Νευροφυσιολογία και Αισθήσεις

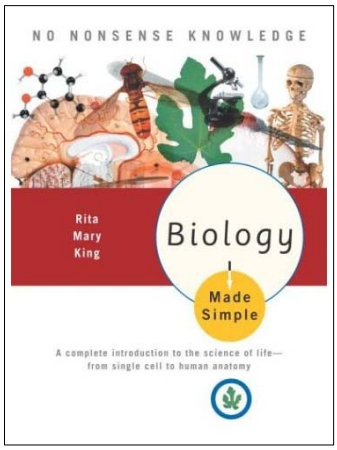
Διάλεξεις 1&2

Φυσιολογία του Κυττάρου – Νευρώνες και Γλοιακά Κύτταρα

(Cell Physiology – Neuron and Glia)

Oh No!

- **What if I never had biology before?**



- Online Courses
  - Carnegie Mellon
    - http://www.cmu.edu/oli/courses/enter_biology.html
  - Palomar College
    - http://waynesword.palomar.edu/bio100.htm

- **Paperback: 208 pages**
- **Publisher: Made Simple Books (Aug 2003)**
- **Language English**
- **ISBN-10: 0767915429**
- **Price: 6 UKP form amazon.co.uk!**

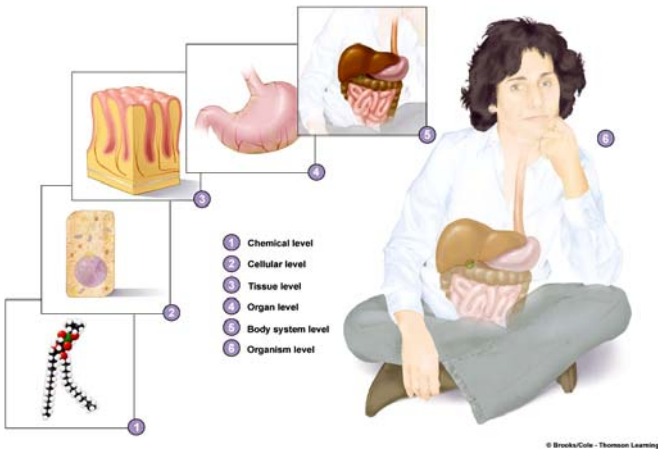
Lecture Objectives

- **Review of cell physiology**
  - Overview of cell structure
  - Major organelles
  - Energy production
  - Membrane structure and cell-to cell adhesions
  - Endocytosis, phagocytosis
- **Tissue/organ/system organization**
- **Homeostasis**

(see notes for more details)

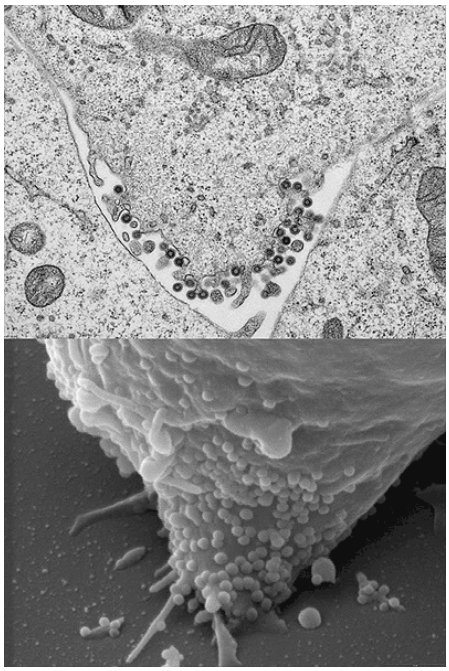
Physiology

- **What is physiology?**
  - Study of the functions of living things
  - Mechanistic approach (vs. teliologic approach)
    - Mechanisms of action instead of results
- **Levels of organization in the body**
  - Molecules
  - Cells (differentiation vs. single cell organisms)
  - Tissues
  - Organs
  - Systems
  - Organisms



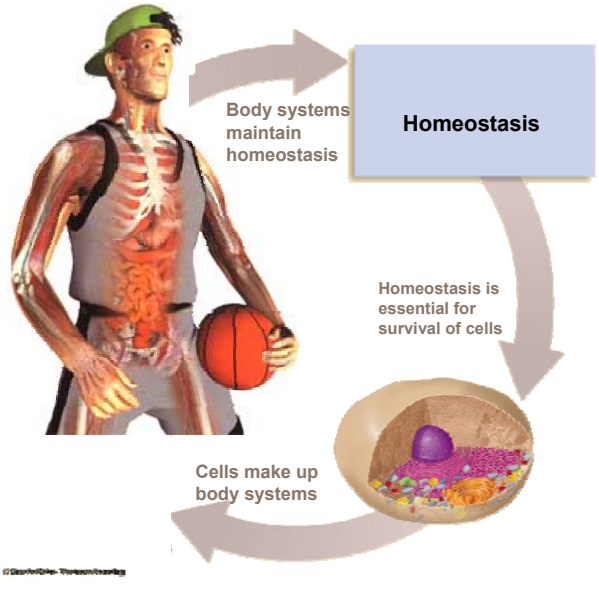
Cells

- **Most cells perform much the same functions**
  - Obtain nutrients and O_2
  - Provide energy from nutrients and O_2
  - Eliminate waste products
  - Synthesize proteins needed fro cell structure, growth and function
  - Control exchange of materials with the local environment
  - Respond to changes in the local environment
  - Reproduce (not all cells)
- **Specialization**
  - Use above functions to perform specific cells (kidney, liver, etc.)



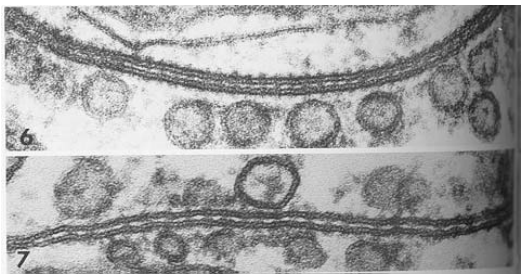
Cell Physiology

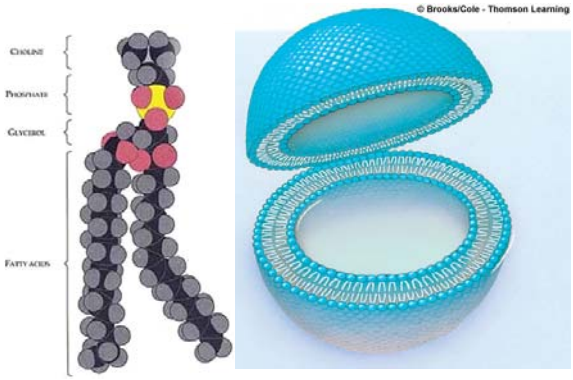
- **Cells are the smallest structural and functional units capable of carrying out life processes**
- **The functional activities of each cell depend on the specific structural properties of the cell**
- **An organisms structure and function depend on the individual and collective characteristics and organization of its cells**
  - Trillions of cells
  - More than 200 types
- **To understand function must study structural components of cells**



Membrane Structure

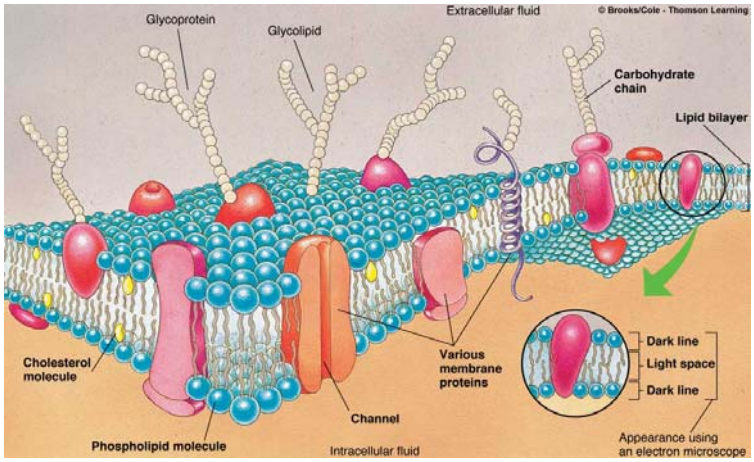
- **Plasma membrane**
  - Fluid lipid bilayer embedded with proteins and cholesterol
- **Phospolipid bilayer**
  - Phospholipids
    - Polar (charged) hydrophilic head
    - Two nonpolar hydrophobic fatty acid chains
  - Assemble in a bilayer which separates two water-based volumes, the ICF and ECF
  - Barrier to passage of water-soluble substances
  - Not solid! “Fluid mosaic surface” → fluidity of membrane





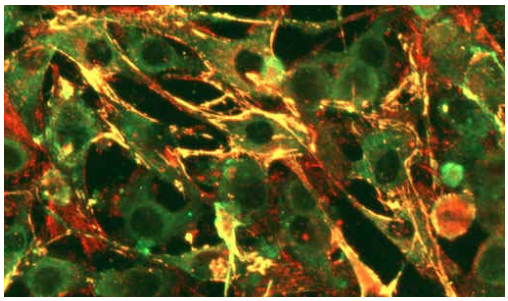
Membrane Structure

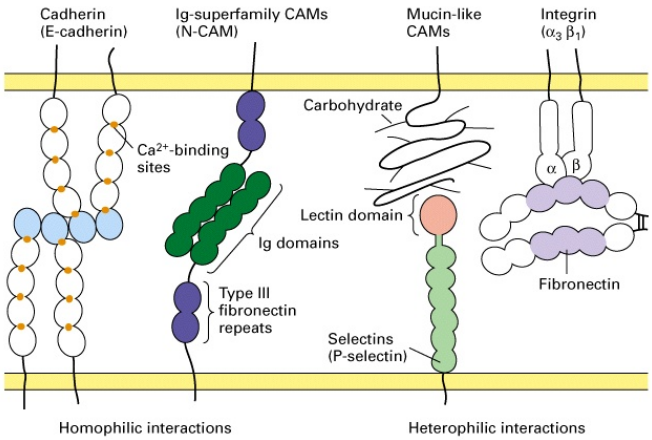
- **Other constituents**
  - Cholesterol stabilizes the membrane
  - Small amounts of carbohydrate “sugars” (glycoproteins or glycolipids)
  - Proteins are attached or inserted in the membrane
    - Channels
    - Carrier molecules
    - Receptors
    - Membrane bound enzymes
    - Cell adhesion molecules



