Chapter 10 – Special Senses: Balance, Taste, and Smell

Objectives

Given the synopsis in this chapter, competence in each objective will be demonstrated by writing short essays, drawing diagrams, and responding to multiple choices or matching questions, at the level of 85% or greater proficiency for each student.

A. To explain the organization of the semicircular canals, utricle and saccule, and the mechanisms responsible for the detection of movement by the hair cells.
B. To explain the circuitry for processing of vestibular information by the central nervous system.
C. To explain the organization of the tongue and the mechanisms responsible for the detection of taste by the taste cells.
D. To explain the circuitry for processing of gustatory information by the central nervous system.
E. To explain the organization of the nose and olfactory epithelium and the mechanisms responsible for the detection of odorants by the olfactory cells.
F. To explain the circuitry for processing of olfactory information by the central nervous system

Vestibular apparatus and balance

Organization of the vestibular apparatus

As was shown earlier in Figure 9.8, the vestibular apparatus is located in the inner ear, includes the semicircular canals, and is positioned lateral to the cochlea. In addition to the semicircular canals, the vestibular apparatus includes the utricle and the saccule, and the vestibular ganglion and nerve. A posterior view of the vestibular apparatus is illustrated in Figure 10.1.

Semicircular Canals

There are three semicircular canals, as shown in Figures 9.8 and 10.1. Each semicircular canal responds to movement of the head in a different plane.

- The superior (anterior) semicircular canal responds to anterior-posterior nodding of the head.
- The posterior semicircular canal responds to left-right tilting of the head
- The lateral semicircular canal responds to horizontal rotation of the head

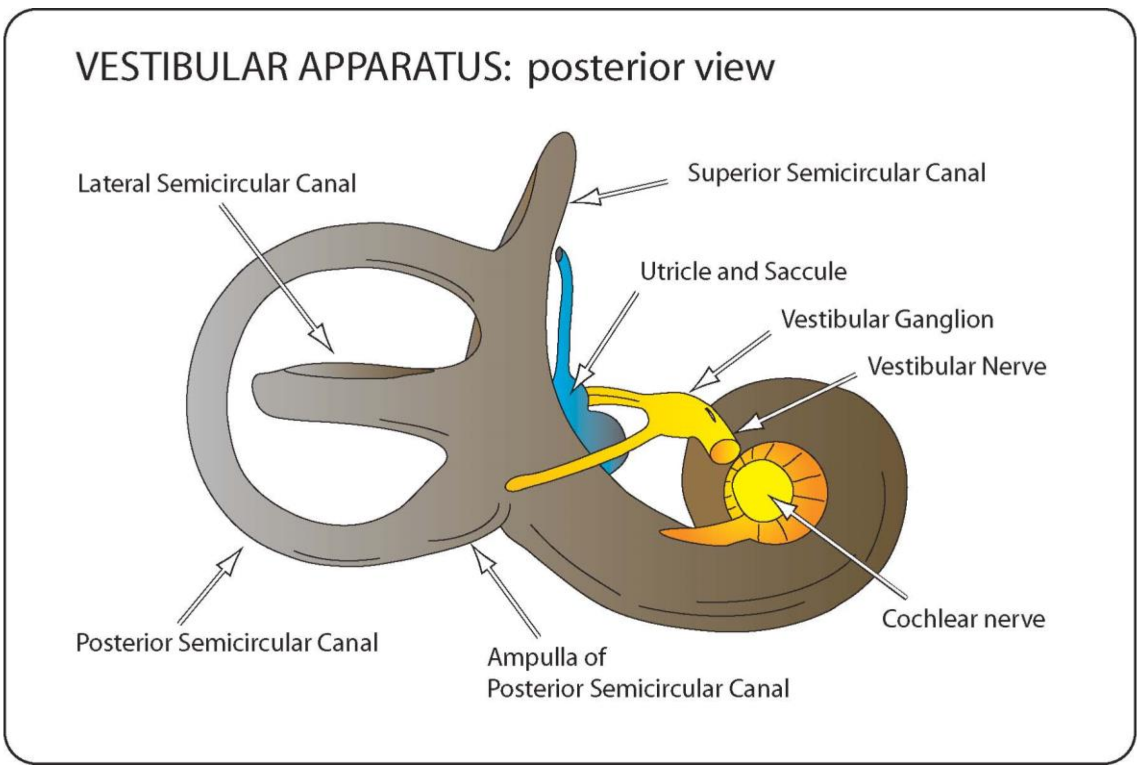

Figure 10.1 © 2007 David G. Ward, Ph.D.

Each semicircular canal includes a swollen area called the **ampulla** that houses the hair cells. The ampulla of a semicircular canal is illustrated in Figure 10.2.

- The semicircular canal and ampulla contain endolymph.
- Hair cells attach to the wall of the ampulla by way of the crista.
- The stereocilia of the hair cells are imbedded in a gelatinous structure called the **cupula.**

Detection of movement by the hair cells

Movement of the head in one direction leads to the relative movement of the endolymph and cupula in the opposite direction, as shown in Figure 10.2. The detection of movement by the hair cells in the ampulla of the semicircular canals is nearly identical to the detection of movement in the cochlea. Please refer to Figure 9.13.

