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Metabolism and Nutrition

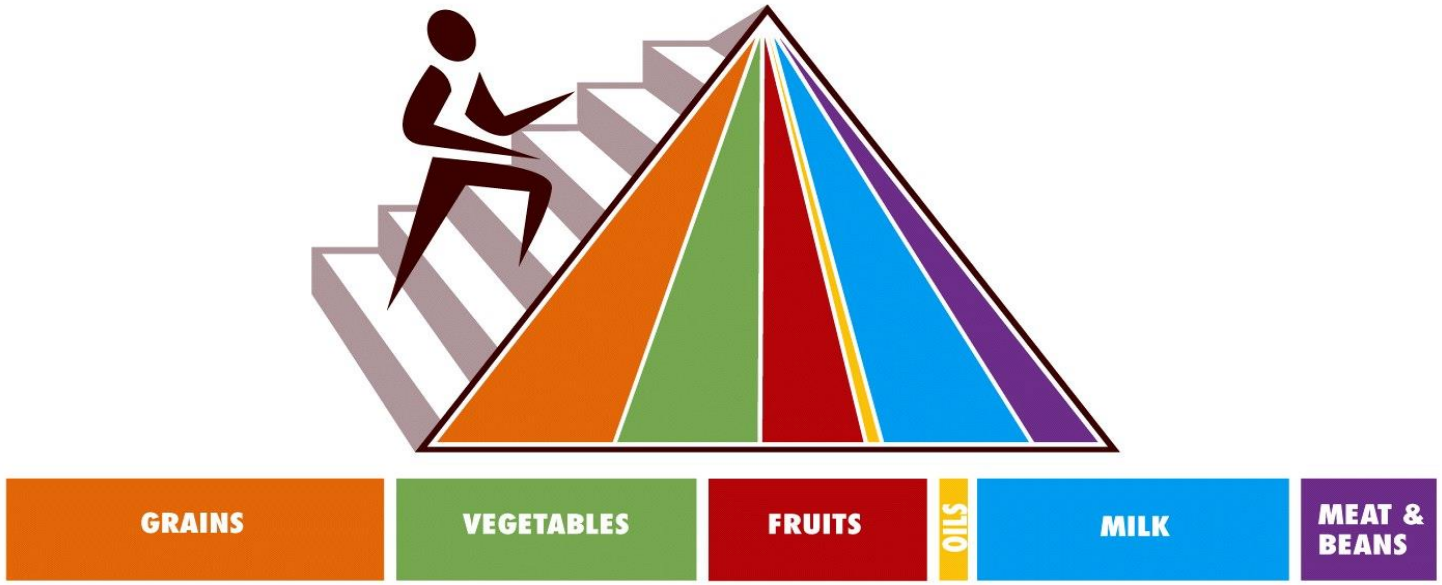
Primary Care Paramedicine

Module: 17

Section: 01b

Metabolism and Nutrition

- Metabolic reactions contribute to homeostasis by harvesting chemical energy from consumed nutrients to contribute to the body's growth, repair, and normal functioning

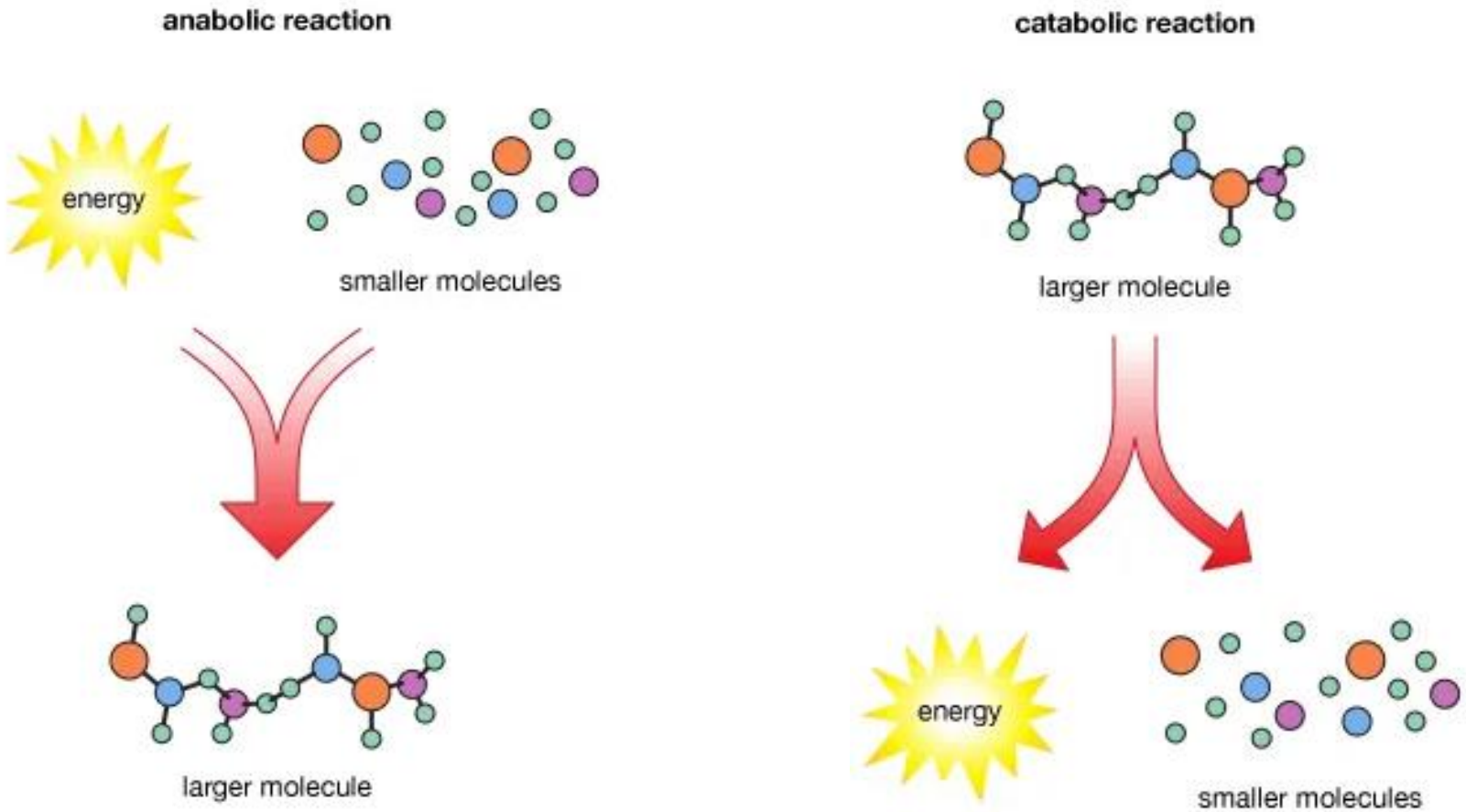


Definitions

- Metabolism
  - Includes all the chemical reactions in the body, including the utilization of nutrients
- Nutrition
  - The acquisition, assimilation and utilization of nutrients

Metabolism and Nutrition

- Metabolism denotes the sum of all body chemical reactions



Metabolism and Nutrition

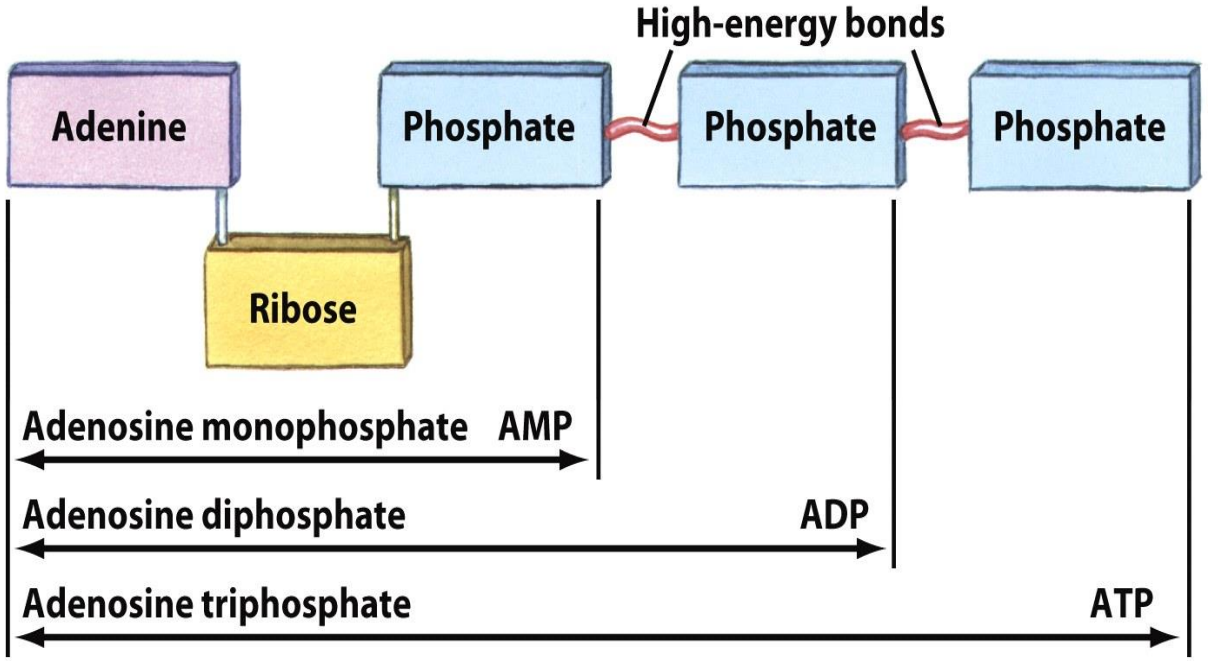
- Metabolism is an energy-balancing act between catabolic reactions and anabolic reactions
  - The molecule that participates most often in energy exchanges in living cells is ATP (adenosine triphosphate), which couples energy releasing catabolic reactions to energy requiring anabolic reactions
    - The exact reactions that occur depend on which enzymes are active in a particular cell at a particular time

Metabolism and Nutrition

- A nutrient is a “food or liquid that supplies the body’s metabolic needs”.
- Nutrients include:
  - A necessary chemical (such as Na^+ and other minerals)
  - A substance that provides energy (such as lipids or carbohydrates like glucose)
  - Something that helps in growth of new body components (such as vitamins)
  - A substance that repairs or maintains body functions (such as proteins, or amino acids to make proteins)

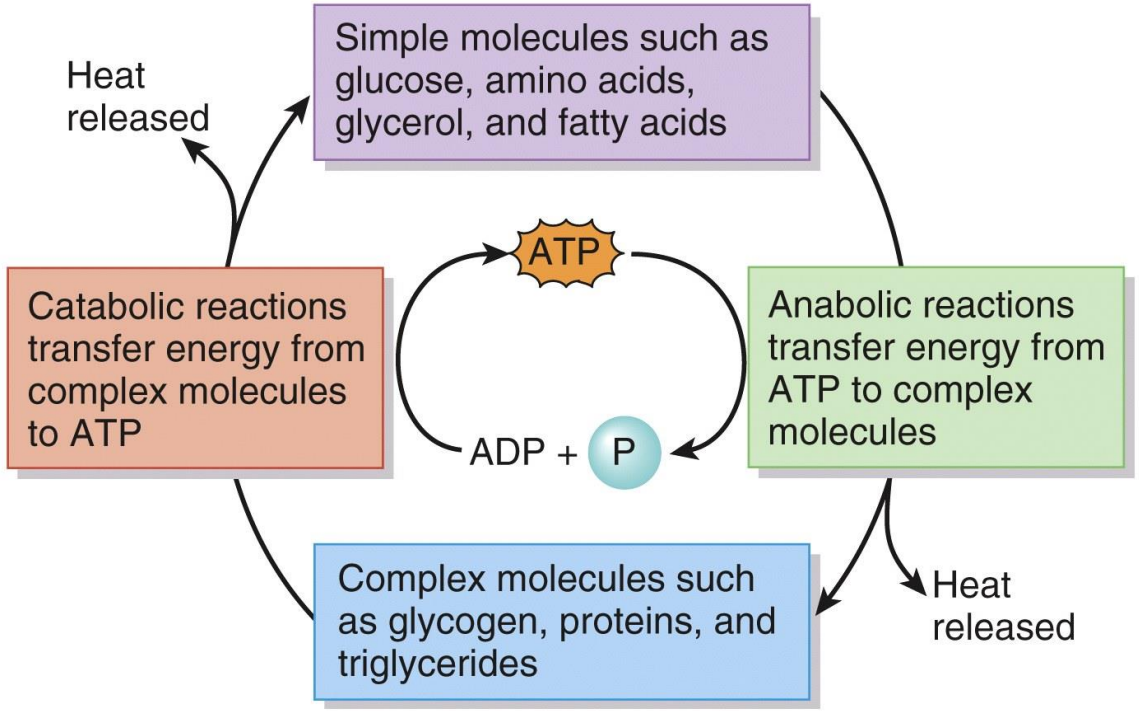
ATP

- Catabolic reactions transfer energy into the “high-energy” phosphate bonds of ATP, where it can be released quickly and easily



ATP

- ATP temporarily stores and transfers energy given off in catabolic reactions and transfers it to anabolic reactions that require energy.



