Introduction/Table of Contents

The following notes are based mainly off of Human Anatomy & Physiology 8th Edition by Marieb and Hoehn and Ross and Wilson Anatomy and Physiology in Health and Illness by Waugh and Grant. There may be other sources used (like my AP Bio notes), and *usually* will be correspondingly footnoted.
Of course, reading the actual textbook will give you a much more in depth view of what to know. These notes are just a concise summary with additional explanations/clarification when needed. There are around nine pages of notes for each of the three systems. Hope this helps, and sorry in advance for any dumb mistakes! ☺

The notes will go in the following order:

Nervous System Parts/Levels

The nervous system has three main functions:

1. Sensory Input
    a. Using receptors to monitor the outer environment
2. Integration
    a. Processing & interpreting the sensory input and combining all of the information (hence integrating) in order to decide what to do
3. Motor Output
    a. Response using effector organs (muscles and glands)

You can remember these functions with the acronym SIM (Sensory input, Integration, Motor output).
Our nervous system is divided into two parts - the central nervous system (CNS) and the peripheral nervous system (PNS).

CNS vs PNS
The CNS is composed of the brain & spinal cord while the PNS consists of everything outside of the CNS, such as nerves. Think of the *central* nervous system's location, and it makes sense.

CNS
The CNS is responsible for integration and commanding. It makes decisions based off of reflexes, current conditions, and past experiences.

PNS
There are two types of nerves in the PNS, the spinal nerves and the cranial nerves. They carry impulses and connect all body parts to the CNS.

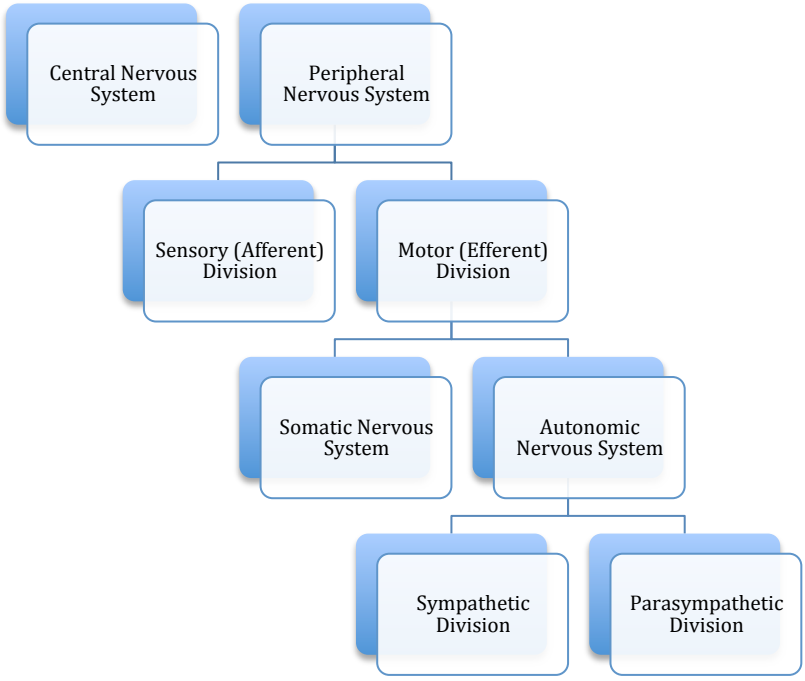
The PNS also has two subdivisions:

- Sensory/Afferent Division
    - Carries impulses from sensory receptors to the CNS
        - The *Sensory* Division *senses* first
    - Somatic **and** visceral sensory nerve fibers
- Motor/Efferent Division
    - Carries impulse from CNS to effector organs (glands and muscles) which activate contraction and secretion, respectively
        - The *Efferent* Division signals *effector* organs
    - Within the Motor Division there are two additional main parts:
        - Somatic nervous system
            - Also known as voluntary nervous system
            - Carries impulse from CNS specifically to skeletal muscles
            - Think somatic motor/voluntary actions relating to skeletal muscles, *soma*tic nervous system gives us control over our *body*
        - Autonomic nervous system

- Also known as ANS or the involuntary nervous system
- Carries impulse from CNS specifically to smooth muscles, cardiac muscles, and glands
- Think visceral motor/involuntary actions (*auto*nomic)

- The ANS is also split into two divisions, the sympathetic and parasympathetic divisions. These two divisions usually work alternately- if one system stimulates something, the other will inhibit it.[1]
  - For example, the sympathetic division will increase contraction/heart rate while the parasympathetic division will decrease heart rate; sympathetic will contract muscles while parasympathetic will relax muscles.
  - However, the sympathetic division does not always increase an action. For example, the sympathetic division decreases saliva production while parasympathetic will increase saliva production. It is better to think of the different between responses as "fight or flight" or "rest and digest" as mentioned later.
- Sympathetic will cause mobilization of the body and the "fight or flight" response
  - Short neurons and a faster system
- Parasympathetic encourages homeostasis and the "rest and digest" response

To remember all of this, think of the following divisions as:



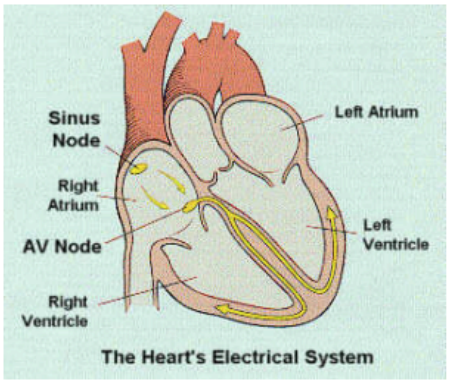
Try to remember this using the acronym series CP, SM, SA, SP!

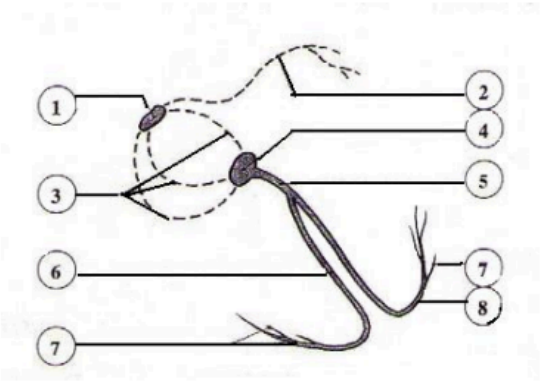
[1] http://www.diffen.com/difference/Parasympathetic_nervous_system_vs_Sympathetic_nervous_system

You can see how the last term of each level/part alternates between "system" and "division", starting with system.

