HUMAN BIOLOGY

CHAPTER 2: The Chemistry of Living Things

2.2. Atoms combine to form molecules

Most common and important elements in living organisms:

99%

1) Oxygen (O)
2) Carbon (C)
3) Hydrogen (H)
4) Nitrogen (N)
5) Calcium (Ca)
6) Phosporus (P)

1%

7) Potassium (K)
8) Sulfur (S)
9) Sodium (Na)
10) Chlorine (Cl)
11) Magnesium (Mg)
12) Iron (Fe)

2.3. Life depends on water

- 60% of our body weight = water
- Important properties:
    - Water molecules are polar
        - Keeps ions dissolved
    - Water is a liquid at body temperature
        - Excellent medium for transporting solutes + occupies space in/between cells
    - Water can absorb and hold heat energy
        - Prevents large increases in body temperature or too much heat loss
        - Quickly lose heat by evaporation of water

➔ water = ideal solvent + important factor for temperature regulation

2.4. The importance of hydrogen ions

- **Hydrogen ion** = single proton without an electron
- H_2O = H^+ (*hydrogen ion*) en OH^- (*hydroxide ion*)
- **Acid** = any molecule that can donate an H^+ ion
    - Pure water + acid = **acidic solution** (higher H^+ concentration than pure water)
- **Base** = any molecule that can accept an H^+ ion
    - Pure water + base = **basic or alkaline solution** (lower H^+ concentration than pure water)
- Acids and bases neutralize each other
- **Ph scale** = measure of hydrogen ion concentration of a solution

    - From 0 to 14
    - Pure water = Ph 7.0
    - Blood = Ph 7.4
    - Important to keep a low concentration of hydrogen ions in the body!
      ➔ They tend to displace other positive ions, altering shape and structure of molecules
- **Buffer** = any substance that tends to minimize the changes in Ph that might otherwise occur when an acid or base is added to a solution
    - important for maintaining homeostasis of Ph in body fluids
    - Pairs of related molecules that have opposite effects (acid form and base form)
    - Most important buffer pair = **bicarbonate and carbonic acid**
        - Maintain homeostasis of Ph in blood

2.5. The organic molecules of living organisms

- **Organic molecules** = contain carbon and other elements held together by covalent bonds
- Carbon (koolstof) = common building block of all organic molecules
    - More stable when its second shell is filled with eight electrons
    - Natural tendency to form 4 covalent bonds with other molecules
    - Almost no limit to the size of organic molecules derived from carbon
- **Macromolecules** = consist of thousands or millions of smaller molecules
- **Dehydration synthesis** = subunits are joined by covalent bonds
    - each time a subunit is added, the equivalent of a water molecule is removed (dehydration)
    - requires energy
- **Hydrolysis** = breakdown of organic macromolecules
    - Equivalent of a water molecule is added, each time a covalent bond between subunits is broken
    - Releases energy
- Living organisms synthesize 4 classes of organic molecules:
  1) carbohydrates
  2) lipids
  3) proteins
  4) nucleic acids

2.6. Carbohydrates

- **Carbohydrates** = carbon + 2 hydrogen + oxygen
- Used for energy and structural support
- **Monosaccharide** = carbon + 2 hydrogen + oxygen
    - Glucose, fructose, ribose and desoxyribose
    - Glucose = energy for cells
- **Oligosaccharides** = short strings of monosaccharides linked together by dehydration synthesis
    - Bvb: table sugar
    - **Disaccharide** = 2 monosaccharide

- **Polysaccharides** = thousands of monosaccharides are joined together
    - Way for cells to store energy
        - Animals: **glycogen** / Plants: **starch**
    - **Cellulose** = structural support (plants)

2.7. Lipids

- Relatively insoluble in water
- **Triglycerides** = (neutral) fats
    - Glycerol + 3 fatty acids (chains of hydrocarbons that end in a carboxyl group (COOH)
    - Saturated fats
        - solid at room temperature
        - Animal fats (butter, bacon grease)
        - Contributes to development of cardiovascular disease
    - Unsaturated fats = oils
        - Liquid at room temperature
    - Stored in adipose tissue
    - Important source of stored energy
- **Phospholipids**
    - Primary structural component of cell membranes
    - Glycerol + 2 fatty acids + phosphate group (PO_4^-) + …
    - One end of molecule is polar (soluble in water), one end is neutral (insoluble in water)
- **Steroids**
    - Relatively insoluble in water
    - Bvb: **cholesterol**
        - Essential structural component of animal cell membranes
        - Source of several important hormones (o.a. estrogen, testosteron)

2.8. Proteins

- Long strings of **amino acids**
- Differences in charge/structure of amino acids ➔ differences in shape/functions of proteins
- Formed by dehydration synthesis
- 3 to 100 amino acids = **polypeptide**
- 100+ amino acids = **protein**
    - *Primary structure*: amino acid sequence
    - *Secondary structure*: how the chain is orientated in space
        - Alpha helix
        - Beta sheet
        - Random coil
    - *Tertiary structure*: how the protein twists and folds to form a 3-dimensional shape
    - *Quaternary structure*: how many polypeptide chains make up the protein and how they associate with each other
- Functions
    - Structural support

    - Muscle contraction
    - Part of cell membrane
    - Enzymes
- **Denaturation** = permanent disruption of protein structure, leading to loss of function
    - Caused by high temperature or changes in pH
- **Enzyme** = biological catalyst
    - Speeds up the rate of chemical reaction without itself being altered or consumed by the reaction
    - Break molecules apart or join them together
    - Reactants (= substrates) ➔ products
- Protein shape is in part determined by chemical/physical environment inside the cell
    - Temperature, pH, ion concentration
      ➔ importance of homeostasis!