REDOX Reactions

- Chemical reactions in which a pair of electrons are exchanged as a means of transferring energy are called REDOX reactions
  - Oxidation is the removal of electrons
  - Reduction is the addition of electrons

Remember:

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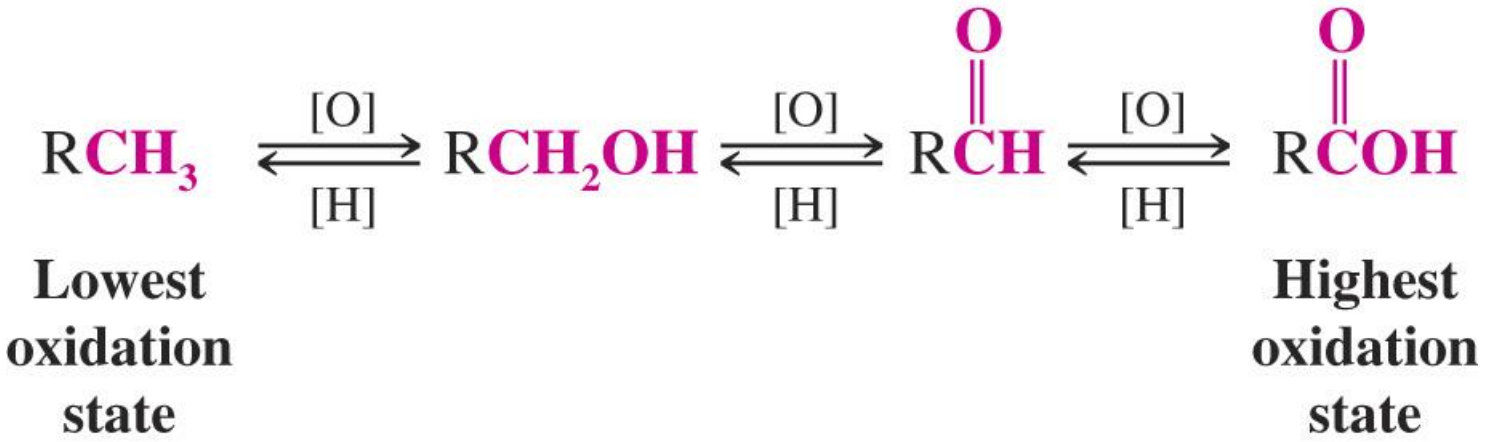
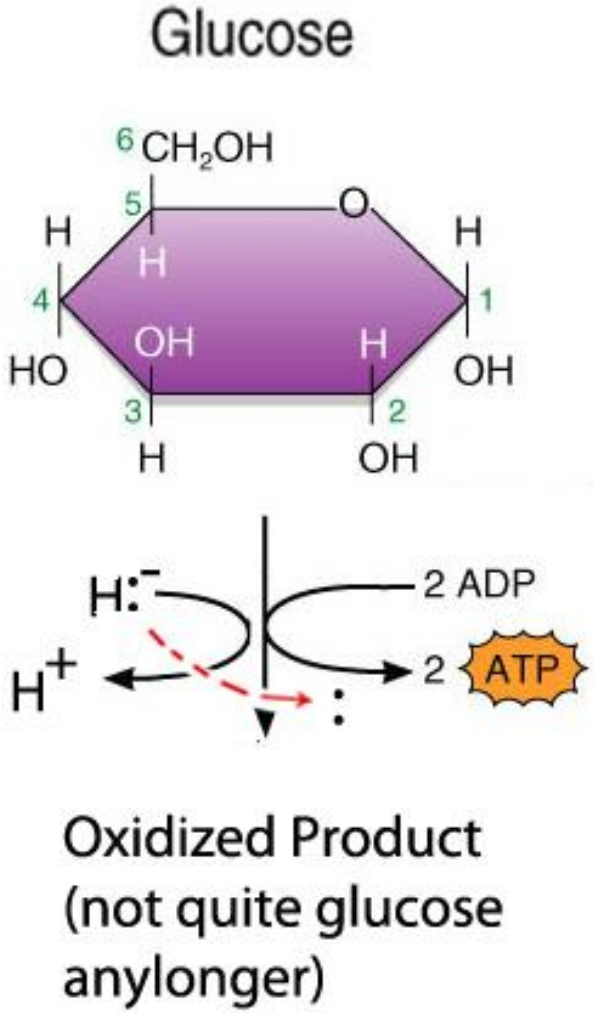


REDOX Reactions

- Mainly we will be looking at the oxidation of glucose by "burning it" in cells through a series of electron transfers to ultimately yield water, carbon dioxide, and ATP
  - Oxidation of glucose leaves the product with a decrease in potential energy

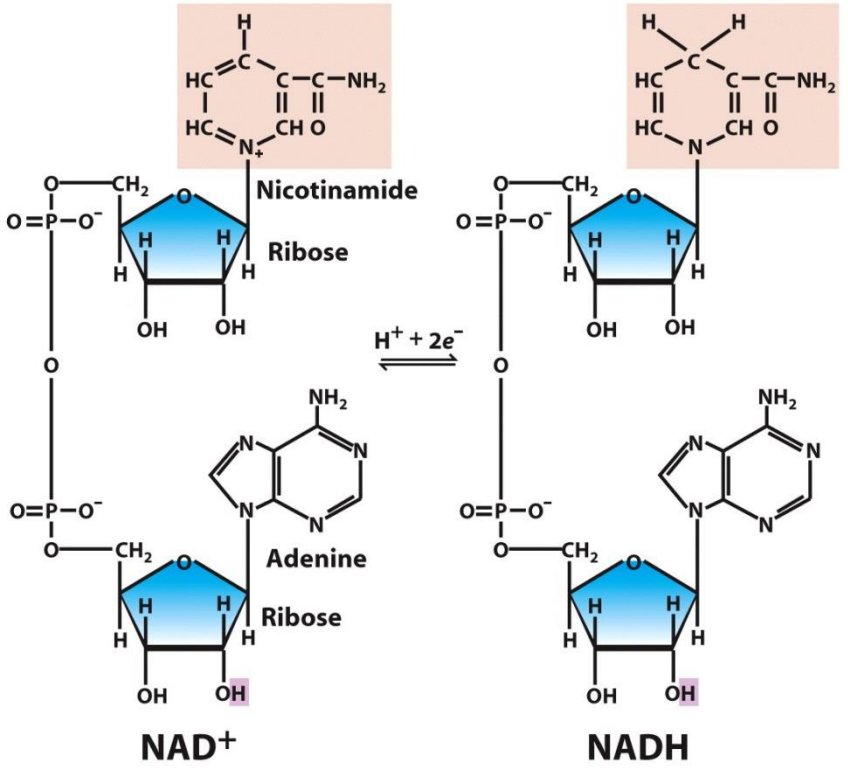
REDOX Reactions

- Many steps in burning glucose require oxidation via a dehydrogenation (REDOX) reaction
  - The liberated electron pair are lost along with an hydrogen atom – this is called a hydride ion, and is represented along with it's electron pair (H^-)
  - If it is represented without the electron pair [H], the electrons and the negative charge are implied



REDOX Reactions

- Instead of transferring electrons directly to ADP to make ATP, they are often transferred to intermediate coenzymes like nicotinamide adenine dinucleotide (NAD) and flavin adenine dinucleotide (FAD) – both are B vitamins



NAD^+ reduced by an electron pair to NADH

Digestion

- Mechanical
  - Mastication
  - Deglutition
  - Peristalsis and segmentation

Digestion

- Gastric Motility
  - Food stored in stomach is mixed with gastric juices to form chyme
  - Ejected into duodenum
  - Controlled by hormonal and nervous systems
    - Fats and nutrients stimulate the release of gastric inhibitory peptide (GIP) into blood
    - When this reaches the wall of stomach inhibits peristalsis
    - Nervous system (via vagus) inhibit peristalsis due to acid presence or distention

Digestion

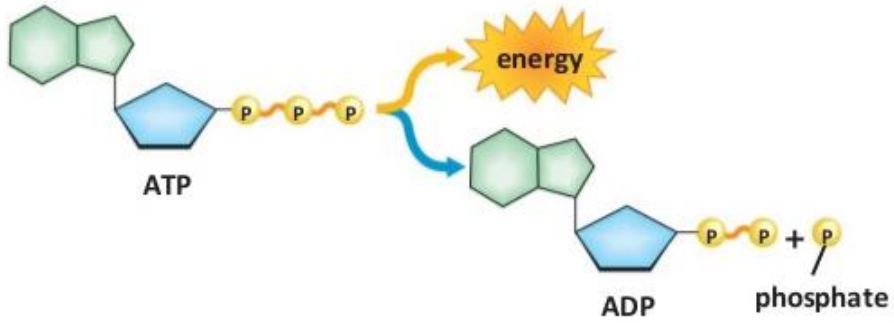
- Intestine Motility
  - Segmentation
    - Mixes chyme with secretions from pancreas, liver and mucosa
  - Peristalsis
    - Regulated by intrinsic stretch reflexes
    - May also be stimulated by cholecystokinin-pancreozymin (CCK) secreted by the mucosa when chyme is present

Digestion

- Chemical Digestion
  - All changes in chemical composition
  - Uses digestive enzymes to catalyze reactions

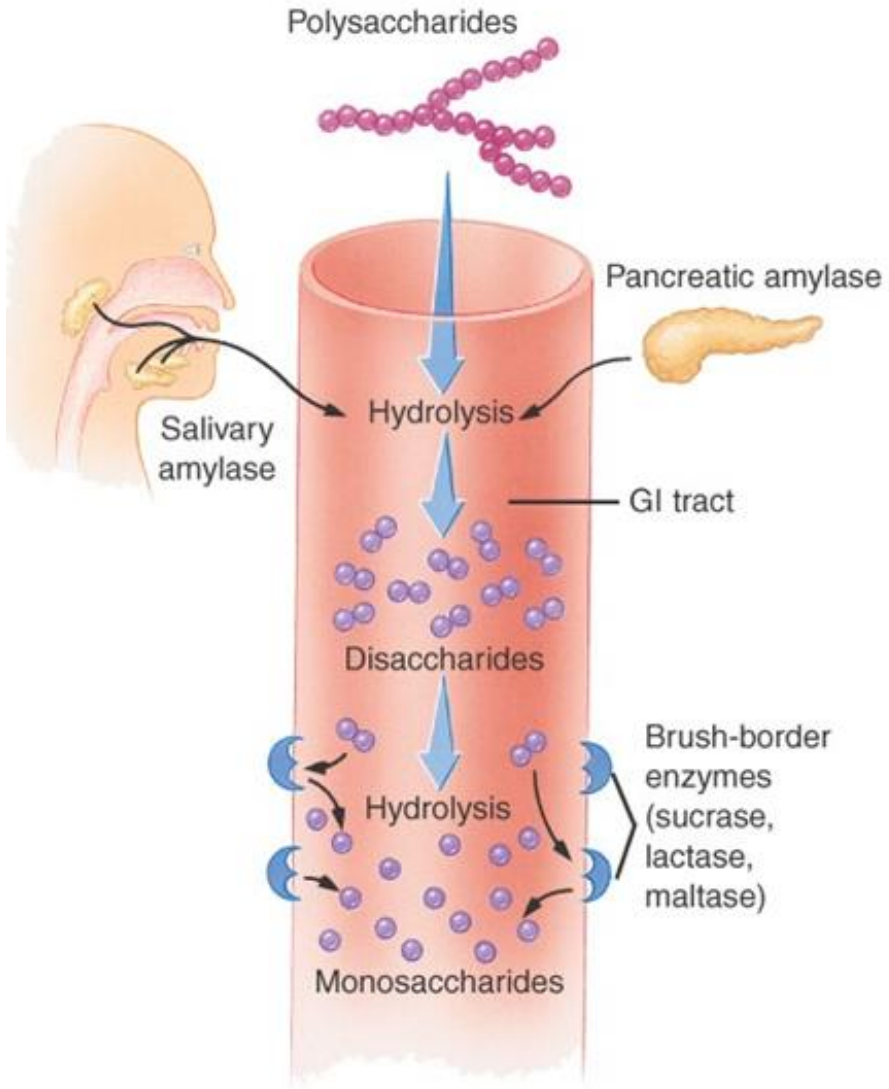
Energy From Foods

- Nutrients are “burned” in the cell as it is used during cellular respiration
- These reactions release energy
- Some is stored as ATP
- Remainder given off as heat



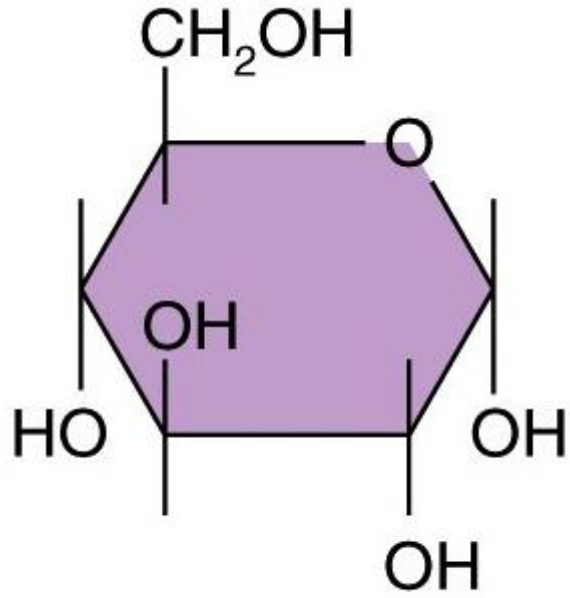
ATP → ADP + P + Energy

Carbohydrates



Carbohydrate Metabolism

- Glucose is the body's preferred source of fuel
  - During digestion, polysaccharides and disaccharides are hydrolyzed into the monosaccharides
    - Glucose (80%), fructose and galactose
  - These three monosaccharides are absorbed into the villi of the small intestine and carried to the liver
    - Hepatocytes convert galactose and fructose to glucose



