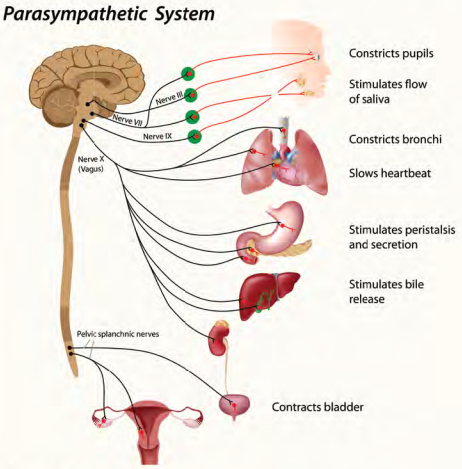
BIOLOGY AND BEHAVIOR

Organization of the Nervous System

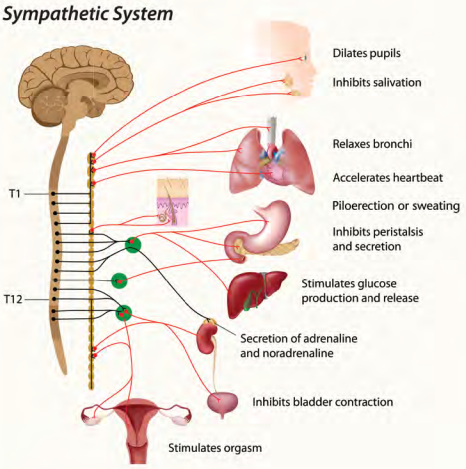
The three types of neurons in the nervous system are motor (efferent), interneurons, and sensory (afferent).

The **parasympathetic** branch of the autonomic system is focused on "rest-and-digest" responses and the **sympathetic** branch is focused on "fight-or-flight" responses.

Parasympathetic System



Sympathetic System



Organization of the Brain

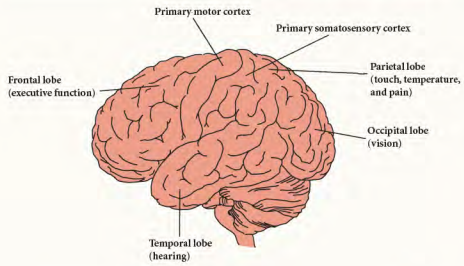
- **Hindbrain:** contains the cerebellum, medulla oblongata, and reticular formation
- **Midbrain:** contains the inferior and superior colliculi
- **Forebrain:** contains the thalamus, hypothalamus, basal ganglia, limbic system, and cerebral cortex

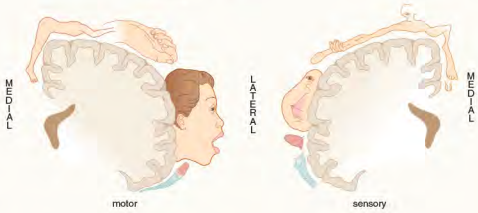
Parts of the Forebrain

- **Thalamus:** relay station for sensory information
- **Hypothalamus:** maintains homeostasis and integrates with the endocrine system through the **hypophyseal portal system** that connects it to the **anterior pituitary**
- **Basal ganglia:** smoothens movements and helps maintain postural stability
- **Limbic system:** controls emotion and memory. Includes **septal nuclei** (pleasure-seeking), **amygdala** (fear and aggression), **hippocampus** (memory), and **fornix** (communication within limbic system).

The **cerebral cortex** is divided into four lobes.

Lobe	Function
Frontal	Executive function, impulse control, long-term planning (prefrontal cortex), motor function (primary motor cortex), speech production (Broca's area)
Parietal	Sensation of touch, pressure, temperature, and pain (somatosensory cortex); spatial processing, orientation, and manipulation
Occipital	Visual processing
Temporal	Sound processing (auditory cortex), speech perception (Wernicke's area), memory, and emotion (limbic system)





Influences on Behavior

Neurotransmitter	Behavior
Acetylcholine	Voluntary muscle control, parasympathetic nervous system, attention, alertness
Epinephrine and Norepinephrine	Fight-or-flight responses, wakefulness, alertness
Dopamine	Smooth movements, postural stability
Serotonin	Mood, sleep, eating, dreaming
GABA	Brain "stabilization"
Endorphins	Natural painkillers

Nature *vs.* nurture is a debate regarding the contributions of genetics (nature) and environment (nurture) to an individual's traits. Family, twin, and adoption studies are used to study nature *vs.* nurture.

SENSATION AND PERCEPTION

Sensation *vs.* Perception

Sensation is the conversion of physical stimuli into neurological signals, while **perception** is the processing of sensory information to make sense of its significance.

- **Sensory receptors** respond to stimuli and trigger electrical signals.
- Sensory neurons transmit information from sensory receptors to the CNS.
- Sensory stimuli are transmitted to **projection areas** in the brain, which further analyze the sensory input.

Threshold: the minimum stimulus that causes a change in signal transduction

Weber's law: states that the just-noticeable difference for a stimulus is proportional to the magnitude of the stimulus, and this proportion is constant over most of the range of possible stimuli

Signal detection theory: the effects of nonsensory factors, such as experiences, motives, and expectations, on perception of stimuli

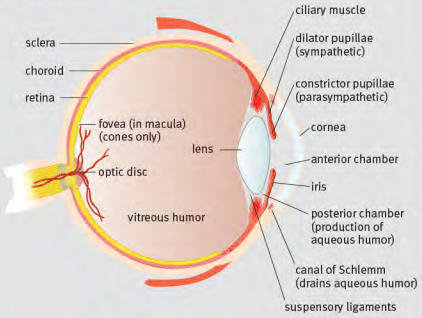
	Subject's Response: "Yes"	Subject's Response: "No"
Signal Present	Hit	Miss
Signal Absent	False alarm	Correct negative

Response bias: examined using signal detection experiments with four possible outcomes: hits, misses, false alarms, and correct negatives

Adaptation: a decrease in response to a stimulus over time

Vision

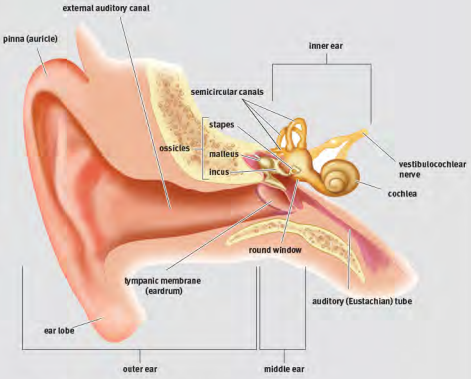
The eye is an organ specialized to detect light in the form of photons.



Visual pathway: retina → optic nerve → optic chiasm → optic tracts → lateral geniculate nucleus (LGN) of thalamus → visual radiations → visual cortex

Hearing and Vestibular Sense

The ear transduces sound waves into electrical signals that can be interpreted by the brain.



- **Cochlea:** detects sound
- **Utricle** and **saccule:** detect linear acceleration
- **Semicircular canals:** detect rotational acceleration

Auditory pathway: cochlea → vestibulocochlear nerve → medial geniculate nucleus (MGN) of thalamus → auditory cortex

Other Senses

- **Smell:** detection of volatile or aerosolized chemicals by **olfactory chemoreceptors** (**olfactory nerves**)
- **Taste:** detection of dissolved compounds by **taste buds** in **papillae**
- **Somatosensation:** four touch modalities (pressure, vibration, pain, and temperature)
- **Kinesthetic sense (proprioception):** ability to tell where one's body is in space

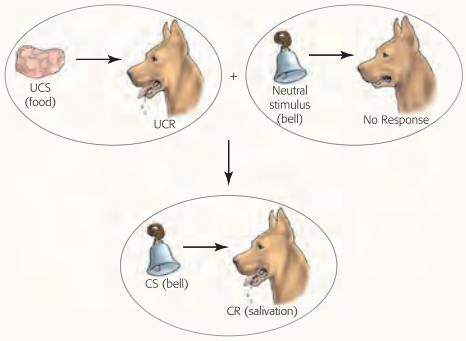
Object Recognition

- **Bottom-up (data-driven) processing:** recognition of objects by parallel processing and feature detection. Slower, but less prone to mistakes
- **Top-down (conceptually-driven) processing:** recognition of an object by memories and expectations, with little attention to detail. Faster, but more prone to mistakes
- **Gestalt principles:** ways that the brain can infer missing parts of an image when it is incomplete

LEARNING AND MEMORY

Learning

- **Habituation:** the process of becoming used to a stimulus
- **Dishabituation:** occurs when a second stimulus intervenes, causing a **resensitization** to the original stimulus
- **Observational learning:** the acquisition of behavior by watching others
- **Associative learning:** pairing together stimuli and responses, or behaviors and consequences
- **Classical conditioning:** a form of associative learning in which a neutral stimulus becomes associated with an **unconditioned stimulus** such that the neutral stimulus alone produces the same response as the unconditioned stimulus; the neutral stimulus thus becomes a **conditioned stimulus**



- **Operant conditioning:** a form of associative learning in which the frequency of a behavior is modified using **reinforcement** (increases behavior) or **punishment** (decreases behavior)

Behavior	Stimulus: Added	Stimulus: Removed
Continues	Positive reinforcement	Negative reinforcement
Stops	Positive punishment	Negative punishment

COGNITION, CONSCIOUSNESS, AND LANGUAGE

Consciousness

Stage	EEG Waves	Features
Awake	Beta and alpha	Able to perceive, process, access, and express information
1	Theta	Light sleep
2	Theta	Sleep spindles and K complexes
3/4	Delta	Slow-wave sleep; dreams; declarative memory consolidation; some sleep disorders
REM	Mostly beta	Appears awake physiologically; dreams; paralyzed; procedural memory consolidation; some sleep disorders

Sleep disorders include **dyssomnias** (amount or timing of sleep), such as insomnia, narcolepsy, sleep apnea, and sleep deprivation; and **parasomnias** (odd behaviors during sleep), such as night terrors and sleepwalking (somnambulism).

