

GLOSSARY

absence seizure A seizure characterized by a brief lapse of consciousness (about 10 seconds or less) and a cessation of motor activities without loss of posture.

accessory olfactory bulb A brain region adjacent to the olfactory bulb, it is the axonal projection target of sensory neurons from the vomeronasal organ. (Figure 6-22)

accessory olfactory system (vomeronasal system)

An anatomically and biochemically distinct system from the main olfactory system, it detects and analyzes nonvolatile chemicals and peptides such as pheromones and cues from predators. (Figure 6-22)

acetylcholine (ACh) Neurotransmitter released by vertebrate motor neurons at the neuromuscular junction. It is also used in the CNS as an excitatory or modulatory neurotransmitter, and in the autonomic nervous system. In some invertebrates such as *Drosophila*, it is the major excitatory neurotransmitter in the CNS. (Figure 3-1; Table 3-2)

acetylcholine receptor (AChR) Receptor for the neurotransmitter acetylcholine. The nicotinic AChRs (nAChRs) are non-selective cation channels; they are the postsynaptic receptor at the vertebrate neuromuscular junction and function as excitatory receptors at some CNS synapses. The metabotropic AChRs (muscarinic AChRs or mAChRs) are G-protein-coupled receptors that play a modulatory role. (Figure 3-20 for nAChR)

acetylcholinesterase An enzyme enriched in the cholinergic synaptic cleft that degrades acetylcholine.

acquisition (of memory) The initial formation of a memory as a consequence of experience and learning.

action potential An elementary unit of nerve impulses that axons use to convey information across long distances. It is all-or-none, regenerative, and propagates unidirectionally in the axon. It is also called a spike. (Figure 2-18; Figure 2-19)

active electrical property A membrane property that is due to voltage-dependent changes in ion conductance. It can reduce or eliminate the attenuation of electrical signals across a distance that occurs due to passive electrical properties.

active transport Movement of a solute across a membrane against its electrochemical gradient via a transporter that uses external energy, such as ATP hydrolysis, light, or movement of another solute down its electrochemical gradient. (Figure 2-8)

active zone An electron-dense region of the presynaptic terminal that contains clusters of synaptic vesicles docked at the presynaptic membrane, ready for release. (Figure 3-3; Figure 3-10)

activity-dependent transcription The process by which neuronal activity regulates gene expression.

adaptation (in evolution) Genetic or phenotypic changes that render an individual and its progeny more likely to survive and reproduce in a particular environment.

adaptation (in sensory systems) The adjustment of the system's sensitivity according to the background level of sensory input.

adeno-associated virus (AAV) A DNA virus widely used to deliver transgenes into post-mitotic neurons. It has a capacity to include about 5 kb of foreign DNA. (Table 13-1)

adenylate cyclase A membrane-associated enzyme that synthesizes cyclic AMP (cAMP) from ATP. (Figure 3-33)

advanced sleep phase syndrome A disorder characterized by very early morning waking and an early evening sleep onset.

afferent An axon that projects from peripheral tissue to the CNS. It can also be generalized to describe an input axon to a particular neural center within the CNS.

agonist A molecule that mimics the action of an endogenous molecule such as a neurotransmitter.

agrin A protein secreted by motor neurons that induces aggregation of acetylcholine receptors in the muscle. (Figure 7-24)

AgRP neuron A neuron in the hypothalamic arcuate nucleus that releases the orexigenic peptides agouti-related protein (AgRP) and neuropeptide Y. (Figure 8-42)

All amacrine cell A type of amacrine cell that links rod bipolars to the pathways that process cone signals. (Figure 4-34)

AKAP (A kinase anchoring protein) An anchoring protein associated with protein kinase A.

all-or-none Having the property of being binary in occurrence. It applies to action potentials, which have the same amplitude and waveform regardless of the strength of the inducing stimulus as long as the stimulus is above threshold.

allele A specific version of a gene.

allelic exclusion A phenomenon in which mRNAs of a gene are transcribed exclusively from one chromosome of a homologous pair. *See also allele*.

allodynia A phenomenon whereby gentle touch or innocuous temperature causes pain when applied to inflamed or injured tissue.

allosteric agonist A molecule that facilitates binding of an endogenous ligand to its receptor. An allosteric agonist binds to a site on a receptor that is different from the site that binds the endogenous ligand.

Alzheimer's disease (AD) A neurodegenerative disorder prevalent in the aging population. It is defined by the combined presence of abundant amyloid plaques and neurofibrillary tangles in postmortem brains, with symptoms including gradual loss of memory, impaired cognitive and intellectual capabilities, and reduced ability to cope with daily life. (Figure 11-2)

amacrine cell An inhibitory neuron whose actions influence the signals that are transmitted from the bipolar cells to the retinal ganglion cells. (Figure 4-28)

AMPA receptor A glutamate-gated ion channel that conducts mostly Na⁺ and K⁺ and can be selectively activated by the drug AMPA (2-amino-3-hydroxy-5-methylisoxazol-4-propanoic acid). It is a heterotetramer containing two or more kinds of subunits (GluA1, GluA2, GluA3, and GluA4) encoded by four genes. (Figure 3-24; Figure 3-26)

amygdala An almond-shaped structure underneath the temporal lobe best known for its role in processing emotion-related information. (Figure 1-8; Figure 10-41)

amyloid plaque An extracellular deposit consisting primarily of aggregates of amyloid β protein. (Figure 11-2)

amyloid precursor protein (APP) A single-pass transmembrane protein from which the amyloid β protein is derived by proteolytic processing. (Figure 11–3)

amyloid β protein (A β) A major component of the amyloid plaques in Alzheimer's disease, it is a 39–43-amino-acid peptide with a strong tendency to form aggregates rich in β -pleated sheets. (Figure 11–4)

amyotrophic lateral sclerosis (ALS) A rapidly progressing motor neuron disease that is usually terminal within a few years after symptoms emerge. It is also known as Lou Gehrig's disease.

analog signaling Signaling that uses continuous values to represent information.

androgen A male sex hormone, such as testosterone and its derivatives.

androgen receptor A cytosolic protein that upon binding of an androgen (such as testosterone) translocates to the nucleus, where it acts as a transcription factor. (Figure 9–24)

anions Negatively charged ions such as Cl[−].

ankyrinG An intracellular scaffolding protein that is highly concentrated in the axon initial segment and nodes of Ranvier.

anosmic Unable to perceive odors.

antagonist A molecule that counters the action of an endogenous molecule. For example, by binding to nAChR in competition with ACh and inhibiting nAChR function, curare acts as an antagonist of ACh.

antagonistic muscles Muscles that perform opposite actions, such as an extensor and a flexor that control the same joint. (Figure 8–8)

antennal lobe The first olfactory processing center in the insect brain. (Figure 6–27)

anterior cingulate cortex (ACC) A neocortical area located near the midline of the frontal lobe. It has extensive connections with the hippocampus and is implicated in long-term memory storage.

anterior pituitary See **pituitary**.

anterograde From the cell body to the axon terminal.

anterograde tracer A molecule used to trace axonal connections. They are taken up primarily by neuronal cell bodies and dendrites and travel down the axons to label their projection sites. (Figure 13–27)

anterolateral column pathway An axonal pathway from the spinal cord to the brainstem, it consists of axons from lamina I dorsal horn projection neurons on the contralateral side of the spinal cord. It mainly relays pain, itch, and temperature signals to the brain. (Figure 6–70)

anteroventral periventricular nucleus (AVPV) A hypothalamic nucleus in the preoptic area that plays a pivotal role in regulating the female ovulatory cycle. (Figure 9–27)

antidromic spike An action potential that propagates from the axon terminal to the cell body in artificial situations in which experimenters electrically stimulate the axon or its terminal.

antiporter A coupled transporter that moves two or more solutes in opposite directions. Also called an exchanger. (Figure 2–10)

anxiety disorders A group of psychiatric disorders that includes generalized anxiety disorders (characterized by persistent worries about impending misfortunes), phobias and panic disorders (characterized by irrational fears), and obsessive-compulsive disorder.

AP5 (2-amino-5-phosphonovaleric acid) A widely used selective NMDA receptor antagonist.

apolipoprotein E (ApoE) A high-density lipoprotein in the brain involved in lipid transport and metabolism. A specific

polymorphic isoform ($\epsilon 4$) is a major risk factor for Alzheimer's disease. (Figure 11–9)

Arc A cytoskeletal protein present at the postsynaptic density that regulates trafficking of glutamate receptors. It is a product of the immediate early gene *Arc*.

archaerhodopsin A light-activated outward proton pump in archaea, it can be used to silence neuronal activity in a heterologous system by light. *See also optogenetics.* (Figure 13–45)

arcuate nucleus A ventromedial hypothalamic nucleus that regulates food intake and energy expenditure.

area X A basal ganglia structure in the songbird that is essential for song learning. (Figure 9–21)

aromatase An intracellular enzyme that converts testosterone to estradiol. (Figure 9–24)

ascending arousal system A neural system consisting of parallel projections from the brainstem and hypothalamus to the forebrain that are essential for maintaining wakefulness. It includes cholinergic projections from the tegmental nuclei, norepinephrine projections from the locus coeruleus, serotonin projections from the raphe nuclei, histamine projections from the tuberomammillary nucleus, and hypocretin projections from the lateral hypothalamus. (Figure 8–52)

association cortex Cortical areas that integrate information from multiple sensory areas and link sensory systems to motor output.

associative learning A type of learning involving the formation of an association between two events, such as the formation of an association between an unconditioned stimulus and a conditioned stimulus in classical conditioning or the formation of an association between a behavior and a reinforcer in operant conditioning.

associativity (of LTP) A property of long-term potentiation (LTP) whereby activation of a synapse that alone would be too weak to produce LTP can nonetheless lead to LTP if it coincides with the strong, LTP-inducing activation of a different synapse onto the same postsynaptic cell. (Figure 10–9)

astrocyte A glial cell present in the gray matter. It plays many roles including synaptic development and function. (Figure 1–9)

asymmetric cell division A cell division in which the two daughter cells are of different types from birth.

ataxia An abnormality in coordinated muscle contraction and movement.

attention The cognitive function in which a subset of sensory information is subjected to further processing at the expense of other information.

attractant A molecular cue that guides axons toward its source. (Figure 5–9)

auditory cortex The part of the cerebral cortex that first receives auditory sensory information. It is located in the temporal lobe. (Figure 1–23)

auditory fear conditioning A classical conditioning procedure in which aversive, fear-inducing stimuli, such as electric shocks, are paired with sound stimuli during training; animals will subsequently exhibit fear responses, such as freezing, in response to sound stimuli alone. It depends on the amygdala but not the hippocampus. Sound can be replaced with other sensory cues such as odor, and the learning procedure is generally called cued fear conditioning.

auditory nerve A bundle of axons from spiral ganglion neurons that transmits auditory information to the brainstem. It also contains efferents from the brainstem that synapse primarily onto outer hair cells. (Figure 6–49)

autism spectrum disorders (ASDs) Neurodevelopmental disorders characterized by deficits in communication and reciprocal social interactions. Patients also exhibit restricted interests and repetitive behaviors.

autocrine Of or related to a form of signaling in which a recipient cell receives a signal produced by itself.

autonomic nervous system The collected parts of the nervous system that regulate the function of internal organs, including the contraction of smooth and cardiac muscles and the activities of glands.

autosomal dominant Of a mutation, having a Mendelian inheritance pattern in which mutation of only one allele of a gene located on an autosome is sufficient to produce a phenotype. It can result from a toxic gain-of-function effect of the mutant allele or a loss-of-function effect due to an insufficient amount of the normal gene product being produced by the remaining wild-type allele. (Figure 11–34)

autosomal recessive Of a mutation, having a Mendelian inheritance pattern in which mutation of both alleles of a gene located on an autosome is required to produce a phenotype. It usually results from a loss-of-function effect of the mutation. (Figure 11–34)

autosome A non-sex chromosome.

axon A long, thin process of a neuron, it often extends far beyond the soma and propagates and transmits signals to other neurons or muscle at its presynaptic terminals. (Figure 1–9)

axon guidance molecules Extracellular cues and cell surface receptors that guide axons along their path towards the appropriate targets. (Figure 5–9)

axon myelination The process by which glial cells wrap their cytoplasmic extensions around axons to increase conduction velocity. (Figure 2–27)

A β fiber A heavily myelinated somatosensory axon. (Figure 6–63)

A β hypothesis The idea that an increase of amyloid β (A β) protein production or accumulation is a common cause of Alzheimer's disease.

A δ fiber A lightly myelinated somatosensory axon. (Figure 6–63)

bacterial artificial chromosome (BAC) A cloning vector (circular DNA molecule that can be grown in bacteria) that can accommodate hundreds of kilobases of foreign DNA. (Figure 13–12)

bacteriorhodopsin A light-driven proton pump in archaea. (Figure 12–20)

ball-and-chain A model of voltage-gated channel inactivation in which a cytoplasmic portion of the channel protein ('ball'), connected to the rest of the channel by a polypeptide chain, blocks the channel pore after the ion channel opens. (Figure 2–32)

barrel A discrete anatomical unit in layer 4 of the rodent primary somatosensory cortex that represents a whisker. The cortical region containing barrels for all whiskers is called barrel cortex. The corresponding discrete units in the brainstem and thalamus are called barrelettes and barreloids, respectively. (Figure 5–27)

barrel cortex See barrel.

basal ganglia A collection of nuclei underneath the cerebral cortex, it includes the striatum, globus pallidus, subthalamic nucleus, and substantia nigra and is essential for motor initiation and control, habit formation, and reward-based learning. (Figure 1–8; Figure 8–22)

basilar membrane An elastic membrane at the base of hair cells in the cochlea. (Figure 6–50)

basket cell A type of GABAergic neuron, it wraps its axon terminals around the cell bodies of pyramidal cells in the cerebral cortex or Purkinje cells in the cerebellar cortex. (Figure 1–15; Figure 3–46)

basolateral amygdala A brain region consisting of two subdivisions, the lateral amygdala and basal amygdala. It receives input from the thalamus, cortex, and hippocampus and sends output to the central amygdala and other brain regions. It is involved in regulating emotion-related behavior. (Figure 10–41)

battery An electrical element that maintains a constant voltage, or electrical potential difference, across its two terminals and that can thus serve as an energy source. (Figure 2–13)

BDNF (brain-derived neurotrophic factor) See neurotrophins and Trk receptors.

bed nucleus of stria terminalis (BNST) A sexually dimorphic brain region that receives direct input from accessory olfactory bulb mitral cells. Its diverse functions include regulation of male courtship behavior. (Figure 9–32)

benzodiazepines A class of drugs that act as allosteric agonists of GABA_A receptors. They are widely used to treat anxiety, pain, epilepsy, and sleep problems. (Figure 11–29)

biased random walk In chemotaxis, a strategy employed by bacteria to move towards an attractant source (or away from a repellent source). When swimming away from an attractant, bacteria exhibit frequent tumbles (reorientation); when swimming towards an attractant, they tumble less frequently. It is also employed by *C. elegans* for chemotaxis. (Figure 12–15)

bilaterians Animals that are bilaterally symmetrical and that have three germ layers. They include all vertebrates and most invertebrate species alive today. (Figure 12–2)

binary expression Expression of a transgene using a strategy in which the regulatory elements (which determine where the transgene is expressed) and the coding sequence are separated into two transgenes. (Figure 13–13)

binocular vision A form of vision involving integration of inputs from the two eyes that carry information about the same visual field location. It is important for depth perception.

binomial distribution A discrete probability distribution that describes the frequency (f) that k events occur in n independent trials, given the probability that an event occurs in each trial is p . $f(k; n, p) = [n!/(k!(n - k)!)] p^k (1 - p)^{n - k}$. (Box 3–1)

biomarker A biological characteristic that is objectively measured and evaluated as an indicator of a normal biological process, a pathogenic process, or a response to a therapeutic intervention. (Figure 11–10)

bipolar Having two processes leaving the cell body.

bipolar cell (in retina) An excitatory neuron that transmits information from the photoreceptors to the retinal ganglion cells and amacrine cells. (Figure 4–25; Figure 4–28)

bipolar disorder A mood disorder in which patients alternate between manic phases (characterized by feelings of grandiosity and tirelessness) and depressive phases (characterized by feelings of sadness, emptiness, and worthlessness).

bitter A taste modality that functions primarily to warn the animal of potential toxic chemicals. It is usually aversive.

blastula The product of cleavage, it is an early-stage embryo consisting of a hollow ball of thousands of cells. (Figure 7–2)

blood-brain barrier (BBB) Derived from endothelial cell tight junctions in the blood vessels of the brain, it prevents the exchange of many substances between the blood and brain tissues.

blue-ON bipolar cell An ON bipolar cell that selectively connects with S-cones. It is activated by short-wavelength light and inhibited by longer-wavelength light. (Figure 4–33)

bone morphogenetic proteins (BMPs) A family of secreted proteins that act as morphogens to pattern embryonic tissues, such as the tissues along the anterior-posterior axis of the telencephalon and the dorsal-ventral axis of the spinal cord.

border cell A cell in the entorhinal cortex that fires when an animal is at a specific edge of an arena.

Boss (Brute of sevenless) Originally identified from a mutation in *Drosophila* that lacks photoreceptor R7, it is a gene that acts cell-nonautonomously in R8 to specify R7 fate. It encodes a transmembrane ligand for the Sevenless receptor tyrosine kinase. (Figure 5–36)

botulinum toxins A family of proteases produced by *Clostridium botulinum*. Different isoforms cleave synaptobrevin, syntaxin, or SNAP-25 at distinct sites.

bradykinin A peptide released during inflammation, it binds to specific G-protein-coupled receptors on the peripheral terminals of nociceptive neurons. (Figure 6–71)

brain The rostral part of the central nervous system located in the head. It is the command center for nervous system functions. (Figure 1–8)

brain slice A fresh section of brain tissue (usually about a few hundred micrometers thick) that largely preserves the three-dimensional architecture for physiological studies of neuronal and local circuit properties *in vitro*.

brainstem A structure that comprises the midbrain, pons, and medulla. (Figure 1–8)

Broca's area An area in the left frontal lobe involved in language production. Patients with lesions in this area have difficulty speaking. (Figure 1–23)

α -bungarotoxin A snake toxin from the venom of *Bungarus* that is a competitive inhibitor of the nicotinic acetylcholine receptor.

C fiber An unmyelinated somatosensory axon. (Figure 6–63)

Ca²⁺ indicator A molecule whose optical properties are dependent on intracellular Ca²⁺ concentration. Ca²⁺ indicators are used as optical sensors of neuronal activity. (Figure 13–38)

cable properties See **passive electrical properties**.

cadherin A Ca²⁺-dependent homophilic cell-adhesion protein.

callosal projection neuron (CPN) A cortical neuron that extends its axon across the corpus callosum to the contralateral cortex. (Figure 7–10)

calmodulin (CaM) A Ca²⁺-binding protein that transduces Ca²⁺ signals to many effectors. (Figure 3–34)

CaM kinase II (CaMKII) A Ca²⁺/calmodulin-dependent serine/threonine kinase that is highly enriched in the postsynaptic densities of excitatory synapses and that regulates synaptic plasticity, such as long-term potentiation. (Figure 3–34; Figure 10–12)

Cambrian A geological period between 542 and 488 million years ago when major phyla within the animal kingdom diversified, as evidenced by an abundance of corresponding fossils. (Figure 12–2)

cAMP-dependent protein kinase A serine/threonine kinase composed of two regulatory and two catalytic subunits. Binding of cAMP to the regulatory subunits leads to dissociation of the catalytic subunits, which can then phosphorylate their substrates. It is also called A kinase, protein kinase A, or PKA. (Figure 3–33)

capacitance (C) The ability of a capacitor to store charge; defined as $C = Q/V$, where Q is the electric charge stored when the voltage across the capacitor is V .

capacitor An electrical element consisting of two parallel conductors separated by a layer of insulator. It is a charge-storing device. (Figure 2–13)

capping The process by which a modified guanosine nucleotide is added to the 5' end of the RNA. (Figure 2–2)

Capricious A *Drosophila* transmembrane protein that contains extracellular leucine-rich repeats and that instructs wiring specificity of axons and dendrites. (Figure 5–39; Figure 7–41)

cardiac muscle Muscle that controls heartbeat.

Cas9 A key protein in the type II CRISPR system, it is an RNA-guided endonuclease containing two separate nuclease domains that generate a double-strand break in DNA complementary to a bound RNA. It is used by bacteria for adaptive immunity and used experimentally for genome engineering. See also **CRISPR** and **guide RNA**. (Figure 13–8)

caspase-3 A key protease that triggers apoptosis, a form of programmed cell death.

castrated male A male from which the testes have been removed.

catecholamines A class of chemicals that includes the neurotransmitters dopamine, norepinephrine, and epinephrine. (Figure 11–20)

cations Positively charged ions such as K⁺ and Na⁺.

CB1 A G-protein-coupled receptor originally identified as the receptor for cannabinoids from the marijuana plant. It serves as a receptor for endocannabinoids under physiological conditions.