2.9. Nucleic acids

- **DNA (deoxyribonucleic acid)**
    - Genetic material of the cell
    - Directs and controls all of life's processes
- **RNA (ribonucleic acid)**
    - Responsible for carrying out instructions of DNA
- Importance:
    - DNA contains the instructions for producing RNA
    - RNA contains the instructions for producing proteins
    - Proteins direct most of life's processes
- Both DNA and RNA are composed of **nucleotides**
    - 8 different nucleotides (4 in RNA + 4 in DNA)
    - DNA:
        - deoxyribose + phosphate group(s) + base
        - base = **adenine, thymine, cytosine** or **guanine**
        - 2 complementary strands (A with T, C with G)
    - RNA:
        - ribose + phosphate group(s) + base
        - base = **adenine, uracil, cytosine** or **guanine**
        - single-stranded molecule (complimentary copy of only one strand of DNA)
        - RNA is shorter (only the segment of DNA that codes for proteins)

2.10. ATP

- **ATP = adenosine triphosphate**
- Adenine base + ribose + triphosphate
- bonds between phosphate groups cointain potential energy ➔ energy source for cells
- Cells can break down ATP for energy:
    - ATP → ADP (adenosine diphosphate) + P_i (inorganic phosphate group) + energy
    - Reaction is reversible!

CHAPTER 3: Structure and Function of cells

- **Cell doctrine:**
  1) All living things are composed of cells and cell products
  2) A single cell is the smallest unit that exhibits all the characteristics of life
  3) All cells come only from preexisting cells

3.1. Cells are classified according to their internal organization

- All cells have a **plasma membrane**
  - Encloses the material inside the cell
- **Eukaryotes**
  - Plasma membrane
  - Nucleus
  - Cytoplasm: cytosol + organelles
- **Prokaryotes**
  - Bacteria
  - Plasma membrane
  - Genetic material isn't enclosed in a nucleus
  - Lack most of the organelles found in eukaryotes

3.2. Cell structure reflects cell function

- Strong link between structure and function
- All cells are small, because:
  - The total metabolic activities of a cell are proportional to its volume of cytoplasm, which is in effect its size
  - All raw materials, energy, and waste can enter or leave the cell only by crossing the plasma membrane
  - As objects get larger, their volume increases more than their surface area
    ➔ The smaller a cell is, the more effectively it can obtain raw materials and get rid of wastes
- **Microvilli** = effective way to increase surface area relative to volume

3.3. A plasma membrane surrounds the cell

- Constructed of:
  - Lipid bilayer
    - polar head (water-soluble) and nonpolar tails (water-insoluble)
    - Polar heads face outward, nonpolar tails face inward
  - Cholesterol
    - Make the plasma membrane more rigid
  - Proteins
    - Transporting molecules and information across the plasma membrane
- Plasma membranes of animal cells are not rigid (flexible)
- Phospholipids and proteins are not anchored to specific positions in the plasma membrane

3.4. Molecules cross the plasma membrane in several ways

1) Passive transport

- Doesn't require energy
- **Diffusion:**
    - Molecules in a gas/liquid move about randomly, colliding with other molecules and changing direction
    - Diffusion = movement of molecules from one region to another as a result of this random motion
    - Molecules will tend to diffuse away from area of high concentration and toward region of low concentration
    - Requires a concentration gradient between 2 points
    - Once the concentration of molecules is the same throughout the solution, a state of equilibrium exists in which molecules diffuse randomly but equally in all directions
- Pure water = solution with the highest possible concentration of water
- Plasma membrane is **selectively permeable**
    - Highly permeable of water, but not to all ions or molecules
    - Net diffusion of water across a selectively permeable membrane = **osmosis**
    - Fluid pressure to exactly oppose osmosis = **osmotic pressure**

Diffusion through the lipid bilayer

- Allows passage of some molecules while restricting others
- 2 important lipid-soluble molecules: O_2 and CO_2

Diffusion through channels

- Constructed of proteins that span the entire lipid bilayer
- Some channels are open all the time, others are gated
- Important in regulating transport of ions (sodium, potassium and calcium) in cells that are electrically excitable

Facilitated transport

- = facilitated diffusion
- Molecule attaches to a membrane protein, triggering a change in the protein's shape or orientation that transfers the molecule to the other side of the membrane
  = **transport protein** or **carrier protein**

2) Active transport

- Can move substances through the plasma membrane against their concentration gradient
- Requires energy (ATP → ADP + P_i + energy)
- **Pumps** = proteins that actively transport molecules across the plasma membrane
    - Bvb: **sodium-potassium pump**
- Not all active transport pumps require ATP: some pumps derive energy from "downhill" facilitated transport and use it to transport another molecule "uphill"

3) Endocytosis or exocytosis

- Some molecules are too big to be transported by the previous methods
- **Endocytosis**: moves material into the cell
- **Exocytosis**: moves material out of the cell

- **Receptor proteins**: span the plasma membrane and can receive and transmit information across the membrane
    - Binding of a molecule to a receptor site (lock-and-key system) triggers biochemical reactions that ultimately cause changes within the cell
    - Highly specific for a particular molecule
- Cells tend to accumulate certain materials depending on what is available in their extracellular environment
- Water diffuses from outside the cell toward the high cytoplasmic solute concentration
    - Would increase cell volume, eventually causing the cell to rupture
- The cell gets rid of ions it doesn't need in large quantities in exchange for those it must stockpile
    - Keeps the solute concentration in cytoplasm identical to the solute concentration of extracellular fluid ➔ no net driving force for diffusion of water

