Foundational Concept 1

Content Category 1A: Structure and function of proteins and their constituent amino acids

Amino Acids (BC, OC)

- Description
    - Absolute configuration at the α position
    - Amino acids as dipolar ions
    - Classifications
        - Acidic or basic
        - Hydrophobic or hydrophilic
- Reactions
    - Sulfur linkage for cysteine and cystine
    - Peptide linkage: polypeptides and proteins
    - Hydrolysis

Protein Structure (BIO, BC, OC)

- Structure
    - 1° structure of proteins
    - 2° structure of proteins
    - 3° structure of proteins; role of proline, cystine, hydrophobic bonding
    - 4° structure of proteins (BIO,BC)
- Conformational stability
    - Denaturing and folding
    - Hydrophobic interactions
    - Solvation layer (entropy) (BC)
- Separation techniques
    - Isoelectric point
    - Electrophoresis

Non-Enzymatic Protein Function (BIO, BC)

- Binding (BC)
- Immune system
- Motors

Enzyme Structure and Function (BIO, BC)

- Function of enzymes in catalyzing biological reactions
- Enzyme classification by reaction type
- Reduction of activation energy
- Substrates and enzyme specificity
- Active Site Model
- Induced-fit Model
- Mechanism of catalysis
    - Cofactors
    - Coenzymes
    - Water-soluble vitamins
- Effects of local conditions on enzyme activity

Control of Enzyme Activity (BIO, BC)

- Kinetics
  - General (catalysis)
  - Michaelis–Menten
  - Cooperativity
- Feedback regulation
- Inhibition – types
  - Competitive
  - Non-competitive
  - Mixed (BC)
  - Uncompetitive (BC)
- Regulatory enzymes
  - Allosteric enzymes
  - Covalently-modified enzymes
  - Zymogen

Content Category 1B: Transmission of genetic information from the gene to the protein

Nucleic Acid Structure and Function (BIO, BC)

- Description
- Nucleotides and nucleosides
  - Sugar phosphate backbone
  - Pyrimidine, purine residues
- Deoxyribonucleic acid (DNA): double helix, Watson–Crick model of DNA structure
- Base pairing specificity: A with T, G with C
- Function in transmission of genetic information
- DNA denaturation, reannealing, and hybridization

DNA Replication (BIO)

- Mechanism of replication: separation of strands, specific coupling of free nucleic acids
- Semiconservative nature of replication
- Specific enzymes involved in replication
- Origins of replication, multiple origins in eukaryotes
- Replicating the ends of DNA molecules

Repair of DNA (BIO)

- Repair during replication
- Repair of mutations

Genetic Code (BIO)

- Central Dogma: DNA → RNA → protein
- The triplet code
- Codon–anticodon relationship
- Degenerate code, wobble pairing
- Missense, nonsense codons
- Initiation, termination codons
- Messenger RNA (mRNA)

Transcription (BIO)

- Transfer RNA (tRNA); ribosomal RNA (rRNA)
- Mechanism of transcription
- mRNA processing in eukaryotes, introns, exons
- Ribozymes, spliceosomes, small nuclear ribonucleoproteins (snRNPs), small nuclear RNAs (snRNAs)
- Functional and evolutionary importance of introns

Translation (BIO)

- Roles of mRNA, tRNA, rRNA
- Role and structure of ribosomes
- Initiation, termination co-factors
- Post-translational modification of proteins

Eukaryotic Chromosome Organization (BIO)

- Chromosomal proteins
- Single copy vs. repetitive DNA
- Supercoiling
- Heterochromatin vs. euchromatin
- Telomeres, centromeres

Control of Gene Expression in Prokaryotes (BIO)

- Operon Concept, Jacob–Monod Model
- Gene repression in bacteria
- Positive control in bacteria

Control of Gene Expression in Eukaryotes (BIO)

