Neuroscience & Behaviour

- **Chronic traumatic encephalopathy**: Derek Boogaard, a professional hockey player for the New York Rangers, died of a drug overdose in 2011 at age 28. After his death, his brain was observed to be reduced in size, with fluid-filled spaces where brain tissue should be (the sulci). Caused by repeated blows to the head.

- Fig. 3.1 Santiago Ramon y Cajal used a Golgi stain to highlight the appearance of neurons. He was the first to see that each neuron is composed of a body with many threads extending outward toward other neurons. He also saw that, surprisingly, the thread of each neuron do not actually touch other neurons.

- *Memorize* Fig. 3.2. The soma is the centre for protein synthesis, energy production, and metabolism. The nucleus houses chromosomes that contain DNA (‘wetware’). Dendrites receive information from other neurons and relay it to the cell body.

- *Memorize* Fig. 3.3, especially be aware of the synaptic gap.

- Axon: the part of a neuron that carries information to other neurons, muscles, or glands.

- Myelin sheath: an insulating layer of fatty material

- Glial cells: support cells found in the myelin sheath; up to 50x(100 billion) neurons.

- Sensory neurons: neurons that receive information from the external world and convey this information to the brain.

- Motor neurons: neurons that carry signals from the spinal cord to the muscles to produce movement.
Interneurons work together in small circuits to perform simple tasks such as identifying the location of a sensory signal, and much more complicated ones, such as recognizing a familiar face.

Purkinje cells are a type of interneuron that carries information from the cerebellum to the rest of the brain and the spinal cord. Connect this to Fig. 3.14; it has something to say about the evolution of the brain.

Pyramidal cells, found in the cerebral cortex, have a triangular body and a single, long dendrite among many smaller dendrites. Connect this to Fig. 3.16; it also has something to say about the evolution of the brain.

Bipolar cells have only one dendrite and a single axon. Connect this to Fig. 4.6, it demonstrates that the retina (eye) is an extrusion of brain matter, not a separate organ.

**Highlights:** What are the surprisingly most important cells in the brain? Glial cells, usually in the form of a myelin sheath, which coats the axon to facilitate the transmission of information. In demyelinating diseases, the myelin sheath deteriorates. Examples: multiple sclerosis, and Alzheimer's.
Electrochemical Actions of Neurons

- Hodgkin and Huxley (1939) work with squid giant axons (100 times larger than humans).
- They inserted a thin wire into the squid axon so that it touched the jelly-like fluid inside.
- Then they placed another wire just outside the axon in the watery fluid that surrounds it.
- They found a substantial difference between the electric charges inside and outside the axon, which they called the **resting potential**.
- Memorize Fig. 3.5 For this course, we will only concern ourselves with the various ions, not voltages.
- The resting potential arises from the differences in ion concentrations inside and outside of the neuron's cell membrane.
- In the resting state there is a higher concentration of K+ (potassium ion) and A- (protein ions) inside the neuron's cell membrane than outside it.
- By contrast, there is a higher concentration of Na+ and Cl- outside the neurons' cell membrane than inside it.
- Now it gets tricky (conceptually, that is). Think of a crowd doing the wave at a Roughrider's game, and it get easier to understand. Let's go to YouTube and search for “neuron action potential anima”
  - https://www.youtube.com/watch?v=iBDXOt_uHTQ
Action Potential: All or None

- The action potential is an electrical signal that is conducted along the length of a neuron's axon to a synapse. This signal will only occur if a **threshold** is reached.

- The action potential is **all or none**. Electrical stimulation below the threshold will fail to produce an action potential, whereas electrical stimulation at or above the threshold will always produce an action potential.

- The action potential always occurs with exactly the same characteristics (the shape of the voltage) whether the stimulus is at or above the threshold.

- The action potential occurs when there is a change of state in the axon's membrane channels.

- During the resting potential, the channels that allow K+ are open. When an electric charge is raised to the threshold value, these channels are briefly shut down.

- Channels that allow the flow of Na+ are opened up. When the channels opens, these Na+ flow inside, increasing the + charge inside the axon relative to the outside. This flow pushes the action potential to its maximum value.

- After the action potential reaches its maximum the membrane channels return to their original state; K+ flows out until the axon returns to its resting potential.

- During this period, the ions are imbalanced, the neuron cannot initiate another action potential. This is the **refractory period**; the ion imbalanced eventually being reversed by a chemical pump in the cell membrane: Na+ outside; K+ inside. Finally: Fig. 3.6 for fine-tuning.
Axons usually end in **terminal buttons**, a structure filled with **vesicles** that contain **neurotransmitters**, chemicals that transmit information across the synapse to a receiving neurons' dendrites.

The dendrites of the receiving neuron contain **receptors**, which initiate or prevent a new electrical signal.

As K+ and Na+ flow across a cell membrane, they move the **presynaptic** neurons from a resting potential to an action potential. The action potential travels down the length of the axon, to the terminal buttons where it stimulates the release of neurotransmitters from vesicles into the synapse.