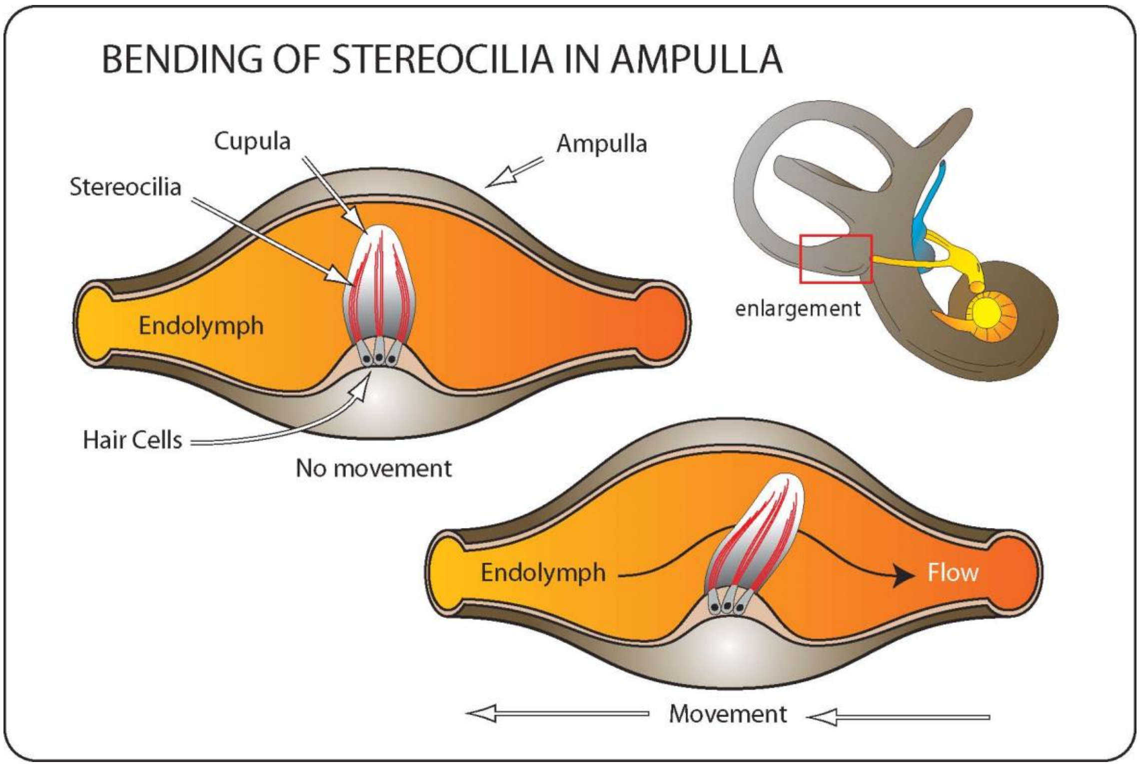

Figure 10.2 © 2007 David G. Ward, Ph.D.

- Movement of the stereocilia toward the tallest cilia (kinocillium) opens movement gated potassium channels and allows potassium ions to enter the cell causing depolarization.
  - The positive charge from the entry of potassium opens voltage gated calcium channels.

  - Calcium ions trigger the fusion of synaptic vesicles with the presynaptic membrane and the release of an excitatory neurotransmitter, most likely glutamate.

- Movement of the stereocilia toward the shortest cilia closes the movement gated potassium channels and leads to hyperpolarization.

The hair cells do not generate action potentials. They release an excitatory neurotransmitter (glutamate) at synaptic connections with the dendrites of vestibular ganglion neurons.

Utricle and Saccule

The utricle and saccule are located at the junction between the semicircular canals and the cochlea, as shown in Figure10.1. Each responds to gravity and linear acceleration.

- The utricle and saccule contain endolymph and mineral crystals called otoliths.
- Hair cells attach to wall of the utricle and saccule by way of the macula.
- The stereocilia of the hair cells are attached to the Otoliths.

Gravity and linear acceleration leads to the movement of the endolymph and otoliths, thus moving the stereocilia. The detection of movement by the hair cells in the utricle and saccule is nearly identical to the detection of movement in the cochlea and semicircular canals. Please refer to Figure 9.13.

Central processing of vestibular signals

Vestibular ganglion cells transmit signals by way of actions potentials generated in response to glutamate from the hair cells.

- Axons from vestibular ganglion cells (first order neurons) travel through the vestibular nerve into the pons, ipsilaterally.
- Axons from first order neurons from the utricle and saccule synapse on second order neurons in the lateral vestibular nucleus.

  - The second order neurons in the lateral vestibular nucleus travel through the vestibulospinal tracts to the spinal cord to control muscle tone in the legs to maintain posture.

- Axons from the first order neurons from the semicircular canals synapse on second order neurons in the medial vestibular nucleus.

  - The second order neurons in the medial vestibular nucleus travel through the medial longitudinal fasciculus to control muscle in the trunk and neck that orient the head.

- Axons from second order neurons from the vestibular nuclei synapse on third order neurons in the contralateral ventral posterior nucleus of the thalamus.
- Axons from third order neurons in ventral posterior nucleus of the thalamus synapse on neurons in the primary sensory cortex.

Tongue and Taste

Organization of the tongue and taste buds

The tongue and pharynx contain receptors for the detection of most taste. The tongue contains many finger-like extensions called papilla. As shown in the photomicrograph in Figure 10.3, the taste buds are located between the papilla.