- Transcriptional regulation
- DNA binding proteins, transcription factors
- Gene amplification and duplication
- Post-transcriptional control, basic concept of splicing (introns, exons)
- Cancer as a failure of normal cellular controls, oncogenes, tumor suppressor genes
- Regulation of chromatin structure
- DNA methylation
- Role of non-coding RNAs

Recombinant DNA and Biotechnology (BIO)

- Gene cloning
- Restriction enzymes
- DNA libraries
- Generation of cDNA
- Hybridization
- Expressing cloned genes
- Polymerase chain reaction
- Gel electrophoresis and southern blotting
- DNA sequencing
- Analyzing gene expression

- Determining gene function
- Stem cells
- Practical applications of DNA technology: medical applications, human gene therapy, pharmaceuticals, forensic evidence, environmental cleanup, agriculture
- Safety and ethics of DNA technology

Content Category 1C: Transmission of heritable information from generation to generation and the processes that increase genetic diversity

Evidence that DNA is Genetic Material (BIO)

Mendelian Concepts (BIO)

- Phenotype and genotype
- Gene
- Locus
- Allele: single and multiple
- Homozygosity and heterozygosity
- Wild-type
- Recessiveness
- Complete dominance
- Co-dominance
- Incomplete dominance, leakage, penetrance, expressivity
- Hybridization: viability
- Gene pool

Meiosis and Other Factors Affecting Genetic Variability (BIO)

- Significance of meiosis
- Important differences between meiosis and mitosis
- Segregation of genes
    - Independent assortment
    - Linkage
    - Recombination
        - Single crossovers
        - Double crossovers
        - Synaptonemal complex
        - Tetrad
    - Sex-linked characteristics
    - Very few genes on Y chromosome
    - Sex determination
    - Cytoplasmic/extranuclear inheritance
- Mutation
    - General concept of mutation — error in DNA sequence
    - Types of mutations: random, translation error, transcription error, base substitution, inversion, addition, deletion, translocation, mispairing
    - Advantageous vs. deleterious mutation
    - Inborn errors of metabolism
    - Relationship of mutagens to carcinogens
- Genetic drift
- Synapsis or crossing-over mechanism for increasing genetic diversity

Analytic Methods (BIO)

- Hardy–Weinberg Principle
- Testcross (Backcross; concepts of parental, F1, and F2 generations)
- Gene mapping: crossover frequencies
- Biometry: statistical methods

Evolution (BIO)

- Natural selection
    - Fitness concept
    - Selection by differential reproduction
    - Concepts of natural and group selection
    - Evolutionary success as increase in percent representation in the gene pool of the next generation
- Speciation
    - Polymorphism
    - Adaptation and specialization
    - Inbreeding
    - Outbreeding
    - Bottlenecks
- Evolutionary time as measured by gradual random changes in genome

Content Category 1D: Principles of bioenergetics and fuel molecule metabolism

Principles of Bioenergetics (BC, GC)

- Bioenergetics/thermodynamics
    - Free energy/Keq
        - Equilibrium constant
        - Relationship of the equilibrium constant and $\Delta G°$
    - Concentration
        - Le Châtelier's Principle
    - Endothermic/exothermic reactions
    - Free energy: G
    - Spontaneous reactions and $\Delta G°$
- Phosphoryl group transfers and ATP
    - ATP hydrolysis $\Delta G << 0$
    - ATP group transfers
- Biological oxidation-reduction
    - Half-reactions
    - Soluble electron carriers
    - Flavoproteins

Carbohydrates (BC, OC)

- Description
    - Nomenclature and classification, common names
    - Absolute configuration
    - Cyclic structure and conformations of hexoses
    - Epimers and anomers
- Hydrolysis of the glycoside linkage
- Monosaccharides

- Disaccharides
- Polysaccharides

Glycolysis, Gluconeogenesis, and the Pentose Phosphate Pathway (BIO, BC)

- Glycolysis (aerobic), substrates and products
    - Feeder pathways: glycogen, starch metabolism
- Fermentation (anaerobic glycolysis)
- Gluconeogenesis (BC)
- Pentose phosphate pathway (BC)
- Net molecular and energetic results of respiration processes