  = primary function of **sodium-potassium pump**
    - 3 binding sites for sodium (inside the cell)
    - Binding of sodium triggers breakdown of ATP to release energy
    - ATP causes pump to change shape, expelling sodium ions and exposing 2 binding sites for potassium (outside the cell)
    - Binding of potassium triggers another change of shape, transporting potassium into the cell
- **Tonicity** = relative concentration of solutes in two fluids
    - Ability of a human cell to control its volume also depends on the tonicity of the extracellular fluid
    - **Isotonic** extracellular fluid has the same concentration as the intracellular fluid
    - **Hypertonic** solution: higher concentration of solutes than intracellular fluid
        - Water diffuses out of the cells, cells shrink (and die)
    - **Hypotonic** solution: lower concentration of solutes than intracellular fluid
        - Water diffuses into the cells, cells swell (and die)

3.5. Internal structures carry out specific functions

- **Nucleus**
    - Information center of the cell
    - Contains most of the cell's genetic material (DNA)
        - DNA controls nearly all activities of the cell
    - **Nuclear membrane** with **nuclear pores**
    - **Nucleolus:** synthesizes RNA and proteins that compose ribosomes
- **Ribosomes**
    - Composed of RNA and certain proteins
    - Either freely floating in cytosol or attached to the endoplasmatic reticulum

- Responsible for making specific proteins

- **Endoplasmatic reticulum (ER)**
  - Synthesizes most of the chemical compounds made by the cell
  - With ribosomes: rough ER
    - Synthesis of proteins
    - Move from rough ER to smooth ER
  - Without ribosomes: smooth ER
    - Synthesis of macromolecules other than protein
      - Mostly lipids (some hormones)
    - Packaging of proteins and lipids for delivery to the Golgi apparatus
- **Golgi apparatus**
  - Cell's refining, packaging, and shipping center
  - Contains enzymes that further refine the products of the ER into final form
- **Vesicles**
  - Membrane-bound spheres that enclose something within the cell
  - *Vesicles that ship and store cellular products*
    - Enclose and transport products of ER and Golgi apparatus
    - Remains in cytoplasm if the products are not immediately needed
  - *Secretory vesicles*
    - Contain products destined for export from the cell
    - Release their contents by exocytosis
  - *Endocytotic vesicles*
    - Enclose bacteria and raw materials from the extracellular environment
    - Bring them into the cell by endocytosis
  - *Peroxisomes and lysosomes*
    - Contain enzymes so powerful that they must be kept within the vesicle to avoid damaging the rest of the cell
    - **Peroxisomes:**
      - destroy various toxic wastes produced in the cell
      - destroy compounds that have entered the cell from outside
      - process occurs entirely within the peroxisome
    - **Lysosomes:**
      - Contain powerful digestive enzymes
      - Fuse with endocytotic vesicles to digest bacteria etc.
      - Dissolve and remove damaged mitochondria
      - When their digestive task is complete, they become **residual bodies** (can be stored in the cell or eliminated by exocytosis)
- **Mitochondria**
  - Provide the cell of energy
  - Smooth outer membrane covers the entire surface
  - Inner membrane with numerous folds that increase the surface area
  - Contain hundreds of protein enzymes to break down food and release energy
  - Energy is used to create ATP, which is then released in the cytosol

- Some cells store raw energy as lipids (fat) or glycogen granules
    - Energy stored in glycogen can be used to produce ATP more quickly than energy derived from fat

3.6. Cells have structures for support and movement

- **Cytoskeleton**
    - loosely structured network of fibers (**microtubules** and **microfilaments**)
    - Framework for the soft plasma membrane
    - Supports and anchors other structures within the cell
- **Cilia**
    - Hairlike, extend from the surface
    - Cilia move materials along the surface of a cell with a brushing motion
    - 9 pairs of fused microtubules surround 2 single microtubules in the center
- **Flagella**
    - found only on sperm cells
    - whiplike movement moves the entire sperm cell from one place to another
    - similar structure as cilia
- **Centrioles**
    - Essential for cell division (see Chapter 17)

3.7. Cells use and transform matter and energy

- **Metabolism** = sum of all the chemical reactions in the organism
- **Metabolic pathways:**
    - Linear: product from one chemical reaction becomes the substrate for the next
    - Cyclic: substrate molecules enter and product molecules exit, but the basic chemical cycle repeats over and over again
    - 2 types:
        - **Anabolism**
            - Molecules are assembled into larger molecules (requires energy)
        - **Catabolism**
            - Larger molecules are broken down (releases energy)
- Nearly every chemical reaction requires a specific enzyme
- Metabolic activities of a cell require a lot of energy
  ➔ Cells get their energy by catabolism of molecules that serve as chemical stores of energy

- Glucose = most readily available source of energy
    - Derived from food or stored glycogen
    - Production of ATP:
      1) glycolysis: glucose ➔ 2 three-carbon pyruvate molecules
      2) preparatory step: pyruvate enters mitochondrion ➔ acetyl CoA + energy
      3) citric acid cycle: acetyl CoA ➔ energy
      4) electron transport system: energy is used to produce ATP from ADP
- Most of the body's energy reserves do not take the form of glycogen
    - Our body may utilize fats and proteins (fig. 3.30, HB p. 74)

- A small amount of ATP can be made in humans by **anaerobic metabolism** (without oxygen) for at least brief periods of time
    - Bvb: glycolysis
    - Glucose ➔ pyruvate ➔ lactic acid
    - Lactic acid causes burning sensation and cramps associated with muscle fatigue when not enough oxygen is available to muscle tissue
    - When oxygen becomes available again, the lactic acid is metabolized by aerobic pathways
    - Glucose is the only fuel that can be used under anaerobic conditions