These receptors float across the synaptic gap and bind to receptor sites on the **postsynaptic** neuron. A new action potential is initiated. This synaptic transmission allows neurons to communicate with each other.

**Memorize Fig. 3.7.**

Neurons tend to form pathways in the brain that are characterized by specific types of neurotransmitters.

Neurotransmitters and receptor sites operate on the lock-and-key principle. Only some neurotransmitters will bind to specific receptor sites on a dendrite. The fit is actually geometric, as well as chemical.

**Reuptake** occurs when neurotransmitters are reabsorbed by the terminal buttons of the presynaptic neuron.
Dendritic Computation

https://www.quantamagazine.org/neural-dendrites-reveal-their-computational-power-20200114/

The dendritic arms of some human neurons can perform logic operations that once seemed to require whole neural networks.

The latest in a long line of evidence comes from scientists’ discovery of a new type of electrical signal in the upper layers of the human cortex.

Laboratory and modeling studies have already shown that tiny compartments in the dendritic arms of cortical neurons can each perform complicated operations in mathematical logic.

But now it seems that individual dendritic compartments can also perform a particular computation — “exclusive OR” — that mathematical theorists had previously categorized as unsolvable by single-neuron systems.

https://science.sciencemag.org/content/367/6473/83

These calcium-mediated dendritic action potentials dCaAPs enabled the dendrites of individual human neocortical pyramidal neurons to classify linearly nonseparable inputs—a computation conventionally thought to require multilayered networks.
Neurotransmitters (Ntx)

- Neurotransmitters can be destroyed by enzymes in a process called **enzyme deactivation**; specific enzymes break down specific neurotransmitters.

- Neurotransmitters can bind to receptor sites on presynaptic neurons called **autoreceptors**, which detect how much of a neurotransmitter has been released into a synapse and signal the neuron to stop releasing when an excess is present.

- **Ach** activates muscles that initiate motor behaviour, and also contributes to the regulation of attention, learning, sleeping, dreaming & memory. Alzheimer's is associated with deterioration of Ach neurons.

- **Dopamine** also regulates motor behaviour, plus motivation, pleasure and emotional arousal. High levels are linked to schizophrenia; low levels to Parkinson's disease.

- **Glutamate** is the major excitatory Ntx, enhancing the transmission between neurons.

- **GABA** is the primary inhibitory Ntx, and tends to stop the firing of neurons.

- Too much glutamate, or too little GABA can cause overactive neurons, leading to seizures.

- **Norepinephrine** is involved in states of vigilance; **Serotonin** is involved in the regulation of sleep, wakefulness, eating, and aggressive behaviour. Low levels of each have been associated with mood disorders.

- Endorphins (endogenous morphines) are chemicals that act within the pain pathways and emotion centres of the brain. Source of the 'runner's high'.

- For therapists, the two most important Ntx are dopamine and serotonin.
Memorize Fig. 3.8 for the next exam. Agonists & Antagonists drugs can enhance or interfere with synaptic transmission at every point in the process.

- **Clonidine** bind to autoreceptors, blocking their inhibitory effect; **caffeine** activates autoreceptors, inhibiting the release of Ntx.

- L-dopa increases production of dopamine; amphetamines increase the production of Ntx.

- **Prozac** blocks the deactivation or **reuptake** of neurotransmitters. **Nicotine** binds to postsynaptic receptors, activating and increasing Ntx.

- **AMPT** blocks production of Ntx; Propanolol binds to postsynaptic receptors and block Ntx binding of norepinephrine, slowing heart rate.

- Botulinium toxin blocks the release of Ntx, involved in Ach muscle contraction. Best known for softening lips in Botox injections.

- Norepinephrine and dopamine play an critical role in mood control, such that increases in either Ntx result in euphoria, wakefulness, and a burst of energy. Norepinephrine also increases heart rate. An overdose of amphetamines or cocaine can cause the heart to contract so rapidly that heartbeats do not last long enough to pump blood effectively, leading to fainting and sometimes death.

- For therapists, the most important is Prozac, a selective serotonin reuptake inhibitor (SSRI); more of the serotonin remains in the synapse longer, elevating mood to relieve depression.
Memorize Fig. 3.9 and Fig. 3.10 for the next exam.

The autonomic nervous system is composed of two subsystems that complement each other. Activation of the sympathetic system serves several aspects of arousal, whereas the parasympathetic system returns the body to its normal resting state.

Fig. 3.11 the Pain Withdrawal Reflex. Connections between the sensory inputs and motor neurons in the spinal cord mediate spinal reflexes, simple pathways in the nervous system the rapidly generate muscle contractions.

The brain sends commands for voluntary movement through the spinal cord to motor neurons, whose axons project out to skeletal muscles.

The textbook is very conservative when discussing spinal cord damage, for a more up-to-date approach, check out https://www.researchgate.net/publication/51717324_Nerve_regeneration_with_aid_of_nanotechnology_and_cellular_engineering