CHAPTER 1

Structure and Function of Neurons

Neurons are the cells of chemical communication in the brain. Human brains comprise tens of billions of neurons, each linked to thousands of other neurons. Thus, the brain has trillions of specialized connections known as synapses. Neurons have many sizes, lengths, and shapes, which determine their functions. Localization within the brain also determines function. When neurons malfunction, behavioral symptoms may occur. When drugs alter neuronal function, behavioral symptoms may be relieved, worsened, or produced. Thus, this chapter briefly describes the structure and function of normal neurons as a basis for understanding psychiatric disorders and their treatments.

Varieties of neurons

General structure

Although this textbook will often portray neurons with a generic structure (such as that shown in Figure 1-1A and B), the truth is that many neurons have unique structures (see Figures 1-2 through 1-8). All neurons have a cell body, known as the soma, and are set up structurally to receive information from other neurons through dendrites, sometimes via spines on the dendrites, and often through an elaborately branching "tree" of dendrites (Figure 1-1A and B). Neurons are also set up structurally to send information to other neurons via an axon, which forms presynaptic terminals as the axon passes by – "en passant" (Figure 1-1A) – or as it ends (in presynaptic axon terminals) (Figure 1-1A).

Structure of unique neurons

Many neurons in the central nervous system have unique structures. For example, each pyramidal cell has a cell body shaped like a triangular pyramid (Figure 1-2A is a somewhat

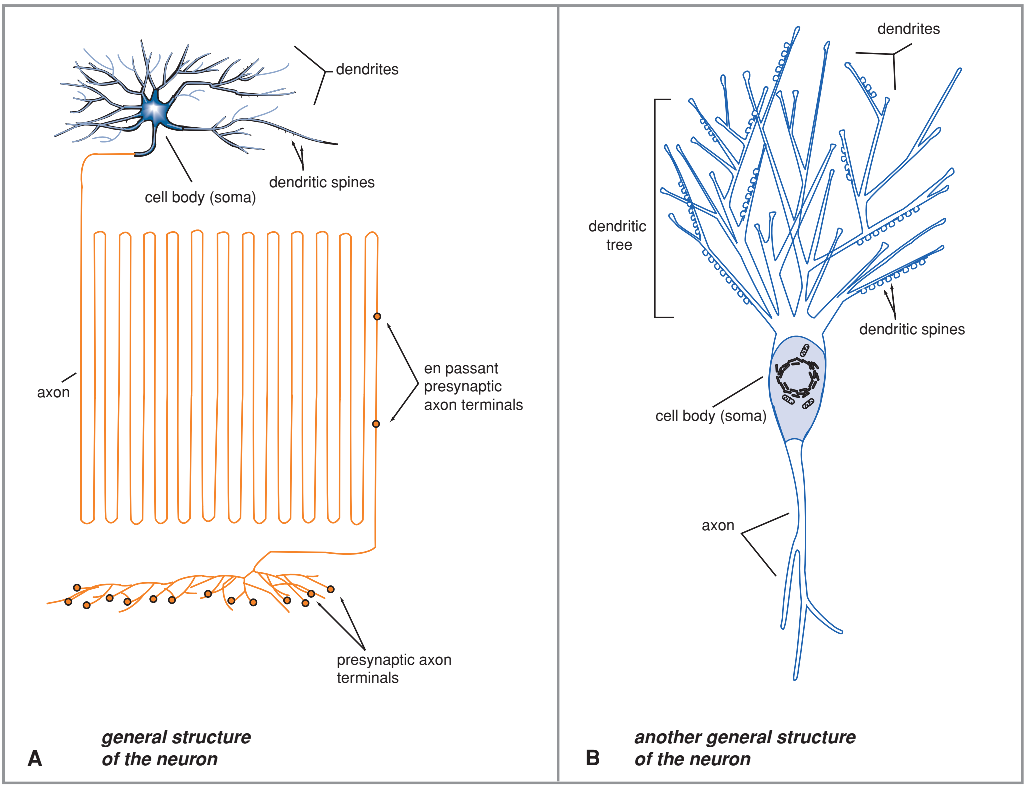

FIGURE 1-1A and B Generic structure of neuron. This is an artist's conception of the generic structure of a neuron. All neurons have a cell body known as the soma, which is the command center of the nerve and contains the nucleus of the cell. All neurons are also set up structurally to both send and receive information. Neurons send information via an axon, which forms presynaptic terminals as it passes by (en passant) or as it ends (**A**). Neurons receive information from other neurons through dendrites, sometimes via spines on the dendrites, and often through an elaborately branching tree of dendrites (**B**). Although all neurons share these properties, they can have unique structures that, in turn, dictate specialized functions.