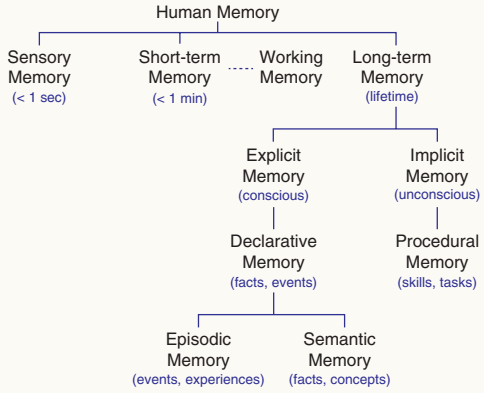
Consciousness-Altering Drugs

Drug addiction is mediated by the **mesolimbic pathway**, which includes the **nucleus accumbens, medial forebrain bundle**, and **ventral tegmental area**. Dopamine is the main neurotransmitter.

Drug Group	Function
Depressants (alcohol, barbiturates, benzodiazepines)	Sense of relaxation and reduced anxiety
Stimulants (amphetamines, cocaine, ecstasy)	Increased arousal
Opiates/opioids (heroin, morphine, opium, pain pills)	Decreased reaction to pain; euphoria
Hallucinogens (LSD, peyote, mescaline, ketamine, psilocybin-containing mushrooms)	Distortions of reality and fantasy; introspection

Marijuana has some features of depressants, stimulants, and hallucinogens (in very high doses).

Memory



- **Encoding:** the process of putting new information into memory

Facts are stored via **semantic networks**. **Retrieval** of information is often based on **priming** interconnected nodes of the semantic network.

Recognition of information is stronger than **recall**.

Piaget's Stages of Cognitive Development

- **Sensorimotor stage:** focuses on manipulating the environment to meet physical needs through **circular reactions**; **object permanence** ends this stage
- **Preoperational stage:** focuses on **symbolic thinking**, **egocentrism** (inability to imagine what another person thinks or feels), and **centration** (focusing on only one aspect of a phenomenon)
- **Concrete operational stage:** focuses on understanding the feelings of others and manipulating physical (concrete) objects
- **Formal operational stage:** focuses on abstract thought and problem-solving

Problem-Solving and Decision-Making

Problem-solving techniques include **trial-and-error**, **algorithms**, **deductive reasoning** (deriving conclusions from general rules) and **inductive reasoning** (deriving generalizations from evidence).

Heuristics (simplified principles used to make decisions, "rules of thumb"), biases, intuition, and emotions may assist decision-making, but may also lead to erroneous or problematic decisions.

Attention

- **Selective attention:** allows one to pay attention to a particular stimulus while determining if additional stimuli require attention in the background
- **Divided attention:** uses **automatic processing** to pay attention to multiple activities at one time

Language Areas in the Brain

- **Wernicke's area:** language comprehension; damage results in **Wernicke's aphasia** (fluent, nonsensical aphasia with lack of comprehension)
- **Broca's area:** motor function of speech; damage results in **Broca's aphasia** (nonfluent aphasia in which generating each word requires great effort)
- **Arcuate fasciculus:** connects Wernicke's and Broca's areas; damage results in **conduction aphasia** (the inability to repeat words despite intact speech generation and comprehension)

MOTIVATION, EMOTION, AND STRESS

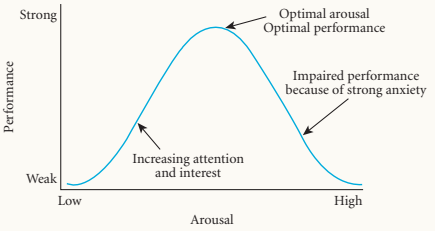
Motivation

Motivation is the purpose or driving force behind our actions.

- **Extrinsic:** based on external circumstances
- **Intrinsic:** based on internal drive or perception

Motivation theories

- **Instinct theory:** innate, fixed patterns of behavior in response to stimuli
- **Arousal theory:** the state of being awake and reactive to stimuli; aim for optimal level of arousal for a given task (Yerkes–Dodson law)



- **Drive reduction theory:** individuals act to relieve internal states of tension
- **Maslow's hierarchy of needs:** prioritizes needs into five categories: physiological needs (highest priority), safety and security, love and belonging, self-esteem, and self-actualization (lowest priority)

Emotion

Seven universal emotions: happiness, sadness, contempt, surprise, fear, disgust, anger

Theories of emotion:

Theory		First response	Second response
James–Lange	STIMULUS	Nervous system arousal	Conscious emotion
Cannon–Bard		Nervous system arousal and conscious emotion	Action
Schachter–Singer		Nervous system arousal and cognitive appraisal	Conscious emotion

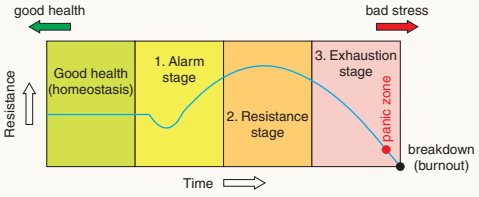
Stress

Stress: the physiological and cognitive response to challenges or life changes

- **Primary appraisal:** classifying a potential stressor as irrelevant, benign–positive, or stressful
- **Secondary appraisal:** directed at evaluating whether the organism can cope with the stress, based on harm, threat, and challenge

Stressor (distress or eustress): anything that leads to a stress response; can include environmental, social, psychological, chemical, and biological stressors

The three stages of the **general adaptation syndrome** are alarm, resistance, and exhaustion.



IDENTITY AND PERSONALITY

Self-Concept and Identity

- **Self-concept:** the sum of the ways in which we describe ourselves: in the present, who we used to be, and who we might be in the future
- **Identities:** individual components of our self-concept related to the groups to which we belong
- **Self-esteem:** our evaluation of ourselves
- **Self-efficacy:** the degree to which we see ourselves as being capable of a given skill in a given situation
- **Locus of control:** a self-evaluation that refers to the way we characterize the influences in our lives. Either **internal** (success or failure is a result of our own actions) or **external** (success or failure is a result of outside factors)

PSYCHOLOGICAL DISORDERS

***Diagnostic and Statistical Manual of Mental Disorders* (DSM):** the guide by which most psychological disorders are characterized, described, and diagnosed.

Types of Psychological Disorders

Schizophrenia: psychotic disorder characterized by distortions of reality and disturbances in content and form of thought, perception, and behavior. **Positive symptoms** include hallucinations, delusions, and disorganized thought and behavior. **Negative symptoms** include disturbance of affect and avolition.

Depressive disorders

- **Major depressive disorder:** contains at least one major depressive episode
- **Pervasive depressive disorder:** a depressed mood (either **dysthymia** or major depression) for at least two years
- **Seasonal affective disorder:** the colloquial name for major depressive disorder with seasonal onset, with depression occurring during winter months

Bipolar and related disorders

- **Bipolar I disorder:** contains at least one manic episode
- **Bipolar II disorder:** contains at least one hypomanic episode and at least one major depressive episode
- **Cyclothymic disorder:** contains hypomanic episodes with dysthymia

Anxiety disorders

- **Generalized anxiety disorder:** constant disproportionate and persistent worry
- **Specific phobias:** irrational fears of specific objects
- **Social anxiety disorder:** anxiety due to social or performance situations
- **Agoraphobia:** fear of places or situations where it is hard for an individual to escape
- **Panic disorder:** recurrent attacks of intense, overwhelming fear and sympathetic nervous system activity with no clear stimulus. It may lead to **agoraphobia**.

Obsessive–compulsive disorder: obsessions (persistent, intrusive thoughts and impulses) and **compulsions** (repetitive tasks that relieve tension but cause significant impairment)

Body dysmorphic disorder: unrealistic negative evaluation of one's appearance or a specific body part

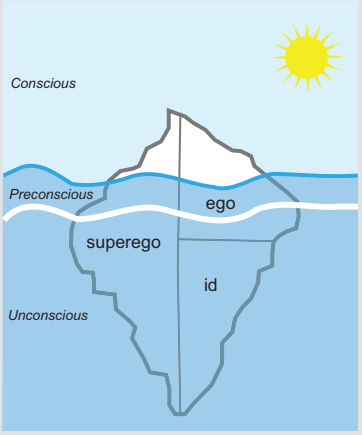
Dissociative disorders

- **Dissociative amnesia:** inability to recall past experience. May involve **dissociative fugue**, a sudden change in location that can involve the assumption of a new identity
- **Dissociative identity disorder:** two or more personalities that take control of behavior
- **Depersonalization/derealization disorder:** feelings of detachment from the mind and body, or from the environment

Formation of Identity

Freud's stages of psychosexual development

- Based on tensions caused by the **libido**, with failure at any given stage leading to **fixation**



Erikson's stages of psychosocial development

- Stem from conflicts that are the result of decisions we are forced to make about ourselves and the environment around us at each phase of our lives
- Stages are trust *vs.* mistrust, autonomy *vs.* shame and doubt, initiative *vs.* guilt, industry *vs.* inferiority, identity *vs.* role confusion, intimacy *vs.* isolation, generativity *vs.* stagnation, integrity *vs.* despair

Kohlberg's theory of moral reasoning development

- Describes the approaches of individuals to resolving moral dilemmas
- Six stages are divided into three main phases: **preconventional**, **conventional**, and **postconventional**

Vygotsky's theory of cultural and biosocial development

- Describes development of language, culture, and skills

Personality

Psychoanalytic perspective: personality results from unconscious urges and desires

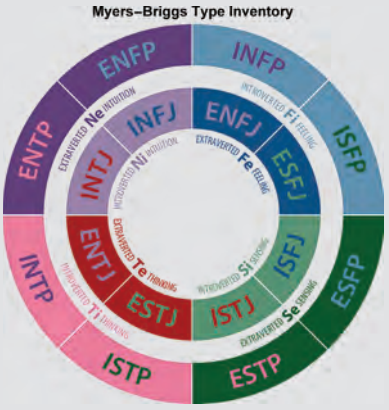
- Freud: id, superego, ego
- Jung: collective unconscious, archetypes

Humanistic perspective: emphasizes internal feelings of healthy individuals as they strive toward happiness and self-realization

- Maslow: hierarchy of needs
- Rogers: unconditional positive regard

Type and trait theory: personality can be described as a number of identifiable traits that carry characteristic behaviors

- Type theories of personality: ancient Greek humors, Sheldon's **somatotypes**, division into **Types A** and **B**, and the **Myers–Briggs Type Inventory**
- Eysenck's three major traits: psychoticism, extraversion, neuroticism
- Trait theorists' Big Five: openness, conscientiousness, extraversion, agreeableness, and neuroticism (OCEAN)
- Allport's three basic types of traits: cardinal, central, and secondary



Somatic symptom and related disorders

- **Somatic symptom disorder:** at least one somatic symptom, which may or may not be linked to an underlying medical condition, that causes disproportionate concern
- **Illness anxiety disorder:** preoccupation with having or coming down with a serious medical condition
- **Conversion disorder:** unexplained symptoms affecting motor or sensory function

