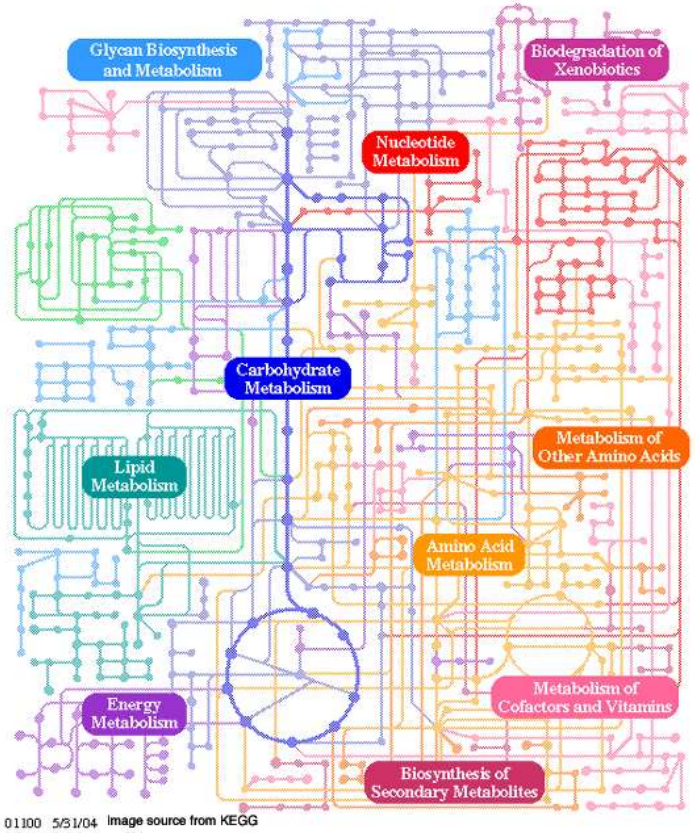
Unit 6

Cell Energy



- Chapter 6~ A*n Introduction to Metabolism*

Metabolism/Bioenergetics

- *Metabolism*: The totality of an organism's chemical processes; managing the material and energy resources of the cell
- *Catabolic pathways*: degradative process such as cellular respiration; releases energy
- *Anabolic pathways*: building process such as protein synthesis; photosynthesis; consumes energy

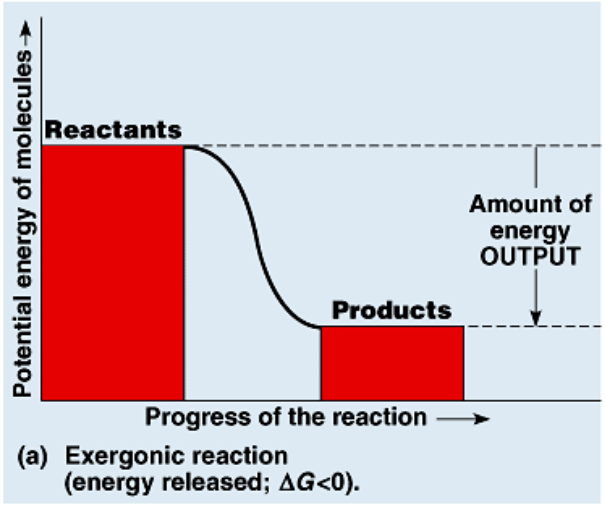
Thermodynamics

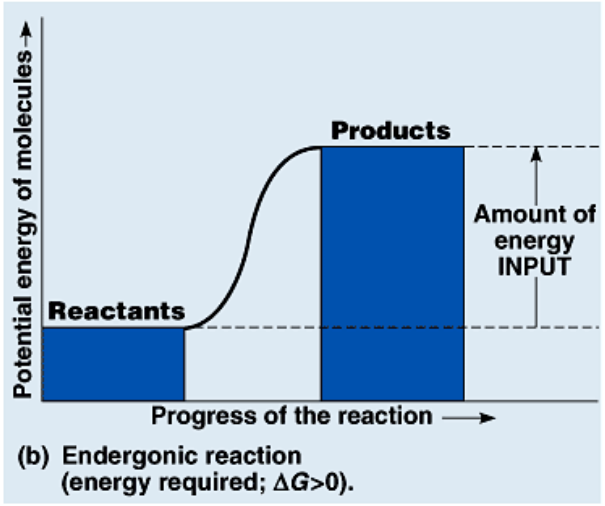
- Energy (E)~ capacity to do work; Kinetic energy~ energy of motion; Potential energy~ stored energy
- Thermodynamics~ study of E transformations
- 1st Law: conservation of energy; E transferred/transformed, not created/destroyed
- 2nd Law: transformations increase entropy (disorder, randomness)

- Combo: *quantity* of E is constant, *quality* is not

Free energy

- *Free energy*: portion of system's E that can perform work (at a constant T)
- Exergonic reaction: net release of free E to surroundings
- Endergonic reaction: absorbs free E from surroundings



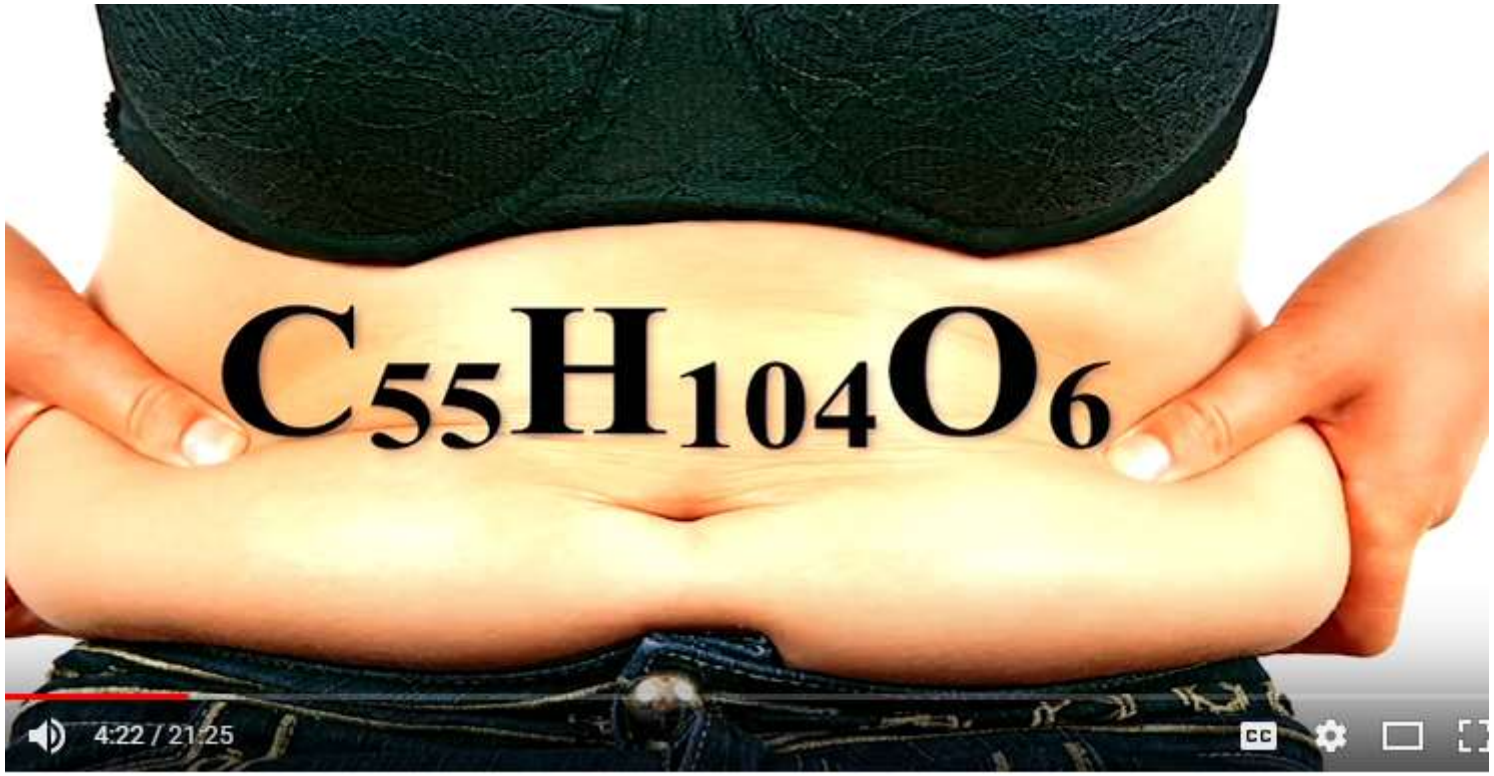


QOD

- When you loose weight, what does it turn into?

The Mathematics of Weight Loss

- https://www.youtube.com/watch?v=vuIlsN32WaE



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Entropic Time

- https://www.youtube.com/watch?v=i6rVHr6OwjI

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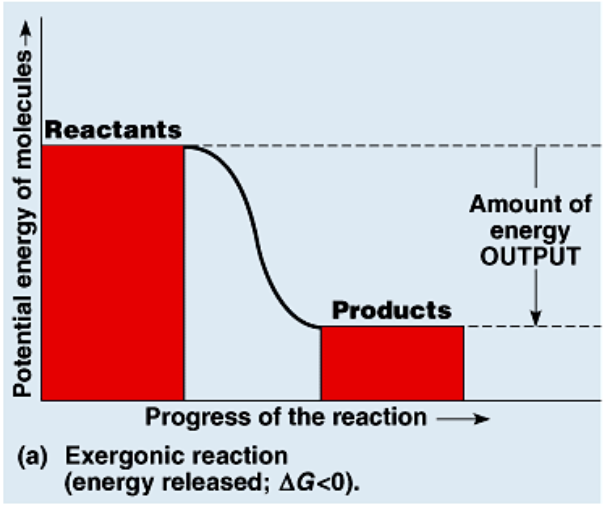
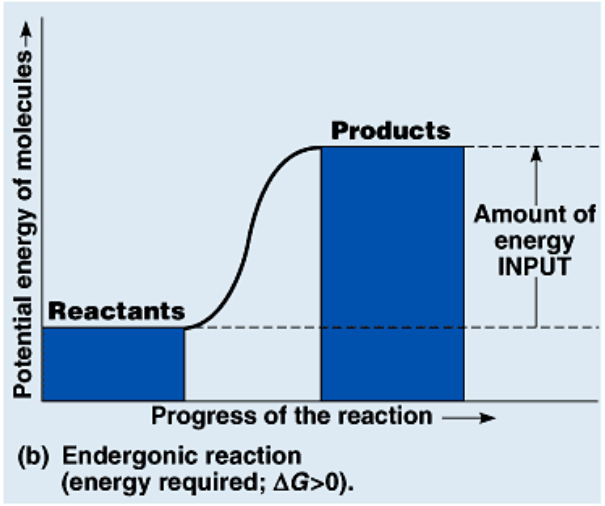
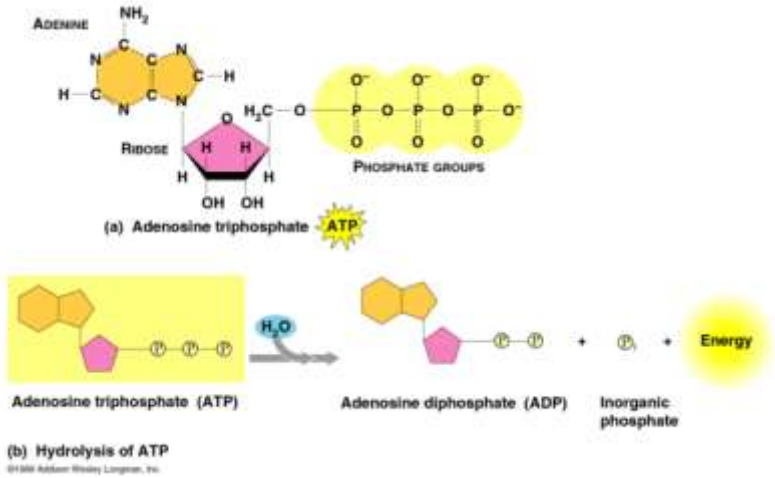




Energy Coupling & ATP

- E coupling: use of exergonic process to drive an endergonic one (ATP)
- *Adenosine triphosphate*
- ATP tail: high negative charge
- ATP hydrolysis: release of free E
- Phosphorylation (phosphorylated intermediate)~ enzymes



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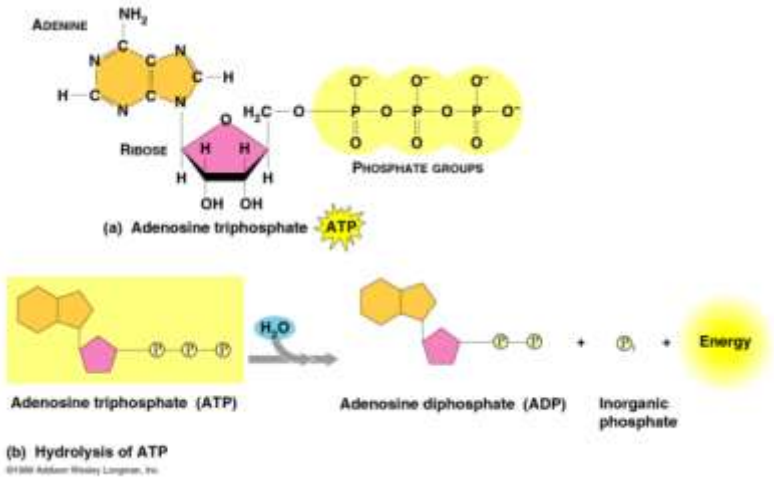
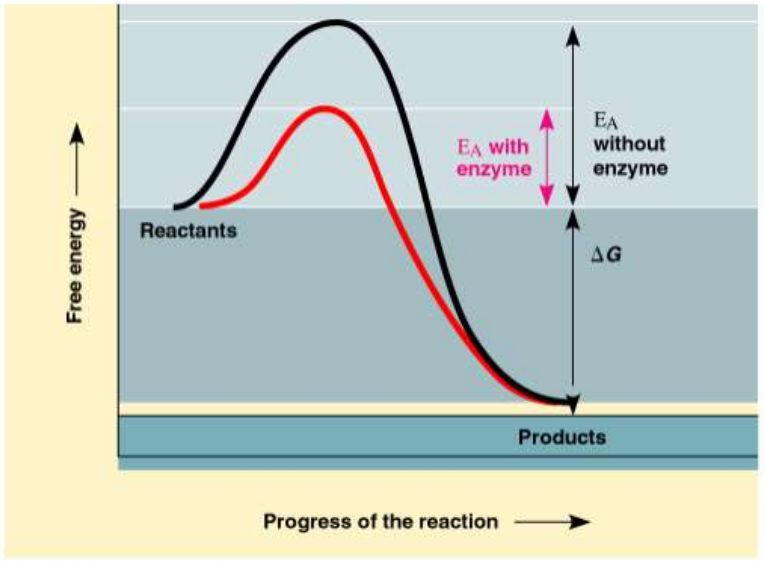


Enzymes

- *Catalytic proteins*: change the rate of reactions w/o being consumed
- *Free Energy of activation* : the Energy required to break bonds
- *Substrate*: enzyme reactant
- *Active site*: pocket or groove on enzyme that binds to substrate
- Induced fit model



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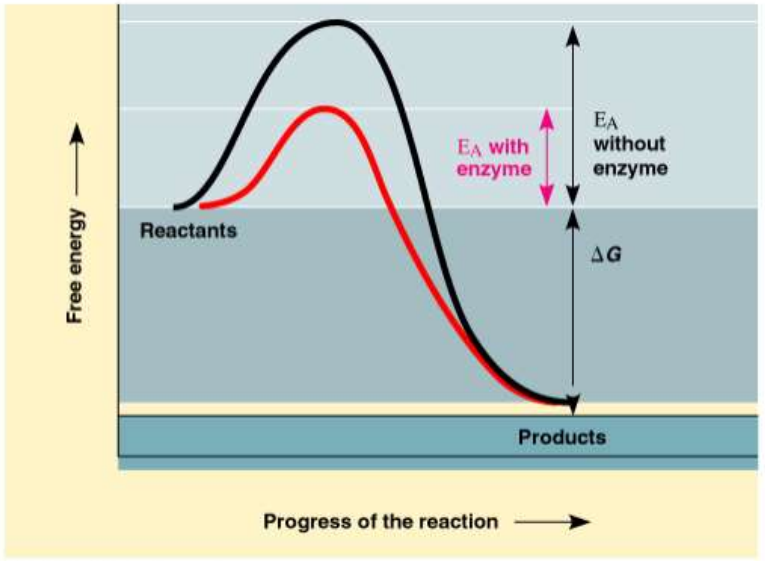
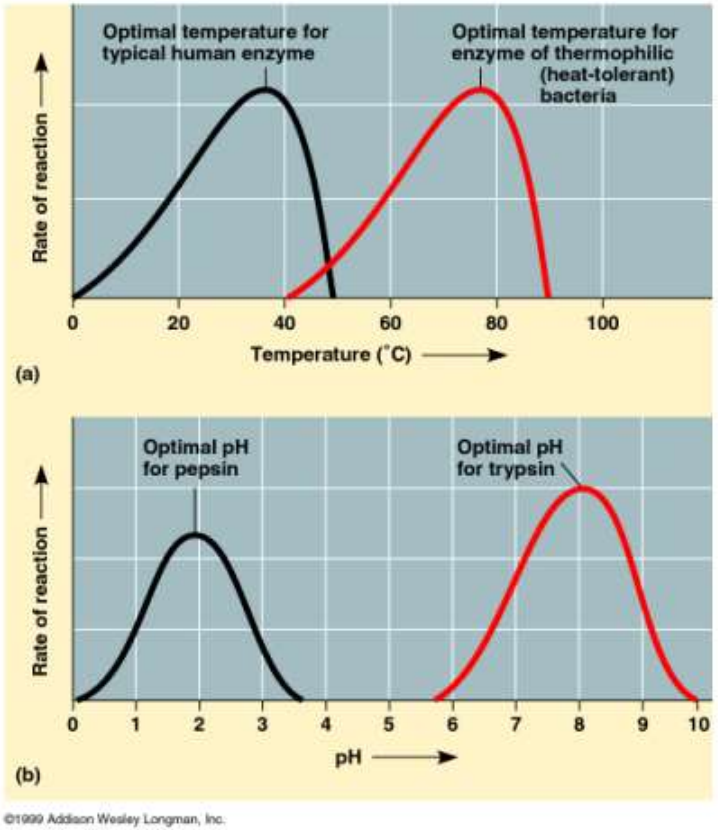


Effects on Enzyme Activity

- Temperature
- pH
- Cofactors:

  inorganic, nonprotein helpers; ex.: zinc, iron, copper
- Coenzymes: organic helpers; ex.: vitamins



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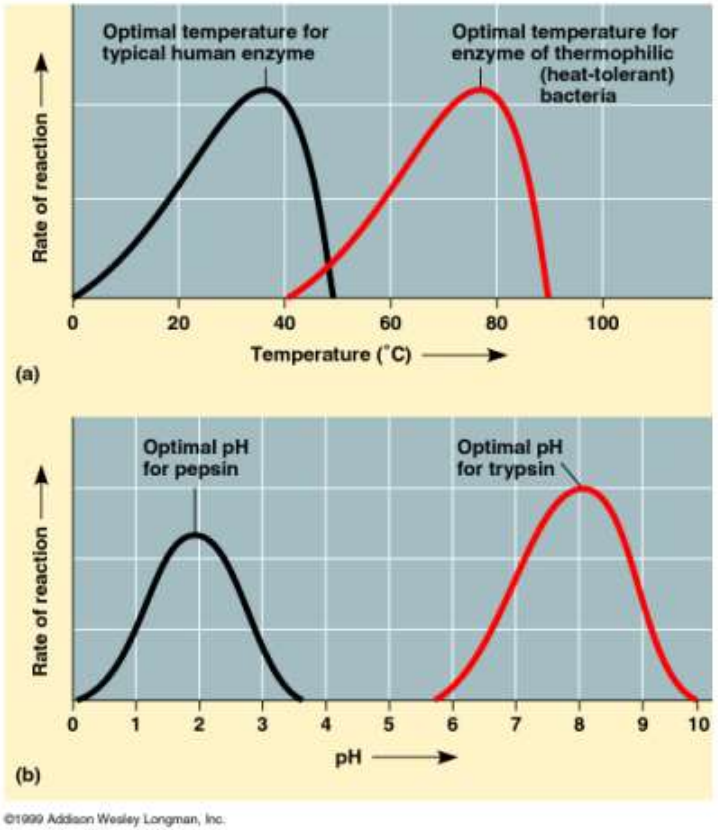
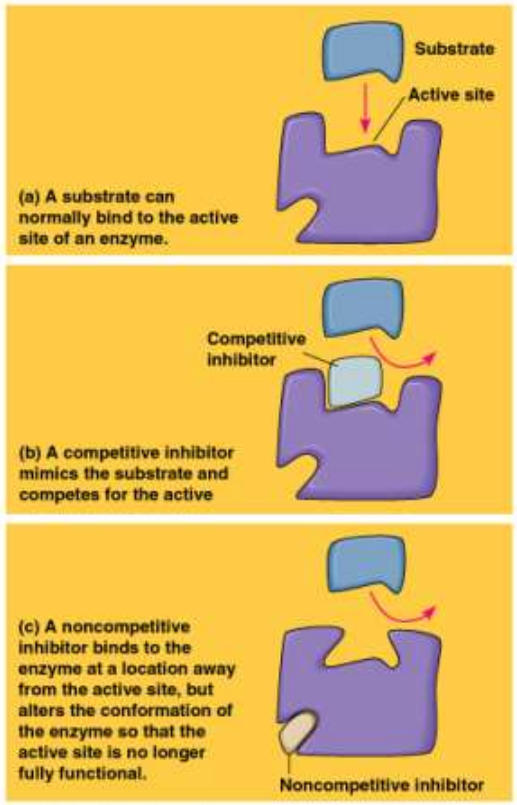