realistic depiction and 1–2B is an icon of a pyramidal cell); each also has an extensively branched spiny apical dendrite and shorter basal dendrites (Figure 1-2B) as well as a single axon emerging from the basal pole of the cell body. Pyramidal neurons are discussed extensively in this textbook because they make up most of the neurons in the functionally important prefrontal cortex as well as elsewhere in the cerebral cortex. Several other neurons are named for the shape of their dendritic tree. For example, basket cells are so named because they have widely ramified dendritic trees that look rather like baskets (Figure 1-3A is a somewhat realistic depiction and 1–3B is an icon of a basket cell). Basket cells function as interneurons in the cortex, and the wide horizontal spread of their axons can make many local inhibitory contacts with the soma of other cortical neurons. Double bouquet cells are also inhibitory interneurons in the cortex and have a very interesting vertical bitufted appearance, almost like two bouquets of flowers (Figure 1-4A is a somewhat realistic depiction and 1–4B is an icon of a double bouquet cell). Each double bouquet cell has a tight bundle of axons that is also vertically oriented, with varicose collaterals that innervate the dendrites of other cortical neurons, including other double bouquet cells, and supply inhibitory input to those neurons. Spiny neurons, not surprisingly, have spiny-looking dendrites (Figure 1-5A

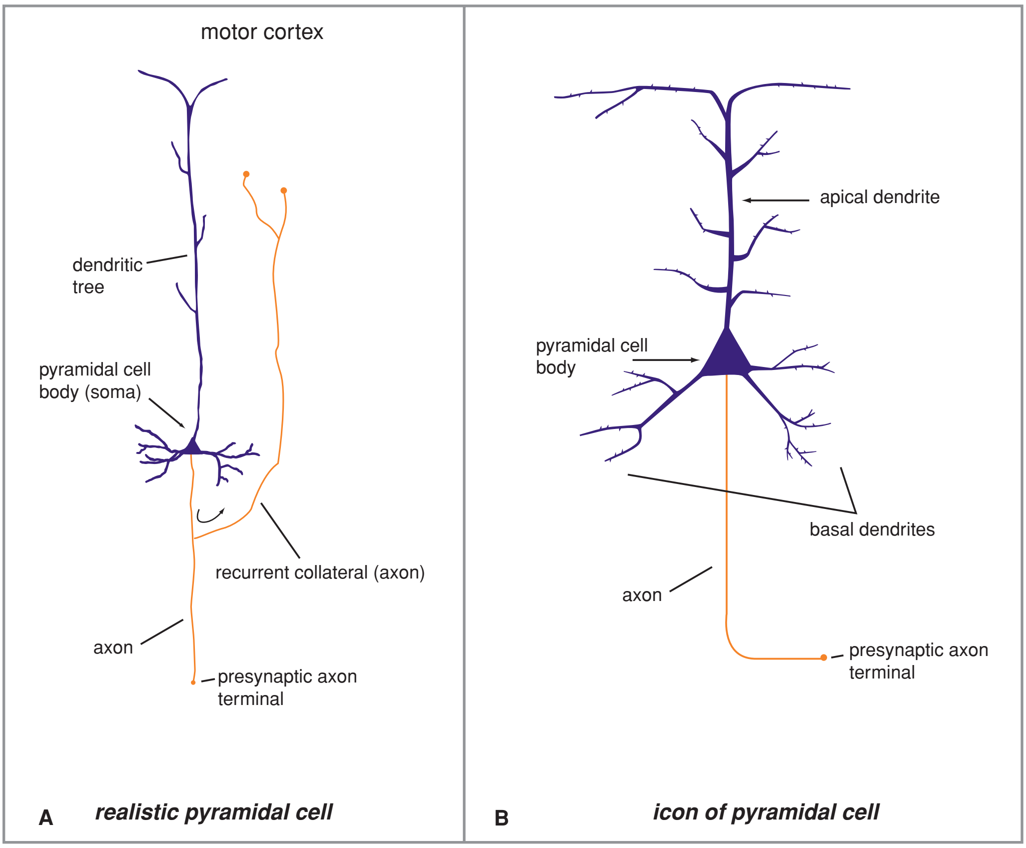

FIGURE 1-2A and B Pyramidal cells. Pyramidal cells (depicted somewhat realistically in **A** and iconically in **B**) have a cell body shaped like a triangular pyramid, an extensively branched spiny apical dendrite, shorter basal dendrites, and a single axon emerging from the basal pole of the cell body. The majority of the neurons in the cerebral cortex, particularly in the prefrontal cortex, are pyramidal neurons.

is a somewhat realistic depiction and 1–5B is an icon of a spiny neuron). Spiny neurons are located in the striatum in large numbers and have a highly ramified dendritic arborization that radiates in all directions and, of course, is densely covered with spines, which receive input from cortex, thalamus, and substantia nigra. Spiny neurons have long axons that either leave the striatum or circle back as recurrent collaterals to innervate neighboring spiny neurons. Finally, Purkinje cells from the cerebellum form a unique dendritic tree that, in fact, looks very much like a real tree (Figure 1-6). This dendritic tree is extensively branched and fans out from an apical position, with a single axon emerging from the basal pole of the cell.