Personality disorders

Patterns of inflexible, maladaptive behavior that cause distress or impaired functioning

- **Cluster A** (odd, eccentric, "weird"): paranoid, schizotypal, schizoid
- **Cluster B** (dramatic, emotional, erratic, "wild"): antisocial, borderline, histrionic, narcissistic
- **Cluster C** (anxious, fearful, "worried"): avoidant, dependent, obsessive–compulsive

SOCIAL PROCESSES, ATTITUDES, AND BEHAVIOR

Group Psychology

- **Social facilitation:** tendency to perform at a different level (better or worse) when others are around
- **Deindividuation:** loss of self-awareness in large groups; can lead to drastic changes in behavior
- **Bystander effect:** in a group, individuals are less likely to respond to a person in need
- **Peer pressure:** social influence placed on an individual by other individuals they consider equals
- **Group polarization:** tendency towards making decisions in a group that are more extreme then the thoughts of the individual group members
- **Groupthink:** tendency to make decisions based on ideas and solutions that arise within the group without considering outside ideas

Culture

- **Assimilation:** one culture begins to melt into another
- **Multiculturalism:** encouragement of multiple cultures within a community to enhance diversity
- **Subculture:** a group that distinguishes itself from the primary culture to which it belongs

Socialization

- **Socialization:** the process of developing and spreading norms, customs, and beliefs
- **Norms:** boundaries of acceptable behavior within society
- **Stigma:** extreme disapproval or dislike of a person or group based on perceived differences
- **Deviance:** any violation of norms, rules, or expectations within a society
- **Conformity:** changing beliefs or behaviors in order to fit into a group or society
- **Compliance:** individuals change behavior based on the request of others; techniques for gaining compliance include **foot-in-the-door**, **door-in-the-face**, **lowball**, and **that's-not-all**
- **Obedience:** change in behavior based on a command from someone seen as an authority figure

SOCIAL INTERACTION

Elements of Social Interaction

- **Status:** a position in society used to classify individuals. Can be **ascribed** (involuntarily assigned), **achieved** (voluntarily earned), or **master** (primary identity)
- **Role:** set of beliefs, values, and norms that define the expectations of a certain status
- **Group:** two or more individuals with similar characteristics who share a sense of unity
- **Network:** observable pattern of social relationships between individuals or groups
- **Organization:** group with a structure and culture designed to achieve specific goals; exists outside of each individual's membership within the organization

Self-Presentation and Interacting with Others

- **Display rules:** unspoken rules that govern the expression of emotion
- **Impression management:** maintenance of a public image through various strategies
- **Dramaturgical approach:** individuals create images of themselves in the same way that actors perform a role in front of an audience

SOCIAL THINKING

Social Behavior

- **Interpersonal attraction:** influenced by physical, social, and psychological factors
- **Aggression:** behavior with the intention to cause harm or increase social dominance
- **Attachment:** an emotional bond to another person; usually refers to the bond between a child and a caregiver
- **Altruism:** helping behavior in which the person's intent is to benefit someone else at a personal cost

SOCIAL PERCEPTION AND BEHAVIOR

Attribution Theory

Focuses on the tendency for individuals to infer the causes of other people's behavior

- **Dispositional (internal)** causes relate to the features of the person who is being considered
- **Situational (external)** causes relate to features of the surroundings or social context
- **Correspondent inference theory:** describes attributions made by observing the intentional (especially unexpected) behaviors performed by another person
- **Fundamental attribution error:** bias toward making dispositional attributions rather than situational attributions

Stereotypes, Prejudice, and Discrimination

- **Stereotypes:** attitudes and impressions that are made based on limited and superficial information
- **Self-fulfilling prophecy:** the phenomenon of a stereotype creating an expectation of a particular group, which creates conditions that lead to confirmation of this stereotype
- **Stereotype threat:** a feeling of anxiety about confirming a negative stereotype
- **Prejudice:** an irrationally based attitude prior to actual experience
- **Ethnocentrism:** the practice of making judgments about other cultures based on the values and beliefs of one's own culture (**in-group** *vs.* **out-group**)
- **Cultural relativism:** studying social groups and cultures on their own terms
- **Discrimination:** when prejudicial attitudes cause differences in treatment of a group

SOCIAL STRUCTURE AND DEMOGRAPHICS

Sociology: Theories and Institutions

- **Functionalism:** focuses on the function and relationships of each component of society
- **Conflict theory:** focuses on how power differentials are created and how they maintain order
- **Symbolic interactionism:** the study of how individuals interact through a shared understanding of words, gestures, and other symbols
- **Social constructionism:** explores how individuals and groups make decisions to agree upon a given social reality

Culture

- **Material culture:** physical items one associates with a given group (art, clothing, foods, buildings)
- **Symbolic culture:** the ideas associated with a cultural group

Demographics

Demographics: the statistical arm of sociology

Migration refers to the movement of people into (immigration) or out of (emigration) a geographical location.

Demographic transition: a model used to represent drops in birth and death rates as a result of industrialization

SOCIAL STRATIFICATION

Social Class

Social stratification is based on **socioeconomic status (SES)**.

- **Class:** a category of people with shared socioeconomic characteristics
- **Power:** the capacity to influence people through real or perceived rewards and punishments
- **Social capital:** the investment people make in society in return for economic or collective rewards
- **Social reproduction:** the passing on of social inequality, especially poverty, to other generations
- **Poverty:** low SES; in the US, the poverty line is the government's calculation of the minimum income requirements to acquire the minimum necessities of life

Epidemiology

Incidence: $\frac{\text{new cases}}{\text{population - at risk}}$ per time

Prevalence: $\frac{\text{number of cases (new or old)}}{\text{total population}}$ per time

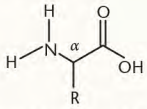
Morbidity: the burden or degree of illness associated with a given disease

Mortality: deaths caused by a given disease

AMINO ACIDS, PEPTIDES, AND PROTEINS

Amino Acids Found in Proteins

Amino acids have an amino group, carboxylic acid, a hydrogen atom, and an **R group** attached to a central α-carbon.



Amino acids are chiral (L), except for glycine; and have the (*S*) configuration, except for cysteine.

Side chains determine the chemistry and function of amino acids:

- **Nonpolar, nonaromatic:** glycine, alanine, valine, leucine, isoleucine, methionine, proline
- **Aromatic:** tryptophan, phenylalanine, tyrosine
- **Polar:** serine, threonine, asparagine, glutamine, cysteine
- **Negatively charged (acidic):** aspartic acid, glutamic acid
- **Positively charged (basic):** lysine, arginine, histidine

Acid–Base Chemistry of Amino Acids

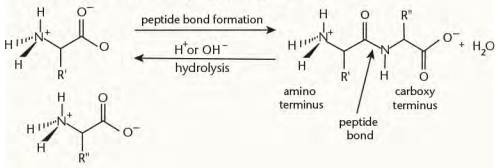
Amino acids are amphoteric.

- At low (acidic) pH: fully protonated
- At neutral pH: zwitterion
- At high (basic) pH: fully deprotonated

pI is determined by averaging the pK_a values that refer to protonation and deprotonation of the zwitterion.

Peptide Bond Formation and Hydrolysis

Peptide bond formation is a **condensation** (**dehydration**) reaction with a nucleophilic amino group attacking an electrophilic carbonyl. Peptide bonds are broken by **hydrolysis**.



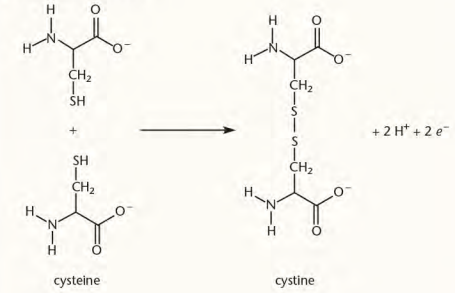
Protein Structure

Primary structure: linear sequence of amino acids

Secondary structure: local structure, stabilized by hydrogen bonding

- α-helices
- β-pleated sheets

Tertiary structure: three-dimensional structure stabilized by hydrophobic interactions, acid–base interactions (salt bridges), hydrogen bonding, and disulfide bonds



Quaternary Structure: interactions between subunits

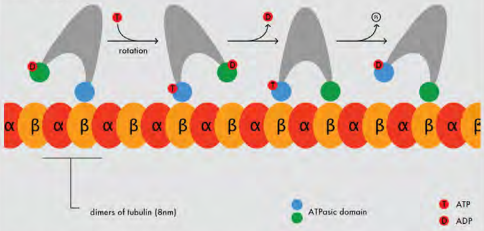
Heat and solutes can cause **denaturation**.

NONENZYMATIC PROTEIN FUNCTION AND PROTEIN ANALYSIS

Cellular Functions

Structural proteins: generally fibrous. Include **collagen**, **elastin**, **keratin**, **actin**, and **tubulin**

Motor proteins: capable of force generation through a conformational change. Include **myosin**, **kinesin**, and **dynein**



Binding proteins: bind a specific substrate, either to sequester it in the body or hold its concentration at steady state

Cell adhesion molecules (CAMs): bind cells to other cells or surfaces. Include **cadherins**, **integrins**, and **selectins**

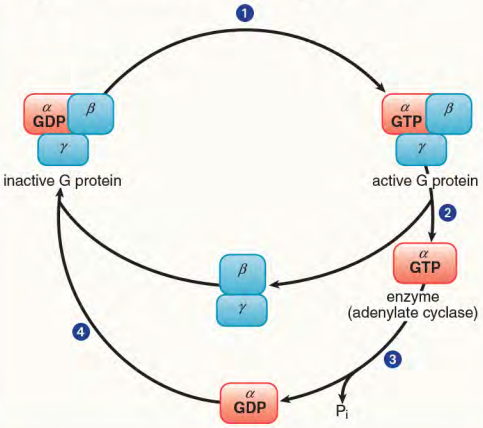
Antibodies (or **immunoglobulins**, **Ig**): target a specific **antigen**, which may be a protein on the surface of a pathogen (invading organism) or a toxin

BIOSIGNALING

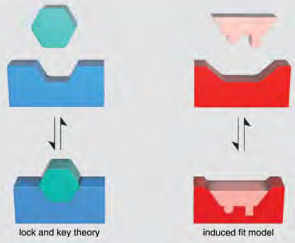
Ion channels can be used for regulating ion flow into or out of a cell. There are three main types of ion channels: **ungated channels**, **voltage-gated channels**, and **ligand-gated channels**.