CCK (cholecystokinin) A neuropeptide produced in the small intestine in response to a rise in fatty acid concentration. It acts as a satiety signal to inhibit eating. (Figure 8–43)

cDNA library A collection of cloned cDNAs, or complementary DNAs, synthesized from mRNA templates derived from a specific tissue.

cell adhesion molecule Cell-surface proteins that bind to their partners in opposing cells or extracellular matrix to facilitate cell-cell or cell-matrix adhesion.

cell assembly A group of neurons whose firing patterns collectively encode information, such as locations of an animal in an environment.

cell-attached patch recording (cell-attached recording) A variant of the patch clamp recording method in which the patch pipette forms a high resistance (gigaohm) seal with the plasma membrane of an intact cell, allowing measurement of ion flow through a small number of channels or a single channel in the patch of membrane underneath the electrode. (Figure 2–30; Figure 13–37)

cell autonomous Of a gene, acting in the cell that produces the gene product.

cell fate The outcome of the developmental decision as to what type of cell it is.

cell lineage The developmental history of a cell, including the identities of all progenitors from which a cell was derived.

cell nonautonomous Of a gene, acting in a cell that does not produce the gene product.

cell theory The idea that all living organisms are composed of cells as basic units.

cell-replacement therapy A treatment strategy in which cells differentiated *in vitro* are transplanted into the body to replace dying cells, such as dopamine neurons in Parkinson's disease.

cell-surface receptor A membrane protein that binds to extracellular ligands and subsequently sends a signal into the recipient cell. (Figure 3–38)

center-surround (receptive field) A property of a visual system neuron's receptive field in which light in the receptive field center and light just outside of the receptive field center are antagonistic. (Figure 4–24). The concept has also been extended beyond the visual system.

central amygdala The output nucleus of the amygdala complex, it receives input from the basolateral amygdala and sends GABAergic output to brainstem nuclei, the autonomic nervous system, the hypothalamus, and neuromodulatory systems to regulate emotion-related behavior. (Figure 10–41; Figure 10–43)

central dogma The principle that genetic information flows from DNA to RNA to protein.

central pattern generator (CPG) A CNS circuit that is capable of producing rhythmic output for coordinated contraction of different muscles without sensory feedback. (Figure 8–12; Figure 8–13)

cerebellum A structure located dorsal to the pons and medulla, it plays an important role in motor coordination, motor learning, and cognitive functions. (Figure 1–8; Figure 8–20)

cerebral cortex The outer layer of the neural tissue in the rostral part of the mammalian brain. It is associated with higher functions including sensory perception, cognition, and control of voluntary movement. (Figure 1–8; Figure 1–23)

CGRP (calcitonin gene-related peptide) A peptide that promotes inflammation when released by the peripheral terminals of sensory neurons. (Figure 6–71)

chandelier cell A type of GABAergic neuron in the cerebral cortex that forms synapses onto the initial axon segments of cortical pyramidal cells. (Figure 3–46)

channel A transmembrane protein or protein complex that forms an aqueous pore that allows specific solutes to pass through directly when it is open. (Figure 2–8)

channelopathies Diseases caused by mutations in ion channels.

channelrhodopsin A member of a class of light-activated cation channels in single-cell green algae used for chemotaxis. (Figure 12–21). *See also channelrhodopsin-2 (ChR2).*

channelrhodopsin-2 (ChR2) A light-activated cation channel from a single-celled green alga, it is widely used to activate neurons in heterologous systems by light. *See also optogenetics.* (Figure 12–21; Figure 13–45)

characteristic frequency The sound frequency to which a given cell in the auditory system is most sensitive.

Charcot-Marie-Tooth (CMT) disease A PNS demyelinating disease characterized by progressive deficits in sensation or movement that preferentially affects neurons with longer axons. Genetic alterations in ~30 genes have been identified as causes of CMT disease.

chemical gradient Concentration difference of the solute on the two sides of the membrane, which contributes to the direction and magnitude of solute movement across the membrane. If the solute is not charged, the chemical gradient alone determines the movement direction: from higher concentration to lower concentration. (Figure 2–9)

chemical synapse A specialized junction between two neurons or between a neuron and a muscle where communication between cells is mediated by the release of neurotransmitters. It comprises a presynaptic terminal and a postsynaptic specialization separated by a synaptic cleft. (Figure 1–14; Figure 3–3)

chemoaffinity hypothesis Proposed by Roger Sperry, it states that growing axons use cell-surface proteins to find their path and connect with appropriate synaptic partners.

chemogenetics An approach that uses chemicals to activate or silence neurons that express receptors specifically engineered to be sensitive to those chemicals.

chemotaxis Movement toward or away from a chemical source.

chlorpromazine A first-generation antipsychotic drug, it is an antagonist of the D₂ dopamine receptor.

chordates Animals with a notochord. (Figure 12–2)

chromatic aberration The phenomenon in which a lens refracts different wavelengths of light differently and thus cannot focus all wavelengths with equal sharpness.

chromophore The light-absorbing portion of a molecule.

ciliary type A type of photoreceptor in which opsins are packed into the primary cilium-derived outer segment. (Figure 12–22)

circadian pacemaker neuron A neuron whose activity in isolation oscillates in a circadian fashion (i.e. with a circa 24 hour period).

circadian rhythms Self-sustained oscillations in an organism's behavior, physiology, and biochemistry, with a period close to 24 hours.

cis-regulatory elements DNA elements, such as transcriptional enhancers, repressors, and insulators, that regulate the expression of genes on the same chromosome.

Cl⁻ channels An ion channel family that allows selective passage of Cl⁻.

clade A branch in the tree of life, consisting of an ancestor species plus all of its descendant species.

cladistic analysis The study of emergence and change of traits of organisms in the context of their phylogenetic relationships.

classical conditioning A form of learning in which repeated pairing of a conditioned stimulus (CS) with an unconditioned stimulus (US) causes a subject to exhibit a novel conditioned response (CR) to the CS. Prior to learning, the CS does not produce the CR, and after learning the CR resembles the unconditioned response (UR), which is elicited without conditioning by the US. It is also called Pavlovian conditioning.

cleavage A series of rapid cell divisions in early embryogenesis that convert a single large zygote cell into thousands of smaller cells. (Figure 7–2)

climbing fiber An axon that climbs dendritic trees of individual Purkinje cells. It originates from a neuron in the inferior olive. (Figure 8–20)

Clock A gene identified from a forward genetic screen in mice for mutations that produce circadian rhythm phenotypes. It encodes a transcriptional activator, CLOCK, that positively regulates the expression of genes whose products feedback to negatively regulate CLOCK function. Its fly homolog serves a similar function. (Figure 8–45)

clonal analysis A method of analyzing the relationships of cells by birth. It involves labeling a progenitor in a way that all its progeny are also labeled.

closed-loop Of a system, having input to the system that is modified by the output of the system. In the context of a behavioral paradigm, having environmental stimuli that induce a behavior in an animal to also change in response to the animal's behavior.

cnidarians Animals that are radially symmetrical, such as hydra, jellyfish, and corals. (Figure 12–2)

CNS (central nervous system) The brain and spinal cord in vertebrates; the brain and nerve cord in some invertebrates.

cochlea A coiled structure in the inner ear that contains fluid-filled chambers and the organ of Corti. (Figure 6–45)

cochlear nuclei Brainstem nuclei where the auditory nerve terminates, consisting of the dorsal and ventral cochlear nuclei. (Figure 6–54)

coding space A theoretical space used to describe the activity of a neuronal population. The firing rate of each neuron in the population constitutes one dimension/axis in this space, and the activity state of the entire population is represented as a point in this space. (Figure 6–30)

cognitive learning A theory of learning with the emphasis of learning as an acquisition of new knowledge rather than simply a modification of behavior.

coincidence detector (in auditory system) A cell that is maximally activated by simultaneous auditory signals from the left ear and the right ear.

coincidence detector (in synaptic transmission) A receptor that opens only in response to concurrent neurotransmitter binding *and* postsynaptic depolarization, such as the NMDA receptor.

collateral An axon branch.

color-opponent RGC A retinal ganglion cell that differentiates signals from cones with distinct spectral sensitivities. The blue-yellow opponent RGC (in all mammals) differentiates short- and longer-wavelength light signals; the green-red opponent RGC (in trichromatic primates) differentiates two long-wavelength light signals. (Figure 4–33)

Comm (Commissureless) A *Drosophila* protein that acts in the secretory pathway to down-regulate cell-surface expression of Robo. (Figure 7–12)

commissural neuron A neuron that projects its axon to the contralateral side of the body. In the vertebrate spinal cord, midline crossing of commissural neurons has been used as a model to study axon guidance.

compact myelin Closely packed layers of glial plasma membranes wrapped around axons.

complex cell A functionally defined primary visual cortex neuronal type present in all layers except layer 4. It has no mutually antagonistic ON and OFF regions and is excited by light bars on a dark background or dark bars on an illuminated background. The stimulus bars must be in a specific orientation but can fall on any part of the receptive field. (Figure 4–40)

conditional knockout The process of disrupting a gene in a specific spatiotemporal pattern or an animal in which a gene has been disrupted in a specific spatiotemporal pattern. The most common strategy for generating conditional knockouts in mice uses Cre/loxP-based recombination. It usually involves inserting a pair of loxP elements in introns that flank (an) essential exon(s) of a gene of interest. The gene of interest is only disrupted in cells in which Cre is active or in cells derived from a progenitor in which Cre was active. (Figure 13–7)

conditioned response (CR) *See classical conditioning.*

conditioned stimulus (CS) *See classical conditioning.*

conductance (g) The degree to which an object or substance passes electricity, it is the inverse of resistance: $g = 1/R$.

conductor An object or substance that passes electric current.

cone A cone-shaped photoreceptor in the vertebrate retina, it contributes to high acuity, motion, and color vision. (Figure 4–2)

confocal fluorescence microscopy (confocal microscopy) A fluorescence microscopy technique in which a detector pinhole is used to collect fluorescence emissions originating only from a focal spot restricted in all three dimensions. By scanning the laser across a plane to record fluorescence emissions from many focal spots, it can produce a thin optical section of whole-mount tissue or a thick tissue section. (Figure 13–19)

connectome A representation of the complete set of synaptic connections among a group of neurons of interest. (Figure 7–28; Figure 13–2)

connexin A protein component of gap junctions in vertebrates. (Figure 3–48)

ω -conotoxin A small peptide from marine snails that specifically blocks presynaptic voltage-gated Ca^{2+} channels and thus inhibits neurotransmitter release.

consolidation (of memory) A step in the process of memory formation that occurs between acquisition and storage, during which a newly acquired memory is solidified.

contextual fear conditioning A learning procedure in which a rodent is subjected to aversive, fear-inducing stimuli, such as electric shocks, in a specific environment (i.e. context). When placed in the same context subsequently, the animal will exhibit a fear response, such as freezing. It depends on both the hippocampus and amygdala.

continuous map A type of neural map in which input field neurons that neighbor each other connect with target field neurons that neighbor each other, as exemplified by the relationship between the retina and the tectum. (Figure 7–33)

contralateral Of the other side of the midline. For example, a contralateral axonal projection is an axon that crosses the midline and terminates on the side of the nervous system opposite the soma.

convergent evolution The independent evolution of similar features in animals from different clades of the phylogenetic tree.

cooperativity (of LTP) A property of long-term potentiation (LTP) whereby LTP can be induced at a synapse if the presynaptic cell releases neurotransmitter while the postsynaptic cell is in a depolarized state, even if transmitter release from the presynaptic cell alone (in the absence of postsynaptic depolarization) is insufficient to induce LTP. (Figure 10–9)

copy number variations (CNVs) Deletions or duplications of chromosome segments that can vary in length from 500 base pairs to several megabases and may contain coding sequences that range from a small fraction of a single gene to many genes.

coronal section A section plane that is perpendicular to the rostral-caudal axis; also called frontal or transverse sections.

corpus callosum A structure composed of axon bundles that link the two cerebral hemispheres. (Figure 7–10)

cortical amygdala Part of the olfactory amygdala complex that receives direct mitral cell input. (Figure 6–19)

corticothalamic projection neuron (CTPN) A cortical neuron, found in layer 6, that projects its axon to the thalamus. (Figure 7–10)

cotransporter A transporter that uses the movement of one solute down its electrochemical gradient to drive the transport of another solute up its concentration gradient.

courtship conditioning The process by which a normal *Drosophila* male learns to reduce his attempts at courtship following repeated rejections by mated females.

CRE (cAMP-response element) *See CREB.*

Cre recombinase A bacteriophage-derived enzyme that catalyzes recombination between two sequence-specific DNA elements called *loxP* sites. (Figure 13–7; Figure 13–13)

CREB (cAMP-response element binding protein) A transcription factor that binds the cAMP response element (CRE), a DNA *cis*-regulatory element in the promoter regions of target genes. It is a substrate for several kinases, including cAMP-dependent protein kinase. (Figure 3–41)

CreER A fusion of the Cre recombinase with the portion of the estrogen receptor responsible for ligand-dependent nuclear trafficking. CreER enters the nucleus only in the presence of tamoxifen, an estrogen analog, and therefore catalyzes recombination in a tamoxifen-dependent manner.

Creutzfeldt-Jakob disease (CJD) See prion diseases.

CRISPR A clustered regularly interspaced short palindromic repeat, it is a genomic locus in some bacteria and archaea that contains repeated DNA elements derived from the genomes of invading pathogens. It is used by bacteria for adaptive immunity, and components of the CRISPR system are used experimentally for genome engineering. *See also Cas9* and **guide RNA**. (Figure 13–8)

critical period A sensitive period during development when experience plays an important role in shaping the wiring properties of the brain.

cryptochrome A protein that acts as a negative regulator of circadian gene expression in mice but as a light sensor for entrainment of circadian rhythms in flies. (Figure 8–46)

curare A plant toxin that is a competitive inhibitor of the nicotinic acetylcholine receptor.

cyclic AMP (cAMP) An intracellular second messenger synthesized from ATP by adenylate cyclase. (Figure 3–33)

cyclic GMP (cGMP) A cyclic nucleotide derived from GTP, one of its functions is to activate the cyclic nucleotide-gated cation channel in vertebrate photoreceptors in the absence of light. (Figure 4–10)

cyclic nucleotide-gated (CNG) channels Non-selective cation channels whose gating is regulated by the concentration of a specific intracellular cyclic nucleotide. (Figure 2–34)

cytoarchitectonics An approach to describe tissue organization using differences in cell density and distribution. (Figure 13–18)

DCC/Unc40 Homologous proteins in vertebrates (DCC, for deleted in colon cancer) and *C. elegans* (Unc40) that act as receptors for netrin/Unc6 and mediate attraction in the absence of Unc5. The *Drosophila* homolog is Frazzled. (Figure 5–10)

de novo mutation A mutation produced in the parental germ line that is present in all of the offspring's cells.

deep brain stimulation (DBS) A treatment strategy used for a number of neurological and psychiatric conditions in which electrodes are surgically implanted to stimulate neurons and axons in specific brain nuclei.

deep cerebellar nuclei The output nuclei of the cerebellum, they receive input from Purkinje cell axons as well as from the collaterals of the mossy and climbing fibers. (Figure 8–20)

delay line A thin axon fiber that carries auditory signals to target neurons at different locations along the axon with different time delays. (Figure 6–55)

Delta A transmembrane ligand that activates Notch. (Figure 7–7)

demyelinating disease A disease in which damage to the myelin sheath decreases the axonal membrane resistance between nodes of Ranvier, leading to disruption of ion channel

organization in the nodal region and reduction in action potential conduction speed.

dendrites Thick, bushy processes of a neuron that receive and integrate synaptic inputs from other neurons. (Figure 1–9)

dendritic spine A small protrusion on a dendrite of certain neurons that receives synaptic input from a partner neuron. The thin spine neck creates chemical and electrical compartments for each spine such that it can be modulated independently from neighboring spines. (Figure 1–9; Figure 3–45)

dendritic tiling A phenomenon in which the dendrites of certain neuronal types collectively cover the entire field exactly once so they can sample the field without redundancy. For example, certain types of retinal neurons collectively cover the retina exactly once. Certain types of somatosensory neurons cover the body surface exactly once. (Figure 4–29)

dendrodendritic synapse A synapse between dendritic processes of two neurons. The reciprocal synapses between the olfactory bulb granule cell dendrites and mitral cell secondary dendrites were the first discovered examples. (Figure 6–18)

dense-core vesicle An intracellular vesicle containing neuropeptides, they are larger and more electron-dense than synaptic vesicles, which contain small molecule neurotransmitters.

dentate gyrus The input part of the hippocampus, consisting of granule cells and their dendrites, which receive input from the entorhinal cortex. (Figure 10–6)

depolarization A change in the electrical potential inside the cell toward a less negative value.

depressing synapse A synapse at which successive presynaptic action potentials trigger progressively smaller postsynaptic responses. (Figure 3–15)

deuterostomes Animals in which the anus appears before the mouth during development. They include all vertebrates. *See also protostomes*. (Figure 12–2)

developmental axon degeneration The process by which axons are fragmented into pieces that are subsequently engulfed by surrounding glia during normal development.

diacylglycerol (DAG) A lipid second messenger that binds to and activates protein kinase C (PKC). (Figure 3–34)

diffusion tensor imaging (DTI) A magnetic resonance imaging technique that allows noninvasive imaging of axon bundles in the white matter based on the direction of water diffusion in a given volume. (Figure 13–26)

digital signaling Signaling that uses discrete values (0s and 1s) to represent information.

direct pathway (in basal ganglia) An axonal projection from a subset of spiny projection neurons that link the striatum directly to the basal ganglia output nuclei, GPi and SNr. (Figure 8–22)

direction-selective retinal ganglion cell (DSGC) A retinal ganglion cell whose firing pattern is influenced by the direction of motion of a stimulus. (Figure 4–30)

discrete map A type of neural map in which input or target neurons or their processes are spatially organized into discrete units (such as glomeruli or layers) representing different qualities (such as cell types). (Figure 7–33)

disinhibition The reduction of the inhibitory output of an inhibitory neuron. (Figure 1–21)

dizygotic twins Non-identical (fraternal) twins who share only 50% of their genes, because they originated from two independent eggs fertilized by two independent sperm.

DNA (deoxyribonucleic acid) Long double-stranded chains of nucleotides. The nucleotides consist of the sugar deoxyribose, a phosphate group, and one of four nitrogenous bases: adenine (A), cytosine (C), guanine (G), or thymidine (T).

DNA microarray A solid substrate containing up to millions of immobilized spots of different oligonucleotides or gene-specific probes. Labeled nucleic acid samples, such as mRNAs extracted from a specific tissue or genomic DNA from an individual, can be hybridized to a DNA microarray to quantify the abundance of different species of nucleic acid molecules in samples. It can be used to determine gene expression patterns or profiles of single-nucleotide and copy number polymorphisms. (Figure 13–16)

DNA shuffling A process by which part or all of the protein-coding sequence of one gene is fused with that of another gene, usually following chromosomal duplication or translocation. The specific type of DNA shuffling that occurs when translocational breakpoints are within introns of two genes is called exon shuffling. (Figure 12–6)

L-dopa The intermediate metabolite between tyrosine and dopamine in the catecholamine biosynthetic pathway. (Figure 11–20)

dopamine A monoamine neuromodulator derived from the amino acid tyrosine. (Figure 11–20; Table 3–2)

Doppler effect A phenomenon whereby the sound frequency detected by an observer increases if the sound-emitting object moves toward the observer and decreases if the sound-emitting object moves away from the observer.

dorsal column pathway An axonal pathway from the spinal cord to the brainstem, it consists of ascending branches of proprioceptive neurons and A β -LTMRs, as well as axons of some dorsal horn projection neurons. (Figure 6–70)

dorsal cortex The evolutionary precursor to the mammalian neocortex in reptiles. It consists of three thin layers (as opposed to the six-layered structure of the mammalian neocortex).

dorsal horn The dorsal part of the spinal gray matter devoted to processing somatosensory information. (Figure 6–70)

dorsal horn projection neuron A neuron located in the dorsal horn of the spinal cord that projects its axon to the brainstem to relay touch signals. (Figure 6–70)

dorsal root The place where somatosensory axons enter the spinal cord. (Figure 8–6)

dorsal root ganglia (DRG) Clusters of somatosensory neurons located along an axis parallel to the spinal cord used for sensation of the body (as opposed to the face). (Figure 6–63)

dorsal stream A visual processing pathway from primary visual cortex to the parietal cortex. It is responsible for analyzing motion and depth; the ‘where’ stream. (Figure 4–48)

dorsal-ventral Of a body axis, from back to belly.

Doublesex (Dsx) A *Drosophila* gene that encodes sex-specific transcription factors produced by sex-specific alternative splicing. The Dsx isoform determines sex-specific somatic structures and also regulates sexual behavior. (Figure 9–4)

Down syndrome A syndrome caused by the presence of an extra copy of Chromosome 21. It is the most common form of intellectual disability with an established genetic etiology.

doxycycline (Dox) A tetracycline analog that readily diffuses across cell membranes and the blood–brain barrier. It is widely used for temporal regulation of gene expression through the tTA/rTA/TRE system. (Figure 13–13)

driver transgene In binary expression, it is the transgene that expresses a transcription factor or a recombinase under the

control of a tissue-specific or temporally regulated promoter. (Figure 13–13)

driving force The force that pushes an ion into or out of a cell, it equals the difference between the membrane potential of the cell and the equilibrium potential of the ion.

drug addiction Compulsive drug use that persists despite long-term negative consequences. It is often associated with loss of self-control and propensity to relapse.

Dscam (Down syndrome cell adhesion molecule) Encoded by a gene on human chromosome 21, which is trisomic in Down syndrome, it is an evolutionary conserved protein that, in insects, exhibits extraordinary molecular diversity due to alternative splicing. (Figure 7–20)

dTRPA1 A *Drosophila* TRP channel that is activated by high temperature. (Figure 13–43)

dye-coupling The diffusion of a small-molecule dye from one cell to another through gap junctions. It is used as a criterion to identify the presence of gap junctions between two cells.

dynamic range In sensory systems, the ratio between the largest and smallest values of a given dimension of sensory stimuli that can be detected and distinguished.

dynamical state A point in a coding space, representing the status of a dynamical system at a given time. *See also coding space.* (Figure 8–28)

dynamical system A physical system whose future state is a function of its current state, its input, and possibly some noise. It can be represented as time-dependent change of neural states in a coding space. *See also coding space.* (Figure 8–28)

dynein A minus-end-directed, microtubule-based motor protein. (Figure 2–6)

eardrum A membrane at the intersection of the mammalian outer ear and middle ear whose vibrations are transmitted by the bones in the middle ear to the cochlea in the inner ear. (Figure 6–45)

echolocation The ability of certain species to use echoes of their own ultrasonic sound pulses to locate objects.

ectoderm The outer germ layer that gives rise to the skin and nervous system. (Figure 7–2)

efferent An axon that projects from the CNS to peripheral targets. It can also be generalized to describe an output axon from a particular neural center within the CNS.

efficacy of synaptic transmission (synaptic efficacy) The strength of a synaptic connection, it is usually measured by the mean magnitude of the postsynaptic response to a defined presynaptic stimulus.