CHAPTER 4: From Cells to Organ Systems

4.1. Tissues

- Multicellular organism: many cells that collectively share the functions of life
- All cells: specialized function that benefits the organism in some way
    - Specialized functions must be organized and integrated
- **Tissues** = groups of specialized cells that are similar in structure and that perform common functions
    - 4 major types: epithelial, connective, muscle and nervous

4.2. Epithelial tissues

- Sheets of cells that line or cover various surfaces and body cavities
- Protect underlying tissues
- Smooth, reduce friction
- **Glandular epithelia (glands):** specialized to synthesize and secrete a product
    - **Exocrine glands:** secrete their products into a hollow organ or duct
    - **Endocrine glands:** secrete hormones into the bloodstream
- Shape:
    - Squamous
        - flattened cells
        - forms the outer surface of the skin and lines the inner surfaces of the blood vessels, lungs, mouth, throat and vagina
    - Cuboidal
        - Cube-shaped cells
        - Forms the kidney tubules and covers the surfaces of the ovaries
    - Columnar
        - Rectangular cells
        - Lines parts of digestive tract, certain reproductive organs and the larynx
- Number of cell layers:
    - Simple epithelium
        - single layer of cells
        - thin; molecules can pass through it
    - Stratified epithelium
        - multiple layers
        - thicker; provides protection for underlying cells
- **basement membrane**
    - supporting noncellular layer
    - anchors the cells to the stronger connective tissue underneath
- **cell junctions**
    - made up of various proteins
    - hold cells together
    - types:
        - tight junctions: nothing can pass between the cells

        - adhesion junctions: some movement between cells, tissues can stretch and bend
        - gap junctions: connecting channels made of proteins that permit movement of ions or water between 2 adjacent cells

4.3. Connective tissue

- supports the softer organs against gravity and connects the parts of the body together
- **Fibrous connective tissues**
    - Connect various body parts, providing strength, support and flexibility
    - Types of fiber:
        - **Collagen fibers**: confer strength; are slightly flexible
        - **Elastic fibers**: can stretch without breaking
        - **Reticular fibers**: internal structural framework for some of the "soft" organs
    - Fibers are embedded in a **ground substance**
        - Contains **fibroblasts:** secrete proteins that compose collagen/elastic/reticular fibers
    - Subclasses: (table 4.1, HB p. 83)
        - Loose
        - Dense
        - Elastic
        - Reticular (lymphoid)
- **Specialized connective tissues**
    - **Cartilage**
        - Transition tissue from which bone develops
        - Maintains the shape of certain body parts and protects and cushions joints
        - Consists primarily of collagen fibers
        - Produced by **chondroblasts**
        - Ground substance contains a lot more water
        - Cells are enclosed in small chambers called **lacunae**
        - No blood vessels
            - Mature cells obtain their nutrition only by diffusion through the ground substance
            - Heals slowly when injured
    - **Bone**
        - Contains only a few living cells
        - Consists of hard mineral deposits of calcium and phosphate
        - Contains numerous blood vessels
            - Can heal quicker
    - **Blood**
        - Cells suspended in **plasma**
        - **Red blood cells** transport oxygen, nutrients and waste products
        - **White blood cells:** function in the immune system
        - **Platelets:** cause blood to clot following an injury
    - **Adipose tissue**

        - Fat storage
        - Almost no fibers and ground substance
        - **Adipocytes** (fat cells)
        - Layer of insulation under the skin
        - Protective layer around internal organs
        - Weight loss reduces the volume of fat cells, but not their number

4.4. Muscle tissue

- Cells that are specialized to shorten (contract), resulting in movement
- Composed of **muscle fibers**
- 3 types:
    - **Skeletal muscle tissue**
        - Connects to tendons, which attach to bones
        - Causes body parts to move
        - Each muscle fiber has many nuclei
        - Voluntary: conscious control over its activity
    - **Cardiac muscle tissue**
        - Found only in the heart
        - Only one nucleus
        - Involuntary: heart can contract rhythmically on its own
    - **Smooth muscle tissue**
        - Surrounds hollow organs and tubes
            - Blood vessels, digestive tract, uterus, bladder
        - Only one nucleus
        - In blood vessels:
            - Generally aligned in a circular fashion around the vessel
            - When smooth muscle cells shorten, the diameter of the blood vessel is reduced
        - Gap junctions between cells, so that nearby cells contract as well
        - Involuntary

4.5. Nervous tissue

- Cells that are specialized for generating and transmitting electrical impulses
- Located in the brain, the spinal cord and the nerves
- Nervous tissue cells = **neurons**
    - **Cell body**: contains nucleus
    - **Dendrites**: receive signals from other neurons
    - **Axon**: transmits electrical impulses over long distances
- **Glial cell**: supporting role by surrounding and protecting neurons and supplying them with nutrients

4.6. Organs and organ systems

- **Organs:** structures composed of 2 or more tissue types joined together that perform a specific function or functions

- **Organ systems**: groups of organs that together serve a broad function that is important to survival either of the individual organism or of the species (reproduction)
  1) Integumentary System *(Chapter 4)*
  2) Skeletal System *(Chapter 5)*
  3) Muscular System *(Chapter 6)*
  4) Circulatory System *(Chapter 8)*
  5) Lymphatic System *(Chapter 9)*
  6) Respiratory System *(Chapter 10)*
  7) Nervous System *(Chapter 11)*
  8) Endocrine System *(Chapter 13)*
  9) Digestive System *(Chapter 14)*
  10) Urinary System *(Chapter 15)*
  11) Reproductive System *(Chapter 16)*

