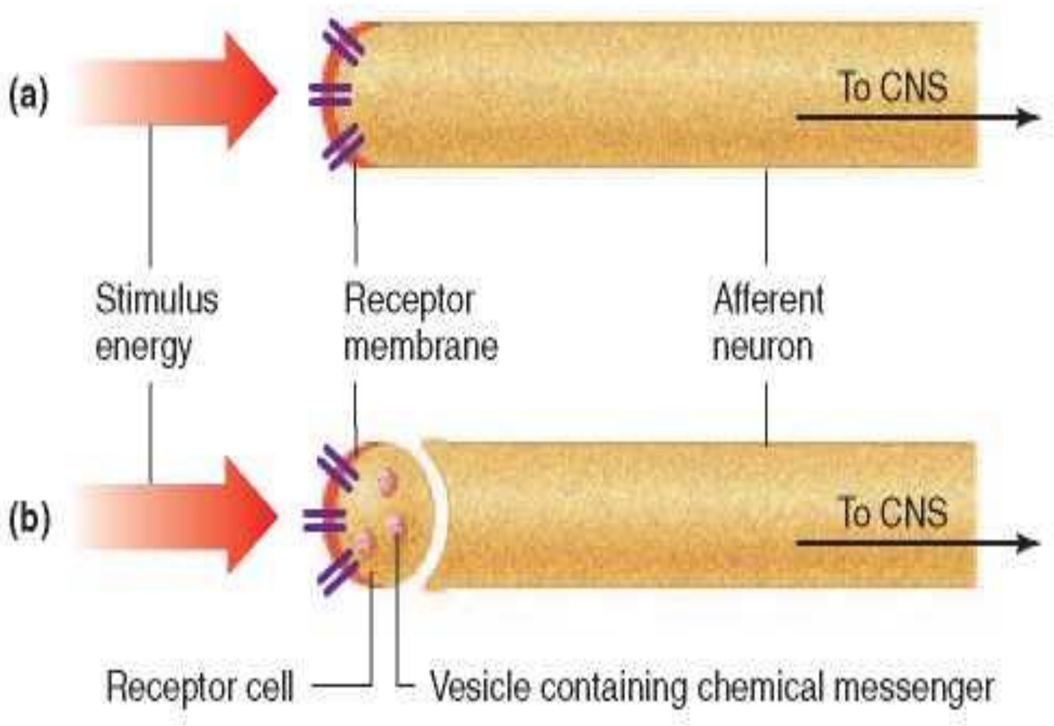
SENSORY PHYSIOLOGY (II)

SENSORY PHYSIOLOGY

- A sensory system is a part of the nervous system that consists of sensory receptor cells that receive stimuli from the external or internal environment, the neural pathways that conduct information from the receptors to the brain or spinal cord, and those parts of the brain that deal primarily with processing the
- information. Information processed by a sensory system may or may not lead to conscious awareness of the stimulus. Regardless of whether the information reaches consciousness, it is called sensory information. If the information does reach consciousness, it can also be called a sensation. A person's understanding of the sensation's meaning is called perception. For example, feeling pain is a sensation, but awareness that a tooth hurts is a perception. Sensations and perceptions occur after modification or processing of sensory information by the CNS. This processing can accentuate, dampen, or otherwise filter sensory afferent information. At present we have little understanding of the final stages in the processing by which patterns of action potentials become sensations or perceptions.
- The initial step of sensory processing is the transformation of stimulus energy first into graded potentials—the receptor potentials—and then into action potentials in nerve fibers. The pattern of action potentials in particular nerve fibers is a code that provides information about the world even though, as is frequently the case with symbols, the action potentials differ vastly from what they represent.
- There are many types of sensory receptors, each of which responds much more readily to one form of energy than to others. The type of energy to which a particular receptor responds in normal functioning is known as its adequate stimulus.