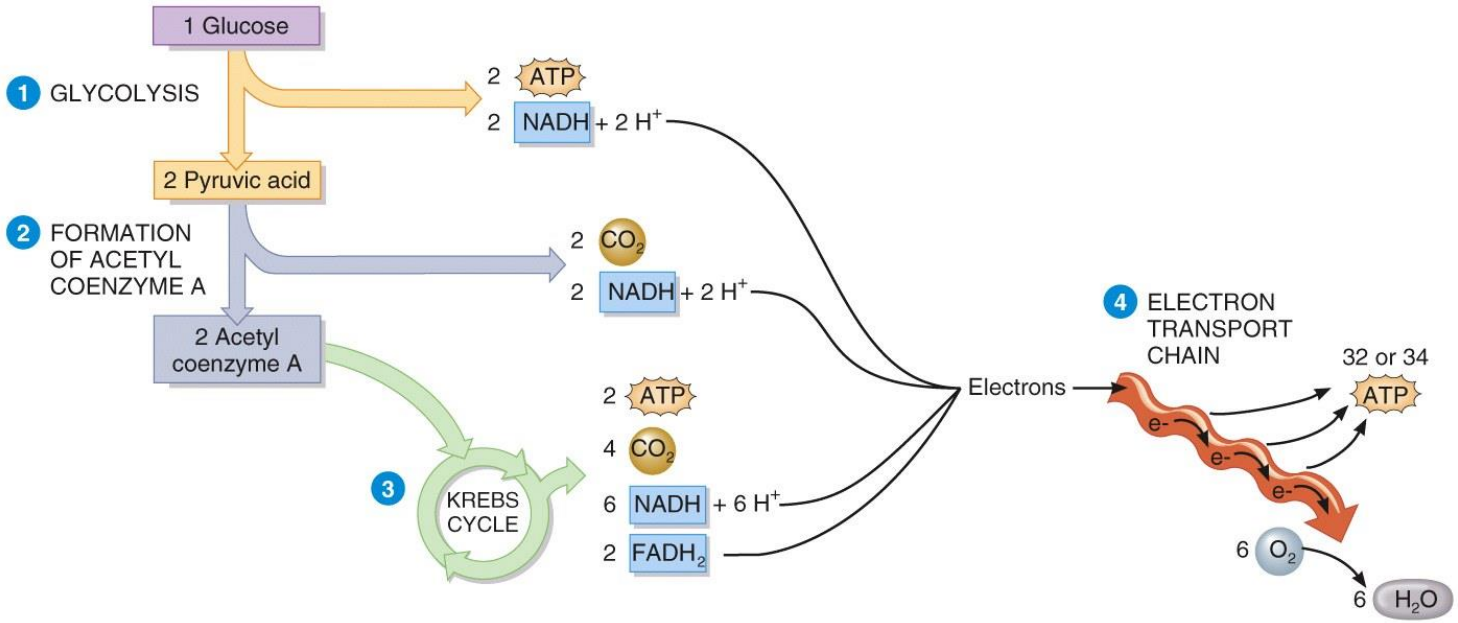
glucose

Carbohydrate Metabolism

- The oxidation of glucose to form ATP…

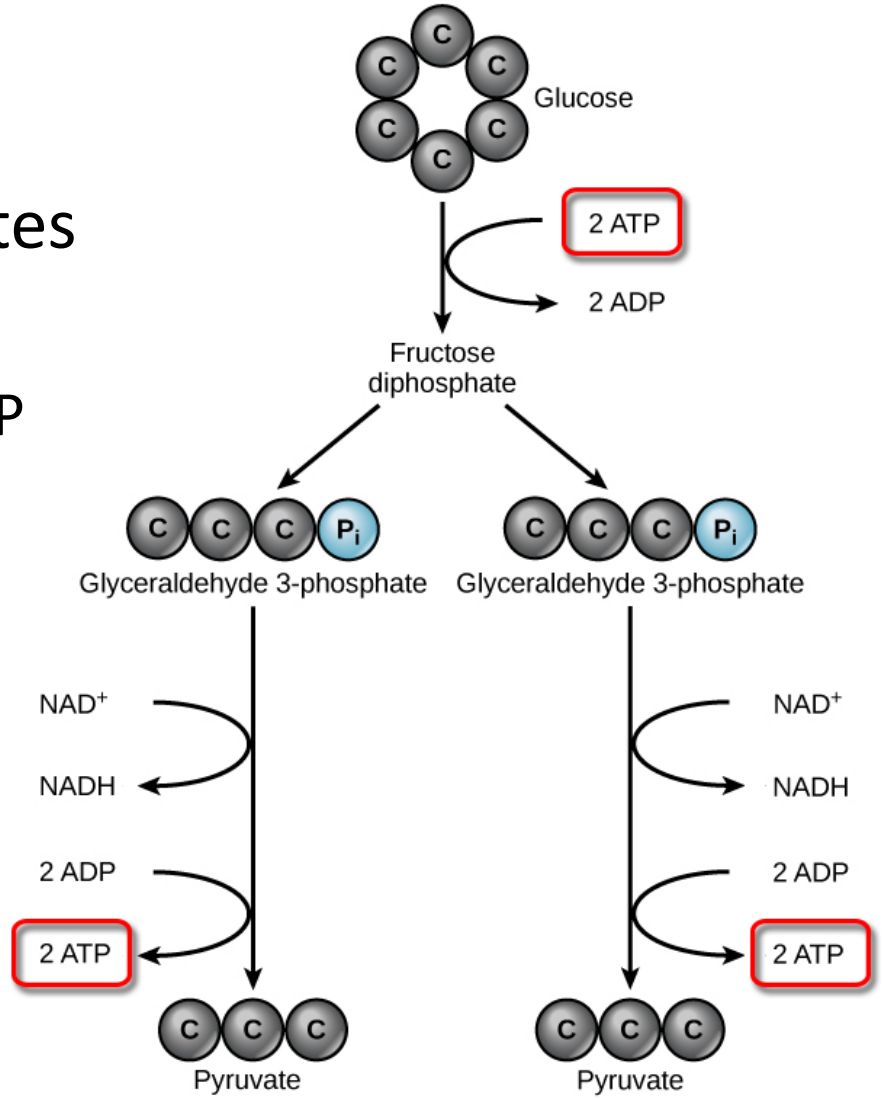
$$\text{Glucose } (C_6H_{12}O_6) + O_2 \longrightarrow CO_2 + H_2O + ATP$$

- … is known as “Cellular Respiration” and occurs in 4 steps



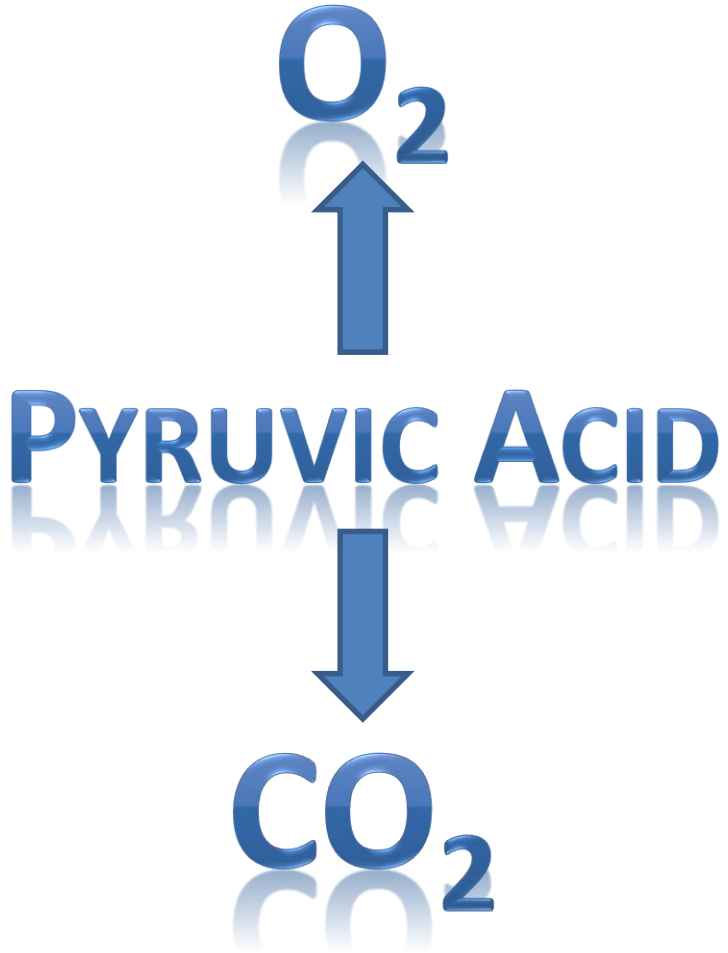
Cellular Respiration

- Step 1 (Glycolysis):
  - 1 Glucose molecule is oxidized into 2 pyruvates
    - Initial reaction requires 2 ATP to begin
    - The process of oxidation ends up producing 4 ATP and 2 NADH
  - This occurs in the cytoplasm of the cell



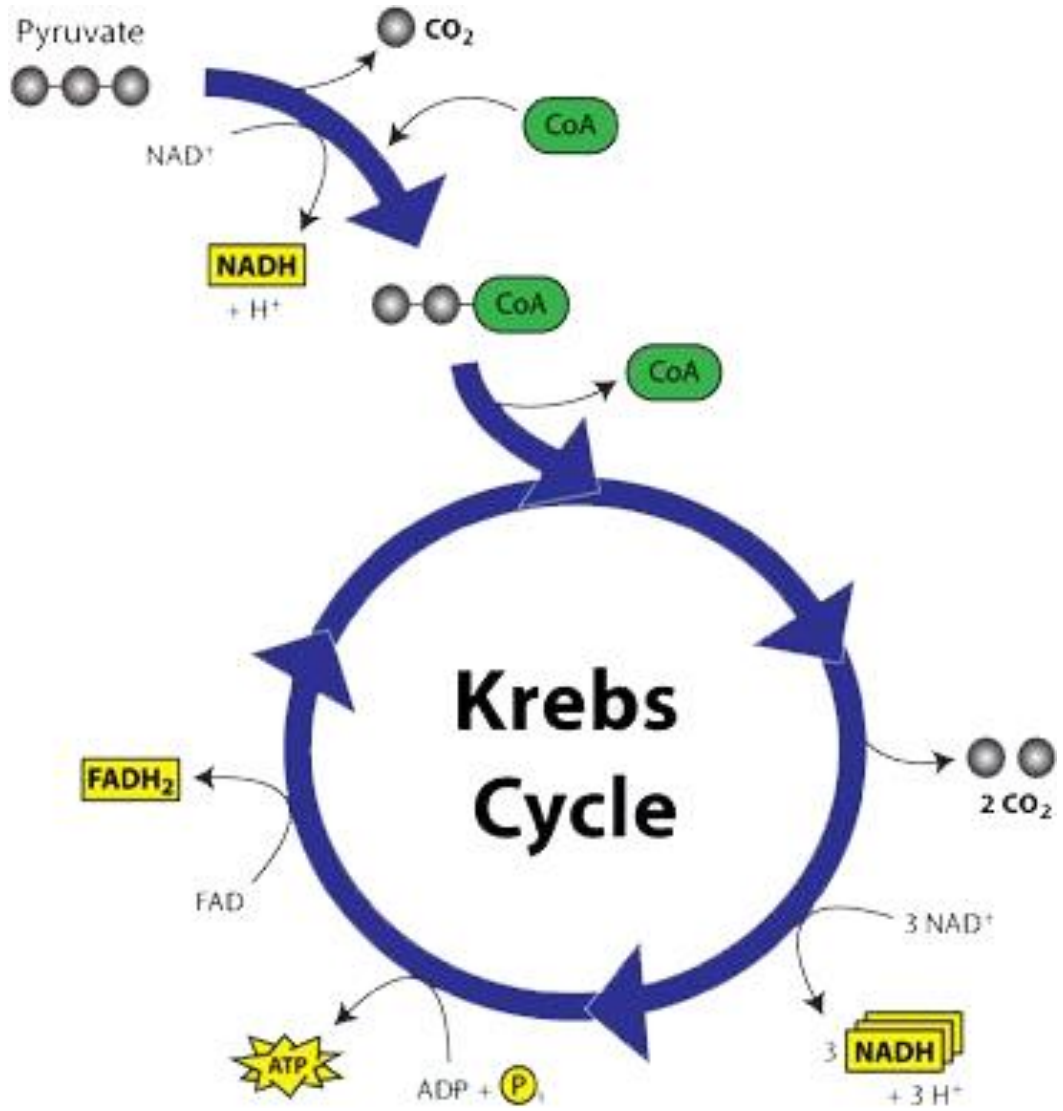
Cellular Respiration

- Step 2:
  - Occurs based on the presence of oxygen or not
  - If sufficient oxygen is present in the cell acetyl-CoA will be formed and cellular respiration continues into the Kreb Cycle
  - If not, lactic acid is formed and the “debt” will need to be repaid at some future time



Cellular Respiration

- Step 3 (Kreb Cycle or Citric Acid Cycle):
  - Pyruvate diffuses into mitochondria
  - REDOX reactions occur breaking off key components of the acetyl-CoA
    - CO_2
    - NADH
    - $FADH_2$