- **Tissue membranes**
  - line body cavities
  - form our skin
  - consist of layer of epithelial tissue and connective tissue
  - Types:
    - **Serous**
      - line and lubricate body cavities to reduce friction between internal organs
    - **Mucous**
      - Line the airways, digestive tract and reproductive passages
      - mucus lubricates the membrane's surface and entraps foreign particles
    - **Synovial**
      - Line the very thin cavities between bones in movable joints
      - Secrete a watery fluid that lubricates the joint
    - **Cutaneous**
      - Outer covering (= skin)
      - Several functions
- **Body cavities**
  - Figure 4.8, HB p. 87
- Describing body position or direction
  - Figure 4.9, HB p. 90

4.7. The skin as an organ system

- **Integumentary system** = skin + accessory structures (hair, nails, glands)
- Functions:
  - Protection from dehydration
  - Protection from injury
  - Defense against invasion by bacteria and viruses
  - Regulation of body temperature

    - Synthesis of an inactive form of vitamin D
    - Sensation: provides information about the external world via receptors for touch, vibration, pain and temperature
- Outer layer of epithelial tissue = **epidermis**
    - Constantly being replaced as cells near the base of the epidermis divide repeatedly, pushing older cells toward the surface
    - **Keratinocytes (= basal cells)**
        - produce keratin (protein)
        - move toward the skin surface, die and dry out
            - epidermis lacks blood vessels, so cells no longer obtain nutrients as they move farther away from the dermis
            - dead cells are shed over time
        - create a nearly waterproof barrier that covers and protects the living cells below
        - allows the skin to heal quickly after injury
    - **melanocytes**
        - produce melanin (pigment)
        - protects us against the sun's ultraviolet radiaton
        - enables people to develop a suntan
        - racial differences in skin color reflect differences in melanocyte activity or in the rate of breakdown of melanin
- Outer layer of connective tissue = **dermis**
    - Primarily dense connective tissue
    - Fibers allow the skin to stretch when we move and give it strength to resist abrasion and tearing
    - Becomes less flexible as we age, because the number of fibers decreases
    - **Fibroblasts** in dermis produce fibers
    - Other structures:
        - **Hair**: shaft + root + follicle
        - **Smooth muscle**: contracts when you are frightened or cold
        - **Sebaceous glands**: secrete an oily fluid that moistens and softens hair and skin
        - **Sweat glands**: produce sweat, which helps regulate body temperature and protect against bacteria
        - **Blood vessels:** supply the cells of the dermis and epidermis with nutrients and remove their wastes + help regulate body temperature
        - **Sensory nerve endings:** provide information about the outside environment
- Supporting layer of loose connective tissue containing fat cells = **hypodermis**

4.8. Multicellular organisms must maintain homeostasis

- **Internal environment**: environment that surrounds the cells of a multicellular organism
- Every cell gets nutrients from the **interstitial fluid** and dumps wastes into it
- Composition of this fluid must be kept fairly constant to sustain life (= **homeostasis**)
- Homeostasis is maintained by **negative feedback** control systems

    - Deviations from the desired condition are automatically detected and counteracted
    - **Controlled variable**: any physical or chemical property that might vary and that must be controlled to maintain homeostasis
    - **Sensor (receptor):** monitors the current value of the controlled variable and sends the information to the control center
    - **Control center:** receives input from the sensor and compares it to the **set point**. Sends signals to an effector when the current value and the set point of the controlled variable differ
    - **Effector**: takes the necessary action to correct the imbalance
- **Positive feedback** control systems
    - Relatively uncommon in living organisms
    - Change in the controlled variable sets in motion a series of events that amplify the original change, rather than returning it to normal
    - Bvb: process of childbirth

CHAPTER 5: The Skeletal System

5.1. The skeletal system consists of connective tissue

- 3 types of connective tissue:
  - Bones
  - Ligaments
  - Cartilage
- **Bones**
  - Consist of calcium minerals + living bone cells, nerves and blood vessels
  - 5 important functions:
    - Support
    - Movement
    - Protection
    - Formation of blood cells
    - Mineral storage
  - Structure:
    - **Diaphysis**: cylindrical shaft
      - Contains **spongy bone** (latticework of **trabeculae**)
    - Long bones of the upper arms/legs: contain **red bone marrow**
      - **Stem cells** in red bone marrow produce red and white blood cells and platelets
    - **Epiphysis**: enlarged knob at each end
    - **Compact bone** forms the shaft and covers each end
      - Made of **osteocytes** arranged in rings in cylindrical structures (= **osteons**)
      - As bone becomes hard, osteocytes become trapped in **lacunae**
      - Osteocytes remain in contact with each other via thin canals (= **canaliculi**)
    - Central cavity in the shaft is filled with **yellow bone marrow**
      - Primarily fat that can be utilized for energy
    - Outer surface: **periosteum** (layer of connective tissue)
      - Contains bone-forming cells
  - In compact bone:
    - Osteocyte nearest the center of an osteon receive nutrients by diffusion from blood vessels that pass through a **central canal**
    - These cells pass nutrients on to adjacent cells via the gap junctions
    - Waste products produced by the osteocytes diffuse in the opposite direction and are removed from the bone by the blood vessels
  - In spongy bone:
    - Structure of spongy bone gives each osteocyte access to blood vessels in red bone marrow
- **Ligaments**
  - Attach bone to bone
  - Consist of dense fibrous connective tissue

    - Confer strength to certain joints while still permitting movement of the bones in relation to each other
- **Cartilage**
    - Smoother and more flexible than bone
    - Found were support under pressure is important and where some movement is necessary
    - 3 types:
        - **Fibrocartilage**
            - Intervertebral disks, menisci
        - **Hyaline cartilage**
            - Embryonic structures that later become the bones
        - **Elastic cartilage**
            - Outer ear, epiglottis