At least one type of neuron is named for its unique axonal structure: the chandelier neuron (Figure 1-7A is a somewhat realistic depiction and 1–7B is an icon of a chandelier neuron). The axons of this cell look like an old-fashioned chandelier, with odd-appearing axon terminals shaped like vertically oriented cartridges, each consisting of a series of axonal swellings linked by thin connecting pieces. Chandelier neurons are yet another type of inhibitory interneuron in the cortex, where the characteristic "chandelier" endings of their axons have a specific function and location – namely, to serve as inhibitory contacts close to the initial segment of axons of pyramidal cells. Thus, chandelier neurons terminate in what

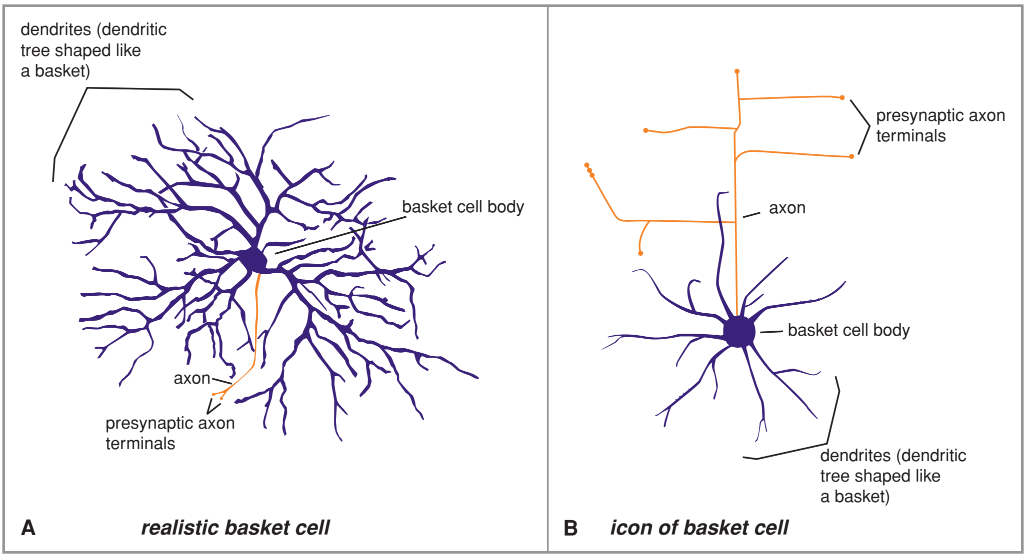

FIGURE 1-3A and B Basket neurons. Basket neurons are named for their widely ramified dendritic trees, which resemble baskets (depicted somewhat realistically in **A** and iconically in **B**). They are cortical interneurons with axons that spread horizontally to make many inhibitory contacts with the soma of other neurons.

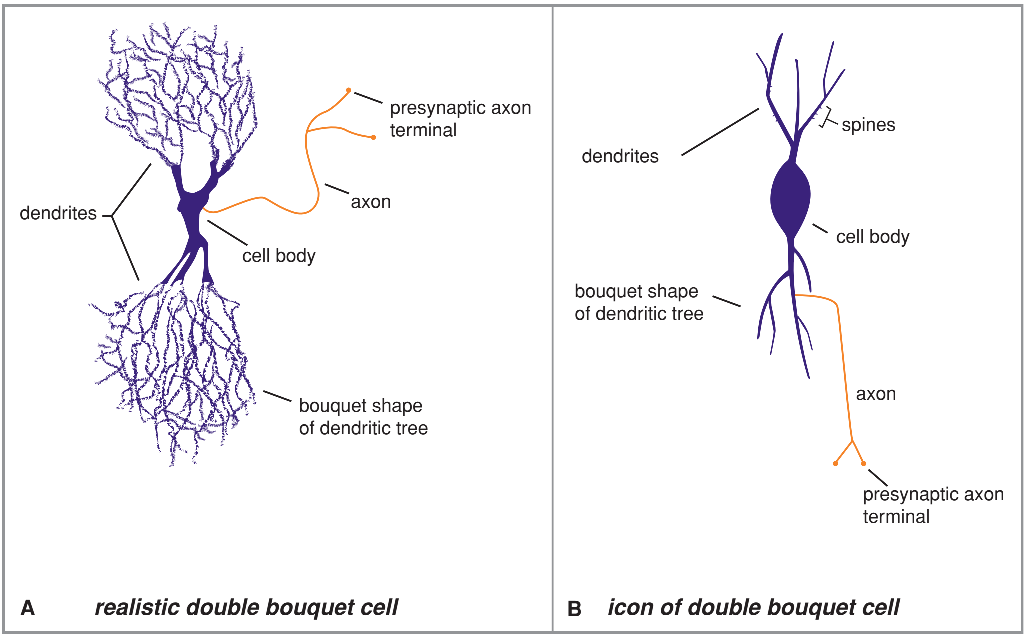

FIGURE 1-4A and B Double bouquet cells. Double bouquet cells are so called because of their vertical bitufted appearance, which resembles two bouquets of flowers (depicted somewhat realistically in **A** and iconically in **B**). Like basket neurons, double bouquet cells are inhibitory interneurons in the cortex. They have a tight bundle of axons that is oriented vertically, with varicose collaterals that innervate the dendrites of other cortical neurons, including other double bouquet cells.