Cell-to-Cell Adhesions

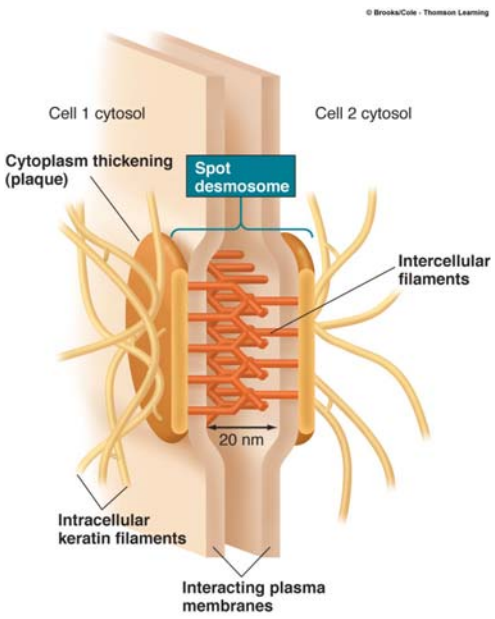
- **Organization of cells into appropriate groupings**
  - Extracellular matrix
  - Cell adhesion molecules
  - Specialized cell junctions
- **Extracellular matrix**
  - Secreted mostly by fibroblasts
  - Fibrous proteins (Collagen, Elastin, Fibronectin)
- **Cell adhesion molecules (CAMs)**
  - Glycoproteins and glycolipids





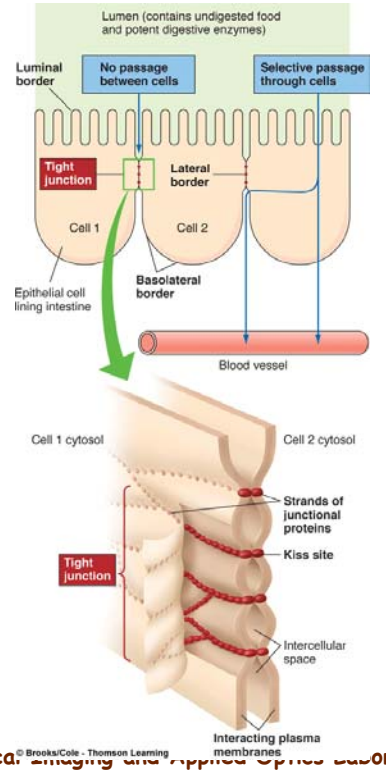
Cell-to-Cell Adhesions

- **Cell Junctions**
  - Directly linking cells
    - Desmosomes
    - Tight Junctions
    - Gap Junctions
- **Desmosomes**
  - Connect adjacent but not touching cells
    - Plaques
    - Glycoproein filaments
  - Common in tissues that are subject to strain
    - Skin, heart, etc
  - Keratin connects them intracellularly forming continuous network



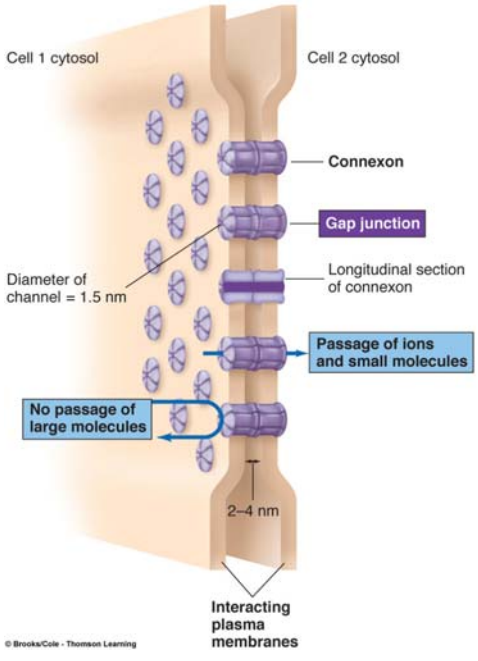
Cell-to-Cell Adhesions

- **Tight Junctions**
  - Bind tightly in contact, blocking passageways
    - Junctional proteins form “kiss” sites
    - Impermeable
    - Materials must pass through cells ➔ well regulated
  - Common in epithelial layers → barriers between compartments



Cell-to-Cell Adhesions

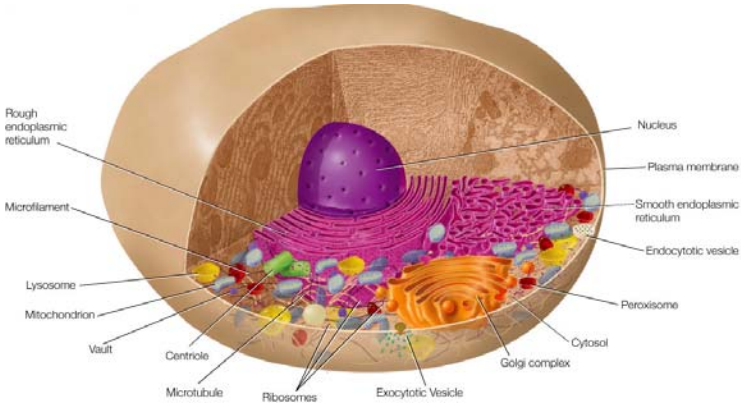
- **Gap Junctions**
  - Connects adjacent cells with small tunells
    - Connexon ➔six protein subunits in a tube-like stucture
    - Two join end-to-end between two cells
    - Small, water soluble, particles can pass, e.g. ions
  - Signaling
  - Abundant in cardiac and smooth muscle → transmit electrical activity



Biomedical Imaging and Applied Optics Laboratory

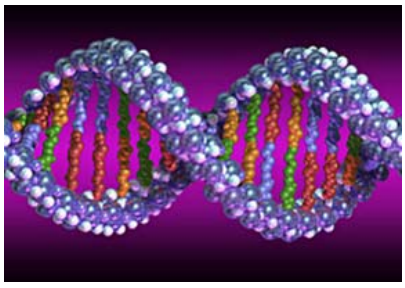
Nucleus

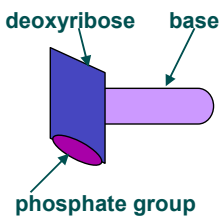
- **Basic Structure**
  - Nucleus
    - Surrounded by nuclear envelope with nuclear pores
    - Contains the genetic material of the cell → deoxyribonucleic acid (DNA)
  - DNA
    - Carries genetic information and serves as blueprint during cell replication
    - Directs protein synthesis

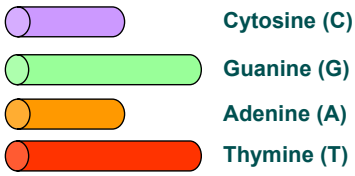


DNA and Protein Synthesis

- **Deoxyribonucleic acid (DNA) is macromolecule**
- **Consists of Nucleotides**
  - Sugar (deoxyribose)
  - Phosphate group
  - Bases
    - Adenine (A), guanine (G), cytosine (C) and thymine (T)
- **Complementarity rule**
  - Adenine only pairs with Thymine
  - Cytosine only pairs with guanine
  - And vice versa
    - A = T and G = C in all spieces
    - (A+T / G + C) is deferent between spiecies

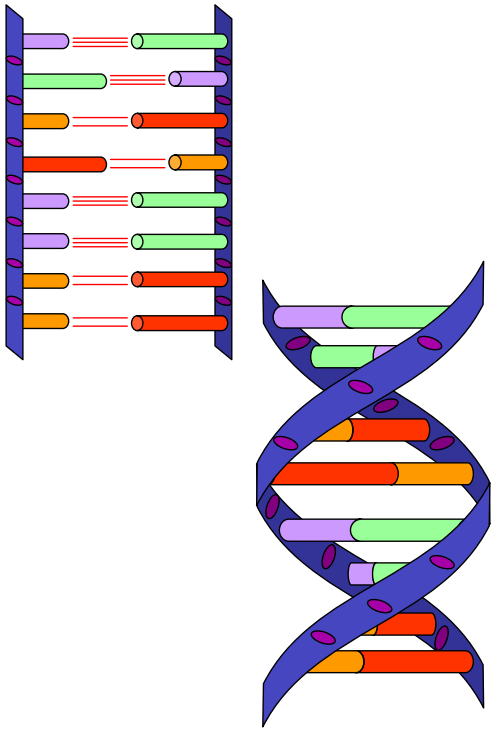






DNA and Protein Synthesis

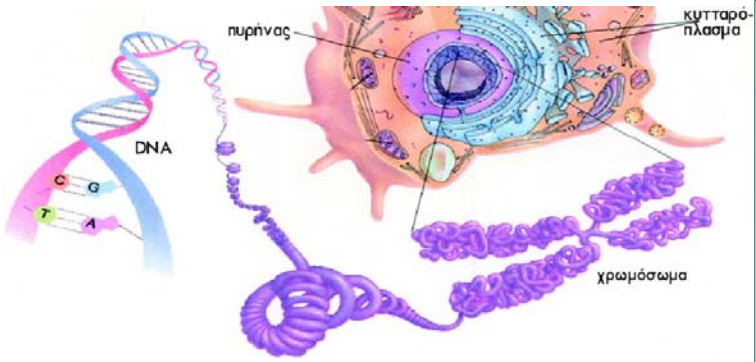
- **DNA double helix**
  - 1953 Watson and Crick → model for DNA double helix
    - X-ray diffraction
    - Perhaps the greatest biological discovery of the 20th century
  - Unique properties
  - Molecule ideal as genetic material
- **Two chains**
  - Right-handed double helix
  - The bases form hydrogen bonds with complimentaries
- **The two chains are complimentary**
  - One defines the other
  - One is the "mold" for synthesizing the other
    - Best molecule for carrying genetic information

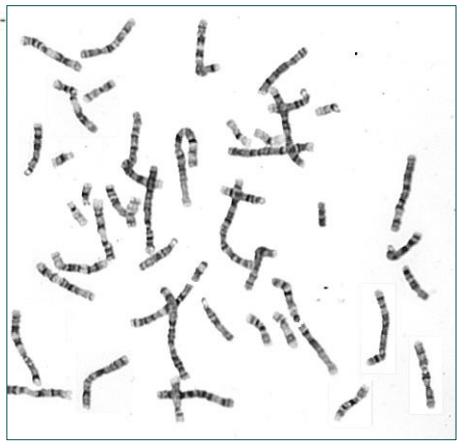


DNA and Protein Synthesis

- **Self replications**
  - "Unzips"
  - Each chain is used to form the complimentary chain
  - Two identical copies of DNA are formed
    - Special enzymes correct mistakes
    - Mistakes do happen (i.e. mutations)
- **Two important characteristics for a genetic material**
  - Replicates without mistakes
    - Pass the information from generation to generation
  - Allows for changes
    - Know as mutations
    - Leads to variations
    - Species adapt better to changing conditions

DNA and Protein Synthesis

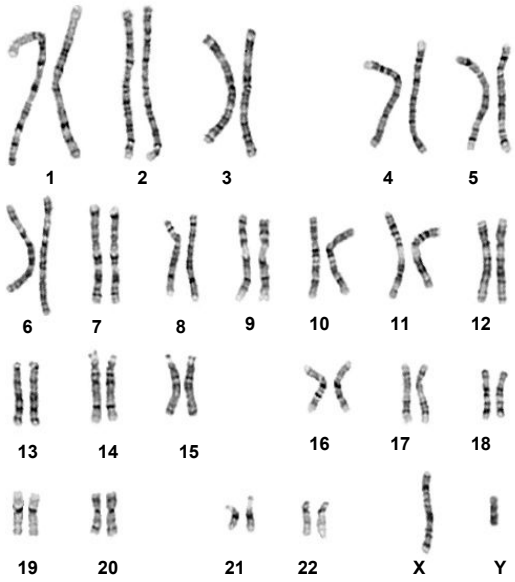




- **Chromosomes**
  - So called because the stain strongly
  - Form in the nucleus
  - The bearers of genetic information in eukaryotic cells
  - Independent “Inheritance units”
  - Main constituent is DNA