5.2. Bone development begins in the embryo

- Fetus: first 2 months
    - Cartilage model forms out of hyaline cartilage by **chondroblasts**
- Fetus: at 2-3 months
    - **Ossification:** cartilage models are replaced by bone
    - After chondroblasts die, the matrix they produced gradually breaks down inside the future shaft of the bone, making room for blood vessels (= **osteoblasts**) to develop
    - Osteoblasts secrete:
        - **osteoid**, which forms internal structure and provides strength
        - enzymes that facilitate bones to become hard (**hydroxyapatite**)
- Childhood and adolescence
    - **Growth plate** (narrow strip of cartilage) remains in each epiphysis
    - Bone lengthens as the 2 growth plates migrate farther apart
- Bone development process is controlled by hormones, secreted by the endocrine glands
    - Childhood: growth hormone
    - Adolescence: sex hormones (testosterone and estrogen)
- At about age 18 in females and 21 in males
    - Sex hormones signal growth plates to stop growing
    - Cartilage is replaced by bone tissue

5.3. Mature bone undergoes remodeling and repair

- **Osteoclast** = bone-dissolving cells
- The areas from which bone has been removed attract new osteoblasts, which produce new bone
- Constant remodeling can actually change the shape of a bone
    - Compression stress on a bone (force of repeated jogging) causes tiny electrical currents within the bone ➔ Stimulates bone-forming activity
      ➔ New bone is laid down in regions under high compressive stress and bone is resorbed in areas of low compressive stress
    - Final shape of the bone tends to match the compressive forces to which it is exposed

- Weight-bearing exercise increases bone mass and strength
- Rates of activity of osteoblasts and osteclasts in adulthood are regulated by hormones that function to maintain calcium homeostasis
    - **Parathyroid hormone (PTH)**
        - Stimulates osteoclasts
    - **Calcitonin**
        - Stimulates osteoblasts

- Repair of bones
    - When you break (fracture) a bone, the blood vessels supplying the bone bleed into the area, producing a mass of clotted blood (= **hematoma**)
    - Fibroblasts migrate to the area
    - Some fibroblasts become chondroblasts
    - They produce a tough fibrocartilage bond (= **callus**) between the 2 broken ends of the bone
    - Osteoclasts remove dead bone and blood cells of the hematoma
    - Osteoblasts create new bone
- Bones rarely break in the same place twice, because the repaired union remains slightly thicker than the original bone
- Repair process slows with age

5.4. The skeleton

- 4 types of bones:
    - Long bones (limbs and fingers)
    - Short bones (wrists)
    - Flat bones (cranial bones, sternum, ribs)
    - Irregular bones
- 3 functions of skeleton:
    - Support
    - Protection
    - Permits movement
- **Axial skeleton**
    - Skull
        - Cranial bones
            - Frontal bone
            - 2 parietal bones
            - 2 temporal bones
            - Sphenoid bone
            - Ethmoid bone
            - Occipital bone
            - Foramen magnum
        - Facial bones
            - 2 maxilla bones
            - 2 palatine bones

        - Vomer bone
        - 2 zygomatic bones
        - 2 nasal bones
        - Lacrimal bones
        - Mandible (lower jaw)
        - Air spaces (**sinuses**)
    - Vertebral column
        - Main axis of the body
        - Supports the head
        - protects the spinal cord
        - serves as the site of attachment for the four limbs and various muscles
        - 33 irregular bones called **vertebrae**
        - 5 regions:
            - **Cervical** (neck) – 7 vertebrae
            - **Thoracic** (chest) – 12 vertebrae
            - **Lumbar** (lower portion of the back) – 5 vertebrae
            - **Sacral** (sacrum or upper pelvic region) – 5 fused vertebrae
            - **Coccygeal** (coccyx or tailbone) – 4 fused vertebrae
        - Vertebrae share 2 points of contact (= **articulations**)
        - **Intervertebral disks**: shock absorbers + give flexibility
            - When intervertebral disk presses against nerve: **hernia**
    - Ribs and sternum
        - 12 pairs of ribs
        - Upper 7 attach via cartilage to the **sternum** (breastbone)
        - 8-10 are joined to the 7^{th} rib by cartilage
        - Bottom 2 = **floating ribs**
        - Ribs, sternum and vertebral column form a protective **rib cage**
- **Appendicular skeleton**
    - **Pectoral girdle**
        - Supporting frame for the upper limbs
        - Right and left **clavicles** (collarbones)
        - Right and left **scapulas** (shoulder blades)
        - Arm and hand
            - Humerus
            - Ulna and radius
            - 8 carpal bones (wrist)
            - 5 metacarpal bones (hand)
            - 14 phalanges (finger bones)
        - **Carpal tunnel syndrome** = due to repetitive typing at a keyboard
    - **Pelvic girdle**
        - Two coxal bones join in the **pubic symphisis**
        - Sacrum (pelvis)
        - Function:
            - support the weight of the upper body against the force of gravity

        - protects the organs inside the pelvic cavity
        - serves as a site of attachment for the legs
    - femur (thighbone)
    - patella (knee cap)
    - tibia + fibula (lower leg)
    - 7 tarsals (ankle)
    - 5 metatarsals (foot)
    - 14 phalanges (toe bones)

