b. extracellular fluid

(1) plasma (fluid in the blood)

(2) interstitial fluid (surrounding cells)

- Major factors maintained

1. concentration of nutrient molecules
    a. cells need energy and building blocks
2. concentration of O_2 and CO_2
    a. O_2 used to make usable energy (ATP)
    b. CO_2 made must be removed
3. concentration of waste products
    a. become toxic at high levels
4. pH
    a. acidity affects enzyme reactions and nerve cell impulses
5. concentration of water, salt and other electrolytes
    a. maintaining cell volume
    b. various functions of electrolytes
6. temperature
    a. too cold or too much heat harmful to cells
7. volume and pressure
    a. blood must be at appropriate volume and pressure to be transported around the body

- 11 Major Organ Systems

- Control Mechanisms
    - body controlled mainly by nervous and endocrine systems
    - parts of a control system (all interdependent)

1. sensor
    a. monitors variable (factor being regulated)
    b. responds to changes (stimuli) by sending input to...
2. integrator
    a. determines set point (appropriate level of variable)
    b. compares set point to input
    c. sends response to...
3. effector
    a. responds to changes

Chapter 2 **Cell Physiology**

- Cell basics

  - typical human cell 10-20 μm in diameter

    (μm = micrometer, 1/1000 mm, 1/1,000,000 m)

  - most cells have 3 major subdivisions

    1. plasma membrane (cell membrane)
       a. defines inside/outside
       b. intracellular fluid (ICF) - inside cell
       c. extracellular fluid (ECF) - outside cell
       d. selectively permeable - controls movement of molecules between ICF and ECF
    2. nucleus
       a. usually near cell center
       b. double layered membrane
       c. contains DNA, "genetic blueprint," directs protein synthesis, control center of cell
    3. cytoplasm
       a. area between nucleus and plasma membrane
       b. contains organelles
          (1) separation of chemical reactions
          (2) specialized for a particular function
       c. cytosol is semiliquid, site of chemical reactions

- Organelles (see table Summary of Cytoplasm Components)

  - endoplasmic reticulum (ER)

    1. interconnected fluid-filled membranous system
    2. two types
       a. smooth - interconnected tubules
       b. rough - interconnected flattened sacs
          (1) has ribosomes which help in protein synthesis (cell also has "free" ribosomes)
    3. rough ER
       a. synthesizes proteins and lipids, releases them to ER lumen
          (1) some will be secreted from the cell (hormones, enzymes), some will become new membrane for the cell or its organelles, or other protein parts of organelles
          (2) once in the lumen the protein can be modified (pieces removed, sugars added)

- Neurons (nerve cells)
  - 3 basic parts
    1. cell body
       a. houses nucleus and organelles
       b. receives signals from other cells (contains receptors for chemical messengers)
    2. dendrites
       a. projections from cell body
       b. increase surface area for receiving signals
    3. axon (nerve fiber)
       a. single elongated projection
       b. conducts APs away from cell body
       c. often has collaterals (side branches)
       d. axon hillock (part of cell body and first part of axon) is area where APs generated in most neurons
       e. ends in branches called axon terminals that release chemical messengers
       f. may be less than a mm or more than a m

- Propagation of an AP
  - Conduction by local current flow (contiguous conduction)
    1. AP at axon hillock
       a. local current flow between this active area and adjacent inactive area causes new AP
       b. AP passed section by section along axon
  - Saltatory conduction
    1. occurs in myelinated fibers
       a. special cells form barrier that is impermeable to ions
          (1) wrap around fiber
          (2) mostly lipids
          (3) formed by oligodendrocytes in central nervous system (CNS), by Schwann cells in peripheral nervous system (PNS)
       b. nodes of Ranvier
          (1) bare spaces between myelin
          (2) contain Na^+ channels
    2. AP "jumps" from node to node
       a. much faster
       b. conserves energy
          (1) fewer ions move so Na^+-K^+ pump uses less ATP restoring gradients

- fiber diameter influences speed of propagation
    1. larger fiber diameter → faster conduction
    2. large myelinated fibers found in areas where information must be transmitted quickly (e.g., fibers innervating skeletal muscle)
    3. smaller unmyelinated fibers found in areas where speed not critical to function (e.g. fibers innervating digestive tract)