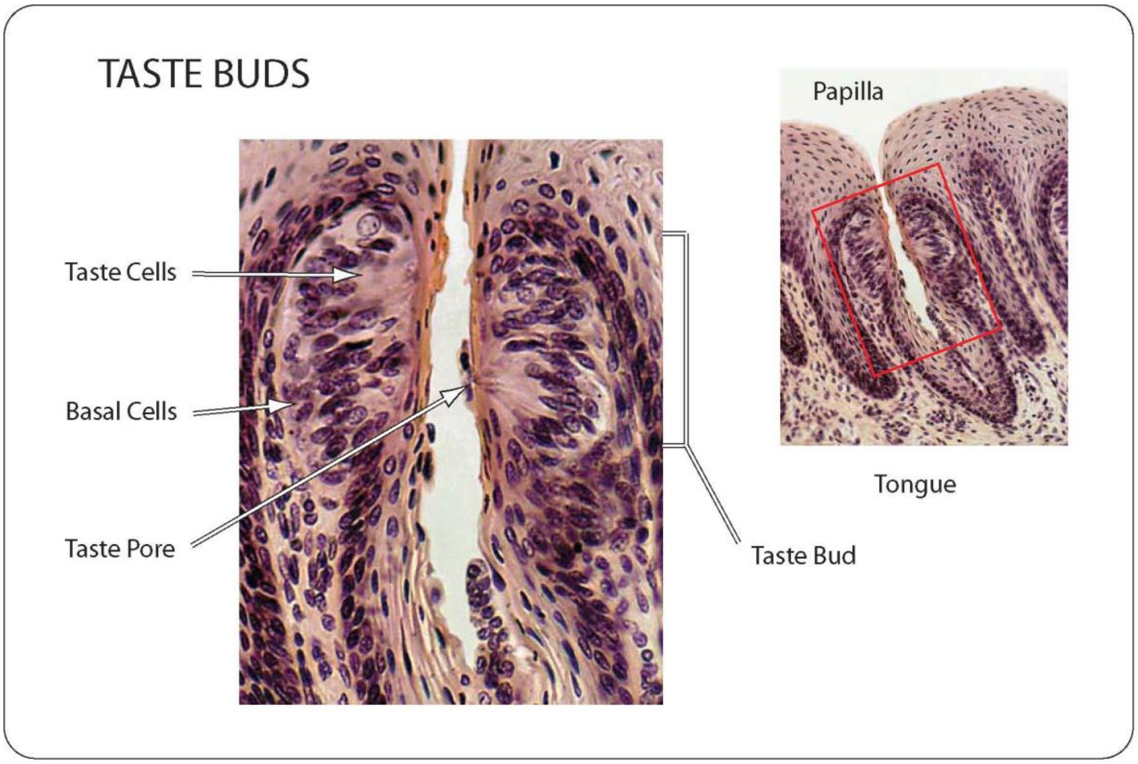

Figure 10.3 © 2007 David G. Ward, Ph.D.

- Basal cells support taste cells which are exposed to the fluid on the tongue by taste pores.
- Taste cells contain receptors that respond to salt, sour, bitter, sweet, and MSG (monosodium glutamate).

Detection of Salt

The detection of salt is illustrated in Figure 10.4.

- Sodium ions from salt enter the cell through amiloride sensitive sodium channels. (Amiloride was first found to inhibit the opening of Na+ channels in the kidney and is used as a diuretic).
- Positive charge from the initial sodium entry opens voltage gated sodium channels.
- Positive charge from the subsequent sodium entry opens voltage gated calcium channels.
- Calcium triggers the fusion of synaptic vesicles with the presynaptic membrane and the release of an excitatory neurotransmitter.

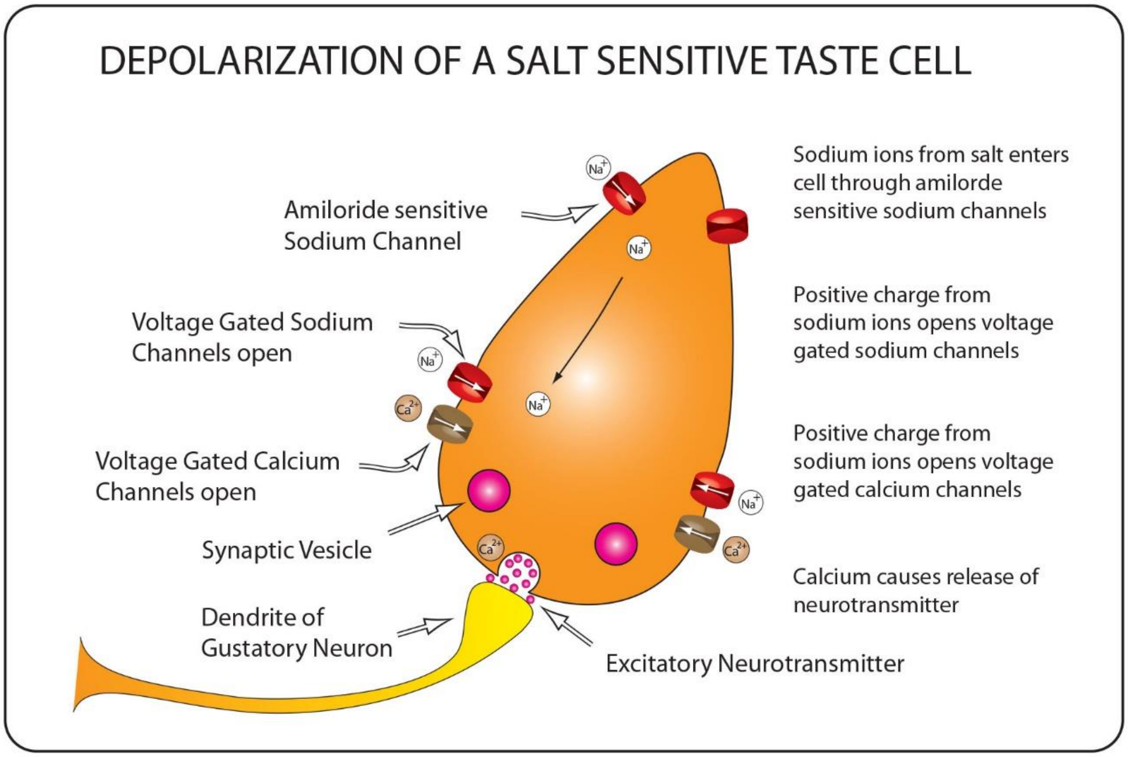

Figure 10.4 © 2007 David G. Ward, Ph.D.

Detection of Sour

The detection of sour is illustrated in Figure 10.5.

- Hydrogen ions close potassium channels or enter the cell through amiloride sensitive sodium channels.
- Positive charge from the potassium or hydrogen ions open voltage gated sodium channels.
- Positive charge from the subsequent sodium entry opens voltage gated calcium channels.
- Calcium triggers the fusion of synaptic vesicles with the presynaptic membrane and the release of an excitatory neurotransmitter.