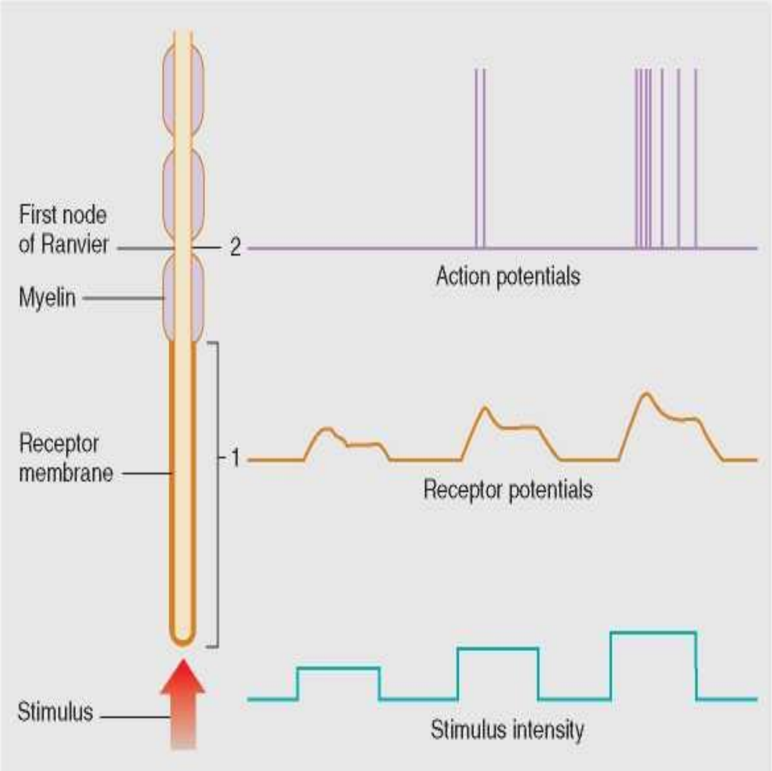
SENSORY RECEPTORS



Schematic diagram of two types of sensory receptors. The sensitive membrane that responds to a stimulus is either (a) an ending of an afferent neuron or (b) on a separate cell adjacent to an afferent neuron. Ion channels (shown in purple) on the receptor membrane alter ion flux and initiate stimulus transduction.

There are several general classes of receptors that are characterized by the type of energy to which they are sensitive. As the name indicates, mechanoreceptors respond to mechanical stimuli, such as pressure or stretch, and are responsible for many types of sensory information, including touch, blood pressure, and muscle tension. Permeability of ion channels on the receptive membrane is altered by these stimuli, changing the membrane potential. Thermoreceptors detect both sen-sations of coldness and warmth, and photoreceptors re-spond to particular light wavelengths. Chemoreceptors respond to the binding of particular chemicals to the receptive membrane. This type of receptor is used in the senses of smell and taste and in the detection of blood concentrations of oxygen and carbon dioxide. Nociceptors are specialized nerve endings that respond to a number of different painful stimuli, such as heat or tissue damage.

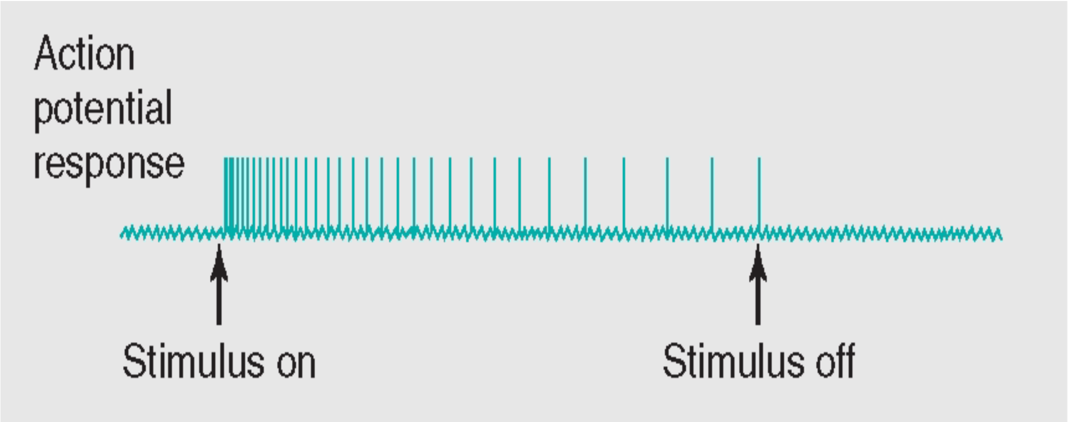
THE RECEPTOR POTENTIAL



An afferent neuron with a receptor ending. Recording electrodes placed at (1) and (2) measure the changes in membrane potential seen on the right in response to different stimulus intensities. The receptor potential arises at the nerve ending (1) and the action potential arises at the first node of Ranvier in the myelin sheath (2). Note that action potentials are not generated at the lowest stimulus intensity.