5.6. Diseases and disorders of the skeletal system

- **Sprain**
    - due to stretched or torn ligaments
    - often accompanied by internal bleeding (bruising, swelling, pain)
    - heal slowly
- **bursitis and tendinitis**
    - inflammation of the bursae or tendons following injury
    - causes:
        - tearing injuries to tendons
        - physical damage caused by blows to the joint
        - bacterial infections
    - heal slowly
    - causes “tennis elbow”
- **Arthritis**
    - Joint inflammation
    - **Osteoarthritis** (most common type)
        - Cartilage covering the ends of the bones wears out
        - Restricts joint movement
        - Joint becomes inflamed and painful
    - **Rheumatoid arthritis**
        - Joint inflammation caused by the body’s own immune system
- **Osteoporosis**
    - Caused by excessive bone loss
    - Leads to brittle, easily broken bones over time
    - Higher risk in older women: decline in estrogen after menopause
    - Can be prevented:
        - Get enough calcium and vitamin D
        - Maintain a constant exercise program
        - Medication

CHAPTER 6: The Muscular System

- **Skeletal muscles**
  - Attach to the skeleton
  - Give strength and mobility
  - Sculpt the body
- **Cardiac muscle**
  - Pumps blood throughout the body
- **Smooth muscle**
  - Propels the child through the birth canal
  - Pushes food through the digestive tract
  - Transports urine from the kidney to the bladder
  - Regulates blood flow

6.1. Muscles produce movement or generate tension

- Muscle movements are voluntary or involuntary
- Muscles:
  - Produce movement
  - resist movement
  - generate heat
- Features:
  - Muscle cells are excitable
    - Contract in response to chemical/electrical signals from other organ systems
  - They contract (shorten), and then they relax (return to original length)
- Skeletal muscles
  - cause bones to move (or prevent them from moving) relative to each other
  - **Synergistic muscles** = muscle groups that work together to create the same movement
  - **Antagonistic muscles** = muscles that oppose each other
  - Most skeletal muscles are attached to bones via **tendons**
  - Each individual muscle produces a very specific movement of one bone relative to another
  - One end of a skeletal muscle (**origin**) joins to a bone that remains relatively stationary
  - The other end of the muscle (**insertion**) attaches to another bone across a joint
    ➔ when the muscle contracts, the insertion is pulled toward the origin
- Single muscle
  - group of individual muscle cells (**muscle fibers**), all with the same origin/insertion and same function
  - arranged in bundles (**fascicles**), enclosed in **fascia** (fibrous connective tissue)
  - At the ends of the muscle all of the fasciae come together, forming the tendons that attach the muscle to bone
- Single muscle cell
  - Each cell contains more than one nucleus
  - Entire interior of the cell is packed with **myofibrils**

        - Contain contractile proteins (**actin** and **myosin**)
        - When myofibrils contract (shorten), the muscle cell also shortens

6.2. Individual muscle cells contract and relax

- Muscle contraction requires energy (ATP)
- In the presence of calcium, myosin splits ATP (ATP → ADP + P_i + energy)
- Energy is used to energize the myosin head so that it can form a cross-bridge and undergo bending
- Once bending has occurred, another molecule of ATP binds to myosin, which causes the myosin head to detach from actin
- Result: shortening of the sacromere
- At the end of the contractile period, energy is used to transport calcium back into the sarcoplasmic reticulum so that relaxation can occur
- An intact molecule of ATP must bind to myosin before myosin can detach from actin
    - Explains **rigor mortis**
- Energy sources for muscle cells (table 6.1, HB p. 128)
    - Stored ATP
        - Stored in small quantities
        - About 10 seconds
        - Must be replenished by other energy sources
    - Stored creatine phosphate
        - 3 to 5 times amount of stored ATP
        - About 30 seconds
        - Converted quickly to ATP
    - Stored glycogen
        - Variable quantity
        - Primarily used during heavy exercise within the first 3-5 minutes
        - One glucose molecule yields only 2 ATP in the absence of oxygen (anaerobic metabolism)
    - Aerobic metabolism
        - Not a stored form of energy
        - Always present
        - One glucose molecule yields 36 ATP (aerobic metabolism)
- After exercise: heavy breathing for a period of time
    - Helps reverse your body's **oxygen debt**
        - muscles used more ATP than was provided by aerobic metabolism
        - anaerobic metabolism produced lactic acid
        - after exercise, you need oxygen to metabolize the lactic acid by aerobic pathways and to replenish energy stores
- **Muscle fatigue** = decline in muscle performance during sustained exercise
    - Causes:
        - lack of sufficient ATP to meet metabolic demands
        - psychological factors

6.3. The activity of muscles can vary

- **isotonic contractions**:
  - whenever a muscle shortens while maintaining a constant force
  - movement
- **isometric contractions**:
  - force is generated, muscle tension increases
  - bones and objects do not move (maintaining a static position)
  - useful to strengthen muscles
- each group of muscle cells is controlled by a single nerve cell (**motor neuron**)
- **motor unit** = motor neuron + all the cells it controls
- when the motor neuron is activated, all the muscle cells in that motor unit are activated together
- how much tension is generated by a muscle depends on:
  - number of muscle cells in each motor unit
    - larger motor units generate more force but offer less control
    - **all-or-none principle**: muscle cells never contract on their own
    - muscle cells always respond with a complete cycle of contraction and relaxation (= a **twitch**) every time they are stimulated by an **action potential**
    - Whole muscles generally maintain an intermediate level of force known as **muscle tone**
  - number of motor units active
    - increasing tone (or force) by activating more motor units = **recruitment**
  - frequency of stimulation of individual motor units
    - laboratory recording of muscle activity = a **myogram**
    - Stimulus-twitch relationship has 3 stages:
      - Latent period
      - Contraction
      - Relaxation
    - Contraction/relaxation cycle of the muscle lasts longer than the stimulus that caused the contraction
    - If additional stimuli arrive at the muscle before the muscle is completely relaxed again, the total force produced becomes greater than the force produced by one twitch alone (= **summation**)
    - If stimulation becomes so frequent that the muscle cannot relax at all, it will remain in a state of maximum contraction (= **tetanus** or **titanic contraction**)