E-I balance The relative strength of synaptic excitation versus synaptic inhibition.

electrical circuit Connected electrical elements that contain at least one closed current path.

electrical gradient Electrical potential difference between the two sides of the membrane, which contributes to the direction and magnitude of movement of a charged solute across the membrane. It promotes the movement of a charged solute toward the side with the opposite charge. (Figure 2–9)

electrical synapse A cell–cell junction enriched in gap junction channels. It transmits (usually bidirectionally) both depolarizing and hyperpolarizing signals between the two cells. *See also gap junction.* (Figure 1–14)

electrochemical gradient A combination of chemical and electrical gradients, which determines the direction

and magnitude of movement of a charged solute across the membrane. (Figure 2–9)

electroencephalography (EEG) A method for recording the electrical potential differences between surface electrodes placed on specific locations of the scalp. It reports the collective electrical activities of many cortical neurons underneath the surface electrodes. (Figure 8–51; Figure 11–47)

electromotility A property of the cochlear outer hair cells whereby hyperpolarization causes the cells to lengthen, and depolarization causes them to shorten, along their long axis. (Figure 6–52)

electron microscopy A microscopic technique that uses beams of electrons to create an image of a specimen. It has much higher resolution than light microscopy and can resolve structures that are separated by a nanometer or less. *See also transmission electron microscopy and scanning electron microscopy.*

electroporation A procedure in which DNA containing a transgene is introduced into cells by applying electrical current to facilitate the transfer of negatively charged DNA molecules into the cells. In animals, this can be achieved by placing a micropipette containing the DNA near the cells of interest and applying electrical current.

embryonic stem (ES) cells Pluripotent cells derived from early embryos that can be propagated indefinitely *in vitro* and that can give rise to all cell types of an embryo *in vivo*. (Figure 11–23)

end-plate current The current that crosses a muscle cell membrane in response to release of acetylcholine from a presynaptic motor neuron.

end-plate potential (EPP) Depolarization produced in a postsynaptic muscle cell by acetylcholine released from a presynaptic motor neuron in response to an action potential. (Figure 3–1)

endocannabinoids Endogenous cannabinoids, which are lipophilic molecules such as anandamide and 2-arachidonylglycerol. They can be produced in response to a rise of intracellular Ca^{2+} concentration in certain postsynaptic neurons and diffuse across the synapse to affect presynaptic neurotransmitter release by binding to the CB1 G-protein-coupled receptor.

endocrine Of or related to a form of signaling in which a recipient cell receives a signal produced by a remote source and delivered through systemic circulation.

endocrine system A system consisting of glands that release hormones into the bloodstream, so that those hormones can circulate throughout the body.

endocytosis The process by which cells retrieve, via budding of intracellular vesicles from the plasma membrane, fluid and proteins from the extracellular space and transmembrane proteins from the cell's plasma membrane. (Figure 2–2)

endoderm The inner germ layer that gives rise to a variety of tissues such as the liver, the inner linings of the gut, and the respiratory tract. (Figure 7–2)

endoplasmic reticulum (ER) A network of membrane-enclosed compartments in eukaryotic cells where secreted and transmembrane proteins are made and into which secreted and transmembrane proteins are translocated. It also serves as a store for intracellular Ca^{2+} . (Figure 2–2)

endosome A membrane-enclosed organelle produced by endocytosis. It carries newly internalized extracellular materials and transmembrane proteins. (Figure 2–2)

engram Physical substrate for memory, it is also called memory trace.

enteric nervous system A division of the autonomic nervous system that is associated with the gastrointestinal tract and that regulates digestion rather independently of the rest of the autonomic nervous system.

entorhinal cortex The part of the temporal cortex overlying the hippocampus. It provides major input to and receives output from the hippocampus. It plays a major role in representing spatial information. (Figure 10–6)

entrainment The process by which a stimulus, such as light, resets the phase of the circadian clock.

Eph receptors Receptor tyrosine kinases that bind ephrins with their extracellular domains. Two Eph receptor subtypes, the EphA and EphB receptors, typically bind ephrin-As and ephrin-Bs, respectively, but this specificity is not absolute. They can also serve as ligands during reverse signaling. (Figure 5–7; Figure 5–12)

ephrins Cell-surface proteins that usually act as ligands for Eph receptors to mediate repulsion during axon guidance. The ephrin family consists of two subfamilies: ephrin-As are attached to the extracellular face of the plasma membrane by GPI, and ephrin-Bs are transmembrane proteins. They can also serve as receptors during reverse signaling. (Figure 5–7; Figure 5–12)

epigenetic modifications Molecular modifications to DNA and chromatin, such as DNA methylation and various forms of post-translational modification of histones. They do not modify the DNA sequence but can alter gene expression.

epilepsy A medical condition characterized by recurrent seizures. *See also seizure.*

epinephrine A hormone produced primarily by chromaffin cells in the adrenal gland that mediates systemic responses to extreme conditions, such as the systemic response associated with fight, fight, and flight. It also acts as a modulatory neurotransmitter in a small group of neurons in the brainstem. (Figure 11–20)

epithelial Na^+ channel (ENaC) A member of a class of Na^+ channels involved in Na^+ reabsorption by epithelial cells, it is also essential in mammals for the taste of low concentrations of salts. Its invertebrate homologs participate in mechanotransduction. (Figure 6–41)

EPSC (excitatory postsynaptic current) An inward current produced by binding of an excitatory neurotransmitter to its receptor. (Figure 3–23)

EPSP (excitatory postsynaptic potential) A transient depolarization of a postsynaptic cell associated with an excitatory postsynaptic current (EPSC). (Figure 3–23)

equilibrium potential The membrane potential at which there is no net flow of an ion across the membrane, because the electrical and chemical forces are equal in magnitude but opposite in direction.

estradiol A steroid hormone produced by the ovaries of sexually mature females. It can also be produced outside the ovaries by the actions of aromatase on testosterone. (Figure 9–24)

estrogen A female sex hormone, such as estradiol.

estrogen receptor A cytosolic protein that upon binding of an estrogen (such as estradiol) translocates to the nucleus, where it acts as a transcription factor. (Figure 9–24)

eukaryote Organism made of cell(s) with a nuclear membrane that separates the genetic material from the rest of the cellular components.

eumetazoan A taxon that includes cnidarians, bilaterians, and the most recent common ancestor of cnidarians and bilaterians. (Figure 12–2)

exchanger *See antiporter.*

excised patch A patch clamp configuration in which the membrane patch underneath the electrode is excised from the cell and placed in a defined medium. It is often used to study the biophysical and biochemical properties of the ion channel(s) in the membrane patch. (Figure 13–37)

excitability A property of a neuron that defines how readily it fires action potentials.

excitable cell A cell that produces action potentials, such as a neuron or a muscle cell. It can also refer to any cell that uses electrical signaling to receive, integrate, propagate, and transmit information.

excitation-contraction coupling A process by which action potentials in muscle cells lead to muscle contraction. It involves actin/myosin-mediated contraction triggered by a rise of intracellular Ca^{2+} concentration. (Figure 8–5)

excitatory neuron A neuron that, when activated, depolarizes its postsynaptic target cells and makes them more likely to fire action potentials.

excitatory neurotransmitter A neurotransmitter that depolarizes postsynaptic target cells and makes them more likely to fire action potentials.

excitotoxicity Toxicity to neurons caused by excessive stimulation by excitatory neurotransmitters such as glutamate, which results in a large or persistent increase in intracellular Ca^{2+} concentration.

exocrine system A system consisting of glands that excrete fluids, such as sweat or tears, locally through specific ducts.

exocytosis The process by which intracellular vesicles fuse with the plasma membrane to release secreted proteins into the extracellular space, and to deliver lipids and transmembrane proteins to the plasma membrane. (Figure 2–2)

exon The part of an RNA molecule that is retained in mRNA after splicing. (Figure 2–2)

exon shuffling See **DNA shuffling**.

explicit memory A form of memory that requires conscious recall, such as memory for names, facts, and events. It is also called declarative memory. (Figure 10–4)

expression cloning A strategy for cloning a gene by transfected cells with pools of cDNAs and using a functional assay to identify the pool that contains the cDNA of interest. The assay is reiterated with progressively divided pools of cDNAs until a single cDNA is identified. (Figure 6–68)

extensor A muscle whose contraction increases the angle of a joint. (Figure 8–8)

extinction In classical conditioning, a decrease in the conditioned response caused by repeated exposure to the conditioned stimulus without the unconditioned stimulus. In operant conditioning, a decrease in a reinforced action or an increase in a punished action when the action is repeatedly not reinforced or punished, respectively.

extracellular recording A technique for recording voltage changes, such as action potentials from a single neuron or synaptic activity from a population of neurons. It utilizes an electrode, often made of metal wire that is insulated except at the tip, which is placed at close range to a neuronal cell body or a synapse-rich region. (Figure 13–31)

exuberant connection Excess connection made during development that is not retained in adulthood.

Eyeless A *Drosophila* transcription factor belonging to the Pax family. It contains a homeobox and a paired box and is required for eye development. Its ectopic expression in other structures,

such as the antenna or the wing precursors, can induce ectopic eye formation. *See also Pax6*.

facilitating synapse A synapse at which successive presynaptic action potentials trigger progressively larger postsynaptic responses. (Figure 3–15)

familial Alzheimer's disease (FAD) A small subset of Alzheimer's disease cases that follows a Mendelian (autosomal dominant) inheritance pattern.

fast axonal transport Intracellular transport at a speed of 50–400 mm per day; cargos subject to fast axonal transport include organelles, as well as transmembrane and secreted proteins. (Figure 2–4)

fear conditioning *See contextual fear conditioning* and *auditory fear conditioning*.

feedback inhibition A circuit motif in which an excitatory neuron both provides output to and receives input from an inhibitory neuron. (Figure 1–21)

feedforward excitation A circuit motif in which serially connected excitatory neurons propagate information across multiple regions of the brain. (Figure 1–21)

feedforward inhibition A circuit motif in which a postsynaptic neuron receives both direct excitatory input from a presynaptic neuron and disynaptic inhibitory input from the same excitatory neuron via an inhibitory interneuron. (Figure 1–21)

fertilization The fusion of sperm and egg to create a genetically new organism. (Figure 7–2)

Fezf2 A transcription factor that specifies subcerebral projection neuron identity. (Figure 7–10)

fibroblast growth factor (FGF) A member of a family of secreted growth factors that act as morphogens to pattern early embryos during development.

field excitatory postsynaptic potential (fEPSP) Excitatory postsynaptic potentials recorded from a population of neurons near the tip of an extracellular electrode. fEPSPs evoked by stimulation of axonal inputs to a population are often used as a measure of the strength of synaptic transmission between the stimulated inputs and neurons near the recording electrode. (Figure 10–8)

filamentous actin (F-actin) A major cytoskeletal element composed of two parallel helical strands of actin polymers. They are also called microfilaments. (Figure 2–5; Figure 8–3)

filopodia A thin, protruding process of the growth cone made of bundled F-actin. (Figure 5–15)

fissure A deep invagination of the cortical surface that separates areas of the cerebral cortex.

fitness With respect to an allele (or phenotype), fitness is the ratio of the frequency of the allele (or phenotype) in a population after one generation of selection to the frequency of the allele (or phenotype) in the same population before the selection. With respect to an individual, fitness is the number of second-generation descendants the type of individual with a particular genome is expected to have.

fixed (of an allele) The state of an allele when every member of the population is homozygous for the allele.

fixed action pattern An instinctive sequence of behaviors, it is largely invariant and runs to completion once triggered.

flavor A synthesis of taste and olfaction.

flexor A muscle whose contraction decreases the angle of a joint. (Figure 8–8)

floor plate A structure at the ventral midline of the spinal cord. (Figure 5–10; Figure 7–8)

FLP recombinase A yeast-derived enzyme that catalyzes recombination between two sequence-specific DNA elements called *FRT* (FLP recognition target) sites. (Figure 13–7; Figure 13–23)

fluorescence resonance energy transfer (FRET)

A phenomenon in which energy is transferred between two fluorophores with an efficiency inversely proportional to the sixth power of the distance between them. It can be used experimentally to determine the distance between two fluorophores. It is also known as Förster resonance energy transfer (FRET).

fluoxetine A widely used antidepressant that acts as a selective serotonin reuptake inhibitor. Its brand name is Prozac. (Figure 11–27). See also SSRI.

Fmr1 See fragile-X syndrome.

FMRP See fragile-X syndrome.

focal seizures Seizures that affect a relatively small, discrete region of the brain.

follicle-stimulating hormone (FSH) See gonadotropins.

forebrain The rostral-most division of the three divisions of the embryonic brain. It gives rise to the cerebral cortex, basal ganglia, hippocampus, amygdala, thalamus, and hypothalamus. (Figure 1–8; Figure 7–3)

forward genetic screen A procedure to identify genes that are necessary for a biological process. It usually involves (1) inducing mutations in a population of experimental animals (such as through radiation, transposon insertion, or treatment with a chemical mutagen) so that each animal carries a different set of random mutations in a small number of genes or a single gene, and (2) identifying mutations that disrupt the biological process of interest based on the phenotypes exhibited by the offspring of the mutagenized animals. (Figure 13–4)

forward signaling See reverse signaling.

Fos An immediate early gene that encodes a transcription factor. Its expression is commonly used as an indicator of recently activated neurons.

fovea The central part of the primate retina that has a high density of cones. (Figure 4–14)

fragile-X syndrome (FXS) A leading cause of inherited intellectual disability, it is caused by expanded trinucleotide repeats in the 5' untranslated region of the *Fmr1* gene, which encodes an RNA binding protein called the fragile X mental retardation protein (FMRP).

Frazzled See DCC/Unc40.

frequency tuning The property whereby a cell in the auditory system is best activated by sounds of a particular frequency. It is usually represented as a V-shaped curve on a frequency-intensity plot.

frontal eye field (FEF) A neocortical area that receives extensive feedforward connections from both the dorsal and ventral streams and sends feedback projections to many visual cortical areas. (Figure 4–48)

frontal lobe One of the four cerebral cortex lobes, it is located at the front of the brain rostral to the central sulcus. (Figure 1–23)

FRT See FLP recombinase.

Fruitless (Fru) A *Drosophila* gene that regulates all aspects of male courtship rituals. The splicing of one of its transcripts is regulated by a hierarchy of sex-determining splicing factors: females express a non-functional splice isoform of the protein while males express a functional form of the protein (*Fru^M*) that acts as a transcription factor. (Figure 9–4)

functional architecture The physical arrangement of neurons in a brain region based on their functional properties.

functional magnetic resonance imaging (fMRI) A non-invasive functional brain imaging technique, it monitors signals originating from changes in blood flow that are closely related to local neuronal activity. It is also called BOLD (blood-oxygen-level dependent) fMRI.

fundamental frequency The frequency of the lowest frequency component of a periodic waveform.

fura-2 A small molecule Ca^{2+} indicator whose optimal excitation wavelength shifts from 380 nm to 350 nm when Ca^{2+} is bound. The ratio of fluorescence intensity measured at excitation wavelengths of 350 nm and 380 nm can be used as a sensitive measure of Ca^{2+} concentration.

fusiform face area A specific area of human temporal cortex that is preferentially activated by images of human faces.

GABA A glutamate derivative that is the predominant inhibitory neurotransmitter in vertebrates and invertebrates. (Figure 3–16; Table 3–2)

GABA_A receptor An ionotropic receptor that is gated by GABA and mediates fast inhibition. (Figure 3–21; Figure 11–29)

GABA_B receptor A metabotropic receptor that is activated by GABA and that mediates slow inhibition.

gain control Modulation of the slope of a system's input-out function, it is often used to restrict output to a limited dynamic range.

gain-of-function experiments Experiment in which a specific component is added to the system. They are often used to test whether the added component is sufficient for the system to function in a specific context.

GAL4 A yeast transcription factor that binds to a DNA element called a UAS (upstream activation sequence) in the promoter regions of genes to activate the transcription of those genes. (Figure 13–13)

galanin A neuropeptide with diverse functions, including the promotion of parental behavior.

ganglion A cluster of neurons located in the peripheral nervous system.

ganglionic eminences Developing ventral telencephalon structures that include the medial, caudal, and lateral ganglionic eminences (MGE, CGE, LGE). They are the birthplaces of cortical GABAergic neurons (MGE and CGE), GABAergic interneurons in the basal ganglia and amygdala (MGE and CGE), and olfactory bulb interneurons and most GABAergic projection neurons in the striatum (LGE). (Figure 7–5)

gap junction The morphological correlate of the electrical synapse, which usually contains hundreds of closely clustered channels that bring the plasma membrane of two neighboring cells together and allow passage of ions and small molecules between the two cells. (Figure 3–38)

gastrin-releasing peptide receptor (GRPR) A G-protein-coupled receptor that is activated by gastrin-releasing peptide and is involved in processing itch signals.

gastrula The product of gastrulation, it is an embryo with a three-layered structure consisting of ectoderm, mesoderm, and endoderm. (Figure 7–2)

gastrulation The process by which an embryo is transformed from a ball of cells into a structure with three distinct layers: ectoderm, mesoderm, and endoderm. (Figure 7–2)

GCaMP A GFP-based genetically encoded Ca^{2+} indicator whose fluorescence increases in response to a rise of Ca^{2+} concentration.

GCAP (guanylate cyclase activating protein) A calcium-binding protein which in its calcium-free form binds to and activates guanylate cyclase.

gene A segment of DNA that carries the instructions for how and when to make specific RNAs and proteins. (Figure 2–2)

gene expression profiling Determining the genes expressed in a sample on a whole-genome scale using methods such as microarray and RNA-seq.

gene therapy The use of DNA and/or genome modification to treat disease.

generalized seizures Seizures that affect multiple, bilateral regions of the brain.

genetic drift The process in which chance events that result in death of an organism or failure of an organism to reproduce can lead to the loss of an allele from a small population and an increase in the prevalence of the remaining allele(s).

genetic mosaic animal An animal that contains cells of more than one genotype. (Figure 5–36; Figure 13–10)

genetic susceptibility locus A genomic locus with variant(s) that increase the probability of carriers developing a trait (such as a disease).

genetically encoded Ca^{2+} indicators Proteins whose fluorescence properties change before and after binding to Ca^{2+} . See also Ca^{2+} indicator. (Figure 13–38)

genome engineering The general process of altering the genome at a predetermined locus, such as deleting a piece of endogenous DNA, inserting a piece of foreign DNA, or creating a specific base-pair change.

genome-wide association study (GWAS) A strategy for identifying genes associated with a specific trait by comparing DNA samples collected from many people with or without the trait. The DNA samples are used to identify single nucleotide polymorphisms throughout the entire genome that are most strongly linked with the trait.

ghrelin A neuropeptide produced by stomach-associated glands in response to a reduced glucose level. It acts as a hunger signal to stimulate eating. (Figure 8–43)

G_i (inhibitory G protein) A $G\alpha$ variant that binds to adenylate cyclase and inhibits its activity.

gill-withdrawal reflex A reflex in the sea slug *Aplysia* in which the gill is withdrawn into the mantle shelf when a tactile stimulus is applied to its siphon. It has been used as a model system to investigate the mechanisms that underlie simple forms of learning and memory.

glia Nonneuronal cells of the nervous system, they play essential roles for the development and function of neurons.

glomerulus A discrete, ball-like structure in the vertebrate olfactory bulb or insect antennal lobe where ORN axons form synapses with the dendrites of their postsynaptic target neurons. (Figure 6–3; Figure 6–17)

GluN1 See NMDA receptor.

GluN2 See NMDA receptor.

glutamate An amino acid that is the predominant excitatory neurotransmitter in vertebrates. (Figure 3–16; Table 3–2)

glutamic acid decarboxylase (GAD) An enzyme that converts glutamate into GABA.

glycine An amino acid that is an inhibitory neurotransmitter released by a subset of brainstem and spinal cord neurons in vertebrates. (Figure 3–16; Table 3–2)

glycine receptor An ionotropic receptor that is gated by glycine and mediates fast inhibition. (Figure 3–21)

Goldman-Hodgkin-Katz (GHK) equation An equation that relates the membrane potential at equilibrium to the membrane permeabilities and concentrations of multiple ions on the two sides of a membrane. A variant of the GHK equation relates the membrane potential at equilibrium to the equilibrium potential and conductance of each ion.

Golgi outpost Fragments of the Golgi apparatus that are located in neuronal dendrites. (Figure 7–18)

Golgi staining A histological staining method, it uses solutions of silver nitrate and potassium dichromate, which react to form a black precipitate (microcrystals of silver chromate). This precipitate accumulates stochastically in a small fraction of the nerve cells so that these cells, and most or all of their elaborate extensions, can be visualized against unstained tissue.

gonadotropin-releasing hormone (GnRH) A pre-hormone released by hypothalamic neurons (called GnRH neurons) that stimulates the release of gonadotropins by anterior pituitary endocrine cells. (Figure 9–27)

gonadotropins A family of hormones that includes luteinizing hormone (LH) and follicle-stimulating hormone (FSH). Released by anterior pituitary endocrine cells, these hormones stimulate the maturation of male testes and female ovaries during puberty. In adults, they stimulate the testes to release testosterone and the ovaries to release estradiol. (Figure 9–27)

GPCR (G-protein-coupled receptor) A member of a receptor family with 7 transmembrane domains that, upon ligand binding, activate trimeric G proteins, which in turn activate intracellular signaling cascades.

GPe (globus pallidus external segment) An intermediate nucleus in the basal ganglia indirect pathway. It contains GABAergic neurons that project to the GPi, SNr, and STN. (Figure 8–22)

GPi (globus pallidus internal segment) One of the two major output nuclei of the basal ganglia. It contains GABAergic neurons that project to the thalamus. (Figure 8–22)

GPI (glycosylphosphatidylinositol) A lipid anchor that can covalently attach to an extracellular protein to anchor it to the plasma membrane. GPI-anchored protein can be released from the membrane by phosphatidylinositol-specific phospholipase C (PI-PLC), which cleaves the bond between the GPI group and the protein.