- The transduction process in all sensory receptors involves the opening or closing of ion channels that receive—either directly or through a second-messenger system—information about the internal and external world.
- The ion channels are present in a specialized receptor membrane located at the distal tip of the cell's single axon or on the receptive membrane of specialized sensory cells. The gating of these ion channels allows a change in the ion fluxes across the re-ceptor membrane, which in turn produces a change in the membrane potential there. This change in potential is a graded potential called a receptor potential.
- The specialized receptor membrane where the initial ion channel changes occur, unlike the axonal plasma membrane, does not generate action potentials. Instead, local current from the receptor membrane flows a short distance along the axon to a region where the membrane has voltage-gated ion channels and can generate action potentials. In myelinated afferent neurons, this region is usually at the first node of Ranvier of the myelin sheath.
- As long as the afferent neuron remains depolarized to or above threshold, action potentials continue to fire and propagate along the afferent neuron.

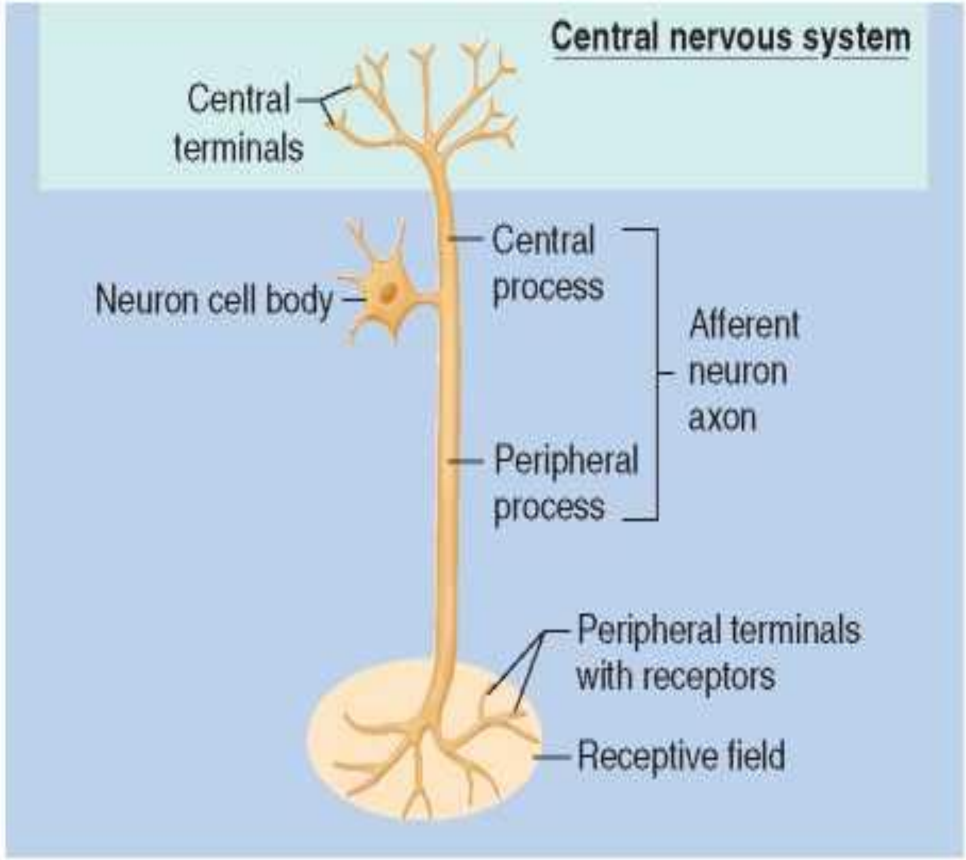
PRIMARY SENSORY CODING



Action potentials in a single afferent nerve fiber showing adaptation to a stimulus of constant strength. Note that the frequency of action potentials decreases even before the stimulus is turned off

- Conversion of receptor potentials into a pattern of action potentials that conveys relevant sensory information to the CNS is termed coding. Characteristics of the stimulus such as type, intensity, duration, and location are encoded within the firing pattern of the excitable cells. This coding begins at the receptive neurons in the peripheral nervous system.
- A single afferent neuron with all its receptor endings makes up a sensory unit. In a few cases, the afferent neuron has a single receptor, but generally the peripheral end of an afferent neuron divides into many fine branches, each terminating with a receptor.
- The portion of the body that, when stimulated, leads to activity in a particular afferent neuron is called the receptive field for that neuron. Receptive fields of neighboring afferent neurons overlap so that stimulation of a single point activates several sensory units; thus, activation at a single sensory unit almost never occurs. As we shall see, the degree of overlap varies in different parts of the body.