Note: Although autonomic motor nerves control (sympathetic) rate/strength of the heart beat (ex: in order to increase oxygen circulation during exercise), **contraction** is triggered by the heart itself. [2]
Picture showing the pathway the heart uses to trigger its own contractions:

ELECTRICAL SYSTEM OF THE HEART





1. **Sinoatrial Node (SA Node)-**Pacemaker of the heart
2. **Intra-atrial Pathway**-carries electricity through atria
3. **Internodal Pathway**-carries electricity through atria
4. **Atriaventricular Node (AV Node)-**Back up pacemaker. Slows conduction
5. **Bundle of His**-last part of conduction in atria
6. **Right Bundle Branch**-carry electricity through R. Ventricle
7. **Purkinje Fibers**-distribute electrical energy to the myocardium
8. **Left Bundle Branch**-carries electricity through L. Ventricle

[3]

Afferent/Efferent Examples

Two afferent examples are skin to CNS (somatic) and Stomach to CNS (visceral)
Two efferent examples are split into somatic and autonomic nervous systems.
For the somatic nervous system, an impulse from the CNS to skeletal muscle is an example.
For the autonomic nervous system, an impulse from the CNS to stomach is an example.

[2] http://www.kidport.com/reflib/science/humanbody/cardiovascular/HeartMuscle.htm
[3] Picture from 2015 Anatomy & Physiology Training Handout

Neuroglia and Neurons

Nervous tissue only has two main types of cells, neuroglia and neurons.

Neuroglia

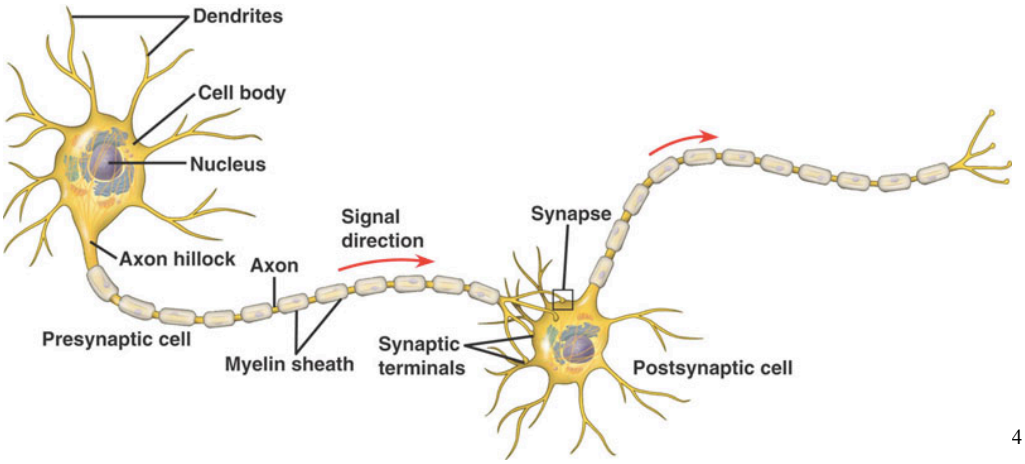
Neuroglias are cells that support neurons. They are also known as **glial cells**.
There are six types (four in CNS; two in PNS) and they have many specialized functions- ranging from promoting neuron health/growth, insulating neurons for a faster conduction of action potentials, etc.
Like neurons, neuroglia/glial cells extend and have a main soma (cell body). Unlike neurons, glial cells have darker-staining nuclei and smaller overall size.

In the CNS, the four types are: astrocytes, microglia, ependymal cells, and oligodendrocytes. Neuroglia are in a 10 to 1 ratio to neurons in the CNS, and are responsible for half of the resulting overall brain mass.
Astrocytes are the majority of supporting neuroglia in the CNS. They are star shaped, and some of the free ends have swellings known as **foot processes.** Astrocytes are found adjacent to blood vessels, their foot processes wrapping around them. The astrocytes foot processes and capillary walls separate the blood from the neurons- this is known as the **blood-brain barrier**. This protects the brain from chemicals and toxic substances. Large molecules, drugs, etc. take a longer time to pass the blood-brain barrier. Substances that quickly cross the barrier include oxygen, alcohol, glucose, etc.
Microglia are egg-shaped and have long processes that touch nearby neurons. Microglia form from monocytes migrating from blood to nervous system prior to birth. They have defensive purposes- they can become phagocytic, remove damaged tissues/microbes, etc. This is crucial since immune system cells are not allowed into the CNS, so microglia act as a corresponding replacement.
Ependymal cells line the ventricles of the brain and the spinal cord. They form a barrier between tissue fluid around the CNS cells and the cerebrospinal fluid filling the cavities (of the brain and spinal cord).
Oligodendrocytes are smaller and have fewer processes than astrocytes. They line around thick neuron fibers (in the CNS) and form/maintain myelin, resulting in coverings called **myelin sheaths**. This relates to Schwann cells in the peripheral nervous system.
Oligodendrocytes are also present around nerve cell bodies in gray matter with a suspected supportive purpose.
In the PNS, the two types are **satellite cells** and **Schwann cells**.
Satellite cells surround the cell bodies of neurons in the PNS- and they share many purposes/functions with astrocytes.
Schwann cells are also known as **neurolemmocytes**. Schwann cells, as mentioned previously, are very similar to oligodendrocytes in the CNS regarding function. Schwann cells wrap around and produce a myelin sheath around thicker nerve fibers in the PNS. They are also mainly in control of regenerating damaged never fibers in the PNS.

You should study this topic in increased depth for competitions, but for now we will go on to neurons.

Neurons

Neurons are also known as nerve cells and the structural unit of the nervous system.