G_q A $G\alpha$ variant that activates phospholipase C, in turn leading to activation of the inositol-phospholipid signaling pathway. (Figure 3–34)

graded potentials (local potentials) Membrane potentials that can change in continuous values, as opposed to the all-or-none property of the action potential. (Figure 2–18)

granule cells Neurons that are granular in appearance because they are densely packed, including three prominent types. The cerebellar granule cells are the most numerous type of neuron in the brain; their cell bodies and dendrites reside in the granular layer of the cerebellar cortex where they receive mossy fiber input; their axons ascend into the molecular layer, where each bifurcates to become a parallel fiber to send glutamatergic output to Purkinje cells. (Figure 8–20). The granule cells in the hippocampus are the major cellular constituents of the dentate gyrus; they receive input from the entorhinal cortex via the perforant path and send glutamatergic output to CA3 pyramidal neurons. (Figure 1–12; Figure 10–6). The olfactory bulb granule cells constitute a large subtype of olfactory bulb interneurons that receive input from the secondary dendrites of mitral cells and send GABAergic output back to mitral cells. (Figure 6–17).

gray matter The parts of the CNS that are enriched with neuronal cell bodies, dendrites, axon terminals, and synapses and that appear gray.

green fluorescent protein (GFP) A jellyfish protein that emits green fluorescence when excited by blue light. It is widely used as a marker for gene expression and for live imaging.

grid cell A cell in the entorhinal cortex whose activity depends on an animal's location in an arena, with peak firing rate occurring at the apices of an imaginary hexagonal grid superimposed on the arena floor. (Figure 10–31)

growth cone A dynamic structure at the tip of a developing neuronal process, it enables the extension of the process and guides its direction.

G_s (stimulatory G protein) A G_α variant that binds to adenylate cyclase and stimulates its activity. (Figure 3–33)

GTPase An enzyme that hydrolyzes GTP, converting it to GDP.

GTPase activating protein (GAP) A protein that switches GTPases off by accelerating the GTPases' endogenous activity, which converts GTP to GDP. (Figure 3–32)

guanine nucleotide exchange factor (GEF) A protein that switches GTPases on by catalyzing the exchange of GDP for GTP. (Figure 3–32)

guanylate cyclase An enzyme that produces cGMP from GTP.

guide RNA In the CRISPR/Cas9 system, an RNA molecule that brings Cas9 to a target DNA sequence, where Cas9 generates a double-strand break. The guide RNA must contain sequences that base-pair with the target DNA. *See also CRISPR and Cas9.* (Figure 13–8)

gustatory nerve A bundle of axons that originate from the basal ends of the taste receptor cells. The nerve projects to the nucleus of the solitary tract in the brainstem, and thus relays taste information from the tongue to the brain. (Figure 6–35)

gyrencephalic Of cortex, having gyri and sulci. (Figure 12–5)

G_α, G_β, G_γ *See trimeric GTP-binding protein.*

habituation A decrease in the magnitude of responses to stimuli that are presented repeatedly.

hair cell The primary sensory cell for audition, it converts mechanical stimuli—movement of stereocilia at its apical end—into electrical signals. (Figure 6–47; Figure 6–50)

halorhodopsin A light-activated inward chloride pump in archaea, it can be used to silence neuronal activity in heterologous system by light. *See also optogenetics.* (Figure 13–45)

harmonics Sounds with frequencies that are integer multiples of the fundamental frequency.

HCN (hyperpolarization-activated cyclic nucleotide-gated) channels Non-selective cation channels that are activated by hyperpolarization and whose gating is influenced additionally by the concentration of a specific intracellular cyclic nucleotide. (Figure 2–34)

head direction cell A cell that fires when an animal's head is facing a specific direction in space, regardless of the animal's location in the environment.

Hebb's rule A postulate by Donald Hebb that describes how learning can be transformed into a lasting memory, it states: "When an axon of cell A is near enough to excite a cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A's efficiency, as one of the cells firing B, is increased."

Hebbian synapse A synapse whose strength can be enhanced by co-activation of pre- and postsynaptic partners.

hedonic value The degree to which something is pleasant or unpleasant, which usually correlates with the degree to which something is potentially beneficial or harmful to an animal.

hemispheres The two sides of the brain.

heritability A measure of the contribution of genetic differences to trait differences within a population. It can be measured in twin studies as $2 \times$ (the correlation of the trait between pairs of monozygotic twins – the correlation of the trait between pairs of dizygotic twins).

herpes simplex virus (HSV) A DNA virus used to deliver transgenes into post-mitotic neurons. It has a capacity to include ~150 kb of foreign DNA. (Table 13–1)

heterophilic binding Binding of two different proteins, usually two different membrane proteins expressed from adjacent cells across the cell junction.

hindbrain The caudal-most division of the three divisions of the embryonic brain. It gives rise to the pons, medulla, and cerebellum. (Figure 1–8; Figure 7–3)

hippocampus A structure underneath the cortical surface of the temporal lobe. It has been most studied for its role in the acquisition of explicit memory and representation of space. (Figure 1–8; Figure 10–6)

histamine A monoamine neuromodulator derived from the amino acid histidine. (Figure 3–16; Table 3–2)

histological sections Slices of frozen or chemically fixed tissue produced by microtomes, with thicknesses ranging from several to several hundred micrometers. They can be stained using a number of different methods and examined under a light microscope.

homeodomain Originally discovered in proteins whose disruption causes transformation of one body part into another, it is a DNA-binding domain shared by all Hox proteins and many other transcription factors. It is also called a homeobox.

homeostasis The maintenance of a steady state of a physiological parameter—such as blood pressure, body temperature, or nutritional level—by feedback physiological and behavioral responses. (Figure 8–34)

homeotic transformation Transformation of one body part to another, such as the transformation of a pair of antennae to a pair of legs in *Drosophila antennapedia* mutants.

homologous recombination Exchange of nucleotide sequences between two identical or highly similar DNA molecules. It occurs naturally in certain cells due to its role in specific biological processes, such as in germ-line cells during meiotic crossing over. It is also used experimentally for genome engineering, such as the generation of knockout and knock-in alleles. (Figure 13–6; Figure 13–8)

homophilic binding Binding of two identical proteins, usually two membrane proteins expressed from adjacent cells across the cell junction.

horizontal cell An inhibitory neuron in the vertebrate retina whose actions influence the signals that are transmitted from the photoreceptors to the bipolar cells. (Figure 4–26)

horizontal gene transfer Gene transfer from one organism to another through mechanisms other than reproduction, such as via viral transduction.

horizontal sections A section plane that is perpendicular to the dorsal–ventral axis.

Hox gene A member of a family of evolutionarily conserved genes that are arranged in genomes in clusters and that encode homeobox-containing transcription factors. *Hox* genes define the anterior–posterior body axes of most invertebrates and all vertebrates and also regulate neuronal fate at later developmental stages. (Figure 12–32)

5-HT *See serotonin.*

HTMR (high-threshold mechanoreceptor) A mechanosensory neuron that senses pain caused by strong mechanical stimuli. (Figure 6–64)

huntingtin *See Huntington's disease.*

Huntington's disease (HD) A dominantly inherited disease that usually strikes patients during midlife. It is characterized initially by depression or mood swings and subsequently by abnormal movements due to degeneration of striatal neurons. It is caused by expanded poly-glutamine repeats in the huntingtin protein. (Figure 11–14)

HVC (high vocal center) A dorsal forebrain nucleus in the songbird essential for song production. (Figure 9–21)

hyperpolarization A change in the electrical potential inside the cell toward a more negative value.

hypocretin (orexin) A neuropeptide expressed by specific lateral hypothalamus neurons, it is important for regulating sleep and eating.

hypogonadotropic hypogonadism A disorder characterized by delayed, reduced, or absent puberty due to reduced gonadotropin levels.

hypothalamus A collection of nuclei ventral to the thalamus, it controls many bodily functions including eating, digesting, metabolic rate, drinking, salt intake, reproduction, body temperature, emergency response, and circadian rhythms. It executes many of these functions by regulating the autonomic nervous system and neuroendocrine system. (Figure 1–8; Figure 8–34)

identified neuron A neuron that can be recognized across individuals of the same species due to its stereotyped location, size, and shape.

Ig CAM (immunoglobulin cell adhesion molecule) A cell adhesion molecule that contains immunoglobulin domains on its extracellular side.

imipramine A tricyclic antidepressant that inhibits the plasma membrane monoamine transporters. (Figure 11–27)

immediate early genes (IEGs) A class of genes whose transcription is rapidly induced by external stimuli without requiring new protein synthesis.

immuno-EM A combination of immunostaining and electron microscopy used to visualize the distribution of individual proteins at an ultrastructural level. (Figure 13–24)

immunostaining A staining method that uses antibodies to visualize the distributions of proteins in fixed tissues. The most common form uses sequential application of two antibodies: a primary antibody that binds the protein of interest and a fluorescence- or enzyme-conjugated secondary antibody that binds to the primary antibody. Protein distribution can be visualized by fluorescence or a color substrate produced by the enzyme conjugated to the secondary antibody.

implicit memory A form of memory in which previous experience aids in the performance of a task without conscious recall. It is also called non-declarative memory or procedural memory. (Figure 10–4)

in situ hybridization A method for determining mRNA distribution in tissues by hybridizing labeled gene-specific nucleic acid probes to fixed histological sections or whole-mount tissues.

in vitro mutagenesis A molecular biology technique used to alter the sequence of a gene in a test tube.

inactivation (of ion channels) A decrease of ion conductance through a channel after an initial increase. The ion channel when inactivated is in a distinct state from when it is closed.

indirect pathway (in basal ganglia) An axonal projection from a subset of spiny projection neurons that terminate in the GPe and STN. (Figure 8–22)

induced pluripotent stem (iPS) cells Pluripotent cells produced experimentally from differentiated cells by a variety of means, such as forced expression of key transcription factors involved in maintaining the pluripotency of embryonic stem cells. (Figure 11–23)

induction A mechanism for determining cell fate in which a cell is born with the same potential to develop into different cell types as its sibling or cousins, and its fate is acquired by receiving external signals (i.e. the cell's fate is 'induced' by external cues).

inferior colliculus A midbrain nucleus that integrates auditory signals from brainstem nuclei. It sends auditory output to the thalamus and to the nearby superior colliculus/tectum. (Figure 6–54)

inferior olive A nucleus in the medulla containing neurons whose axonal projections to the cerebellum form climbing fibers. (Figure 8–20)

inhibitory neuron A neuron that, when activated, hyperpolarizes its postsynaptic target cells and makes them less likely to fire action potentials.

inhibitory neurotransmitter A neurotransmitter that hyperpolarizes postsynaptic target cells and makes them less likely to fire action potentials.

initial segment of the axon The segment of the axon closest to the neuronal cell body, it is usually the site of action potential initiation.

innate A trait or behavior that is genetically programmed and that is thus with an organism from birth rather than acquired by experience.

innate song The song a songbird would sing if raised in acoustic isolation during the sensory stage of song learning.

innexins A protein component of gap junctions in invertebrates.

inositol 1,4,5-triphosphate (IP₃) A second messenger that binds to the IP₃ receptor on the endoplasmic reticulum (ER) membrane to trigger the release of ER-stored Ca²⁺ into the cytosol. (Figure 3–34)

input specificity (of LTP) A property of long-term potentiation (LTP) whereby LTP occurs only at synapses that have experienced an LTP-inducing stimulus and not at unstimulated synapses on the same postsynaptic neuron. (Figure 10–9)

insular cortex A part of the cerebral cortex that represents taste, pain, and interoception. (Figure 6–35; Figure 8–33)

insulator An object or substance that does not allow electric current to pass. It is equivalent to a resistor with infinite resistance.

insulin A peptide hormone produced by the pancreas in response to a rise in blood glucose level after meals. It regulates carbohydrate metabolism throughout the body, and also regulates food intake through its actions on target neurons in the brain. (Figure 8–43)

intellectual disability A condition characterized by deficits in general mental abilities such as reasoning, problem-solving, planning, abstract thinking, judgment, and learning.

interaural level difference (ILD) The level difference of a sound that is received in the left ear and the right ear, used for sound localization.

interaural time difference (ITD) The difference in the arrival time of a sound at the left ear and the right ear, used for sound localization.

intermediate progenitor A progenitor cell produced by division of a radial glial cell. It divides further to give rise to post-mitotic neurons. (Figure 7–4)

interneuron A neuron with the axon confined to the specific CNS region that houses the neuron's cell body, it is also called local neuron in this context. It may also refer to any neuron that is not a motor or a sensory neuron.

interoception The sense of the state of internal organs.

intersectional methods (in genetics) Strategies that use two orthogonal binary expression systems to refine patterns of transgene expression. (Figure 13–14)

interstitial branching Extending a collateral from the side of a growing process. (Figure 7–19)

intracellular recording A procedure for measuring the membrane potential of a cell using an electrode inserted into or continuous with the cytoplasm. (Figure 13–31)

intracellular vesicle A small, membrane-enclosed organelle in the cytoplasm of a eukaryotic cell. (Figure 2–2)

intrinsic properties The electrophysiological properties of a neuron determined by the composition, concentration, subcellular distribution, and biophysical properties of ion channels it expresses.

intrinsic signal imaging A method for measuring neuronal activity based on changes in the optical properties of tissue surrounding active neurons, primarily as a result of changes in blood oxygenation in those regions. (Figure 4–42)

intrinsically photosensitive retinal ganglion cell (ipRGC) A type of RGC that expresses melanopsin and that can be directly depolarized by light. (Figure 4–36)

intron The part of an RNA molecule that is removed during splicing. (Figure 2–2)

inward-rectifier K⁺ channels A subfamily of K⁺ channels that preferentially pass inward currents over outward currents; i.e. these channels pass current at membrane potentials more hyperpolarized than E_K but allow minimal outward currents at membrane potentials more positive than E_K . (Figure 2–34)

ion channel A channel that allows the passage of one or more specific species of ion.

ionotropic receptor A neurotransmitter receptor that functions as a neurotransmitter-gated ion channel to allow rapid (within a few milliseconds) membrane potential changes in response to neurotransmitter binding. (Figure 3–21)

iontophoresis A technique by which ions or charged chemicals are locally applied from a micropipette via a current pulse.

IP₃ receptor An IP₃-gated Ca²⁺ channel on the ER membrane. (Figure 3–34)

iproniazid The first antidepressant discovered serendipitously in the 1950s. It is an inhibitor of monoamine oxidase. (Figure 11–27)

IPSC (inhibitory postsynaptic current) An outward current produced by binding of an inhibitory neurotransmitter to its receptor. The fast component is usually mediated by Cl[−] influx through the GABA_A receptor or glycine receptor.

ipsilateral Of the same side of the midline. For example, an ipsilateral axonal projection is an axon that does not cross the midline and therefore terminates on the same side of the nervous system as the soma.

IPSP (inhibitory postsynaptic potential) A transient hyperpolarization of a postsynaptic cell associated with an inhibitory postsynaptic current (IPSC).

I–V curve A graphical representation of the relationship between the current that passes through a piece of ion-channel-containing membrane (I) and the voltage across the membrane (V). (Figure 3–17)

K⁺ channels Ion channels that allow selective passage of K⁺, they constitute the most diverse channel family. (Figure 2–34)

K⁺–Cl[−] cotransporter A transporter that couples K⁺ and Cl[−] export to help maintain the Cl[−] gradient across the membrane. (Figure 2–12)

kainate receptor A glutamate-gated ion channel that conducts Na⁺ and K⁺ and that can be selectively activated by the drug kainate (kainic acid).

kinesins A family of microtubule-based motor proteins that are mostly plus-end-directed. (Figure 2–6; Figure 2–7)

Kiss1R A G-protein-coupled receptor for kisspeptins, it is also called GPR54.

kisspeptins A family of neuropeptides encoded by the *Kiss1* gene that play an important role in activating GnRH neurons. (Figure 9–27)

knee-jerk reflex The involuntary forward movement of the lower leg due to the contraction of the quadriceps femoris muscle (an extensor) and relaxation of the hamstring muscle (a flexor). A tap of the knee (patellar ligament) stretches the muscle spindle in the quadriceps muscle and activates the proprioceptive sensory neurons. Sensory neuron activation initiates the reflex through monosynaptic excitation of motor neurons that excite the quadriceps femoris muscle and disynaptic inhibition of motor neurons that excite the hamstring muscle. (Figure 1–19)

knock-in A variation of the knockout procedure in which an *in vitro* engineered gene—either a transgene or a variant of an endogenous gene—is inserted into a specific chromosomal locus; the procedure can produce changes to endogenous genes as small as a single base pair.

knockout A genetic engineering procedure that inactivates a specific gene. In the mouse, it is usually achieved by homologous recombination in embryonic stem cells to create a mutation in the target gene. The resulting mutant mouse is called a knockout mouse for that particular gene. (Figure 13–6)

kuru See prion diseases.

lamellipodia A veil-like meshwork of the growth cone made of branched F-actin. (Figure 5–15)

lamina (in insect visual system) The first neuropil layer underneath the retina in the insect compound eye. (Figure 5–35)

landmark-based strategy A navigational strategy in which animals use external cues to determine their locations.

laser-scanning two-photon imaging See two-photon microscopy.

late LTP A long-lasting phase of long-term potentiation (LTP), usually lasting longer than 3 hours and requiring new protein synthesis and likely new gene expression.

lateral geniculate nucleus (LGN) A thalamic nucleus that receives visual input from retinal ganglion cell axons and sends output to the primary visual cortex. (Figure 4–35; Figure 4–37)

lateral horn A second-order olfactory center for odor-mediated innate behavior in the insect brain. It and the mushroom body are the two major output sites for projection neuron axons. (Figure 6–27)

lateral inhibition (in cell fate determination) The process by which neighboring cells are prevented from adopting identical

fates through cell-cell interactions, such as those mediated by Notch/Delta. (Figure 7–7)

lateral inhibition (in information processing) A circuit motif in which an inhibitory neuron receives excitatory input from one or several parallel streams of excitatory neurons, and sends inhibitory output to many or all of the postsynaptic targets of these excitatory neurons. It is widely used in sensory systems. (Figure 1–21)

lateral intraparietal area (LIP) A cortical area in the primate parietal lobe implicated in making the decision to move eyes in a particular direction. (Figure 4–48)

length constant (space constant, λ) A key parameter that defines the passive electrical properties of electrical signaling. It is equal to the distance along a neuronal process over which the amplitude of a membrane potential change decays to $1/e$ or about 37% of its original value.

lentivirus A retrovirus that can infect post-mitotic neurons. It has a capacity to include ~8 kb foreign DNA. (Table 13–1)

leptin A hormone secreted by the fat tissues that negatively regulates food intake through its actions on specific neurons in the brain. (Figure 8–38)

Lewy bodies Intracellular inclusions that are a defining pathological feature of most forms of Parkinson's disease.

lidocaine An anesthetic that blocks action potential propagation by inhibiting voltage-gated Na^+ channels.

ligand A molecule that binds to its receptor.

ligand-gated ion channel A transmembrane protein complex that directly conducts ions in response to the binding of a neurotransmitter or other ligand.

light microscopy The most widely used microscopic technique in biology. It uses beams of visible light (photons) to create an image of a specimen and, with the exception of some methods for super-resolution fluorescence microscopy, can only resolve structures greater than 200 nm apart.

light-sheet fluorescence microscopy A fluorescence microscopy technique in which only the focal plane (i.e. a single plane in the z-dimension) is illuminated with a thin sheet of a laser beam from the side. All fluorescence emissions in the focal plane are collected simultaneously by a detector. (Figure 13–19)

lissencephalic Of cortex, being smooth. (Figure 12–5)

LKB1 A protein kinase essential for determining axon fate during the establishment of neuronal polarity.

LMAN (lateral magnocellular nucleus of the anterior nidopallium) A forebrain nucleus in the songbird that is essential for song learning but not for song production. (Figure 9–21)

lobula complex Neuropil underneath the medulla in the insect compound eye. (Figure 5–35)

local field potential Electrical potential at an extracellular recording site relative to a distal ground. Usually filtered to remove high-frequency signals, it reflects collective dendritic and synaptic activities of many neurons near the electrode. (Figure 10–8)

local interneuron (LN) (in insect olfactory system) A neuron whose processes are restricted to the antennal lobe. (Figure 6–27)

local neuron See **interneuron**.

local protein synthesis Translation of mRNA into protein in a neuron's cytoplasmic extensions (usually dendrites) rather than in the cell body.

locus coeruleus A brainstem nucleus consisting of norepinephrine neurons that project widely across the brain. (Figure 8–54)

long-range cue (in axon guidance) A secreted protein that can act at a distance from its cell of origin. (Figure 5–9)

long-term depression (LTD) A long-lasting decrease of synaptic efficacy that can be induced experimentally by specific stimulus conditions.

long-term memory Memory that lasts hours to years. (Figure 10–4)

long-term potentiation (LTP) A long-lasting enhancement of synaptic efficacy. It can be induced experimentally under a variety of conditions, such as high-frequency stimulation of input axons. (Figure 10–8)

long-term synaptic plasticity A change in the efficacy of synaptic transmission that lasts hours to the lifetime of the animal.

loose-patch recording A technique in which a patch electrode is placed against the cell membrane without forming a gigohm seal. It can only be used to record spiking activity (not sub-threshold activity), but, unlike whole-cell recording, does not affect the intracellular content of the recorded cell.

lordosis A posture that female rodents assume when sexually aroused. It facilitates sexual intercourse.

loss-of-function experiment An experiment in which a specific component is disrupted, often used to determine if the missing component is necessary for the system to function.

loss-of-function mutation A mutation that disrupts the function of a gene.

lower envelope principle The idea that the limits of psychophysical performance are determined by the sensitivities of the most sensitive individual neurons. (Figure 6–72)

loxP See **Cre recombinase**.

LRP4 (low-density lipoprotein receptor-related protein-4) Along with MuSK, it is an agrin receptor in muscle. It also signals back to motor axons to trigger presynaptic differentiation in a MuSK-independent manner. (Figure 7–24)

LTMRs (low-threshold mechanoreceptors) Touch sensitive somatosensory neurons that innervate hair follicles, specialized epithelial cells, and encapsulated corpuscles in the skin. They respond to vibration, indentation, pressure, and stretch of the skin, as well as to the movement or deflection of hairs. (Figure 6–63)

luteinizing hormone (LH) See **gonadotropins**.

lysosome A membrane-enclosed organelle that contains enzymes for protein degradation. (Figure 2–2)

M pathway A visual processing pathway from the retina to the visual cortex that originates from retinal ganglion cells with large receptive fields and engages lateral geniculate nucleus cells in the magnocellular layers. It carries information about luminance and has excellent contrast and temporal sensitivity. (Figure 4–48)

macular degeneration A disease that causes photoreceptors in the fovea to die, impairing high-acuity vision.

major depression A mood disorder characterized by persistent feelings of sadness, emptiness, and worthlessness.

major urinary protein (MUP) A highly stable protein found in the urine, which is used by some species to mark an individual's territory for a long duration.