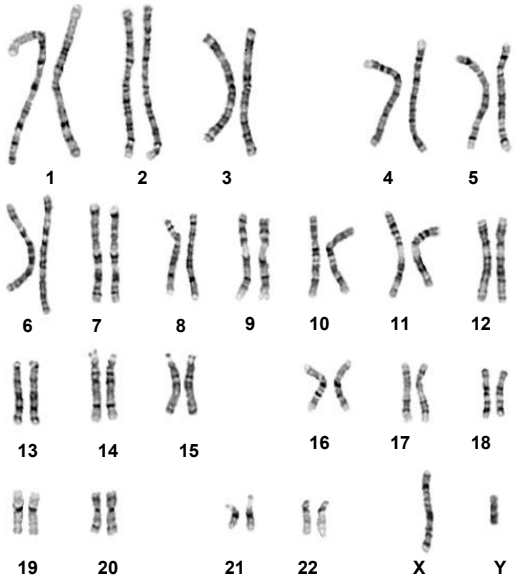
DNA and Protein Synthesis

- **Number of chromosomes**
  - Specific for each species
    - humans → 46
    - Olive trees → 46
    - Worms → 1
    - Crabs → 200 και πλέον
    - In general between 10 and 50
  - They differentiate one species from another
    - Not so much the number of chromosomes but the genetic information contained



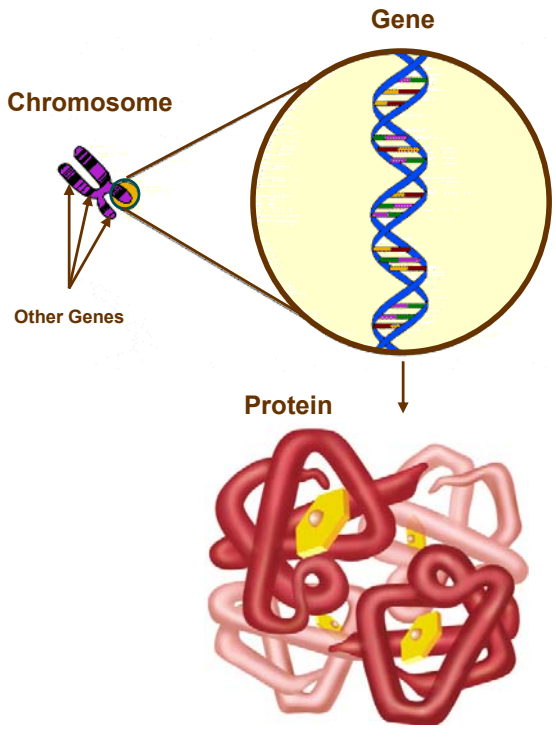
DNA and Protein Synthesis

- **Chromosomes**
  - In pairs in somatic cells
    - A pair of each → diploid cell (or 2n)
    - 46 chromosomes → 23 different pairs
  - Each pair
    - Homologous chromosomes
    - Same size and shape
    - Exception: sex chromosomes (X and Y)
  - In gametes
    - only one chromosome of each → haploid cells (or 1n)



DNA and Protein Synthesis

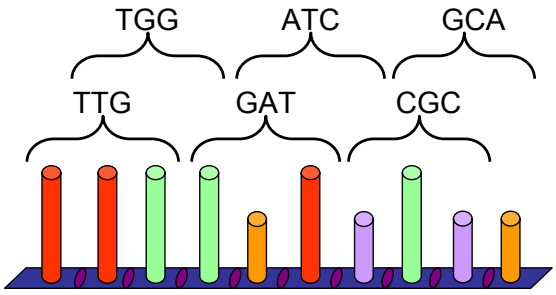
- **Chromosomes**
  - Contain hundreds or thousand of genes
  - In linear order
- **Gene**
  - Unit of information
  - Defines a characteristic of the species
    - Color of the iris in humans
    - Length of wings in flies
    - Color of peas
    - etc.
  - A specific series of nucleotides
  - Define the structure of all proteins
    - The function of the protein is related, directly (if it is a structural protein) or indirectly (if it is an enzyme), with a genetic feature
- **Number of different genes**
  - Viruses ~ 5-15
  - Mammals ~ 50.000
  - Humans > 100.000 (;)



Biomedical Imaging and Applied Optics Laboratory

DNA and Protein Synthesis

- **Proteins**
  - Combinations of 20 aminoacids
- **How can you encode with 4 bases;**
  - One base system
    - A, T, G, C
    - 4 possible codes
  - Two base system
    - AA, AT, AG, AC, TA, TT, etc
    - 16 (4^2) possible codes
  - Three base system
    - AAA, AAT, …, GCT, GTT, etc
    - 64 (4^3) possible codes
    - Triplets → codons
- **DNA Code**
  - Three base system
  - Start and Stop codons
  - Degenerate
  - Overlapping



ACT
ACC
ACA
ACG } **Threonine**

TGG } **Tryptophane**

DNA and Protein Synthesis

- **Transcription**
  - Transfer of information from DNA
  - Synthesis of RNA (mRNA)
- **RNA**
  - Copy of one gene
  - Same code
    - Uracil (U) instead of Thymine (T)
- **RNA Synthesis**
  - Precise
  - Mistakes can happen
  - Mistakes are not passed to next generation

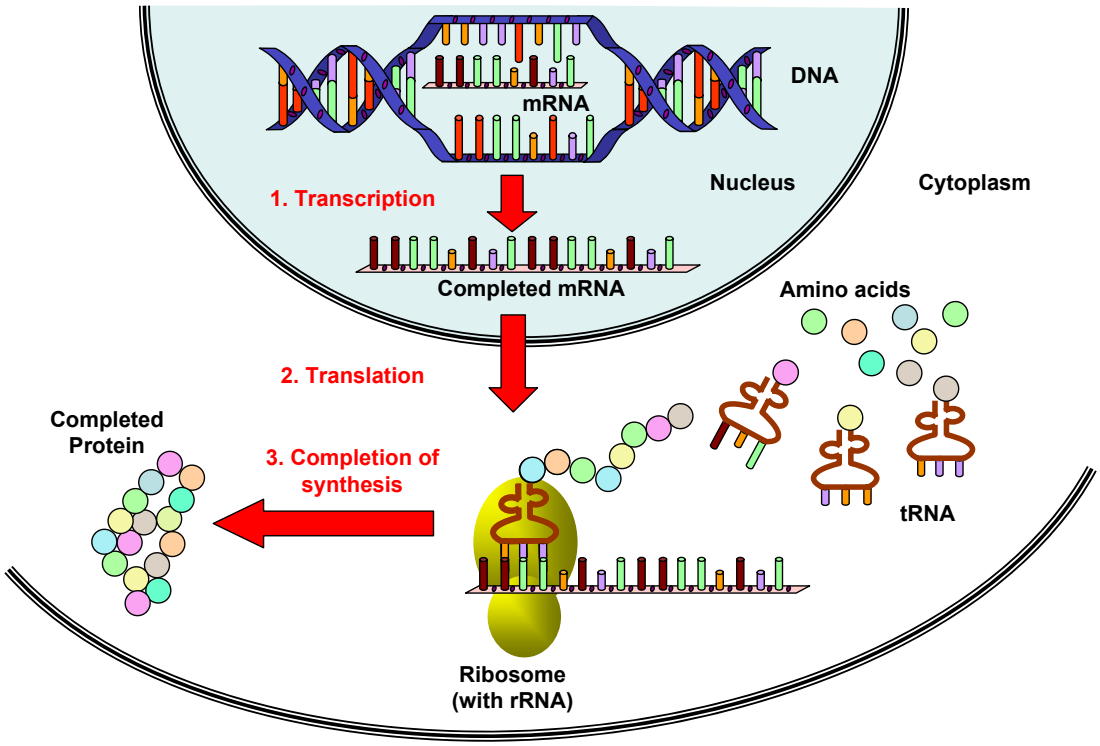
Central Dogma of Molecular Biology

Self replication

Transcription

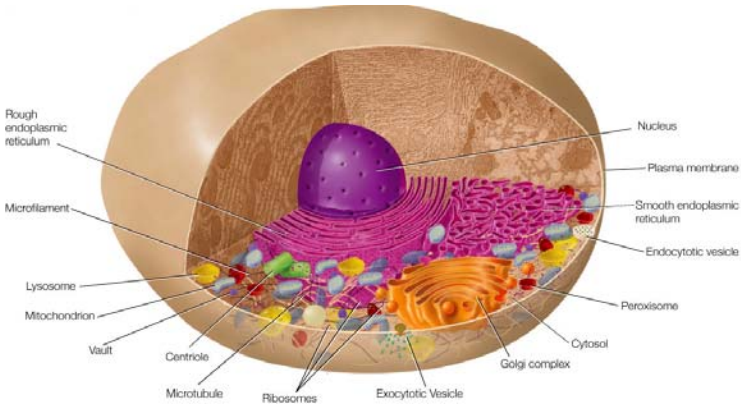
Translation

DNA and Protein Synthesis



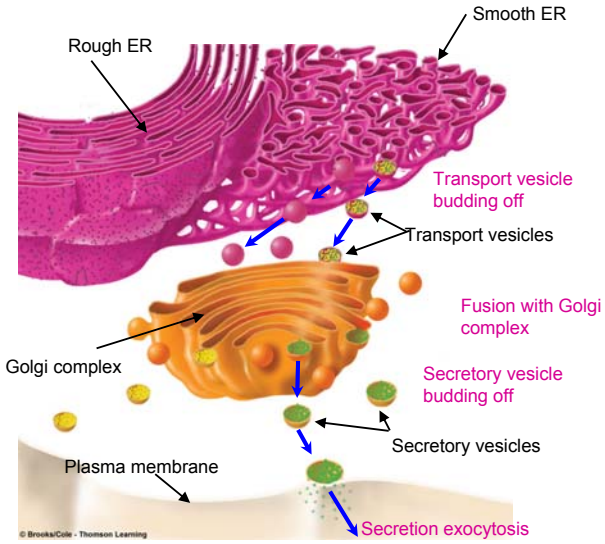
Cytoplasm

- **Basic Structure**
  - Cytoplasm
    - Various organelles
      - Endoplasmic reticulum
      - Golgi complex
      - Lysosomes
      - Peroxisomes
      - Mitochondria
      - Vaults
    - Cytosol (= cell, gel-like, liquid)
      - Enzymatic regulation of intermediary metabolism
      - Ribosomal protein synthesis
      - Storage of fat, carbohydrates
      - Includes the cytoskeleton