- Refractory period
    1. ensures APs propagated in only one direction
    2. membrane that just had AP not very sensitive to further stimulation
        a. absolute refractory period
            (1) no amount of stimulation will induce another AP
            (2) time between when Na^+ gates first opened and when they are in their "ready to open" conformation
        b. relative refractory period
            (1) needs stronger than usual stimulation to produce another AP
            (2) only some Na^+ gates ready to open, some K^+ gates still open
    3. lasts for one to a few msec

- All-or-none law
    1. a membrane responds with a maximal AP or it doesn't respond at all
        a. a stimulus that doesn't reach threshold never initiates an AP
    2. nervous system differentiates between relatively weak or strong stimuli by frequency of APs
        a. stronger stimuli → more APs/sec

- Synapses and neuronal integration
    - neuron terminates at...
        1. muscle
        2. gland
        3. another neuron
    - Synapse basics
        1. junction between axon terminal of one neuron and dendrites or cell body of next neuron
        2. most neurons have thousands of synaptic inputs
        3. anatomy of a synapse
            a. presynaptic neuron
                (1) conducts APs toward synapse

b. cerebellum - procedural memories (a.k.a. skill memories involving motor pathways, e.g., playing piano, typing, riding a bike)

- types of memory
  1. short-term
     a. immediately stored
     b. limited capacity
     c. retrieved rapidly
     d. forgetting is permanent (unless consolidated)
     e. transient changes in preexisting synapses (changes in amount of nt released via modification of Ca^{2+} channels, may involve cAMP pathways)
  2. long-term
     a. longer storage time, enhanced by practice
     b. large storage capacity
     c. more slowly retrieved
     d. quite stable, forgetting usually transient
     e. permanent changes in neurons (formation of new synapses, synthesis of proteins in pre or postsynaptic membranes, changes in amount of nt released)

- factors influencing consolidation
  1. emotional state - transfer better when more alert and motivated
  2. repetition
  3. association of new information with old information

- cerebellum
  - different portions specialize in particular functions (mostly ipsilateral)
    1. maintains balance and equilibrium, important in movement
    3. enhances muscle tone
    4. coordinates voluntary movements
       a. input from cortical motor areas and peripheral receptors (indirect)
       b. ensures smooth, precise movement
    5. plans and initiates voluntary movement
       a. output to cortical motor areas
    6. procedural memories

- brain stem
  - all incoming and outgoing fibers pass through, most synapse here for processing
  - functions
    1. cranial nerve origin
    2. contains nuclei for control of autonomic activities
       a. cardiovascular center (force and rate of heart contraction, blood pressure)
       b. respiratory centers (rate and depth of breathing)
       c. many others such as vomiting, hiccuping, swallowing, coughing, sneezing
    3. modulates pain
    4. regulates equilibrium and posture reflexes
    5. contains reticular formation
       a. receives/integrates all synaptic input
       b. controls cortical alertness (reticular activating system - RAS)
       c. important in ability to direct attention
    6. contains sleep centers

- Sleep
  - an active process in which an individual is not consciously aware of surroundings but can be aroused by external stimuli
  - types of sleep
    1. slow-wave sleep
       a. from light sleep to deep sleep and back
       b. characterized by frequent movement, small decrease in heart and respiratory rate, and blood pressure
    2. paradoxical (REM) sleep
       a. brain activity similar to awake state
       b. characterized by lack of movement (except eyes), irregular heart and respiratory rate and blood pressure, dreaming
  - probably controlled by 3 centers that interact to produce the stages of sleep (arousal system, slow wave center, REM center)
  - functions
    1. time to restore chemical/physiological processes
    2. accomplish changes for learning and memory

4. both systems usually partially active
    a. called sympathetic or parasympathetic tone, or tonic activity
5. when one increases its rate of firing and the other decreases it is called dominance
    a. sympathetic dominance results in increase of oxygen/nutrient rich blood flow to skeletal muscles (vessels dilate), heart beats faster and more forcefully, blood pressure increases, respiratory airways dilate, glycogen and fat stores broken down, digestive and urinary activities inhibited, pupils dilate, sweating
    b. parasympathetic dominance results in normal resting functions like digestion and urinary function being increased, while inhibiting sympathetic activities
6. allows precise control over body functions
7. exceptions...
    a. innervated blood vessels (most arterioles and veins) have only sympathetic fibers (regulated by increasing/decreasing rate from tonic level)
    b. most sweat glands have only sympathetic fibers, and postganglionic fibers release ACh
    c. salivary glands have dual innervation, but both stimulate secretion