Enzyme Inhibitors

- Irreversible (covalent); reversible (weak bonds)
- *Competitive*: competes for active site (reversible); mimics the substrate
- *Noncompetitive*: bind to another part of enzyme (*allosteric site*) altering its conformation (shape); poisons, antibiotics



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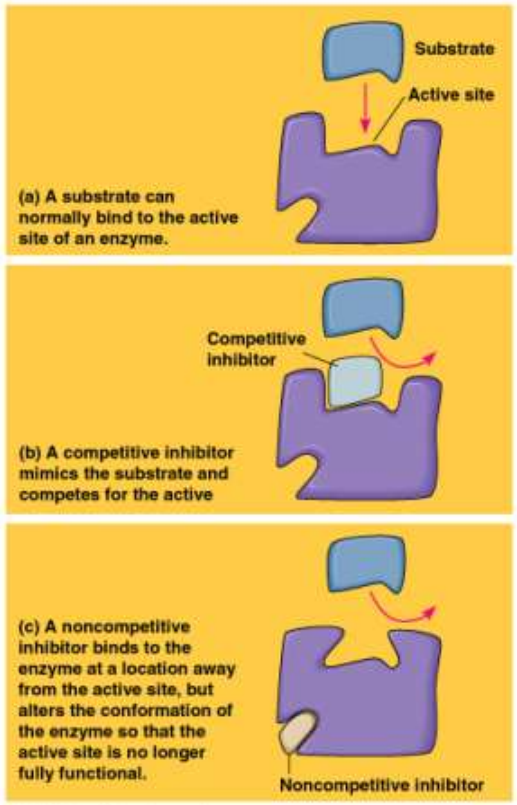


How Enzymes Work

http://highered.mcgraw-hill.com/olcweb/cgi/pluginpop.cgi?it=swf::640::480::/sites/dl/free/0003292010/819778/How_Enzymes_Work.swf::How%20Enzymes%20Work

Enzyme Modelling Lab

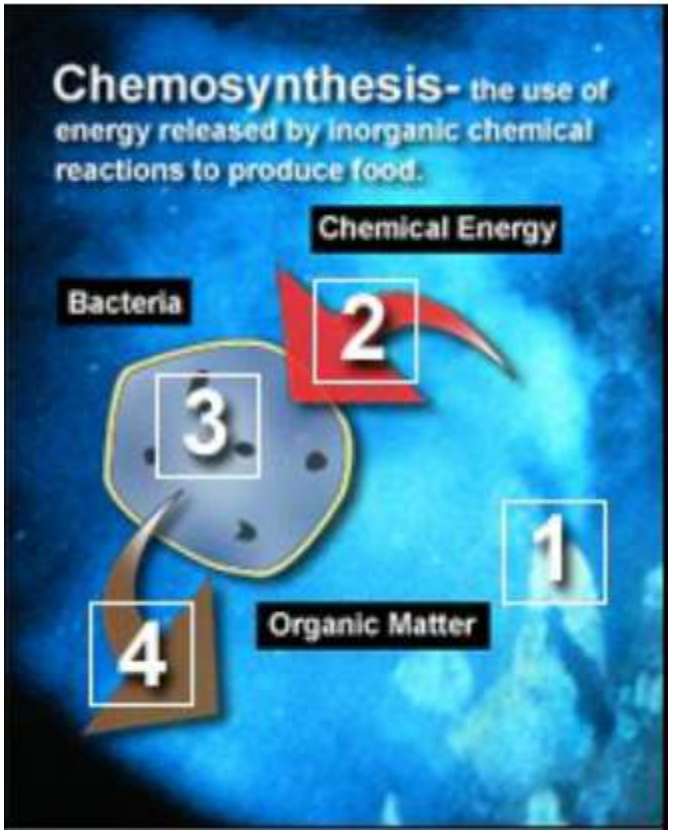
- **Pre-Lab:**
- **Vocabulary**
  - Enzyme
  - Active site
  - Substrate
  - Anabolism
  - Catabolism
  - Competitive inhibitor
  - Allosteric inhibitor

- **Procedure:**
- Use the enzyme models to demonstrate anabolism and catabolism
- Use the enzyme models with extra foam to illustrate competitive and allosteric inhibition

- **Data:** Draw and Describe each model in 3-5 bullets, label each model
- **Analysis:** 1. Discuss the benefits and limitations of enzymes 2. Explain the role of inhibitors in controlling enzymatic reactions
- Conclusion: Sum it up

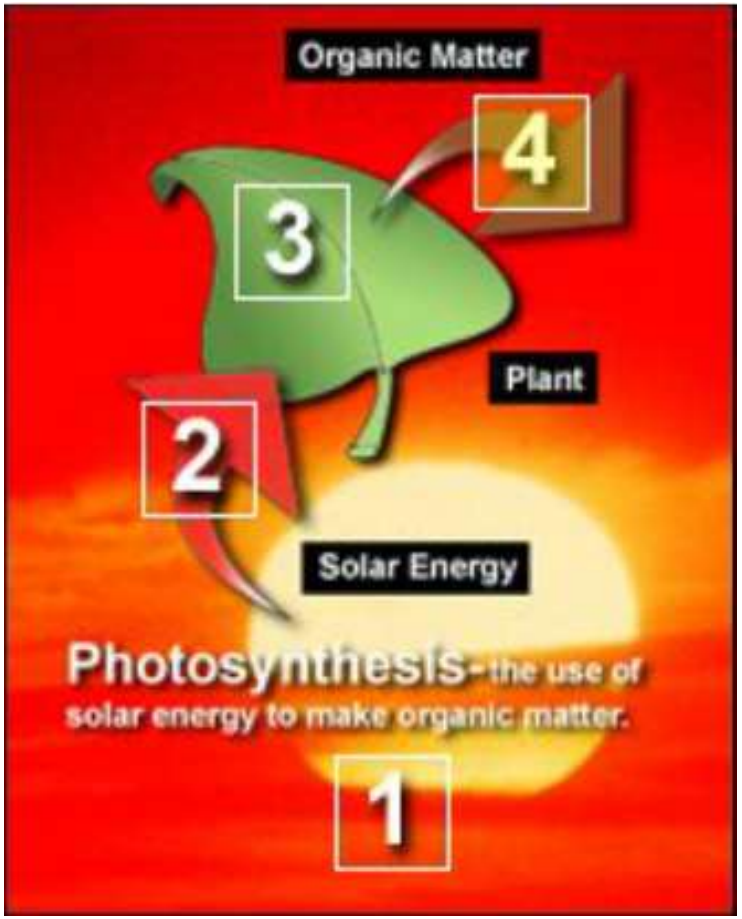
Chemosynthesis

- organisms use the energy released by chemical reactions to make a sugar, but different species use different pathways.
- $CO_2 + 4H_2S + O_2 \rightarrow CH_20 + 4S + 3H_2O$
- bacterial communities have been found in hot springs on land, and on the sea floor around hydrothermal vents, cold seeps, whale carcasses, and sunken ships



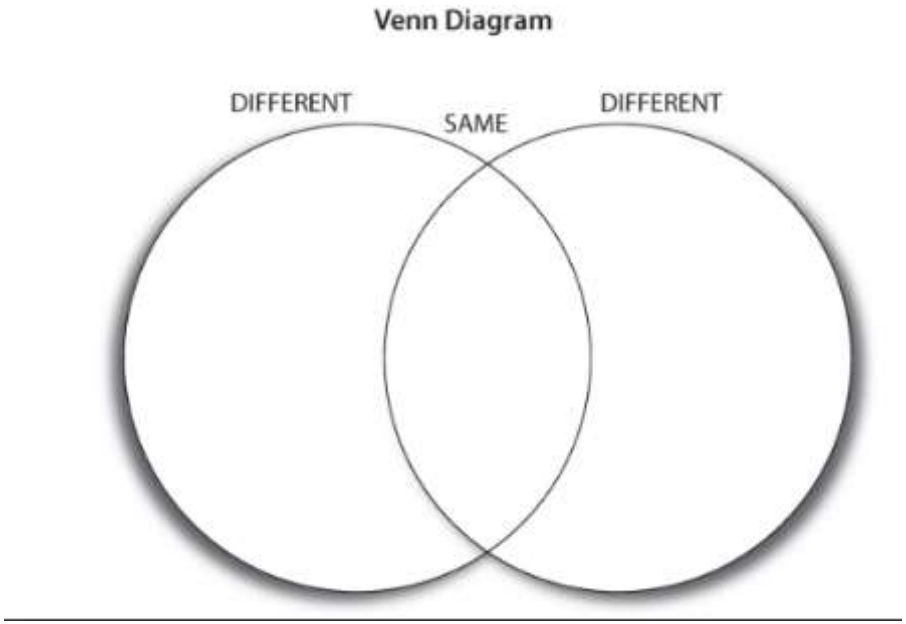
Photosynthesis

- organisms use solar energy to turn carbon dioxide and water into sugar and oxygen.
- $CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$
- occurs in plants and some bacteria, wherever there is sunlight - on land, in shallow water, even inside and below clear ice.



Venn Diagram

- QOD
- Please make a Venn Diagram for Photosynthesis and Chemosynthesis
- Include at least 5 bullets in each section, these may be equations, pictures examples and locations



AP BIOLOGY

- *Cellular Respiration: Harvesting Chemical Energy*


CYCLES ATTACHED
TO THESE RAILINGS
WILL BE REMOVED
KREBS
CYCLE

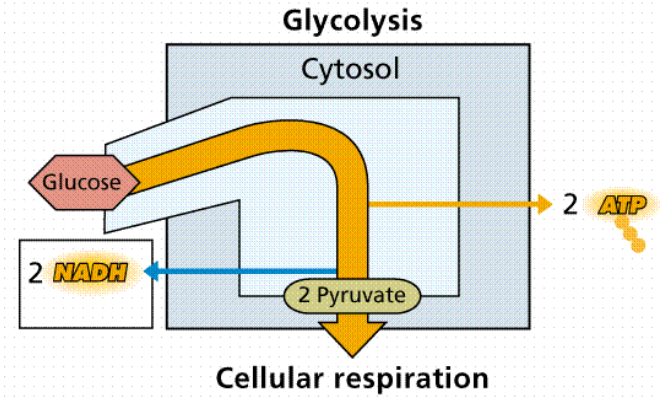
QOD

- Classify each of the following as heterotroph or autotroph:
- Grass
- Deer
- Lichen
- mushroom

Principles of Energy Harvest

- Catabolic pathway
  - Fermentation
  - Cellular Respiration

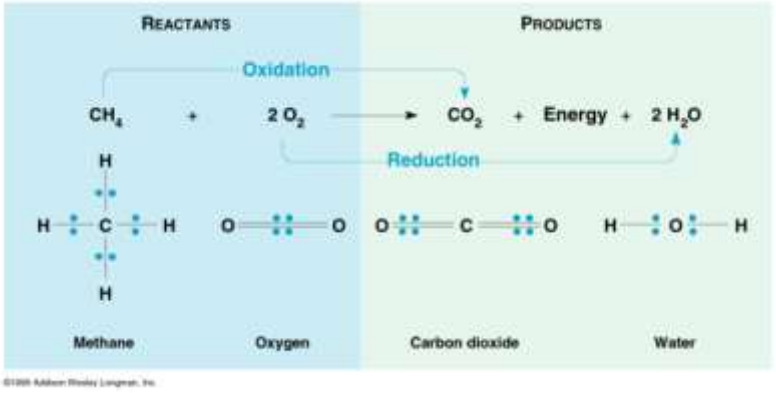
$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + E$ (ATP + heat)



Redox reactions

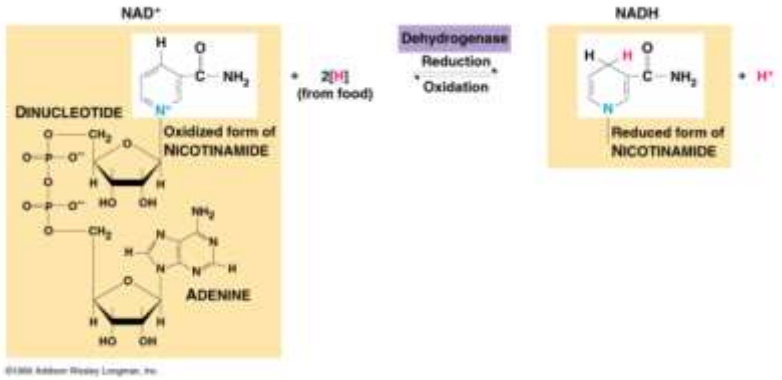
- Oxidation-reduction
- OIL RIG (LEO GER)

  (adding e- reduces + charge)
- Oxidation is e- loss; reduction is e- gain
- Reducing agent:
  e- donor
- Oxidizing agent:
  e- acceptor



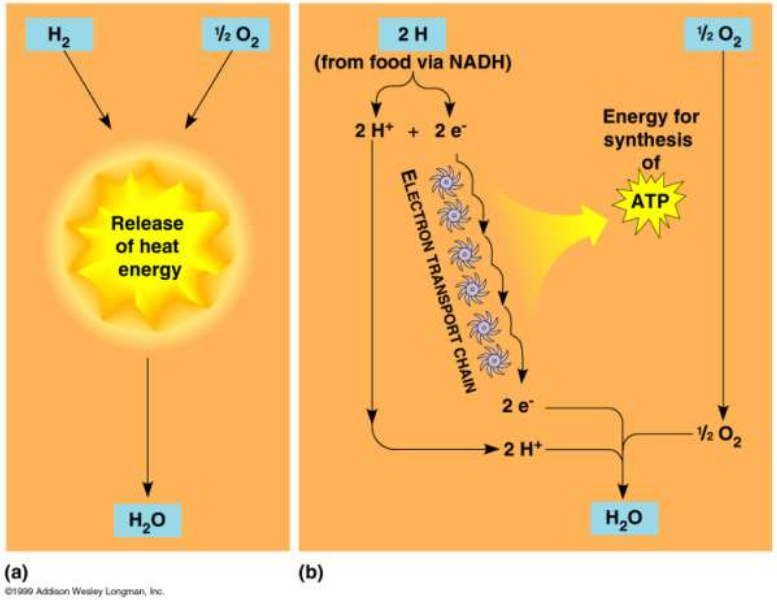
Oxidizing agent in respiration

- NAD+ (nicotinamide adenine dinucleotide)
- Removes electrons from food (series of reactions)
- NAD $^{+}$ is reduced to NADH
- Enzyme action: dehydrogenase
- Oxygen is the eventual e- acceptor



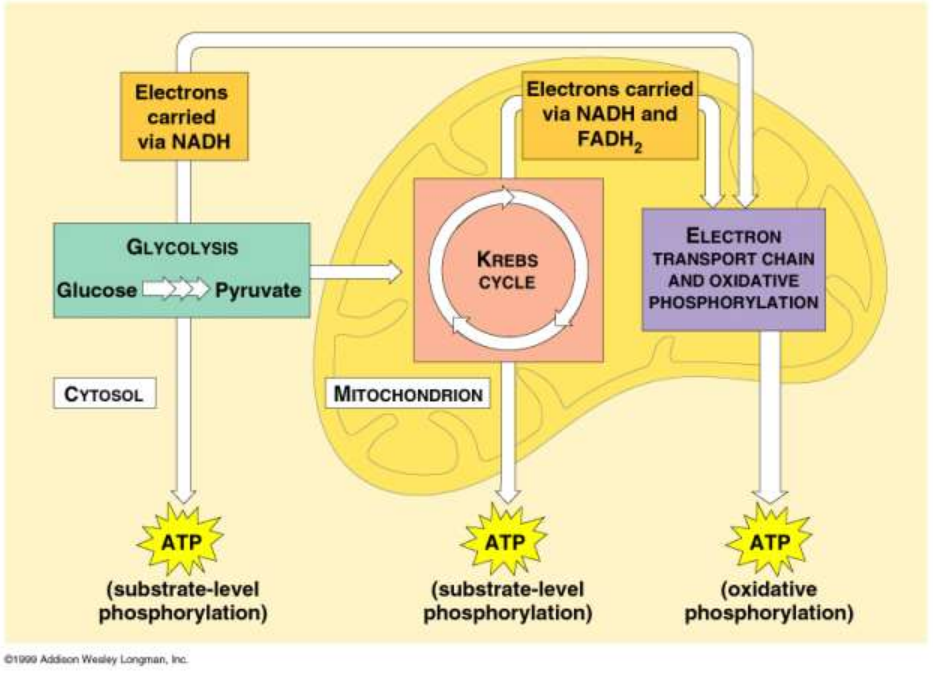
Electron transport chains

- Electron carrier molecules (membrane proteins)
- Shuttles electrons that release energy used to make ATP
- Sequence of reactions that prevents energy release in 1 explosive step
- Electron route: food---> NADH ---> electron transport chain ---> oxygen



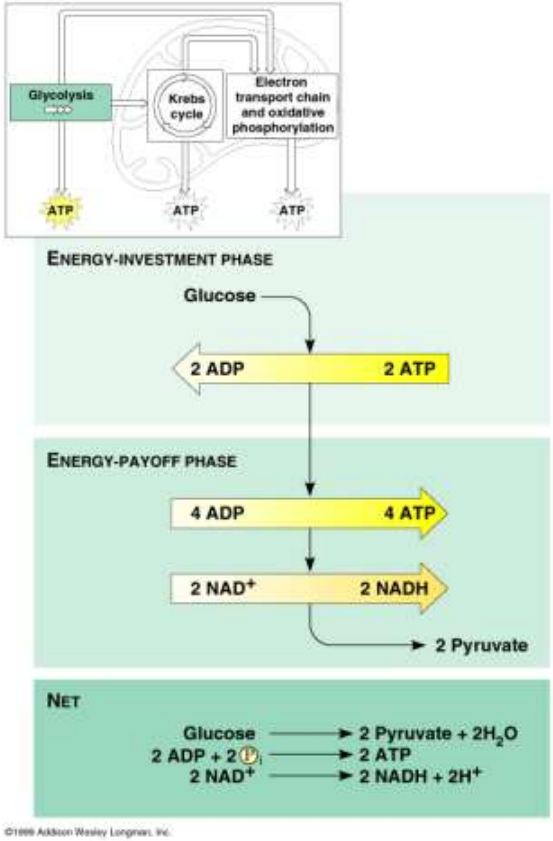
Cellular respiration

- Glycolysis: cytosol; degrades glucose into pyruvate
- Kreb's Cycle: mitochondrial matrix; pyruvate into carbon dioxide
- Electron Transport Chain: inner membrane of mitochondrion; electrons passed to oxygen



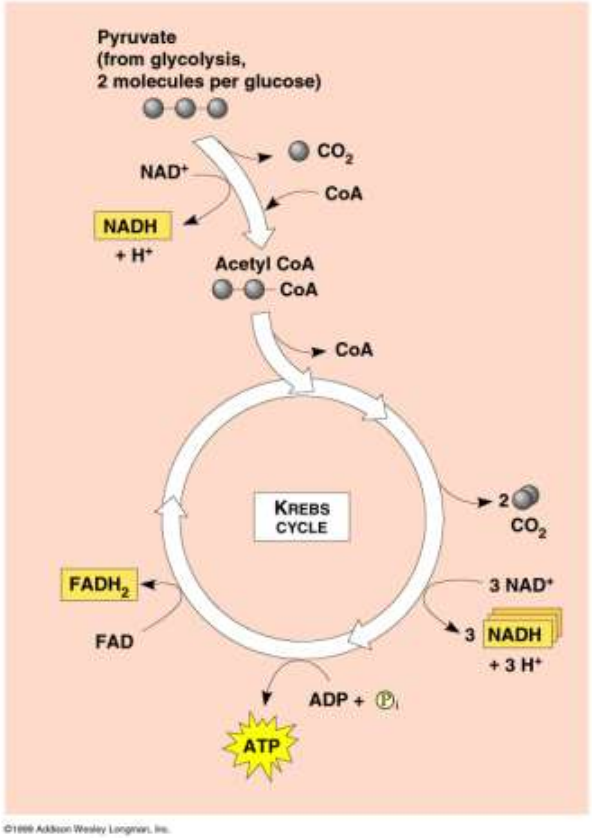
Glycolysis

- 1 Glucose ---> 2 pyruvate molecules
- Energy investment phase: cell uses ATP to phosphorylate fuel
- Energy payoff phase: ATP is produced by substrate-level phosphorylation and NAD+ is reduced to NADH by food oxidation
- Net energy yield per glucose molecule: 2 ATP plus 2 NADH; no CO2 is released; occurs aerobically or anaerobically