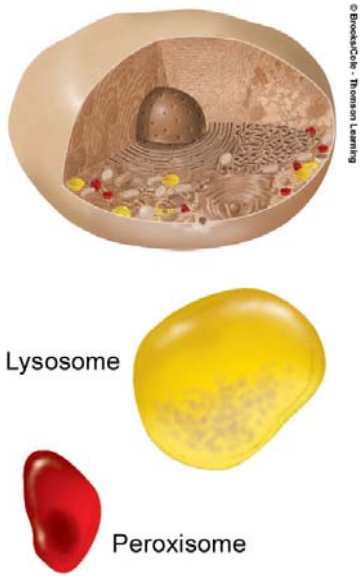
Endoplasmic Reticulum (ER)

- **Endoplasmic Reticulum**
  - Protein and lipid synthesis
  - Elaborate fluid-filled membrane system
  - Rough ER
    - Rough appearance, flattened sacks
    - Proteins synthesized and released in the ER lumen
    - Lipids synthesized for cell walls
  - Smooth ER
    - Smooth appearance, small interconnected tubules
    - Packaging for molecules to be released
    - Transport vesicles bud off → Golgi apparatus for further processing
- **Golgi Complex**
  - Two major roles
    - Processing the raw proteins into their final form
    - Sorting and directing the destination
  - Stack of flattened membrane-enclosed sacs (a.k.a. cisternae)



Lysosomes

- **Serve as the intracellular digestive system**
- **Small sacs full of powerful hydrolytic enzymes**
- **Vary in size**
- **Break down organic molecules from foreign materials (e.g. bacteria)**
- **Material internalized by endocytosis**

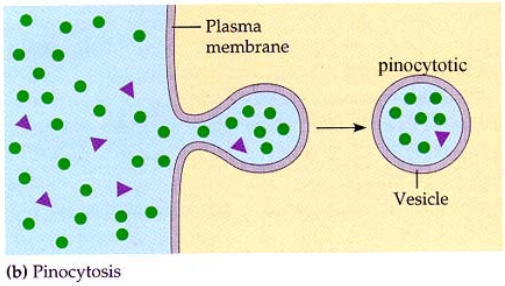


Peroxisomes

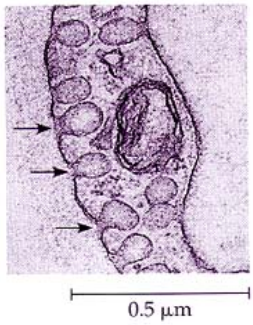
- **Detoxify waste products or foreign toxic compounds (e.g. alcohol)**
- **Similar in structure to lysosomes, only smaller**
- **Contain oxidative enzymes**
  - Use oxygen to strip hydrogen from organic molecules
- **Major product generated is hydrogen peroxide (H_2O_2)**
  - Powerful oxidant
  - Must not accumulate or escape
  - Enzyme ***catalase*** breaks into H_2O and O_2

Endocytosis

- **Endocytosis**
  - Pinocytosis
  - Receptor-mediated endocytosis
  - Phagocytosis
- **Pinocytosis**
  - Bring ECF into the cell or retrieve extra plasma membrane added by exocytotic vesicles
  - Procedure
    - Coat proteins bind to the ECF side
    - Membrane dips
    - Dynamin pinches the pouch off

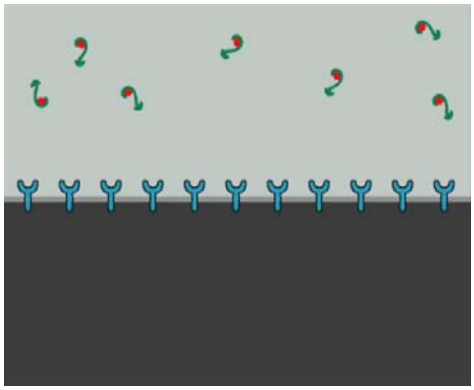


(b) Pinocytosis



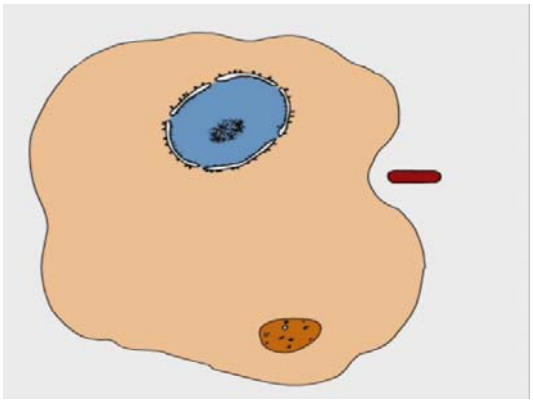
Endocytosis

- **Receptor-Mediated Endocytosis**
  - Highly selective process to internalized needed molecules
  - Procedure
    - Molecule binds to receptor
    - Proteins coat ICF side
    - Membrane sinks in and seals at the surface
  - Important for cholesterol, vitamin B12, insulin, iron, etc, uptake
  - Used by viruses to enter the cell (e.g. Flu and HIV)



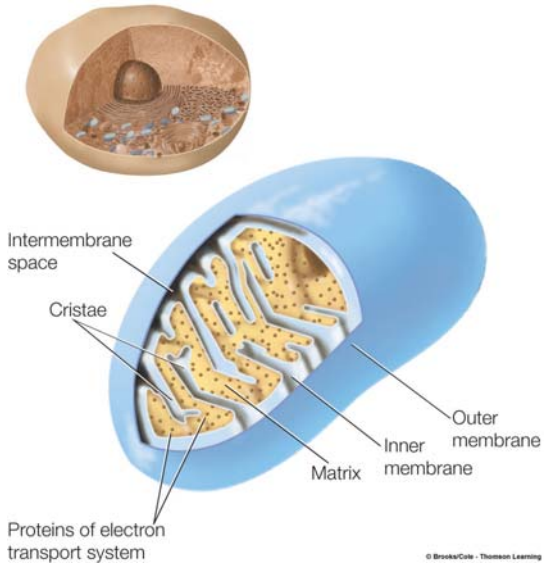
Endocytosis

- **Phagocytosis**
  - Internalization of large multimolecular particles
  - Performed by phagocytes (mainly white blood cells)
  - Procedure
    - Encounter of particle
    - Extension of pseudopods
    - Internalized into vesicle
    - Fusion with lysosome
    - Break down of engulfed material
    - Useful byproducts



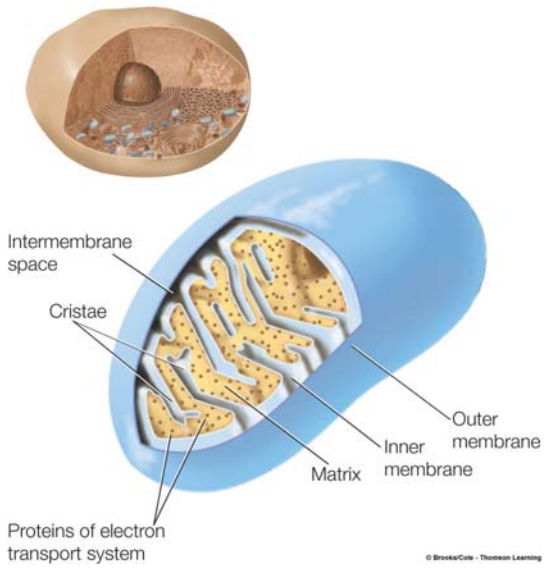
Mitochondria

- **Generate 90% of the cells's energy**
- **Number varies (100s-1000s) depending on the cell type's energy needs**
- **About the size of bacteria → descendants of engulfed bacteria**
- **Possess their own DNA**
  - Produce products needed to generate energy
  - Flaws
    - Can be passed from mother to children
    - Accumulate over time (implicated in aging and degenerative diseases)



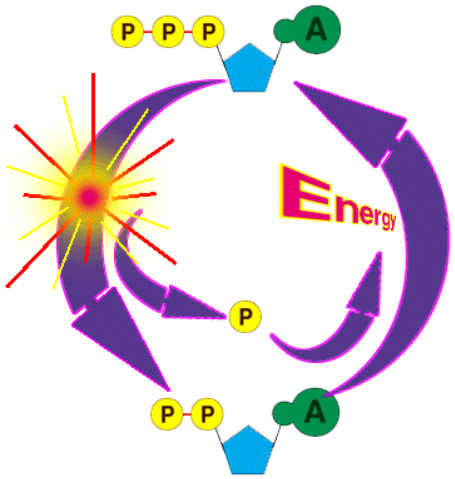
Mitochondria

- **Structure**
  - Double membrane
  - Smooth outer membrane
  - Inner membrane with cristae (infoldings)
    - Increased surface area
    - Contains enzymes of the electron transport chain
  - Matrix
    - Contains enzymes of the cytric cycle



Energy Production

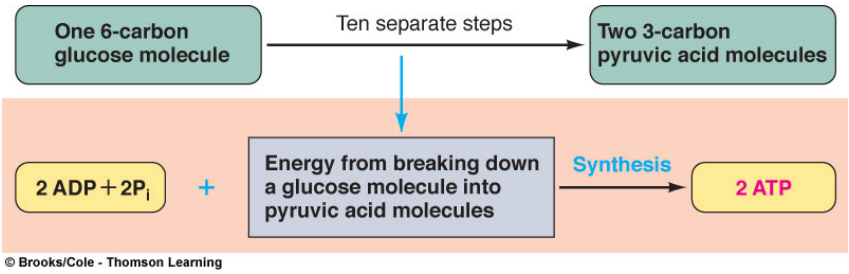
- **Energy derived from carbon bonds of ingested food**
  - Food broken up into smaller absorbable units
  - E.g. carbohydrates → glucose
  - Absorbed into blood
  - Delivered to tissues
  - Uptake of molecules into cells
- **Processed and stored into a usable form**
  - High energy phosphate bonds of adenosine triphospate (ATP)
  - Split of one P yields ADP and energy
  - Three steps (Glucose)
    - Glycolysis
    - Citric acid cycle
    - Electron transport chain



$$ATP \xrightarrow{\text{splitting}} (ADP + P_i) + energy$$

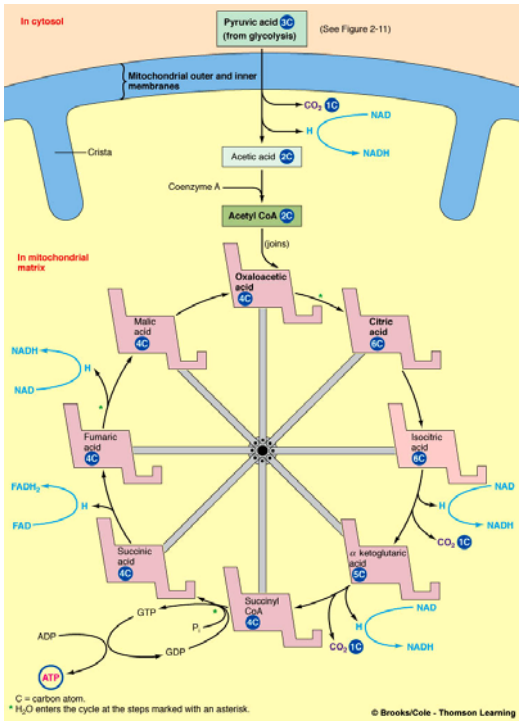
Energy Production

- **Glycolysis**
  - Occurs in the cytosol
  - 10 sequential reactions
  - Break glucose into 3 pyruvic acid molecules
  - Release 2 ATP molecules
  - Not efficient
    - Most of the energy still in the pyruvic acid
  - Mitochondria come into play