- role of adrenal gland
    1. an endocrine gland with cortex and medulla
    2. adrenal medulla secretes hormones when stimulated by sympathetic preganglionic fibers
        a. NE and epinephrine released (reinforce sympathetic activity)

- receptor proteins
    1. response of tissue to nt depends on type of receptor on tissue cells
        a. binding of nt induces response via second messenger

    2. ACh receptors (cholinergic)
        a. nicotinic - on postganglionic cell bodies in all autonomic ganglia and on cells of adrenal medulla (in sympathetic and parasympathetic)
            (1) always excitatory response
        b. muscarinic - on effector cell membranes (parasympathetic)
            (1) excitatory or inhibitory depending on organ

area with more receptors, more ion channels open)

(3) a graded potential, magnitude depends on amount of ACh and duration of binding

f. a large enough EPP triggers AP in muscle fiber membrane surrounding motor end plate (typically one EPP enough)

(1) spreads by local current flow throughout muscle fiber, resulting in muscle contraction

g. an enzyme in motor end plate breaks down ACh to end APs

(1) acetylcholinesterase (AChE)

(2) allows control of movement

c. good for low intensity endurance, resist fatigue (postural muscles in back and legs)

2. fast-glycolytic
    a. large (more myofilaments), contract quickly (lots of force, high ATPase activity)
    b. use anaerobic glycolysis (few mitochondria, little myoglobin, lots of glycogen & glycolytic enzymes)
    c. good for short duration high intensity movement (arms for lifting)
3. fast-oxidative
    a. medium sized, contract quickly (lots of force)
    b. mostly oxidative phosphorylation, some anaerobic glycolysis (characteristics of slow-ox and fast-gly)
    c. good for intermediate activities

- training can lead to changes in fiber type
    1. endurance exercise converts fast-glycolytic to fast-oxidative, weight lifting does the opposite
        a. changes in amount of mitochondria, blood supply, size, etc.
    2. typically cannot convert between slow and fast fibers
        a. depends on nerve supply

- Control of skeletal muscle
    - 3 levels of input
        1. spinal cord (spinal reflexes)
        2. corticospinal (pyramidal) motor system
            a. from primary motor cortex
            b. activity planned by premotor and supplementary motor areas, and cerebellum
            c. mainly precise movements, especially of hands/fingers, face
        3. multineuronal (extrapyramidal) motor system
            a. complex pathways including primary motor cortex, reticular formation, cerebellum, basal nuclei, thalamus, premotor and supplementary motor areas
            b. mainly regulation of posture and large muscle groups (subconscious)

    - afferent signals
        1. necessary for coordinated activity
        2. muscle proprioceptors sense changes in length and tension
            a. inform brain
            b. local spinal reflexes

- Cell-mediated immunity
  - macrophages "present antigen" to T cells (often to B cells also)
    1. macrophage phagocytizes antigen and places it on its surface
    2. appropriate type of T cell binds and is activated to reproduce and differentiate

  - T cells require both non-self and self antigen to bind and destroy a cell

  - types of T cells
    1. cytotoxic T cells (killer cells or CD8 cells)
       a. destroy virus-infected, cancer or transplanted cells
          (1) direct killing by releasing perforin to poke holes and lyse cell
          (2) indirect by signaling for apoptosis (programmed cell death)
    2. helper T cells (CD4)
       a. secrete cytokines that regulate nearly all aspects of immune response, including...
          (1) B cell growth factor
          (2) T cell growth factor (interleukin 2)
          (3) chemotaxins
          (4) macrophage-migration-inhibiting factor keeps macrophages in area and makes them more powerful
    3. suppressor T cells
       a. do not need presented antigen to be active
       b. limit responses of other immune cells
       c. reproduce more slowly than other immune cells and shut down immune responses after they've served their purpose