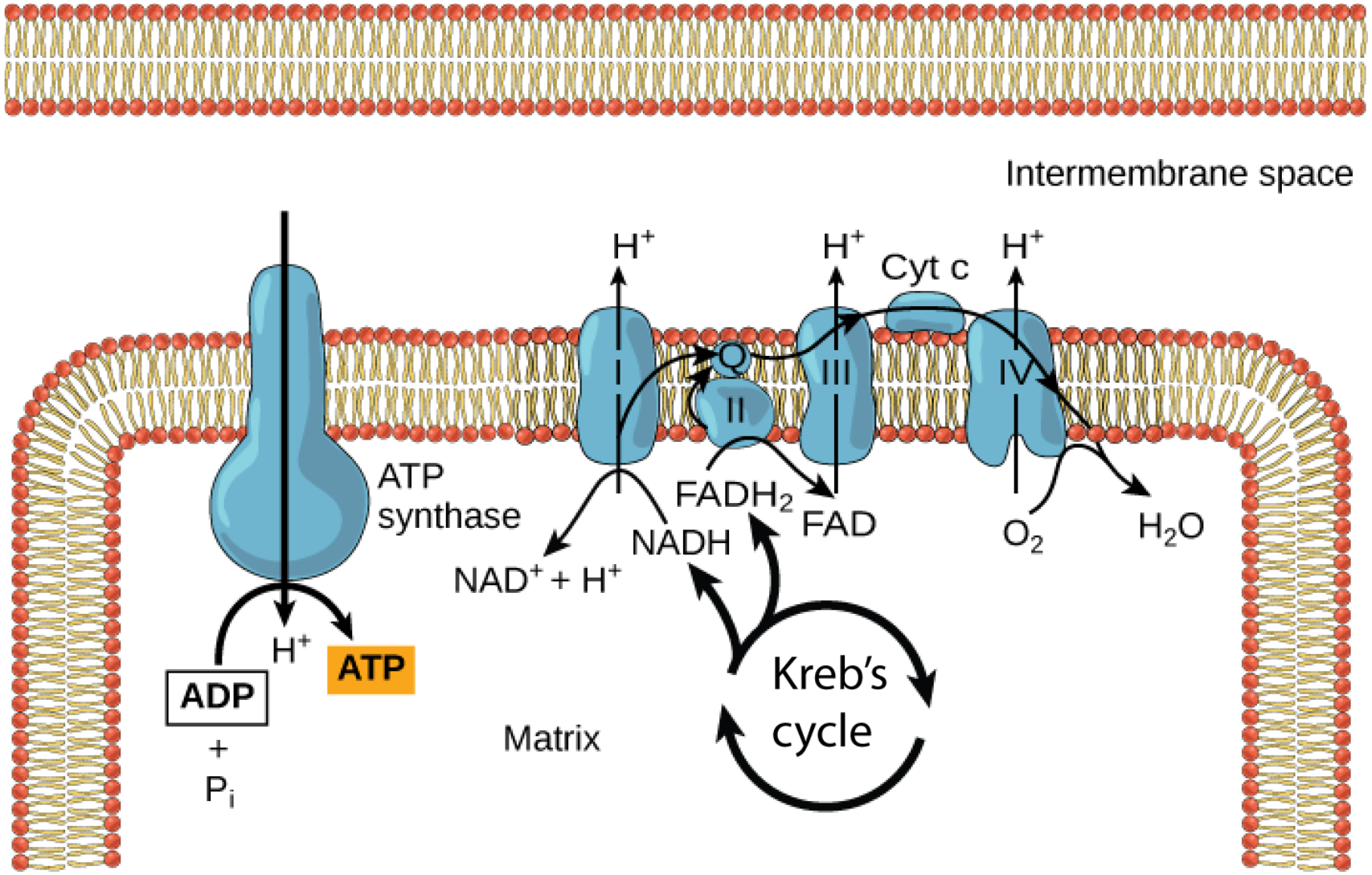
Kreb Cycle

- The process of cellular respiration to this point has yielded some energy but not all:
  - Glycolysis
    - 2 ATP (net)
    - 2 NADH
  - Kreb Cycle
    - ATP 1 X 2 = 2
    - NADH 4 X 2 = 8
    - $FADH_2$ 1 X 2 = 2
- In order to achieve full energy the products have to enter the electron transport chain

Cellular Respiration

- Step 4 (electron transport chain):
  - A system for extracting the energy stored in the NADH and $FADH_2$
  - Occurs within the mitochondria
    - Each NADH will produce 3 ATP
    - Each $FADH_2$ will produce 2 ATP

Cellular Respiration



Kreb Cycle

- The process of cellular respiration to this point has yielded 38 ATP molecules:
  - Glycolysis
    - ATP (net) (2)
  - Kreb Cycle
    - ATP (2)
  - Electron transport chain (NADH and $FADH_2$ that have been produced through step 1 and 2 and converted to ATP)
    - NADH → ATP (30)
    - FADH → ATP (4)

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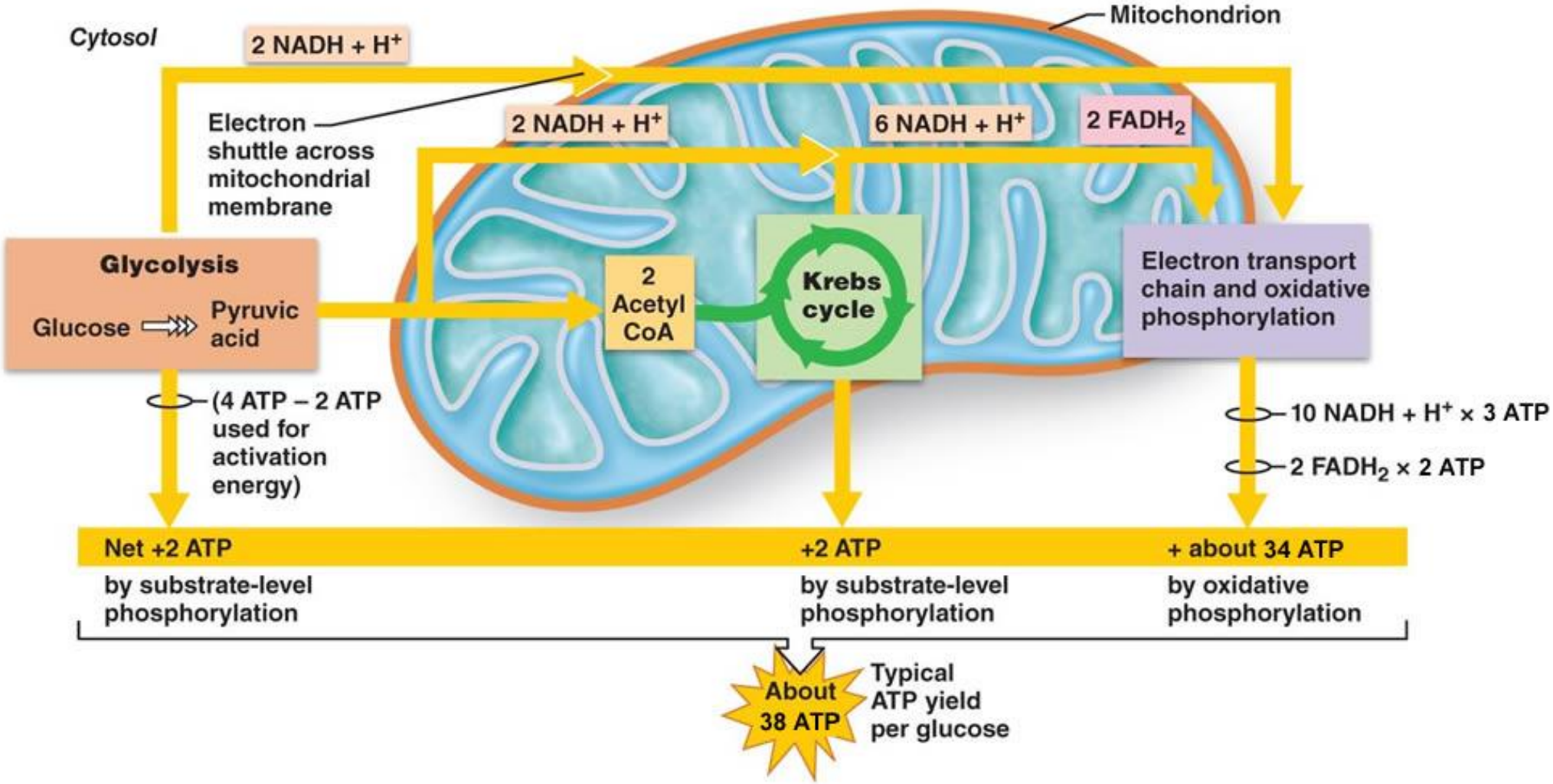
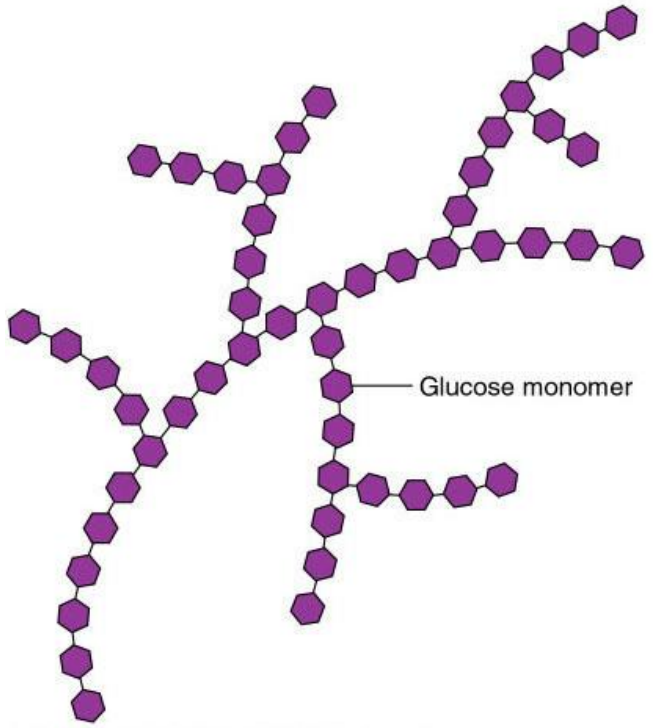
Summary of Cellular Respiration



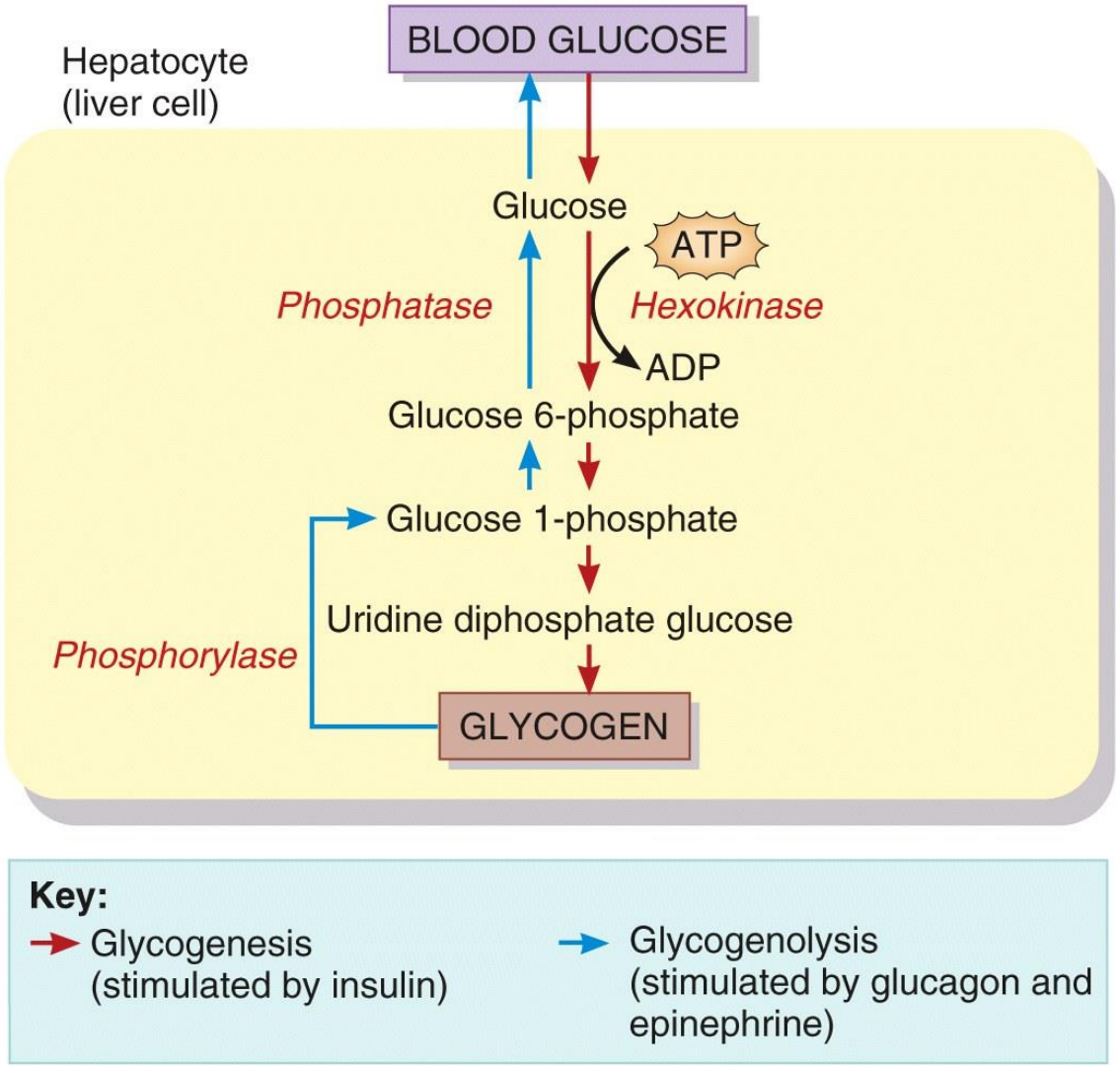
Glucose Storage

- If glucose is not needed immediately for ATP production
  - Combined with many other molecules of glucose to form glycogen (polysaccharide) and stored in the liver
  - This process is called Glycogenesis



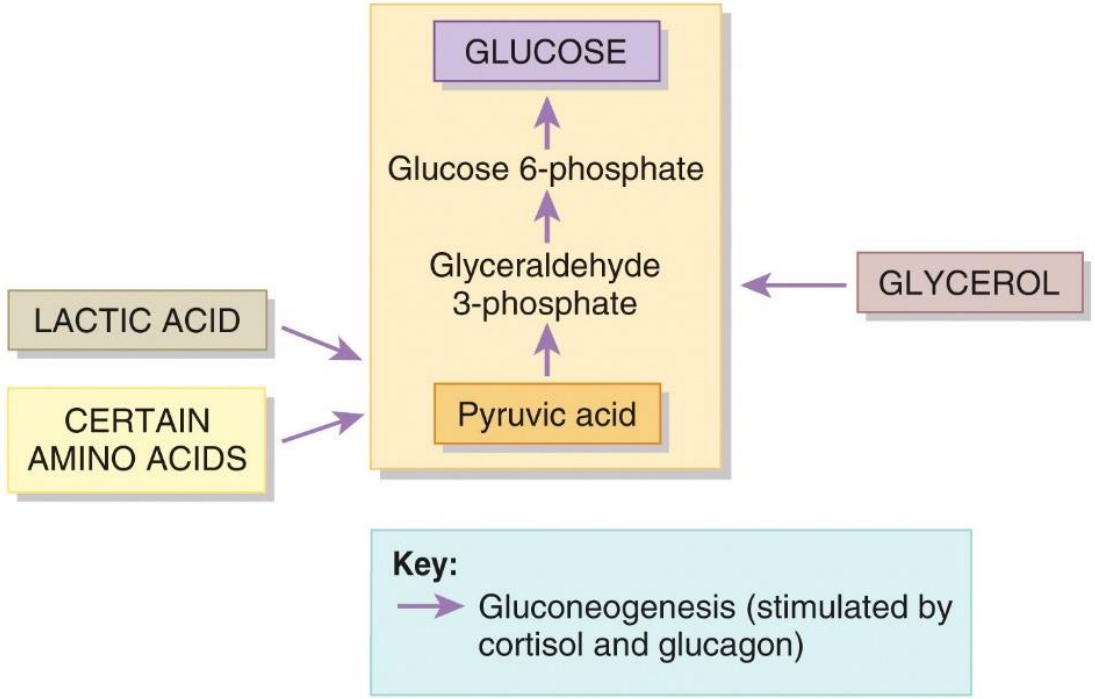
Glucose Release

- Glycogenolysis:
  - When body activities require ATP
  - Stored glycogen is broken down into glucose and released into the blood