[4]

Here you can see the basic anatomy of a neuron. You can see the main **cell body** (also known as the **perikaryon**- peri means "around" and kary means "nucleus") present with its contained **nucleus**. Extending out from the neuron are **dendrites** and a single **axon**. The part of the cell body where the axon rises from is called the **axon hillock**. On the axon you can see bulges along the extending axon. They are spaced apart by "gaps" in the myelin sheath known as **nodes of Ranvier** (they are also known as **myelin sheath gaps**). They occur in intervals of about 1 millimeter. The bulge is actually a cell called a **Schwann cell** that is rolled around the axon numerous times. The axon eventually leads into 10,000+ **terminal branches/telodendria**. The endings of these branches are commonly known as **axon terminals**.
If you recall, Schwann cells and oligodendrocytes produce **myelin sheaths** that wrap around nerve fibers. Myelin protects and insulates the nerve fibers- this insulation allows for nerve impulses to be transmitted at a faster rate. This is why **myelinated fibers** can conduct nerve impulses much more quickly than **unmyelinated fibers**. Additionally, as shown by the picture above, myelin sheaths are around the axons- not the dendrites of neurons.
This is just the basic anatomy of a neuron. Make sure to study other parts, such as the **neurolemma**, **Nissl bodies**, etc.

They have many properties, two to remember being irritability and conductivity. Here, irritability does not equate to a grumpy attitude- instead it indicates the ability to **initiate nerve impulses in response to stimuli** from outside or inside the body.
Conductivity describes the ability **to transmit an impulse**.

There are many structural and functional classes of neurons. For example, you should study the structural classes of neurons including **multipolar**, **bipolar**, and **unipolar** (also known as **pseudounipolar).**

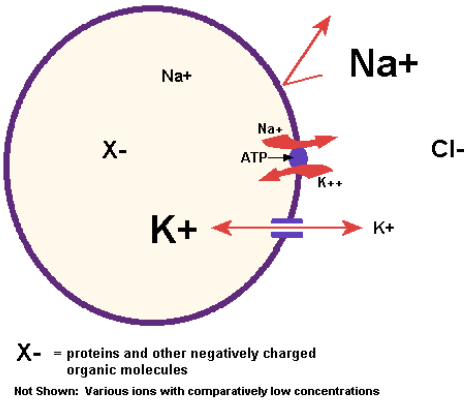
Membrane/Action Potentials/Graded Potentials

This is a really brief overview on how impulses are transmitted- AP Biology tends to cover this topic as well. Just know a few key facts:

[4] http://biomedicalengineering.yolasite.com/neurons.php

For clarification, **voltage** is a measure of the potential energy between two different points… so greater the difference, the higher the voltage is.

Resting membrane potential is usually at -70 mv. When the mv is less than zero, the inside of the membrane is less charged than the outside.
Creating the resting membrane potential is reliant on the concentrations of positive ions (Na+ and K+), which can go in and out of the cell based off of ion channels.

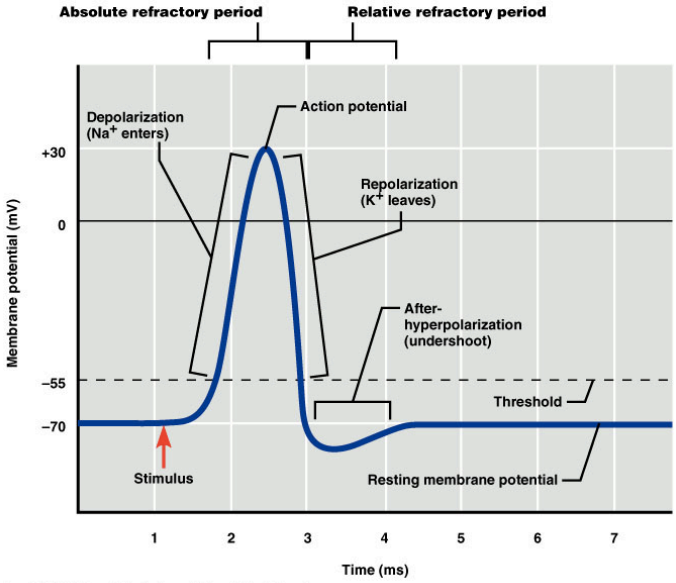


[5]

The Na+ concentration is high outside of the cell, while the K+ concentration is high inside of the cell.
You can remember this by thinking in antisocial views- "Na-h" for going (and staying) outside and "oK" for staying inside.

The reason why the resting membrane potential is -70 mv is because K+ diffuses out of the cell more easily through its concentration gradient (this is important) than Na+ goes into the cell along its own concentration gradient.
After a while, the Na+ and K+ concentration gradient would even out and eliminate the temporary negative membrane potential, but this does not happen due to ATP powered sodium-potassium pumps that move three Na+ out of the cell for every two K+. This ensures that the outside of the cell is more positive than the inside at the resting membrane potential.
Remember, three Na+ go out for every two K+!

[5] https://courses.washington.edu/conj/membpot/equilpot.htm



[6]

Depolarization means that there is a decrease in the membrane potential (and a decrease in the difference between inside and outside of the cell).
Repolarization means that there is an increase in the membrane potential (and an increase in the difference between inside and outside of the cell).

You must be careful with your understanding of these terms because the resting membrane potential is originally negative. When depolarization occurs, the cell cytoplasm is becoming more positive when compared to at resting potential. This means that the membrane potential DECREASES, and the numerical difference (voltage/potential) is smaller and becomes LESS negative, which means it becomes more positive. The opposite is the same for repolarization, the membrane potential INCREASES and the numerical voltage becomes MORE negative.
Just roughly remember the above shown graph to avoid any confusion.

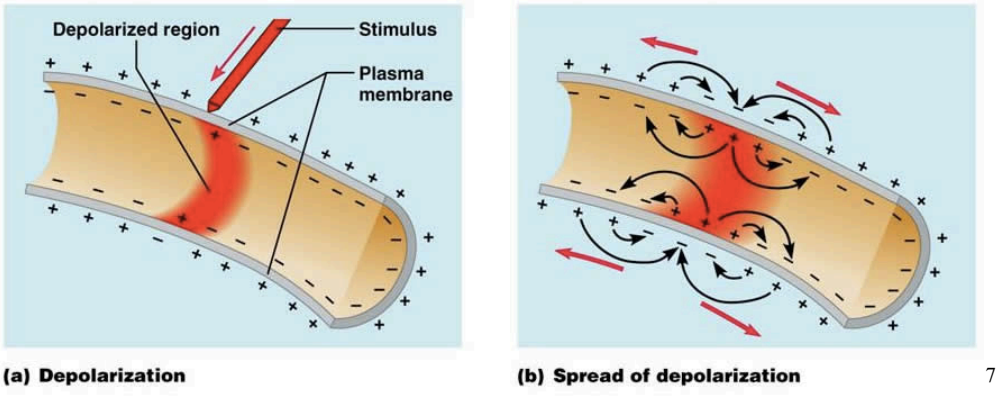
When a change in membrane potential occurs, either a **graded potential** or an **action potential** occurs.