Principles of Metabolic Regulation (BC)

- Regulation of metabolic pathways (BIO, BC)
    - Maintenance of a dynamic steady state
- Regulation of glycolysis and gluconeogenesis
- Metabolism of glycogen
- Regulation of glycogen synthesis and breakdown
    - Allosteric and hormonal control
- Analysis of metabolic control

Citric Acid Cycle (BIO, BC)

- Acetyl-CoA production (BC)
- Reactions of the cycle, substrates and products
- Regulation of the cycle
- Net molecular and energetic results of respiration processes

Metabolism of Fatty Acids and Proteins (BIO, BC)

- Description of fatty acids (BC)
- Digestion, mobilization, and transport of fats
- Oxidation of fatty acids
    - Saturated fats
    - Unsaturated fats
- Ketone bodies (BC)
- Anabolism of fats (BIO)
- Non-template synthesis: biosynthesis of lipids and polysaccharides (BIO)
- Metabolism of proteins (BIO)

Oxidative Phosphorylation (BIO, BC)

- Electron transport chain and oxidative phosphorylation, substrates and products, general features of the pathway
- Electron transfer in mitochondria
    - NADH, NADPH
    - Flavoproteins
    - Cytochromes
- ATP synthase, chemiosmotic coupling
    - Proton motive force
- Net molecular and energetic results of respiration processes

- Regulation of oxidative phosphorylation
- Mitochondria, apoptosis, oxidative stress (BC)

Hormonal Regulation and Integration of Metabolism (BC)

- Higher level integration of hormone structure and function
- Tissue specific metabolism
- Hormonal regulation of fuel metabolism
- Obesity and regulation of body mass

Foundational Concept 2

Category 2A: Assemblies of molecules, cells, and groups of cells within single cellular and multicellular organisms

Plasma Membrane (BIO, BC)

- General function in cell containment
- Composition of membranes
    - Lipid components (BIO, BC, OC)
        - Phospholipids (and phosphatids)
        - Steroids
        - Waxes
    - Protein components
    - Fluid mosaic model
- Membrane dynamics
- Solute transport across membranes
    - Thermodynamic considerations
    - Osmosis
        - Colligative properties; osmotic pressure (GC)
    - Passive transport
    - Active transport
        - Sodium/potassium pump
- Membrane channels
- Membrane potential
- Membrane receptors
- Exocytosis and endocytosis
- Intercellular junctions (BIO)
    - Gap junctions
    - Tight junctions
    - Desmosomes

Membrane-Bound Organelles and Defining Characteristics of Eukaryotic Cells (BIO)

- Defining characteristics of eukaryotic cells
- Nucleus
    - Compartmentalization, storage of genetic information
    - Nucleolus: location and function
    - Nuclear envelope, nuclear pores
- Mitochondria
    - Site of ATP production

    - Inner and outer membrane structure (BIO, BC)
    - Self-replication
- Lysosomes: membrane-bound vesicles containing hydrolytic enzymes
- Endoplasmic reticulum
    - Rough and smooth components
    - Rough endoplasmic reticulum site of ribosomes
    - Double membrane structure
    - Role in membrane biosynthesis
    - Role in biosynthesis of secreted proteins
- Golgi apparatus: general structure and role in packaging and secretion
- Peroxisomes: organelles that collect peroxides

Cytoskeleton (BIO)

- General function in cell support and movement
- Microfilaments: composition and role in cleavage and contractility
- Microtubules: composition and role in support and transport
- Intermediate filaments, role in support
- Composition and function of cilia and flagella
- Centrioles, microtubule organizing centers

Tissues Formed From Eukaryotic Cells (BIO)

- Epithelial Cells
- Connective tissue cells

Content Category 2B: The structure, growth, physiology, and genetics of prokaryotes and viruses

Cell Theory (BIO)