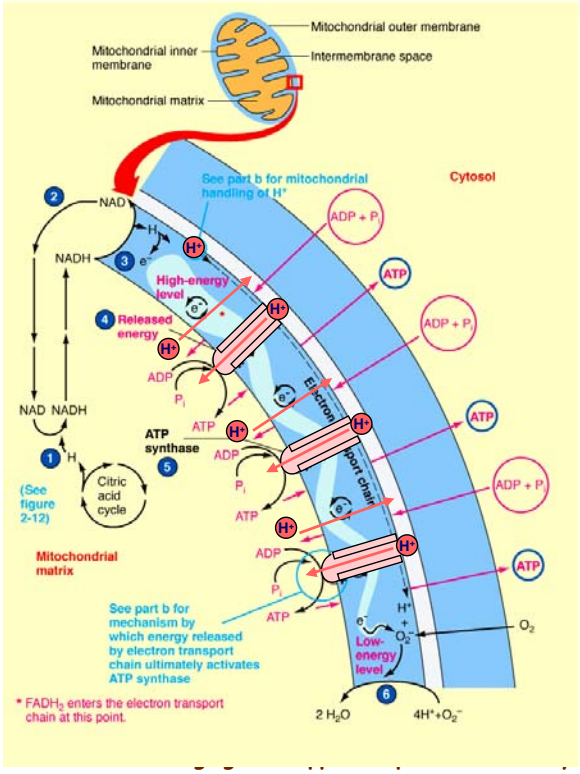
Energy Production

- **Citric Acid or Kerbs Cycle**
  - Occurs in the mitochondria
  - Requires O_2 (derived from molecules involved)
  - 2 ATP molecules from each pyruvic acid
- **Important points**
  - Carbon atoms released
    - Form CO_2
  - Hydrogen released
    - Binds to hydrogen carrier molecules
    - To be subsequently used in the electron transport chain
  - Hydrogen carrier molecules
    - Nicotinamide Adenine Dinucleotide (NAD) from B vitamin niacin
    - Flavine Adenine Dinucleotide (FAD) from B vitamin riboflavin



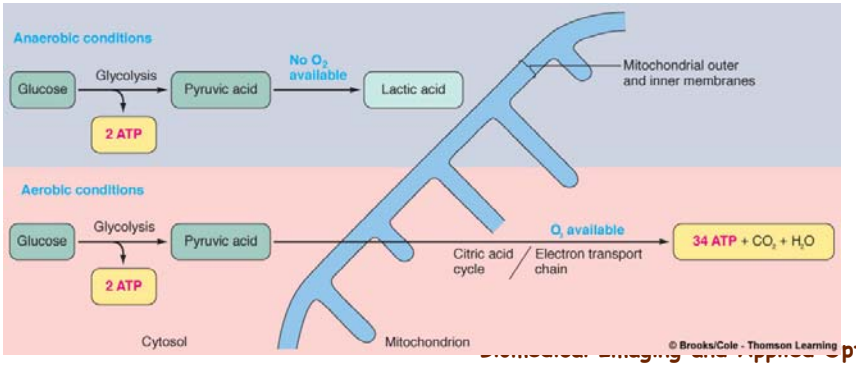
Energy Production

- **Electron transport chain**
  - Oxidative phosphorilation
  - Electron carriers arranged in specific ordered structure within the cristae membrane
  - Carrier molecules deliver hydrogen and high energy electrons to the chain
  - Electrons move down the chain using their energy to transport hydrogen (against its concentration gradient) in the intermembrane space
  - After 3 successive transports the weakened electrons are passed to O_2 (from breathing) → form H_2O
  - The hydrogen returns back to the matrix through channels which activate ATP synthase



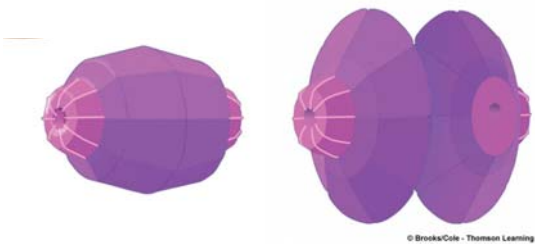
Energy Production

- **Burn vs. Oxidative phosphorylation**
  - Controlled storage of energy
- **Aerobic vs. Anaerobic Conditions**
  - Glycolysis alone not sufficient to sustain body
  - Exception
    - Muscle→ energy during short bursts of strenuous exercise
    - RBCs → no mitochondria but also not many metabolic needs



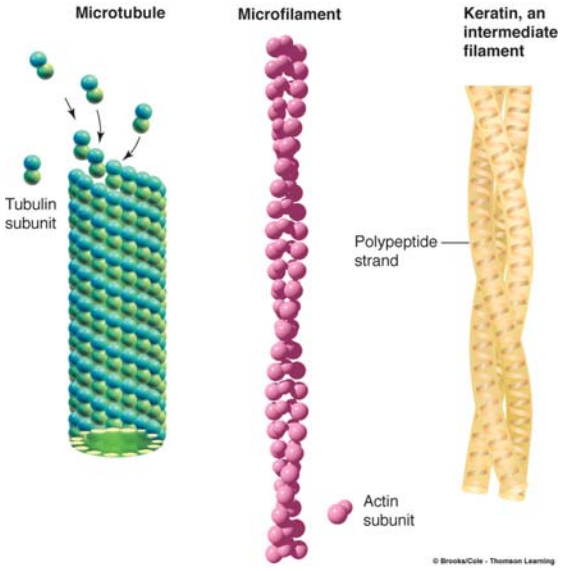
Vaults

- **Newly discovered organelles (1990s)**
- **Octagonal shaped, barrel like, structures**
- **Sometimes can be seen open**
- **Function not well understood**
  - Transport of molecules from nucleus to cytoplasm (nuclear pores are also octagonals of the same size)
    - Ribosomal units
    - mRNA



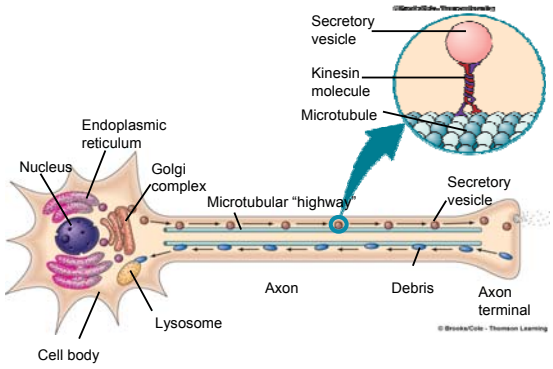
Cytoskeleton

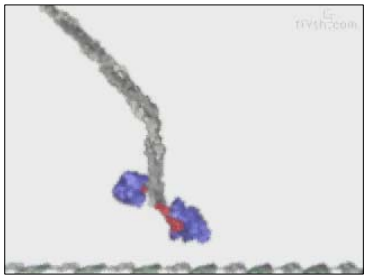
- **Structural proteins in the cells responsible for**
  - Maintaining structure and shape
  - Movement of parts or the whole cell
  - Signaling (?)
- **Three major components**
  - Microtubules
    - Tubulin forming tubes, 22 nm diameter
  - Microfilaments
    - Actin and myosin forming twisted strands, 6 nm diameter
  - Intermediate filaments
    - Various proteins forming irregular thread-like strands, 7-11 nm diameter



Cytoskeleton

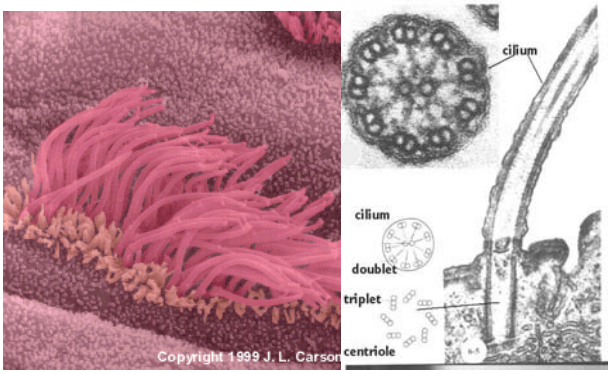
- **Microtubules**
  - Function
    - Maintain asymmetric shapes
    - Facilitate complex movements
  - Maintain structure
    - Stabilize long axons of neurons
  - Transport of secretory vesicles
    - Secretory vesicles leave the Golgi apparatus
    - Transported along microtubules to the axon terminal – kinesin (globular protein with "feet") → expenditure of ATP
    - Debris transported back – dynein → expenditure of ATP
    - Some viruses, like herpis, use the same transport mechanism

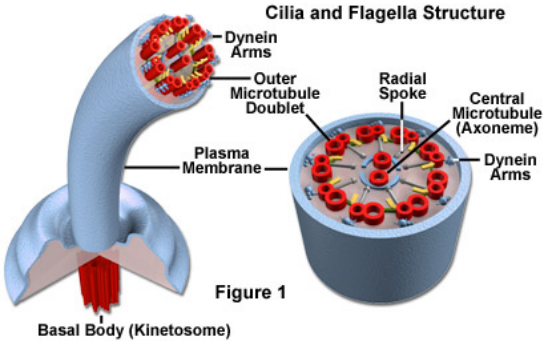




Cytoskeleton

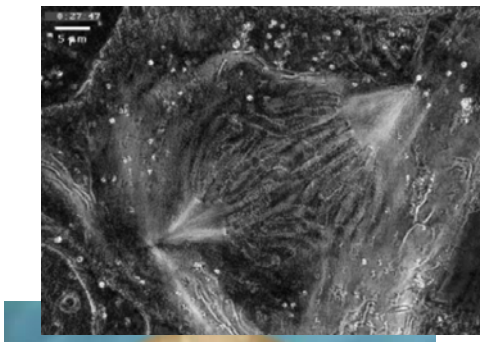
- Movement of cilia and flagella
  - Cilia
    - Numerous tiny hair-like protrusions
    - Beat in unison, e.g.
    - respiratory tract → move foreign bodies out
    - oviducts → move ovum to the uterus
  - Flagellum: single, whip-like appendage
    - Sperm → movement and alignment with ovum
  - Structure
    - Nine double (fused microtubules) arranged around two single microtubules
    - Accessory proteins including “arms” of dynein
    - Sliding of tubes along each other causes the motion
  - Control mechanisms of cilia not well understood