<u>Graded Potentials</u>
Changes in membrane potentials (depolarization or hyperpolarization) can cause currents to flow from one membrane to another, changing the membrane potential in a domino effect. However, as indicated by its name, graded potentials have a magnitude determined by the strength of their stimulus- and quickly die out (also known as **decremental**). There is a short span of distance that graded potentials can affect. When long distance communication is essential, graded potentials can achieve a certain threshold and trigger action potentials.
There are different types of graded potentials. The graded potential from stimulus received by a sensory neuron receptor is known as a **receptor potential** or **generator potential**. When the stimulus is from a neurotransmitter of a neuron the resulting graded

[6] http://www.apsubiology.org/anatomy/2010/2010_Exam_Reviews/Exam_3_Review/CH_11_Membrane_Potential.htm

potential is a **postsynaptic potential** (the neuron subsequent the synapse is being affected).

Usually a small part of a neuron's plasma membrane is depolarized (due to a stimulus) to start a graded potential. Recall what depolarization is, the usually negative INSIDE of the cell begins to turn positive due to a stimulus. Ions will move due to the reduction in membrane potential (negative → positive; positive → negative). Essentially, ions try to neutralize eachother and move around. Outside the membrane, the positive ions surrounding the negative ions from the stimulus will try to move towards the negative ions in order to neutralize them. They leave a vacant spot where negative ions can replace them. The resulting negative ions on the outside of the membrane will move the depolarized positive ions on the inside of the membranes out to neutralize adjacent membranes. See the picture below for a much clearer visualization.



[7]

A plasma membrane is permeable, and will eventually allow the ions to neutralize and return to normal through channels.

Action Potentials

Action potentials, also known as **nerve impulses**, only form from cells with **excitable membranes**. Some examples of these include neurons and muscle cells. During an action potential, the voltage change/total amplitude is 100 mV, going from -70 mV to +30 mV. Like in the image shown discussing depolarization and repolarization, the sequence of events are usually stimulus, depolarization, action potential, repolarization, hyperpolarization, and a return to membrane potential.

They differ from graded potentials because they are not decremental (do not lose strength over distance) so they are effective for long distance signals.

Initial graded potentials become action potentials at the axon hillock mentioned previously. We also mentioned previously the steps of an action potential (see graph on previous page) and how Na+/K+ affect membrane potentials. Voltage-gated ion channels maintain Na+ and K+ levels. Na+ channels have two gates, one is an **activation gate** that opens during depolarization and another is an **inactivation gate** that closes the gate after it opens. Na+ only passes through when both gates are open. K+ channels, on the other hand, only have one gate that is also open after depolarization (with a delay). When Na+ enters, local currents depolarize adjacent membranes and trigger more action potentials. However, to trigger an action potential in the first place the depolarization must reach a **threshold point**.

[7] https://dundeemedstudentnotes.wordpress.com/2012/04/06/graded-potentials/

Synapse

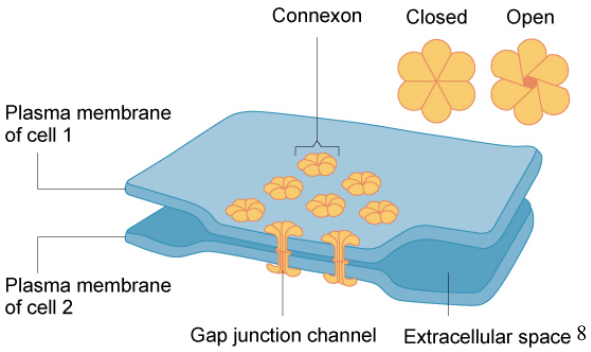
The synapse is any junction between two neurons OR a neuron and an effector cell. Information transfer occurs here.
There is some basic terminology to know about synapses.

Axodendritic synapses are synapses between the axons of one neuron and (you guessed it) the dendrites of another neuron.
Similarly, **axosomatic synapses** are from axon of a neuron to cell body of another. As said before, *soma* = cell body.
There are less common synapses including **axoaxonic synapses**, **dendrodendritic synapses**, and **dendrosomatic synapses**. Axoaxonic synapses are between axons, dendrodendritic are between dendrites, and dendrosomatic synapses are between dendrites and cell bodies.

Impulses flow from the **presynaptic neuron** (sender) to the **postsynaptic neuron** (receiver).
Between the presynaptic neuron and the postsynaptic neuron is the **synaptic cleft**, a 30-50 nm wide fluid space.

There are two main varieties of synapses: **electrical** and **chemical**.

Electrical synapses are less common and involve **gap junctions**, allowing very rapid impulse transmission.



As you can see, gap junctions allow for direct transfer between the cytoplasms of two cells. The protein channels are known as connexons.

Chemical synapses involve the release and reception of chemical neurotransmitters. An example of this is the neuromuscular junction.
The general steps are the following:

- First, the action potential reaches the presynaptic axon terminal. Voltage-gated Ca2+ and Na+ ion channels open due to the depolarization from the action potential. Ca2+ goes from the extracellular fluid and enters the axon terminal.
- The Ca2+ arriving in the axon terminal results in synaptic vesicles containing neurotransmitters to undergo exocytosis. (You can research this specific process in depth).

[8] https://cnx.org/contents/8Uypx7vu@7/Connections-between-Cells-and-

- After exocytosis, the neurotransmitters are in the synaptic cleft. The Ca2+ triggering this is removed. Neurotransmitters diffuse and bind to receptors on the postsynaptic membrane.
- When neurotransmitters bind to receptors, ion channels are opened and graded potentials occur.
- The neurotransmitters either go through reuptake, degradation, or diffusion to remove their effect.

There are many classes of neurotransmitters based on both structure and function. I will discuss some neurotransmitters.