- History and development
- Impact on biology

Classification and Structure of Prokaryotic Cells (BIO)

- Prokaryotic domains
    - Archaea
    - Bacteria
- Major classifications of bacteria by shape
    - Bacilli (rod-shaped)
    - Spirilli (spiral-shaped)
    - Cocci (spherical)
- Lack of nuclear membrane and mitotic apparatus
- Lack of typical eukaryotic organelles
- Presence of cell wall in bacteria
- Flagellar propulsion, mechanism

Growth and Physiology of Prokaryotic Cells (BIO)

- Reproduction by fission
- High degree of genetic adaptability, acquisition of antibiotic resistance
- Exponential growth

- Existence of anaerobic and aerobic variants
- Parasitic and symbiotic
- Chemotaxis

Genetics of Prokaryotic Cells (BIO)

- Existence of plasmids, extragenomic DNA
- Transformation: incorporation into bacterial genome of DNA fragments from external medium
- Conjugation
- Transposons (also present in eukaryotic cells)

Virus Structure (BIO)

- General structural characteristics (nucleic acid and protein, enveloped and nonenveloped)
- Lack organelles and nucleus
- Structural aspects of typical bacteriophage
- Genomic content — RNA or DNA
- Size relative to bacteria and eukaryotic cells

Viral Life Cycle (BIO)

- Self-replicating biological units that must reproduce within specific host cell
- Generalized phage and animal virus life cycles
    - Attachment to host, penetration of cell membrane or cell wall, and entry of viral genetic material
    - Use of host synthetic mechanism to replicate viral components
    - Self-assembly and release of new viral particles
- Transduction: transfer of genetic material by viruses
- Retrovirus life cycle: integration into host DNA, reverse transcriptase, HIV
- Prions and viroids: subviral particles

Content Category 2C: Processes of cell division, differentiation, and specialization

Mitosis (BIO)

- Mitotic process: prophase, metaphase, anaphase, telophase, interphase
- Mitotic structures
    - Centrioles, asters, spindles
    - Chromatids, centromeres, kinetochores
    - Nuclear membrane breakdown and reorganization
    - Mechanisms of chromosome movement
- Phases of cell cycle: G0, G1, S, G2, M
- Growth arrest
- Control of cell cycle
- Loss of cell cycle controls in cancer cells

Biosignalling (BC)

- Oncogenes, apoptosis

Reproductive System (BIO)

- Gametogenesis by meiosis
- Ovum and sperm
    - Differences in formation
    - Differences in morphology
    - Relative contribution to next generation
- Reproductive sequence: fertilization; implantation; development; birth

Embryogenesis (BIO)

- Stages of early development (order and general features of each)
    - Fertilization
    - Cleavage
    - Blastula formation
    - Gastrulation
        - First cell movements
        - Formation of primary germ layers (endoderm, mesoderm, ectoderm)
    - Neurulation
- Major structures arising out of primary germ layers
- Neural crest
- Environment–gene interaction in Development

Mechanisms of Development (BIO)

- Cell specialization
    - Determination
    - Differentiation
    - Tissue types
- Cell–cell communication in development
- Cell migration
- Pluripotency: stem cells
- Gene regulation in development
- Programmed cell death
- Existence of regenerative capacity in various species
- Senescence and aging

Foundational Concept 3

Content Category 3A: Structure and functions of the nervous and endocrine systems and ways in which these systems coordinate the organ systems

Nervous System: Structure and Function (BIO)

- Major Functions
    - High level control and integration of body systems
    - Adaptive capability to external influences
- Sensor and effector neurons
- Sympathetic and parasympathetic nervous systems: antagonistic control
- Reflexes
    - Feedback loop, reflex arc
    - Role of spinal cord and supraspinal circuits
- Integration with endocrine system: feedback control

Nerve Cell (BIO)