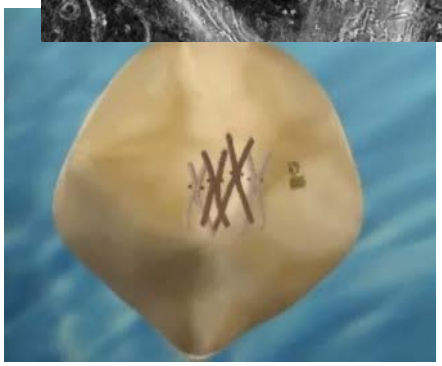




Cytoskeleton

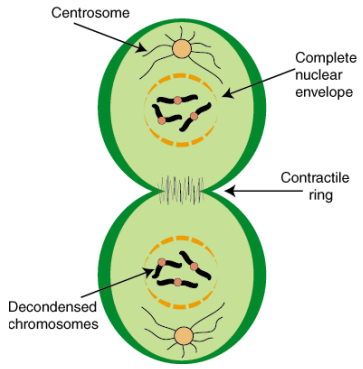
- Formation of the mitotic spindle
  - During mitosis the DNA-containing chromosomes are duplicated
  - Must be divided equally between the two daughter cells
  - Pulled apart by mitotic spindle → transiently assembled microtubules starting from tube-like structures, the centrioles

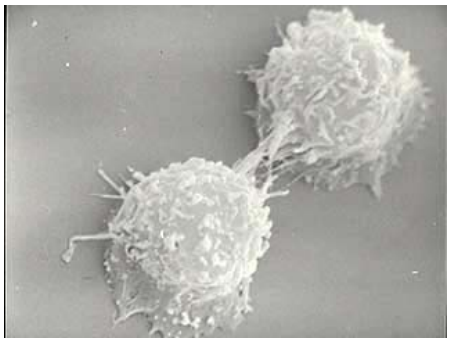




Cytoskeleton

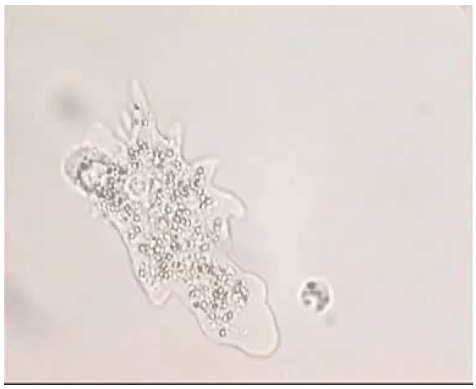
- **Microfilaments**
  - Function
    - Cell contractile systems
    - Mechanical stiffeners for specific cell projections
  - Contraction of muscle
    - Chapter 8
  - Separation of cells during division
    - Contractile ring

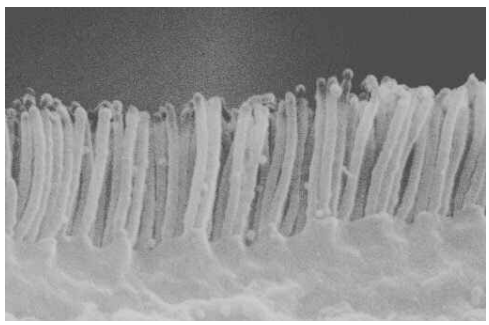




Cytoskeleton

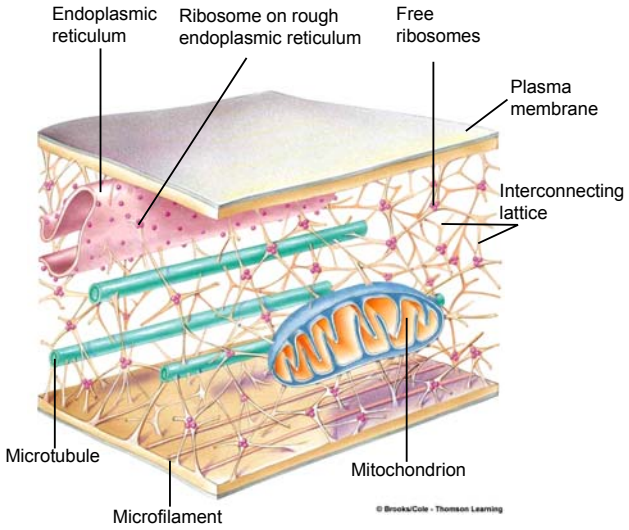
- Cell locomotion
  - White blood cells and fibroblasts
  - Amoeboid movement
  - Pseudopods extend and contract to move the cell → actin networks which grow at the leading edge and simultaneously disassembled at the rear
- Mechanical stiffeners
  - Microvilli → Non-motile projections of epithelial cells (increased surface area for absorption)





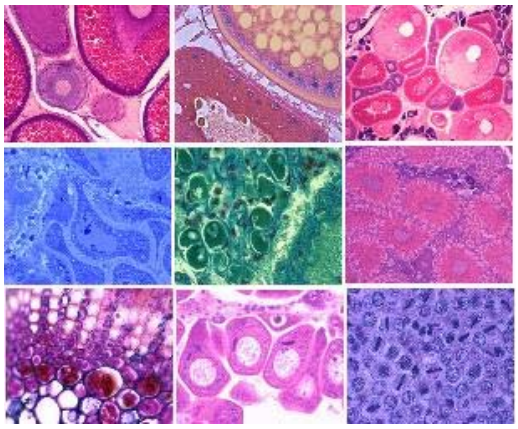
Cytoskeleton

- **Intermediate filaments**
  - Function
    - Maintain the structural integrity of the cell
    - Resist externally applied stress
  - Varying compositions to suit the cell type's needs
    - E.g. keratin network in skin cells



Tissues

- **Combination of**
  - Cells of similar structure and function
  - Varying amounts of extracellular material
- **Basic tissue types**
  - Muscle tissue
  - Nerve tissue
  - Epithelial tissue
  - Connective tissue

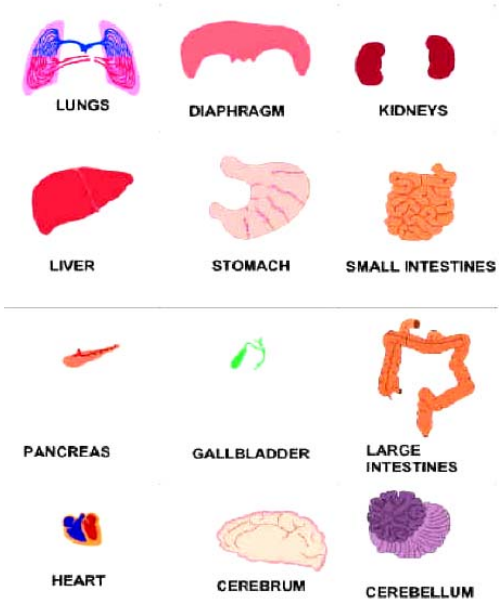


Tissues

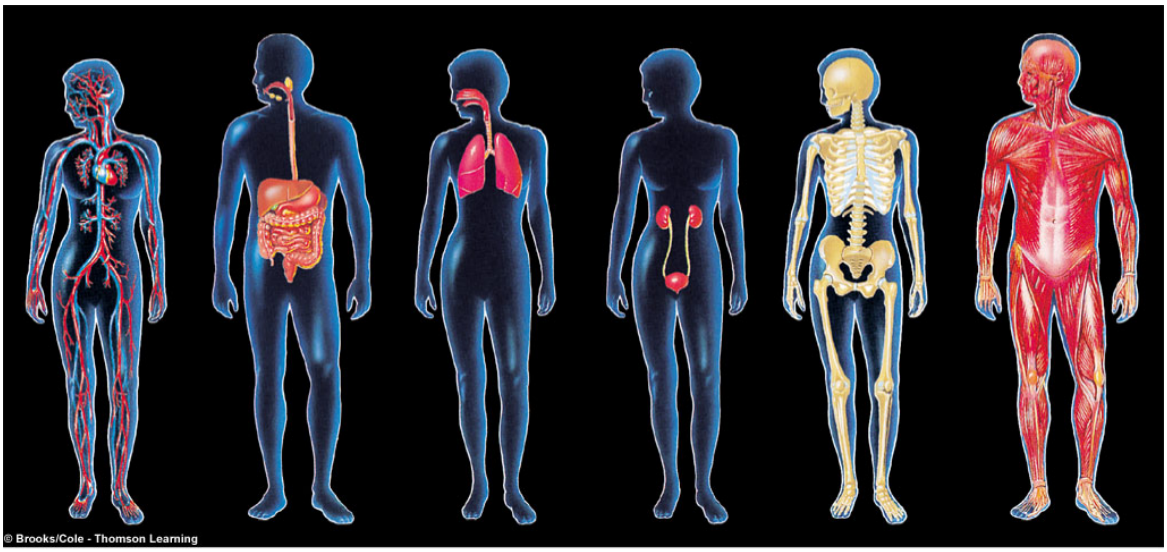
- **Muscle tissue**
  - Contracting and generating force
  - Skeletal muscle → movement
  - Cardiac muscle → heart
  - Smooth muscle → GI, blood vessels
- **Nerve tissue**
  - Information transport and processing
  - Initiate and transmit electrical and chemical signals
- **Epithelial tissue**
  - Serve as boundaries and specialize in the exchange of materials
  - Epithelial sheets and secretory glands (endocrine and exocrine)
- **Connective tissue**
  - Connect, support and anchor other tissues
    - Loose connective tissue, tendons, bone, blood, etc
  - Few cells with abundant extracellular material
  - Produce specific structural proteins (e.g. collagen, elastin)

Organs and Systems

- **Organ**
  - Collection of two or more tissues
  - Combine to perform specific task
  - e.g stomach (epithelial sheets and glands, smooth muscle connective tissue) → food digestion
- **System**
  - A collection of organs which perform a specific task
  - e.g. digestive system (mouth, larynx, esophagus, stomach, small and large intestine, pancreas) → absorption of food