Neurotransmitters by Chemical Structure

Acetylcholine (ACh), as mentioned before, are present at the neuromuscular junction. ACh is synthesized from acetic acid and choline by the enzyme **choline acetyltransferase**. After release, they are degraded to acetic acid and choline by the enzyme **acetylcholinesterase (AChE).** The choline is reused for future synthesis of ACh.
Biogenic amines are mainly in the brain and play a part in the biological clock and emotions. Biogenic amines include **catecholamines**. Some examples are **serotonin**, **dopamine**, **histamine**, etc.
Amino acids also act as neurotransmitters. Examples include **glycine** and **glutamate**. These amino acids are secreted in the CNS.
Peptides (specifically **neuropeptides**) have many different effects. They can mediate or reduce feelings of pain, etc. Examples include **endorphins, somatostatin,** and **tachykinins**.
Purines are extremely common, just like amino acids. A famous example is ATP. Adenosine, a part of ATP, can also act as a purine neurotransmitter. ATP can trigger different responses based on the receptor it is bound to. Adenosine works as an inhibitor in the brain.
Gases and **Lipids** can also act as neurotransmitters. Examples include **nitric oxide, carbon monoxide,** and **endocannabinoids**.

Neurotransmitters by Function

Neurotransmitters are either excitatory or inhibitory, meaning they either cause depolarization or hyperpolarization respectively. Some neurotransmitters can have both effects.
Neurotransmitters can also be direct or indirect. Direct neurotransmitters bind/open ion channels, changing the membrane potential. They cause rapid responses. Indirect neurotransmitters last longer and are more flexible due to **second messengers**, which are discussed later in the hormone section (page 22).

Neurotransmitter Receptors

Neurotransmitter receptors are split into two main categories- **channel linked receptors** and **G protein-linked receptors**.
Channel linked receptors, also known as **ionotropic receptors**, are the previously mentioned ligand-gated ion channels that are responsible for direct neurotransmitter effects. When a ligand binds to the receptor, the protein changes shape and ions can pass through the channel.

G protein-linked receptors are responsible for the previously mentioned indirect neurotransmitter effects. After a neurotransmitter binds to a G protein-linked receptor, the G protein is activated and control second messengers. The second messengers then correspondingly regulate ion channels or kinase enzymes (to activate a cascade). They can act in other ways as well for a variety of effects.

Note: If you studied the muscular system last year, you should be familiar with this concept (specifically with acetylcholine). Make sure to take the time to study/understand this in depth!

Homeostatic Imbalances

There are many life-controlling diseases, disorders, and other dysfunctions related to the nervous system. The following is just a brief overview, so feel free to study them in depth.

Injuries

Concussion

Blows to the head can result in a concussion. Usually, symptoms involve dizziness and loss of consciousness. Most concussions are do not have long-term effects.

Contusion

A contusion occurs after repeated, serious concussions- resulting in permanent damage that can have visible, lasting effects such as comas.

Dementia

Dementia is the mental deterioration caused by atrophy/degeneration of the cerebral cortex. It is irreversible and impairs personality, memory, etc.

Huntington's Disease

Huntington's disease is hereditary and controlled by a dominant gene. It usually occurs during the 30s or 40s of a person. The mutation causes **huntingtin** protein to accumulate and destroy brain tissue, eventually affecting the cerebral cortex. Visible symptoms include jerky movements called **chorea**, which stems from the Greek word for "dance". Following later stages of the disease personality changes, dementia, and death occur. However, since Huntington's disease occurs during the later stages of life, there is still a high possibility for the dominant gene to be passed onto offspring.

Alzheimer's Disease

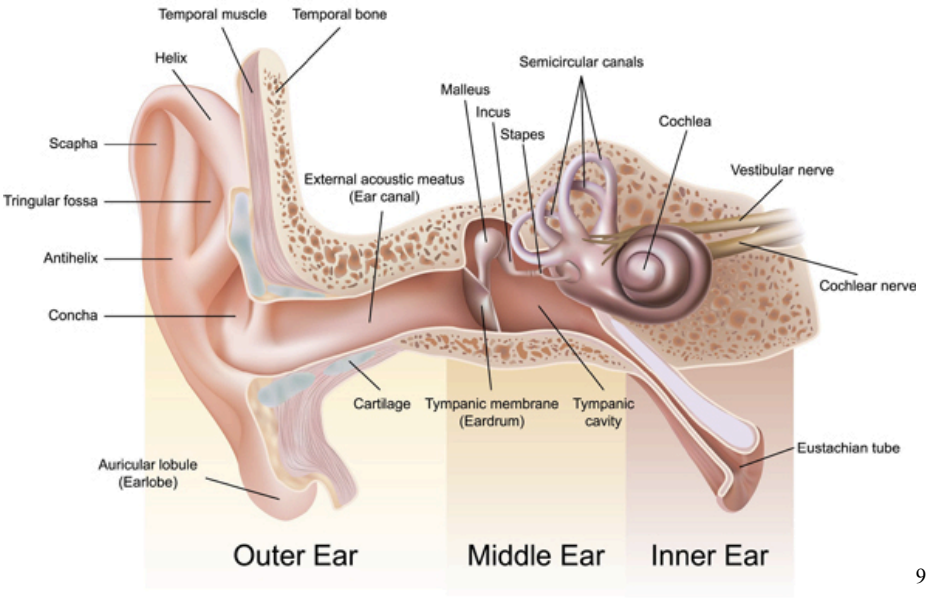
The most common form of dementia, its major symptom is memory loss. There are many other effects such as personality changes, hallucinations, etc.

The causes have been associated with accumulating plaques between neurons made of **beta-amyloid peptide.** There may be genetic factors causing the disease.

Sense Organs

Ear

The ear has three divisions/parts: the outer ear, middle ear, and inner ear.



[9]

Outer/External Ear

Two main parts are the auditory canal and pinna.

The pinna is also known as the auricle. It is the ear projecting from the side of the head. The outer ridge, as you can see in the picture, is called the **helix**. The earlobe is also known as the **lobule**, as also indicated.

The auditory canal is also known as the **external acoustic meatus**. Just for a visual, it is not perfectly straight and takes on a slight S-shape. It is a couple of centimeters (about 2.5 cm) long and goes from the auricle to the eardum, also known as the **tympanic membrane.**

Middle Ear

The middle ear is also known as the **tympanic cavity**. The superiorly arching cavity is naturally called the **epitympanic recess**. On the posterior wall of the epitympanic recess is the **mastoid antrum**. Laterally to the cavity is the eardrum and medially there are two openings in the bony lining. The superior opening is known as the **oval/vestibular window** and the inferior is called the **round/cochlear window**. The middle ear is connected to the nasopharynx through the **pharyngotympanic/auditory tube**, which explains why the mucosa of the middle ear and pharynx is continuous. This tube is usually flat/closed but can open during actions like swallowing or yawning opens it briefly equalizing external and internal pressure- which is necessary to avoid sound distortion and allowing the eardrum to vibrate freely.