MARCM (mosaic analysis with a repressible cell marker) A genetic mosaic method in *Drosophila* used to label individual neurons or groups of neurons that share the same lineage and at the same time to delete an endogenous gene or express a transgene specifically in these labeled neurons. (Figure 13–23)

Martinotti cell A type of GABAergic neuron in the cerebral cortex that forms synapses onto the distal dendrites of cortical pyramidal cells. (Figure 3–46)

massively parallel processing An information processing method, it utilizes a large number of units to perform a set of coordinated computations in parallel. It is a key feature of the nervous system.

maximum parsimony A means of generating phylogenetic predictions by selecting the interpretation of the experimental data that posits the fewest number of evolutionary changes among all the potential interpretations.

MC4R A G-protein-coupled receptor that is activated by α -MSH. (Figure 8–42)

mechanosensory neurons Somatosensory neurons that are activated by mechanical force and are responsible for proprioception, touch, and a subset of pain sensations.

mechanotransduction The process in sensory cells by which mechanical stimuli are converted to electrical signals.

mechanotransduction channel An ion channel that is gated by mechanical force.

MeCP2 (methyl-CpG-binding protein 2) A nuclear protein that binds to DNA at methylated CpG sites (i.e. adjacent cytosine and guanine nucleotides). It is highly expressed in developing and adult neurons. (Figure 11–36) *See also Rett syndrome.*

medial amygdala Part of the olfactory amygdala complex that receives direct input from accessory olfactory bulb mitral cells. It is sexually dimorphic and regulates male courtship behavior. (Figure 9–32)

medial geniculate nucleus A thalamic nucleus that processes and relays auditory signals to the auditory cortex. (Figure 6–54)

medial-lateral Of a body axis, from midline to side.

medial preoptic area (MPOA) A sexually dimorphic nucleus in the anterior hypothalamus that regulates male courtship behavior. (Figure 9–28; Figure 9–32)

medulla The caudal-most part of the brainstem between the pons and the spinal cord.

medulla (in insect visual system) A neuropil that lies beneath the lamina in the insect compound eye. (Figure 5–35)

Melissner corpuscle A specialized structure closely associated with the peripheral ending of the rapidly adapting type I (RAI) LTMR. (Figure 6–64)

melanopsin An opsin expressed by vertebrate intrinsically photosensitive retinal ganglion cells (ipRGCs). It is a member of the c-opsin subfamily, whose members are most widely used in invertebrate visual systems.

membrane potential The electrical potential difference between the inside of the cell and the extracellular environment.

memory The process in which information is encoded, stored, and retrieved. It can also be defined as the lasting changes in the brain that retain the learned information.

Merkel cell A specialized epithelial cell at the junction of the dermis and epidermis. It is closely associated with the peripheral ending of the slowly adapting type I (SAI) LTMR. (Figure 6–64)

mesencephalic locomotor region (MLR) A midbrain region where electrical stimulation evokes locomotor activity.

mesoderm The middle germ layer that gives rise to the skeletal system, connective tissues, muscle, and the circulatory system. (Figure 7–2)

messenger RNA (mRNA) A mature RNA molecule that has undergone 5' capping, 3' polyadenylation, and splicing to remove

introns and that is exported to the cytoplasm to direct protein synthesis. (Figure 2–2)

metabotropic receptor A neurotransmitter receptor that regulates ion channel conductance indirectly through intracellular signaling cascades, modulating membrane potential over a timescale of tens of milliseconds to seconds. (Figure 3–22)

microglia A glial cell that functions as the resident immune cell of the nervous system. It engulfs damaged cells and debris. (Figure 1–9)

microneurography A neurophysiological technique used to record neuronal activity in the peripheral nerves of awake human subjects.

microRNA A short, noncoding RNA (21–26 nucleotides in length) widely used in eukaryotic organisms to regulate gene expression. It triggers the degradation and inhibits the translation of mRNAs with complementary sequences. *See also RNA interference.*

microstimulation Delivery of small currents through an extracellular electrode with the goal of activating a limited number of nearby neurons.

microtubule A major cytoskeletal element composed of hollow cylinders of 13 parallel protofilaments made of α - and β -tubulin. (Figure 2–5)

midbrain The rostral-most part of the brainstem, it includes the tectum (superior and inferior colliculus in mammals) dorsally and the tegmentum ventrally. It is also the middle part of the three divisions of the embryonic brain caudal to the forebrain and rostral to the hindbrain. It is also called the mesencephalon. (Figure 1–8; Figure 7–3)

middle temporal visual area (MT) A high-order visual cortical area in the dorsal stream specialized for analyzing motion signals. (Figure 4–48)

midget ganglion cell An A retinal ganglion cell with a small receptive field used for high-acuity vision and green-red color vision. (Figure 4–33)

miniature end-plate potential (mEPP) Small depolarization of the muscle cell in response to spontaneous neurotransmitter release from the motor neuron. (Figure 3–2)

mitogen-activated protein (MAP) kinase cascade A kinase cascade that acts downstream of the small GTPase Ras and other signaling molecules. The cascade consists of three serine/threonine kinases represented by Raf, Mek, and Erk (also called mitogen-activated kinase). Ras-GTP activates Raf, which phosphorylates and activates Mek, which in turn phosphorylates and activates Erk. (Figure 3–39)

mitotic recombination Exchange of a portion of homologous maternal and paternal chromosomes during mitotic cell division. It can create daughter cells homozygous for alleles on portions of the paternal or maternal chromosomes. (Figure 13–10; Figure 13–23)

mitral cell A second-order neuron in the vertebrate olfactory bulb, it receives input from ORNs and sends output to the olfactory cortex. It differs from a tufted cell, also a second-order neuron in the vertebrate olfactory bulb, in its cell body location in the olfactory bulb and axon termination pattern in the olfactory cortex. (Figure 6–17)

modulatory neurons Neurons that release modulatory neurotransmitters. They can act on both excitatory and inhibitory neurons to up- or down-regulate their excitability or synaptic transmission.

modulatory neurotransmitter (neuromodulator)

A neurotransmitter that can bidirectionally change the membrane potential, excitability, or neurotransmitter release of its postsynaptic target neurons.

molecular clock A technique that utilizes the rates of sequence changes, calibrated against fossil records, to estimate the times at which two species diverged.

monoamine neurotransmitter A neurotransmitter, such as serotonin, dopamine, norepinephrine, and histamine, derived from an aromatic amino acid.

monoamine oxidase An enzyme that oxidizes dopamine, norepinephrine, and serotonin, leading to their degradation. (Figure 11–24)

monozygotic (identical) twins Twins produced from the same fertilized egg or zygote, they share 100% of their genomes.

morphine The active ingredient of opiates.

morphogen A diffusible signaling protein that can cause cells located at different distances from the source to adopt different fates.

Morris water maze A navigation task in which rats and mice learn to locate a hidden platform in a pool of milky water using distant cues in the room.

Mosaic analysis A method for analyzing the cell types in which the function of a gene is important by creating genetic mosaic animals containing both wild-type and mutant cells that are usually differentially marked.

mossy fiber An axon that has elaborate terminal arborizations. The two most prominent types are found in the cerebellum and hippocampus. The cerebellar mossy fiber is an axon that terminates in the granular layer of the cerebellar cortex, where it synapses onto granule cells. It originates from a neuron residing in the pons, medulla, or spinal cord. (Figure 8–20). The hippocampal mossy fiber is an axon of a dentate gyrus granule cell, which synapses onto CA3 pyramidal neuron dendrites. (Figure 10–6)

motor homunculus A map in the primary motor cortex that corresponds to movement of specific body parts. Nearby areas in the motor cortical areas represent movement control of nearby body parts. (Figure 1–25)

motor neuron A type of neuron that extends dendrites within the CNS (the spinal cord or brainstem in vertebrates) and projects its axon out of the CNS to innervate a muscle. (Figure 1–15; Figure 8–9)

motor pool A cluster of motor neurons that innervate the same muscle. (Figure 8–6)

motor protein A protein that converts energy from ATP hydrolysis to movement along the cytoskeletal polymers.

motor system The collected parts of the nervous system that control the contraction of skeletal muscles and thereby enable movement and maintain body posture.

motor unit A motor neuron and the set of muscle fibers it innervates. (Figure 8–6)

motor unit size The number of muscle fibers a motor neuron innervates.

mount A posture that male rodents assume when sexually aroused. It facilitates sexual intercourse.

MrgprA3 A G-protein-coupled receptor that is activated by the pruritogen chloroquine.

α-MSH (α-melanocyte-stimulating hormone) A neuropeptide released by POMC neurons in the arcuate nucleus that reduces food intake.

mTOR (mammalian target of rapamycin) A key protein in intracellular signaling pathways that plays an important role in regulating protein translation. (Figure 11–45)

Müller glia A glial cell in the retina where the conversion of all-trans retinal to 11-cis retinal occurs to assist the recovery process in cones.

multi-electrode array A device used to record the spiking activities of many individual neurons. The electrodes can be arrayed either horizontally or vertically. (Figure 4–47; Figure 13–33)

multiple sclerosis (MS) A common adult-onset CNS demyelinating disease, it is characterized by inflammatory plaques in the white matter caused by immune cell attack of myelin. The cause is still mostly unknown.

multipolar Having more than two processes leaving the cell body.

muscarinic AChR See **acetylcholine receptor (AChR)**.

muscimol A mushroom-derived toxin that is a potent activator of the GABA_A receptor.

muscle fiber A muscle cell.

muscle spindle A special apparatus in muscle cells that sense muscles stretches. It has embedded endings of peripheral branches of the proprioceptive somatosensory neurons. (Figure 1–19; Figure 6–63)

mushroom body A second-order olfactory center for odor-mediated learning and memory in the insect brain, it and the lateral horn are the two major output sites for projection neuron axons. (Figure 6–27; Figure 10–29)

MuSK A muscle-specific receptor tyrosine kinase, it acts together with LRP4 as an agrin receptor to promote acetylcholine receptor clustering. (Figure 7–24)

mutation A change in DNA, including the insertion, deletion, or alteration of one or more base pairs.

myelin sheath Cytoplasmic extensions of oligodendrocytes and Schwann cells, they wrap around the axons with multi-layered glial plasma membrane to increase resistance and decrease capacitance for action potential propagation. See also **axon myelination**. (Figure 2–26; Figure 2–27)

myofibril A thread-like longitudinal structure in muscle cells composed of repeating sarcomeres and responsible for muscle contraction. (Figure 8–3)

myosin An F-actin-based motor protein. (Figure 8–3)

Na⁺-K⁺ ATPase A pump that uses energy derived from ATP hydrolysis to pump Na⁺ out of a cell and K⁺ into a cell against their respective electrochemical gradients. It helps maintain the Na⁺ and K⁺ concentration differences across the membrane. (Figure 2–12)

β2 nAChR A subunit of nicotinic acetylcholine receptors that, among other functions, is essential for cholinergic retinal wave propagation. See also **acetylcholine receptor (AChR)**.

narcolepsy A disorder characterized by difficulty staying awake during the day, especially following moments of happiness or excitement. It is caused either by a deficiency of the neuropeptide hypocretin or by dysfunction of hypocretin-expressing neurons.

nasal (in retinal map) In the direction of the nose.

natural selection A key mechanism of evolution, it is the process by which genetic variations that confer individuals a better chance of reproductive success become more common in a population over time. (Figure 12–1)

nature In the context of *nature versus nurture*, ‘nature’ is the contribution of genetic inheritance to brain function and behavior.

nematocin *C. elegans* ortholog of vertebrate oxytocin and vasopressin. (Figure 9–45)

neocortex The largest part of the mammalian cerebral cortex, it typically contains six layers and is evolutionarily the newest part of the cerebral cortex.

Nernst equation An equation that relates the equilibrium potential of an ion to the concentrations of the ion on the two sides of a membrane.

nerve A discrete bundle of axons in the peripheral nervous system.

nerve growth factor (NGF) A prototypical neurotrophin, it is a target-derived secreted protein that supports the survival and axon growth of sensory and sympathetic neurons. (Figure 7–31; Figure 7–32)

nerve impulse Historical name for transient changes in membrane potential that propagate along axons, it is the same as action potential.

netrin/Unc6 Homologous secreted proteins originally identified by biochemical purification (netrins in vertebrates) and genetic screen (Unc6 in *C. elegans*). They are widely used axon guidance cues first discovered in the context of midline guidance in both *C. elegans* and vertebrates. (Figure 5–10)

neural circuit An ensemble of interconnected neurons that act together to perform specific functions.

neural crest cells A special group of cells at the junction of the dorsal neural tube and the overlying epidermal cells. They migrate away from the neural tube to produce diverse cell types, including cells of the peripheral nervous system. (Figure 7–2)

neural plasticity Changes of the nervous system in response to experience and learning.

neural plate The layer of ectodermal cells overlaying the notochord that invaginates and gives rise to the neural tube during neurulation. (Figure 7–2)

neural progenitor A dividing cell that gives rise to neurons and glia. In vertebrates, it is usually located near the ventricle in the developing vertebrate CNS. (Figure 7–4)

neural prosthetic device A device that can substitute a sensory or motor function that has been disrupted due to an injury or a disease. For example, population activity of neurons in the motor cortex can be used to control an external device such as a robotic arm or a computer cursor to help patients who suffer from paralysis or motor neuron diseases. (Figure 8–29)

neural tube A hollow tube surrounded by layers of neuroectodermal cells, it is the embryonic precursor to the vertebrate CNS. (Figure 7–2)

neuraxis Axis of the CNS. The rostral-caudal neuraxis follows the curvature of the embryonic neural tube; the dorsal-ventral neuraxis is perpendicular to the rostral-caudal neuraxis. (Figure 1–8)

neurexin A protein on the presynaptic membrane that mediates synaptic adhesion. A major binding partner is neuroligin. (Figure 7–25)

neuroblast A neuronal progenitor.

neurodegenerative disorders Disorders characterized by progressive neuronal dysfunction, including loss of synapses, atrophy of dendrites and axons, and death of neurons.

neuroendocrine system The collected parts of the nervous system that control the secretion of hormones to regulate an animal's physiology and behavior in response to sensory stimuli and brain states.

neuroethology A branch of science that emphasizes the study of animal behavior in the natural environment.

neurofascin An immunoglobulin superfamily molecule that, among other functions, serves as a cue in Purkinje cells to instruct targeting of basket cell axons and presynaptic terminals to the correct subcellular domain.

neurofibrillary tangle An intracellular fibril consisting of an abnormal accumulation of hyper-phosphorylated tau, a microtubule-binding protein. (Figure 11–2)

neurofilament An intermediate filament (a cytoskeletal polymer with a diameter between F-actin and microtubules) in vertebrate neurons. It is concentrated in axons and provides stability to axons.

neurogenic inflammation Inflammation triggered by release of neuropeptides such as substance P and calcitonin gene-related peptide from the peripheral terminals of sensory neurons.

neuroligin A protein on the postsynaptic membrane that mediates synaptic adhesion. A major binding partner is neurexin. (Figure 7–25)

neuromuscular junction The synapse between a motor neuron's presynaptic terminals and a skeletal muscle cell. (Figure 3–1; Figure 7–28)

neuron (nerve cell) An electrically excitable cell that receives, integrates, propagates, and transmits information as the working unit of the nervous system.

neuron doctrine The principle that individual neurons are the working units of the nervous system.

neuronal polarity The distinction between axons and dendrites.

neuronal process Cytoplasmic extension of a neuron.

neuropeptide A polypeptide a few to a few dozen amino acids in length that acts as a neurotransmitter.

neuropil A structure composed mostly of synapses.

neuropilin-1 (Nrp1) A co-receptor for semaphorin.

neurotransmitter reuptake The process by which neurotransmitters in the synaptic cleft are transported either into nearby glial cells or back into the presynaptic cytosol and into synaptic vesicles. (Figure 3–12)

neurotransmitters Molecules that are stored in synaptic vesicles (or dense-core vesicles in the case of neuropeptides) in the presynaptic terminals, are released into the synaptic cleft triggered by presynaptic depolarization, and activate ionotropic or metabotropic receptors on a postsynaptic target cell. (Figure 3–16; Table 3–2)

neurotrophic hypothesis The idea that the survival of developing neurons depends on neurotrophins produced by the neurons' postsynaptic targets.

neurotrophin-3 (NT3) See **neurotrophins**.

neurotrophin-4 (NT4) See **neurotrophins**.

neurotrophins A family of secreted signaling proteins that regulate the survival, morphology, and physiology of target neurons through binding to specific receptors on those neurons. Mammalian neurotrophins include nerve growth factor (NGF), brain-derived neurotrophic factor (BDNF), neurotrophin-3 (NT3), and neurotrophin-4 (NT4). (Figure 3–39; Figure 7–32). See also **Trk receptors, p75NTR**.

neurulation The developmental process in vertebrate embryos leading to formation of the neural tube, which gives rise to the nervous system. (Figure 7–2)

nicotinic AChR See **acetylcholine receptor (AChR)**.

Nissl stain A stain that labels RNA and thus highlights the rough endoplasmic reticulum in cytoplasm. Nissl stains are basic (that is, proton-accepting, positively charged) dyes such as cresyl violet that bind to RNA molecules (which are negatively charged). (Figure 13–18)

NMDA receptor A glutamate-gated ion channel that conducts Na^+ , K^+ , and Ca^{2+} and can be activated by the drug NMDA (N-methyl-D-aspartate). Its opening requires both binding of glutamate and postsynaptic depolarization. It is a heterotetramer of two GluN1 subunits encoded by a single gene, and two GluN2 subunits, of which there are four variants (GluN2A, GluN2B, GluN2C, GluN2D) each encoded by separate genes. (Figure 3–24; Figure 3–25)

nociception The sense of pain.

nociceptive neuron A somatosensory neuron that senses pain.

nodes of Ranvier Periodic gaps in the myelination of an axon, usually 200 μm to 2 mm apart, where the axon surface is exposed to the extracellular ionic environment. They contain high concentrations of voltage-gated Na^+ and K^+ channels that regenerate action potentials. (Figure 2–26)

nonhomologous end joining An endogenous DNA repair system, it re-joins the two ends of a DNA molecule with a double-strand break. It often creates a small deletion or duplication at the breakpoint as a result of the repair process. (Figure 13–8)

non-spiking neuron A neuron that uses graded potentials rather than action potentials to transmit information.

non-synonymous substitutions Nucleotide changes in DNA that result in corresponding amino acid changes in the protein encoded by that DNA.

norepinephrine A monoamine neuromodulator derived from dopamine. (Figure 11–20; Table 3–2)

northern blot A method for determining the amount of a specific RNA in an RNA mixture. RNAs are separated by gel electrophoresis and are then transferred to a membrane; labeled nucleic acid probes are then hybridized to the membrane to visualize specific RNA molecules that hybridize to the probe. It can be used to determine RNA expression patterns. (Figure 6–9)

Notch A transmembrane receptor widely involved in diversifying cell fate during development. Binding of a ligand to Notch triggers proteolytic cleavage of Notch in the transmembrane domain to release the Notch intracellular domain, which can then enter the nucleus to regulate gene expression. (Figure 7–7)

notochord A midline mesodermal structure in vertebrate embryos ventral to the spinal cord that produces secreted cues for patterning the spinal cord. (Figure 7–2; Figure 7–8)

NREM sleep Non-rapid eye movement (NREM) sleep, or sleep stages other than REM sleep. (Figure 8–51)

nucleus accumbens The major part of the ventral striatum, it receives input preferentially from the prefrontal cortex, thalamus, hippocampus, and amygdala. (Figure 11–31)

nucleus laminaris (NL) A brainstem nucleus in the barn owl that analyzes interaural time differences. It is analogous to the medial superior olive nucleus in mammals.

nucleus of the solitary tract (NTS) A nucleus in the brainstem that receives input from the taste system as well as sensory information from internal organs. (Figure 6–35)

null direction The direction of stimulus motion that elicits the lowest firing rate of a direction-sensitive visual system neuron.

