely to deposit cholesterol in artery walls (plaque)
- **HDLs (40% protein) --- “good cholesterol”**
  - carry cholesterol from cells to liver for elimination
Fate of Lipids

- Oxidized to produce ATP
- Excess stored in adipose tissue or liver
- Synthesize structural or important molecules
  - phospholipids of plasma membranes
  - lipoproteins that transport cholesterol
  - thromboplastin for blood clotting
  - myelin sheaths to speed up nerve conduction
  - cholesterol used to synthesize bile salts and steroid hormones.
Triglyceride Storage

- Adipose tissue removes triglycerides from chylomicrons and VLDL and stores it
  - 50% subcutaneous, 12% near kidneys, 15% in omenta, 15% in genital area, 8% between muscles
- Fats in adipose tissue are ever-changing
  - released, transported & deposited in other adipose
- Triglycerides store more easily than glycogen
  - do not exert osmotic pressure on cell membranes
  - are hydrophobic
Lipid Catabolism: Lipolysis & Glycerol

- Triglycerides are split into fatty acids & glycerol by lipase
  - glycerol
    - if cell ATP levels are high, converted into glucose
    - if cell ATP levels are low, converted into pyruvic acid which enters aerobic pathway to ATP production
Lipolysis & Fatty acids

- Fatty acids are converted to Acetyl CoA and enter Krebs cycle
Lipid Anabolism: Lipogenesis

- Synthesis of lipids by liver cells = lipogenesis
  - from amino acids
  - from glucose
- Stimulated by insulin when eat excess calories
Fate of Proteins

• Proteins are broken down into amino acids
  – transported to the liver

• Usage
  – oxidized to produce ATP
  – used to synthesize new proteins
    • enzymes, hemoglobin, antibodies, hormones, fibrinogen, actin, myosin, collagen, elastin & keratin
  – excess converted into glucose or triglycerides
    • no storage is possible

• Absorption into body cells is stimulated by insulinlike growth factors (IGFs) & insulin
Protein Catabolism

- Breakdown of protein into amino acids
- Liver cells convert amino acids into substances that can enter the Krebs cycle
- Converted substances enter the Krebs cycle to produce ATP
Protein Anabolism

• Production of new proteins by formation of peptide bonds between amino acids
  – 10 essential amino acids are ones we must eat because we cannot synthesize them
  – Nonessential amino acids can be synthesized by transamination (transfer of an amino group to a substance to create an amino acid)

• Occurs on ribosomes in almost every cell

• Stimulated by insulin-like growth factor, thyroid hormone, insulin, estrogen & testosterone
Minerals

- Inorganic substances = 4% body weight
- Functions
  - calcium & phosphorus form part of the matrix of bone
  - help regulate enzymatic reactions
    - calcium, iron, magnesium & manganese
  - magnesium is catalyst for conversion of ADP to ATP
  - form buffer systems
  - regulate osmosis of water
  - generation of nerve impulses
Vitamins

• Organic nutrients needed in very small amounts
  – serve as coenzymes, (help enzymes)
• Most cannot be synthesized by the body
• Fat-soluble vitamins
  – absorbed with dietary fats by the small intestine
  – stored in liver and include vitamins A, D, E, and K
• Water-soluble vitamins are absorbed along with water in the GI tract
  – body does not store---excess excreted in urine
  – includes the B vitamins and vitamin C