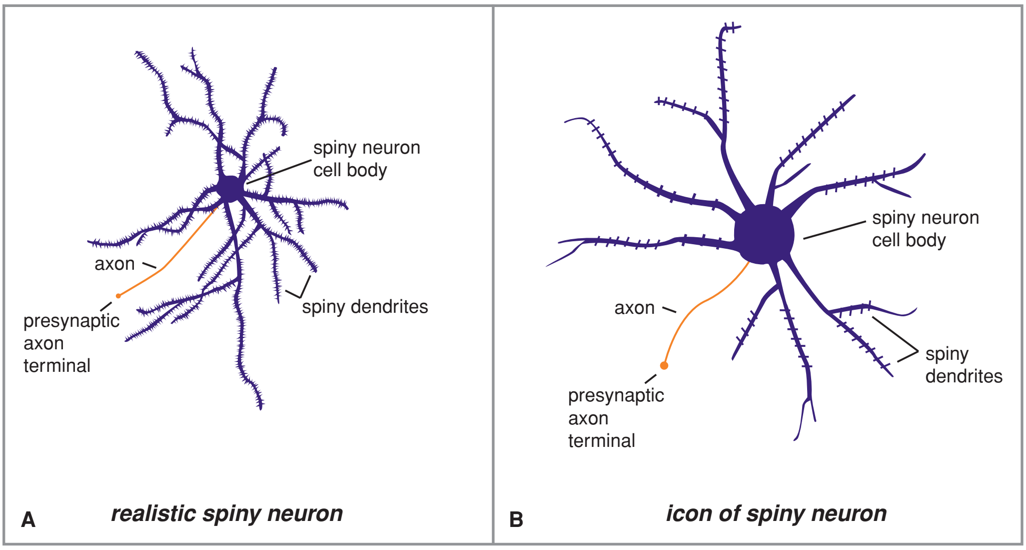

FIGURE 1-5A and B Spiny neurons. The dendrites of spiny neurons radiate in all directions and are densely covered with spines (depicted somewhat realistically in **A** and iconically in **B**). Spiny neurons are located in the striatum in large numbers and receive input from cortex, thalamus, and substantia nigra. The axons of spiny neurons are long and either leave the striatum or circle back as recurrent collaterals to innervate neighboring spiny neurons.

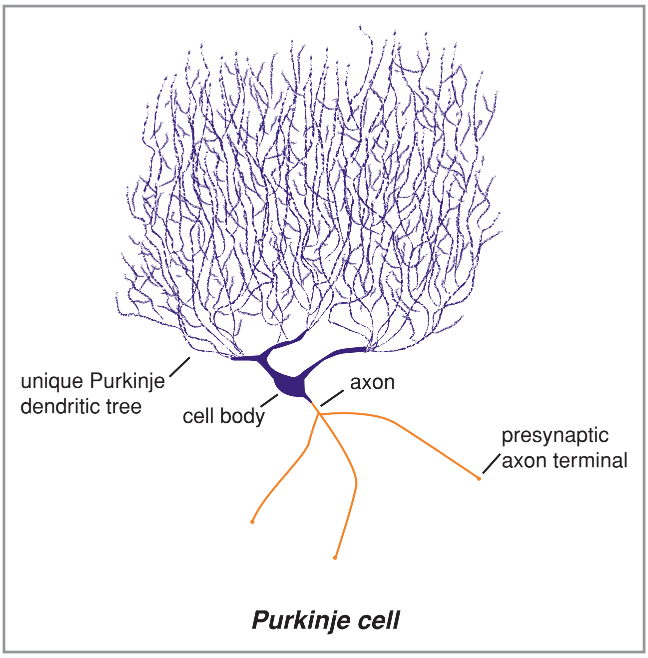

FIGURE 1-6 Purkinje cells. Purkinje cells from the cerebellum have extensively branched dendritic trees fanning out from an apical position, with a single axon emerging from the basal poll of the cell.

is called an axoaxonic synapse. Since the initial segment of a pyramidal cell's axon is the most influential location in determining whether that axon will fire or not, the chandelier neuron can potentially provide the most powerful inhibitory input to a pyramidal neuron, possibly even being able to completely shut down a pyramidal cell's firing. Many chandelier