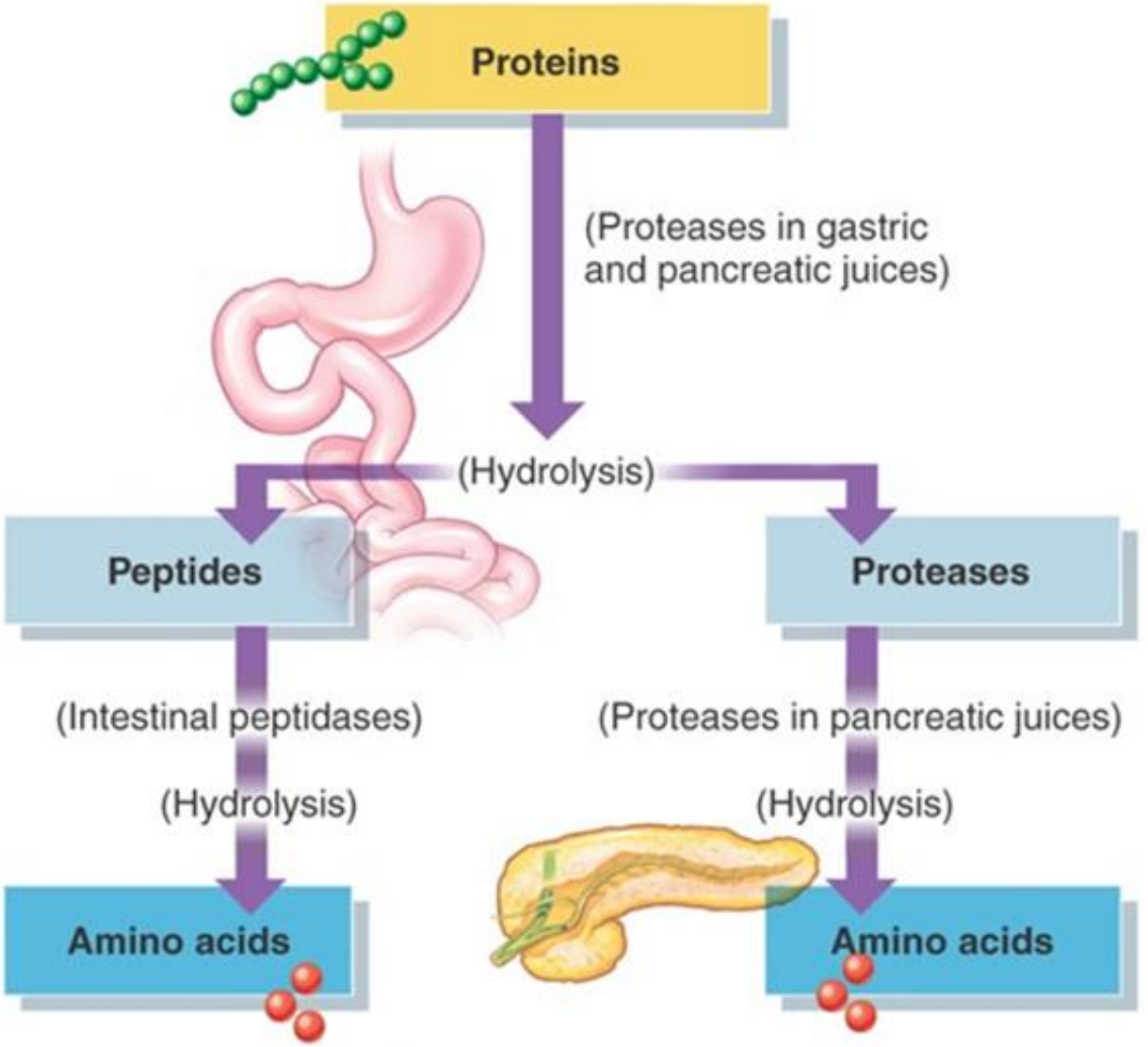


Making Glucose

- Gluconeogenesis:
  - The process of forming “new” glucose or its metabolites from fat or protein (from non-carbohydrate sources)
  - Can still yield ATP but also has harmful by-products
    - Keytonic Acid



Proteins


Proteins
(Proteases in gastric and pancreatic juices)
(Hydrolysis)
Peptides
Proteases
(Intestinal peptidases)
(Proteases in pancreatic juices)
(Hydrolysis)
(Hydrolysis)
Amino acids
Amino acids

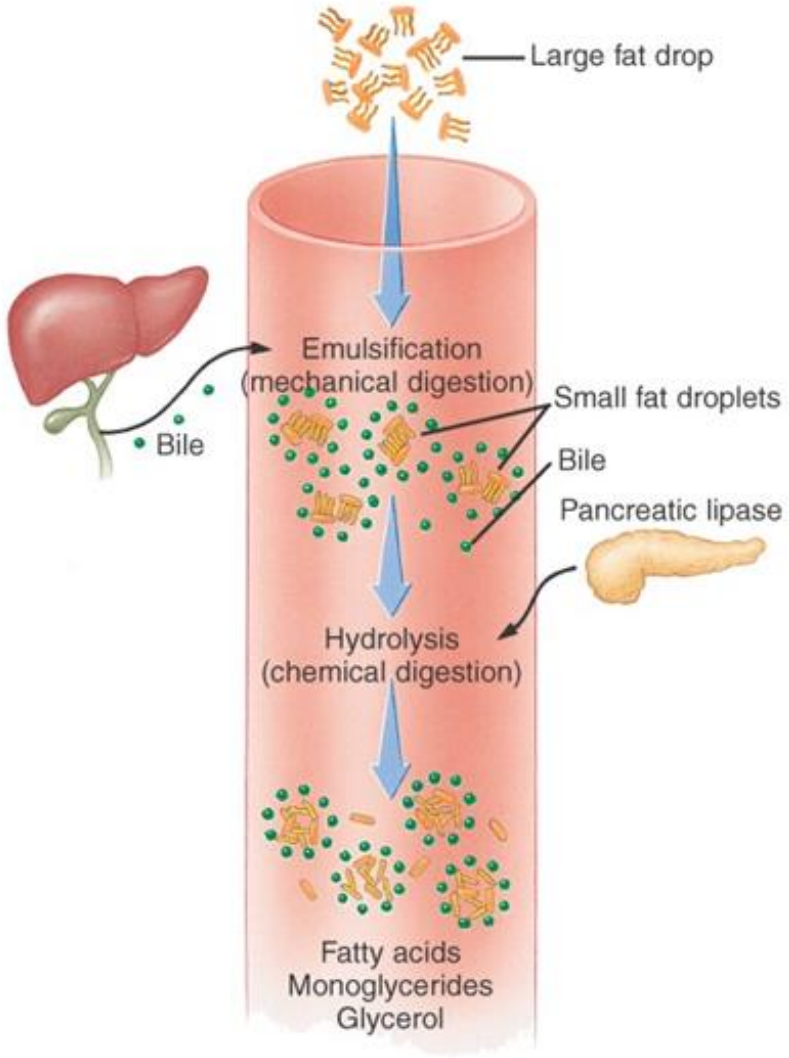
Protein Metabolism

- Proteins are not a primary source of energy; and unlike lipids and sugars, proteins are not stored
  - Yet a certain amount of protein catabolism occurs in the body each day as proteins from worn-out cells are broken down into amino acids
    - Some amino acids are converted into other amino acids, peptide bonds are re-formed, and new proteins are synthesized as part of the recycling process

Protein Metabolism

- In protein synthesis, transamination refers to the transfer of an amino group (NH_2) to pyruvic acid or another acid in the Krebs cycle to form an amino acid
- In protein catabolism, deamination refers to the removal of an amino group leaving the carbons of a carboxylic acid to be used to make ATP
  - Essential amino acids are the 10 amino acids that can't be synthesized by the body
  - Non-essential amino acids are the others that can be synthesized by the body

Fats

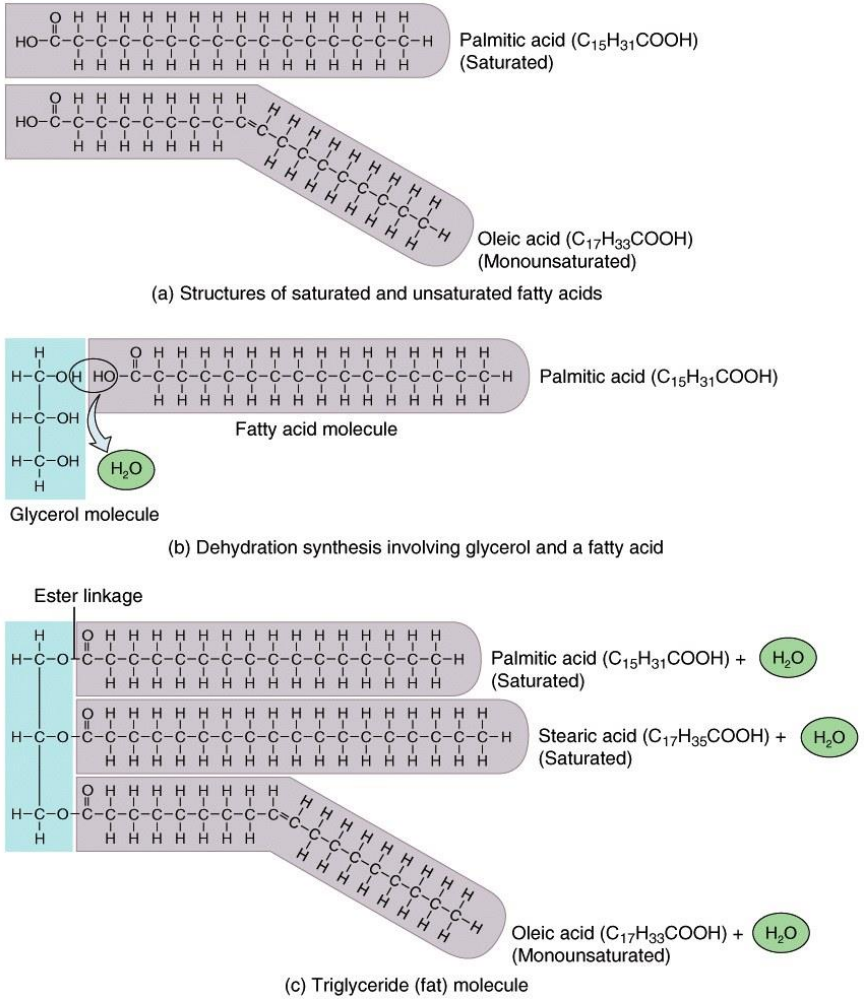

Large fat drop
Emulsification
(mechanical digestion)
Small fat droplets
Bile
Bile
Pancreatic lipase
Hydrolysis
(chemical digestion)
Fatty acids
Monoglycerides
Glycerol

Lipids

- Although the word “fat” is commonly used to mean lipids, fats are, in fact, just one subgroup of lipids called triglycerides
  - Other lipids include waxes, sterols (steroid hormones), fat-soluble vitamins (such as vitamins A, D, E and K), monoglycerides, diglycerides, phospholipids, and others
  - For metabolic purposes, triglycerides are a condensed form of useable energy

Lipids

- All triglycerides are composed of a glycerol backbone combined with 3 fatty acids
  - Fatty acids are anywhere from 4 to 24 carbons long, and they may have all single carbon-carbon bonds (saturated), or some double or triple bonds (making them unsaturated)

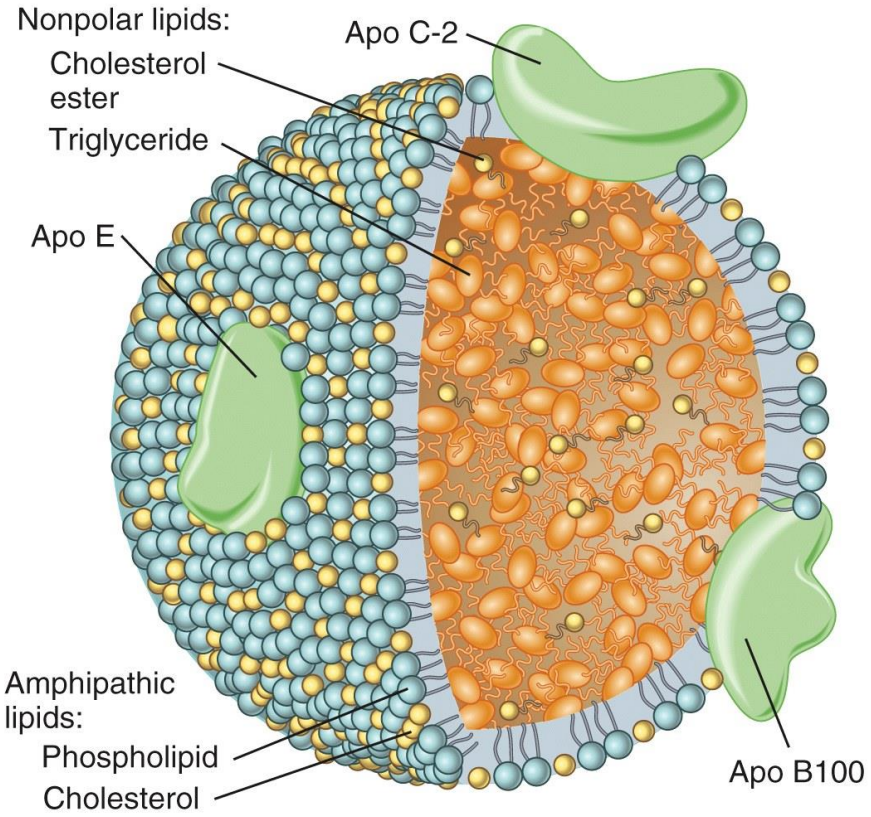


Lipids

- Triglycerides are nonpolar, and therefore very hydrophobic molecules
  - To be transported in watery blood, they must first be made more water-soluble by combining them with carrier molecules called lipoproteins (produced in the liver)
  - Lipoproteins vary in their size, density, and the amount of cholesterol and protein in their make-up