Enzyme-linked receptors participate in cell signaling through extracellular ligand binding and initiation of second messenger cascades.

G protein-coupled receptors have a membrane-bound protein associated with a trimeric **G protein**. They also initiate second messenger systems.



ENZYMES



- **Ligases** are responsible for joining two large biomolecules, often of the same type.
- **Isomerases** catalyze the interconversion of isomers, including both constitutional and stereoisomers.
- **Lyases** catalyze cleavage without the addition of water and without the transfer of electrons. The reverse reaction (synthesis) is usually more biologically important.
- **Hydrolases** catalyze cleavage with the addition of water.
- **Oxidoreductases** catalyze oxidation–reduction reactions that involve the transfer of electrons.
- **Transferases** move a functional group from one molecule to another molecule.

Enzymes, like all catalysts, lower the activation energy necessary for reactions. They do not alter the free energy (ΔG) or enthalpy (ΔH) change that accompanies the reaction nor the final equilibrium position; rather, they change the rate (kinetics) at which equilibrium is reached.

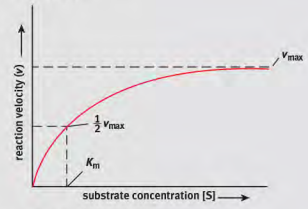
Enzyme Kinetics

Saturation kinetics: As substrate concentration increases, the reaction rate also increases until a maximum value is reached.

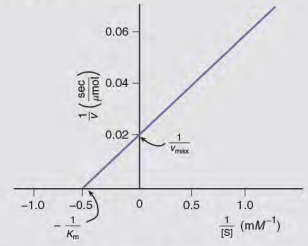
$$v = \frac{v_{max}[S]}{K_m + [S]}$$

At one-half v_{max}, $[S] = K_m$

Michaelis–Menten



Lineweaver–Burk



Cooperative enzymes show a **sigmoidal** curve.

Regulation of Enzyme Activity

	Competitive	Noncompetitive	Mixed	Uncompetitive
Binding Site	Active site	Allosteric site	Allosteric site	Allosteric site
Impact on K_m	Increases	No change	Increases or Decreases	Decreases
Impact on v_{max}	No change	Decreases	Decreases	Decreases

CARBOHYDRATE STRUCTURE AND FUNCTION

Carbohydrate Classification

Carbohydrates are organized by their number of carbon atoms and functional groups.

- 3-carbon sugars are **trioses**, 4-carbon sugars are **tetroses**, and so on.
- Sugars with aldehydes as their most oxidized group are **aldoses**; sugars with ketones as their most oxidized group are **ketoses**.

Sugars with the highest-numbered chiral carbon with the –OH group on the right (in a Fischer projection) are D-sugars; those with the –OH on the left are L-sugars. D- and L-forms of the same sugar are **enantiomers**.

Diastereomers differ at at least one—but not all—chiral carbons. Also include:

- **Epimers** differ at exactly one chiral carbon.
- **Anomers** are a subtype of epimers that differ at the anomeric carbon.

Cyclic Sugar Molecules

Cyclization describes the ring formation of carbohydrates from their straight-chain forms.

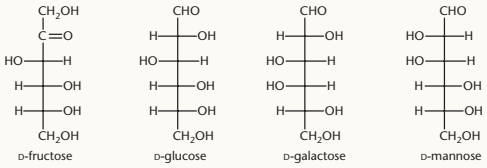
When rings form, the anomeric carbon can take on either an α- or β-conformation.

The **anomeric carbon** is the new chiral center formed in ring closure; it was the carbon containing the carbonyl in the straight-chain form.

- **α-anomers** have the –OH on the anomeric carbon *trans* to the free $-CH_2OH$ group.
- **β-anomers** have the –OH on the anomeric carbon *cis* to the free $-CH_2OH$ group.

During **mutarotation**, one anomeric form shifts to another, with the straight-chain form as an intermediate.

Monosaccharides



Monosaccharides are single carbohydrate units and can undergo three main reactions: **oxidation–reduction**, **esterification**, and **glycoside formation**.

Glycoside formation is the basis for building complex carbohydrates and requires the anomeric carbon to link to another sugar.

Sugars with a –H replacing an –OH group are termed **deoxy sugars**.

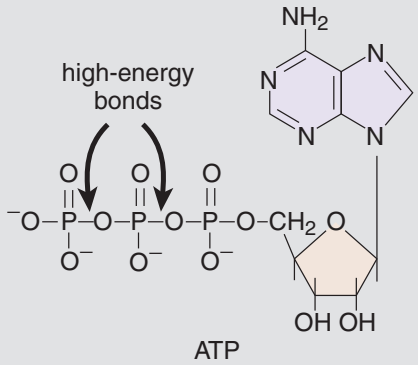
Disaccharides

Common **disaccharides** include **sucrose** (glucose-α-1,2-fructose), **lactose** (galactose-β-1,4-glucose), and **maltose** (glucose-α-1,4-glucose).

Polysaccharides

- **Cellulose:** main structural component of plant cell walls; main source of fiber in the human diet
- **Starches (amylose and amylopectin):** main energy storage forms for plants
- **Glycogen:** a major energy storage form for animals

DNA AND BIOTECHNOLOGY



DNA Structure

Nucleosides contain a five-carbon sugar bound to a nitrogenous base; **nucleotides** are nucleosides with one to three phosphate groups added.

Nucleotides in DNA contain deoxyribose; in RNA, they contain ribose.

Nucleotides are abbreviated by letter: adenine (A), cytosine (C), guanine (G), thymine (T), and uracil (U).

Watson–Crick Model

- The DNA backbone is composed of alternating sugar and phosphate groups, and is always read **5'** to **3'**.
- There are two strands with **antiparallel** polarity, wound into a **double helix**.
- **Purines** (A and G) always pair with **pyrimidines** (C, U, and T). In DNA, A pairs with T (via two hydrogen bonds) and C pairs with G (via three hydrogen bonds). In RNA, A pairs with U (via two hydrogen bonds).
- **Chargaff's rules:** purines and pyrimidines are equal in number in a DNA molecule. The amount of A equals the amount of T, and the amount of C equals the amount of G.

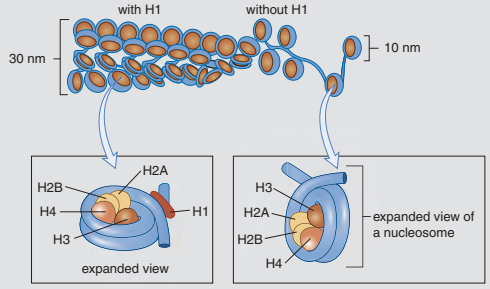
DNA strands can be pulled apart (**denatured**) and brought back together (**reannealed**).

Eukaryotic Chromosome Organization

DNA is organized into 46 chromosomes in human cells.

In eukaryotes, DNA is wound around **histone proteins** (H2A, H2B, H3, and H4) to form **nucleosomes**, which may be stabilized by another histone protein (H1). DNA and its associated histones make up **chromatin** in the nucleus.

- **Heterochromatin** is dense, transcriptionally silent DNA.
- **Euchromatin** is less dense, transcriptionally active DNA.



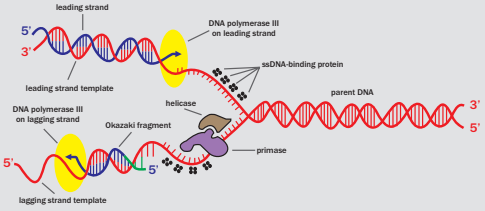
Telomeres are the ends of chromosomes. They contain a high GC-content to prevent unraveling of the DNA.

Centromeres are located in the middle of chromosomes and hold sister chromatids together until they are separated during anaphase in mitosis. They also contain a high GC-content.

DNA Replication

Step in Replication	Prokaryotic Cells	Eukaryotic Cells (Nuclei)
Origin of replication	One per chromosome	Multiple per chromosome
Unwinding of DNA double helix	Helicase	Helicase
Stabilization of unwound template strands	Single-stranded DNA-binding protein	Single-stranded DNA-binding protein
Synthesis of RNA primers	Primase	Primase
Synthesis of DNA	DNA polymerase III	DNA polymerases α and δ
Removal of RNA primers	DNA polymerase I (5′→3′ exonuclease)	RNase H (5′→3′ exonuclease)
Replacement of RNA with DNA	DNA polymerase I	DNA polymerase δ
Joining of Okazaki fragments	DNA ligase	DNA ligase
Removal of positive supercoils ahead of advancing replication forks	DNA topoisomerase II (DNA gyrase)	DNA topoisomerase II (DNA gyrase)
Synthesis of telomeres	Not applicable	Telomerase

DNA replication is **semiconservative**: one old **parent strand** and one new **daughter strand** is incorporated into each of the two new DNA molecules.



DNA polymerase synthesizes new DNA strands, reading the template DNA 3′ to 5′ and synthesizing the new strand 5′ to 3′.

- The **leading strand** requires only one primer and can then be synthesized continuously.
- The **lagging strand** requires many primers and is synthesized in discrete sections called **Okazaki fragments**.

Recombinant DNA and Biotechnology

Recombinant DNA is DNA composed of nucleotides from two different sources.

DNA cloning introduces a fragment of DNA into a **vector plasmid**. A **restriction enzyme** (**restriction endonuclease**) cuts both the plasmid and the fragment, leaving them with **sticky ends**, which can bind.

Once replicated, the bacterial cells can be used to create a protein of interest, or can be lysed to allow for isolation of the fragment of interest from the vector.

DNA libraries are large collections of known DNA sequences.

- **Genomic libraries** contain large fragments of DNA, including both coding and noncoding regions of the genome. They cannot be used to make recombinant proteins or for gene therapy.
- **cDNA libraries** (**expression libraries**) contain smaller fragments of DNA, and only include the exons of genes expressed by the sample tissue. They can be used to make recombinant proteins or for gene therapy.

Hybridization is the joining of complementary base pair sequences.

Polymerase chain reaction (**PCR**) is an automated process by which millions of copies of a DNA sequence can be created from a very small sample by hybridization.

DNA molecules can be separated by size using **agarose gel electrophoresis**.

Southern blotting can be used to detect the presence and quantity of various DNA strands in a sample. After electrophoresis, the sample is transferred to a membrane that can be **probed** with single-stranded DNA molecules to look for a sequence of interest.