Kreb's Cycle

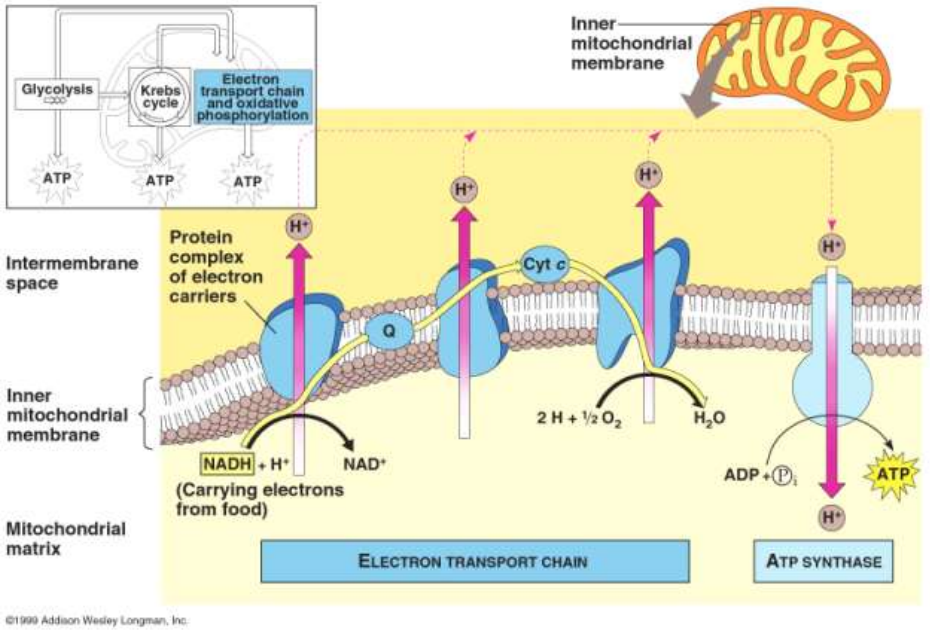
- If molecular oxygen is present…….
- Each pyruvate is converted into acetyl CoA (begin w/ 2):CO2 is released;
- NAD+ ---> NADH;
- coenzyme A (from B vitamin),
- makes molecule very reactive
- From this point, each turn 2 C atoms enter (pyruvate) and 2 exit (carbon dioxide)
- Oxaloacetate is regenerated (the "cycle")
- For each pyruvate that enters:
  - 3 NAD+ reduced to NADH;
  - 1 FADH reduced to FADH2
  - 1 ATP molecule



Electron transport chain

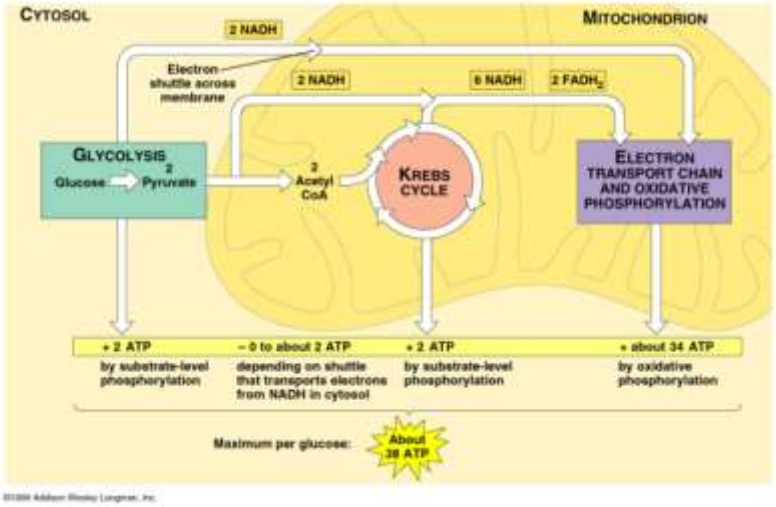
- Cytochromes carry electron carrier molecules (NADH & FADH2) down to oxygen
- Chemiosmosis: energy coupling mechanism

- ATP synthase: produces ATP by using the H+ gradient (proton-motive force) pumped into the inner membrane space from the electron transport chain; this enzyme harnesses the flow of H+ back into the matrix to phosphorylate ADP to ATP (oxidative phosphorylation)



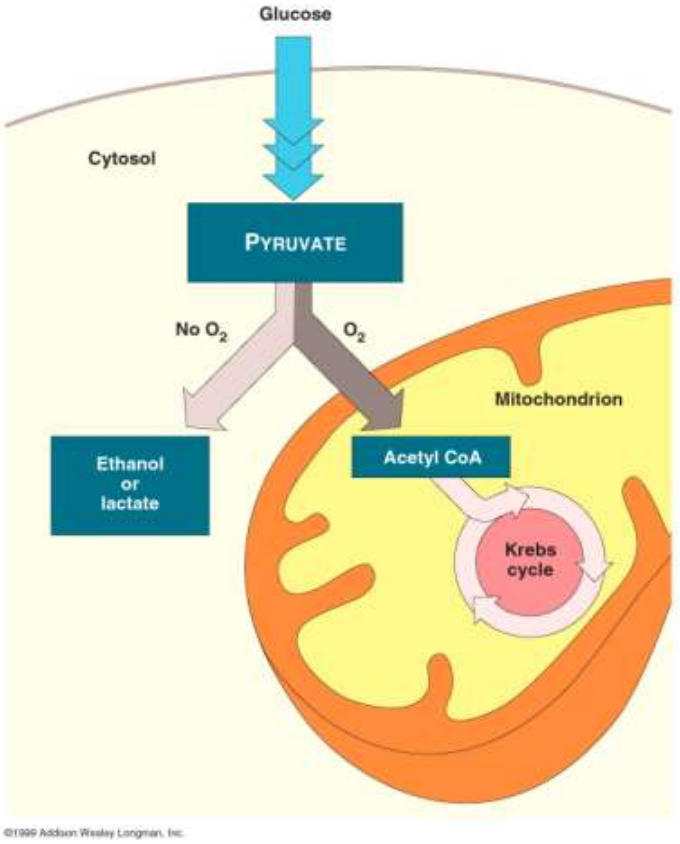
Review: Cellular Respiration

- <u>Glycolysis:</u>
- 2 ATP (substrate-level phosphorylation)
- <u>Kreb's Cycle:</u>
- 2 ATP (substrate-level phosphorylation)
- <u>Electron transport & oxidative phosphorylation:</u> 2 NADH (glycolysis) = 6ATP 2 NADH (acetyl CoA) = 6ATP 6 NADH (Kreb's) = 18 ATP 2 FADH2 (Kreb's) = 4 ATP
- *<u>38 TOTAL ATP/glucose</u>*



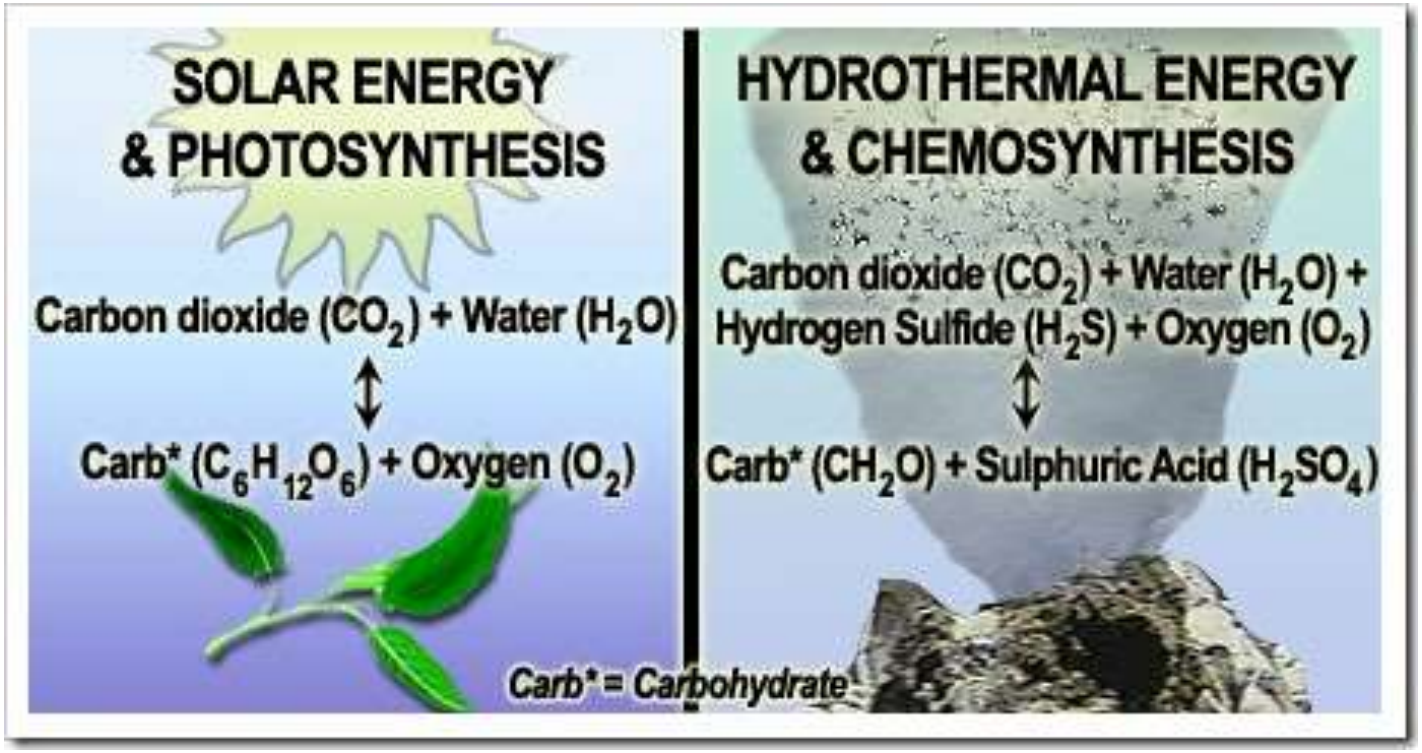
Related metabolic processes

- Fermentation:
- alcohol~ pyruvate to ethanol
- lactic acid~ pyruvate to lactate
- Facultative anaerobes (yeast/bacteria)
- Beta-oxidation
  - lipid catabolism



Photosynthesis

Chemosynthesis v Photosynthesis



QOD - Photosynthesis and chemosynthesis are both fundamental metabolic processes for converting energy into useable forms for living organisms. Compare and contrast the two processes.

Photosynthesis in nature

Autotrophs:

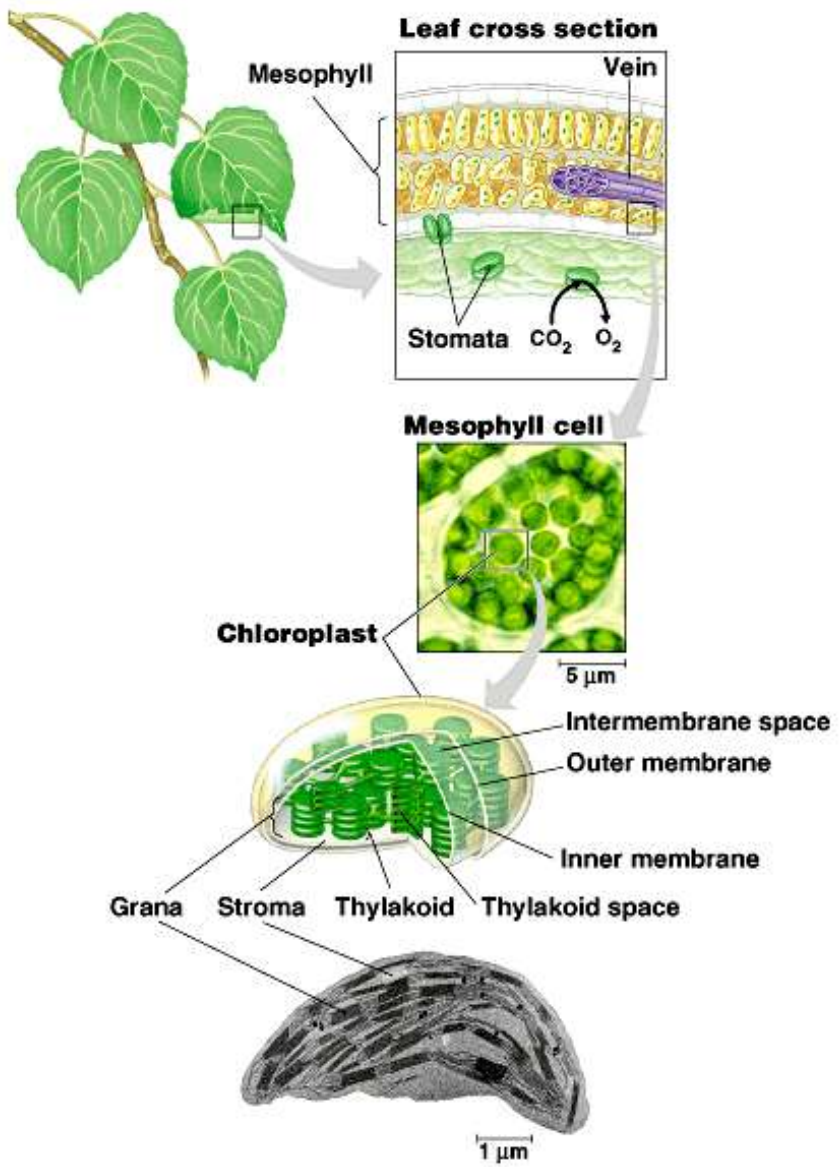
biotic producers; photoautotrophs; chemoautotrophs; obtains organic food without eating other organisms

Heterotrophs:

biotic consumers; obtains organic food by eating other organisms or their by-products (includes decomposers)

The chloroplast

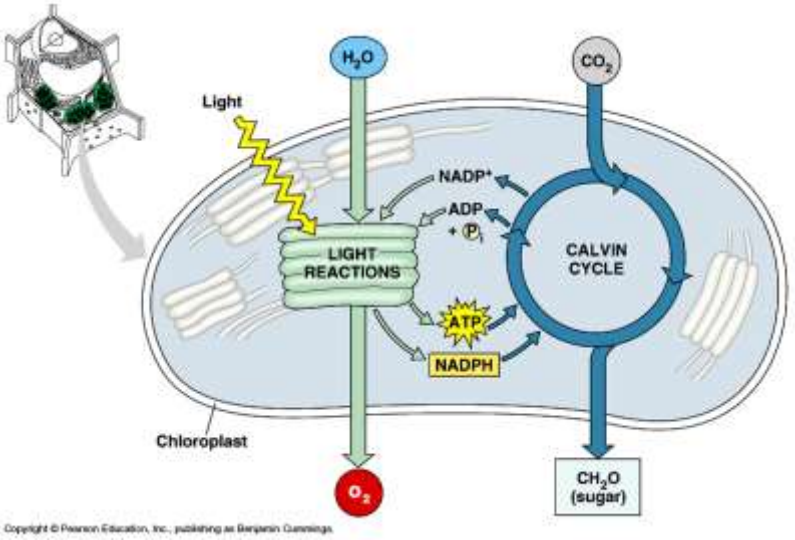
- Sites of photosynthesis
- Pigment: chlorophyll
- Plant cell: mesophyll
- Gas exchange: stomata
- Double membrane
- Thylakoids, grana, stroma



Photosynthesis: an overview

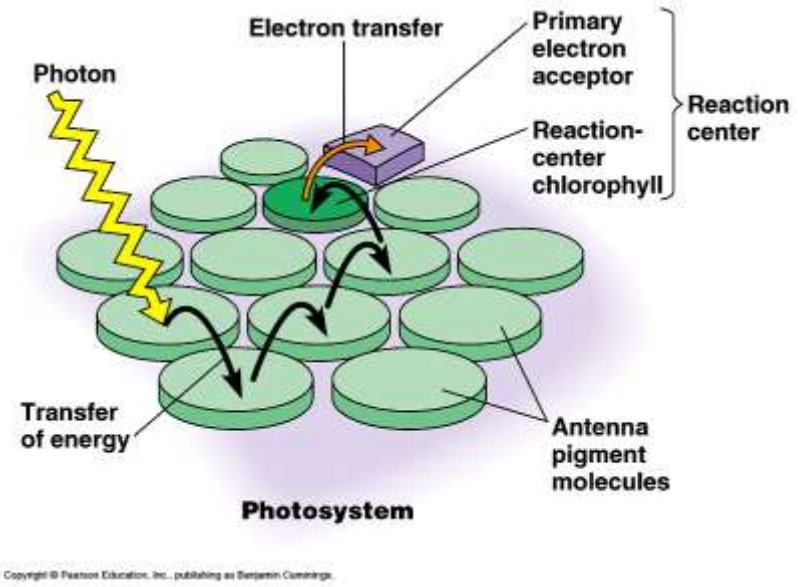
- Redox process
- H2O is split, e- (along w/ H+) are transferred to CO2, reducing it to sugar
- <u>2 major steps:</u>
  - light reactions ("*photo*")
  - NADP+ (electron acceptor) to NADPH
- <u>Photophosphorylation:</u>
  - ADP ---> ATP
  - Calvin cycle ("*synthesis*")

<u>Carbon fixation:</u>
carbon into organics



Photosystems

- Light harvesting units of the thylakoid membrane
- Composed mainly of protein and pigment antenna complexes
- Antenna pigment molecules are struck by photons
- Energy is passed to reaction centers (redox location)
- Excited e- from chlorophyll is trapped by a primary e- acceptor



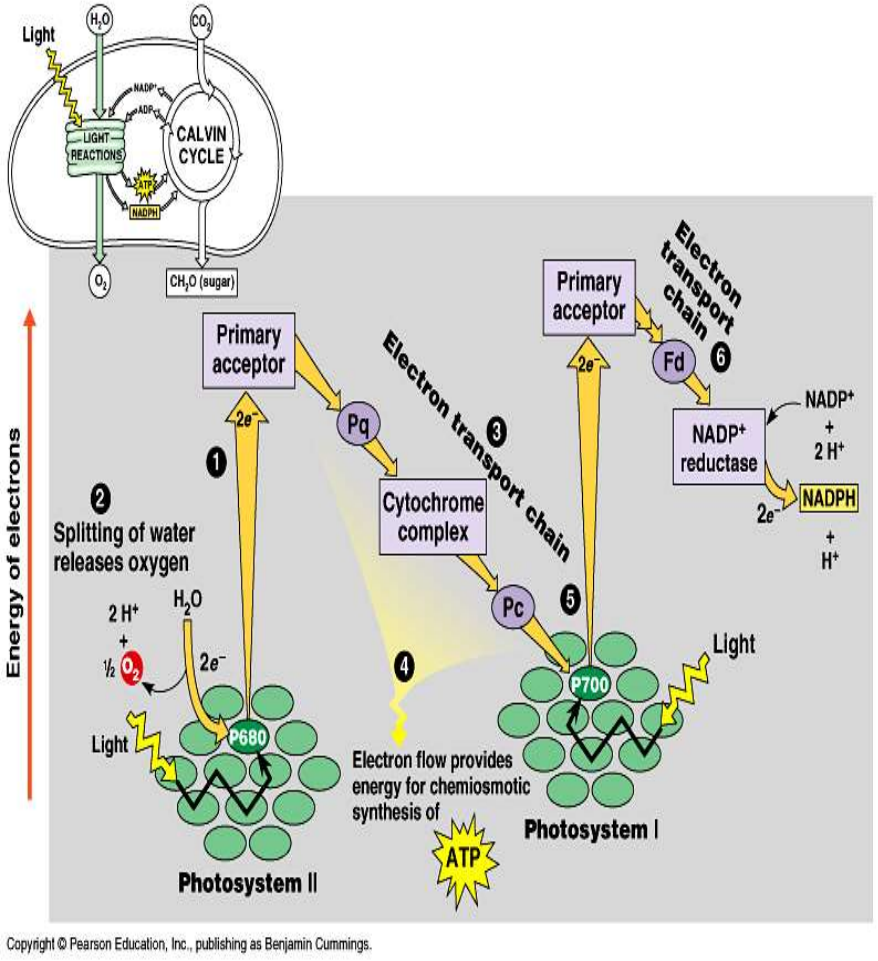
Noncyclic electron flow

<u>Photosystem II (P680):</u>

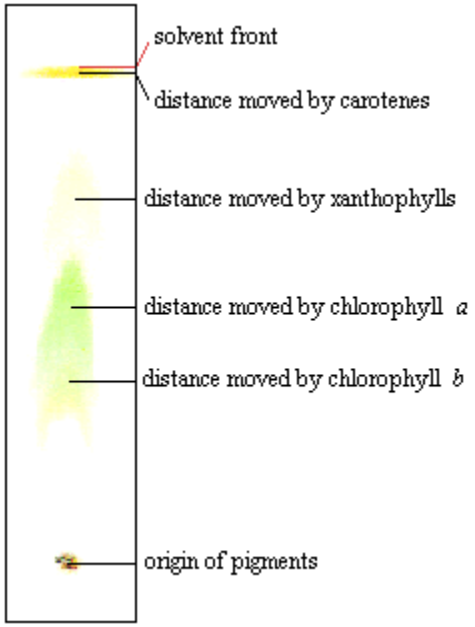
- photons excite chlorophyll e- to an acceptor
- e- are replaced by **splitting of H2O** (**release of O2**)
- e-'s travel to Photosystem I down an electron transport chain (Pq~cytochromes~Pc)
- as e- fall, ADP ---> ATP (noncyclic photophosphorylation)

<u>Photosystem I (P700):</u>

- 'fallen' e- replace excited e- to primary e-acceptor
- 2nd ETC (Fd~NADP+ reductase) transfers e- to NADP+ ---> NADPH (...to Calvin cycle…)
- These photosystems produce equal amounts of **ATP and NADPH**