  - Cells that blur the boundaries of innate and adaptive immunity
    1. innate lymphoid cells (ILCs) similar duties as T cells but faster and less powerful
    2. innate response activator cells (IRA) B cells recognize bacteria and produce cytokines to activate other innate cells (not typical of B cells)

- CO_2
    1. 10% dissolved in blood
    2. 30% as $HbCO_2$ (carbaminohemoglobin)
        a. removal of O_2 from HbO_2 at tissues increases the affinity of Hb for CO_2 (Haldane effect)
    3. 60% as HCO_3^- (bicarbonate, more soluble than CO_2)
        a. $CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$
        b. can occur in plasma, but more efficient in RBCs because of enzyme carbonic anhydrase
        c. HCO_3^--Cl^- carrier in RBC membrane
            (1) HCO_3^- out of RBCs at tissues, in at lungs
            (2) Cl^- into RBCs down electrical gradient at tissues, out at lungs (chloride shift)
        d. most of the accumulated H^+ binds to Hb (helps buffer the blood)

- Control of Respiration
    - medullary respiratory center
        1. pattern probably established by pacemaker activity in rostral ventromedial medulla (Pre-Botzinger complex)
        2. dorsal respiratory group (DRG) responsible for quiet breathing
            a. inspiratory neurons terminate on motor neurons in spinal cord which supply inspiratory muscles
            b. quiet expiration begins when neurons stop firing
        3. ventral respiratory group (VRG) important when demands for ventilation increase
            a. not active in quiet breathing
            b. stimulate motor neurons supplying expiratory muscles

    - pons respiratory centers
        1. pneumotaxic and apneustic centers "fine tune" medullary centers to produce smooth inspirations and expirations

    - Hering-Breuer reflex
        1. pulmonary stretch receptors in airways are activated at large tidal volumes
            a. inhibit inspiratory neurons

Chapter 14 **Urinary System**

- The Kidney is the major functional organ, other organs carry urine out of the body

  - basic functions

    1. water balance and osmolarity
    2. electrolyte (ion) balance
    3. maintain plasma volume, long term regulation of blood pressure
    4. acid/base balance
    5. excrete wastes (urea, uric acid, creatinine) and other materials
    6. secrete erythropoietin
    7. secrete renin (Na^+ balance)
    8. converts vitamin D to its active form

  - nephron is the functional unit of the kidney

    1. arrangement forms cortex and medulla
    2. glomerulus
       a. tuft of capillaries that filters blood
       b. renal artery branches to form afferent and efferent arteriole for each nephron
          (1) afferent arteriole divides to form peritubular capillaries (supply renal tissue with blood)
    3. tubule
       a. glomerular capsule surrounds glomerulus and collects filtrate
       b. proximal convoluted tubule (PCT)
       c. loop
       d. distal convoluted tubule (DCT)
       e. collecting duct/tubule - drains fluid from several nephrons to renal pelvis
    4. juxtaglomerular apparatus
       a. regulates kidney function
       b. macula densa - specialized cells of DCT as it passes by glomerulus
       c. granular cells (juxtaglomerular cells or JG cells) are specialized smooth muscle cells of arterioles
    5. 2 types of nephrons
       a. cortical - lie mainly in cortex (80%)
       b. juxtamedullary - loops dip to end of medulla (important in urine concentration/conserving water)
          (1) vasa recta are blood vessels that run near long loop

(4) sufficient in MAP 80-180 mmHg range

c. extrinsic sympathetic control

(1) GFR changed based on need (override autoregulation to reg BP)

(2) baroreceptor reflex

decreased plasma volume → generalized vasoconstriction, including afferent arteriole → decreased GFR → conservation of fluids

increased BP → vasodilation → increased GFR → eliminate more fluids

(3) can alter K_f by closing off part of capillaries and filtration slits

- Tubular Reabsorption
  - typically nephrons reabsorb 99% of the water, 100% of the sugar, 99.5% of the salt that is filtered
  - different portions of tubule specialize in particular substances
  - most substances pass through tubule cells (transepithelial transport)
  - can be active or passive
    1. if any step is active, reabsorption of that substance is considered active