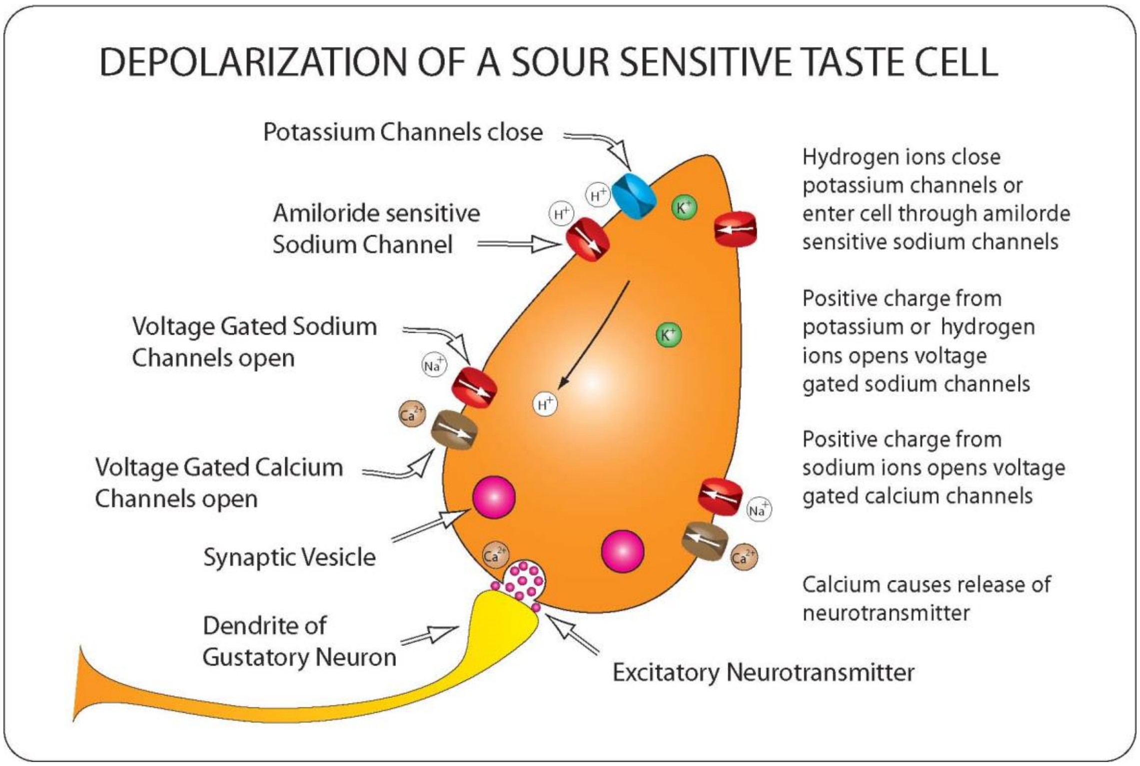

Figure 10.5 © 2007 David G. Ward, Ph.D.

Detection of Bitter, Sweet, and Umami (MSG)

The detection of bitter, sweet, and umami (MSG) is illustrated in Figure 10.6 and in Figure 10.7.

- Bitter, sweet, and umami (MSG) tastants bind to specific G-protein coupled taste receptors.
- G-protein alpha is activated (releases ADP and binds to ATP).
- Activated G-protein alpha activates phospholipase C.
- Phospholipase C converts PIP2 to IP3
- IP3 opens IP3 gated sodium channels.
- IP3 also opens calcium channels in the endoplasmic reticulum.
- Positive charge from the sodium ions opens voltage gated calcium channels.
- Calcium triggers the fusion of synaptic vesicles with the presynaptic membrane and the release of an excitatory neurotransmitter.

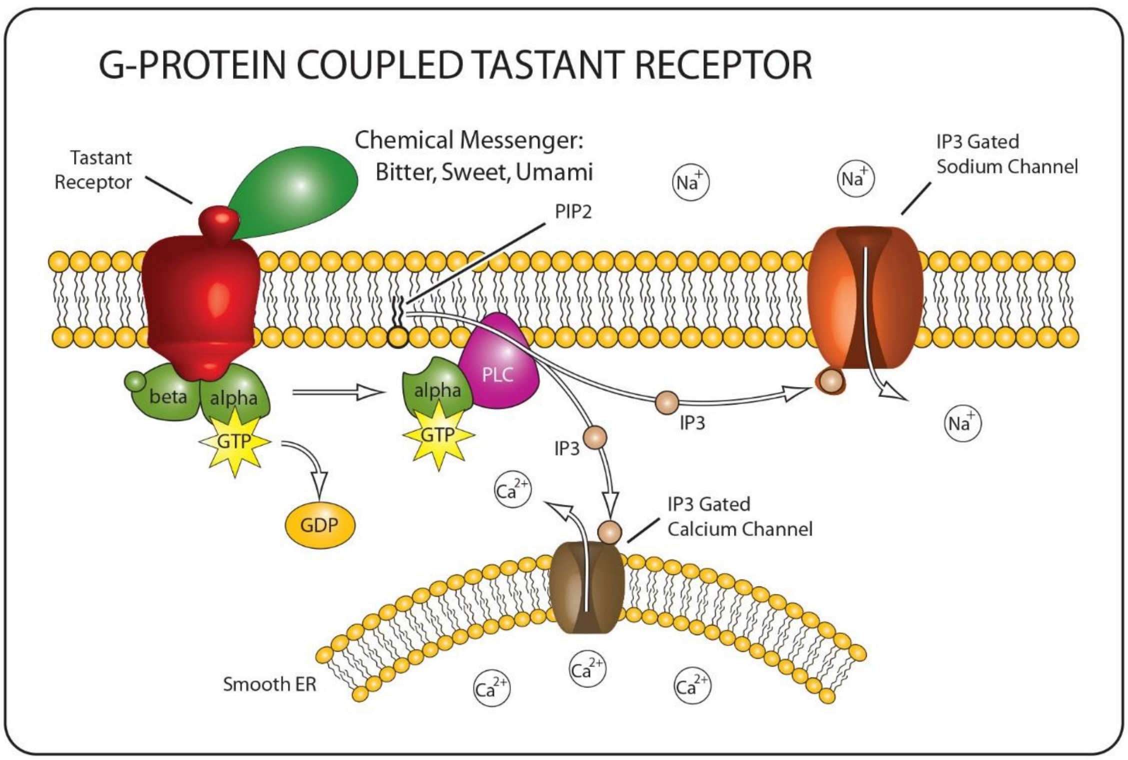

Figure 10.6 © 2014 David G. Ward, Ph.D.