DNA sequencing uses **dideoxyribonucleotides**, which terminate the DNA chain because they lack a 3′ –OH group.

RNA AND THE GENETIC CODE

Central Dogma: DNA → RNA → proteins

The Genetic Code

Degenerate code allows multiple codons to encode for the same amino acid.

- **Initiation:** AUG
- **Termination:** UAA, UGA, UAG
- Redundancy and **wobble** (third base in the codon) allow mutations to occur without affecting the protein.

Point mutations can cause:

- **Silent** mutations, with no effect on protein synthesis
- **Nonsense (truncation)** mutations, which produce a premature stop codon
- **Missense** mutations, which produce a codon that codes for a different amino acid
- **Frameshift mutations**, which result from nucleotide addition or deletion and change the reading frame of subsequent codons

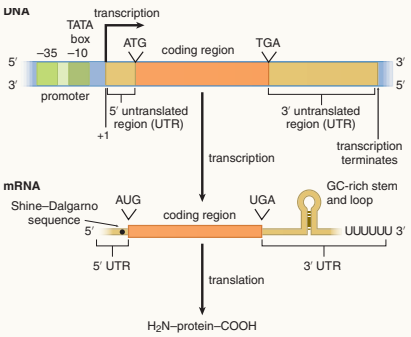
RNA is structurally similar to DNA except:

- Substitution of a ribose sugar for deoxyribose
- Substitution of uracil for thymine
- Single-stranded instead of double-stranded

There are three major types of RNA in transcription:

- **Messenger RNA (mRNA):** carries the message from DNA in the nucleus via transcription of the gene; travels into the cytoplasm to be translated
- **Transfer RNA (tRNA):** brings in amino acids; recognizes the codon on the mRNA using its anticodon
- **Ribosomal RNA (rRNA):** makes up much of the ribosome; enzymatically active

Transcription



Steps:

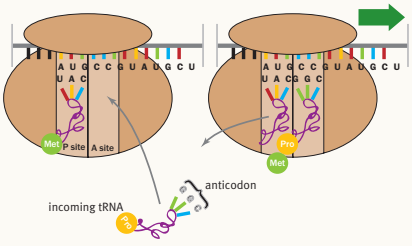
- Helicase and topoisomerase unwind DNA double helix.
- **RNA polymerase II** binds to **TATA box** within **promoter** region of gene (25 base pairs upstream from first transcribed base).
- **hnRNA** synthesized from DNA template (antisense) strand.

Posttranscriptional modifications:

- 7-methylguanylate triphosphate cap added to 5′ end
- Polyadenosyl (poly-A) tail added to 3′ end
- Splicing done by **spliceosome**; introns removed and exons ligated together. **Alternative splicing** combines different exons to acquire different gene products.

Translation

Occurs at the ribosome.



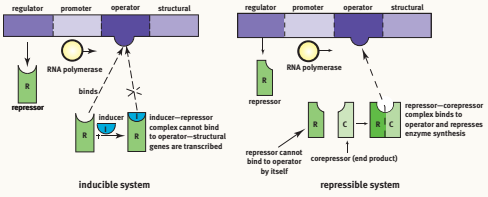
Three stages: **initiation**, **elongation**, **termination**

Posttranslational modifications:

- Folding by **chaperones**
- Formation of quaternary structure
- Cleavage of proteins or signal sequences
- Covalent addition of other biomolecules (phosphorylation, carboxylation, glycosylation, prenylation)

Control of Gene Expression in Prokaryotes

Operons (Jacob–Monod model) are inducible or repressible clusters of genes transcribed as a single mRNA.



Control of Gene Expression in Eukaryotes

Transcription factors search for promoter and enhancer regions in the DNA.

- **Promoters** are within 25 base pairs of the transcription start site.
- **Enhancers** are more than 25 base pairs away from the transcription start site.

BIOLOGICAL MEMBRANES

Membrane Transport

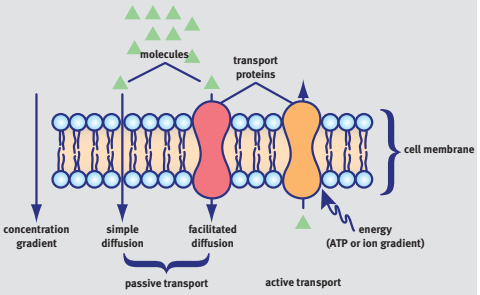
Osmotic pressure, a **colligative property**, is the pressure applied to a pure solvent to prevent osmosis and is related to the concentration of the solution.

$$\Pi = iMRT$$

Passive transport does not require ATP because the molecule is moving down its concentration gradient or from an area of higher concentration to an area of lower concentration.

- **Simple diffusion** does not require a transporter. Small, nonpolar molecules passively move from an area of high concentration to an area of low concentration until equilibrium is achieved.
- **Osmosis** describes the diffusion of water across a selectively permeable membrane.
- **Facilitated diffusion** uses transport proteins to move impermeable solutes across the cell membrane.

Active transport requires energy in the form of ATP (**primary**) or an existing favorable ion gradient (**secondary**). Secondary active transport can be further classified as **symport** or **antiport**.



Endocytosis and **exocytosis** are methods of engulfing material into cells or releasing material to the exterior of cells, both via the cell membrane. **Pinocytosis** is the ingestion of liquid into the cell from vesicles formed from the cell membrane and **phagocytosis** is the ingestion of solid material.

CARBOHYDRATE METABOLISM

Glycolysis

Occurs in the cytoplasm of all cells, and does not require oxygen. Yields 2 ATP per glucose. Important enzymes include:

- **Glucokinase:** present in the pancreatic β-islet cells as part of the glucose sensor and is responsive to insulin in the liver
- **Hexokinase:** traps glucose
- **Phosphofructokinase-1** (**PFK-1**): rate-limiting step
- **Phosphofructokinase-2** (**PFK-2**): produces F2,6-BP, which activates PFK-1
- **Glyceraldehyde-3-phosphate dehydrogenase:** produces NADH
- **3-phosphoglycerate kinase** and **pyruvate kinase:** perform **substrate-level phosphorylation**

Glucokinase/hexokinase, PFK-1, and pyruvate kinase catalyze irreversible reactions.

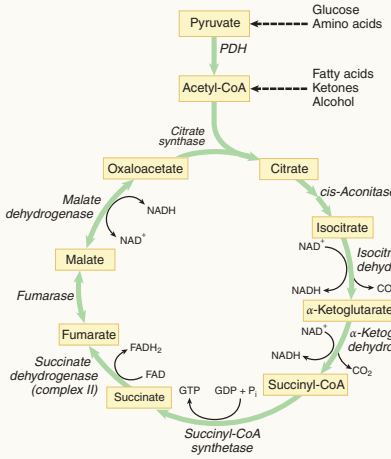
The NADH produced in glycolysis is oxidized aerobically by the mitochondrial electron transport chain and anaerobically by cytoplasmic **lactate dehydrogenase**.

Pyruvate Dehydrogenase

- Converts pyruvate to acetyl-CoA. Stimulated by insulin and inhibited by acetyl-CoA.

The Citric Acid Cycle

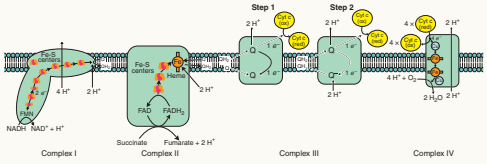
Takes place in mitochondrial matrix. Main purpose is to oxidize acetyl-CoA to CO_2 and generate high-energy electron carriers (NADH and $FADH_2$) and GTP.



The Electron Transport Chain

Takes place on the matrix-facing surface of the inner mitochondrial membrane.

NADH donates electrons to the chain, which are passed from one complex to the next. Reduction potentials increase down the chain, until the electrons end up on oxygen, which has the highest reduction potential.



NADH cannot cross the inner mitochondrial membrane, so must use one of two shuttle mechanisms to transfer its electrons to energy carriers in the mitochondrial matrix: the **glycerol 3-phosphate shuttle** or the **malate–aspartate shuttle**.

Oxidative Phosphorylation

The **proton-motive force** is the electrochemical gradient generated by the electron transport chain across the inner mitochondrial membrane. The intermembrane space has a higher concentration of protons than the matrix; this gradient stores energy, which can be used to form ATP via **chemiosmotic coupling**.

ATP synthase is the enzyme responsible for generating ATP from ADP and an inorganic phosphate (P_i).

Summary of the energy yield of the various carbohydrate metabolism processes:

- Glycolysis: 2 NADH and 2 ATP
- Pyruvate dehydrogenase: 1 NADH (2 NADH per molecule of glucose because each glucose forms two molecules of pyruvate)
- Citric acid cycle: 3 NADH, 1 $FADH_2$, and 1 GTP (6 NADH, 2 $FADH_2$, and 2 GTP per molecule of glucose)
- Each NADH: 2.5 ATP; 10 NADH form 25 ATP
- Each $FADH_2$: 1.5 ATP; 2 $FADH_2$ form 3 ATP
- GTP are converted to ATP.
- 2 ATP from glycolysis + 2 ATP (GTP) from citric acid cycle + 25 ATP from NADH + 3 ATP from $FADH_2$ = 32 ATP per molecule of glucose (optimal). 30–32 ATP per molecule of glucose is the commonly accepted range for energy yield

Glycogenesis and Glycogenolysis

Glycogenesis (glycogen synthesis) is the building of glycogen using two main enzymes:

- **Glycogen synthase**, which creates α-1,4 glycosidic links between glucose molecules. It is activated by insulin in the liver and muscles.
- **Branching enzyme**, which moves a block of oligoglucose from one chain and connects it as a branch using an α-1,6 glycosidic link.

Glycogenolysis is the breakdown of glycogen using two main enzymes:

- **Glycogen phosphorylase**, which removes single glucose 1-phosphate molecules by breaking α-1,4 glycosidic links. In the liver, it is activated by glucagon to prevent low blood sugar. In exercising skeletal muscle, it is activated by epinephrine and AMP to provide glucose for the muscle itself.
- **Debranching enzyme**, which moves a block of oligoglucose from one branch and connects it to the chain using an α-1,4 glycosidic link.

Gluconeogenesis

Occurs in both the cytoplasm and mitochondria, predominantly in the liver. Most of gluconeogenesis is just the reverse of glycolysis, using the same enzymes.