Sample Chromatography Bands



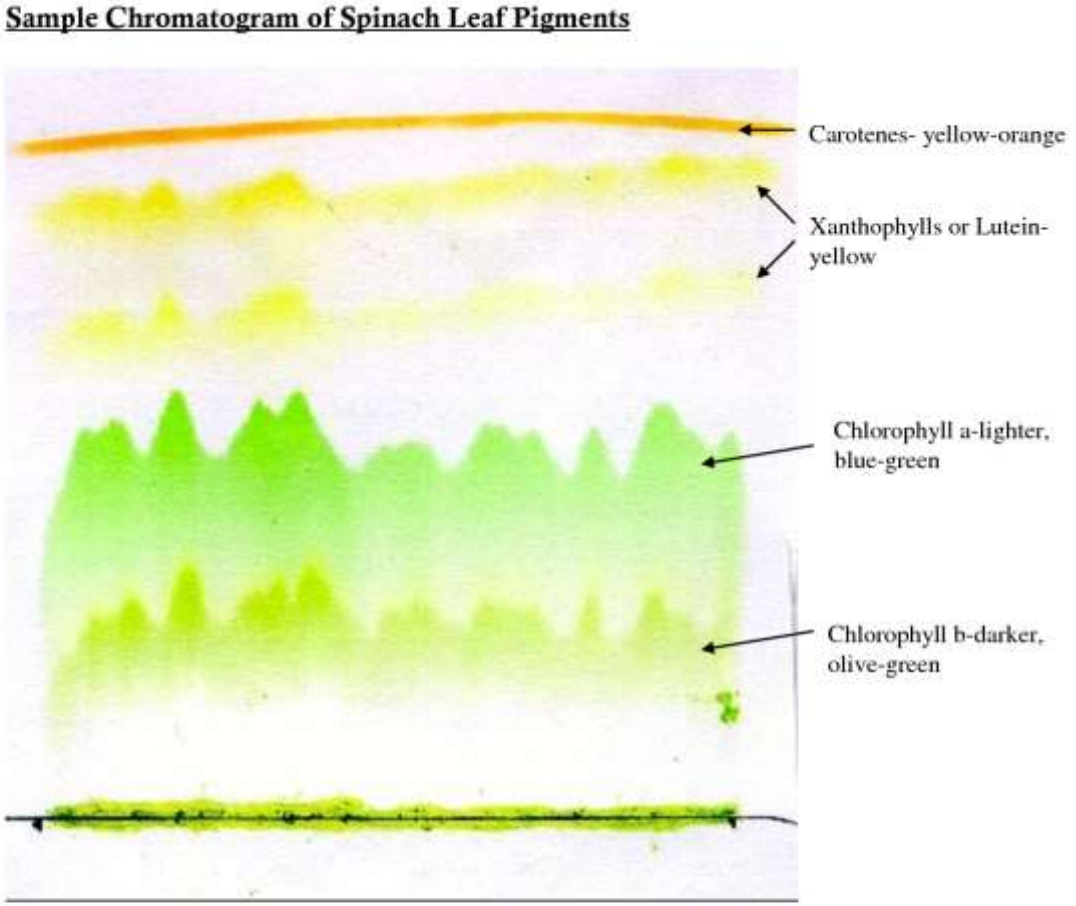
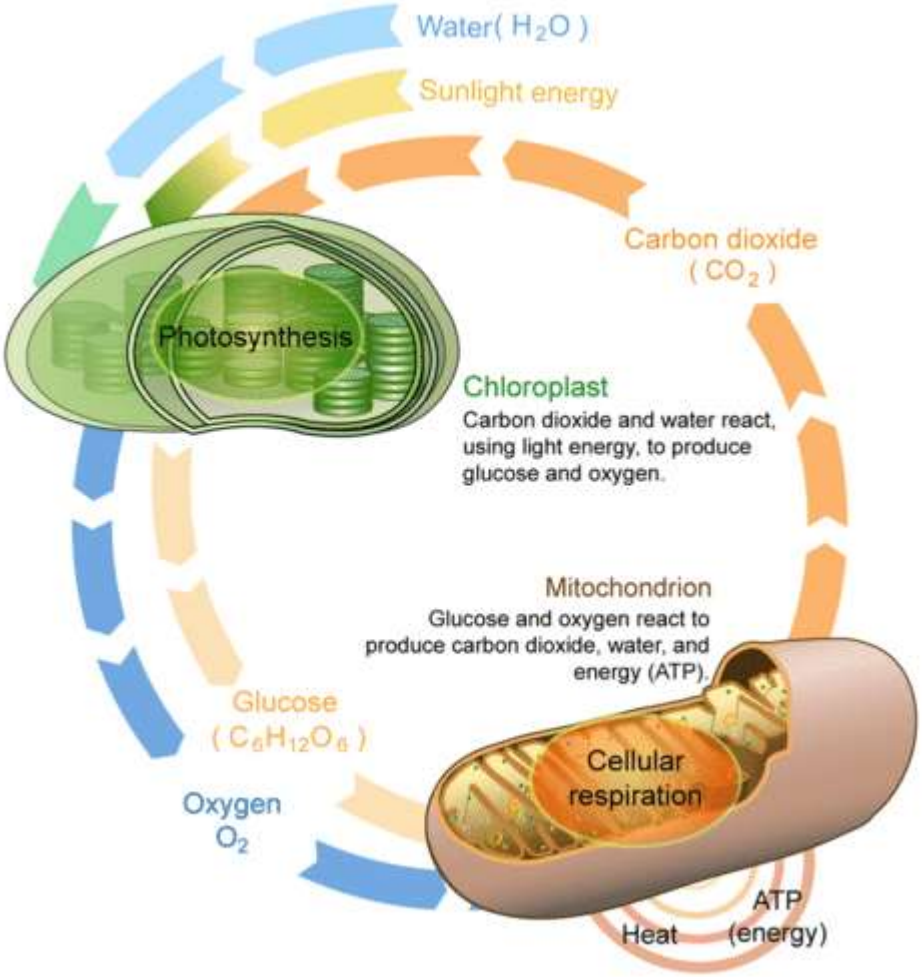


Table 2: Rf values using standards to confirm the carotenoids (Lorenz, Todd, 1998)

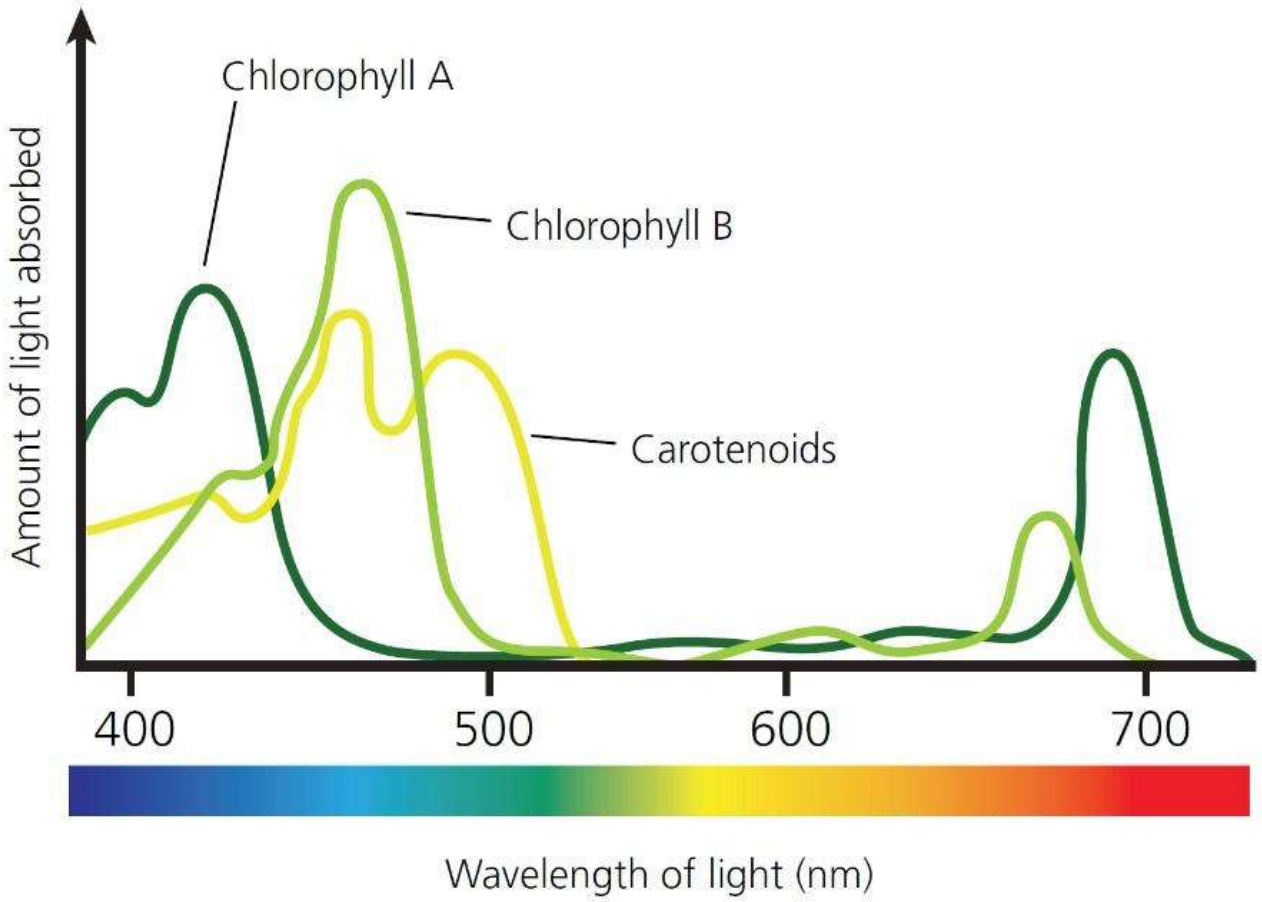
Carotenoid	Typical Rf value
β-carotene	0.99
Echinenone	0.87
Astaxanthin Di-esters	0.75
Astaxanthin Monoesters	0.50
Canthaxanthin	0.40
Astaxanthin Free	0.33
Lutein	0.25

QOD

- What is the relationship between photosynthesis and respiration?:

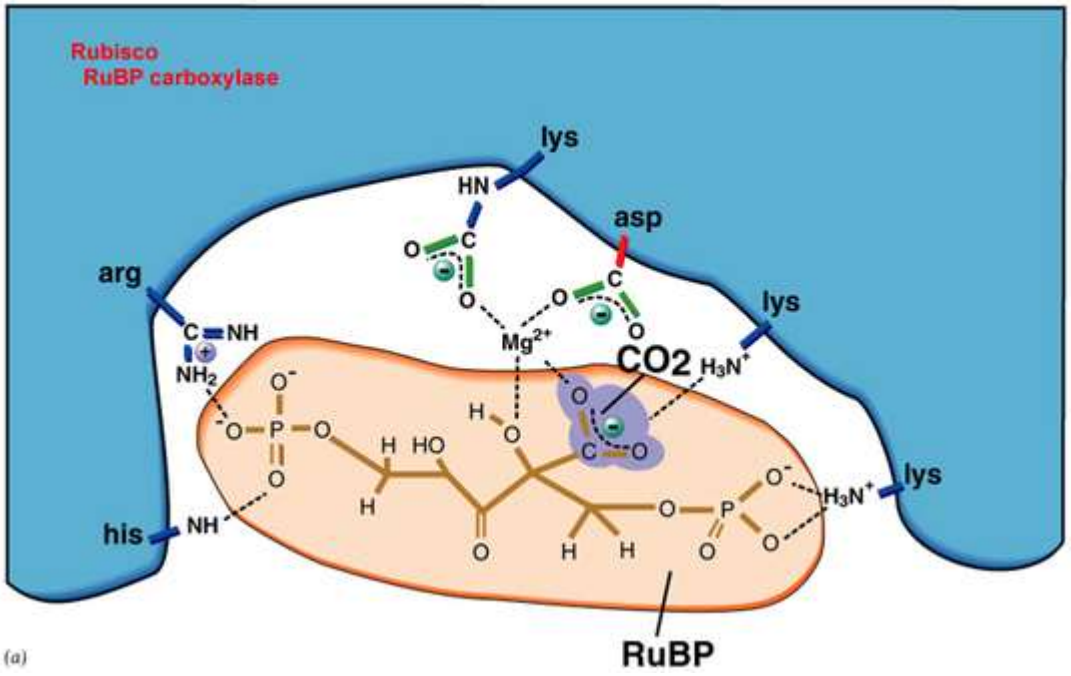


Absorption spectrum



RUBISCO

- The most prevalent protein on the planet

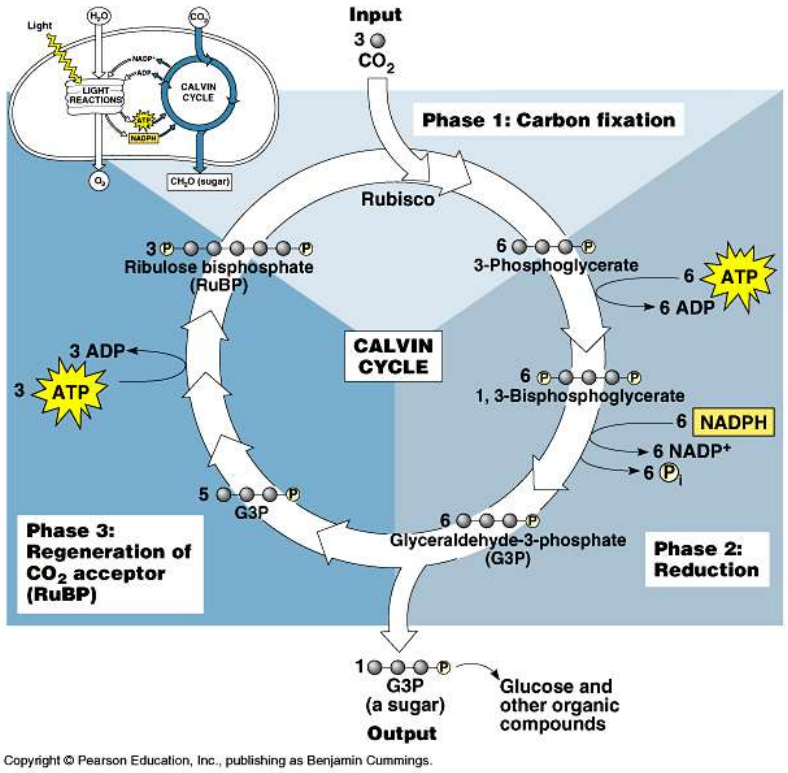


The Calvin cycle

3 molecules of CO2 are 'fixed' into glyceraldehyde 3-phosphate (G3P)

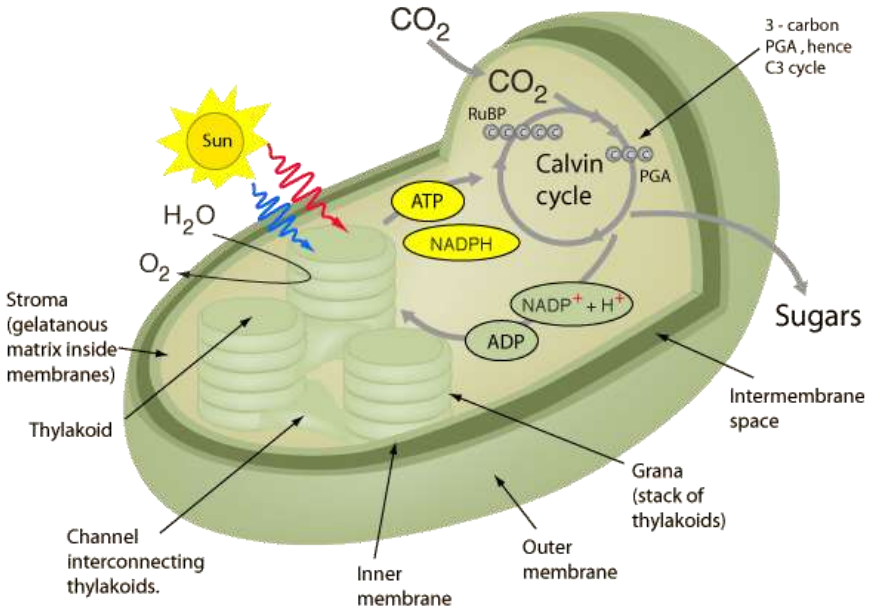
Phases:

- 1- Carbon fixation~ each CO2 is attached to RuBP (rubisco enzyme)
- 2- Reduction~ electrons from NADPH reduces to G3P; ATP used up
- 3- Regeneration~ G3P rearranged to RuBP; ATP used; cycle continues



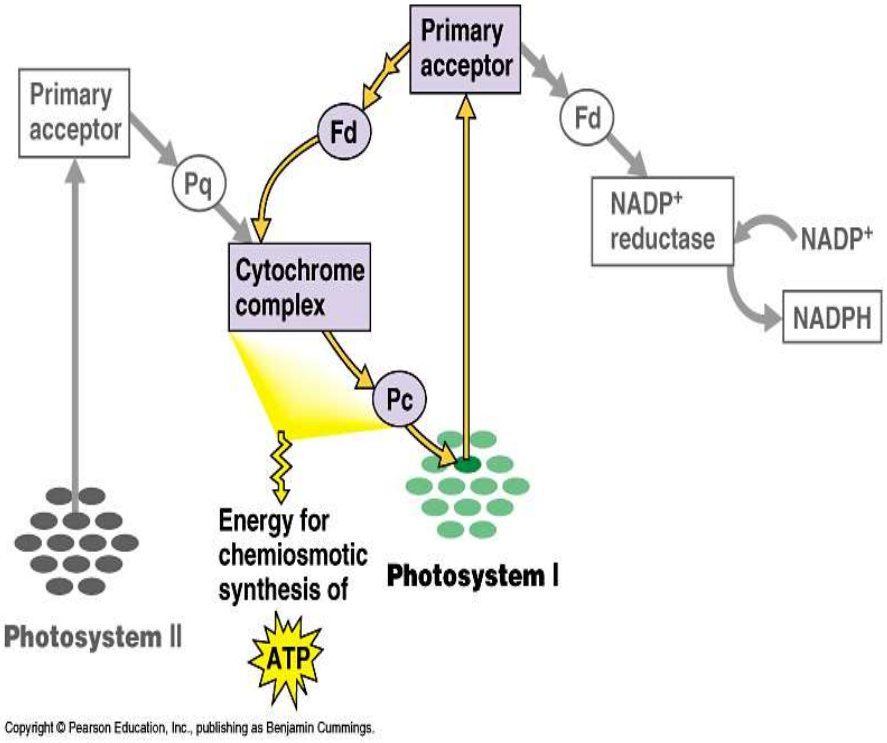
Calvin Cycle, net synthesis

- For each G**3**P (and for **3** CO2)…….
  Consumption of 9 ATP's & 6 NADPH (light reactions regenerate these molecules)
- G**3**P can then be used by the plant to make glucose and other organic compounds



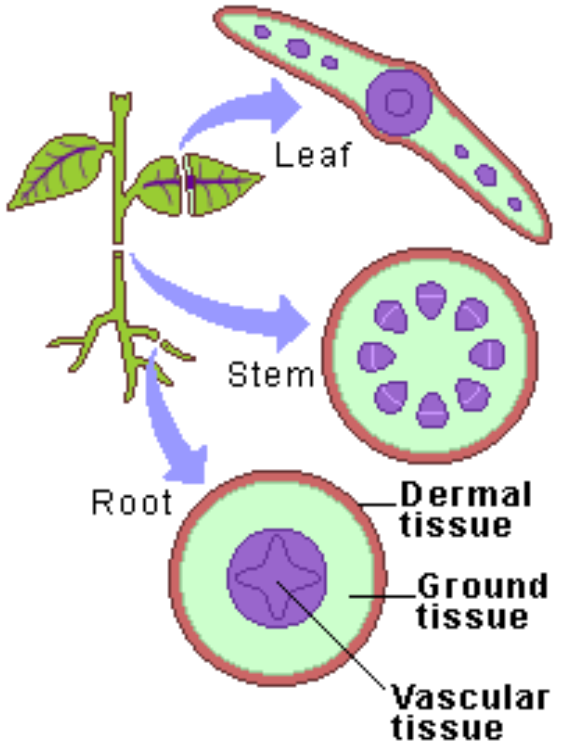
Cyclic electron flow

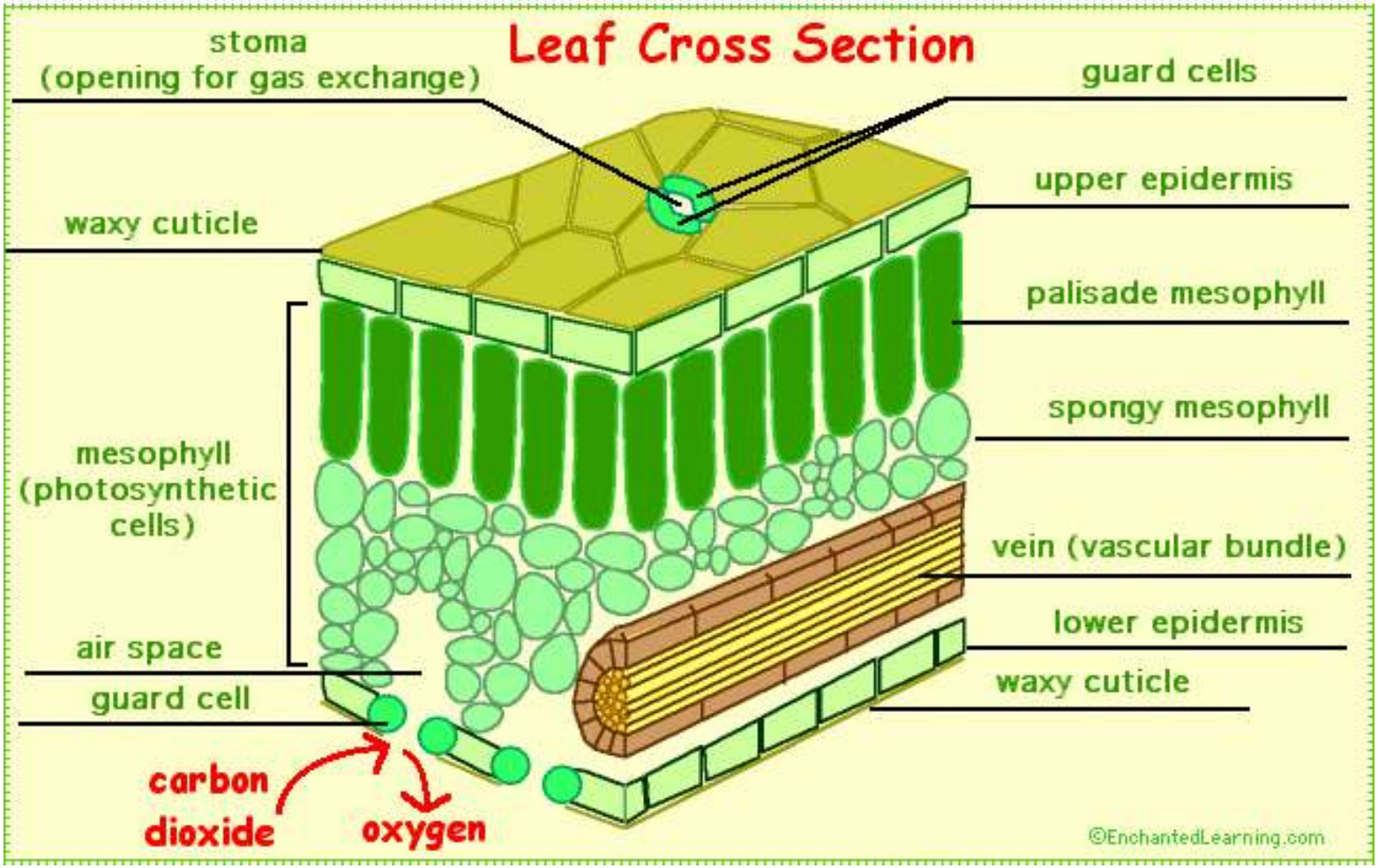
- Alternative cycle when ATP is deficient
- Photosystem I used but not II; produces ATP but no NADPH
- Why? The Calvin cycle consumes more ATP than NADPH…….
- Cyclic photophosphorylation