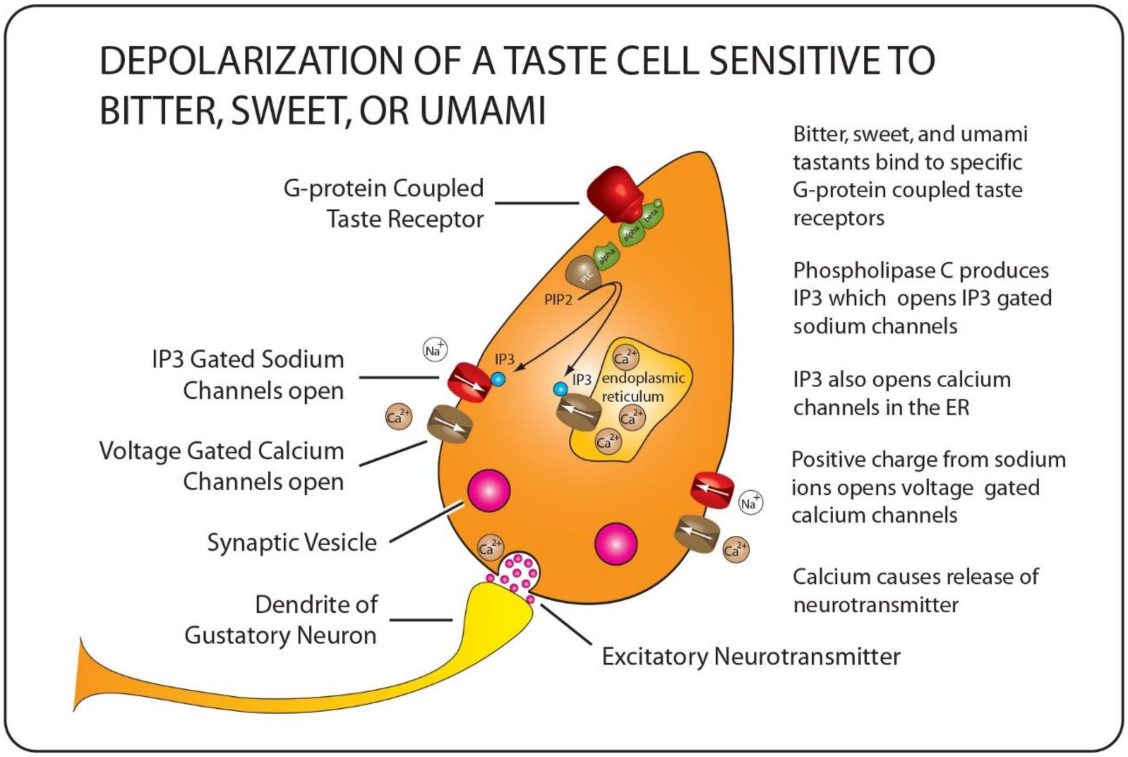

Figure 10.7 © 2014 David G. Ward, Ph.D.

Central Gustatory Pathways

The facial nerve carries taste signals from the anterior 2/3 of the tongue. The glossopharyngeal nerve carries taste signals from the posterior 1/3 of the tongue. The vagus nerve carries taste signals from the pharynx. The major gustatory pathways are shown in Figure 10.8.

- Axons from sensory neurons (first order neurons) of the facial, glossopharyngeal, and vagus nerves travel from various ganglia into the medulla oblongata, ipsilaterally.

    - Axons of the facial nerve (VII) travel from the geniculate ganglion.
    - Axons of the glossopharyngeal nerve (IX) travel from the jugular ganglion.
    - Axons of the vagus nerve (X) travel from the nodose ganglion.

- The axons of the first order neurons synapse on second order neurons in the gustatory nucleus of the solitary tract.
    - The second order neurons connect to a variety of neurons in the brain stem, hypothalamus and limbic system involved in the autonomic control of visceral function.
- Axons of the second order neurons crossover to travel contralaterally to synapse on third order neurons in the contralateral thalamus (ventral posterior nucleus).
- Axons of the third order neurons from the thalamus travel in the internal capsule to synapse on fourth order neurons in the primary gustatory cortex.