Numb A *Drosophila* protein that is segregated asymmetrically to daughter cells during sensory organ precursor and neuroblast

divisions. It is essential for conferring different fates to the two daughter cells of an asymmetric division. (Figure 7–6)

nurture In the context of *nature versus nurture*, ‘nurture’ is the contribution of environmental factors to brain function and behavior.

occipital lobe One of the four cerebral cortex lobes; it is located at the back of the brain. (Figure 1–23)

octopamine A neurotransmitter in some invertebrate nervous systems that is chemically similar to norepinephrine in vertebrates.

ocular dominance Preference for receiving and/or representing visual input from one eye over the other eye. In the primary visual cortex of some mammals, such as cats and monkeys, cells in the same vertical columns share the same ocular dominance, thus producing ocular dominance columns. (Figure 4–43)

ocular dominance column See **ocular dominance**.

odds ratio In genetics, a measure of the effect of a genetic variant on the likelihood of having a particular trait, such as a disease. It is calculated by dividing the probability of having the trait among people with the genetic variant by the probability of having the trait among people without the genetic variant.

odorant A molecule that elicits olfactory perception, it is usually volatile.

odorant receptor A receptor on the surface of olfactory cilia that binds odorants. (Figure 6–9)

OFF bipolar A bipolar cell that expresses ionotropic glutamate receptors and is depolarized by glutamate release from photoreceptors. Its membrane potential changes follow the sign of photoreceptors such that it is hyperpolarized by light. (Figure 4–25)

Ohm's law An equation that relates current (I) to voltage (V) and resistance (R): $I = V/R$.

olfactory bulb The first olfactory processing center in the vertebrate brain. (Figure 6–3; Figure 6–17)

olfactory cilium A dendritic branch of an olfactory receptor neuron enriched for odorant receptors. (Figure 6–3)

olfactory cortex Brain regions that receive direct input from mitral/tufted cells, including the anterior olfactory nucleus, piriform cortex, olfactory tubercle, cortical amygdala, and entorhinal cortex. (Figure 6–19)

olfactory epithelium The epithelial layer in the nose that houses the olfactory receptor neurons. (Figure 6–3)

olfactory processing channel A discrete information processing unit in the olfactory system consisting of olfactory receptor neurons (ORNs) that express a given odorant receptor, the glomerular target of those ORNs, and second-order neurons that send dendrites to the same glomerulus.

olfactory receptor neuron (ORN) The primary sensory neuron in the olfactory system, it converts odorant binding to odorant receptor proteins into an electrical signal that is relayed to the brain via its axon. (Figure 6–3)

oligodendrocyte A glial cell in the CNS that wraps axons with its cytoplasmic extension to form myelin sheath. (Figure 1–9)

ommatidium A repeating unit of the arthropod compound eye. In *Drosophila*, each ommatidium contains eight photoreceptors. (Figure 5–35)

ON bipolar A bipolar cell that expresses metabotropic glutamate receptors and is inhibited by glutamate release from photoreceptors. Its membrane potential changes are opposite in sign to those of the photoreceptors such that it is depolarized by light. (Figure 4–25)

open probability The proportion of time that an individual ion channel is open and able to conduct current.

operant conditioning A form of learning in which a subject associates performance of a specific action (e.g. pressing a lever) with a particular outcome, such as delivery of a reinforcer (e.g. food) or a punishment (e.g. an electrical shock).

opioid receptors A subfamily of G-protein-coupled receptors that serve as receptors for opioids, including morphine and endogenous opioid neuropeptides. They are widely distributed across the nervous system.

opioids Molecules that have effects similar to opiates such as morphine. They include opiates from opium poppy and endogenous neuropeptides such as encephalin, endorphin, and dynorphin.

opsin A member of a family of G-protein-coupled receptors expressed in photoreceptors of multicellular organisms, it is associated with retinal and converts photon absorption to the activation of a trimeric GTP-binding protein. In microbes, it is a member of light-induced channels or pumps, which are not G-protein-coupled receptors.

optic chiasm The midline structure where a fraction of retinal ganglion cell axons cross to the side of the brain contralateral to the eye of origin. (Figure 4–35)

optic lobe The part of the insect brain that consists of the retina, lamina, medulla, and lobula complex and that is used to analyze visual signals. (Figure 5–35)

optic nerve The bundle of retinal ganglion cell axons, it sends visual information from the eye to the brain. (Figure 4–35)

optic tract The bundles of retinal ganglion cell axons distal to the optic chiasm. (Figure 4–35)

optical imaging An approach that uses changes of fluorescence or other optical properties as indicators of neuronal activity.

optogenetics The set of methods used to manipulate neuronal activity by using light to activate a genetically encoded effector, most commonly microbial opsins (e.g. channelrhodopsin-2, archaerhodopsin, halorhodopsin). (Figure 13–45)

organ of Corti An organ in the cochlea that consists of hair cells, the surrounding support cells, and the basilar membrane. (Figure 6–45)

organization-activation model A central principle in endocrinology, it proposes that sex hormones have two different types of effects: ‘organizational’ effects during development, which configure the brain in a sex-typical manner, and ‘activational’ effects in adults, which stimulate male- or female-typical sexual behaviors. (Figure 9–25)

otolith organ A sensory organ in the vestibular system that senses linear acceleration and stationary head tilts. (Figure 6–59)

outer radial glia (oRG) A type of radial glia whose cell bodies are located in the subventricular zone. They serve along with ventricular zone radial glia as neural progenitors. They are greatly expanded in number in human neocortex compared with mouse neocortex and likely contribute to increased neuronal production in mammals with large neocortices. *See also radial glia.* (Figure 12–37)

outer segment A cytoplasmic extension of a rod or a cone, it contains a highly specialized photon detection apparatus made of tightly stacked membrane disks enriched in opsins. (Figure 4–2)

outgroup A group of organisms that is closely related to but falls outside of a set of organisms of interest. It is used as a reference group in determining the phylogenetic relationships among a set of organisms.

ovariectomized female A female from which the ovaries have been removed.

oxytocin A hormone secreted by hypothalamic neurons in the posterior pituitary and a neuropeptide released by some CNS neurons. It regulates maternal and social behavior.

P pathway A visual processing pathway from the retina to the visual cortex that originates from retinal ganglion cells with small receptive fields and engages lateral geniculate nucleus cells in the parvocellular layers. It carries information about high-acuity and color vision. (Figure 4–48)

p75NTR A 75 kilodalton neurotrophin receptor that has a low affinity for all neurotrophins and is also a receptor for all proneurotrophins. (Figure 7–32)

pacemaker A cell that can produce rhythmic output in the absence of input.

Pacinian corpuscle An encapsulated structure closely associated with the ending of the rapidly adapting type II (RAII) LTMR. (Figure 6–64)

PALM *See super-resolution fluorescence microscopy.*

parabiosis The joining of the circulatory systems of two animals so that they have limited exchange of substances in systemic circulation.

parabrachial nucleus A brainstem nucleus that transmits ascending signals from the visceral sensory system and pain somatosensory system to the thalamus, amygdala, hypothalamus, and brainstem autonomic centers. (Figure 6–70; Figure 8–33)

paracrine Of or related to a form of signaling in which a recipient cell receives a signal produced by nearby cells.

parallel fiber The portion of the axon of a cerebellar granule cell that runs in parallel to the pial surface and crosses Purkinje cell dendrites at a right angle. (Figure 8–20)

parasympathetic nervous system A branch of the autonomic nervous system that facilitates energy conservation. Activation of the parasympathetic nervous system slows down the heart rate, decreases blood flow, constricts airways in the lung, and stimulates salivation and digestion. (Figure 8–31; Figure 8–32)

paraventricular hypothalamic nucleus (PVH) A hypothalamic nucleus involved in multiple physiological functions, including the release of oxytocin and vasopressin into the bloodstream through axonal projections in the posterior pituitary and the descending control of autonomic nervous system functions. (Figure 8–43)

parietal lobe One of the four cerebral cortex lobes, it is located behind the frontal lobe and above the occipital lobe. (Figure 1–23)

Parkinson’s disease (PD) A common neurodegenerative disease caused by death of substantia nigra dopamine neurons. It primarily affects movement control, with symptoms that include shaking, rigidity, slowness, and difficulty walking. (Figure 11–16)

parthenogenesis A reproductive process in which embryos develop from unfertilized eggs and which therefore does not involve exchange of genetic materials.

passive electrical properties Membrane properties in the absence of voltage-dependent conductance. Two salient examples are: (1) a sharp change of electrical signal (e.g. a current pulse) becomes more spread temporally as the signal travels along a neuronal process because of membrane capacitance; (2) the magnitude of electrical signal becomes attenuated across a distance because of membrane conductance. They are also called cable properties. (Figure 2–16)

passive transport Movement of a solute across a membrane down its electrochemical gradient via a channel or a transporter. (Figure 2–8)

patch clamp recording An electrophysiological recording technique that utilizes a glass electrode (patch pipette) to form a high-resistance seal with the membrane. It has several variants, including cell-attached patch, excised patch, and whole-cell recording. (Figure 13–37)

patch pipette See **patch clamp recording**.

path-integration strategy A navigational strategy in which animals use the speed, duration, and direction of their own movement to calculate their current position with respect to their starting position.

Pax6 A member of the Pax family of transcription factors, it contains a homeobox and a paired box. It regulates the patterning of the cerebral cortex and spinal cord and is required for eye development in mammals. Its *Drosophila* homolog is Eyeless. See also **Eyeless**.

PDZ domain Acronym for a domain shared by PSD-95, Discs large (a *Drosophila* protein implicated in cell proliferation and associated with postsynaptic density), and ZO-1 (an epithelial tight junction protein). It is a protein–protein interaction domain that binds to a specific protein sequence motif that is present at the C-terminal end of many transmembrane receptors.

percept A specifically perceived object or the brain representation of the object.

perforant path Axons of neurons in the superficial layer of the entorhinal cortex that project to the hippocampus. (Figure 10–6)

peri-stimulus time histogram (PSTH) A graph that plots firing rates of neurons as a function of time after stimulus onset.

periaqueductal gray (PAG) A midbrain gray matter structure surrounding the cerebral aqueduct. It serves many functions including the descending control of pain and the execution of defensive behavior such as freezing. (Figure 6–70)

periglomerular cell A member of diverse types of interneurons that receive direct input from olfactory receptor neuron (ORN) axons or from apical dendrites of mitral cells and that send (mostly inhibitory) output to targets within the same glomerulus, or in nearby glomeruli. (Figure 6–17)

Period A fruit fly gene discovered based on mutations that speed up, slow down, or disrupt circadian rhythms. It encodes a protein that participates in the negative regulation of its own transcription, and its mammalian homologs serve a similar function. (Figure 8–45)

permeability The ability of a membrane to conduct specific ions, determined principally by the number of open channels capable of conducting those ions.

perturbation experiment An experiment in which key parameters in a biological system are altered, usually under the experimenter's control, in order to study the consequences.

pharmacodynamics The effects of a drug in the body, including the intended effects on target molecules and processes as well as the unintended side effects.

pharmacokinetics The effects of the body's biological processes on a drug, including the drug's absorption, distribution, metabolism, and excretion.

phase locking A property whereby the spikes of auditory neurons occur at a specific phase of each cycle of a sound wave. (Figure 6–51)

phasic Of a neuronal firing pattern, bursts of action potentials in response to specific stimuli.

pheromone A substance produced by an individual to elicit a specific reaction from other individuals of the same species.

phosphodiesterase (PDE) An enzyme that hydrolyzes cyclic AMP (cAMP) to AMP, or cGMP to GMP.

phospholipase C (PLC) A membrane-associated enzyme that is activated by G_q and cleaves inositol-phospholipids to produce inositol 1,4,5-triphosphate (IP_3) and diacylglycerol (DAG). (Figure 3–34)

photoreceptor A cell that converts light into electrical signals. (Figure 4–2; Figure 12–23)

phototaxis Movement toward or away from a light source.

phototransduction The biochemical reactions triggered by photon absorption. (Figure 4–10)

phrenology A discipline created by Franz Joseph Gall with the goal of mapping the functions of brain areas by studying the shape and size of bumps and ridges on the skull, which were thought to be correlated with an individual's talents and character traits. (Figure 1–22)

phylogenetic tree A branching diagram showing the relationships among different organisms. It is constructed based on the similarities and differences of different organisms' traits, such as nucleotide and protein sequences. (Figure 12–2)

picrotoxin A plant toxin that is a potent blocker of the $GABA_A$ receptor.

Plezo A mechanotransduction channel with over 30 transmembrane segments for each subunit. (Figure 6–66)

pigment cell A cell in the pigment epithelium layer of the retina adjacent to the outer segments of photoreceptors that reflects light and converts all-*trans* retinal back to 11-*cis* retinal to assist the recovery process in rods.

piriform cortex The largest olfactory cortical region, it is a three-layered cortex separated from more dorsally located neocortex by the rhinal sulcus. (Figure 6–19)

pituitary The endocrine center of the brain, it is located ventral to the hypothalamus. The posterior pituitary contains axon terminals of hypothalamic neurons that directly release hormones into the bloodstream. The anterior pituitary contains endocrine cells that release hormones into the bloodstream in response to prehormones originated from hypothalamic neurons and transmitted by specialized portal vessels. (Figure 8–35)

place cell A hippocampal cell that fires maximally when the animal is at a particular place in an environment.

place field The physical location in an environment that elicits maximal firing of a particular place cell.

placebo effect In the context of pain perception, the phenomenon whereby the perception of pain can be reduced in some patients by the mistaken belief that they have received a treatment thought to reduce pain.

plasma membrane dopamine transporter (DAT) See **plasma membrane monoamine transporters**.

plasma membrane monoamine transporters (PMATs) A family of proteins on the presynaptic membrane that transport serotonin [serotonin transporter (SERT)], dopamine [dopamine transporter (DAT)], or norepinephrine [norepinephrine transporter (NET)] from synaptic cleft into the presynaptic cytosol. (Figure 11–24). See also **plasma membrane neurotransmitter transporter**.

plasma membrane neurotransmitter transporter A transmembrane protein on the presynaptic or glial plasma membrane that transports neurotransmitters from the extracellular space into the cell using energy from the co-transport of Na^+ down its electrochemical gradient. (Figure 3–12)

plexin A member of a class of proteins that serve as receptors for the axon guidance cues, semaphorins.

pluripotent cell A cell that has the potential to develop into all cell types of an embryo.

PNS (peripheral nervous system) Neural tissue and cells outside the central nervous system (CNS), including the nerves that connect the CNS with the body and internal organs as well as isolated ganglia outside of the CNS.

Poisson distribution A discrete probability distribution in which the frequency (f) that k events occur can be determined by a single parameter λ (the mean frequency of occurrence, which equals the product of n and p in the binomial distribution). $f(k; \lambda) = (\lambda^k / k!) e^{-\lambda}$. It is an approximation of the binomial distribution when n is large and p is small. (Box 3–1)

polyadenylation The process by which a long sequence of adenine nucleotides is added to the 3' end of the mRNA. (Figure 2–2)

polymerase chain reaction (PCR) A highly sensitive DNA amplification technique that uses a pair of oligonucleotide primers to amplify the DNA segment between the sequences corresponding to the primers through cycles of DNA replication.

polymodal neuron In the somatosensory system, a neuron that responds to stimuli of more than one sensory modality.

polymorphism In the context of genetics, a DNA sequence variation among individuals of the same species.

POMC neuron A neuron in the arcuate nucleus that expresses pro-opiomelanocortin (POMC), a precursor protein for multiple peptides including the anorexigenic peptide α -melanocyte-stimulating hormone (α -MSH). (Figure 8–42)

pons The middle part of the brainstem caudal to the midbrain and rostral to the medulla. (Figure 1–8)

population vector (in movement control) The sum of the preferred direction vectors of a population of neurons weighted by the firing rate of each neuron. The preferred direction of a neuron is a vector in a three-dimensional space pointing in the direction towards which movement elicits the highest firing rate of the neuron. (Figure 8–27)

positional cloning A molecular genetic technique that uses molecular and genetic markers on specific chromosomes to identify a gene that causes a particular phenotype or disease.

positive selection The process by which an allele that is beneficial to an organism becomes more prevalent in a population.

positron emission tomography (PET) A non-invasive three-dimensional imaging technique for measuring the distribution of positron-emitting probes introduced into the body.

posterior pituitary See **pituitary**.

postganglionic neuron A neuron whose cell body is located in a sympathetic or parasympathetic ganglion in the peripheral nervous system and whose axon innervates effectors such as smooth muscle, cardiac muscle, and glands. (Figure 8–32)

postsynaptic specialization A structure on a postsynaptic target cell that is adjacent to a presynaptic terminal, it is enriched for neurotransmitter receptors as well as signaling and scaffolding molecules. It is also called postsynaptic density because it is electron dense in electron microscopic images.

Potocki-Lupski syndrome A neurodevelopmental disorder characterized by mild intellectual disability and autistic symptoms. It is caused by duplication of a chromosome segment (that includes *Rai1* and many other genes) reciprocal to the common deletion that causes Smith-Magenis syndrome.

power stroke The process by which myosin and actin filaments move relative to each other. It involves the conversion of chemical energy from ATP hydrolysis into mechanical force by the myosin motor. (Figure 8–4)

precedence effect The ability of a first-arriving sound to suppress the perception of later-arriving sounds.

preferred direction The direction of stimulus motion that elicits the highest firing rate of a direction-sensitive visual system neuron.

prefrontal cortex A neocortical area anterior to the motor cortex, it is an executive control center that integrates multisensory information, mediates working memory, and performs complex executive functions such as goal selection and decision making.

preganglionic neuron A neuron whose cell body is located within the CNS and whose axon synapses onto the postganglionic neurons in the sympathetic or parasympathetic ganglion. (Figure 8–32)

premotor cortex Areas of motor cortex anterior to the primary motor cortex. Its neurons send axons primarily to primary motor cortex.

premotor neuron A spinal cord or brainstem neuron that is presynaptic to motor neurons and thereby participates directly in controlling the firing of the motor neurons. (Figure 8–10)

presenilin One of two members of a family (consisting of presenilin-1 and presenilin-2) of multi-pass transmembrane proteins that function as subunits of the γ -secretase complex. They were originally identified based on mutations that cause familial Alzheimer's disease. (Figure 11–5)

prestin A protein that mediates electromotility in the cochlear outer hair cells.

presynaptic facilitation The process by which neurotransmitter release from cell A onto the presynaptic terminal of cell B leads to an increase in neurotransmitter release from cell B.

presynaptic inhibition The process by which neurotransmitter release from cell A onto the presynaptic terminal of cell B leads to a decrease in neurotransmitter release from cell B.

presynaptic terminal A structure at the end (or along the trunk) of an axon that is specialized for releasing neurotransmitters onto target cells. (Figure 1–9)

pretectum A brainstem structure that receives retinal ganglion cell axon input and regulates pupil, lens, and eye movement reflexes. (Figure 4–35)

primary antibody An antibody that selectively recognizes a specific protein.

primary auditory cortex (A1) The part of the cerebral cortex that first receives auditory sensory information. (Figure 6–54)

primary cilium A short, single, non-motile cilium that projects from the surface of many animal cell types and is used often as a signaling center.

primary motor cortex (M1) The part of the cerebral cortex that sends descending axons directly to motor neurons to control muscle contraction. (Figure 1–25)

primary somatosensory cortex The part of the cerebral cortex that first receives somatosensory information from the body. (Figure 1–25)

primary visual cortex (V1) The visual cortical area that receives direct input from the lateral geniculate nucleus. (Figure 4–38; Figure 4–45)

principal component analysis (PCA) A statistical method used to reduce the dimensionality of a dataset. The axes of the reduced

dataset are called principal components and their orientations in the non-reduced space are selected to maximize the spread of the data along each principal component—data are most spread along the axis of the first principal component, followed by the axis of the second principal component, and so forth.

prion diseases Diseases characterized by the propagation across the brain of prion protein (PrP) that adopts a specific conformation (PrP^{Sc}), which aggregates and causes massive neurodegeneration and neuronal death. PrP^{Sc} spreads by interacting with PrP in its innocuous cellular conformation (PrP^{C}) to induce a conformational change and convert it into PrP^{Sc} . Prion diseases include scrapie in sheep and goats, mad cow disease in cows, kuru (a human disease that occurred in certain tribes that observed ritual cannibalism), and Creutzfeldt-Jakob disease (CJD, a human disease in which mutations in the *Prp* gene make PrP^{C} more prone to adopt the PrP^{Sc} conformation spontaneously). (Figure 11–13)

prion hypothesis The idea that the infectious agent in scrapie is solely proteinaceous in nature.

programmed cell death (apoptosis) A form of cell death in which a cell kills itself by initiating a cell-death program.

projection neuron A neuron with an axon that projects outside the CNS region that houses the neuron's cell body. In the insect olfactory system, it is a second-order neuron (PN) that receives input from olfactory receptor neuron (ORN) axons and sends output to higher olfactory centers, analogous to a vertebrate mitral/tufted cell. (Figure 6–27)

prokaryote A single-cell organism without a nucleus. Prokaryotes are members of one of two domains of life: eubacteria or archaea.

proprioception The sense of body position and movement.

proprioceptive neurons Somatosensory neurons that have peripheral endings embedded in the muscle spindles, tendons, and joints for sensation of muscle stretch and tension. (Figure 6–63)

prostaglandin A lipid released during inflammation, it binds to specific G-protein-coupled receptors on the peripheral terminals of nociceptive neurons. (Figure 6–71)

protein A specific sequence of amino acids linked by peptide bonds to form a chain.

protein kinase A (PKA) See **cAMP-dependent protein kinase**.

protein kinase C (PKC) A serine/threonine kinase with diverse substrates that is activated by binding of both diacylglycerol and Ca^{2+} . (Figure 3–34)

protein phosphatase An enzyme that removes phosphates from phosphorylated proteins, thus counteracting the actions of kinases.

proteinopathy A disease caused by altered protein conformations, interactions, and homeostasis.

protocadherin A member of a class of cell adhesion molecules in vertebrates whose structures and biochemical properties resemble those of cadherins.

protostomes Animals in which the mouth appears before the anus during development. They include most invertebrate phyla. *See also deuterostomes.* (Figure 12–2)

prurition The sense of itch.

pruritogen A chemical that causes the sensation of itch.

PSD-95 (postsynaptic density protein of 95 kilodalton) A postsynaptic scaffolding protein highly enriched at the glutamatergic synapse. (Figure 3–27; Figure 7–25)

pseudogene A gene that has been rendered nonfunctional by stop codons in the coding sequences or by other disrupting mutations. Such disrupting mutation(s) is prevalent in a given species.

psychometric function The quantitative relationship between a parameter of a physical stimulus and the response or perception of a subject.

psychophysical study An experimental approach that characterizes the relationship between physical stimuli and the sensations or behaviors they elicit.

psychosis The mental state characterized by hallucinations and/or delusions.

psychostimulant A drug that transiently produces euphoria and suppresses fatigue.

pump A transporter that uses external energy, such as ATP hydrolysis or light, to actively move a solute across a membrane against its electrochemical gradient. (Figure 2–10)

Purkinje cell GABAergic neuron of the cerebellar cortex with highly branched planar dendritic trees. It receives excitatory input from parallel fibers (axons of cerebellar granule cells) and climbing fibers from inferior olive neurons, and sends output to the deep cerebellar nuclei. (Figure 1–11; Figure 8–20)

pyramidal neuron A type of glutamatergic neuron that has a pyramid-shaped cell body with an apical dendrite and several basal dendrites that further branch. It is abundant in mammalian cerebral cortex and hippocampus. (Figure 1–15)

quantal hypothesis of neurotransmitter release The idea that neurotransmitters are released in discrete packages of relatively uniform size.

quantal yield The number of synaptic vesicle exocytosis events in response to a single action potential.