The three irreversible steps of glycolysis must be bypassed by different enzymes:

- Pyruvate carboxylase and PEP carboxykinase bypass pyruvate kinase
- Fructose-1,6-bisphosphatase bypasses phosphofructokinase-1
- Glucose-6-phosphatase bypasses hexokinase/glucokinase

The Pentose Phosphate Pathway

Occurs in the cytoplasm of most cells, generating **NADPH** and sugars for biosynthesis. Rate-limiting enzyme is **glucose-6-phosphate dehydrogenase**, which is activated by $NADP^+$ and inhibited by NADPH and insulin.

BIOENERGETICS AND REGULATION OF METABOLISM

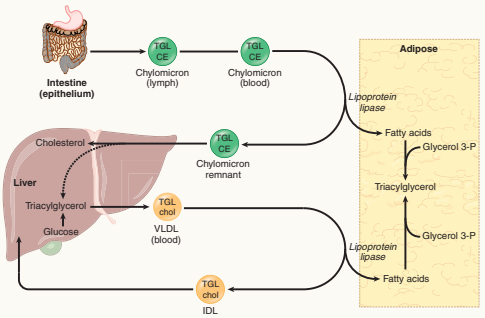
Metabolic States

- In the **postprandial/well-fed (absorptive) state**, insulin secretion is high and anabolic metabolism prevails.
- In the **postabsorptive (fasting) state**, insulin secretion decreases while glucagon and catecholamine secretion increases.
- Prolonged fasting (**starvation**) dramatically increases glucagon and catecholamine secretion. Most tissues rely on fatty acids.

LIPID AND AMINO ACID METABOLISM

Lipid Transport

Lipids are transported via **chylomicrons**, **VLDL**, **IDL**, **LDL**, and **HDL**.



Cholesterol Metabolism

- Cholesterol may be obtained through dietary sources or through synthesis in the liver.
- The key enzyme in cholesterol biosynthesis is **HMG-CoA reductase**.

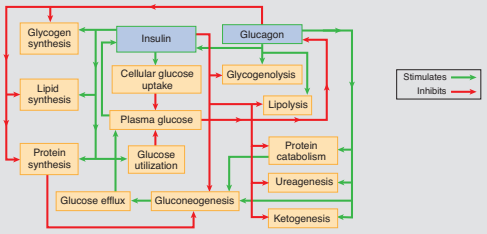
Palmitic acid, the only fatty acid that humans can synthesize, is produced in the cytoplasm from acetyl-CoA transported out of the mitochondria.

Fatty acid oxidation occurs in the mitochondria, following transport by the carnitine shuttle, via **β-oxidation**.

Ketone bodies form (**ketogenesis**) during a prolonged starvation state due to excess acetyl-CoA in the liver. **Ketolysis** regenerates acetyl-CoA for use as an energy source in peripheral tissues.

Protein Catabolism

Protein digestion occurs primarily in the small intestine. Carbon skeletons of amino acids are used for energy, either through gluconeogenesis or ketone body formation. Amino groups are fed into the **urea cycle** for excretion.



Tissue-Specific Metabolism

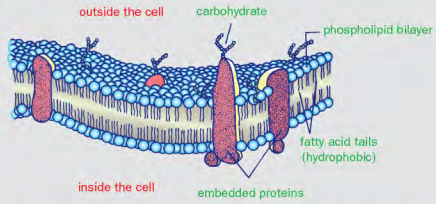
- Liver: maintains blood glucose through glycogenolysis and gluconeogenesis. Processes lipids, cholesterol, bile, urea, and toxins.
- Adipose: stores and releases lipids
- Resting muscle: conserves carbohydrates as glycogen and uses free fatty acids for fuel
- Active muscle: may use anaerobic metabolism, oxidative phosphorylation, direct phosphorylation (creatine phosphate), or fatty acid oxidation
- Cardiac muscle: uses fatty acid oxidation
- Brain: uses glucose except in prolonged starvation, when it can use ketolysis

THE CELL

Organelles of Eukaryotic Cells

- **Nucleus:** contains all of the genetic material necessary for replication of the cell
- **Mitochondrion:** location of many metabolic processes (pyruvate dehydrogenase, citric acid cycle, ETC, oxidative phosphorylation, β-oxidation, some of gluconeogenesis, urea cycle) and ATP production
- **Lysosomes:** membrane-bound structures containing hydrolytic enzymes capable of breaking down many different substrates
- **Rough endoplasmic reticulum:** interconnected membranous structure with ribosomes studding the outside; site of synthesis of proteins destined for insertion into a membrane or secretion
- **Smooth endoplasmic reticulum:** interconnected membranous structure where lipid synthesis and detoxification occurs
- **Golgi apparatus:** membrane-bound sacs where posttranslational modification of proteins occurs
- **Peroxisomes:** organelle containing hydrogen peroxide; site of β-oxidation of very long chain fatty acids

Fluid Mosaic Model and Membrane Traffic



- Phospholipid bilayer with cholesterol and embedded proteins
- Exterior: hydrophilic phosphate head groups
- Interior: hydrophobic fatty acids

The original form of the **cell theory** consisted of three basic tenets:

- All living things are composed of cells.
- The cell is the basic functional unit of life.
- Cells arise only from preexisting cells.

A fourth tenet has been added as a result of advances in molecular biology: cells carry genetic information in the form of DNA. This genetic material is passed on from parent to daughter cell.

Eukaryotes contain membrane-bound organelles such as a nucleus, while prokaryotes are simpler cells without a nucleus.

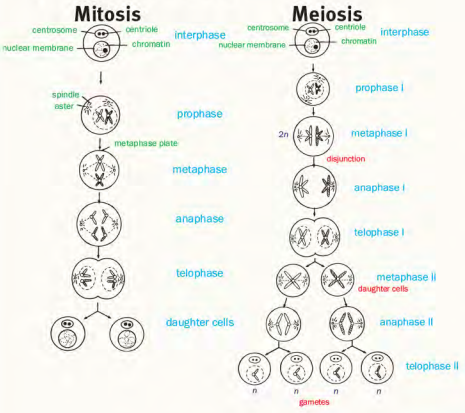
Prokaryotes

- Classified by shape: Spherical bacteria are known as **cocci**, while rod-shaped bacteria are known as **bacilli**. Spiral-shaped bacteria are known as **spirilli**.
- Cell wall and cell membrane form the envelope. Composition of the cell wall further classifies bacteria into gram-positive and gram-negative. **Gram-positive** bacteria have large quantities of peptidoglycan in the cell wall, while **gram-negative** bacteria have much smaller quantities of peptidoglycan with lipopolysaccharides.
- Structure of flagella in bacteria is much different than that of eukaryotes. Prokaryotic flagella contain a basal body that serves as the engine for motion.
- All prokaryotes divide by **binary fission**. The circular chromosome replicates and attaches to the cell wall; the plasma membrane and cell wall grow along the midline, forming daughter cells.

REPRODUCTION

Cell Division

- G_1: cell increases its organelles and cytoplasm
- S: DNA replication
- G_2: same as G_1
- M: the cell divides in two
- Mitosis = PMAT
- Meiosis = PMAT $\times$ 2



Sexual Reproduction

Meiosis I:

- Two pairs of sister chromatids form tetrads during prophase I.
- Crossing over leads to genetic recombination in prophase I.
- Homologous chromosomes separate during metaphase I.

Meiosis II:

- Essentially identical to mitosis, but no replication.
- Meiosis occurs in **spermatogenesis** (sperm formation) and **oogenesis** (egg formation).

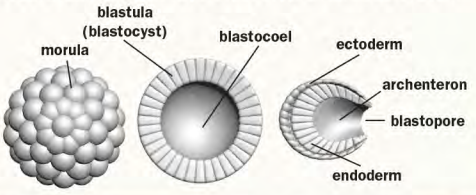
Four Stages of Early Development

Cleavage: mitotic divisions

Implantation: embryo implants during blastula stage

Gastrulation: ectoderm, endoderm, and mesoderm form

Neurulation: germ layers develop a nervous system



Ectoderm "Attract"oderm	Nervous system, epidermis, lens of eye, inner ear
Endoderm "Endernal" organs	Lining of digestive tract, lungs, liver and pancreas
Mesoderm "Means"oderm	Muscles, skeleton, circulatory system, gonads, kidney

The Liver's Roles in Homeostasis

1. Gluconeogenesis
2. Processing of nitrogenous wastes (urea)
3. Detoxification of wastes/chemicals/drugs
4. Storage of iron and vitamin A
5. Synthesis of bile and blood proteins
6. β-Oxidation of fatty acids to ketones
7. Interconversion of carbohydrates fats, and amino acids

Layers of the Skin

- Stratum corneum
- Stratum lucidum
- Stratum granulosum
- Stratum spinosum
- Stratum basalis

HOMEOSTASIS

Osmoregulation

- **Filtration** at the glomerulus. Filtrate (fluid and small solutes) passes through. *Passive*
- **Secretion** of acids, bases, and ions from interstitial fluid to filtrate. Maintains pH, [K^+] and [waste]. *Passive and Active*
- **Reabsorption:** essential substances and water flow from filtrate to blood. Enabled by osmolarity gradient and selective permeability of the walls. *Passive and Active*

Hormonal Regulation

Aldosterone

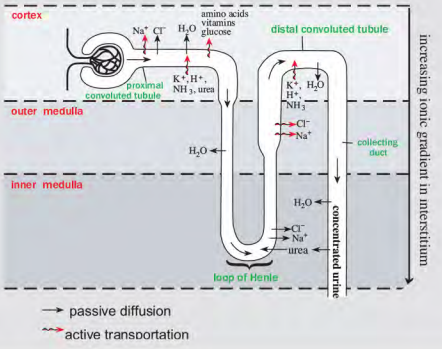
- Stimulates Na^+ reabsorption, K^+ and H^+ secretion, increasing water reabsorption, blood volume, and blood pressure
- Secreted from adrenal cortex
- Is regulated by the renin–angiotensin–aldosterone system

ADH (Vasopressin)

Increases collecting duct's permeability to water to increase water reabsorption

- Is secreted from posterior pituitary with high [solute] in the blood

Kidneys regulate [salt] and [water] in the blood. Their functional unit is the nephron.