  - Na^+ reabsorption
    1. occurs via Na^+-K^+ ATPase in the basolateral membrane
       a. creates gradients for diffusion
       b. tied to reabsorption of other substances (glucose, amino acids, water, Cl^-, urea)
       c. occurs in PCT and loop - automatically reabsorb most Na^+ (92%)
       d. DCT and collecting tubule - hormonal control, reabsorption according to need
    2. renin-angiotensin-aldosterone system
       a. in response to decreased NaCl/dec. ECF volume/dec. BP, macula densa signals granular cells to release renin (an enzyme)
       b. angiotensinogen → angiotensin I
       c. angiotensin I → angiotensin II in lungs
          (1) vasoconstriction of arterioles
          (2) stimulates thirst
          (3) stimulates vasopressin release (H_2O reabsorption)
          (4) adrenal cortex releases aldosterone - promotes insertion of more Na^+ channels and Na^+-K^+ pumps into cells of DCT and collecting tubule (Cl^- and H_2O follow Na^+)

- Micturition (urination)
  - urethra has two sphincter muscles that prevent leaking of urine
    1. internal urethral sphincter made of smooth muscle (involuntary)
    2. external urethral sphincter made of skeletal muscle (voluntary)
  - micturition reflex occurs when stretch receptors in bladder are activated and parasympathetic fibers stimulated
    1. occurs at 250-400 ml urine
    2. parasympathetic stimulation causes bladder to contract, opening internal sphincter and inhibiting motor neurons to external sphincter
       a. we become conscious of having to urinate, but we can temporarily override reflex until it's convenient

- Hypothalamus and Anterior Pituitary (adenohypophysis)

  - Anterior pituitary produces hormones and releases them in response to hormones from hypothalamus

    1. hypothalamus secretes tropic hormones (releasing and inhibiting hormones)
    2. anterior pituitary tropic hormones act on other endocrine glands
        a. thyroid stimulating hormone (TSH, thyrotropin)
            (1) growth and secretion of thyroid gland
            (2) thyrotropin releasing hormone (TRH)
        b. adrenocorticotropic hormone (ACTH, adrenocorticotropin)
            (1) growth and secretion of adrenal cortex (cortisol)
            (2) corticotropin releasing hormone (CRH)
        c. gonadotropins
            (1) secretion of sex hormones by gonads
            (2) gonadotropin releasing hormone (GnRH)
        d. growth hormone (GH, somatotropin)
            (1) regulates growth and metabolism
            (2) growth hormone releasing hormone (GHRH) and growth hormone inhibiting hormone (GHIH)
    3. nontropic anterior pituitary hormone
        a. prolactin (PRL)
            (1) breast development and milk production in typical female
            (2) prolactin releasing factor (PRF) and prolactin inhibiting hormone (PIH)

  - Growth Hormone

    1. stimulates production of IGF-1 (somatomedins) mainly in liver that then act on target cells (most cells) to promote growth
        a. growth of cells in size/number
            (1) stimulates protein synthesis and cellular uptake of amino acids
            (2) inhibits protein breakdown
        b. growth of bones in length/thickness
    2. conserves glucose (for brain) and use fat stores
        a. increases blood fatty acids for muscle use
        b. triggered by exercise, stress, changes in blood nutrient levels such as increase in amino acids, decrease in fatty acids
        c. maintains body during fasting

Chapter 20 **Reproductive System**

- Basics
  - Primary reproductive organs (gonads)
    1. major functions
       a. produce gametes (gametogenesis)
          (1) sperm in typical male
          (2) ova in typical female
       b. secrete sex hormones (androgens & estrogens)
          (1) mainly testosterone (male)
          (2) mainly estrogen & progesterone (female)
          (3) important in the development of secondary sex characteristics (hair distribution, body shape, voice change) as well as major reproductive functions and development

  - essential reproductive functions in the typical male
    1. spermatogenesis
    2. delivery of sperm to female

  - essential reproductive functions in the typical female
    1. oogenesis
    2. receive sperm and transport for fertilization
    3. maintain fetus
    4. parturition and nourishment of infant

  - sex differentiation

- Spermatogenesis
  - begins at puberty

  - parts of sperm
    1. head contains DNA
       a. acrosome has enzymes to penetrate egg
    2. midpiece has mitochondria
    3. tail is for movement