R-C circuit A circuit that contains both resistors and capacitors. (Figure 2–14)

RA (robust nucleus of the arcopallium) A dorsal forebrain nucleus in the songbird essential for song production. It functions downstream of the HVC. (Figure 9–21)

Rab A member of a family of small monomeric GTPases involved in intracellular vesicle trafficking.

rabies virus A neurotropic RNA virus that spreads within the nervous system of its host naturally by crossing synapses. It has been modified for the use of retrograde trans-synaptic tracing. (Figure 13–30)

radial glia Progenitor cell in the ventricular zone that extends two radial processes—one to the ventricle and the other to the pial surface of the developing cortex. These radial processes serve as substrates for neuronal migration. (Figure 7–4)

random mutagenesis See **forward genetic screen**.

random X-inactivation A process in which one of the two X chromosomes in female mammals is randomly inactivated in each cell during early development.

raphe nuclei Brainstem nuclei enriched for serotonin neurons that project widely across the brain. (Figure 8–54)

Ras A member of a family of small monomeric GTPases involved in signaling pathways necessary for cell growth and differentiation.

readily releasable pool A small subset of synaptic vesicles that are docked at the active zone, primed by an ATP-dependent process to achieve a high-energy configuration that includes pre-assembled SNARE complexes.

receptive field In the visual system, the area of the visual field that influences the activity of a given neuron. In the somatosensory system, the area of the body where stimuli can influence the firing of a neuron.

receptor A protein that binds and responds to a specific signaling molecule.

receptor potential A type of graded potential induced at the peripheral endings of sensory neurons by sensory stimuli.

receptor tyrosine kinase (RTK) A transmembrane protein with an N-terminal extracellular ligand-binding domain and a C-terminal intracellular tyrosine kinase domain. Upon ligand binding, receptor tyrosine kinases add phosphates to tyrosine residues of target proteins.

recording electrode An electrode used to measure membrane potential changes.

recovery (photoreceptor) The process by which light-activated photoreceptor cells return to the dark state. (Figure 4-11)

recurrent (cross) inhibition A circuit motif in which two parallel excitatory pathways mutually inhibit each other via inhibitory interneurons. (Figure 1-21)

refractory period A time window after an action potential during which another action potential cannot be initiated. (Figure 2-25)

regeneration (axon) Re-extension of axon after injury, including formation of synaptic connections with their original partners.

regenerative Having the property of propagating without attenuation in amplitude, it applies to action potentials. (Figure 2-25)

regulator of G protein signaling (RGS) A protein that acts as a GTPase activating protein for a trimeric GTP-binding protein.

release probability The probability that an active zone will release one or more synaptic vesicles following an action potential.

releasers The essential features of a stimulus that activate a fixed action pattern.

REM sleep A stage of sleep that is characterized by rapid eye movement. (Figure 8-51)

repellent A molecular cue that guides axons away from its source. (Figure 5-9)

reserpine A first-generation antipsychotic drug, it is an inhibitor of monoamine oxidase.

reserve pool A large subset of vesicles in the axon terminal available to replenish the readily releasable pool.

resistance (R) The degree to which an object or substance opposes the passage of electrical current, it is the inverse of conductance: $R = 1/g$.

resistor An electrical element through which passage of current is limited. Current flow through a resistor produces a voltage difference across its two terminals. (Figure 2-13)

responder transgene In binary expression, it is the transgene containing the coding sequence for the protein or RNA of interest, along with binding or recombinase sites for the transcription factor or recombinase, respectively, encoded by the driver transgene. (Figure 13-13)

resting potential The membrane potential of a neuron at rest (i.e. in the absence of action potentials or synaptic input), which is typically between -50 and -80 millivolts relative to the extracellular fluid. (Figure 2-11)

reticular theory The idea that the processes of nerve cells fuse and form a giant net that constitutes the working unit of the nervous system. It has been mostly disproven (with the exception of electrical synapses, that allow limited exchange of ions and small molecules between partner neurons).

retina A layered structure at the back of the vertebrate eye made of five major neuronal types (photoreceptors, horizontal cells, bipolar cells, amacrine cells, and retinal ganglion cells) and support cells. Collectively, these cells convert light into electrical signals, extract biologically relevant signals from the outputs of photoreceptors, and transmit these signals to the brain. (Figure 4-2)

retinal A chromophore covalently linked with an opsin, it changes its configuration after photon absorption. (Figure 4-6; Figure 12-20)

retinal ganglion cell (RGC) The output cell of the retina that transmits information from the eye to the brain. (Figure 4-2; Figure 4-28)

retinal wave The spread of spontaneous excitation of retinal neurons, including retinal ganglion cells and amacrine cells, across the developing retina. (Figure 5-21)

retinotopy The topographical arrangement of cells in the visual pathway according to the position of the retinal ganglion cells that transmit signals to them.

retrieval (of memory) The recall of a memory.

retrograde From the axon terminal to the cell body.

retrograde flow The flow of F-actin from the leading edge of the growth cone to its center powered by the myosin motor. It contributes to dynamic changes of growth cone shape. (Figure 5-15)

retrograde tracer A molecule used to trace axonal connections. It is taken up primarily by axon terminals and transported back to the cell bodies. (Figure 13-27)

retrograde trans-synaptic tracing See **trans-synaptic tracing**.

Rett syndrome A neurodevelopmental disorder in girls caused by disruption of an X-linked gene encoding methyl-CpG binding protein 2 (MeCP2). Patients usually develop normally for the first 6–18 months. Their development then slows, arrests, and regresses, with severe deficits that include social withdrawal, loss of language, and motor symptoms. See also **MeCP2**.

reversal potential (E_{rev}) The membrane potential at which the current flow through an ion channel changes direction.

reverse genetics The strategy or process of disrupting a pre-designated gene to identify its loss-of-function phenotypes. (Figure 13-4)

reverse signalling The process by which a protein that ‘normally’ functions as a ligand functions as a receptor and a protein that ‘normally’ functions as a receptor functions as a ligand. The originally discovered (‘normal’) signalling mode is referred to as forward signalling. (Figure 5-12)

reward prediction error A theoretical value representing the difference between a received reward and the predicted reward. It is represented by a population of midbrain dopamine neurons.

rhabdomeric type A type of photoreceptor in which the apical surface folds into microvilli that house opsins. (Figure 12-22)

Rho A member of a family of small monomeric GTPases involved in actin cytoskeleton regulation.

rhodopsin A photosensitive molecule in the rod consisting of opsin covalently attached to retinal, a chromophore derived from vitamin A. (Figure 4-6)

RNA editing A post-transcriptional modification that alters a nucleotide sequence of an RNA transcript after it is synthesized.

RNA splicing The process by which introns are removed from RNA molecules. In the case of alternative splicing a subset of exons is removed as well. (Figure 2–2)

RNA-seq A technique in which RNA molecules from a given tissue are sequenced one by one in a massively parallel fashion using next generation sequencing methods. It is used to obtain information about which genes are expressed and at what level in a genome-wide scale.

RNAi (RNA Interference) A genetic technique for knocking down the expression of a gene of interest by producing a double-stranded RNA with a sequence corresponding to that of the gene of interest. (Figure 13–9)

Robo (Roundabout) A receptor for Slit. (Figure 7–13)

rod A rod-shaped photoreceptor in the vertebrate retina, it is a very sensitive photon detector specialized for night vision. (Figure 4–2)

rostral-caudal (anterior-posterior) Of a body axis, from head to tail.

rTA See tTA.

Ruffini ending An encapsulated structure closely associated with the ending of the slowly adapting type II (SAII) LTMR. (Figure 6–64)

ryanodine receptor A Ca^{2+} channel on the ER membrane that is activated by an increase in intracellular Ca^{2+} concentration and that thus amplifies cytosolic Ca^{2+} signals. It is also activated by the plant-derived agonist ryanodine. (Figure 3–41)

saccade A rapid movement of the eyes between fixation points.

sagittal section A section plane that is perpendicular to the medial-lateral axis.

saltatory conduction The process by which an action potential in a myelinated axon ‘jumps’ from one node of Ranvier to the next. (Figure 2–26)

salty A taste modality that functions primarily to reveal the salt content of food. It is usually appetitive at a low concentration and aversive at a high concentration.

sarcomere The contractile element of a myofibril composed of overlapping F-actin (thin filaments) and myosin (thick filaments). (Figure 8–3)

sarcoplasmic reticulum A special endoplasmic reticulum derivative that extends throughout muscle cells. Ca^{2+} released from the sarcoplasmic reticulum mediates the excitation–contraction coupling. (Figure 8–5)

Satb2 A transcription factor that specifies callosal projection neuron identity. (Figure 7–10)

savings A phenomenon whereby less effort is required for an animal to re-learn something it has previously learned and then forgotten.

scanning electron microscopy (SEM) A form of electron microscopy that produces images by scanning the surface of a biological specimen, collecting information regarding the interaction of the electron beam with the surface areas.

Schaffer collateral An axonal branch of a hippocampal CA3 pyramidal neuron that synapses onto CA1 pyramidal neurons. (Figure 10–6)

schizophrenia A psychiatric disorder characterized by a set of positive symptoms (those not present in control people, such as hallucinations and delusions), negative symptoms (those, such as social withdrawal and lack of motivation, that reflect an absence

of some characteristic that is normally present), and cognitive impairment (such as deficiencies in memory, attention, and executive functions).

Schwann cell A glial cell in the PNS that wraps axons with its cytoplasmic extension to form myelin sheath. (Figure 2–27)

sciatic nerve A nerve consisting of sensory and motor axons that innervates the leg.

scrapple See prion diseases.

secondary antibody An antibody that recognizes selectively primary antibodies made by specific animal species. It is usually conjugated to a fluorophore or to an enzyme that produces a color substrate.

secondary dendrite A mitral cell dendrite that extends laterally, it is used to form reciprocal synapses with granule cells and other olfactory bulb interneurons to spread information across different olfactory processing channels. It is distinct from the primary (apical) dendrite of mitral cells that extends to the glomerulus. (Figure 6–17)

α -secretase An extracellular protease that cleaves amyloid precursor protein (APP) in the middle of the amyloid β ($\text{A}\beta$) peptide and prevents the production of pathology-associated $\text{A}\beta$. (Figure 11–3)

β -secretase An extracellular protease that cleaves amyloid precursor protein (APP) at the N-terminus of amyloid β ($\text{A}\beta$) to produce, along with γ -secretase, the intact $\text{A}\beta$ peptide. (Figure 11–3)

γ -secretase An intra-membrane protease that cleaves α - or β -secretase-processed amyloid precursor protein (APP) at the C-terminus of amyloid β ($\text{A}\beta$). (Figure 11–3)

secreted protein A protein that is destined for export from the cell. (Figure 2–2)

seizure An episode involving abnormal synchronous firing of large groups of neurons. (Figure 11–47)

selective sweep The reduction or elimination of nucleotide variations as a result of strong positive selection of a nearby chromosome locus.

selectivity filter The part of an ion channel pore that is responsible for discriminating between the different ionic species so that only some species can pass through the channel. (Figure 2–33)

self-avoidance The process in which different axonal or dendritic branches from the same neuron are repelled by each other to avoid overlap of processes from a single cell.

Sema1A, Sema2A, Sema2B (Semaphorins-1A, -2A, -2B) Axon guidance molecules of the semaphorin family in invertebrates; Sema1A is a transmembrane isoform, whereas Sema2A and Sema2B are secreted isoforms.

Sema3A (Semaphorin-3A) A secreted axon guidance molecule of the semaphorin family in vertebrates.

semaphorins Evolutionarily conserved and widely used axon guidance cues, they consist of secreted and transmembrane variants and mostly act as repellents. Some transmembrane variants can also act as receptors. (Figure 5–9)

semicircular canal A sensory organ in the vestibular system that senses angular acceleration in a specific plane. (Figure 6–59)

sensitization An increase in the magnitude of a response to a stimulus after a different kind of stimulus, often noxious, has been applied.

sensorimotor stage The period of song learning in birds when a young bird starts to produce his own immature song, which he compares with the tutor song template he has memorized. He

then adjusts his own song until it closely matches the tutor's song. (Figure 9–21)

sensory homunculus A map in the primary somatosensory cortex, it corresponds to sensation of specific body parts. Nearby somatosensory cortical areas represent sensation from nearby body surface. (Figure 1–25)

sensory neuron A neuron that directly responds to external stimuli, such as light, sound, chemical, thermal, or mechanical stimuli.

sensory organ precursor (SOP) In *Drosophila*, a progenitor cell whose asymmetric divisions give rise to different cells (a socket cell, hair cell, sheath cell, and sensory neuron) in the external sensory organ. (Figure 7–6)

sensory rhodopsin Type I rhodopsin used in prokaryotes for phototaxis. (Figure 12–20)

sensory stage The period of song learning in birds when a young bird hears and memorizes the song of a tutor. (Figure 9–21)

serial electron microscopic (EM) reconstruction A method in which consecutive electron micrographs of thin sections are aligned to produce a three-dimensional volume. (Figure 13–29)

serial processing An information processing method in which processing units are arranged in sequential steps.

serine/threonine kinase An enzyme that adds a phosphate onto specific serine or threonine residues of target proteins.

serotonin A monoamine neurotransmitter derived from the amino acid tryptophan that primarily acts as neuromodulator. It is also called 5-HT for 5-hydroxytryptamine. (Figure 3–16; Table 3–2)

Sevenless Originally identified from a mutation in *Drosophila* that lacks photoreceptor R7, it is a gene that acts cell-autonomously in R7 to specify the R7 fate. It encodes a receptor tyrosine kinase. (Figure 5–36)

sex chromosome The chromosome whose presence or number determines the sex of an organism.

Sex lethal (*Sxl*) A *Drosophila* gene that encodes a splicing factor which acts at the top of the sex-determination hierarchy. (Figure 9–4)

sex-linked Of a mutation, having a Mendelian inheritance pattern characteristic of genes located on a sex chromosome. (Figure 11–34)

sex peptide In *Drosophila*, a peptide transferred with sperm from males to females during mating. It reduces female receptivity to courtship.

sexually dimorphic Of a trait, differing between females and males.

SH2 (Src homology 2) domain A domain present in many signaling proteins, it binds phosphorylated tyrosines in the context of specific amino acid sequences.

Shaker Identified as a mutation in *Drosophila* that causes defects in a fast and transient K⁺ current in muscles and neurons. Its corresponding gene encodes a voltage-gated K⁺ channel.

short-range cue (in axon guidance) A cell-surface protein that can exert its guidance effects only when axons contact the cell that produces it. (Figure 5–9)

short-term memory Memory that lasts seconds to minutes. (Figure 10–4)

short-term synaptic plasticity A change in the efficacy of synaptic transmission that lasts milliseconds to minutes.

sign In sensory physiology, the direction in which a neuron's activity or membrane potential is changed by a stimulus (for example, the sign is positive if a neuron is depolarized by a

stimulus, and the sign is negative if a neuron is hyperpolarized by a stimulus).

signal transduction The process by which an extracellular signal is relayed via intracellular pathways to varied effectors to produce specific biological effects.

silent synapse A glutamatergic synapse that contains NMDA but not AMPA receptors on the postsynaptic membrane. It can be activated by presynaptic glutamate release that coincides with postsynaptic depolarization but not by presynaptic glutamate release alone.

simple cell A functionally defined neuronal type enriched in layer 4 of the primary visual cortex. It is best excited by a bar of light in a specific orientation, and it has separate ON and OFF regions that, when stimulated together, cancel each other's effect. (Figure 4–39)

single channel conductance (γ) Conductance of a single ion channel when open.

single nucleotide polymorphism (SNP) A single nucleotide of DNA in the genome that varies between members of a species.

single-unit recording Extracellular recording of the firing pattern of an individual neuron. *See also extracellular recording.* (Figure 13–31)

siRNA (short interfering RNA) Double-stranded RNA with a length similar to microRNA (21–26 nucleotides). It directs a protein complex to degrade the target mRNA through base pairing. *See also RNA interference.*

size principle The idea that within a motor pool, motor neurons that have smaller motor unit sizes (with smaller axon diameters and cell bodies) fire before neurons with larger motor unit sizes during muscle contraction. (Figure 8–7)

Slit A secreted protein best studied as a repulsive ligand involved in midline axon guidance in many species, from insects to vertebrates. (Figure 7–13)

slow axonal transport Intracellular transport at a speed of 0.2–8 mm per day. Cargos subject to slow axonal transport mostly include cytosolic proteins and cytoskeletal components. (Figure 2–4)

SM protein A protein related to yeast Sec1 and mammalian Munc18, it binds SNAREs and is essential for vesicle fusion.

small bistratified RGC A blue–yellow color opponent retinal ganglion cell. *See also color-opponent RGC.* (Figure 4–33)

Smith-Magenis syndrome A neurodevelopmental disorder characterized by mild-to-moderate intellectual disability, delayed speech, sleep disturbances, impaired impulse control, and other behavioral problems. It is caused by mutations that disrupt the function of one copy of a single gene called *Rai1* (retinoic acid induced 1) or by loss of one copy of a chromosome segment that includes *Rai1*.

smooth muscle Muscle that controls movement of tissue within the digestive, respiratory, vascular, excretory, and reproductive systems.

SNAP-25 A t-SNARE attached to the plasma membrane via lipid modification. (Figure 3–8)

SNAREs (soluble NSF-attachment protein receptors) Proteins on intracellular vesicles and target membranes that form a complex and mediate membrane fusion. (Figure 3–8)

SNC (substantia nigra pars compacta) A midbrain nucleus containing dopamine neurons that project mainly to the dorsal striatum. (Figure 8–22)

SNr (substantia nigra pars reticulata) One of the two major output nuclei of the basal ganglia, it contains GABAergic neurons

that project to the thalamus, superior colliculus, and brainstem motor control nuclei. (Figure 8–22)

solute A water-soluble molecule such as an inorganic ion, nutrient, metabolite, or neurotransmitter.

soma Cell body of a neuron or any cell.

somatic mutation A mutation that occurs in a progenitor cell and that thus affects only the cells derived from that progenitor.

somatosensory system The collected parts of the nervous system that provide bodily sensation.

somatostatin A neuropeptide whose transcription is regulated by a signaling cascade involving cAMP, PKA, and CREB. It is a marker for a subset of cortical GABAergic neurons.

Sonic Hedgehog (Shh) A morphogen that determines cell fate by regulating the expression of specific transcription factors in many developmental contexts. For instance, floor-plate-derived Shh is responsible for determining the different fates of neuronal progenitors located at different positions along the dorsal–ventral axis of the ventral spinal cord. It is also used as a midline attractant for commissural axons. (Figure 7–8)

sour A taste modality that functions primarily to warn the animal of potentially spoiled food. It is usually aversive.

Southern blotting A method for determining the amount of a specific DNA in a DNA mixture. DNA molecules are separated by gel electrophoresis and are then transferred to a membrane; labeled nucleic acid probes are then hybridized to the membrane to visualize specific DNA molecules that hybridize to the probe.

spatial integration (in dendrites) The summation of postsynaptic potentials produced by synchronous activation of synapses located at different spatial locations on the postsynaptic neuron. (Figure 3–43)

spectral sensitivity The relationship between a response (e.g. of a photosensitive cell or molecule) and the wavelength of the stimulus light.

spike *See action potential.*

spike-timing-dependent plasticity (STDP) A change of synaptic efficacy induced when pre- and postsynaptic neurons repeatedly fire within a restricted time window: synaptic efficacy is potentiated if the presynaptic neuron fires prior to the postsynaptic neuron, and synaptic efficacy is depressed if the presynaptic neuron fires after the postsynaptic neuron.

spinal cord The caudal part of the vertebrate CNS enclosed by the vertebral column. (Figure 1–8)

spinocerebellar ataxia One of a collection of neurodegenerative diseases, which share motor defects such as ataxia and are caused by poly-glutamine expansion in a number of proteins. (Table 11–1)

spinocervical tract pathway An axonal pathway from the dorsal spinal cord to the lateral cervical nucleus that relays a subset of touch signals, particularly from hairy skin.

spiny projection neuron The most numerous type of neuron in the striatum, it is a GABAergic neuron that projects either directly or indirectly to the output nuclei of the basal ganglia. It is also called medium spiny neuron. (Figure 8–22)

spiral ganglion neuron A bipolar neuron whose peripheral axon receives auditory information from a hair cell in the cochlea and whose central axon transmits information to the brainstem as part of the auditory nerve. (Figure 6–49)

spontaneous neuronal activity Firing of neurons in the absence of environmental stimuli.

sporadic Of a human disease, occurring in a patient without an identifiable family history of the disease.

Sry (*Sex determining region Y*) A gene located on the Y chromosome in mammals, it encodes a transcription factor that determines testes differentiation and other male-specific characteristics.

SSRI (selective serotonin reuptake inhibitor) An inhibitor of the plasma membrane serotonin transporter. It prolongs the action of serotonin in the synaptic cleft.

starburst amacrine cell (SAC) A class of GABAergic inhibitory neurons in the retina that also release acetylcholine. It is a crucial cell type that shapes the responses of direction-selective retinal ganglion cells. It also participates in generating retinal waves essential for activity-dependent wiring of the visual system. (Figure 4–31)

starter cell *See trans-synaptic tracing.*

STED *See super-resolution fluorescence microscopy.*

stereocilium A rigid bundled F-actin-based cylinder located on the apical surface of a hair cell. Stereocilia on the same hair cell are arranged in rows of increasing height like a staircase. (Figure 6–47; Figure 6–50)

stereotactic injection The use of a three-dimensional coordinate system to inject substances such as viruses into a small target region of tissue in an animal.

stereotyped axon pruning The pruning of exuberant axons with an invariable outcome.

stereotypy A trait or behavior that is largely invariant in different individual organisms.

stimulating electrode An electrode used to pass current into a neuron, usually with the goal of changing the membrane potential of a neuron or its processes.

stomatogastric ganglion (STG) A crustacean ganglion that controls stomach contraction. It has been used as a model system to study central pattern generators and rhythmic activity in neuronal circuits. (Figure 8–13)

storage (of memory) A step in between acquisition and retrieval, in which a memory is encoded as a persistent representation somewhere in the nervous system.