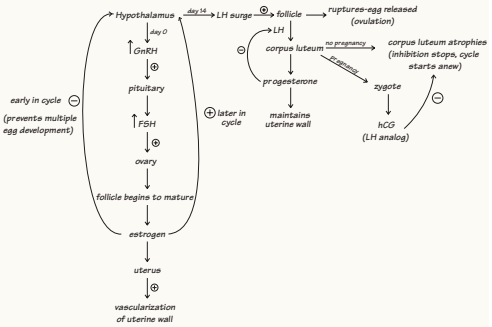
ENDOCRINE SYSTEM

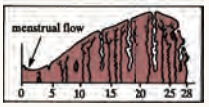
Direct hormones directly stimulate organs; tropic hormones stimulate other glands.
Mechanisms of hormone action: **peptides** act via second messengers and **steroids** act via hormone/receptor binding to DNA. Amino acid-derivative hormones may do either.

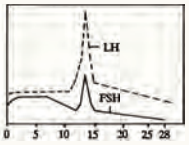
Hormone	Source	Action
Follicle-stimulating (FSH)	Anterior pituitary	Stimulates follicle maturation; spermatogenesis
Luteinizing (LH)		Stimulates ovulation; testosterone synthesis
Adrenocorticotropic (ACTH)		Stimulates adrenal cortex to make and secrete glucocorticoids
Thyroid-stimulating (TSH)		Stimulates the thyroid to produce thyroid hormones
Prolactin		Stimulates milk production and secretion
Endorphins		Inhibits the perception of pain in the brain
Growth hormone		Stimulates bone and muscle growth/lipolysis
Oxytocin	Hypothalamus; stored in posterior pituitary	Stimulates uterine contractions during labor, milk secretion during lactation
Antidiuretic (ADH, vasopressin)		Stimulates water reabsorption in kidneys
Thyroid hormones (T_3, T_4)	Thyroid	Stimulates metabolic activity
Calcitonin		Decreases (tones down) blood calcium level
Parathyroid hormone	Parathyroid	Increases blood calcium level
Glucocorticoids	Adrenal cortex	Increases blood glucose level and decreases protein synthesis; anti-inflammatory
Mineralocorticoids		Increases water reabsorption in kidneys
Epinephrine, Norepinephrine	Adrenal medulla	Increases blood glucose level and heart rate
Glucagon	Pancreas	Stimulates conversion of glycogen to glucose in the liver; increases blood glucose
Insulin		Lowers blood glucose; increases glycogen stores
Somatostatin		Supresses secretion of glucagon and insulin
Testosterone	Testes	Maintains male secondary sexual characteristics
Estrogen	Ovary/Placenta	Maintains female secondary sexual characteristics
Progesterone		Promotes growth/maintenance of endometrium
Melatonin	Pineal	Regulates sleep–wake cycles
Atrial natriuretic peptide	Heart	Involved in osmoregulation and vasodilation
Thymosin	Thymus	Stimulates T-cell development

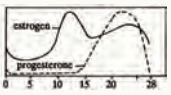
Four Stages of Menstrual Cycle:

1. **Follicular:** FSH causes growth of a follicle
2. **Ovulation:** LH causes follicle to release egg
3. **Luteal:** corpus luteum forms
4. **Menstruation:** endometrial lining sheds



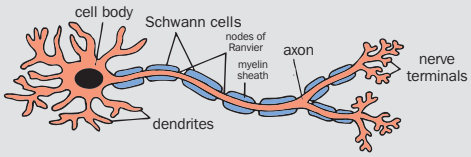






NERVOUS SYSTEM

The functional unit is the neuron:



Resting Potential:

- 3 Na^+ pumped out for every 2 K^+ pumped in

Action Potential:

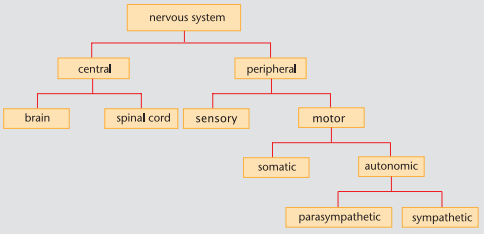
- Stimulus acts on the neuron, depolarizing the membrane of the cell body

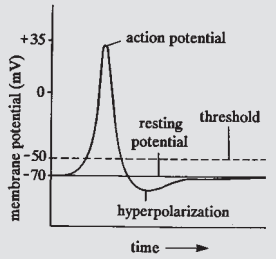
Impulse Propagation:

- Depolarization (Na^+ rushing into axon) followed by repolarization (K^+ rushing out of axon) along the nerve axon

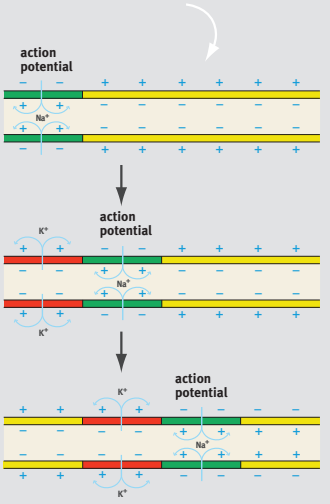
The Synapse:

- At the synaptic knob, voltage-gated Ca^{2+} channels open, sending Ca^{2+} into the cell.
- Vesicles fuse with presynaptic membrane sending the neurotransmitter across the **synaptic cleft**.
- Neurotransmitter binds to receptors on the postsynaptic membrane, triggering depolarization.





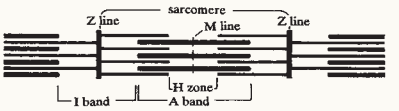
I	Rest	All gates closed
II	Depolarization	Na^+ gates open
III	Repolarization	Na^+ gates inactivate K^+ gates open
IV	Hyperpolarization	All gates closed



MUSCULOSKELETAL SYSTEM

Sarcomere

- Contractile unit of the fibers in skeletal muscle
- Contains thin actin and thick myosin filaments



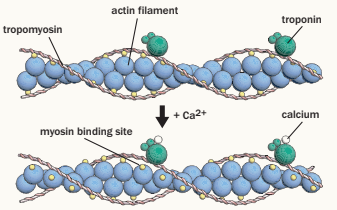
Contraction

Initiation:

- Depolarization of a neuron leads to an action potential.

Sarcomere shortening:

- Sarcoplasmic reticulum releases Ca^{2+}.
- Ca^{2+} binds to troponin on the actin filament.
- Tropomyosin shifts, exposing myosin-binding sites.
- Myosin binds, ATPase activity allows myosin to pull thin filaments towards the center of the H zone, and then ATP causes dissociation.



Relaxation:

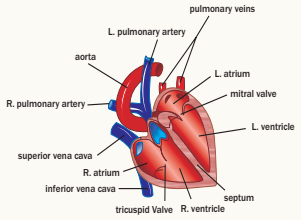
- Ca^{2+} is pumped back into the sarcoplasmic reticulum.

Bone Formation and Remodeling

- **Osteoblast:** builds bone
- **Osteoclast:** breaks down bone
- **Reformation:** inorganic ions are absorbed from the blood for use in bone
- **Degradation (resorption):** inorganic ions are released into the blood

CIRCULATION

Circulatory Pathway Through Heart



Superior and inferior vena cava → right atrium → right ventricle → pulmonary arteries → lungs→ pulmonary veins → left atrium → left ventricle → aorta → body

Three portal systems: Blood travels through an extra capillary bed before returning to the heart.

- Liver (hepatic), kidney, and brain (hypophyseal)

Fetal Circulation

- **Foramen ovale:** connects right and left atria
- **Ductus arteriosus:** connects pulmonary artery to aorta. Along with foramen ovale, shunts blood away from lungs
- **Ductus venosus:** connects umbilical vein to inferior vena cava, connecting umbilical circulation to central circulation

Blood Components

Plasma: aqueous mix of nutrients, wastes, hormones, blood proteins, gases, and salts

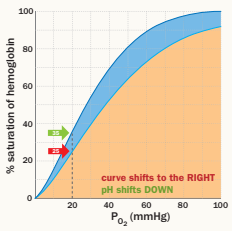
Erythrocytes (red blood cells): carry oxygen

- Hemoglobin: four subunits carry O_2 and CO_2. Iron controls binding and releasing.
- Oxygen–hemoglobin dissociation:

Factors leading to right shift of curve:

- ↑ Temperature
- **Bohr Effect**

  ↓ pH, ↑ P_{CO_2}



- O_2 release to tissues enhanced when H^+ allosterically binds to Hb. ↑ P_{CO_2} leads to ↑ $[H^+]$:

$$CO_2 + H_2O \overset{\text{carbonic anhydrase}}{\rightleftharpoons} H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

Leukocytes (white blood cells): function in immunity

Platelets: clotting

- Platelets release thromboplastin, which (along with cofactors calcium and vitamin K) converts inactive prothrombin to active thrombin.
- Thrombin converts fibrinogen into fibrin, which surrounds blood cells to form the clot.

Blood Typing

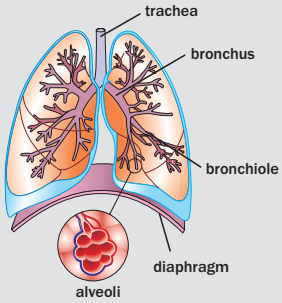
Antigens are located on the surface of red blood cells.

Blood type	RBC antigen	Antibodies	Donates to:	Receives From:
A	A	anti-B	A, AB	A, O
B	B	anti-A	B, AB	B, O
AB	A, B	None	AB only	All
O	None	anti-A, B	All	O only

Blood cells with Rh factor are Rh^+; these individuals produce no anti-Rh antibody. Rh^- blood cells lack the antigen; these individuals produce an antibody if exposed.

RESPIRATION

Gas Exchange

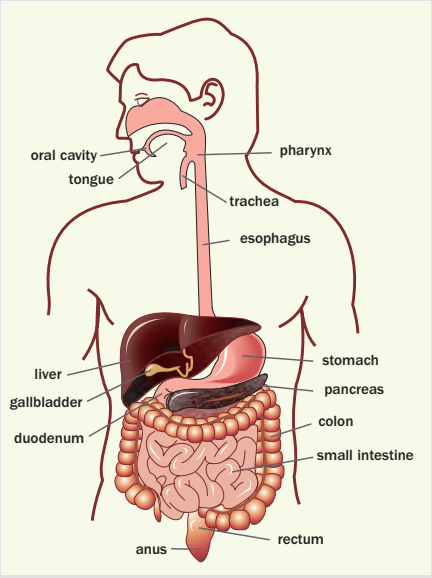


- Exchange occurs across the thin walls of **alveoli**.
- Deoxygenated blood enters the pulmonary capillaries that surround the alveoli.
- O_2 from the inhaled air diffuses down its gradient into the capillaries, where it binds with hemoglobin and returns to the heart.
- CO_2 from the tissues diffuses from the capillaries to the alveoli, and is exhaled.