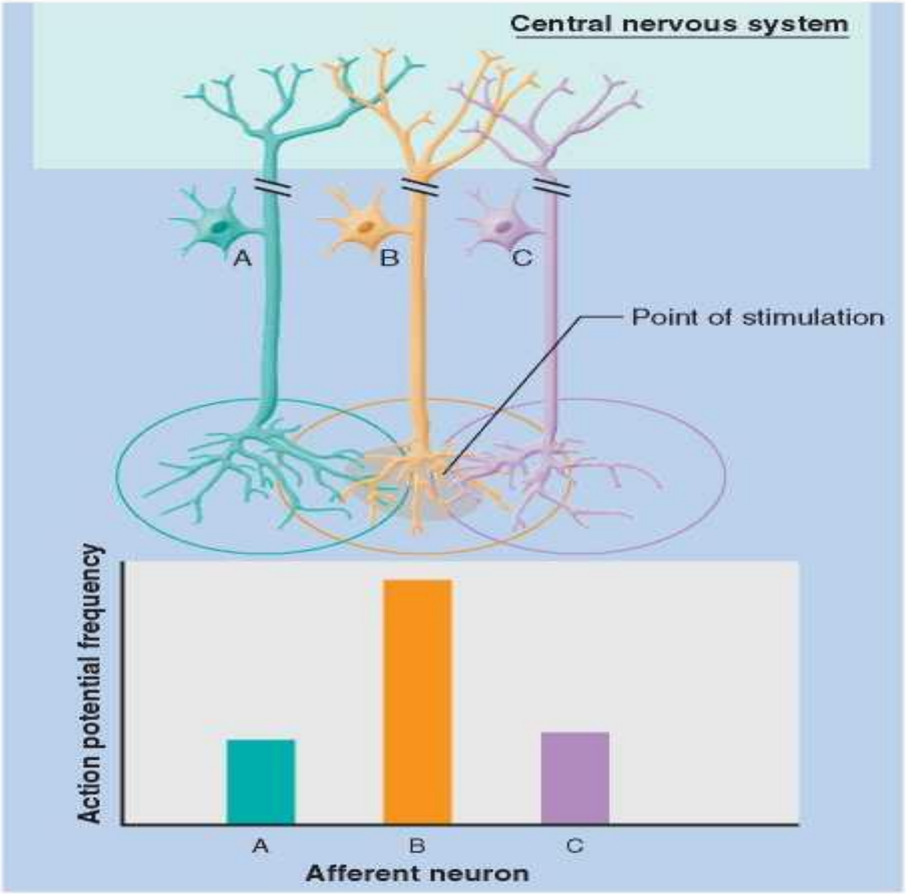
STIMULUS TYPE



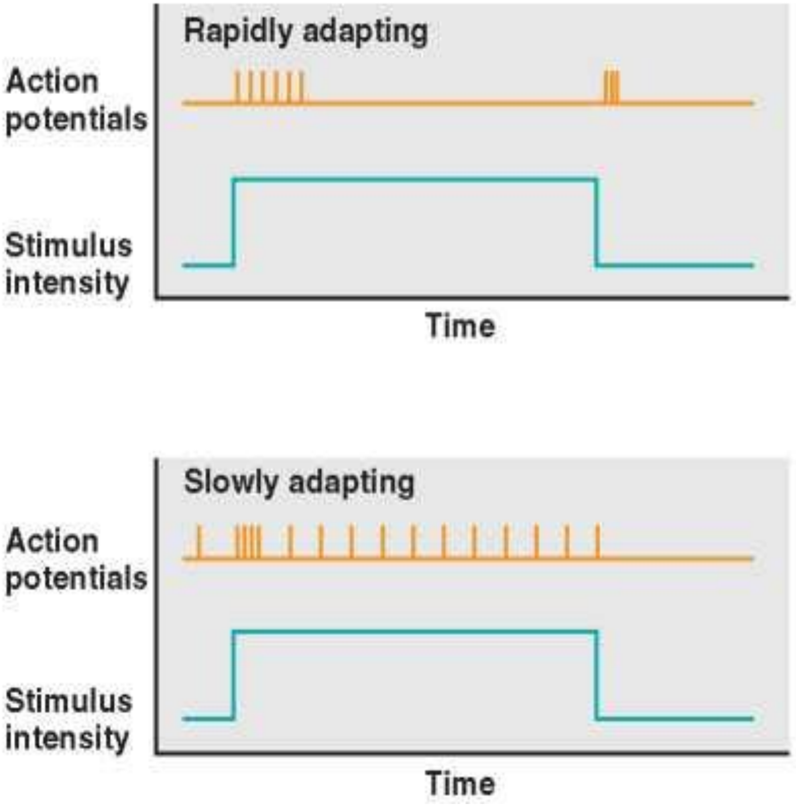
A sensory unit including the location of sensory receptors, the processes reaching peripherally and centrally from the cell body, and the terminals in the CNS. Also shown is the receptive field of this neuron.