Lipoproteins

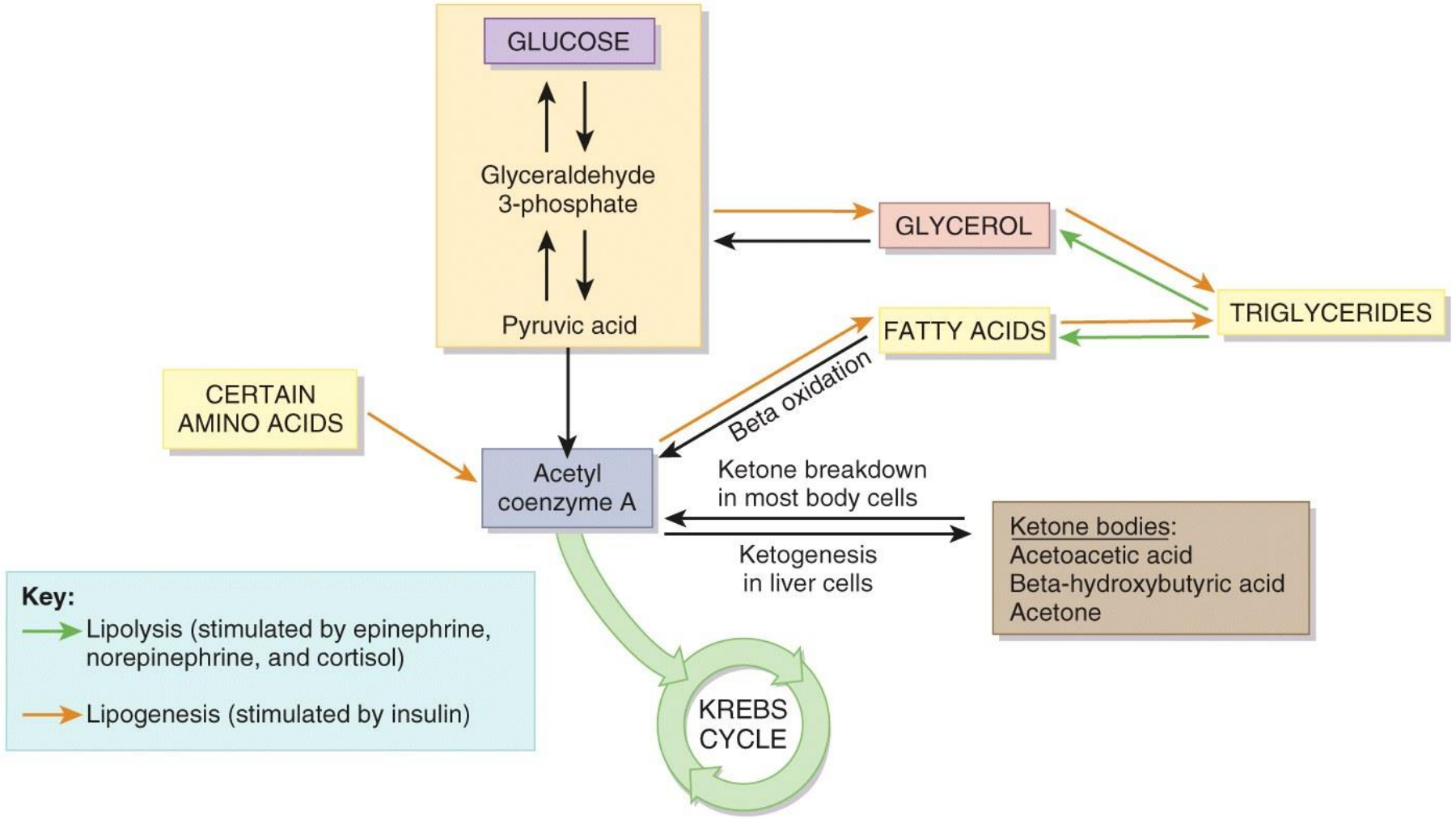
- In general, however, all lipoproteins have:
  - An outer shell that is made hydrophilic due to polar proteins (plus amphipathic phospholipid and cholesterol)
  - An inner core that is hydrophobic - a place where the triglycerides are transported



Lipid Metabolism

- Lipogenesis means fat synthesis
    - If the body has no immediate needs, lipids are stored in adipose tissue
- Lipolysis refers to the oxidation (catabolism) of lipids to yield glucose (which then yields ATP)
  - Results in ketoacids being formed (keytone bodies) that must be eliminated by the kidney to maintain homeostasis
  - Ketogenesis is normal but an excess results in a metabolic acidosis

Lipid Metabolism



Metabolic Adaptations

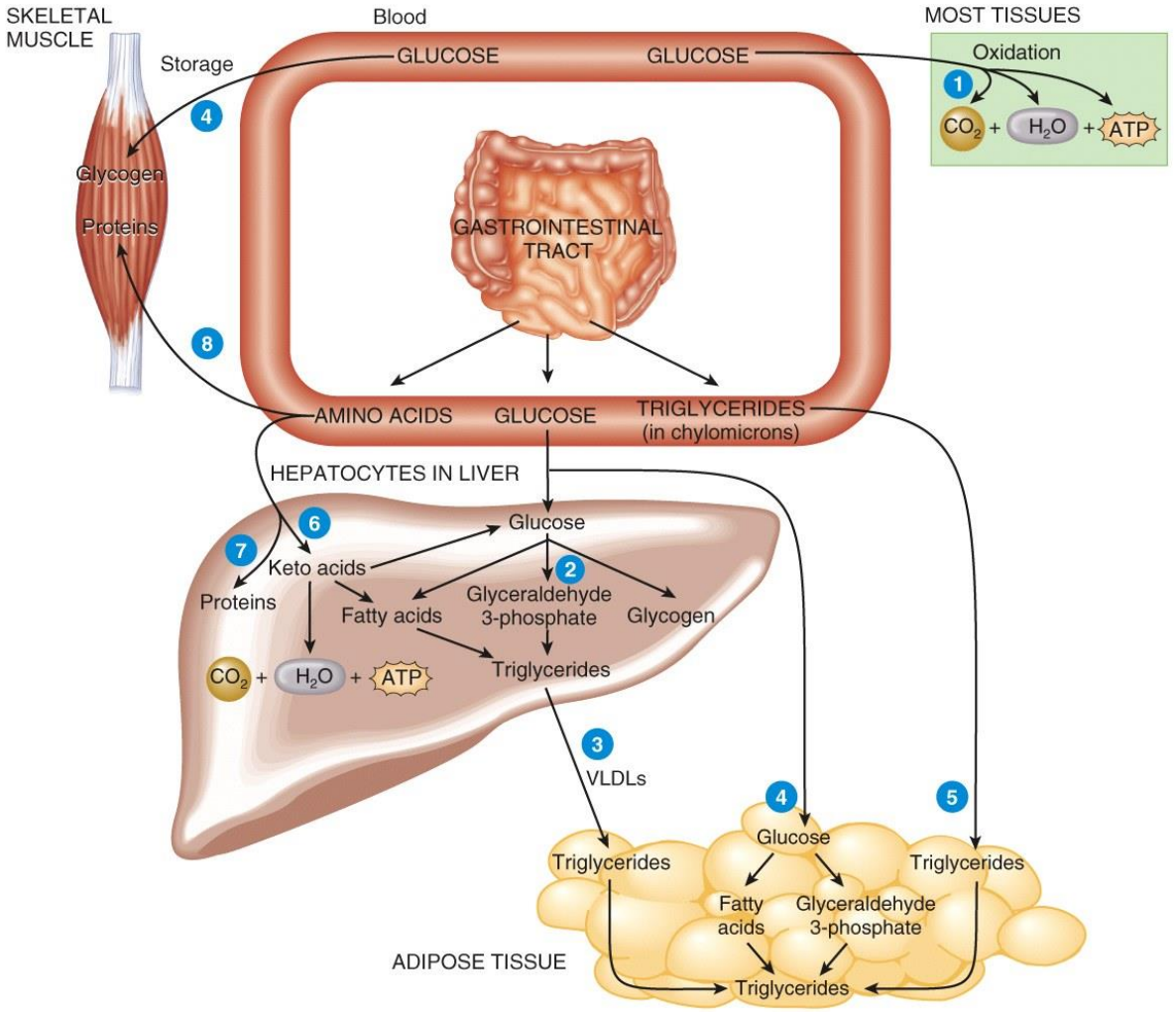
- During the absorptive state ingested nutrients enter the blood stream and glucose is readily available
- During the post-absorptive state absorption of nutrients from GI tract is complete and energy needs must be met by fuels in the body
  - Maintaining a steady blood glucose is critical because the nervous system and red blood cells depend solely on glucose as an energy source
    - The effects of insulin dominate

The Absorptive State

- Soon after a meal glucose, amino acids, and lipid nutrients enter the blood. Triglycerides enter the blood carried in large lipoproteins called chylomicrons. There are 2 metabolic hallmarks of this state:
  - Glucose is oxidized to produce ATP in all body cells
  - Any excess fuel molecules are stored in hepatocytes, adipocytes, and skeletal muscle cells
- Pancreatic beta cells begin to release insulin to promote entry of glucose and amino acids into cells

The Absorptive State

- During the absorptive state, most body cells are concerned with producing ATP by oxidizing glucose