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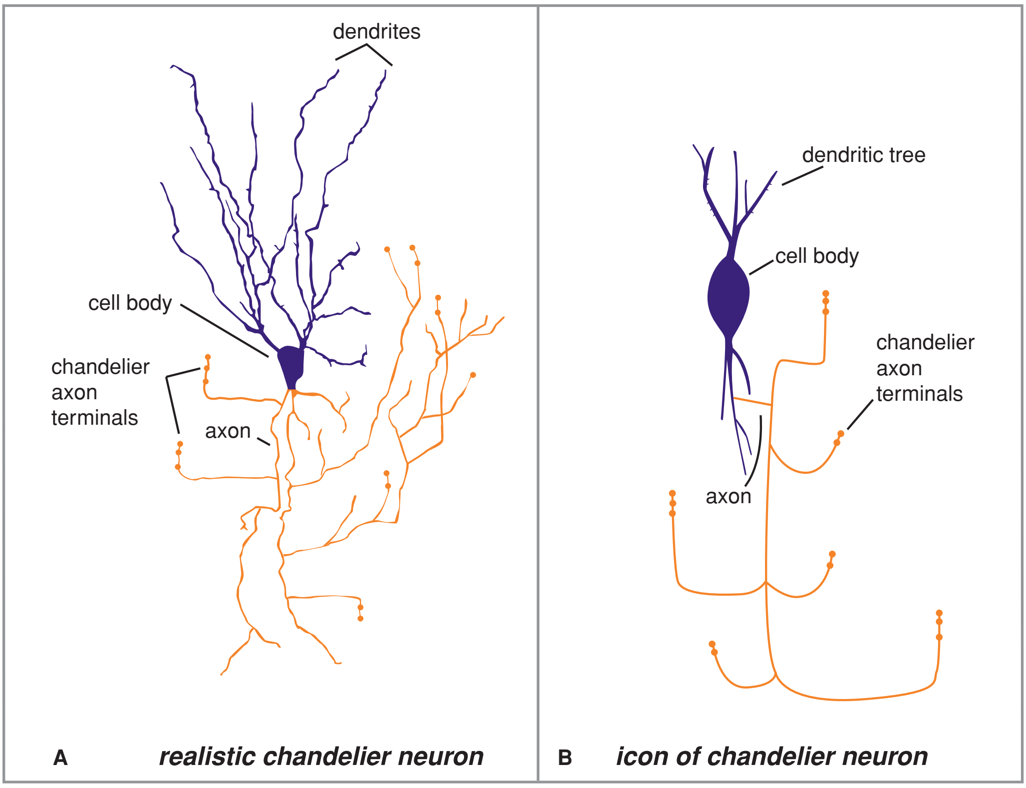

FIGURE 1-7A and B Chandelier neurons. The chandelier neuron is named for its unique axonal structure (depicted somewhat realistically in **A** and iconically in **B**). The axons resemble an old-fashioned chandelier with axon terminals shaped like vertically oriented cartridges, each consisting of a series of axonal swellings linked together by thin connecting pieces. Like basket neurons and double bouquet cells, chandelier neurons are inhibitory interneurons in the cortex. The "chandelier" endings of their axons come into close contact with the initial segments of pyramidal cell axons, forming what is called an axoaxonic synapse. The chandelier neuron can potentially provide powerful inhibitory input to a pyramidal neuron via this synapse, possibly even completely shutting down a pyramidal cell's firing. Many chandelier neurons provide input to a given pyramidal cell, and each chandelier neuron can provide input to several pyramidal cells.

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Internal operations and the functioning of a neuron

Subcellular organelles

In order to do its duties, the neuron contains various internal working parts that have specialized functions, from subcellular organelles and protein synthetic machinery to internal superhighways for transport of these materials into dendrites and axons on specialized molecular "motors." Specific neuronal functions are associated with each anatomical zone of a neuron (Figure 1-8). For example, the soma and dendrites together form the somatodendritic zone, which has the function of "reception." Neurons receive a wide variety of signals, sometimes simultaneously and sometimes sequentially, from other neurons, environment, chemicals, hormones, light, drugs, and so on. In addition to receiving this mass of incoming information, the somatic zone also serves as a "chemical integrator" of it all. It does this