Fetal Respiration

- Fetal hemoglobin has a higher affinity for oxygen than adult hemoglobin.
- Gas and nutrient exchanges occur across the placenta.

DIGESTION



Lipid Digestion

- When chyme is present, the duodenum secretes the hormone cholecystokinin (CCK) into the blood.
- CCK stimulates the secretion of pancreatic enzymes and bile, and promotes satiety.
- Bile is made in the liver and emulsifies fat in the small intestine; it's not an enzyme.
- Lipase is an enzyme made in the pancreas that hydrolyzes lipids in the small intestine.

Carbohydrate Digestion

Enzyme	Production Site	Function Site	Hydrolysis Reaction
Salivary amylase (ptyalin)	Salivary glands	Mouth	Starch → maltose
Pancreatic amylase	Pancreas	Small intestine	Starch → maltose
Maltase	Intestinal glands	Small intestine	Maltose → 2 glucoses
Sucrase	Intestinal glands	Small intestine	Sucrose → glucose, fructose
Lactase	Intestinal glands	Small intestine	Lactose → glucose, galactose

Protein Digestion

Enzyme	Production Site	Function Site	Function
Pepsin	Gastric glands (chief cells)	Stomach	Hydrolyzes specific peptide bonds
Trypsin	Pancreas	Small Intestine	Hydrolyzes specific peptide bonds Converts chymotrypsinogen to chymotrypsin
Chymotrypsin			Hydrolyzes specific peptide bonds
Carboxypeptidases A and B			Hydrolyzes terminal peptide bond at C-terminus
Aminopeptidase	Intestinal glands		Hydrolyzes terminal peptide bond at N-terminus
Dipeptidases			Hydrolyzes pairs of amino acids
Enteropeptidase			Converts trypsinogen to trypsin

IMMUNE SYSTEM

- The body distinguishes between "self" and "nonself" (antigens).

Humoral Immunity (Specific Defense)

B-lymphocytes

memory cells remember antigen, speed up secondary response

plasma cells make and release antibodies (**IgG**, **IgA**, **IgM**, **IgD**, **IgE**), which induce antigen phagocytosis

- **Active imumunity:** antibodies are produced during an immune response
- **Passive immunity:** antibodies produced by one organism are transferred to another organism

Cell-Mediated Immunity (Specific Defense)

T-lymphocytes

cytotoxic T-cells destroy cells directly

helper T-cells activate B- and T-cells and macrophages by secreting lymphokines

suppressor T-cells regulate B- and T-cells to decrease anti-antigen activity

memory cells

Nonspecific Immune Response

Includes skin, passages lined with cilia, macrophages, inflammatory response, and interferons (proteins that help prevent the spread of a virus)

Lymphatic System

- Lymph vessels meet at the thoracic duct in the upper chest and neck, draining into the left subclavian vein of the cardiovascular system.
- Vessels carry **lymph** (excess interstitial fluid), and **lacteals** collect fats by absorbing chylomicrons in the small intestine.
- **Lymph nodes** are swellings along the vessels with phagocytic cells (leukocytes); they remove foreign particles from lymph.

CLASSICAL GENETICS

Law of segregation: Homologous alleles (chromosomes) separate so that each gamete has one copy of each gene.

- If both parents are Rr, the alleles separate to give a genotypic ratio of 1:2:1 and a phenotypic ratio of 3:1.

Law of independent assortment: Alleles of unlinked genes assort independently in meiosis.

- For two traits: AaBb parents will produce AB, Ab, aB, and ab gametes.
- The phenotypic ratio for this cross is 9:3:3:1.

Statistical Calculations

- The probability of producing a genotype that requires multiple events to occur equals the *product* of the probability of each event.
- The probability of producing a genotype that can be the result of multiple different events equals the *sum* of each probability minus the probability of multiple events occurring.

Genetic Mapping

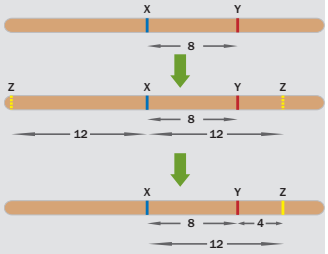
- Crossing over during meiosis I can unlink genes (prophase I).
- Genes are most likely unlinked when far apart.
- One map unit is 1% recombinant frequency (1 centimorgan).

Given recombination frequencies

X and Y: 8%

X and Z: 12%

Y and Z: 4%



Patterns of Inheritance

- Autosomal recessive: skips generations
- Autosomal dominant: appears in every generation
- X-linked (sex-linked): no male-to-male transmission, and more males are affected

EVOLUTION

- When frequencies are stable, the population is in **Hardy–Weinberg equilibrium:** no mutations, large population, random mating, no migration, and equal reproductive success

$$p + q = 1;\ p^2 + 2pq + q^2 = 1$$

p = frequency of dominant allele

q = frequency of recessive allele

p^2 = frequency of dominant homozygotes

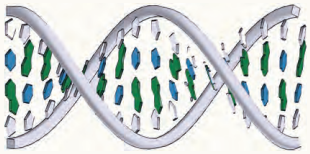
$2pq$ = frequency of heterozygotes

q^2 = frequency of recessive homozygotes

MOLECULAR GENETICS

Nucleic Acids

- Basic unit: nucleotide (sugar, nitrogenous base, phosphate)
- DNA's sugar: deoxyribose; RNA's sugar: ribose
- 2 types of bases: double-ringed purines (adenine, guanine) and single-ringed pyrimidines (cytosine, uracil, thymine)
- DNA double helix: antiparallel strands joined by base pairs (A=T, G≡C)
- RNA is usually single-stranded: A pairs with U, not T



Transcriptional Regulation (Prokaryotes)

Regulated by the **operon:**

- Structural genes: have DNA that codes for protein
- Operator gene: repressor binding site
- Promoter gene: RNA polymerase's 1st binding site
- Inducible systems need an inducer for transcription to occur. Repressible systems need a corepressor to inhibit transcription.

Mutations

- **Point:** One nucleotide is substituted by another; they are silent if the sequence of amino acids doesn't change.
- **Frameshift:** Insertions or deletions shift reading frame. Protein doesn't form, or is nonfunctional.

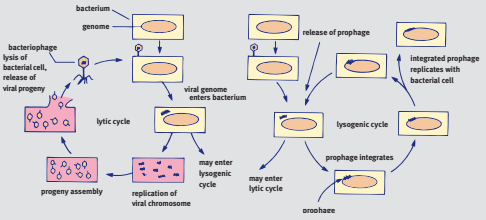
Viruses

- Acellular structures of double- or single-stranded DNA or RNA in a protein coat
- Lytic cycle: virus kills the host cell
- Lysogenic cycle: virus enters host genome

GENETICS OF PROKARYOTIC CELLS

Many bacteria contain **plasmids**, or extragenomic material. Plasmids that can be integrated into the genome are known as **episomes**.

- **Transformation** occurs when a bacterium acquires a piece of genetic material from the environment and integrates that piece of genetic material into the host cell genome. This is a common method by which antibiotic resistance can be acquired.
- **Conjugation** is the bacterial form of mating (sexual reproduction). It involves two cells forming a cytoplasmic bridge between them that allows for the transfer of genetic material. The transfer is one-way, from the donor male (+) to the recipient female (–). The bridge is made from appendages called **sex pili** that are found on the donor male. To form the pili, bacteria must contain plasmids known as **sex factors**.
- **Transduction** occurs when a bacteriophage acquires genetic information from a host cell. Sometimes, when the new virions are assembled in a host cell, some of the genetic material from the host cell is packaged along with the viral genetic material. Then, the bacteriophage infects another bacterium, resulting in transfer of bacterial genetic material.



DATA ANALYSIS

A researcher performed the following experiments in order to investigate the metabolism of two different strains of bacteria, Strain 1 and Strain 2.

Experiment 1

Strains 1 and 2 were incubated in separate broth cultures for 24 hours at 37°C. A sample of each culture was streaked onto three different plates—A, B, and C—each containing a different starch–agar medium; the plates were then incubated for another 48 hours at 37°C. The plates were then examined for surface colony growth and stained with iodine solution to determine the extent of starch digestion.

Table 1

	Surface Colony Growth			Starch Digestion		
	A	B	C	A	B	C
Strain 1	+	+	+	–	–	–
Strain 2	+	+	–	+	+	–

key: + = growth; – = no growth

Experiment 2

The two strains were incubated in the same manner as in Experiment 1. Two 100 mL portions of agar were poured into two beakers, which were maintained at 43°C. Next, 0.2 mL of broth culture from Strain 1 was pipetted into the first beaker, and 0.2 mL of broth culture from Strain 2 was pipetted into the second beaker. The agar was swirled around to distribute the bacteria evenly through the media, and then poured onto plates. These plates were incubated for 48 hours at 37°C and then examined for colony growth both on the agar surface and lower down within the oxygen-poor agar layer.

Table 2

	Surface Colony Growth	Deep-Agar Colony Growth
Strain 1	+	–
Strain 2	+	+

key: + = growth; – = no growth

Once incubated, bacteria will grow if nutrients they can metabolize are available. Keep this in mind as you interpret the procedure and results.

Experiment 1 and Table 1: What are the important aspects? **Two strains** (1 and 2) undergo **identical incubation** on **3 plates with different starch agars.** Look at Table 1, one strain at a time. The researcher observes growth and starch digestion. Strain 1 grows on all plates, but doesn't digest the starch: it must be using another nutrient to grow. We don't know that Strain 1 *can't* digest starch—we just know that it's not digesting it in the first 48 hours. Strain 2 uses starch to grow on plates A and B, but doesn't digest starch or grow on plate C. Again, we don't know that Strain 2 *can't* digest the starch in medium C—we just know it's not doing so in the first 48 hours.

Experiment 2 and Table 2: Note the significant differences between the two experiments. This time, the strains were **separately** distributed **within the agar** instead of jointly streaked on top of multiple agars. The researcher observes growth on top and within, the assumption being that the top is oxygen-rich and within is oxygen-poor. What does it mean that Strain 1 only grows in an oxygen-rich environment? It is an obligate aerobe that requires oxygen for metabolism. What does it mean that Strain 2 can grow in oxygen-rich *and* oxygen-poor environments? It is a facultative anaerobe.