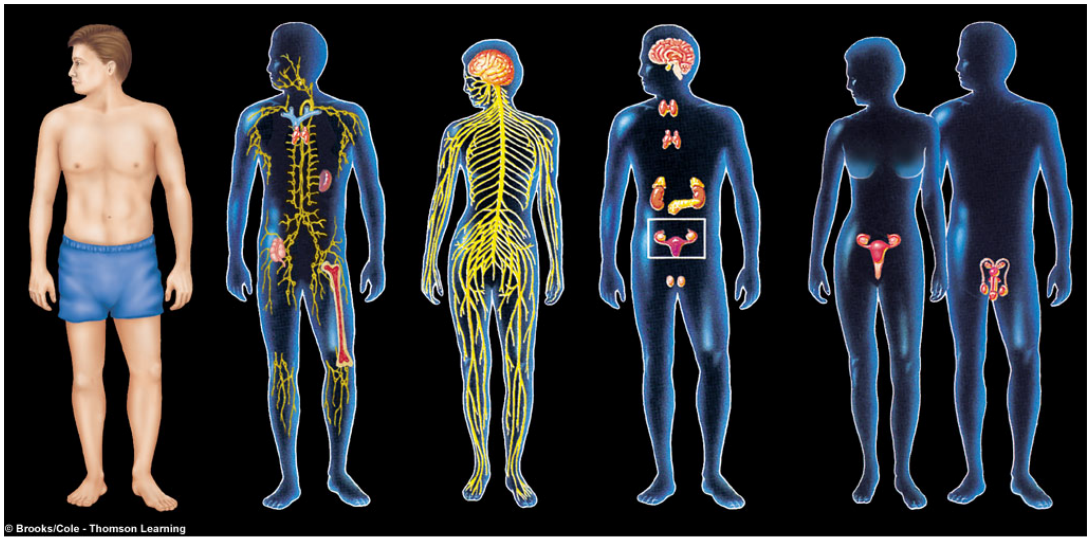


Systems



Circulatory system	Digestive system	Respiratory system	Urinary system	Skeletal system	Muscular system
heart, blood, blood vessels	mouth, pharynx, esophagus, stomach, small intestine, large intestine, salivary glands, exocrine pancreas, liver, gallbladder	Nose, pharynx, larynx, trachea, bronchi, lungs	kidneys, ureters, urinary bladder, urethra	bones, cartilage, joints	skeletal muscles

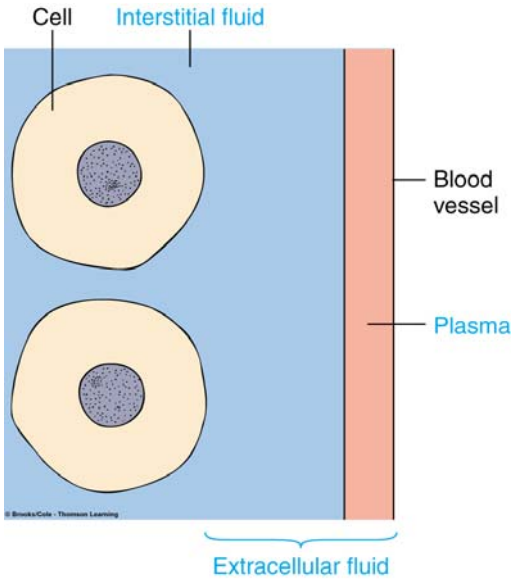
Systems



Integumentary system	Immune system	Nervous system	Endocrine system	Reproductive system
skin, hair, nails	lymph nodes, thymus, bone marrow, tonsils, adenoids, spleen, appendix, and, not shown, white blood cells, gut-associated lymphoid tissue, and skin-associated lymphoid tissue	brain, spinal cord, peripheral nerves, and, not shown, special sense organs	all hormone-secreting tissues, including hypothalamus, pituitary, thyroid, adrenals, endocrine pancreas, gonads, kidneys, pineal, thymus, and, not shown, parathyroids, intestine, heart, and skin	Male: testes, penis, prostate gland, seminal vesicles, bulbourethral glands, and associated ducts Female: ovaries, oviducts, uterus, vagina, breasts

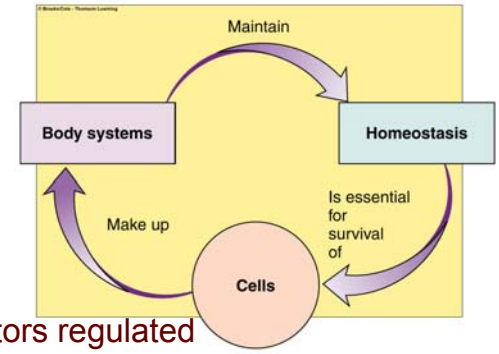
Internal Environment

- **Cells in multicellular organisms**
  - Contribute to organism survival
  - Most are not in contact with the external environment
- **Watery internal environment**
  - Appropriately maintained to support life and functioning
  - Intracellular fluid (ICF)
    - The fluid in all the cells
  - Extracellular fluid (ECF)
    - The fluid outside the cells
    - Interstitial fluid (in between cells)
    - Plasma (in blood vessels)



Homeostasis

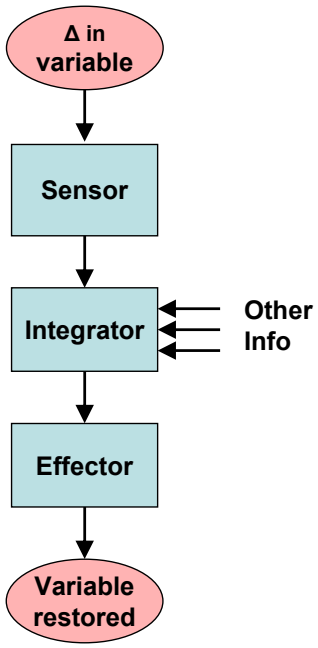
- **Homeostasis**
  - A state of the internal environment which is compatible with life
  - Maintained at approximately stable levels
    - All cells, tissues and systems contribute
    - Many aspects are maintained
  - Dynamic state
    - External perturbations
    - Short term transient responses or long term adaptation
    - Return to steady state



- Factors regulated
  - Concentration of nutrient molecules
  - Concentration of O_2 and CO_2
  - Concentration of waste products
  - pH
  - Concentration of water, salt and other electrolytes
  - Volume and pressure
  - Temperature

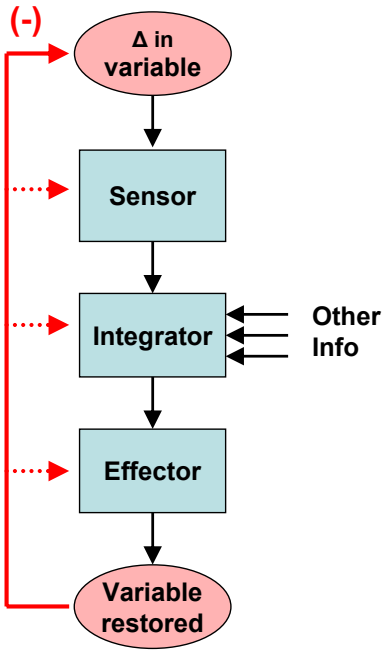
Homeostasis

- **Homeostatic control systems**
  1. Detect deviation from normal
  2. Integrate relevant information
  3. Make appropriate adjustments
- **Intrinsic control**
  - Local to the organ
  - E.g. chemical changes in exercising muscle → vasodilation → more O_2
- **Extrinsic control**
  - Actions in response to changes outside the organ
  - Coordinated action of organs and systems
  - Mediated by the nervous and endocrine systems
  - E.g. overall response to exercise (short term and long term)



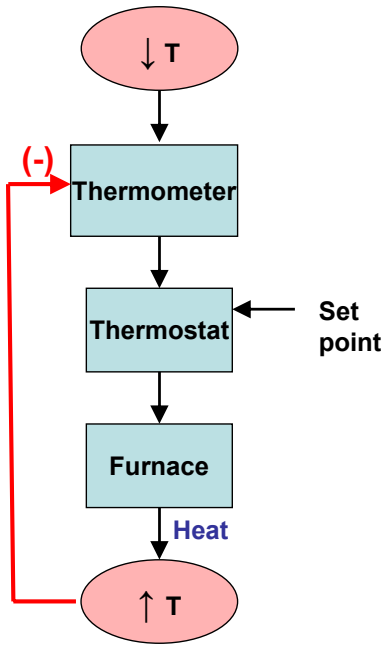
Homeostasis

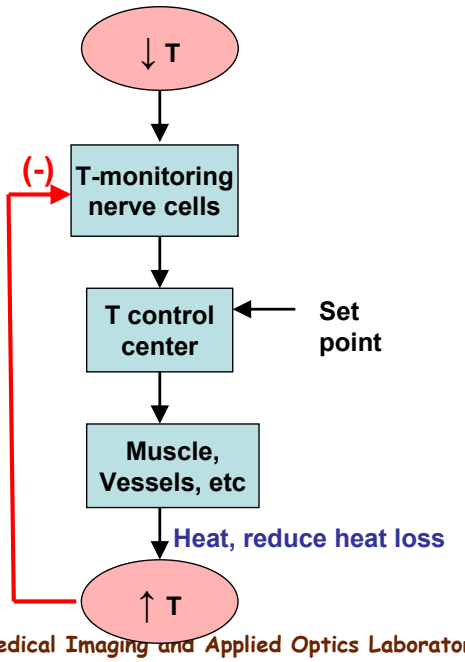
- **Feedback**
  - Mechanism that tends to stabilize the physiological factor being regulated
- **Negative feedback**
  - Change in a variable initiates response to the opposite direction
  - Tends to correct the change and return the system to its steady state



Homeostasis

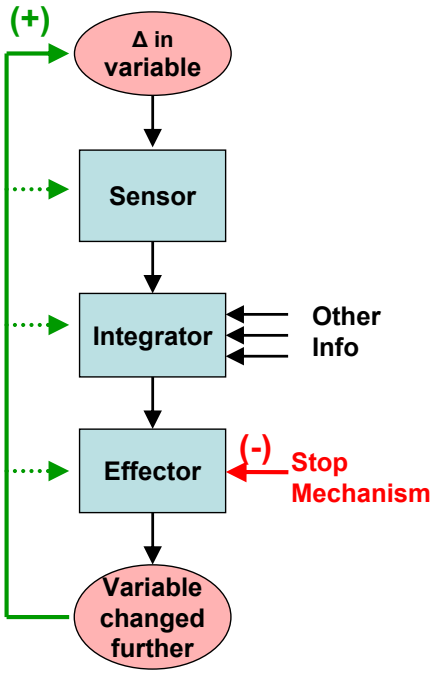
- **Example of negative feedback**
  - Temperature control – Home and Body





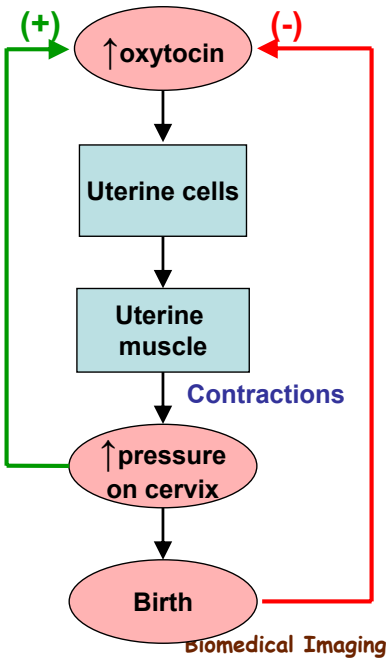
Homeostasis

- **Positive feedback**
  - Change in a variable initiates response to the further amplify the change
  - Tends to amplify the change initiated from the external perturbation
  - Not as common as negative feedback
  - Always a stop mechanism required
  - Appears when abnormal circumstances disable negative feedback