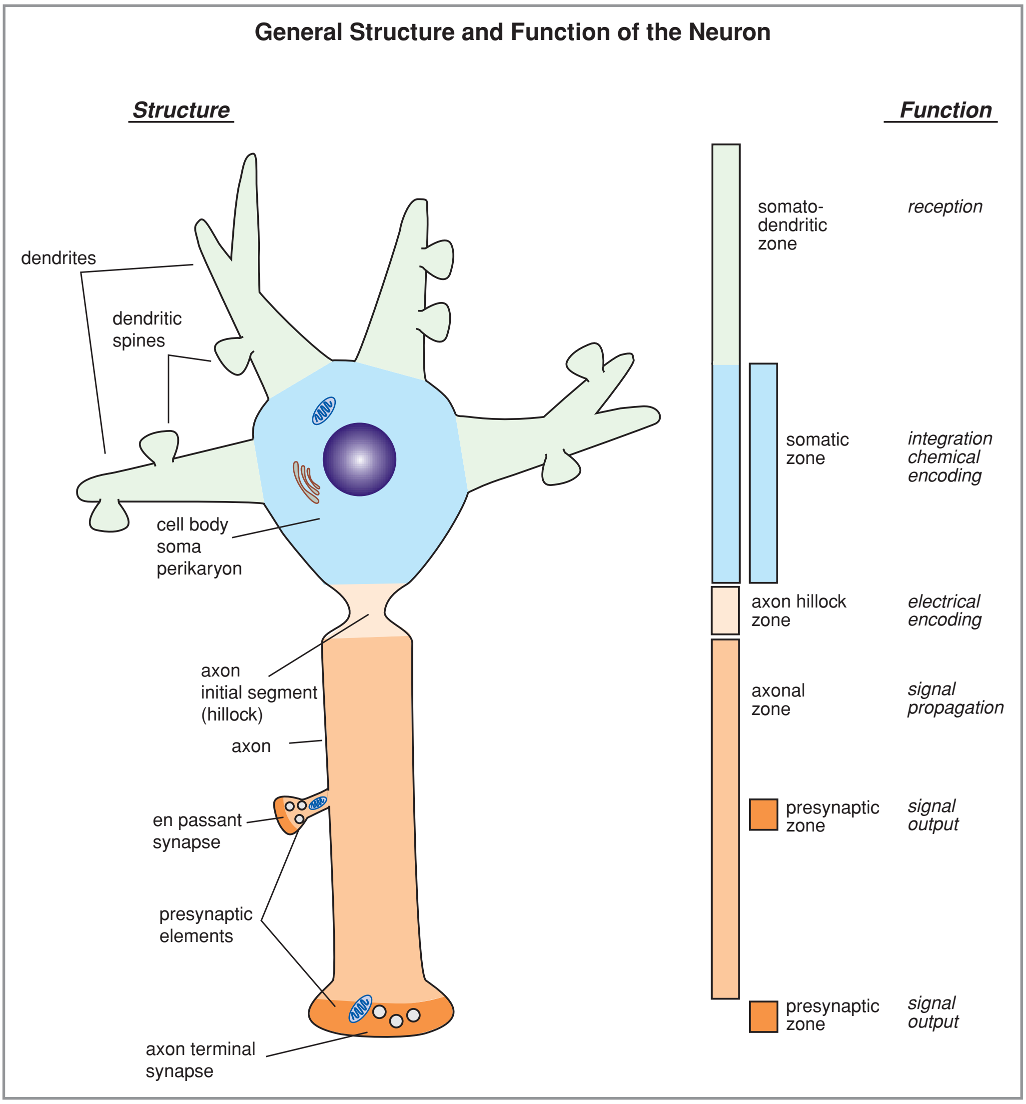

FIGURE 1-8 Anatomic zones of neurons. The different anatomic zones of neurons are associated with specific functions, as shown here. The soma and dendrites form the somatodendritic zone, which has the function of receiving a wide variety of signals from other neurons. The somatic zone also serves as a chemical integrator of incoming information: incoming signals from postsynaptic dendrites are decoded by the genome (located in the cell nucleus in the soma), which then encodes chemical signals destined for either internal or external communication. The initial segment of the axon, the axon hillock, serves as an electrical integrator, controlling whether or not the neuron will fire in response to incoming electrical information. The axon propagates these signals, with electrical signals traveling along the membrane of the axon and chemical signals traveling within its internal structural matrix. The presynaptic zone at the end of the axon contains unique structures that convert chemical and electrical signals into signal output.

by first generating cascades of incoming chemical signals from its postsynaptic dendrites, which speak directly with its genome, located in the cell nucleus in the soma (Figure 1-8). These incoming volleys of chemical information are then decoded and read by the genome, after which the genome adds its own reaction to this information by encoding chemical

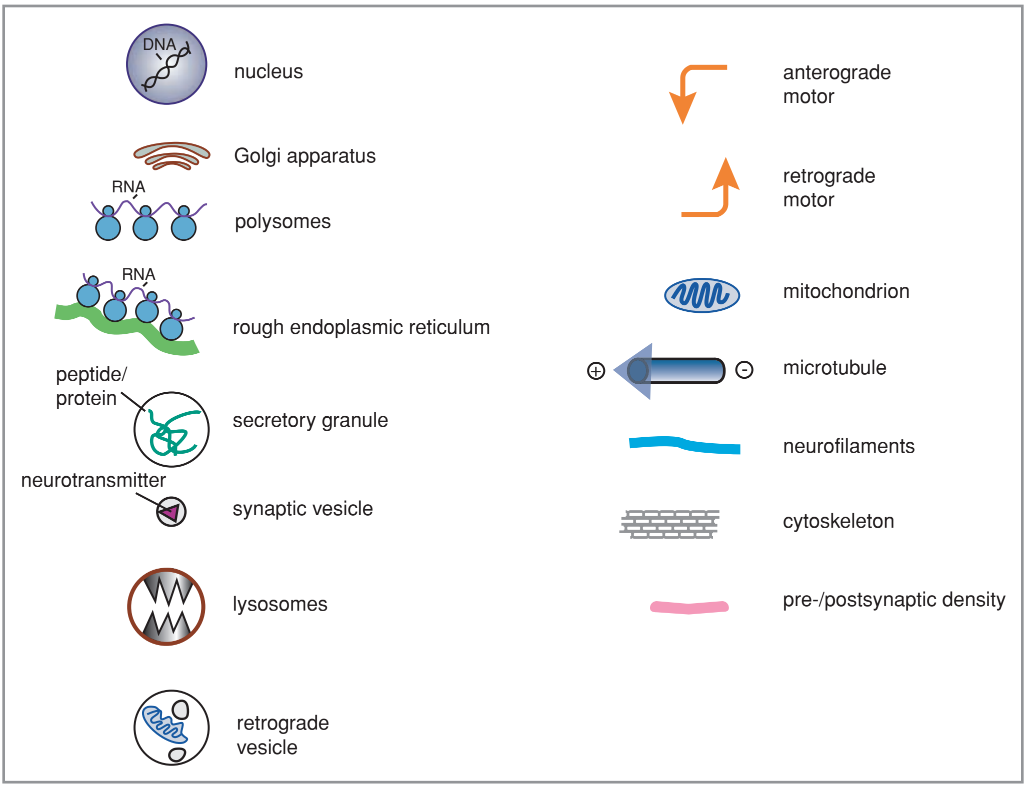

FIGURE 1-9 Neuronal components. Depicted here are many neuronal components manufactured by the cell nucleus, which contains the neuron's DNA. These components are located in specific locations within the neuron and have specific functions.

signals destined either for internal communication within its own neuronal boundaries or for external communication via its neuronal connections.