- Cell body: site of nucleus, organelles
- Dendrites: branched extensions of cell body
- Axon: structure and function
- Myelin sheath, Schwann cells, insulation of axon
- Nodes of Ranvier: propagation of nerve impulse along axon
- Synapse: site of impulse propagation between cells
- Synaptic activity: transmitter molecules
- Resting potential: electrochemical gradient
- Action potential
    - Threshold, all-or-none
    - Sodium/potassium pump
- Excitatory and inhibitory nerve fibers: summation, frequency of firing
- Glial cells, neuroglia

Electrochemistry (GC)

- Concentration Cell: Direction of Electron Flow, Nernst Equation

Biosignalling (BC)

- G-protein-coupled receptors
    - Voltage gated
    - Ligand gated
- Receptor enzymes
- Gated ion channels

Lipids (BC, OC)

- Description; Structure
    - Steroids
    - Terpenes and terpenoids

Endocrine System: Hormones and Their Sources (BIO)

- Function of endocrine system: specific chemical control at cell, tissue, and organ level
- Definitions of endocrine glands, hormones
- Major endocrine glands: names, locations, products
- Major types of hormones
- Neuroendrocrinology — relation between neurons and hormonal systems

Endocrine System: Mechanisms of Hormone Action (BIO)

- Cellular mechanisms of hormone action
- Transport of hormones: blood supply
- Specificity of hormones: target tissue
- Integration with nervous system: feedback control
- Regulation by second messengers

Category 3B: Structure and integrative functions of the main organ systems

Respiratory System (BIO)

- General function
  - Gas exchange, thermoregulation
  - Protection against disease: particulate matter
- Structure of lungs and alveoli
- Breathing mechanisms
  - Diaphragm, rib cage, differential pressure
  - Resiliency and surface tension effects
- Thermoregulation: nasal and tracheal capillary beds; evaporation, panting
- Particulate filtration: nasal hairs, mucus/cilia system in lungs
- Alveolar gas exchange
  - Diffusion, differential partial pressure
  - Henry's Law (GC)
- pH control
- Regulation by nervous control
  - CO2 sensitivity

Circulatory System (BIO)

- Functions: circulation of oxygen, nutrients, hormones, ions and fluids, removal of metabolic waste
- Role in thermoregulation
- Four-chambered heart: structure and function
- Endothelial cells
- Systolic and diastolic pressure
- Pulmonary and systemic circulation
- Arterial and venous systems (arteries, arterioles, venules, veins)
  - Structural and functional differences
  - Pressure and flow characteristics
- Capillary beds
  - Mechanisms of gas and solute exchange
  - Mechanism of heat exchange
  - Source of peripheral resistance
- Composition of blood
  - Plasma, chemicals, blood cells
  - Erythrocyte production and destruction; spleen, bone marrow
  - Regulation of plasma volume
- Coagulation, clotting mechanisms
- Oxygen transport by blood
  - Hemoglobin, hematocrit
  - Oxygen content
  - Oxygen affinity
- Carbon dioxide transport and level in blood
- Nervous and endocrine control

Lymphatic System (BIO)

- Structure of lymphatic system
- Major functions
  - Equalization of fluid distribution
  - Transport of proteins and large glycerides
  - Production of lymphocytes involved in immune reactions

    - Return of materials to the blood

Immune System (BIO)

- Innate (non-specific) vs. adaptive (specific) immunity
- Adaptive immune system cells
    - T-lymphocytes
    - B-lymphocytes
- Innate immune system cells
    - Macrophages
    - Phagocytes
- Tissues
    - Bone marrow
    - Spleen
    - Thymus
    - Lymph nodes
- Concept of antigen and antibody
- Antigen presentation
- Clonal selection
- Antigen-antibody recognition
- Structure of antibody molecule
- Recognition of self vs. non-self, autoimmune diseases
- Major histocompatibility complex

Digestive System (BIO)