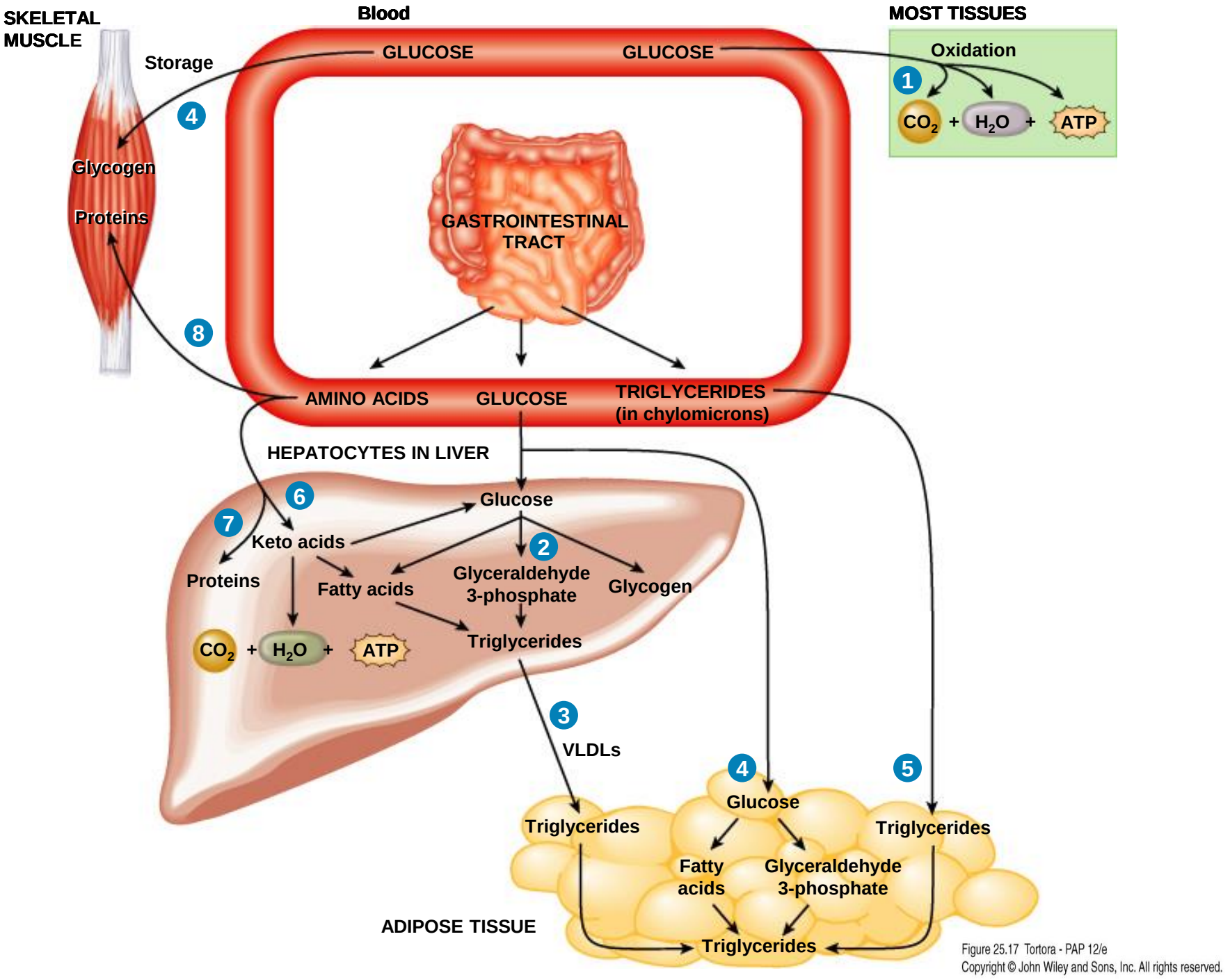


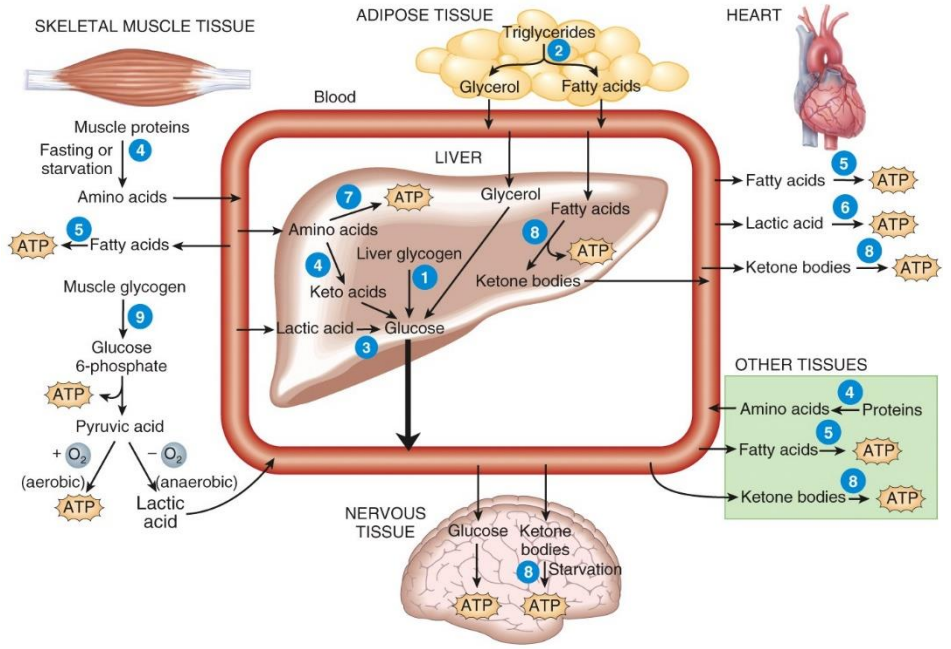
Figure 25.17 Tortora - PAP 12/e

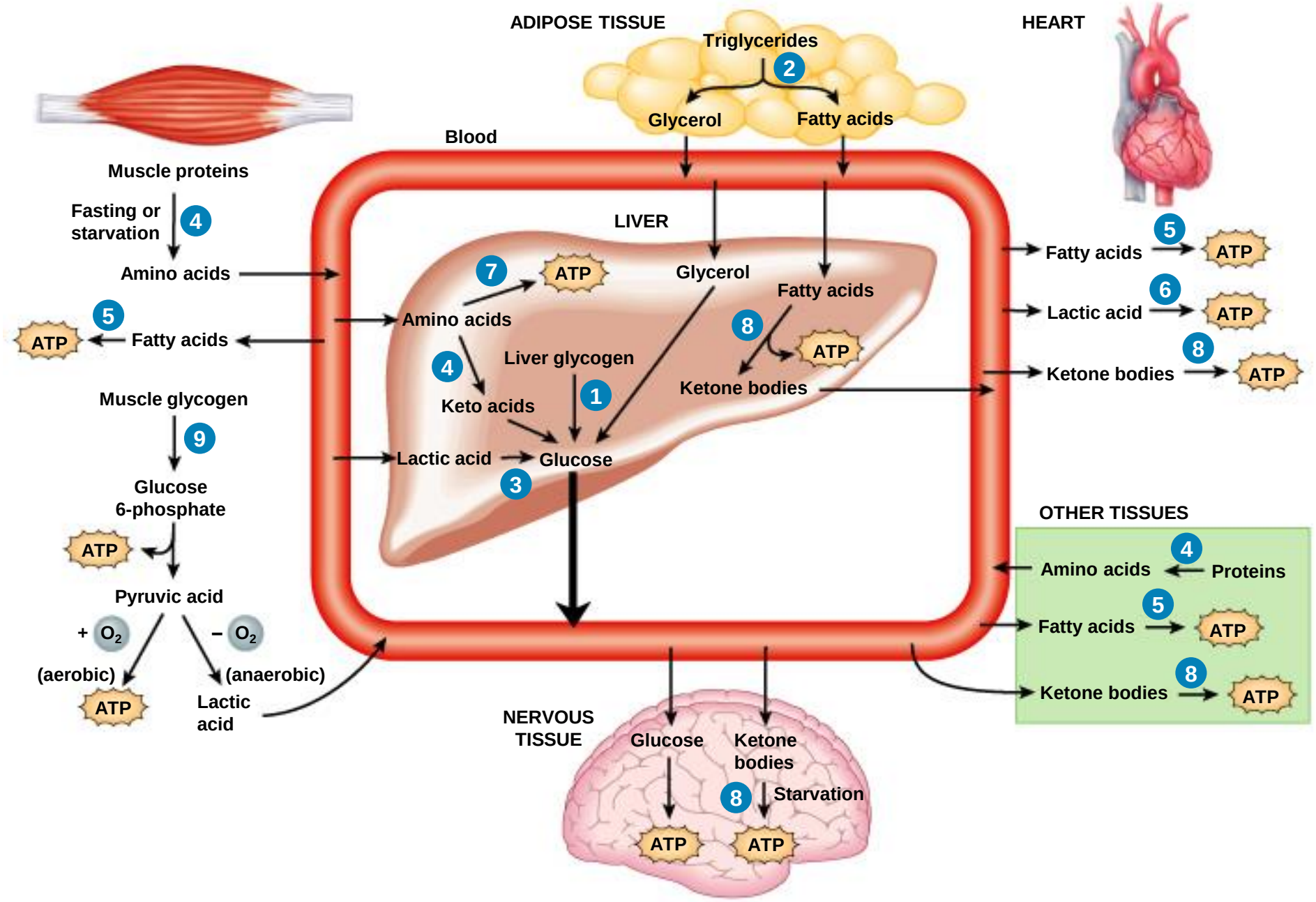
The Post- Absorptive State

- About 4 hours after the last meal absorption in the small intestine is nearly complete and blood glucose levels start to fall. The main metabolic challenge at this point is to maintain normal blood glucose levels
  - As blood glucose levels decline, insulin secretion falls and glucagon secretion increases
    - Blood glucose levels are sustained by the breakdown of liver glycogen, lipolysis, and gluconeogenesis using lactic acid and/or amino acids

The Post-Absorptive State

- The process is supported by sympathetic nerve endings that release norepinephrine and by the adrenal medulla that releases epinephrine and norepinephrine directly into the blood




ADIPOSE TISSUE
Triglycerides
2
Glycerol
Fatty acids
HEART
Blood
Muscle proteins
Fasting or starvation
4
Amino acids
LIVER
7
ATP
Glycerol
Fatty acids
Amino acids
8
ATP
5
ATP
Fatty acids
4
Liver glycogen
Ketone bodies
Keto acids
1
Muscle glycogen
9
Lactic acid
Glucose
3
Glucose 6-phosphate
ATP
Pyruvic acid
+ O2
– O2
(aerobic)
(anaerobic)
ATP
Lactic acid
5
ATP
Fatty acids
6
ATP
Lactic acid
8
ATP
Ketone bodies
OTHER TISSUES
4
Amino acids
Proteins
5
ATP
Fatty acids
8
ATP
Ketone bodies
NERVOUS TISSUE
Glucose
Ketone bodies
8
Starvation
ATP
ATP

Residues

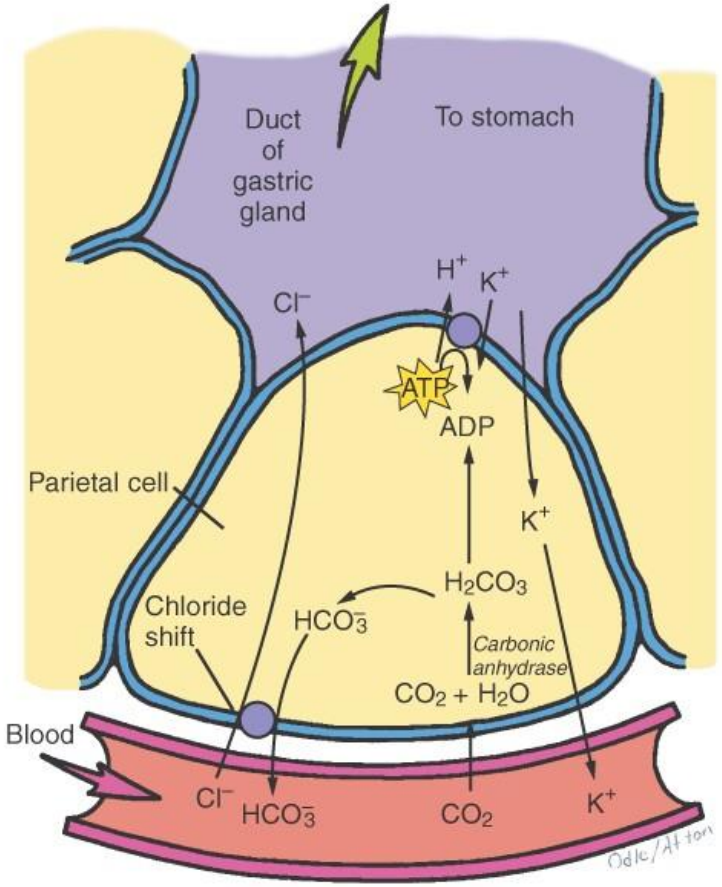
- Components of food that resist digestion
- Eliminated as feces

Secretions

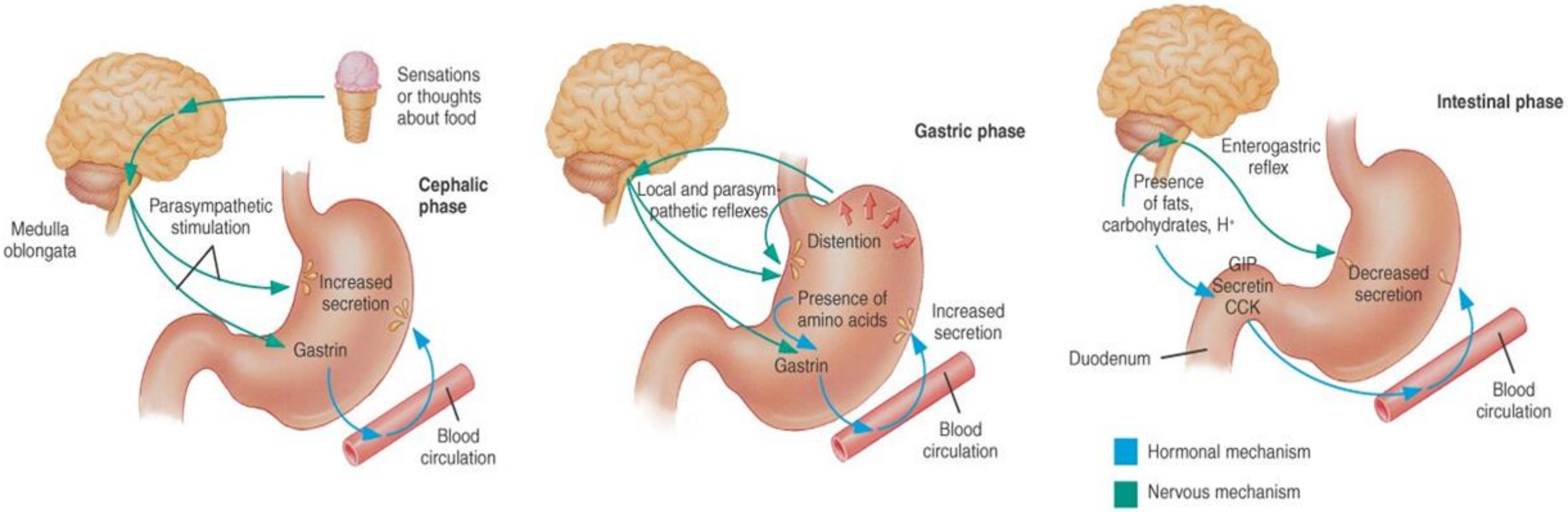
- Saliva
  - Secreted by salivary glands
  - Mostly water
  - Contains
    - Amylase — Carbohydrate digestive enzyme
    - Lipase — Lipid digestive enzyme
    - $NaHCO_3$ — Helps produce alkaline environment for amylase
  - Helps mechanically digest food

Secretions

- Gastric Juice
  - Chief cells
    - Secrete enzymes of gastric juice (pepsinogen)
    - Inactive form of pepsin (breakdown most proteins), activate by HCl
  - Parietal Cells
    - HCl
      - » Kills bacteria and give acidic environment for enzymes
    - Intrinsic Factor
      - » Aids in B12 absorption