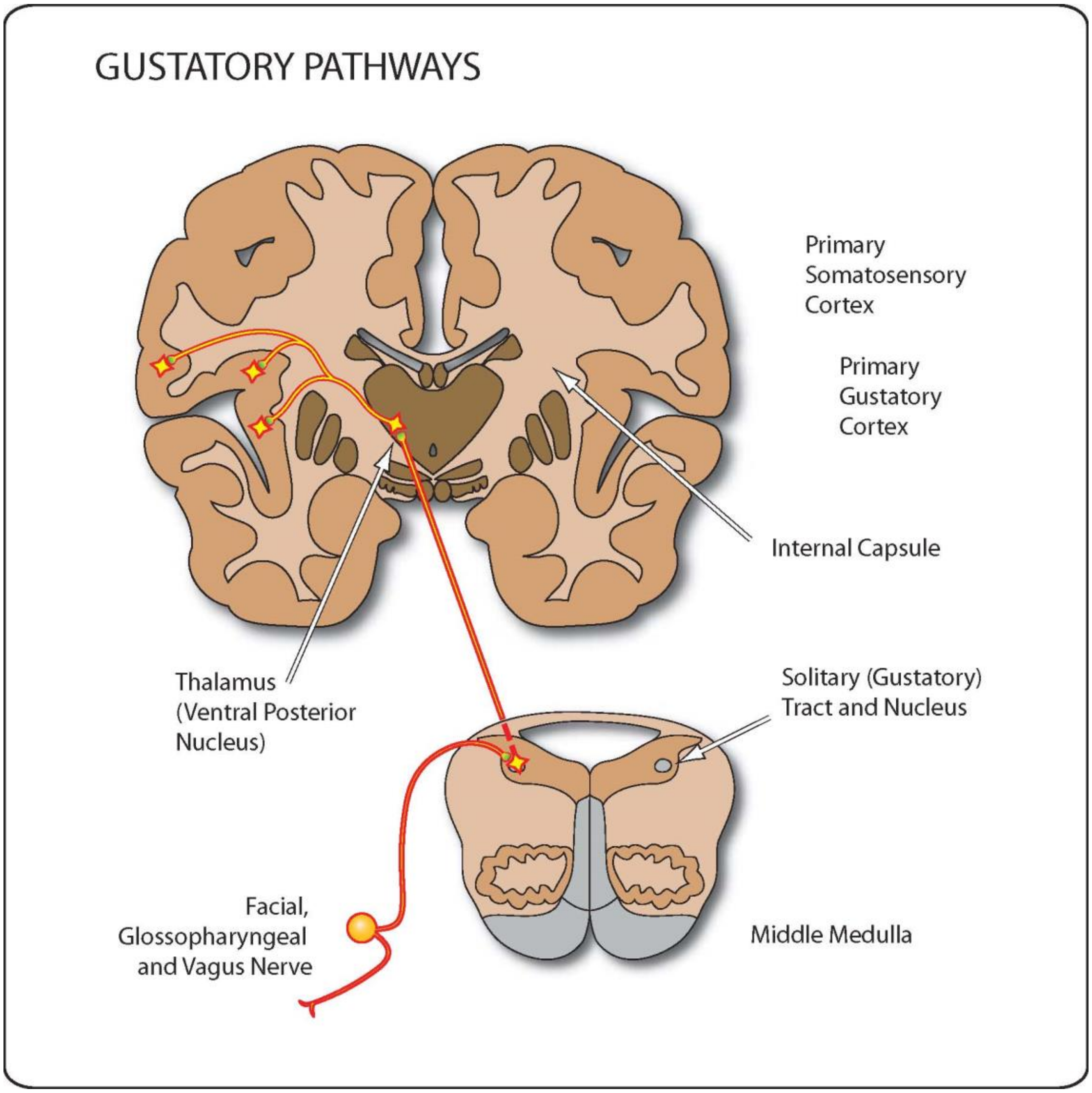

Figure 10.8 © 2007 David G. Ward, Ph.D.

Nose and Smell

Nose and Olfactory Epithelium

The olfactory epithelium contains receptors for the detection of most smells. As shown in Figure 10.9, the olfactory epithelium covers the superior, middle and inferior concha of the nasal cavity. As air passes from the external nares to the internal nares, receptors of olfactory cells are exposed to various odorants.

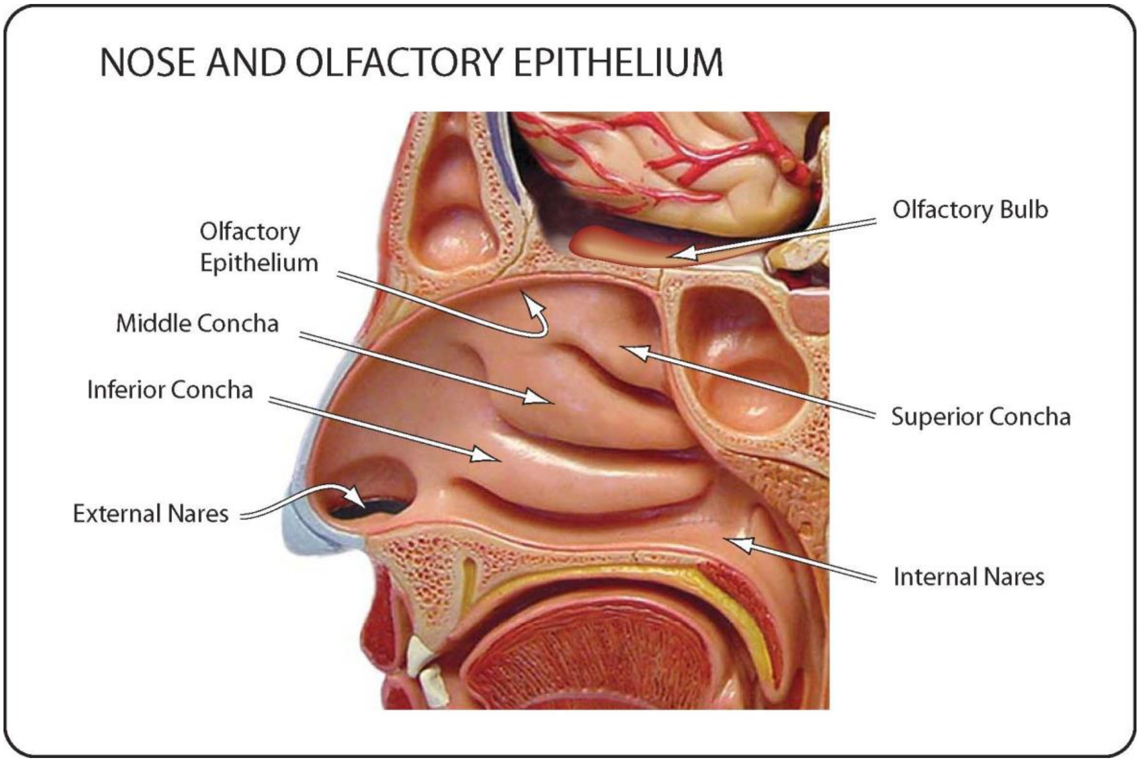

Figure 10.9 © 2007 David G. Ward, Ph.D.