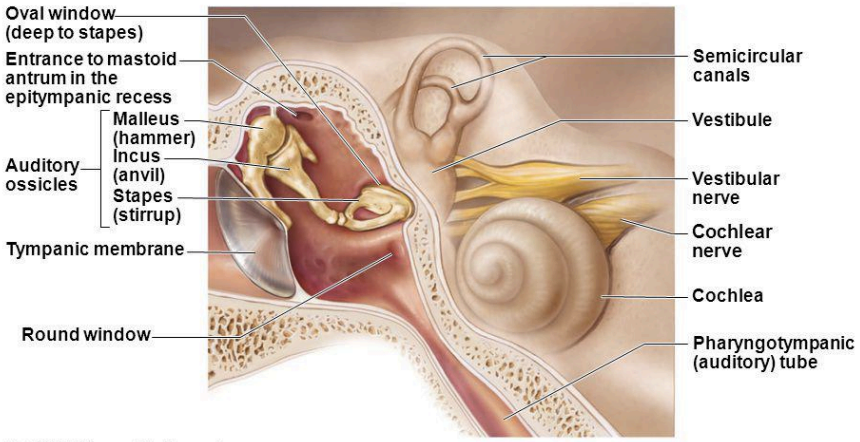
[9] http://www.audiologyspecialists.com/anatomy-of-the-ear

Inner/Internal Ear

Also known as the labyrinth due to its complexity. It contains two major divisions.

The **bony/osseous labyrinth** relates to channels/cavities inside of the bone.
It contains three regions: the *cochlea*, *semicircular canals*, and the *vestibule*.
The fluid in the bony labyrinth is known as **perilymph** (think peri means around).

The **membranous labyrinth** represents the membranous sacs and ducts within the bony labyrinth.
The fluid in the membranous labyrinth is known as **endolymph**. (Note: For a clearer mental visual, the fluid that the membranous labyrinth is suspended in/surrounded by is the perilymph, hence the name).



(b) Middle and internal ear

[10]

The **vestibule**, as shown, is medial to the middle ear. Although it is hard to see, the vestibule is anterior to the semicircular canals and posterior to the cochlea. This cavity contains two membranous sacs, the **saccule** and the **utricle**.
The saccule is continuous with the cochlear duct while the utricle is continuous with the semicircular ducts. You can remember this by knowing saccule has more "c's" than utricle, and the cochlea starts with a c (and looks similar).

The **semicircular canals** have three separate canals- the **anterior, posterior, and lateral**. In the picture above, the lateral canal is not shown. Each canal's duct has a swelling at one of the ends that open up to the vestibule called the **ampulla**.

The **cochlea** is the snail-like bony spiral (Note: "cochlea" means snail in Latin). In the cochlear duct is the **spiral organ of Corti**. This is important for hearing, and the **cochlear nerve** runs from the spiral organ to the brain.

Each of the three bony labyrinth divisions has receptors associated with different response roles (ex: responding to changes in head position). You should study this in depth.

[10] http://slideplayer.com/slide/2758509/

Balance

Our sense of balance is greatly affected by our ears. The perilymph and endolymph shift along with the head, stimulating hair cells and sensory receptors as a result (specifically in the utricle, saccule, and ampulla). Impulses are transferred into the vestibulocochlear nerve and then into the cerebellum, where other impulses are coordinated in order to allow for control on body posture and position.

Homeostatic Imbalances

Deafness is when hearing loss occurs. There are two types- **conduction deafness** and **sensorineural deafness**.

Conduction deafness occurs when fluids in the inner ear are disturbed. A common example of conduction deafness is **otosclerosis**, which usually is when excess bony tissue causes bones in the middle ear to be fused and conjoined, reducing the vibrations conducted and the resulting sound heard.

Sensorineural deafness occurs when neural structures get damaged, for example hair cells/hearing receptors. One type of sensorineural deafness is called **presbycusis**. As we age, we gradually lose our ability to hear. Initially, we usually become unable to detect high-pitched sounds. Causes can be due to aging and exposure to noise as a stressor.

Hearing loss can also occur in children. For example, a sore throat can cause inflammation in the middle ear and resulting hearing loss- a condition called **otitis media**. Otitis media can be treated with antibiotics.

Eye

For fun facts (possibly to add to your cheatsheet!) 70% of sensory receptors are located in the eyes. This shows the emphasis on the special sense of vision. There are also some accessory structures to mention.

Accessory Structures

Eyebrows prevent sweat, dust, etc. from your forehead going into your eyes.

Eyelids (also known as palpebrae) cover above and below the eye. The upper eyelid is more versatile. Eyelid muscles allow for blinking to occur, which prevents drying by spreading secretions across the eyeball. Internally, the eyelid is supported by **tarsal plates**. The tarsal plates also anchor muscles which open and close the eyes. In the tarsal plates, there are also important modified sebaceous glands known as **tarsal glands** or **Meibomian glands**. They secrete an oily substance that is spread over the conjunctiva (see below) by blinking.
Eyelashes are hairs extending from the eyelids free edges. Note: If you didn't study the integumentary system, the eyelash hair follicles are connected to **sebaceous glands** (they secrete oil). Between the hair follicles are modified sweat glands known as **ciliary glands**.

The **conjunctiva** is a fine, transparent mucous membrane that lines the eyelids and the anterior eyeball. The **conjunctiva** produces a mucus to prevent drying (that is spread during blinking).

When the conjunctive or eyelashes are touched, the eyelids are closed reflexively.

The **lacrimal apparatus** of each eye contains one **lacrimal gland** (with its ducts) and two **lacrimal canaliculi**. The lacrimal gland is on the lateral end of the eye in the frontal bones and releases a **lacrimal secretion** (aka tears). This dilute saline solution is spread across the eyeball and eventually drains into the **lacrimal canaliculi**. The two openings to the two, paired lacrimal canaliculi are called **lacrimal puncta**. The tears are drained through the lacrimal canaliculi into the **lacrimal sac** and then go down the **nasolacrimal duct**. This membranous duct extends from the lower lacrimal sac to the nasal cavity. The rate of secretion and drainage of tears are usually well balanced, but the rate of secretion greatly increases in response to foreign substances or emotional states, causing the act of "crying".