- Another term for stimulus type (heat, cold, sound, or pressure, for example) is stimulus modality. Modalities can be divided into submodalities: Cold and warm are submodalities of temperature, whereas salt, sweet, bitter, and sour are submodalities of taste. The type of sensory receptor activated by a stimulus plays the primary role in coding the stimulus modality.
- A given receptor type is particularly sensitive to one stimulus modality—the adequate stimulus—because of the signal transduction mechanisms and ion channels incorporated in the receptor's plasma membrane.
- All the receptors of a single afferent neuron are pref-erentially sensitive to the same type of stimulus. For ex-ample, they are all sensitive to cold or all to pressure. Adjacent sensory units, however, may be sensitive to different types of stimuli. Since the receptive fields for different modalities overlap, a single stimulus, such as an ice cube on the skin, can give rise simultaneously to the sensations of touch and temperature.

STIMULUS LOCATION AND DURATION



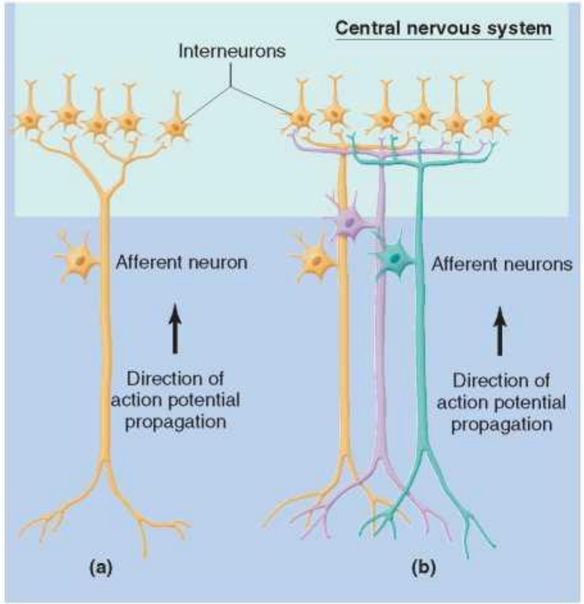
A stimulus point falls within the overlapping receptive fields of three afferent neurons. Note the difference in receptor response (that is, the action potential frequency in the three neurons) due to the difference in receptor distribution under the stimulus (low receptor density in A and C, high in B)



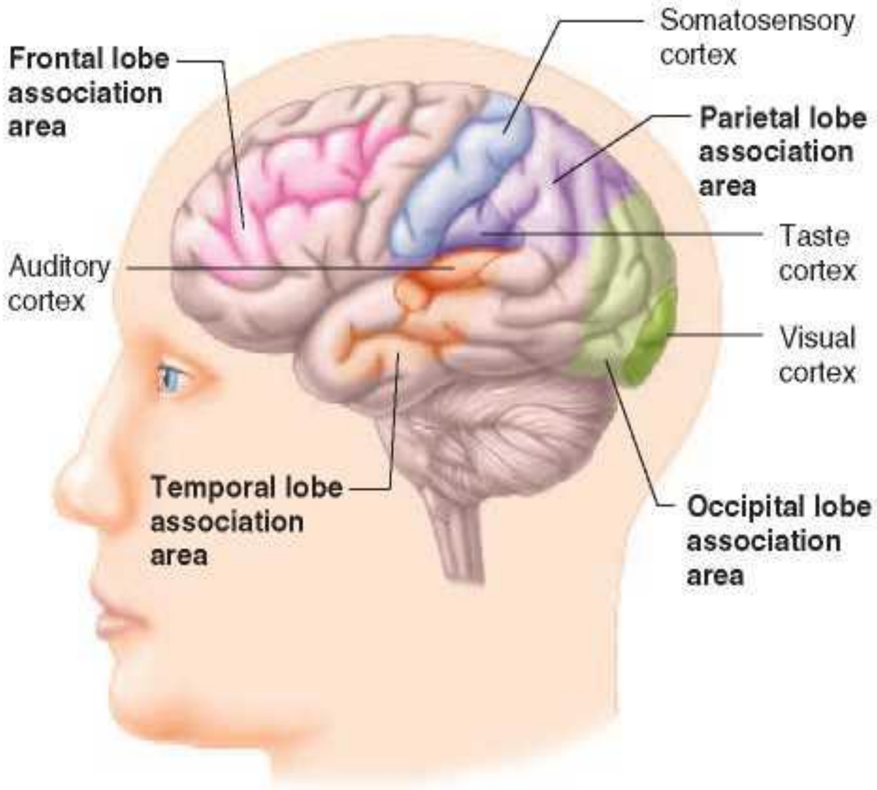
Rapidly and slowly adapting receptors. The top line in each graph indicates the action potential firing of the afferent nerve fiber from the receptor, and the bottom line, application of the stimulus