STORM *See super-resolution fluorescence microscopy.*

striatum The part of the basal ganglia that receives convergent input from the cerebral cortex and thalamus. Also called caudate–putamen because in some species, the striatum has two separate regions called caudate and putamen, respectively. (Figure 8–22)

subcerebral projection neuron (SCPN) A cortical neuron, found in layer 5, that projects its axon to subcortical targets, such as the pons, superior colliculus, and spinal cord. (Figure 7–10)

substance P A neuropeptide that promotes inflammation when released by the peripheral terminals of sensory neurons. (Figure 6–71)

substantia nigra A midbrain structure named after the high levels of melanin pigments present in the dopamine neurons of healthy human subjects. (Figure 11–16). *See also SNC and SNr.*

subthalamic nucleus (STN) An intermediate nucleus in the basal ganglia indirect pathway, it contains glutamatergic neurons that project to the GPi and SNr. These neurons receive GABAergic input from the GPe and glutamatergic input from the cerebral cortex. (Figure 8–22)

sub-threshold stimulus A stimulus that is insufficient to cause a neuron to generate an action potential. (Figure 2–18)

super-resolution fluorescence microscopy A set of fluorescence microscopy techniques capable of imaging specimens at resolutions below the diffraction limit of light. For example, STED (*stimulated emission depletion microscopy*)

achieves super resolution by exciting fluorophores in a region of tissue smaller than the diffraction limit through depletion of fluorescence in an annulus surrounding a central focal spot. STORM (stochastic optical reconstruction microscopy) and PALM (photoactivated localization microscopy) achieve super resolution by photoactivating a random small subset of photo-switchable fluorophores at any one time, such that the position of each fluorophore can be localized to a precision much finer than the resolution limits set by diffraction; repeated rounds of imaging and deactivation enable the reconstruction of the entire imaging field. (Figure 13–25)

superior colliculus A multi-layered midbrain structure in mammals that receives retinal ganglion cell axonal input, as well as input from other sensory systems. It regulates head orientation and eye movement and is analogous to the tectum in non-mammalian vertebrates. (Figure 4–35)

superior olivary nuclei Brainstem nuclei in mammals where auditory signals from the left ear and right ear first converge. The medial superior olivary nucleus (MSO) analyzes interaural time differences, whereas the lateral superior olivary nucleus (LSO) analyzes interaural sound level differences. (Figure 6–57)

suprachiasmatic nucleus (SCN) A hypothalamic nucleus that is the master regulator of circadian rhythms and light entrainment in mammals. (Figure 8–34; Figure 8–49)

supra-threshold stimulus A stimulus that can cause a neuron to generate an action potential. (Figure 2–18)

sweet A taste modality that functions primarily to detect the sugar content of food. It is usually appetitive.

sympathetic nervous system A branch of the autonomic nervous system that facilitates energy expenditure, such as in the case of an emergency response. Activation of the sympathetic nervous system speeds up the heart rate, increases blood flow, relaxes airways in the lungs, inhibits salivation and digestion, and stimulates the production of the hormone epinephrine (adrenaline) from the adrenal glands. (Figure 8–31; Figure 8–32)

symporter A coupled transporter that moves two or more solutes in the same direction. (Figure 2–10)

synapse A site at which information is transferred from one neuron to another neuron or a muscle cell. It consists of a presynaptic terminal and a postsynaptic specialization separated by a synaptic cleft.

synapse elimination The process by which extra synapses are removed during development. It is best described at the vertebrate neuromuscular junction where the innervation of muscle cells by multiple motor neurons is refined during early postnatal development so that each muscle cell is innervated by a single motor neuron in adults. (Figure 7–27)

synaptic cleft A 20–100 nm gap that separates the presynaptic terminal of a neuron from its target cell. (Figure 1–14; Figure 3–3)

synaptic efficacy See **efficacy of synaptic transmission**.

synaptic failure An event in which an action potential in a presynaptic neuron does not produce a postsynaptic response.

synaptic plasticity The ability to change the efficacy of synaptic transmission, usually in response to experience and neuronal activity.

synaptic potential A type of graded potential produced at postsynaptic sites in response to neurotransmitter release by presynaptic partners.

synaptic tagging The hypothesis that induction of LTP at a synapse causes the production of a ‘tag’ at the synapse and that newly synthesized macromolecules necessary for stabilization of LTP are selectively captured by the tag. The hypothesis explains how the input specificity of LTP is maintained despite the cell-

wide distribution of newly synthesized macromolecules required for LTP.

synaptic transmission The process of neurotransmitter release from the presynaptic neuron and neurotransmitter reception by the postsynaptic neuron.

synaptic vesicle A small, membrane-enclosed organelle (typically about 40 nm in diameter) enriched at the presynaptic terminal. They are filled with neurotransmitters and, upon stimulation, fuse with the plasma membrane to release neurotransmitters into the synaptic cleft. (Figure 3–4; Figure 3–7)

synaptic weight matrix A network of synapses between ensembles of input neurons and output neurons, where the strength (weight) of each synapse can vary between 0 (no connection) and 1 (maximal strength connection). (Figure 10–5)

synaptobrevin A transmembrane SNARE on the synaptic vesicle (i.e. a v-SNARE), it is also named VAMP. (Figure 3–8)

synaptotagmin A Ca^{2+} -binding transmembrane protein on the synaptic vesicle that serves as a Ca^{2+} sensor to trigger neurotransmitter release.

syndromic disorder A disorder characterized by a defined constellation of behavioral, cognitive, and physical symptoms.

synonymous substitutions Nucleotide changes in DNA that do not result in amino acid changes in the protein encoded by that DNA. They are used in calculations of genetic drift.

syntaxin A transmembrane SNARE on the target plasma membrane (i.e. a t-SNARE). (Figure 3–8)

α -synuclein A protein normally enriched in the presynaptic terminal. It is a major component of Lewy bodies, a defining pathological feature of most forms of Parkinson’s disease.

T1R1 A G-protein-coupled receptor and a subunit (along with T1R3) of the mammalian umami taste receptor. (Figure 6–41)

T1R2 A G-protein-coupled receptor and a subunit (along with T1R3) of the mammalian sweet taste receptor. (Figure 6–41)

T1R3 A G-protein-coupled receptor and a shared subunit of the mammalian umami and sweet taste receptors. (Figure 6–41)

T2Rs A family of G-protein-coupled receptors that are the mammalian bitter taste receptors. (Figure 6–41)

tamoxifen See **CreER**.

tastant A nonvolatile and hydrophilic molecule in saliva that elicits taste perception.

taste bud A cluster of tens of taste receptor cells, with their apical endings facing the surface of the tongue. (Figure 6–35)

taste pore Collected apical endings of taste receptor cells in a taste bud. (Figure 6–35)

taste receptor cell A sensory neuron on the surface of the tongue and oral cavity, it converts tastant binding to taste receptor proteins to an electrical signal that is transmitted to the peripheral terminals of the gustatory nerve. (Figure 6–35)

tau A microtubule binding protein that is highly enriched in axons.

tauopathies Neurodegenerative diseases characterized by the presence of neurofibrillary tangles, which consist of aggregates of hyperphosphorylated tau.

Tbr1 A transcription factor that specifies corticothalamic projection neuron identity. (Figure 7–10)

tectorial membrane A membrane on the apical side of hair cells apposed to the stereocilia. (Figure 6–50)

tectum The major target of retinal ganglion cells in the brains of amphibians and lower vertebrates. It is a midbrain structure analogous to the mammalian superior colliculus. (Figure 5–5)

telencephalon The anterior part of the forebrain, including the olfactory bulb, cerebral cortex, hippocampus, and basal ganglia. (Figure 7–3)

temporal (in retinal map) In the direction of the temple.

temporal integration (in dendrites) The summation of postsynaptic potentials produced by activation of synapses within a finite time window. (Figure 3–43)

temporal lobe One of the four cerebral cortex lobes, it is located at the side of the brain. (Figure 1–23)

testosterone A steroid hormone that promotes the development of the male reproductive system (masculinization) and inhibits the development of the female reproductive system (de-feminization). In adults, it stimulates sexual behaviors. (Figure 9–24)

tetanus toxin A protease produced by *Clostridium tetani* that cleaves synaptobrevin at a specific site, thereby inhibiting neurotransmitter release.

tetraethylammonium (TEA) A chemical that selectively blocks voltage-gated K⁺ channels.

tetrode An extracellular electrode containing four wires that enable four independent recordings of spiking activities of neurons nearby the electrode tip. The firing patterns of up to ~20 neurons can be resolved based on their different action potential amplitudes and waveforms.

tetrodotoxin (TTX) A toxin that potently blocks voltage-gated Na⁺ channels across animal species and is widely used experimentally to silence neuronal firing. It is produced by symbiotic bacteria in puffer fish, rough-skinned newt, and some octopi. (Figure 2–29)

thalamic cortical axons (TCAs) Axons of thalamic neurons that project to the cortex.

thalamus A structure situated between the cerebral cortex and the midbrain, it relays sensory and motor signals to the cerebral cortex through its extensive bidirectional connections with cortex. (Figure 1–8)

theory of dynamic polarization The idea that every neuron has (1) a receptive component, the cell body and dendrites; (2) a transmission component, the axon; and (3) an effector component, the axon terminals. According to this theory, originally proposed by Ramón y Cajal, neuronal signals flow from dendrites and cell bodies to the axon.

thermosensation The sense of temperature.

thermosensory neuron A somatosensory neuron that senses temperature.

threshold (of action potential) The membrane potential above which an action potential is generated. (Figure 2–18)

thrombospondin (TSP) A member of a family of secreted proteins with diverse functions. It can be produced by astrocytes to stimulate synapse formation.

time constant (τ) The product of resistance and capacitance in an R-C circuit, it is a measure of the rate at which both a capacitor charges or discharges and the voltage across a resistor changes in response to changes in current. In neurons, τ corresponds to the time required for the membrane potential change to reach 63% (1 - 1/e) of its maximal value in response to a sudden change of current flow.

Timeless A fruit fly gene discovered based on mutations that affect circadian rhythms. It encodes a protein that participates in the negative regulation of its own transcription. (Figure 8–46)

Timothy syndrome Characterized by cardiac arrhythmia and autistic symptoms, it is caused by mutation in the gene encoding a voltage-gated Ca²⁺ channel, Ca_v1.2. (Figure 11–45)

tip link The connection between adjacent stereocilia, it consists of cadherin-23 on the taller stereocilium and protocadherin-15 on the shorter stereocilium. (Figure 6–47)

tonic Of a neuronal firing pattern, regularly timed and repetitive.

tonic-clonic seizure A seizure associated with loss of consciousness and a predictable sequence of motor activity: patients first stiffen and extend all extremities (tonic phase) and then undergo full-body spasms during which muscles alternately flex and relax (clonic phase).

tonotopic map The ordered arrangement of cells in the auditory system in physical space according to their frequency tuning. The cochlea and multiple brain regions contain tonotopic maps. (Figure 6–49)

topographic map An ordered representation in the brain of features of either the external world or the animal's interaction with the world. For examples, see **retinotopy**, **sensory homunculus**, and **motor homunculus**.

touch sensory neurons See **LTMRs**.

transcription The process by which RNA polymerase uses DNA as a template to synthesize RNAs. (Figure 2–2)

transcription factor A DNA-binding protein that regulates transcription of target genes.

transcription unit The part of the gene that serves as a template for RNA synthesis. (Figure 2–2)

transcytosis The process by which transmembrane or extracellular proteins are first retrieved by endocytosis in one cellular compartment and then delivered for exocytosis at another cellular compartment.

transducin A trimeric GTP-binding protein that links light-activated rhodopsin (or cone opsin) to phosphodiesterase activation in vertebrate photoreceptors. (Figure 4–8)

Transformer (Tra) A *Drosophila* gene that encodes a splicing factor which acts downstream of *Sex lethal* (*Sxl*) but upstream of *Doublesex* (*Dsx*) and *Fruitless* (*Fru*). (Figure 9–4)

transgene An *in vitro* engineered gene that is introduced into somatic cells or the germ line of an organism. (Figure 13–11)

transgenic organism An organism that contains a transgene, usually in the germ line.

translation The process by which an mRNA is decoded by ribosomes for protein synthesis. (Figure 2–2)

transmembrane protein A protein that is destined to span the lipid bilayer of a membrane. (Figure 2–2)

transmission electron microscopy (TEM) A form of electron microscopy in which high voltage electron beams transmitted through ultra-thin (typically under 100 nm) sections of biological specimens are used to create images.

transporter A transmembrane protein or protein complex that has two separate gates that open and close sequentially to allow solutes to move from one side of the membrane to the other. (Figure 2–8)

trans-synaptic tracing A method that labels the synaptic partners of a given neuron or a population of neurons of interest (starter cell or cells). A retrograde trans-synaptic tracer labels presynaptic partners of starter cells, whereas an anterograde trans-synaptic tracer labels postsynaptic partners of starter cells. (Figure 13–30)

transverse tubules (T tubules) An invagination of the plasma membrane that extends into the muscle cell interior, bringing the plasma membrane close to the sarcoplasmic reticulum, such that depolarization effectively triggers Ca²⁺ release from the sarcoplasmic reticulum throughout the entire large muscle cell. (Figure 8–5)

TRE (tetracycline response elements) The DNA sequences to which tTA or rtTA bind. (Figure 13–13). *See also tTA.*

trichromat Organisms that have three different cones for color vision—the S-cone, M-cone, and L-cone.

trigeminal ganglia Clusters of somatosensory neurons near the brainstem involved in sensation of the face.

trimeric GTP-binding protein (G protein) A GTP-binding protein complex composed of a $\text{G}\alpha$, a $\text{G}\beta$, and a $\text{G}\gamma$ subunit with an intrinsic GTPase activity in $\text{G}\alpha$. It has many variants, which couple different GPCRs to diverse signaling pathways. *See also G_s , G_v , and G_q .*

Trk receptors A family of neurotrophin receptors that are receptor tyrosine kinases. It includes TrkA, TrkB, and TrkC. (Figure 3–39; Figure 7–32)

TRP channels Non-selective cation channels that share sequence similarities with the *Drosophila* transient receptor potential (TRP) protein. (Figure 2–34)

TRPM8 A non-selective cation channel that is activated by menthol and by temperatures $< 26^\circ\text{C}$. (Figure 6–68)

TRPV1 A non-selective cation channel that is activated by capsaicin and by temperatures $> 43^\circ\text{C}$. (Figure 6–68)

Tsc1, Tsc2 *See tuberous sclerosis.*

t-SNARE A SNARE located on the target membrane, such as syntaxin.

tTA (tetracycline-repressible transcriptional activator) A bacterial transcription factor widely used in heterologous systems, including transgenic mice, to control expression of a transgene. It drives expression of target genes whose promoters contain a tetracycline response element (TRE), but its activity is repressed by tetracycline or its analog doxycycline. A variant called rtTA (reverse tTA) activates TRE-driven transgenes in the presence but not the absence of doxycycline. (Figure 13–13)

tuberomammillary nucleus A hypothalamic nucleus rich in histamine neurons. (Figure 8–52)

tuberous sclerosis Characterized by non-malignant tumors in the brain and other organs as well as by symptoms of autism spectrum disorders, it is caused by mutations in genes encoding *Tsc1* or *Tsc2*, the products of which are negative regulators of mTOR-mediated translational control. (Figure 11–45)

tufted cell *See mitral cell.*

two-photon microscopy A microscopy technique that relies on simultaneous absorption of two long-wavelength photons in order to excite a fluorophore. Compared with confocal microscopy, it produces less photo-damage because only at the focal plane is the density of photons high enough to cause substantial fluorescence emission. Like confocal microscopy, it relies on laser scanning of imaging spots across a plane to produce an optical section. (Figure 13–39)

type III neuregulin-1 (Nrg1-III) An axonal cell-surface protein, the expression level of which determines the degree of axon myelination by Schwann cells.

tyrosine hydroxylase An enzyme that converts L-tyrosine to L-dopa, it is the rate-limiting enzyme in the catecholamine biosynthetic pathway. (Figure 11–20)

UAS *See GAL4.*

ubiquitin-proteasome system A protein degradation system present in all eukaryotes.

umami A taste modality that functions primarily to detect the amino acid content of food. It is usually appetitive.

Unc5 A co-receptor for netrin/Unc6 that acts together with DCC/Unc40 to mediate repulsion.

Unc6 *See netrin/Unc6.*

Unc40 *See DCC/Unc40.*

unconditioned response (UR) *See classical conditioning.*

unconditioned stimulus (US) *See classical conditioning.*

unipolar Having one process leaving the cell body that gives rise to both dendritic and axonal branches. (Figure 1–15)

V1 *See primary visual cortex.*

vagus nerve A cranial nerve in the parasympathetic nervous system that connects the brainstem with internal organs. (Figure 8–32)

variations Differences in genes or inheritable traits.

vasopressin A hormone secreted by hypothalamic neurons in the posterior pituitary and a neuropeptide released by certain CNS neurons. It regulates water balance and social behavior.

V-ATPase A proton pump on the synaptic vesicle that pumps protons (H^+) into the vesicle against their electrochemical gradient using energy derived from ATP hydrolysis. (Figure 3–12)

ventral horn The ventral part of the spinal gray matter where motor neurons reside. (Figure 8–6)

ventral nerve cord An invertebrate CNS structure posterior to the brain. It is analogous to the vertebrate spinal cord. (Figure 7–11; Figure 7–12)

ventral pallidum A basal ganglia region that is a major target of GABAergic projection neurons from the nucleus accumbens. (Figure 9–44)

ventral root The place where motor axons exit the spinal cord. (Figure 8–6)

ventral stream A visual processing pathway from the primary visual cortex to the temporal cortex. It is responsible for analyzing form and color; the ‘what’ stream. (Figure 4–48)

ventral tegmental area (VTA) A midbrain nucleus containing dopamine neurons that project mainly to the ventral striatum (nucleus accumbens) and prefrontal cortex. (Figure 8–22; Figure 11–31)

ventricle A cavity derived from the lumen of the neural tube. It is filled with cerebrospinal fluid. (Figure 7–5)

ventricular zone A layer of cells adjacent to the ventricles. (Figure 7–4)

ventromedial hypothalamic nucleus (VMH) A hypothalamic nucleus whose best characterized roles include regulating female lordosis and male mounting and aggression. (Figure 9–32)

vesicular monoamine transporter (VMAT) A transmembrane protein on synaptic vesicles that transports dopamine, norepinephrine, and serotonin from the presynaptic cytosol into synaptic vesicles. (Figure 11–24). *See also vesicular neurotransmitter transporter.*

vesicular neurotransmitter transporter A transmembrane protein on the synaptic vesicle that transports neurotransmitters from the presynaptic cytosol into the vesicle using energy from the transport of protons down their electrochemical gradient. (Figure 3–12)

vestibular ganglion neuron A bipolar neuron whose peripheral axon receives vestibular information from a cell in an otolith organ or a semicircular canal and whose central axon transmits information to the brainstem as part of the vestibular nerve.

vestibular nerve A collection of axons from vestibular ganglion neurons that transmits vestibular information to the brainstem. (Figure 6–59)

vestibular nuclei Brainstem nuclei where the vestibular nerve terminates. They also receive input from other sensory systems such as the somatosensory systems. (Figure 6–60)

vestibular system The collected parts of the nervous system that sense the movement and orientation of the head and use this information to regulate a variety of functions including balance, spatial orientation, coordination of head and eye movements, and perception of self-motion.

vestibulo-ocular reflex (VOR) A reflexive eye movement that stabilizes images on the retina during head movement by moving the eyes in the direction opposite to the head movement. (Figure 6–61)

viral transduction The process by which a virus infects a host cell, introducing its genome. It is widely used for transgene expression in somatic cells.

visceral motor neurons Pre- and postganglionic neurons in the autonomic nervous system.

visceral sensory neuron A sensory neuron whose peripheral branch innervates an internal organ and whose central branch extends to the spinal cord or brainstem. (Figure 8–33)

visual cortex The part of the cerebral cortex that is dedicated to analyzing visual information.

visual field The portion of external world that can be seen at a given time.

voltage clamp An experimental technique used to measure the ion currents through the membrane while holding (i.e. ‘clamping’) the membrane potential at a set level. (Figure 2–21)

voltage-gated Ca^{2+} channel An ion channel that allows selective passage of Ca^{2+} and whose conductance is regulated by the membrane potential. (Figure 2–34)

voltage-gated ion channel An ion channel whose conductance changes as a function of the membrane potential. At a single channel level, a channel is either open or closed; membrane potential change alters its open probability. (Figure 2–30)

voltage-sensitive dye A molecule whose optical properties change in response to membrane potential changes.

volume transmission The secretion of neurotransmitters (usually neuromodulators) into the extracellular space outside the confines of morphologically defined synapses, where they can affect multiple nearby target cells.

vomeronasal organ (VNO) A special structure located at the front of the nose that houses sensory neurons of the accessory olfactory system. (Figure 6–22)

vomeronasal system *See accessory olfactory system.*

v-SNARE A SNARE located on a vesicle, such as synaptobrevin.

VOR gain The ratio of rotation of the eyes to the rotation of the head in the vestibulo-ocular reflex.

Wallerian degeneration The process by which distal axons are eliminated after they are severed from the somata.

Weber’s Law In sensory perception, the property that the just-noticeable difference between two sensory stimuli is proportional to the magnitude of the stimulus.

Wernicke’s area An area in the left temporal lobe involved in language comprehension. Patients with lesions in this area have difficulty understanding language. (Figure 1–23)

western blot A method for determining the amount of a specific protein in a protein mixture. Proteins are separated by gel electrophoresis and are then transferred to a membrane; labeled antibodies are then used to visualize specific proteins bound by the antibody. It can be used to determine protein expression patterns.

white matter The parts of the CNS that are enriched with oligodendrocytes and myelinated axons and that appear white because of the high lipid content of the myelin.

whole-cell patch recording (whole-cell recording) A form of intracellular recording in which a glass electrode forms a high-resistance seal with the plasma membrane of the recorded cell. After formation of the seal, the membrane underneath the patch electrode is ruptured, such that the interior of the patch electrode and the cytoplasm form a single compartment. *See also patch clamp recording.* (Figure 13–37)

whole-mount A tissue specimen that has not been sectioned.

Wnts A family of secreted proteins that act as morphogens to pattern embryonic tissues, such as the tissues along the anterior-posterior axis of vertebrates and *C. elegans*. They can also serve as cues for axon guidance and for directing where synapses form along an axon.

working memory Short-term explicit memory, such as temporary retention of facts. (Figure 10–4)

zygote A fertilized egg. (Figure 7–2)