Another anatomical zone is that of the axon hillock, also called the axon's initial segment (Figure 1-8). Its job is to serve as an "electrical integrator" of all the incoming electrical information and decide whether or not to "fire" the neuron. Directly connected to the axon hillock is the axon itself, which propagates electrical signals along its membrane and chemical signals within its internal structural matrix. At the end of the axon is a specialized zone with unique structures that allow it to convert the chemical and electrical signals arriving there into signal output to the next neuron.

How does all of this happen? It is done by orchestrating many specialized neuronal instruments to work together in amazing functional harmony – at least when things are working normally. Many components of a functioning neuron are shown in Figure 1-9. A representation of where these components are localized within the neuron is shown in Figure 1-10. These specialized neuronal instruments are put into action in the remaining figures of this chapter (Figures 1-11 through 1-20). The specific roles that these specialized neuronal instruments play in neuronal functioning as shown in these figures are explained briefly here.

As already mentioned, the cell nucleus, containing the neuron's DNA, is located in the neuron's soma and is responsible for manufacturing essentially all the components shown

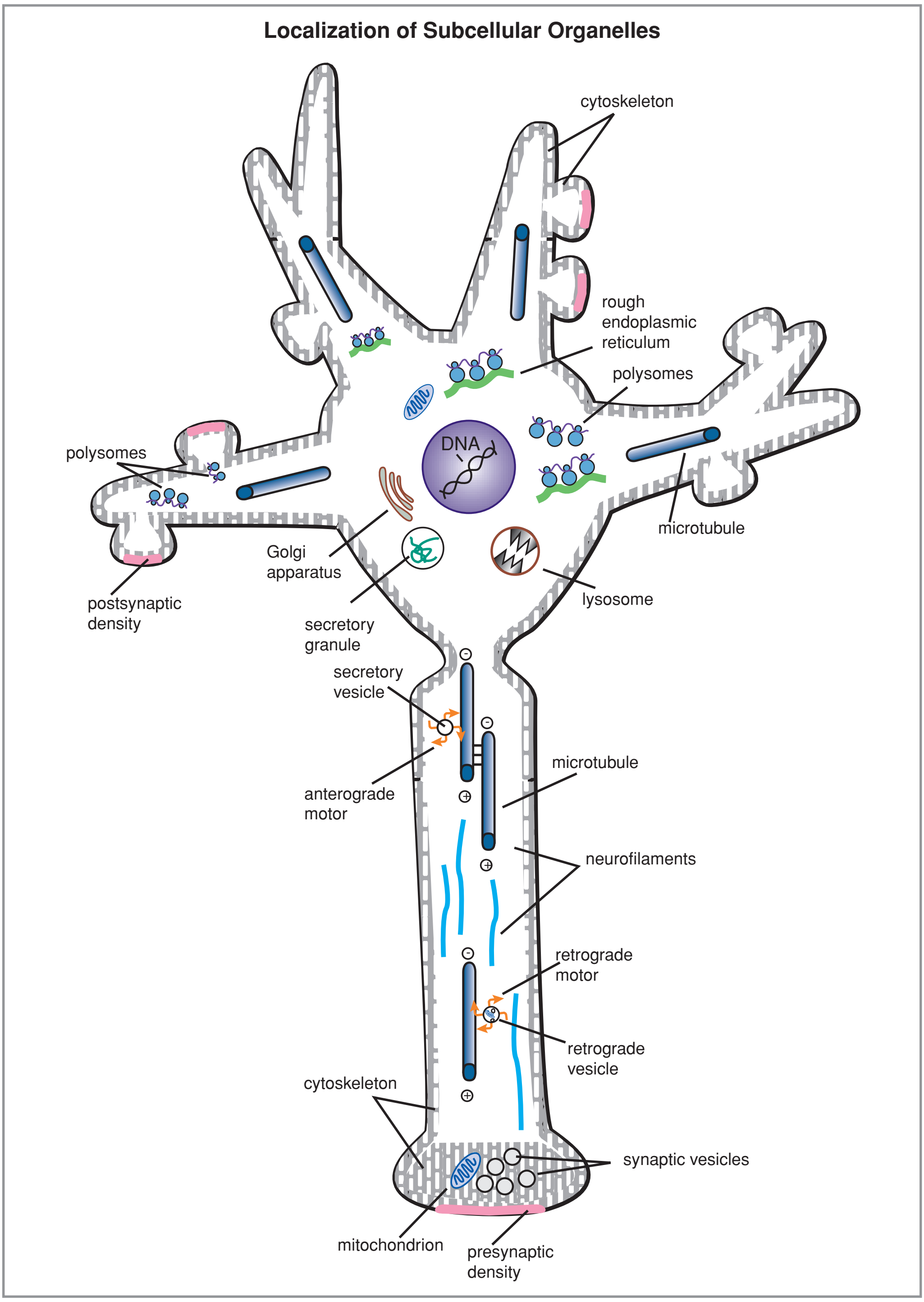

FIGURE 1-10 Localization of neuronal components. The function of each neuronal component is unique; in addition, each component is distributed differently throughout the neuron, as shown here. Thus, different parts of the neuron are associated with different functions. For example, DNA transcription occurs only in the soma, while protein synthesis, which involves polysomes and endoplasmic reticulum, occurs both in the soma and in dendrites.