There are six **extrinsic eye muscles** that control the eyeball. There are four rectus muscles and two oblique muscles. Their locations and functions are indicated by their names (ex: superior, lateral, etc.).

Eyeball

The eyeball, similar to the earth, has two poles: the **anterior pole** and the **posterior pole**.

Tissue Layers

In the wall of the eye there are three layers of tissue, the **outer fibrous layer, middle vascular layer, and the inner nervous tissue layer.**
You can remember by thinking the outside is a fibrous layer that maintains the shape of the eyeball; the middle contains the essential blood vessels; the inner tissue layer contains nerve cells.

The outer fibrous layer includes the **sclera** and **cornea**.
The sclera, also known as the white of the eyes, is the outermost layer of the eyeball- however, anteriorly the sclera become continuous with the cornea. The sclera is connected with the previously mentioned extrinsic muscles.
The cornea is clear and transparent, allowing light rays to pass into the eye (reaching the retina- which will be explained later). The cornea is convex anteriorly and bends all of the light to focus on the retina.

The middle vascular layer is also known as the **uveal tract**. It includes the choroid, ciliary body, and iris.
The **choroid** is very rich in blood vessels and has a dark brown color that is a result of melanocytes. The produced melanin absorbs the light to prevent the light from scattering/reflecting excessively.
The **ciliary body** is an anterior continuation of the choroid. It contains **ciliary muscles** (which are smooth muscles!) and **ciliary processes**. The ciliary muscles control lens shape/thickness, resulting in alternate bending of light and focus on the retina. The **ciliary zonule** (which connects the ciliary processes to the lens) hold the lens in an upright position. The ciliary processes contain capillaries secreting aqueous fluid between the lens and cornea (also known as the anterior segment/anterior + posterior chambers).
The **iris** is the visibly colored part of the eye. It divides the anterior segment (space between the lens and cornea) into the anterior and posterior chambers. These chambers, as mentioned before, have aqueous fluid secreted by the ciliary processes. It is continuous with the ciliary body, but has a round opening known as the **pupil** in order to let light enter the eye.
Like mentioned before, ciliary muscles are smooth muscles. This means that Autonomic System (see page 3) controls them. Parasympathetic and sympathetic nerves accordingly control the iris. Parasympathetic nerves in the iris cause the pupil to constrict while sympathetic nerves cause the pupil to dilate.

The inner layer contains the **retina**. It is very fragile and is stimulated by light rays. This layer has two types of photoreceptors- **cones** and **rods**. Rods operate in dim light (they are more sensitive to light) but do not result in sharp/colored vision. Cones operate in bright light, and give sharp/colored vision. You can remember this by a cone shape- converging to a sharp and focused point.
At the eye's posterior point is a region called the **macula lutea**, also known as yellow spot. In the center of the yellow spot there is a small pit known as the **fovea centralis**. The fovea centralis only contains cones (the macula lutea mostly contains

cones but has some rods). As you approach the anterior part of the retina, the number of rods increases relative to the number of cones. The **optic disc** is the exit for the optic never. It is also known as the **blind spot** because there are no photoreceptors on it (our brain makes up for this using a process called **filling in**).

Eyeball Structures

There are structures (not wall tissue) inside of the eyeball including the **aqueous humor**, the **vitreous humor**, and the **lens**.

The lens, as mentioned, controls the focus of light reaching the retina. IT is held in place by the ciliary zonule. It is an elastic, biconvex structure that is transparent (no blood vessels). We mentioned before that the ciliary muscle controls the thickness of the lens. The lens becomes thicker when viewing a object nearby, and vice versa for an object far away.

The separated anterior chamber is filled with different fluids in each of its parts. The posterior chamber/segment is filled with vitreous humor while the anterior chamber/segment is filled with aqueous humor. You can remember this by the common “a” starting “anterior” and “aqueous”. The vitreous humor and aqueous humor have specific functions and differences that you should study.

Smell

The sense of smell, also known as **olfaction**, is situated in the nasal canal. Olfaction receptors are chemoreceptors that detect chemicals known as **odorants** in solution. Olfaction in humans is not nearly as efficient as it is in other animals, explaining why animals widely use secreted pheromones as a way of chemical communication.

Olfactory Epithelium

This is the main organ responsible for olfaction.
The olfactory epithelium is a patch of epithelium at the roof of the nasal cavity that is around 3-5 centimeters squared.
Sniffing allows for more air to reach the olfactory epithelium and aids the process of olfaction.
On the olfactory epithelium are **olfactory receptor cells**, which are bipolar neurons. From each dendrite several **olfactory cilia** extend, optimizing the surface area and resulting reception.

The loss of smell is known as **anosmia** and is commonly a result of head injuries that affect olfactory nerves. Anosmia can also possibly be a result of nasal cavity inflammations and aging.

Taste

The sense of taste is also known as gustation. Like olfaction, gustation involves the stimulation of chemoreceptors. Gustation is affected greatly by olfaction- around 80% of our sense of taste is affected by what we smell. The mouth has other receptors (**mechanoreceptors, thermoreceptors,** etc.) that affect the resulting taste. For example, warm/hot foods can excite pain receptors in the mouth and "enhance" taste.

The sensory receptor organs for taste are known as **taste buds**, which are mostly present on the **papillae** of the tongue. Other taste buds can be found on the pharynx, inner cheeks, soft palate, and epiglottis. We have around 10,000 total taste buds.
Papillae on the tongue are projections in different shapes. For example **fungiform papillae**, found all over the tongue, have a mushroom shape. Other types you should be familiar with are **foliate papillae**, **circumvallate**, and **vallate papillae.**

Each individual taste bud has 50-100 epithelial cells that are mainly either basal cells or gustatory cells. Basal cells divide and differentiate into new gustatory cells. Each gustatory cell has projecting **gustatory hairs** that act as the receptor membranes of gustatory cells. There are different types of gustatory cells, for example one type releases serotonin while another type releases ATP.
Taste bud cells do frequently get damaged from hot foods and friction. Luckily, taste bud cells are replaced every 7-10 days.