NEURAL PATHWAYS IN SENSORY SYSTEMS

The afferent sensory neurons form the first link in a chain consisting of three or more neurons connected end to end by synapses. A bundle of parallel, three-neuron chains together form a sensory pathway. The chains in a given pathway run parallel to each other in the central nervous system and, with one exception, carry information to the part of the cerebral cortex responsible for conscious recognition of the information.



a) Divergence of an afferent neuron on to many interneurons.
b) Convergence of input from several afferent neurons onto single interneurons.



Primary sensory areas and areas of association cortex

SENSORY PATHWAYS

- Most sensory pathways convey information about only a single type of sensory information. Thus, one pathway is influenced only by information from mechanoreceptors, whereas another is influenced only by information from thermoreceptors. This allows the brain to distinguish the different types of sensory information even though all of it is being transmitted by essentially the same signal, the action potential.
- The ascending pathways in the spinal cord and brain that carry information about single types of stimuli are known as the specific ascending pathways. The specific pathways pass to the brainstem and thalamus, and the final neurons in the pathways go from there to specific sensory areas of the cerebral cortex. The olfactory pathways are an exception because they go to parts of the limbic system rather than to the thalamus and because they terminate in the limbic system.
- The specific pathways cross to the side of the central nervous system that is opposite to the location of their sensory receptors. Thus, information from receptors on the right side of the body is transmitted to the left cerebral hemisphere and vice versa.
- The specific ascending pathways that transmit information from somatic receptors—that is, the receptors in the framework or outer walls of the body, including skin, skeletal muscle, tendons, and joints— go to the somatosensory cortex.

FACTORS THAT AFFECT PERCEPTION

- Afferent information is influenced by sensory receptor mechanisms (for example by adaptation), and by processing of the information along afferent pathways.
- Factors such as emotions, personality, experience, and social background can influence perceptions so that two people can witness the same events and yet perceive them differently.
- Not all information entering the central nervous system gives rise to conscious sensation. Actually, this is a very good thing because many unwanted signals are generated by the extreme sensitivity of our sensory receptors.
- It is possible to detect one action potential generated by a certain type of mechanoreceptor. Although these receptors are capable of giving rise to sensations, much of their information is canceled out by receptor or central mechanisms .
- Perception involves three processes—transducing stimulus energy into action potentials by the receptor, transmitting data through the nervous system, and interpreting data— cannot be separated. Sensory information is processed at each synapse along the afferent pathways and at many levels of the central nervous system, with the more complex stages receiving input only after it has been processed by the more elementary systems.
- The hierarchical processing of afferent information along individual pathways is an important organizational principle of sensory systems. A second important principle is that information is processed by *parallel* pathways, each of which handles a limited aspect of the neural signals generated by the sensory transducers. A third principle is that information at each stage along the pathway is modified by "top-down” influences serving emotions, attention, memory, and language.

REVIEW QUESTIONS

- Describe the general process of transduction in a receptor that is a cell separate from the afferent neuron. Include in your description the following terms: specificity, stimulus, receptor potential, neurotransmitter, graded potential, and action potential.
- List several ways in which the magnitude of a receptor potential can be varied.
- Describe the relationship between sensory information processing in the primary cortical sensory areas and in the cortical association areas.
- List several ways in which sensory information can be distorted.
- How does the nervous system distinguish between stimuli of different types?
- How is information about stimulus intensity coded by the nervous system?
- Make a diagram showing how a specific ascending pathway relays information from peripheral receptors to the cerebral cortex.