Organization of Olfactory Cells and Bulb

As shown in Figure 10.10, olfactory cells are anchored in the olfactory epithelium. The receptors extend onto the surface of the epithelium where they are covered in mucus. The axons of the **olfactory cells** pass through the **cribriform plate** to synapse with dendrites of **olfactory neurons** (ganglion cells) in the **olfactory bulb**.

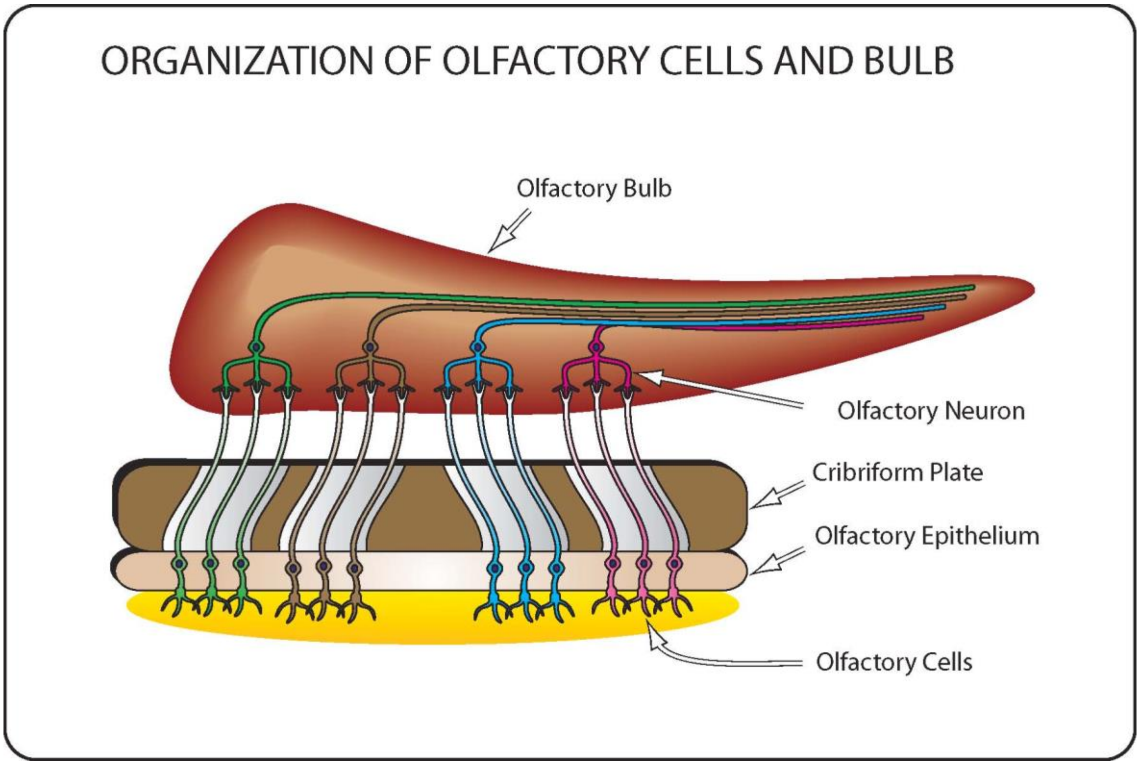

Figure 10.10 © 2007 David G. Ward, Ph.D.

Detection of odorants

The detection of odorants is illustrated in Figure 10.11 and 10.12.

- Odorants bind to a G-protein coupled olfactory receptor.
- G-protein alpha is activated (releases ADP and binds to ATP).
- Activated G-protein alpha activates adenyl cyclase.
- Adenyl cyclase converts ATP to cAMP.
- cAMP opens cAMP gated sodium/calcium channels.
- Calcium seems to open chloride channels and enhances depolarization. (Intracellular chloride concentrations are normally high in olfactory cells.)