6.4. Cardiac and smooth muscles have special features

- Cardiac and smooth muscles are involuntary muscle
- Cardiac muscles
  - Those with the fastest rhythm = **pacemaker cells**
    - Rest of the cells follow their faster pace
  - **Intercalated discs** contain gap junctions that permit one cell to electrically stimulate the next one

- Smooth muscles
    - Also joined by gap junctions that permit the cells to activate each other
- Cardiac and smooth muscle do respond to stimulation by nerves as well
    - Effect may be either inhibitory or stimulatory
    - Nerve stimulation can also change the contractile force of smooth muscle
- Speed and sustainability of contraction
    - Speed and sustainability: skeletal > cardiac > smooth muscle
    - Cardiac muscle cells: cycles of contraction and relaxation
        - necessary so that the muscle doesn't fatigue
    - Smooth muscle: partially contracted all the time
        - Almost never fatigues because it contracts so slowly that its ATP usage is always less than its production capability
- Arrangement of myosin and actin filaments
    - Cardiac and skeletal muscle: Regular array of thick and thin filaments arranged in sarcomeres (**striated muscle**)
    - Smooth muscle: thick and thin filaments are arranged in bundles that attach at various angles to the cell membrane

CHAPTER 7: Blood

- **Circulatory system** = heart + blood vessels + blood

7.1. The components and functions of blood

- **Blood** = specialized connective tissue
- 3 functions:
  - Transportation
    - Oxygen, nutrients, hormones, waste products
  - Regulation
    - Body temperature, volume of water, pH of body fluids
  - Defense
    - Protection against infections and illness, prevent excessive blood loss
- Adults: 5-6L (males) / 4-5L (females) of blood
- **Plasma** (55%)
  - Water (90% of plasma)
  - Electrolytes (ions): sodium, calcium, potassium, …
  - Proteins
    - **Albumins**
      - Maintain blood volume and transport electrocytes, hormones and wastes
    - **Globulins**
      - Serve as antibodies and transport substances
    - **clotting proteins**
      - contribute to blood clotting
  - Hormones
  - Gases (O_2, CO_2, NO)
  - Nutrients (glucose) and waste
- Formed elements (45%)
  - **Red blood cells (RBC's)**
  - **White blood cells (WBC's)**
  - **Platelets**

- **Red blood cells (RBC's)**
  - **= erythrocytes**
  - transport O_2 and CO_2
  - shape makes them flexible
  - have no nucleus or organelles
  - **hemoglobin**
    - concentration of protein
    - 4 polypeptide chains, each containing a heme group (iron in heme group can bond with an O_2 molecule)
    - M: 14-18 gr/dl – V: 12-15 gr/dl
    - Lung: O_2 diffuses into blood plasma and then into RBC's
    - O_2 attaches to the iron atoms

        - Binding removes some O_2 from the plasma, making room for more O_2 to diffuse into the plasma
          ➔ Hemoglobin with 4 O_2 molecules = **oxyhemoglobin** (bright red color)
        - in body tissues, concentration of dissolved O_2 and Ph are lower
        - hemoglobin releases O_2 into body tissues
          ➔ Hemoglobin that has given up its O_2 = **desoxyhemoglobin** (dark red color)
        - also transports some CO_2
    - **hematocrit**
        - percentage of blood that consists of red blood cells
        - relative measure of the oxygen-carrying capacity of blood
        - low hematocrit may signal **anemia** (underproduction of RBC's)
        - high hematocrit may signal **polycythemia** (overproduction of RBC's) and increases risk of blood clots

- All blood cells and platelets originate from **stem cells** in the red bone marrow

RBC's have a short life span

- Stem cells ➔ **erythroblasts** ➔ RBC's
- Cannot reproduce ➔ all new RBC's must originate from dividing stem cells
- Live for only ±120 days (due to lack of nucleus)
- RBC's must be produced throughout life
- Old and damaged RBC's are destroyed in the liver and spleen by **macrophages** = **phagocytosis**
- RBC's recycled:
    - Amino acids used to produce new proteins
    - Iron molecules returned to red bone marrow
    - Heme group ➔ **bilirubin** (yellow pigment)
        - transported to liver and eliminated via feces
        - can cause **jaundice**

RBC production is regulated by a hormone

- = negative feedback control loop
- Cells in the kidneys monitor availability of oxygen
- Low oxygen availability signals the cells to secrete **erythropoietin (EPO)**
    - EPO stimulates stem cells to produce more RBC's
- When oxygen-carrying capacity of blood rises again, cells cut back on EPO production
    - RBC production decreases
- Injecting commercial EPO to increase RBC production = **blood doping**

White blood cells defend the body

- 1% of whole blood = WBC's (**leukocytes**)
- Have a nucleus, but no hemoglobin

- Crucial role in defending the body against disease and injury
- **Granular leukocytes (granulocytes)** and **agranular leukocytes (agranulocytes)**
    - Contain granules (vesicles) that are filled with enzymes
- Mature in red bone marrow (exception: T-lymphocytes mature in the thymus gland)
- Life span: a few hours to 9 days (agranular live longer than granular)
- Dead and injured WBC's: removed by liver and spleen
- Level of WBC's rises when body is attacked
    - WBC's produce chemicals that circulate in blood back to bone marrow, where they stimulate production of WBC's
-