Plant Tissues

- Vascular
  - transport
- Dermal
  - protection
- Ground
  - Photosynthesis
  - Storage
  - support
  -




Leaf Cross Section
stoma
(opening for gas exchange)
guard cells
upper epidermis
waxy cuticle
palisade mesophyll
spongy mesophyll
mesophyll
(photosynthetic
cells)
vein (vascular bundle)
lower epidermis
air space
waxy cuticle
guard cell
carbon
dioxide
oxygen
©EnchantedLearning.com

Photorespiration

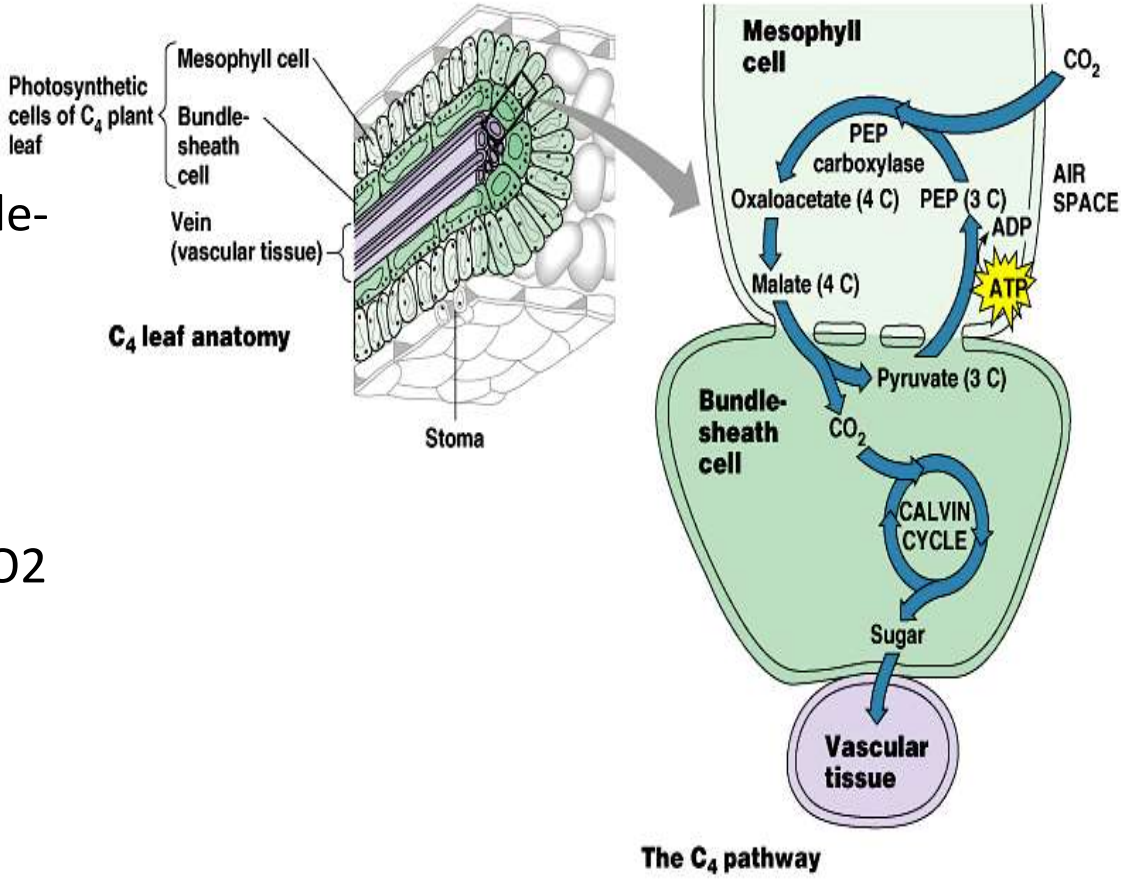
Photorespiration: on hot/dry days; stomata close;no ATP or food generated

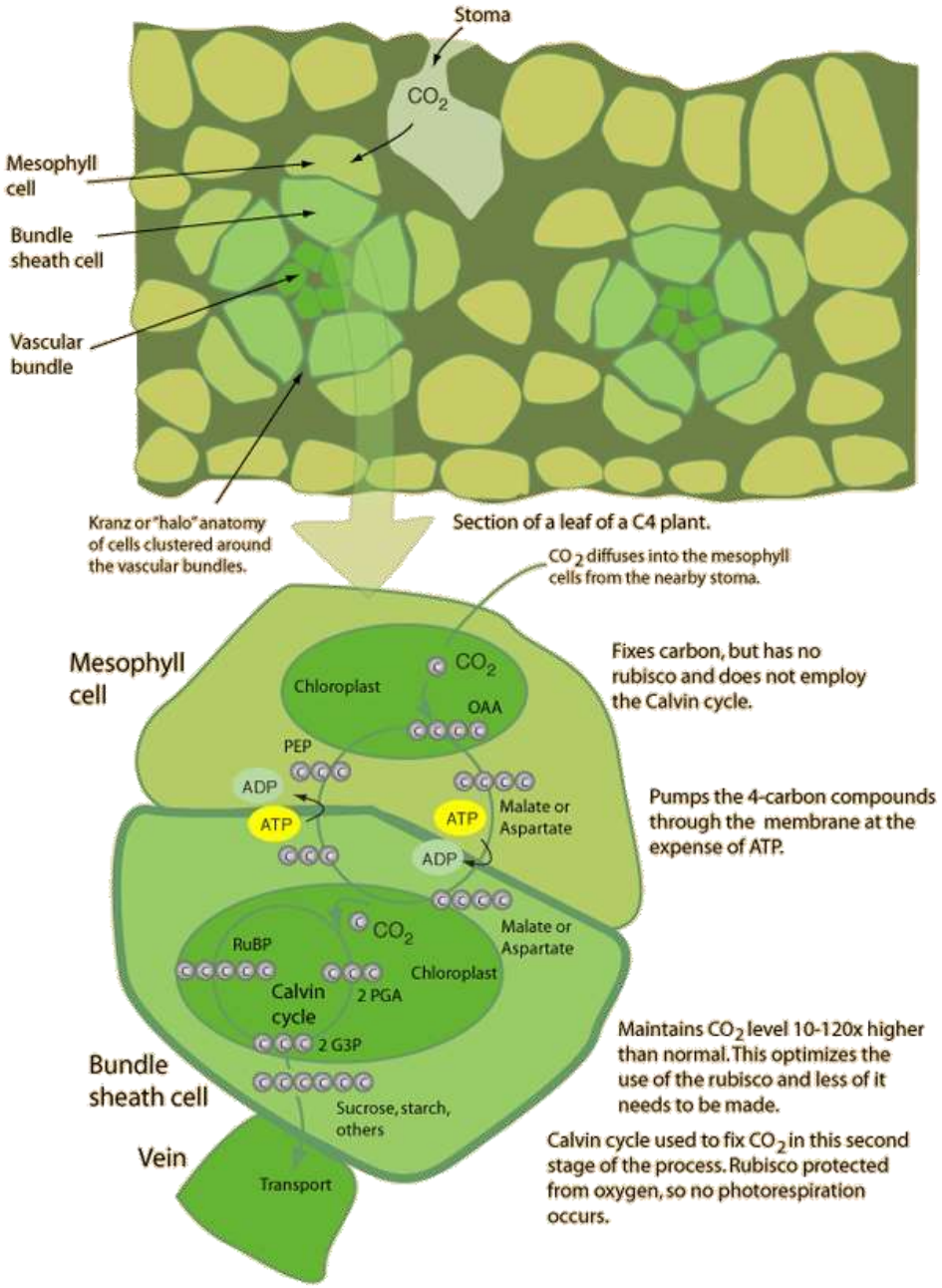
- *Two Solutions…..*

Alternative carbon fixation methods, I

C4 plants:

- 2 photosynthetic cells, bundle-sheath & mesophyll;
- PEP carboxylase (instead of rubisco)
- fixes CO2 in mesophyll;
- new 4C molecule releases CO2
- Happens in: grasses (monocots) like maize and sugarcane




Stoma
CO_2
Mesophyll cell
Bundle sheath cell
Vascular bundle
Kranz or "halo" anatomy of cells clustered around the vascular bundles.
Section of a leaf of a C4 plant.
CO_2 diffuses into the mesophyll cells from the nearby stoma.
Mesophyll cell
Chloroplast
CO_2
OAA
Fixes carbon, but has no rubisco and does not employ the Calvin cycle.
PEP
ADP
ATP
ATP
Malate or Aspartate
Pumps the 4-carbon compounds through the membrane at the expense of ATP.
ADP
CO_2
Malate or Aspartate
RuBP
Chloroplast
Calvin cycle
2 PGA
2 G3P
Maintains CO_2 level 10-120x higher than normal. This optimizes the use of the rubisco and less of it needs to be made.
Bundle sheath cell
Sucrose, starch, others
Vein
Transport
Calvin cycle used to fix CO_2 in this second stage of the process. Rubisco protected from oxygen, so no photorespiration occurs.

Location

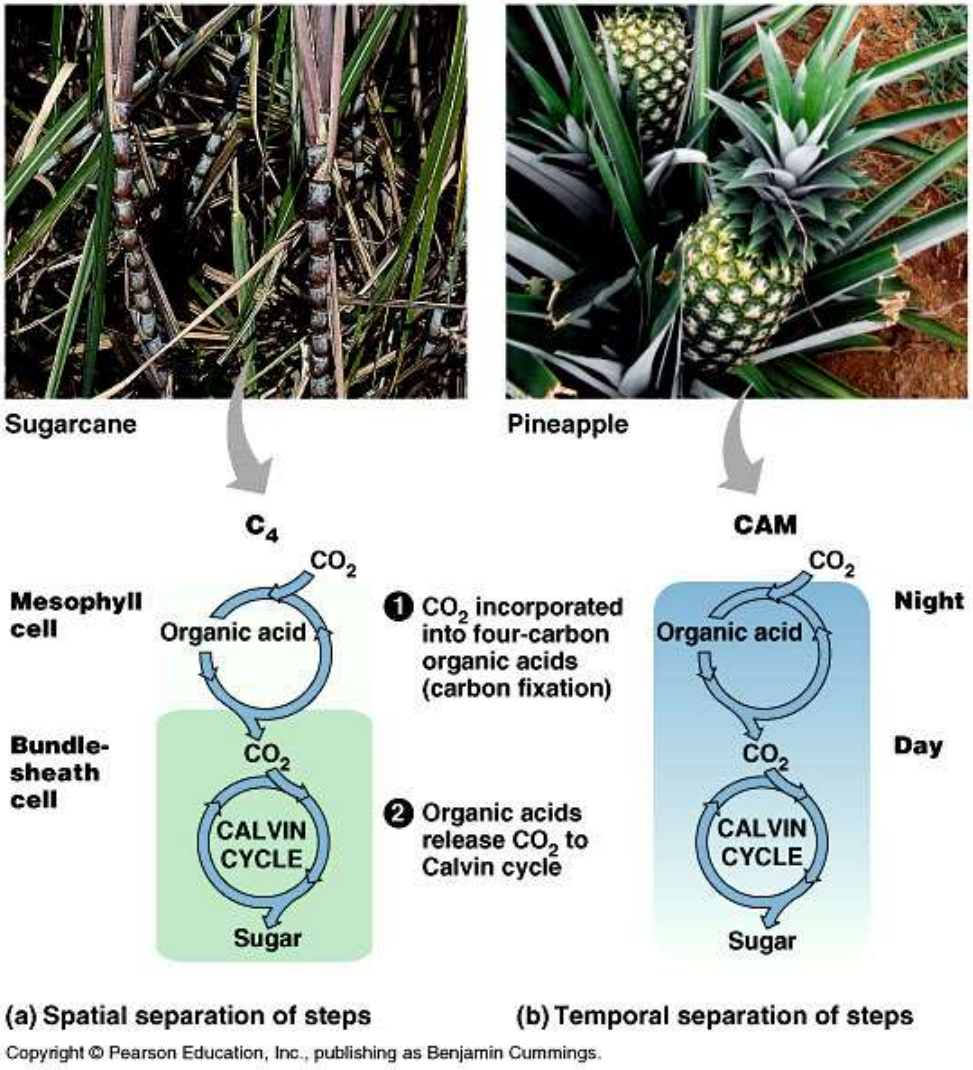
Alternative carbon fixation methods, II

CAM plants:

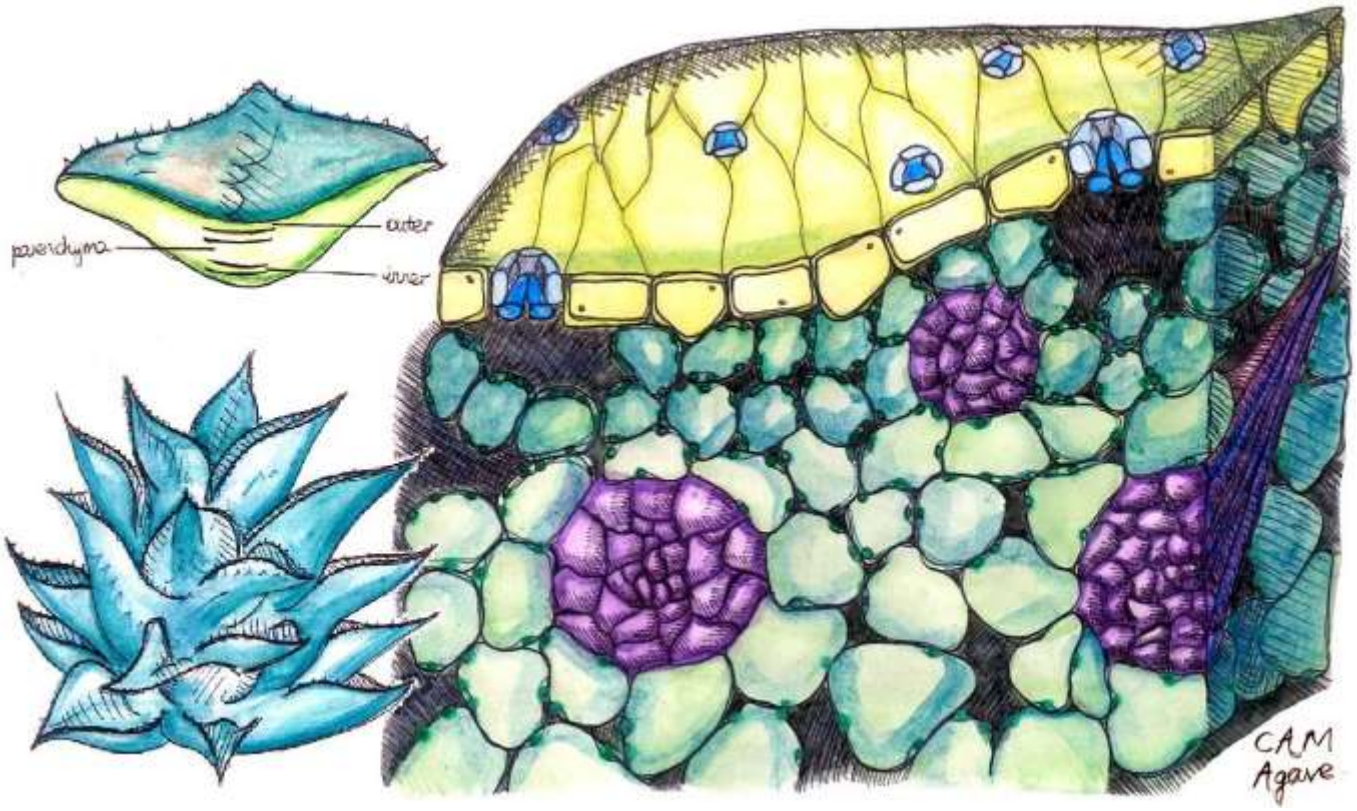
open stomata during night, close during day

(crassulacean acid metabolism);

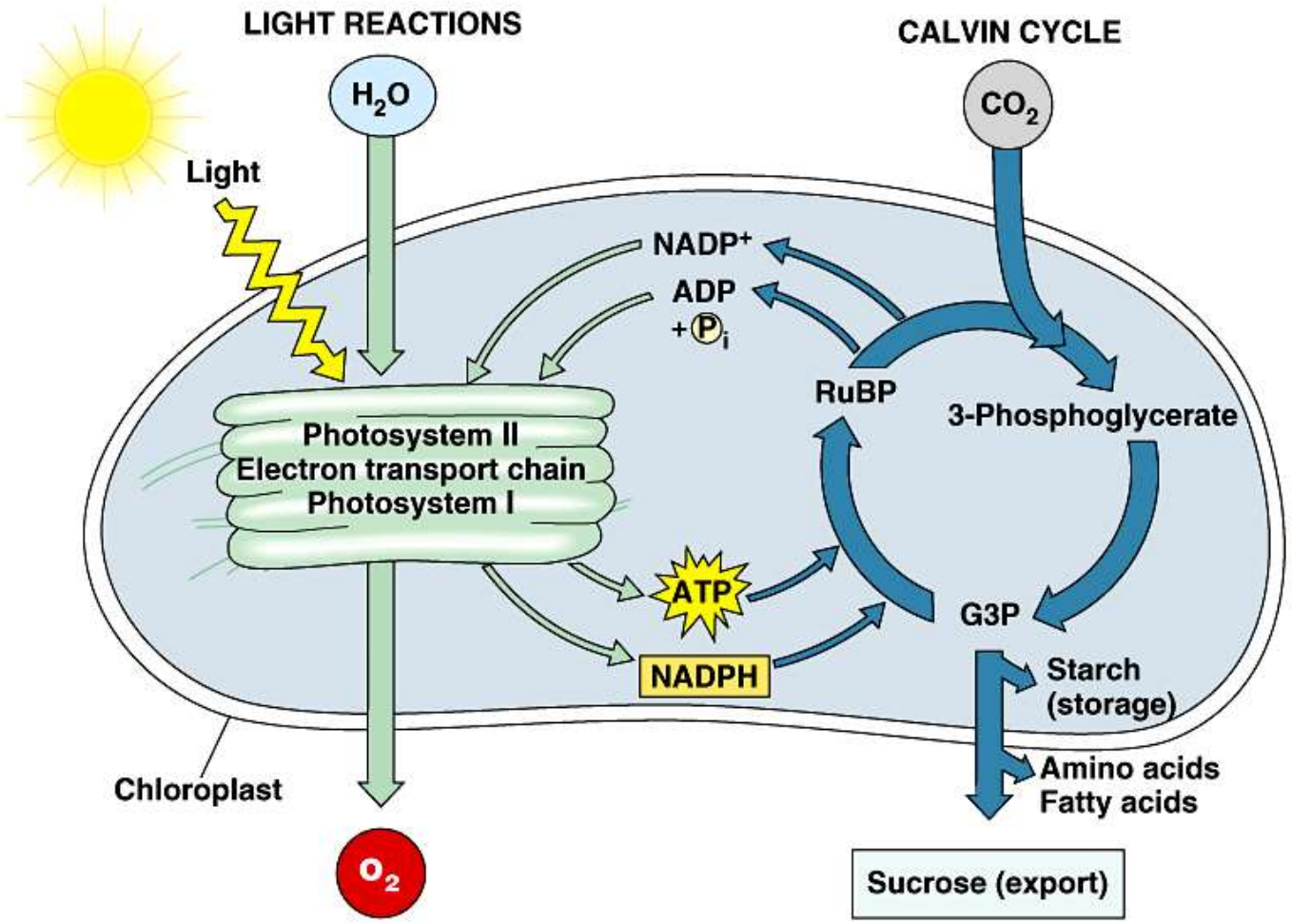
cacti, pineapples, etc.