Phases of Secretions



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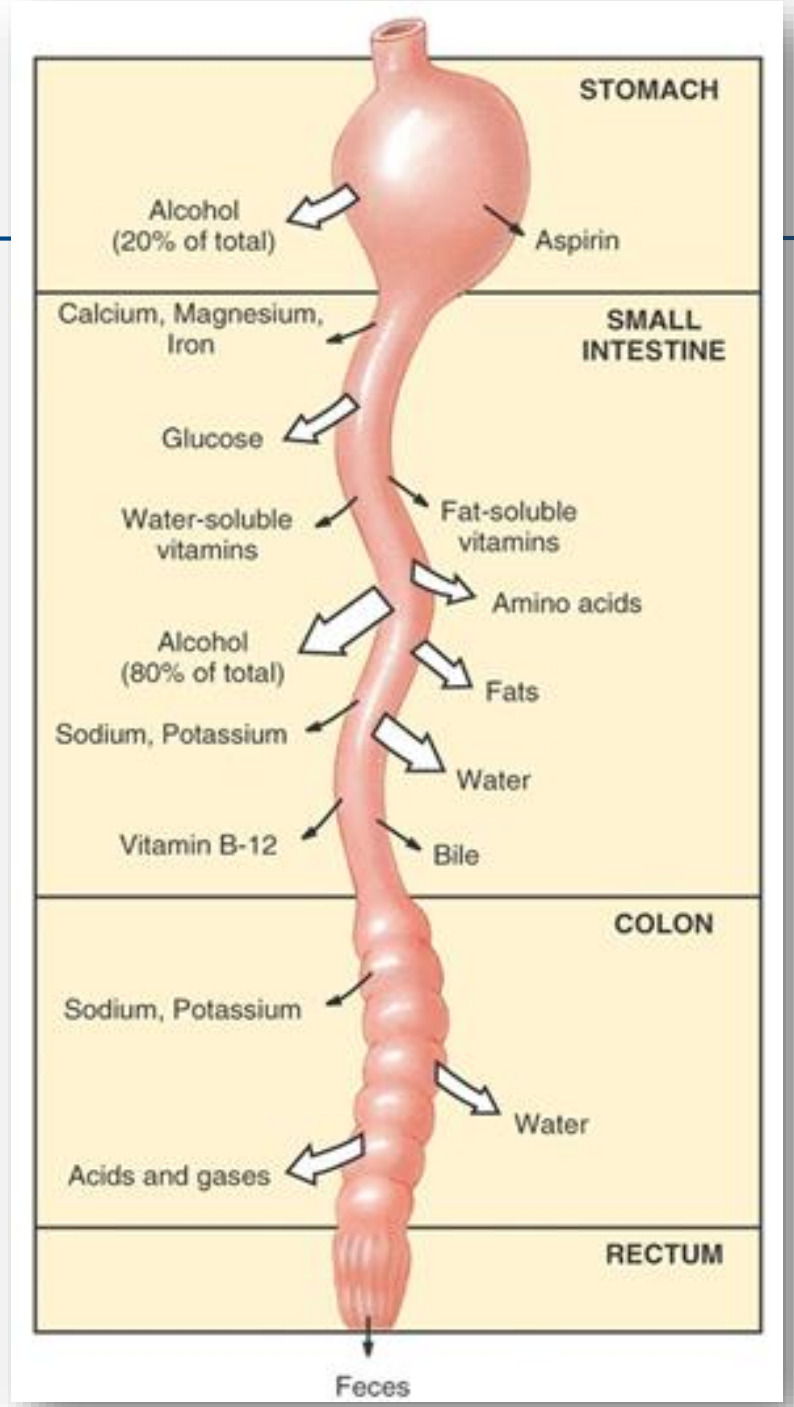
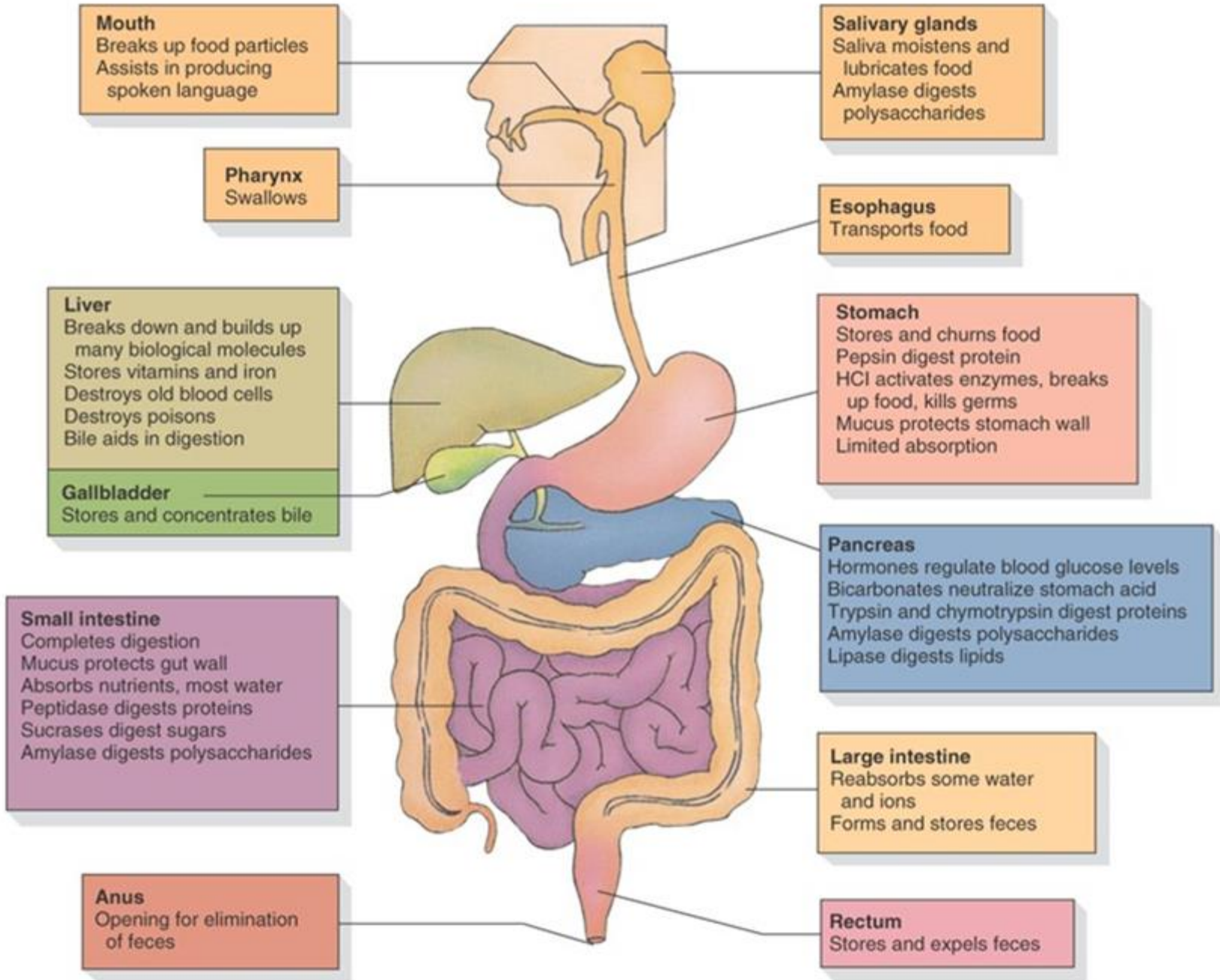
Absorption



Elimination

- Expulsion of feces from digestive tract (defecation)
- Reflex of stimulation of receptors in rectal mucosa


Mouth
Breaks up food particles
Assists in producing spoken language
Salivary glands
Saliva moistens and lubricates food
Amylase digests polysaccharides
Pharynx
Swallows
Esophagus
Transports food
Liver
Breaks down and builds up many biological molecules
Stores vitamins and iron
Destroys old blood cells
Destroys poisons
Bile aids in digestion
Stomach
Stores and churns food
Pepsin digest protein
HCl activates enzymes, breaks up food, kills germs
Mucus protects stomach wall
Limited absorption
Gallbladder
Stores and concentrates bile
Pancreas
Hormones regulate blood glucose levels
Bicarbonates neutralize stomach acid
Trypsin and chymotrypsin digest proteins
Amylase digests polysaccharides
Lipase digests lipids
Small intestine
Completes digestion
Mucus protects gut wall
Absorbs nutrients, most water
Peptidase digests proteins
Sucrases digest sugars
Amylase digests polysaccharides
Large intestine
Reabsorbs some water and ions
Forms and stores feces
Anus
Opening for elimination of feces
Rectum
Stores and expels feces

Uses of Energy

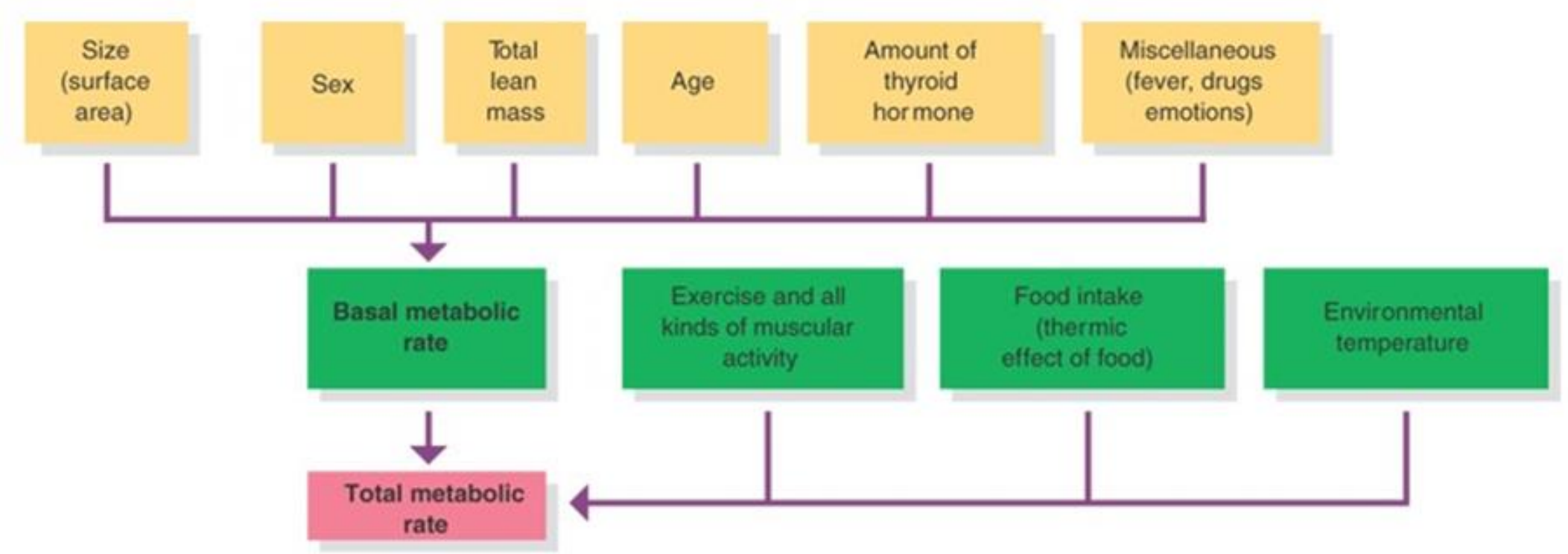
- Energy derived from food is measured in kcal or C
- 1 C is the amount of energy required to raise 1 kg of water 1°C
- Energy is used in 3 ways:
  - Basal metabolism
  - Physical activity
  - Thermogenesis

Uses of Energy

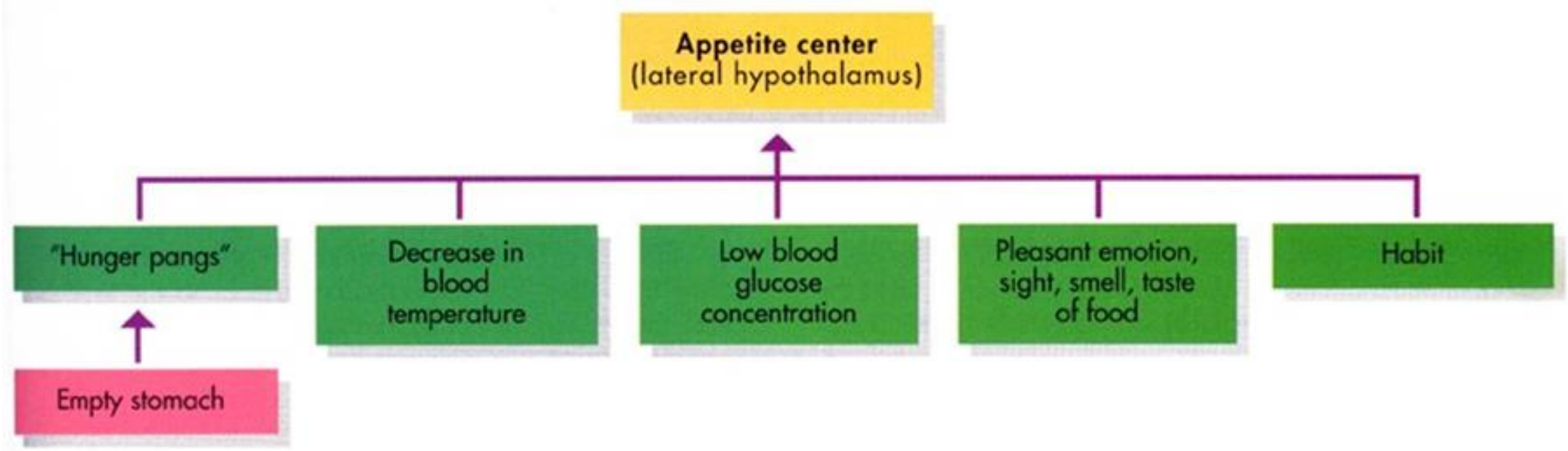
- Basal metabolism
  - The basilar metabolic rate (BMR) is the energy required to maintain the body functioning at a minimal level
  - May be influenced by
    - Size (more muscle – more metabolism)
    - Sex (males are higher)
    - Age (decreases)
    - Hormones (may increase)
    - Fever (increase)
    - Drugs (caffeine….increase)
    - Emotions (increase)

Total Metabolic Rate

- Amount of energy used or expended by the body in a given time (kcal/hr)



Regulation of Food Intake



Uses of Energy

- Physical Activity
  - Muscular contractions require energy
  - Accounts for only 25% of use
  - May increase with increased activity
  - Can be controlled voluntarily
- Thermogenesis
  - Energy used to digesting food
  - Accounts for only 10% of usage

Body Temperature

- Maintenance of the core temp is essential for enzyme function
- Average temp 37.6 °C
- Temp at the body surface is called the shell temperature and is typically 37°C (heat loss area)
- Shell temp is lower than core temp

Body Temperature

Heat Production

- Produced by catabolism of nutrients
  - 40% is used for biological activities
  - Remainder is heat energy
- Changes in temp signal body to maintain homeostasis

Body Temperature

- What happens when you are in a:
  - Hot environment?
  - Cold environment?
- Is temperature regulation negative or positive feedback?