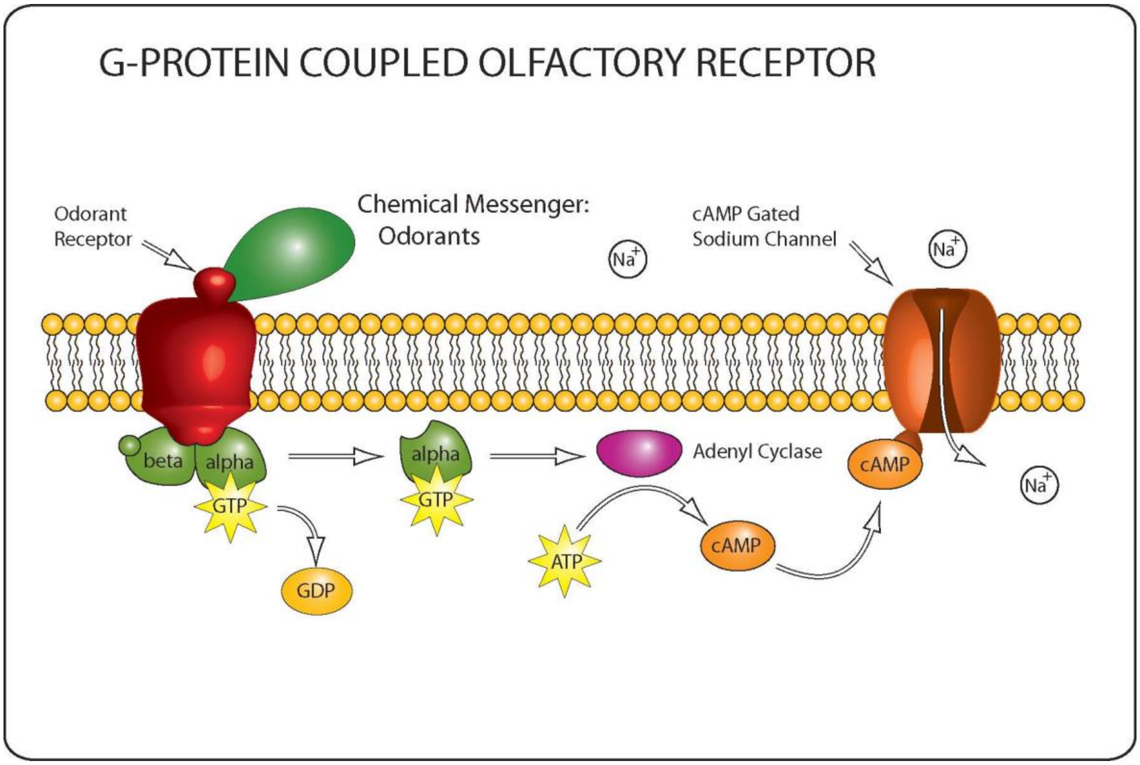

Figure 10.11 © 2007 David G. Ward, Ph.D.

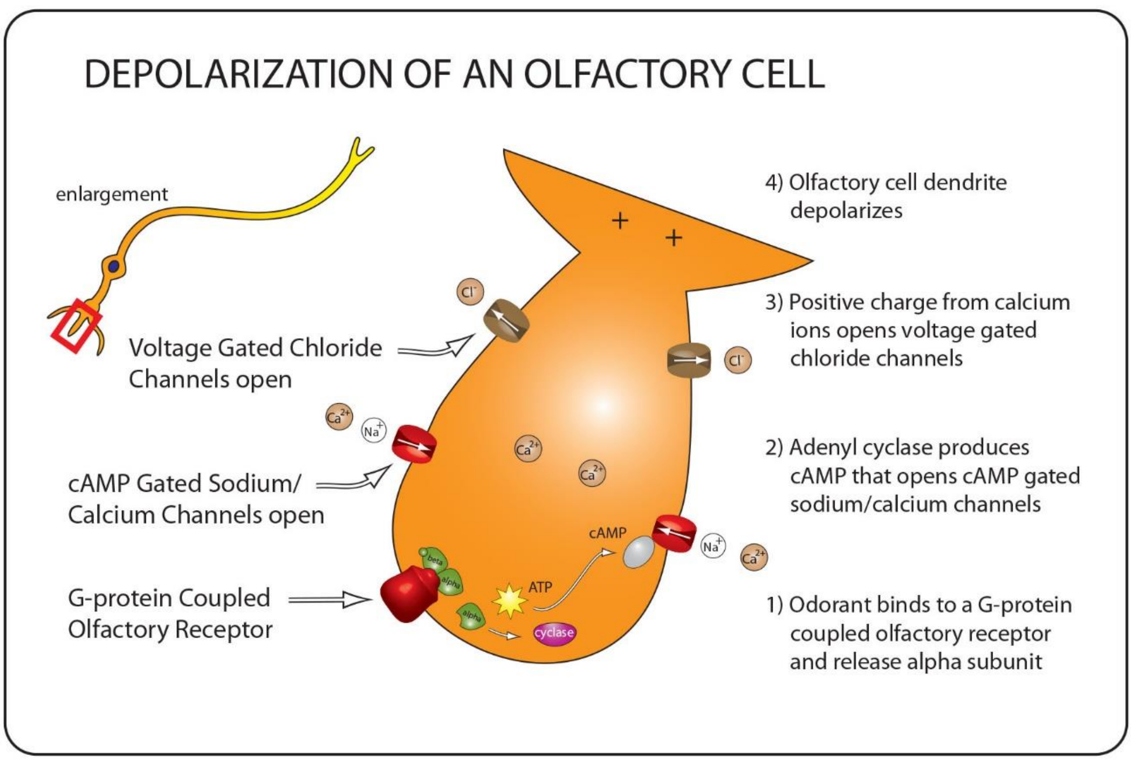

Figure 10.12 © 2014 David G. Ward, Ph.D.

Thereafter, the positive charge generates action potentials that are propagated along the axon of the olfactory cells and into the olfactory bulb.

- Once the Positive charge from the action potential reaches the synaptic bulbs of the olfactory cells voltage gated calcium channels open.
- Calcium enters the synaptic bulb and triggers the fusion of synaptic vesicles with the presynaptic membrane and the release of an excitatory neurotransmitter.
- The excitatory neurotransmitter (probably glutamate) then depolarizes the dendrites of olfactory neurons in the olfactory bulb.

Central Olfactory Pathways

The axons of the olfactory neurons (ganglion cells) in the olfactory bulb will carry the olfactory signals to other brain structures for further processing.

- Some axons from the olfactory bulb travel directly into the olfactory cortex and related temporal lobe and limbic structures.
- Other axons from the olfactory bulb synapse with second order neurons in the olfactory tubercle (located just anterior to the optic chiasm).
- Axons of the second order neurons in the olfactory tubercle travel ipsilateral to synapse on third order neurons in the thalamus (medial dorsal nucleus).
- Axons of the third order neurons from the thalamus travel to the orbitofrontal cortex.

It appears that several parallel pathways mediate different olfactory functions, including odor discrimination, conscious perception, motivational and emotional features, and memory.

Quiz Yourself

1-5. Matching
A) 1) ______
B) 2) ______
C) 3) ______
4) ______
5) ______

6-10. Matching
A) 6) ______
B) 7) ______
C) 8) ______
D) 9) ______
E) 10) ______

11-15. Place in order the.
A) 11) ______
B) 12) ______
C) 13) ______
D) 14) ______
E) 15) ______

16-20. Place in order the.
A) 16) ______
B) 17) ______
C) 18) ______
D) 19) ______
E) 20) ______

Fill in

21..

22..

23..

24..

25..

Short Essays

1. Describe the organization of the vestibular apparatus and explain the mechanisms responsible for the detection of body position and movement by hair cells.
2. .
3. .
4. .