CAM Photosynthesis in Agave



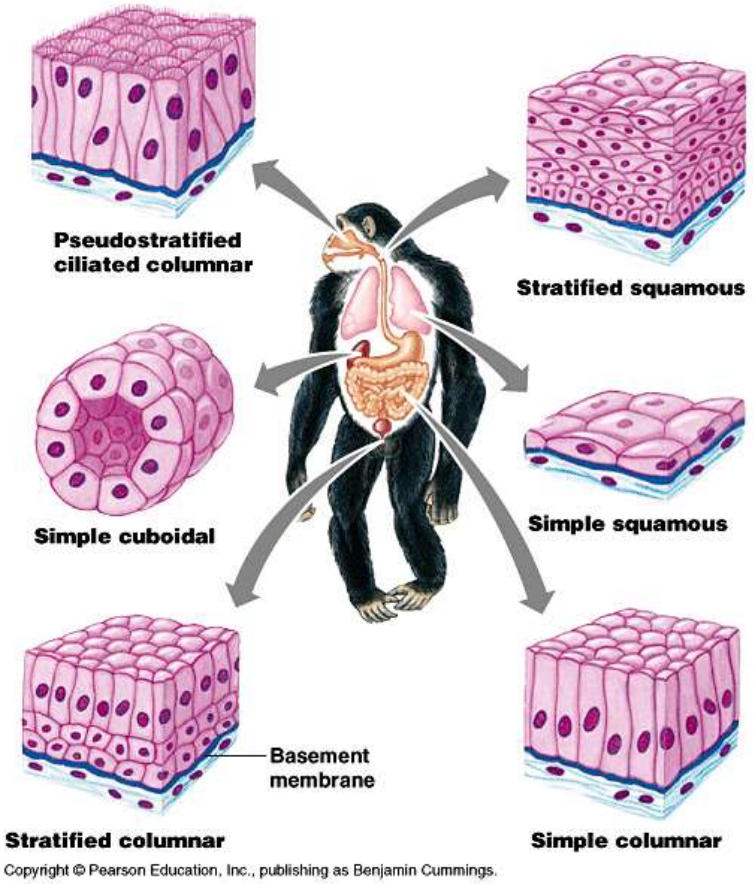
A review of photosynthesis



- Chapter 43
- *An Introduction to Animal Structure and Function*

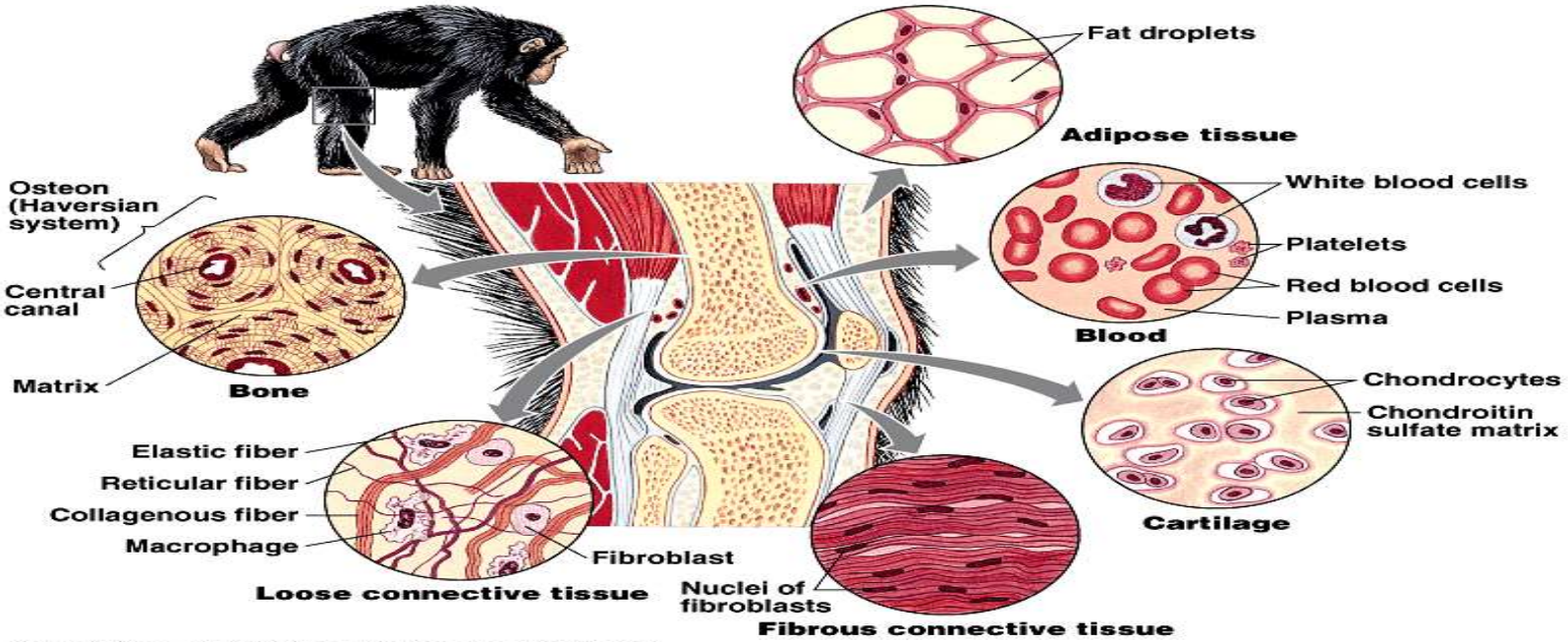
Tissues: groups of cells with a common structure and function (4 types)

- *Anatomy*: structure
- *Physiology*: function
- <u>1- Epithelial:</u> outside of body and lines organs and cavities; held together by tight junctions
- *basement membrane*: dense mat of extracellular matrix
- Simple: single layer of cells
- Stratified: multiple tiers of cells
- Cuboidal (like dice)
- Columnar (like bricks on end)
- Squamous (like floor tiles)
- mucous membrane



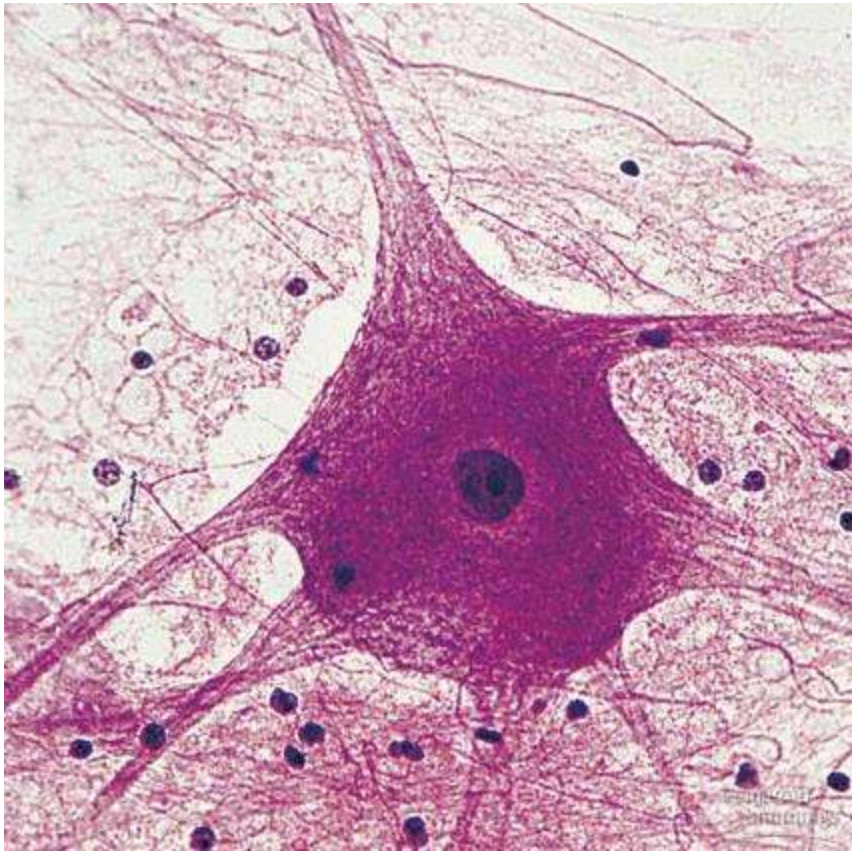
Tissues, II

- <u>2- Connective:</u> bind and support other tissues; scattered cells through matrix; 3 kinds:
- A-Collagenous fibers (collagen protein) B-Elastic fibers (elastin protein) C-Reticular fibers (thin branched collagen fibers)
- <u>Loose connective tissue:</u> binds epithelia to underlying tissue; holds organs
- 1-Fibroblasts- secretes extracellular proteins 2-Macrophages- amoeboid WBC's; phagocytosis 3-Adipose tissue- fat storage; insulation
- <u>Fibrous connective tissue:</u> parallel bundles of cells
- 1-Tendons- muscles to bones 2-Ligaments- bones to bones; joints (*BOBOL*I)
- <u>Cartilage</u>: collagen in a rubbery matrix (*chondroitin*); flexible support
- <u>Bone</u>: mineralized tissue by *osteoblasts*
- Blood: liquid plasma matrix; *erythrocytes* (RBC's) carry O2; *leukocytes* (WBC's) immunity



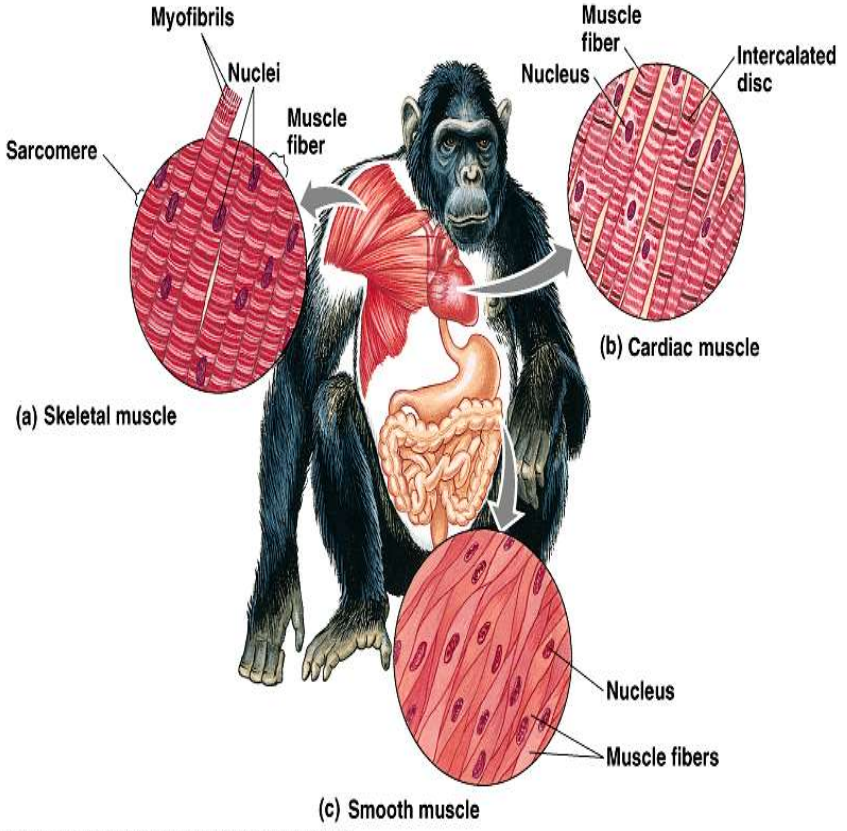
Tissues, III

- 3-Nervous: senses stimuli and transmits signals from 1 part of the animal to another
- *Neuron*: functional unit that transmits impulses
- *Dendrites*: transmit impulses from tips to rest of neuron
- *Axons*: transmit impulses toward another neuron or effector



Tissues, IV

- 4- Muscle: capable of contracting when stimulated by nerve impulses; myofibrils composed of proteins actin and myosin; 3 types:
- A- *Skeletal*: voluntary movement (striated)
- B- *Cardiac*: contractile wall of heart (branched striated)
- C- *Smooth*: involuntary activities (no striations)



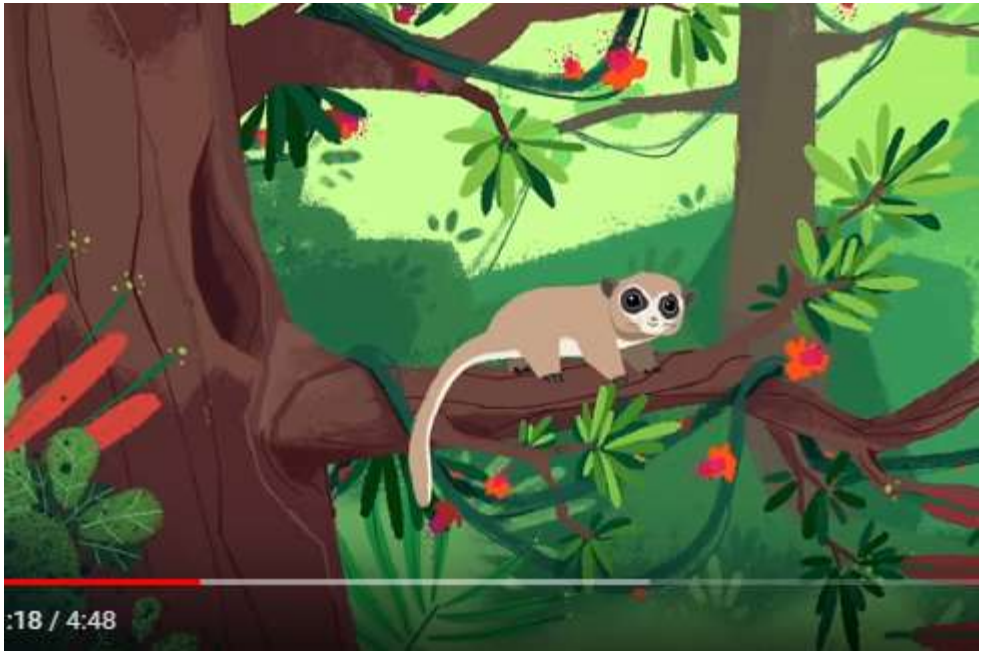
Organ systems

- Organ: organization of tissues
- Mesentaries: suspension of organs (connective tissue)
- Thoracic cavity (lungs and heart)
- Abdominal cavity (intestines)
- Diaphragm (respiration)
- Organ systems……

- *Digestive*-food processing
- *Circulatory*-internal distribution
- *Respiratory*-gas exchange
- *Immune/Lymphatic*-defense
- *Excretory*-waste disposal; osmoregulation
- *Endocrine*-coordination of body activities
- *Reproductive*-reproduction
- *Nervous*-detection of stimuli
- *Integumentary*-protection
- *Skeletal*-support; protection
- *Muscular*-movement; locomotion

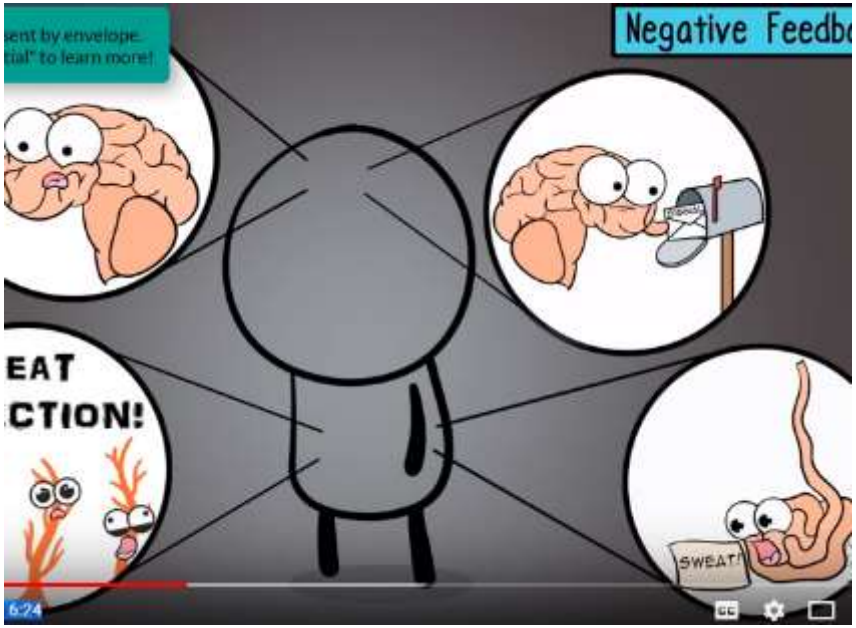
Hibernation vs Sleep

- https://ed.ted.com/lessons/what-s-the-difference-between-hibernation-and-sleep-sheena-faherty



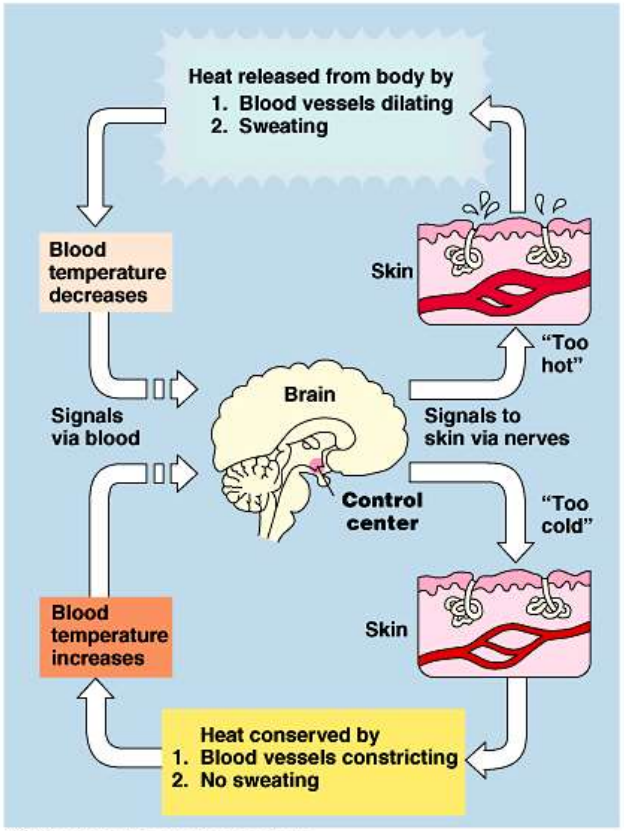
Homeostasis and Feedback

- https://www.youtube.com/watch?v=Iz0Q9nTZCw4



Internal regulation

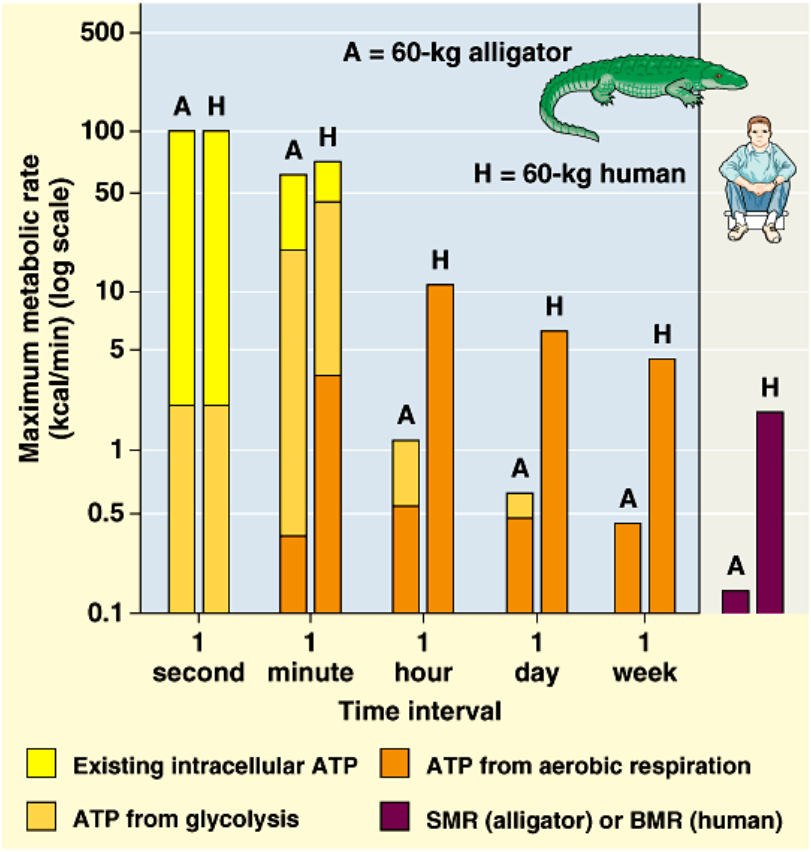
- *Homeostasis*: “steady state” or internal balance
- *Negative feedback*: change in a physiological variable that is being monitored triggers a response that counteracts the initial fluctuation; i.e., body temperature
- *Positive feedback*: physiological control mechanism in which a change in some variable triggers mechanisms that amplify the change; i.e., uterine contractions at childbirth



(b) Control of body temperature

Metabolism: sum of all energy-requiring biochemical reactions

- Catabolic processes of cellular respiration
- Calorie; kilocalorie/C
- *Endotherms*: bodies warmed by metabolic heat
- *Ectotherms*: bodies warmed by environment
- *Basal Metabolic Rate* (BMR): minimal rate powering basic functions of life (endotherms)
- *Standard Metabolic Rate* (SMR): minimal rate powering basic functions of life (ectotherms)



QOD?

- What are the costs and benefits of maintaining homeostasis?