- Ingestion
    - Saliva as lubrication and source of enzymes
    - Ingestion; esophagus, transport function
- Stomach
    - Storage and churning of food
    - Low pH, gastric juice, mucal protection against self-destruction
    - Production of digestive enzymes, site of digestion
    - Structure (gross)
- Liver
    - Structural relationship of liver within gastrointestinal system
    - Production of bile
    - Role in blood glucose regulation, detoxification
- Bile
    - Storage in gall bladder
    - Function
- Pancreas
    - Production of enzymes
    - Transport of enzymes to small intestine
- Small intestine
    - Absorption of food molecules and water
    - Function and structure of villi
    - Production of enzymes, site of digestion
    - Neutralization of stomach acid
    - Structure (anatomic subdivisions)
- Large intestine
    - Absorption of water

    - Bacterial flora
    - Structure (gross)
- Rectum: storage and elimination of waste, feces
- Muscular control
    - Peristalsis
- Endocrine control
    - Hormones
    - Target tissues
- Nervous control: the enteric nervous system

Excretory System (BIO)

- Roles in homeostasis
    - Blood pressure
    - Osmoregulation
    - Acid–base balance
    - Removal of soluble nitrogenous waste
- Kidney structure
    - Cortex
    - Medulla
- Nephron structure
    - Glomerulus
    - Bowman's capsule
    - Proximal tubule
    - Loop of Henle
    - Distal tubule
    - Collecting duct
- Formation of urine
    - Glomerular filtration
    - Secretion and reabsorption of solutes
    - Concentration of urine
    - Counter-current multiplier mechanism
- Storage and elimination: ureter, bladder, urethra
- Osmoregulation: capillary reabsorption of H_2O, amino acids, glucose, ions
- Muscular control: sphincter muscle

Reproductive System (BIO)

- Male and female reproductive structures and their functions
    - Gonads
    - Genitalia
    - Differences between male and female structures
- Hormonal control of reproduction
    - Male and female sexual development
    - Female reproductive cycle
    - Pregnancy, parturition, lactation
    - Integration with nervous control

Muscle System (BIO)

- Important Functions
    - Support: mobility

    - Peripheral circulatory assistance
    - Thermoregulation (shivering reflex)
- Structure of three basic muscle types: striated, smooth, cardiac
- Muscle Structure and control of contraction
    - T-tubule system
    - Contractile apparatus
    - Sarcoplasmic reticulum
    - Fiber type
    - Contractile velocity of different muscle types
- Regulation of cardiac muscle contraction
- Oxygen debt: fatigue
- Nervous Control
    - Motor neurons
    - Neuromuscular junction, motor end plates
    - Sympathetic and parasympathetic innervation
    - Voluntary and involuntary muscles

Specialized Cell – Muscle Cell (BIO)

- Structural Characteristics of Striated, Smooth, and Cardiac Muscle
- Abundant Mitochondria in Red Muscle Cells: ATP Source
- Organization of Contractile Elements: Actin and Myosin Filaments, Crossbridges, Sliding Filament Model
- Sarcomeres: "I" and "A" Bands, "M" and "Z" Lines, "H" Zone
- Presence of Troponin and Tropomyosin
- Calcium Regulation of Contraction

Skeletal System (BIO)

- Functions
    - Structural rigidity and support
    - Calcium storage
    - Physical protection
- Skeletal structure
    - Specialization of bone types, structures
    - Joint structures
    - Endoskeleton vs. exoskeleton
- Bone structure
    - Calcium/protein matrix
    - Cellular composition of bone
- Cartilage: structure and function
- Ligaments, tendons
- Endocrine control

Skin System (BIO)

- Structure
    - Layer differentiation, cell types
    - Relative impermeability to water
- Functions in homeostasis and osmoregulation
- Functions in thermoregulation
    - Hair, erectile musculature

    - Fat layer for insulation
    - Sweat glands, location in dermis
    - Vasoconstriction and vasodilation in surface capillaries
- Physical protection
    - Nails, calluses, hair
    - Protection against abrasion, disease organisms
- Hormonal control: sweating, vasodilation, and vasoconstriction