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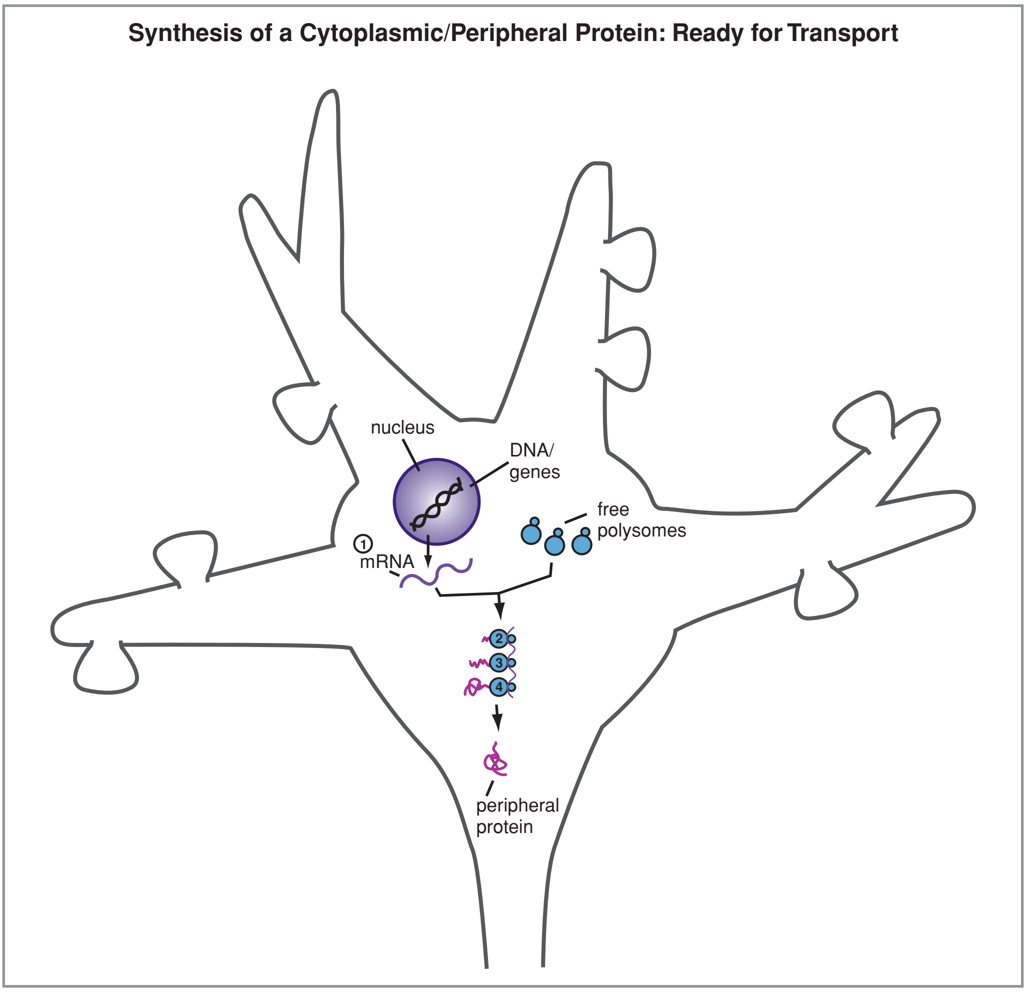

FIGURE 1-11 Protein synthesis. Most of the structural and regulatory molecules of a neuron are proteins. When DNA is transcribed into RNA, it is read by one of two types of ribosomes: free polysomes, which are not membrane bound, or rough endoplasmic reticula, which are membrane bound. Proteins are then synthesized on/within the ribosomes. Peripheral proteins, which are soluble and live in the cytoplasm, are synthesized on free polysomes and transported directly into the dendrites and axons.

in Figures 1-9 and 1-10. As can be seen from Figure 1-10, these components have specific locations within the neuron's specialized structure; therefore some functions occur in one part of the neuron but not another. For example, all the nuclear DNA is transcribed in the soma but all protein synthesis does not occur there, because the synthetic machinery of polysomes and endoplasmic reticulum exists in dendrites as well as the soma but not to any great extent in axons (Figure 1-10). The vital function of transport occurs in both axons and dendrites, but there are more microtubules for transport in dendrites and more neurofilaments for transport in axons (Figure 1-10). Cytoskeletal support proteins exist along the membranes of the entire neuron, but postsynaptic density proteins exist only in dendrites and soma membranes and at the beginning and end of axons, whereas presynaptic density proteins exist only in axon terminals (Figure 1-10).