Homeostasis

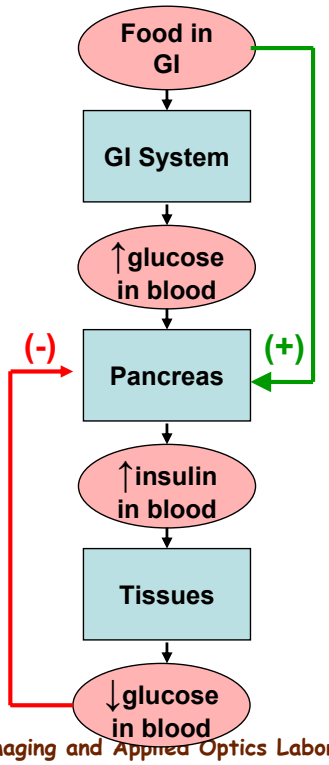
- **Example of positive feedback**
  - Birth



Homeostasis

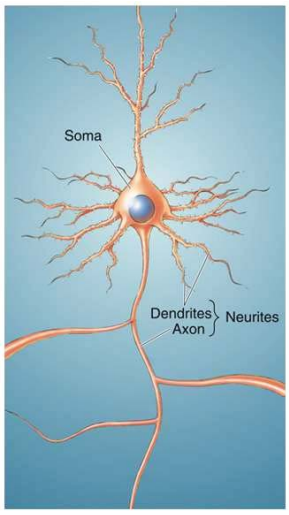
- **Feedforward Mechanisms**
  - Initiate responses in anticipation of change
  - E.g. food in the gastrointestinal → insulin secretion in anticipation of glucose arrival

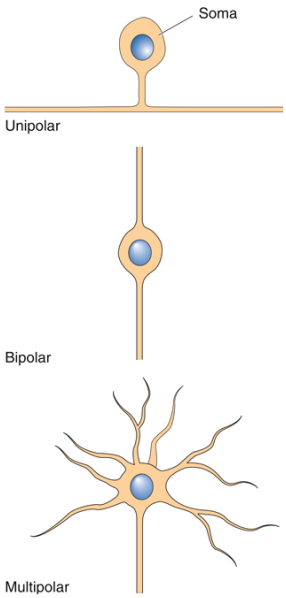
- **Disruption in homeostasis**
  - →pathophysiology



Neurons

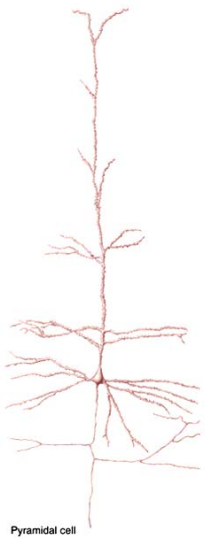
- **Neurons have two parts**
  - Soma and perikaryon
  - Neurites: Axons and dendrites
- **Classified based on neurite number**
  - One → Unipolar
  - Two → Bipolar
  - Many → Multipolar





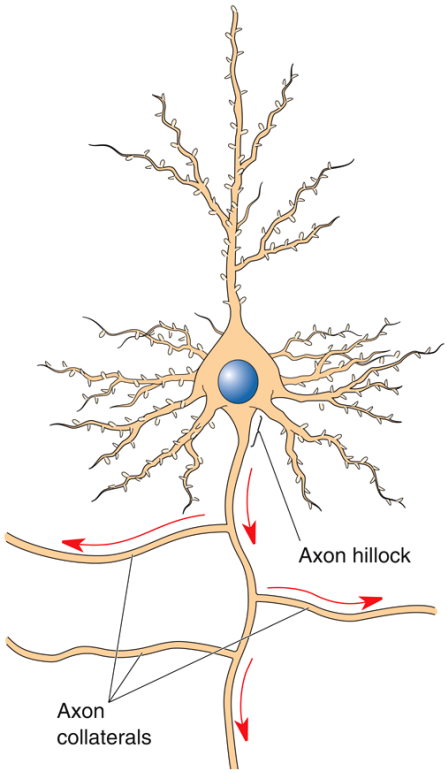
Neurons

- **Classified based on morphology of dendrites**
  - Stellate and pyramidal
  - Spiny and aspinous
- **Further classified by**
  - Their role in the CNS
    - Sensory, motor, etc
  - Their axon length
    - Golgi Type I
    - Golgi Type II
  - The type of their neurotransmitter
    - E.g. Cholinergic → Acetylcholine at the synapse



Neurons

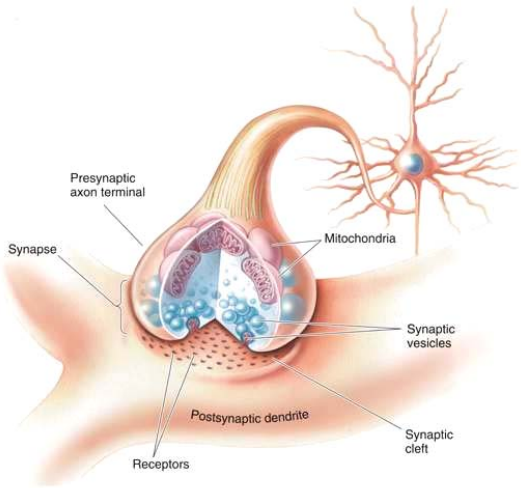
- **Axon**
  - Beginning → Axon hillock
  - Middle → Axon proper
  - End → Axon terminal
- **Difference between axon and soma**
  - No ER in the axon
  - Microtubule in the axon
- **Axon Terminal**
  - In the axon terminal (unlike the axon)
    - No microtubules
    - Synaptic vesicles
    - Plentiful cell membrane
    - Large number of mitochondria



Neuroscience: Exploring the Brain, 3rd Ed, Bear, Connors, and Paradiso Copyright © 2007 Lippincott Williams & Wilkins

Neurons

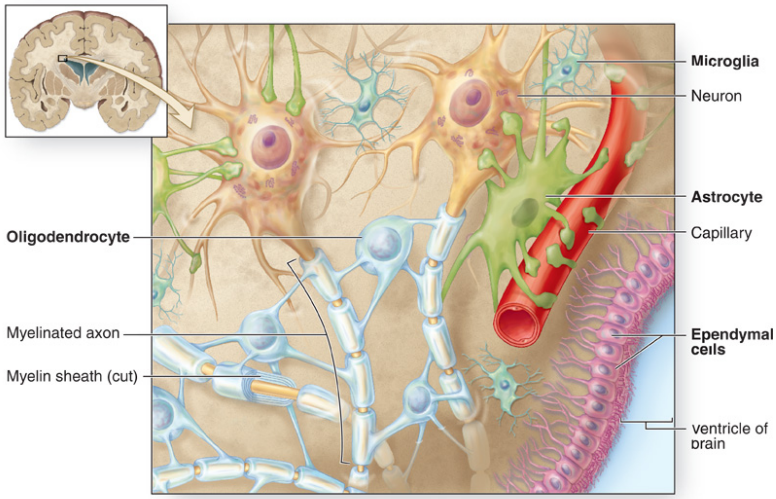
- **Synapse**
  - Communication between neurons
  - Conversion of Electrical signals to Chemical
  - Transmission of (chemical) information
  - Synapse malfunction can cause mental disorders
- **Dendrites**
  - The “antennas” of neurons
  - Have receptors for the secretions of the synapses
  - Dendritic spines
    - Accept and modulate signals



Neuroscience: Exploring the Brain, 3rd Ed, Bear, Connors, and Paradiso Copyright © 2007 Lippincott Williams & Wilkins

Glial Cells

- **90 % of all CNS cells or 50 % of CNS volume**
- **Communicate chemically (not electrically)**
- **Role**
  - Support the neurons physically and metabolically
  - Actively modulate the properties of synapses (important in learning and memory)
- **Types of glial cells**
  - Astrocytes
  - Oligodendrocytes
  - Microglia
  - Ependymal Cells

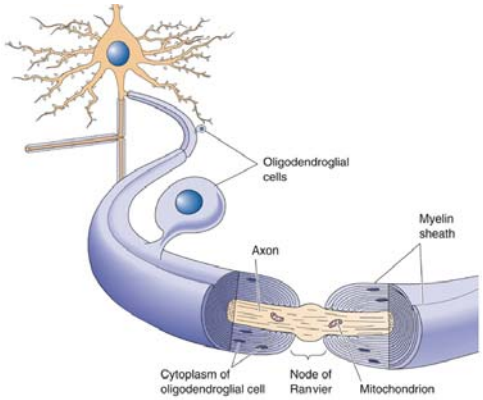


Glial Cells

- **Astrocytes**
  - Maintain neuron position and distance
  - Guide the neurons (like scaffolds) during development
  - Cause the formation, by blood vessels, of the blood-brain barrier
  - Heal traumas and form scar in the CNS
  - Reabsorb and break down the neurotransmitters glutamate and GABA thus reducing their effect
  - Reabsorb excess K+ (from the action of neurons) so that ECF concentrations remain constant
  - Communicate chemically between them and with neurons and play a role in memory and learning

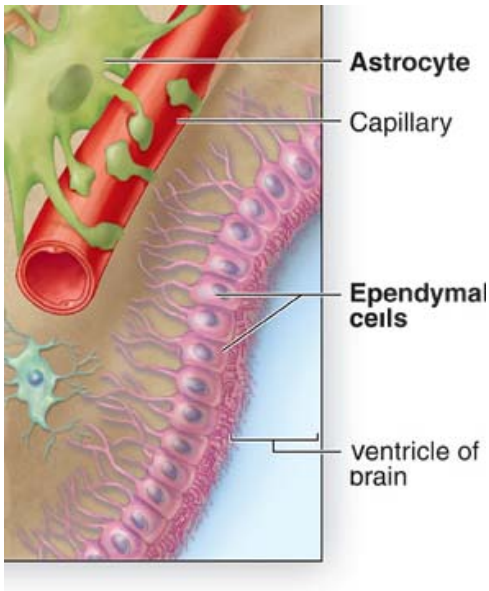
Glial Cells

- **Myelinating Glia**
  - Oligodendrocytes in the CNS and Schwann cells in the PNS
  - Form multilear myelin sheath
    - No movement of ions through myelin
  - Nodes of Ranvier
    - Areas between myelin sheaths
    - Movement of ions
  - Role will be explained in the action potential lecture
- **Microglia**
  - Immune cells of the CNS
    - When activated become spherical and attact with chemicals
    - Hyperactive microglia may play a role in neurodegenerative disorders
  - Secrete *Nerve Growth Factor*
    - Necessary for proper function of all other CNS cells



Glial Cells

- **Ependymal Cells**
  - Cover the lumens which contain cerebrospinal fluid (CSF)
    - Ventricles and central canal
  - Produce CSF
  - Moving cilia help in the flow of CSF
  - Stem cells for other glial cells and neurons in the hippocampus
- **Most cancers in the brain arise from glial cells (gliomas)**
  - Neurons don't replicate!



Next Lecture …

Διάλεξη 3
Κυτταρική Μεμβράνη Σε Ηρεμία
(Membrane at Rest)