A Scientific Sea Shanty: Banting's Imparted Years

https://www.youtube.com/watch?v=He7X5jGt8lY

Vocabulary for concept map

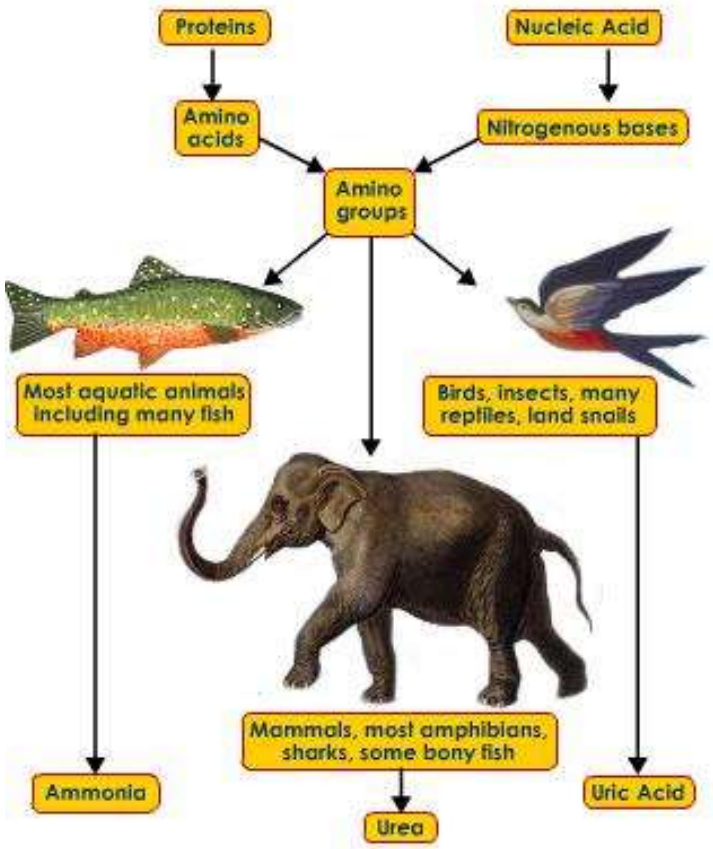
- Fever
- Hibernation
- Torpor
- thermogenesis
- Endotherm
- Ectotherm
- Evaporation

- convection
- Conduction
- Positive feedback
- Negative feedback
- Dynamic equilibrium
- Stimulus
- Response
- Sensor

Lecture #19 Date_____

- Chapter 44 ~ *Regulating the Internal Environment*

QOD



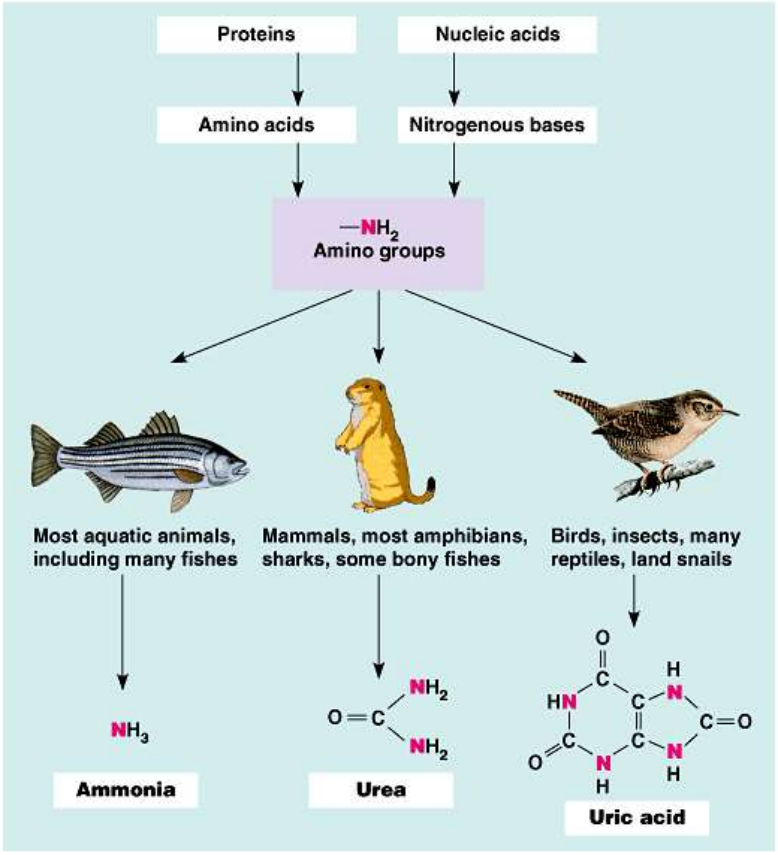
- Nitrogenous waste can be excreted in several forms. List three and give the evolutionary purpose that it serves while explaining what animal might excrete this waste.

Homeostasis: regulation of internal environment

- Thermoregulation internal temperature
- Osmoregulation solute and water balance
- Excretion nitrogen containing waste

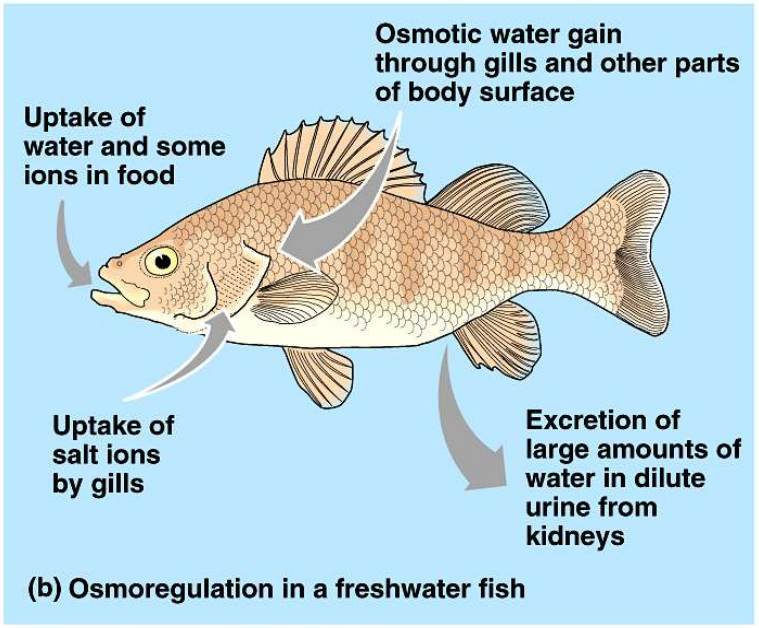
Water balance and waste disposal

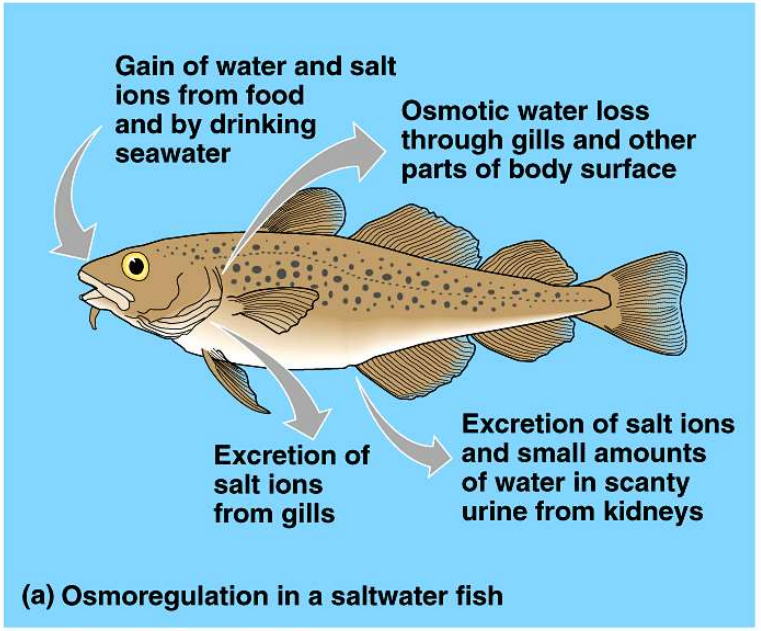
- Osmoregulation:
  management of the body's water content and solute composition
- Nitrogenous wastes:
  breakdown products of proteins and nucleic acids; ammonia-very toxic
- Deamination~
- Ammonia: most aquatic animals,
  many fish
- Urea: mammals, most amphibians,
  sharks, bony fish (in liver;
  combo of NH_3 and CO_2)
- Uric acid: birds, insects, many
  reptiles, land snails



Osmoregulators

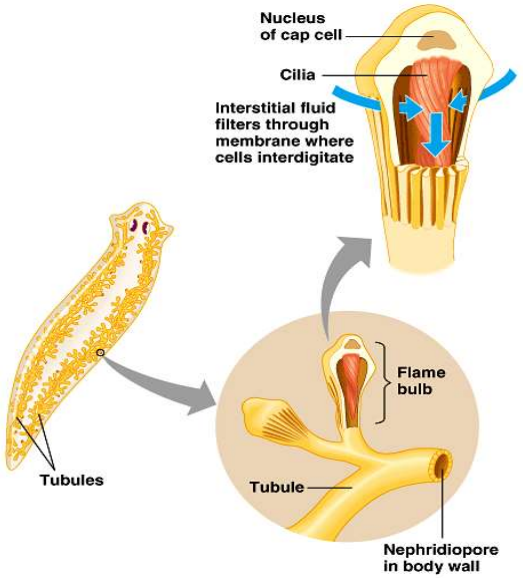
- Osmoconformer: no active adjustment of internal osmolarity (marine animals); isoosmotic to environment
- Osmoregulator: adjust internal osmolarity (freshwater, marine, terrestrial)
- Freshwater fishes (hyperosmotic)- gains water, loses; excretes large amounts of urine salt vs. marine fishes (hypoosmotic)- loses water, gains salt; drinks large amount of saltwater

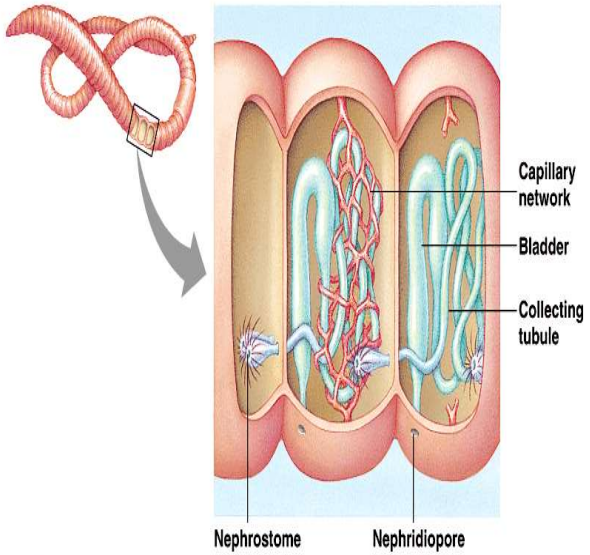


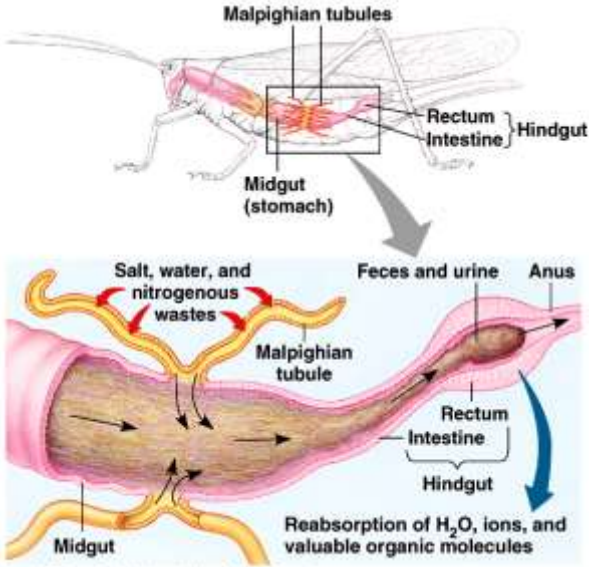


Excretory Systems

- Production of urine by 2 steps: • Filtration (nonselective) • Reabsorption (secretion of solutes)
- Protonephridia ~ flatworms (“flame-bulb” systems)
- Metanephridia ~ annelids (ciliated funnel system)
- Malpighian tubules ~ insects (tubes in digestive tract)
- Kidneys ~ vertebrates

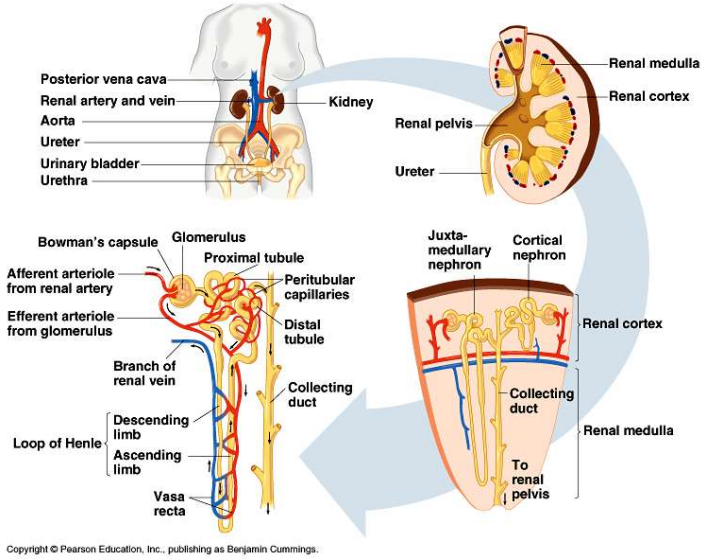






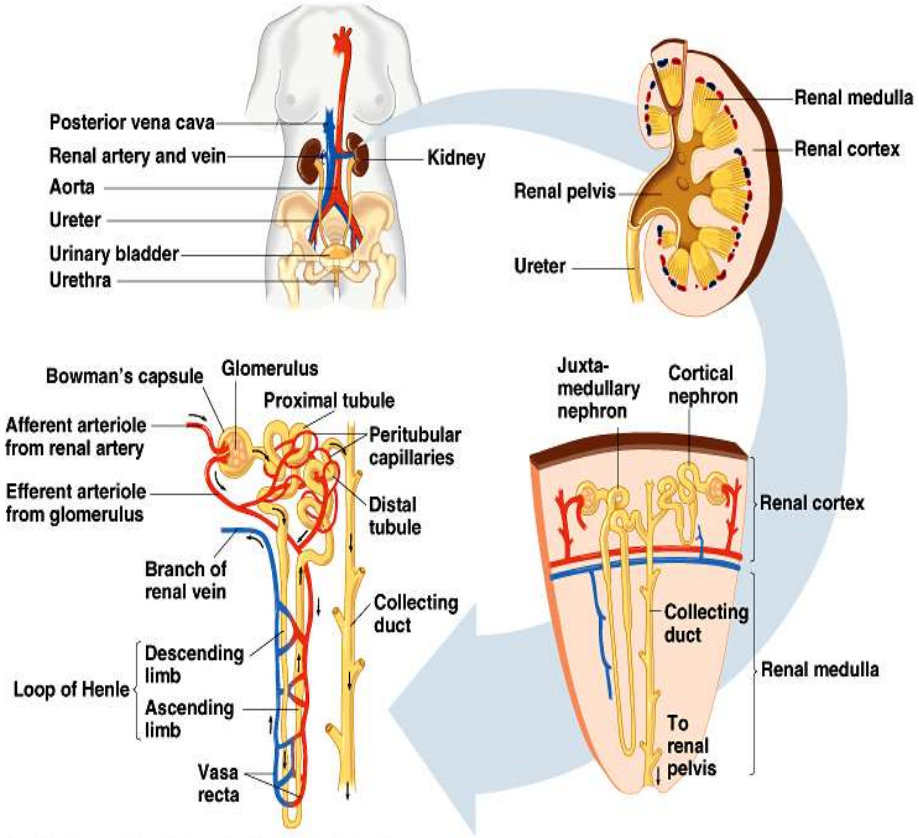
Nephron Structure

- Afferent arteriole: supplies blood to nephron from renal artery
- Glomerulus: ball of capillaries
- Efferent arteriole: blood from glomerulus
- Bowman's capsule:surrounds glomerulus
- Proximal tubule: secretion & reabsorption
- Peritubular capillaries: from efferent arteriole; surround proximal & distal tubules
- Loop of Henle: water & salt balance
- Distal tubule: secretion & reabsorption
- Collecting duct: carries filtrate to renal pelvis



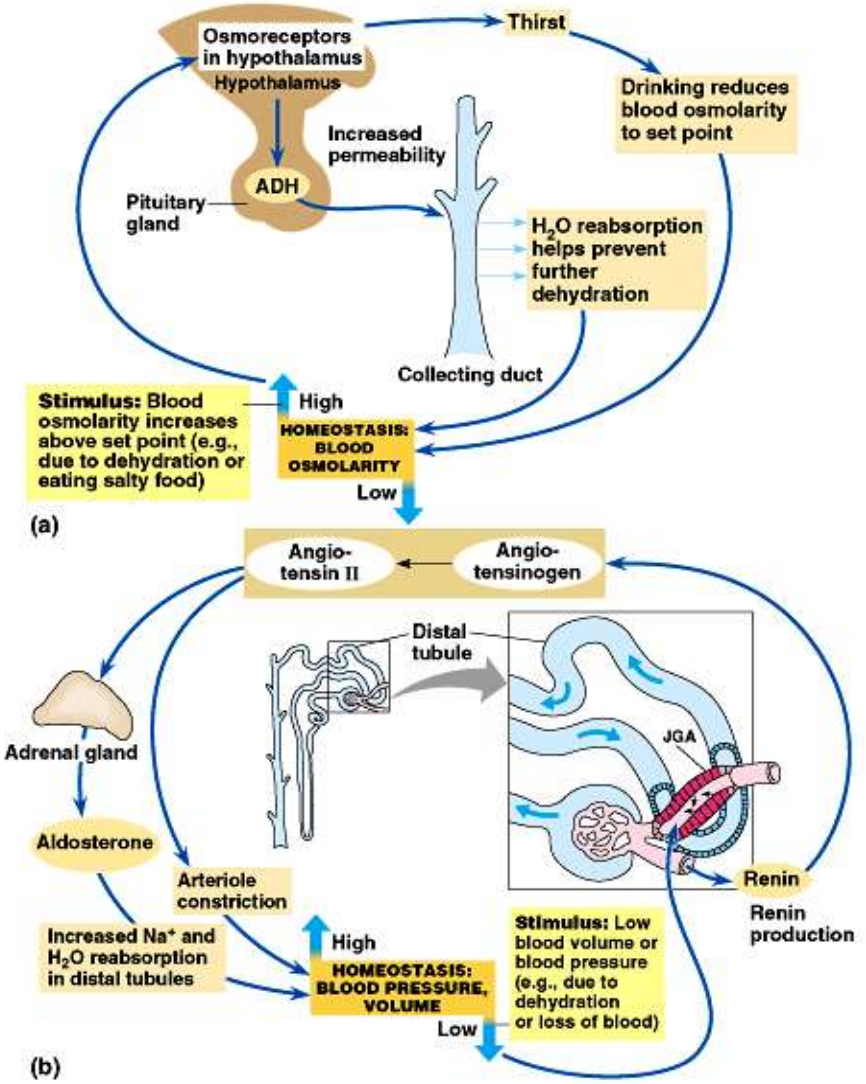
Kidney Functional Units

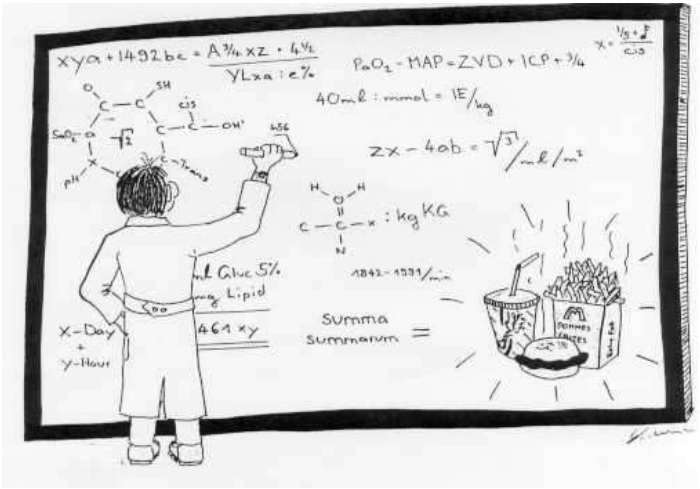
- Renal artery/vein: kidney blood flow
- Ureter: urine excretory duct
- Urinary bladder: urine storage
- Urethra: urine elimination tube
- Renal cortex (outer region)
- Renal medulla (inner region)
- Nephron: functional unit of kidney
- Cortical nephrons (cortex; 80%)
- Juxtamedullary nephrons (medulla; 20%)



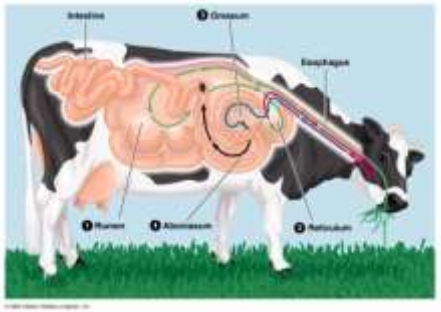
Kidney regulation: hormones

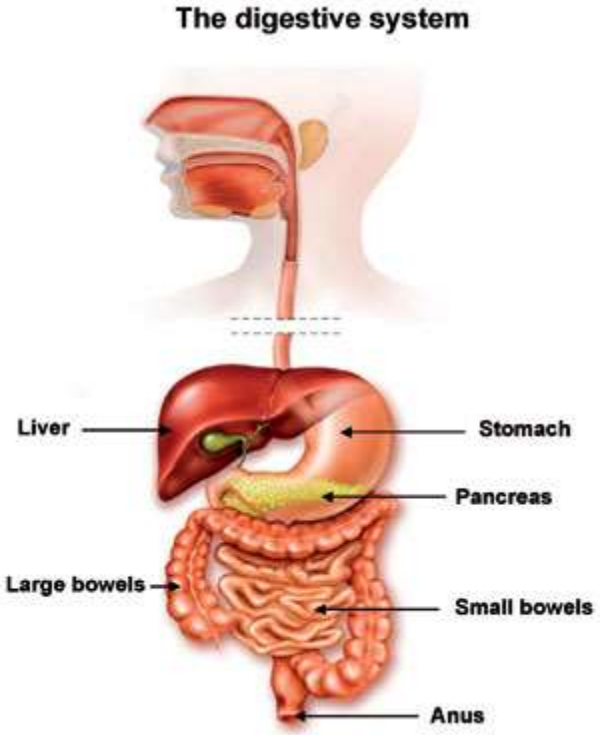
- **Antidiuretic hormone (ADH)** ~ secretion increases permeability of distal tubules and collecting ducts to water (H2O back to body); inhibited by alcohol and coffee
- **Juxtaglomerular apparatus (JGA)** ~ reduced salt intake--->enzyme renin initiates conversion of angiotension (plasma protein) to angiotension II (peptide); increase blood pressure and blood volume by constricting capillaries
- **Angiotension II** also stimulates adrenal glands to secrete aldosterone; acts on distal tubules to reabsorb more sodium, thereby increasing blood pressure (renin-angiotension-aldosterone system; RAAS)
- **Atrial natriuretic factor (ANF)** ~ walls of atria; inhibits release of renin, salt reabsorption, and aldosterone release



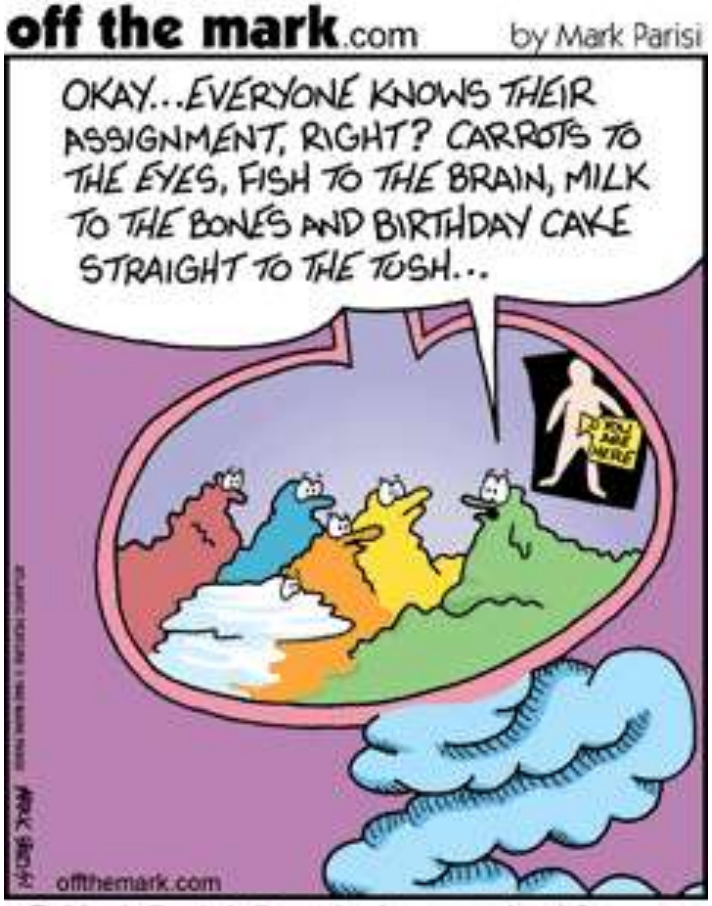


- *Animal Nutrition*





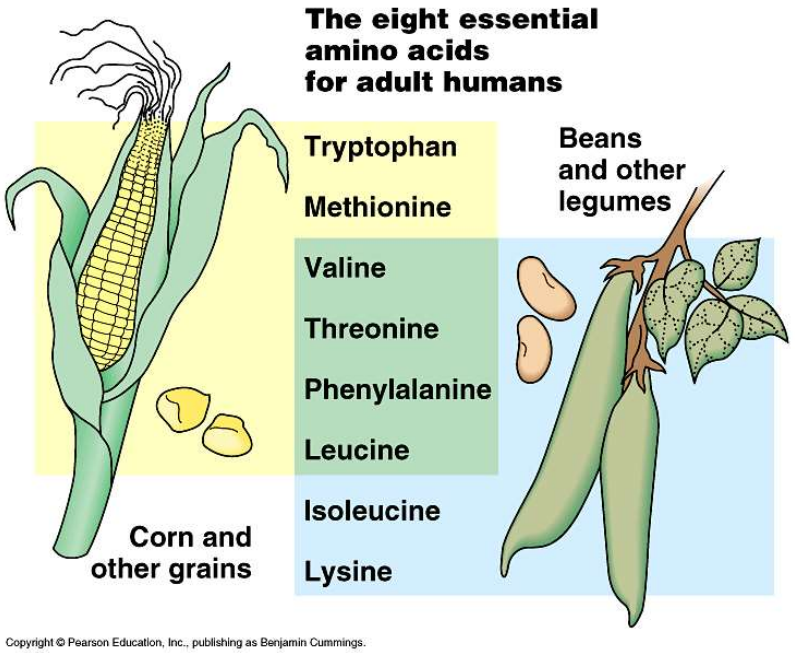
QOD



For a cheeseburger, list the organic macromolecules that make up each part.

Nutritional requirements

- *Undernourishment*: caloric deficiency
- *Overnourishment* (obesity): excessive food intake
- *Malnourishment*: essential nutrient deficiency
- *Essential nutrients*: materials that must be obtained in preassembled form
- *Essential amino acids*: the 8 amino acids that must be obtained in the diet
- *Essential fatty acids*: unsaturated fatty acids
- *Vitamins*: organic coenzymes
- *Minerals*: inorganic cofactors



Food types/feeding mechanisms

Opportunistic

Herbivore: eat autotrophs

Carnivore: eat other animals

Omnivore: both

Feeding Adaptations

Suspension-feeders: sift food from water (baleen whale)

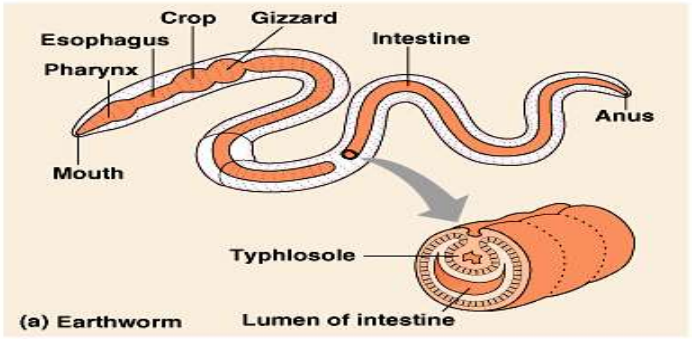
Substrate-feeders: live in or on their food (leaf miner) (earthworm: *deposit-feeder*)

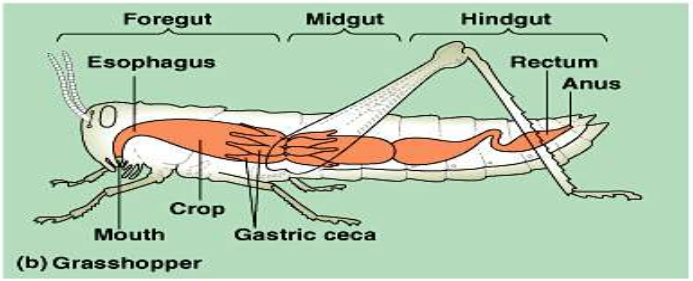
Fluid-feeders: suck fluids from a host (mosquito)

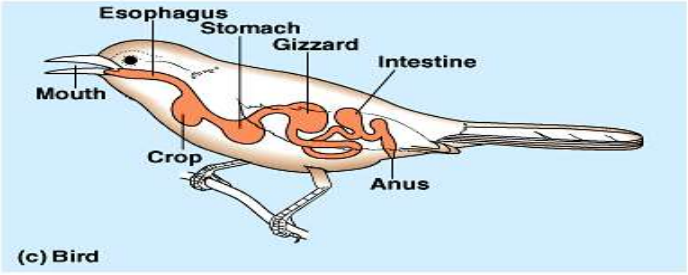
Bulk-feeders: eat large pieces of food (most animals)

Overview of food processing

- 1-Ingestion: act of eating
- 2-Digestion: process of food break down
- *enzymatic hydrolysis*
- *intracellular*: breakdown within cells (sponges)
- *extracellular*: breakdown outside cells (most animals)
- alimentary canals (digestive tract)
- 3- Absorption: cells take up small molecules
- 4- Elimination: removal of undigested material

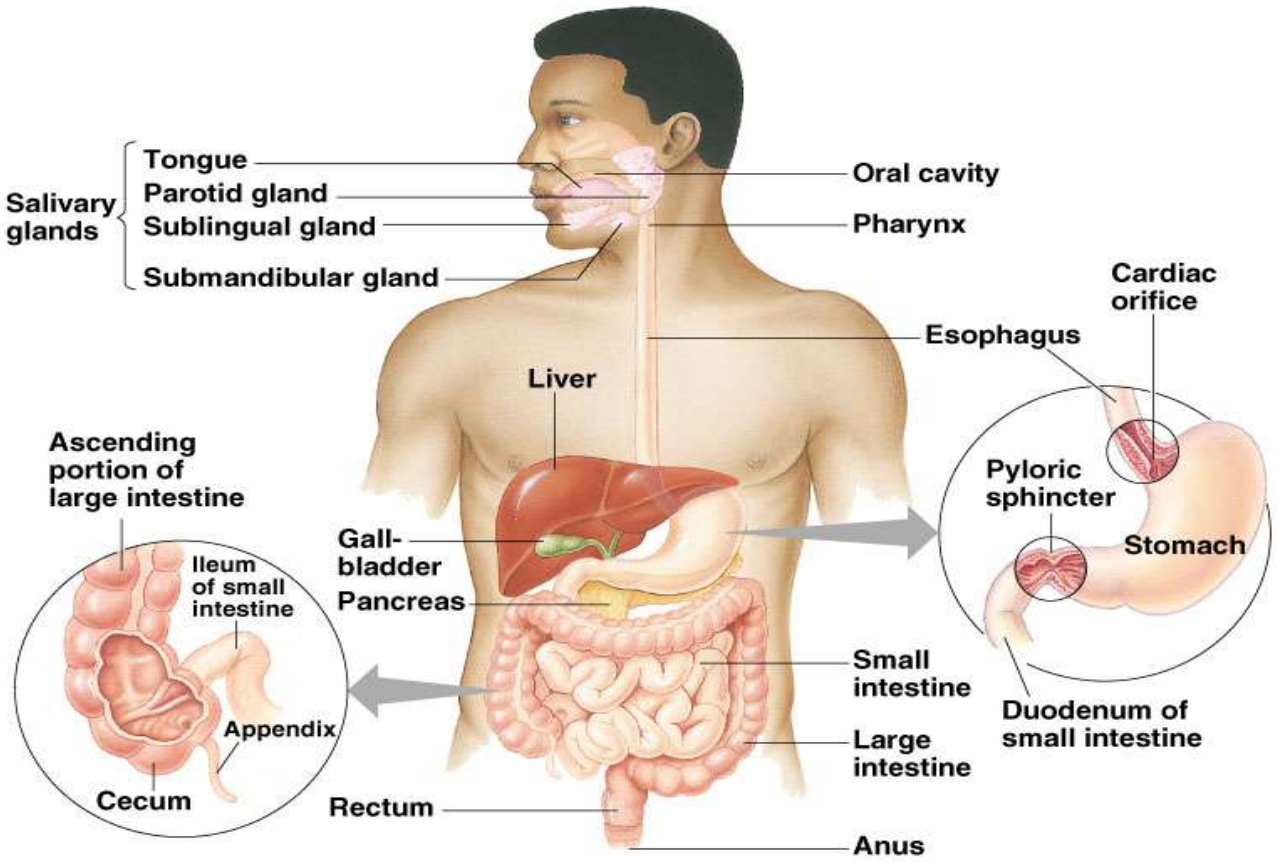






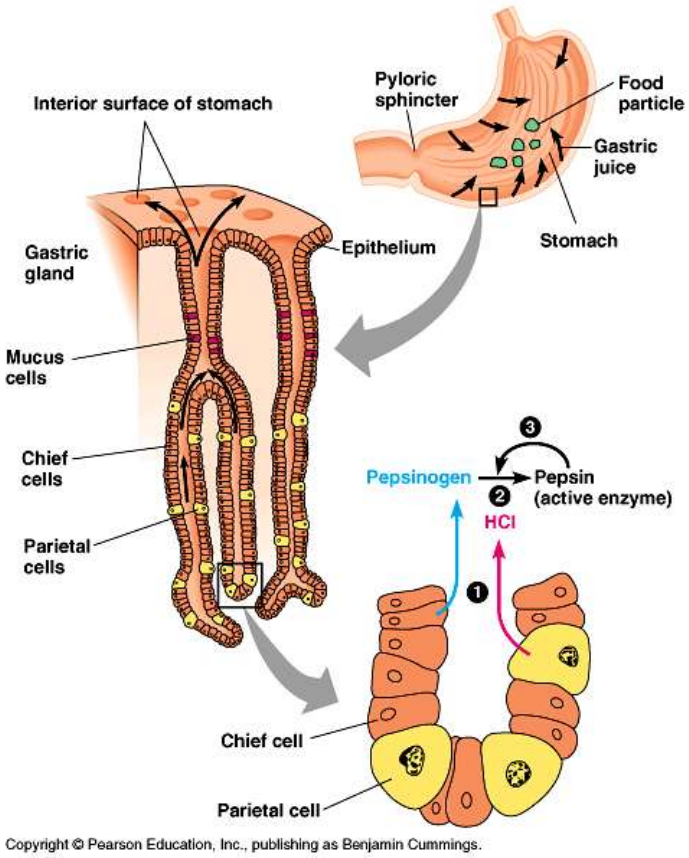
Mammalian digestion, I

- Peristalsis: rhythmic waves of contraction by smooth muscle
- Sphincters: ring-like valves that regulate passage of material
- Accessory glands: salivary glands; pancreas; liver; gall bladder



Mammalian digestion, II

- Oral cavity
  - •salivary amylase
  - •bolus
- Pharynx
  - •epiglottis
- Esophagus
- Stomach
  - •gastric juice (HCl)
  - •pepsin/pepsinogen
  - •acid chyme
  - •pyloric sphincter



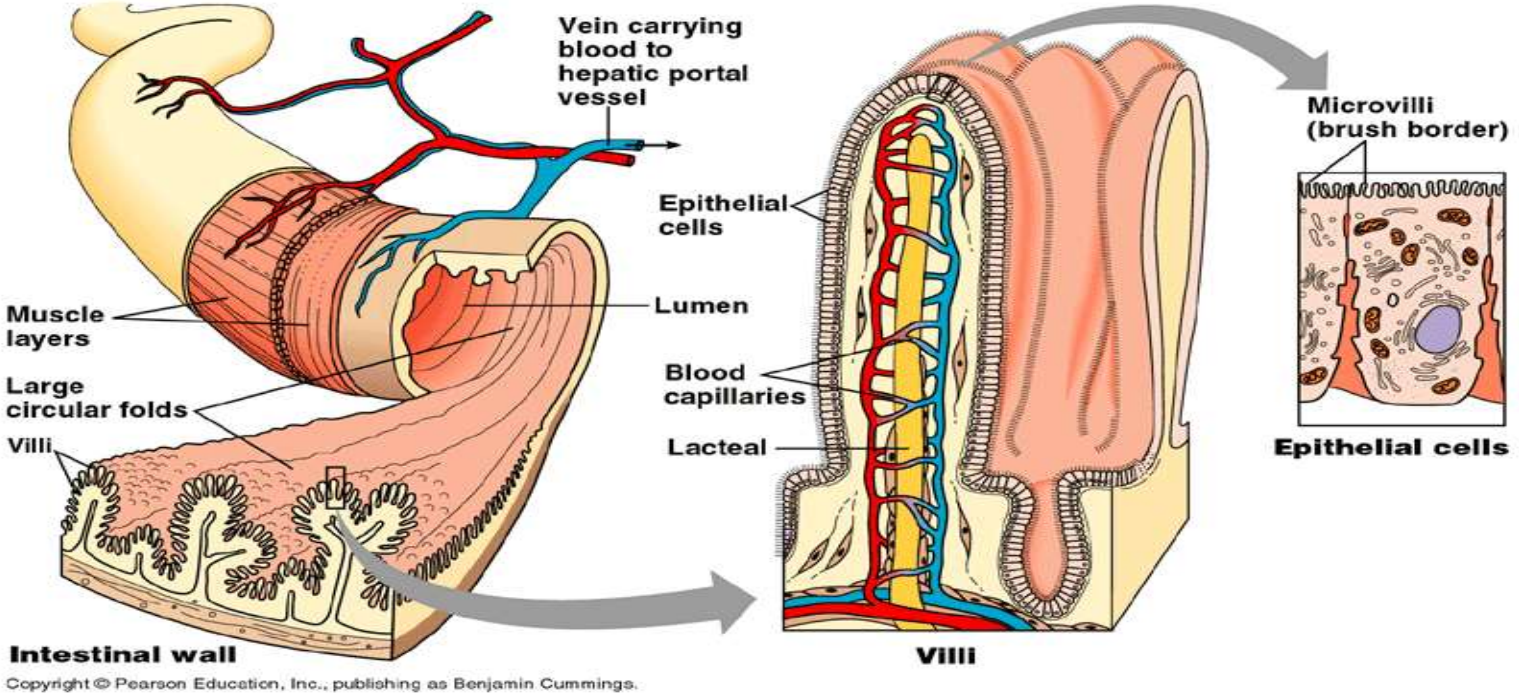
Mammalian digestion, III

- Small intestine •duodenum •bile
- Intestinal digestion: a-carbohydrate b-protein c- nucleic acid d-fat

	(a) Carbohydrate digestion	(b) Protein digestion	(c) Nucleic acid digestion	(d) Fat digestion
Oral cavity, pharynx, esophagus	Polysaccharides (starch, glycogen) ↓ **Salivary amylase** Smaller polysaccharides, maltose			
Stomach		Proteins ↓ **Pepsin** Small polypeptides		
Lumen of small intestine	Polysaccharides ↓ **Pancreatic amylases** Maltose and other disaccharides	Polypeptides ↓ **Trypsin, Chymotrypsin** Smaller polypeptides ↓ **Aminopeptidase, Carboxypeptidase** Amino acids	DNA, RNA ↓ **Nucleases** Nucleotides	Fat globules ↓ **Bile salts** Fat droplets (emulsified) ↓ **Lipase** Glycerol, fatty acids, glycerides
Epithelium of small intestine (brush border)	↓ **Disaccharidases** Monosaccharides	Small peptides ↓ **Dipeptidases** Amino acids	↓ **Nucleotidases** Nucleosides ↓ **Nucleosidases** Nitrogenous bases, sugars, phosphates	

Mammalian digestion, IV

- Villi / microvilli
- Lacteal (lymphatic)
- Chylomicrons (fats mixed with cholesterol)
- Hepatic portal vessel

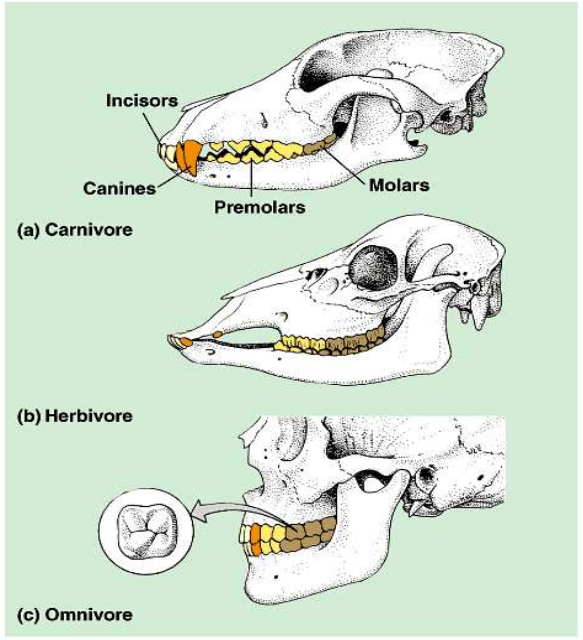


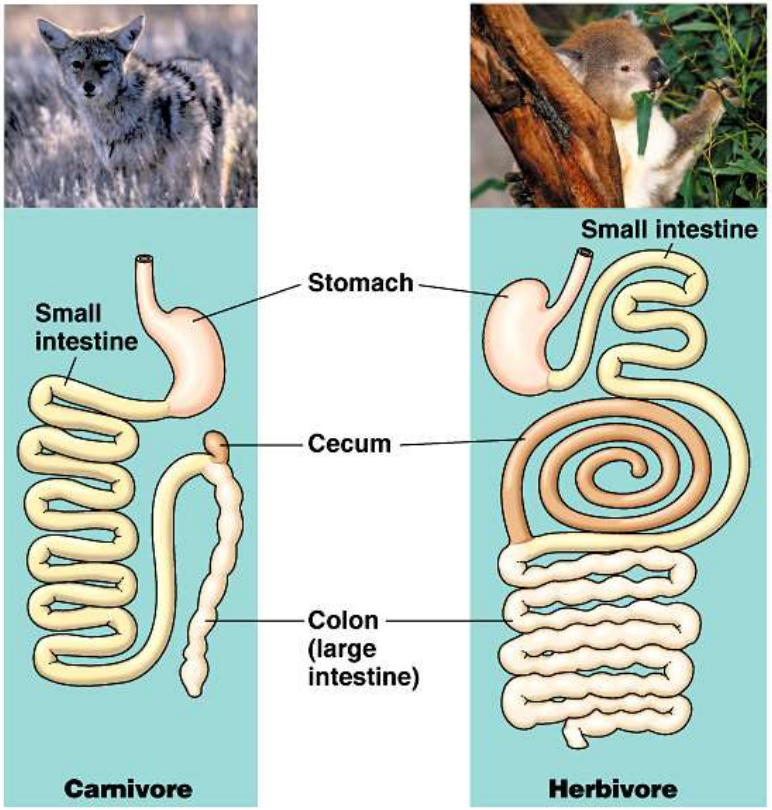
Mammalian digestion, V

- Hormonal Action:
- Gastrin food---> stomach wall ---> gastric juice
- Enterogastrones (duodenum)
- 1-Secretin acidic chyme---> pancreas to release bicarbonate
- 2-Cholecystokinin (CCK) amino/fatty acids---> pancreas to release enzymes and gall bladder to release bile
- Large intestine (colon)
- Cecum
- Appendix
- Feces
- Rectum/anus

Evolutionary adaptations

- Dentition: an animal's assortment of teeth
- Digestive system length
- Symbiosis
- Ruminants





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