The food chemical that binds to receptors in gustatory cell membranes is known as a **tastant**. The tastant is "tasted" by dissolving into the saliva, diffusing into the taste pore, and then contacting the gustatory hairs.

There are five groups of taste sensations: sweet, sour, salty, bitter, and umami. Different parts of our tongues can be vaguely associated with specific sensations, although you can experience all groups of taste sensations from all areas with taste buds.
Each individual gustatory cell is only able to have receptors for one of the mentioned taste sensations. Each gustatory cell also have different thresholds in order to be activated- for examples, bitter receptors can detect tastants that are present in very small amounts.

When someone likes or dislikes a taste, it usually ties into homeostasis. For example, poisons and spoiled foods are bitter/sour as a "warning taste".

Taste disorders can be a result from respiratory tract infections, head injuries, chemicals, radiation from cancer treatment, etc. Because taste receptors are associated with three different nerves (**facial nerve (VII)**, **glossopharyngeal nerve (IX),** and the **vagus nerve (X)**) smell disorders are more common than taste disorders.

Endocrine System

Unlike the nervous system, which utilizes electrochemical impulse to regulate its activity, the endocrine system uses hormones which bind to cellular receptors in order to initiate a response (that can take anywhere from seconds to days).
The response, although slower, usually is more prolonged than responses by the nervous system. This is why the endocrine system controls lasting (sometimes continuous) processes like growth, development, energy balance, etc.
There are two types of glands- **exocrine glands** and **endocrine glands**. Exocrine glands have ducts that carry substances without hormones like sweat and saliva (ex: sudoriferous glands). Endocrine glands produce hormones and do not use ducts. They release hormones into their surroundings.
The main endocrine glands include the **pituitary, adrenal, pineal, parathyroid**, and **thyroid glands**. Be sure to study the location of these main glands! The **hypothalamus** is the bridge between the nervous system and the endocrine system- it functions with both and can be considered a **neuroendocrine organ**.
Other organs can contain endocrine tissue (ex: pancreas) and many other organs have at least a few endocrine cells (ex: adipose cells, which make up fat, release hormones).
You may want to put paracrines and autocrines on your cheatsheet, as it is not universally accepted as part of the endocrine system- we'll have to wait for the rules guide to find out.

Hormones

There are many types of hormones, but they are largely classified as either (mostly) **amino acid based** or **steroids** (usually derived from cholesterol). A considerable third class called **eicosanoids** includes lipids. They are more similar to paracrines and autocrines and not really considered hormones due to their short range. Hormones do not influence the whole body- they only influence the cell activity of their specific **target cells**. There are many actions/changes that can occur due to a hormonal stimulus.

The difference in solubility between amino acid based hormones and steroid hormones results in a key difference in the location/type of receptor the hormone acts upon. Amino acid based hormones are water-soluble (excluding thyroid hormones) so they cannot pass completely through the plasma membrane and enter the cell- they can only reach receptors that are in the plasma membrane. Steroid hormones, on the other hand, are lipid-soluble (allowing them to enter into the cell) and can act on intracellular receptors. There are a few bends to this guideline, but keep this correlation in mind.

If amino acid based hormones can't enter a cell, how do they initiate a response? They use **second messengers**. If you want to study a specific example of this, you can study cyclic AMP (also known as cAMP), which is also relevant in the nervous system.

As mentioned before, hormones only have an effect on their specific target cell. The target cell has receptors that specifically bind to the hormone. However, other factors may also affect the effectiveness of the hormone.

Hormone Interactions

Hormones also interact together. The three main types are **permissiveness, synergism,** and **antagonism**.
Permissiveness occurs when one hormone inhibits the effects of another hormone. For example, thyroid hormones are necessary for the effects of reproductive hormones. This ensures that development of the reproductive system occurs during specific stages of life.
Synergism occurs when multiple hormones have a shared, amplified effect on a target cell. Examples include glucagon and epinephrine, which intensify the amount of glucose released by the liver into the blood.
Antagonism is similar to permissiveness, but instead is when one hormone counteracts/opposes the action of another hormone. Insulin and glucagon are in an antagonistic relationship- insulin lowers blood glucose levels while glucagon increases blood glucose levels.

The overproduction of hormones is known as **hypersecretion** and the underproduction of hormones is known as **hyposecretion**.
Tumors and autoimmune diseases cause many endocrine disorders.

Local Hormones

Not all hormones are secreted by specific endocrine glands.
Histamine, for example, is created by mast cells in the tissue and basophils in the blood. It is an immune response that results in inflammation.
Serotonin is present in platelets, brain, and intestinal wall. It relates to intestinal secretion, contraction of smooth muscles, and **haemostasis**, or blood clotting.
Gastrointestinal hormones affect the secretion of digestive juices. Some examples of gastrointestinal hormones include **gastrin, secretin**, and **cholecystokinin** (also known as **CCK**).
Prostaglandins have many regulating effects, including regulating blood pressure, labor contractions, inflammation, etc.

Pituitary Gland/Hypothalamus

The pituitary gland is also known as **hypophysis,** which means "to grow under". It can be visualized as a pea on a stalk, the stalk being the **infundibulum** that connects the pituitary gland with the superior hypothalamus. It secretes many important hormones (at least nine known hormones) such as **growth hormone**, **thyroid stimulating hormone, prolactin,** etc.

There are two lobes of the pituitary gland- the anterior and posterior lobes. The hypothalamus influences each of these lobes differently.

Posterior Lobe

The posterior lobe of the pituitary gland is made of nerve fiber and glial-like cells called **pituicytes**. It can be considered an extension of the brain and hypothalamic tissue. The posterior lobe with the infundibulum is a region known as the **neurohypophysis**.

A nerve bundle connects the posterior lobe with the hypothalamus called the **hypothalamic-hypophyseal tract**. The posterior lobe is not considered an endocrine gland because it is a storage area for hormones created in the hypothalamus, and releases these **neurohormones** in response to nerve impulses from the hypothalamus. These two neurohormones are specifically **oxytocin** and **antidiuretic hormone (ADH)**, created by two separate neurosecretory cells. Note: Neurohormones are hormones secreted by neurons.

Oxytocin affects uterine smooth muscle and breast muscles. It stimulates contractions in the uterus to begin labor and contractions in cells around the lactating breast to eject milk. Both of these effects are examples of positive feedback mechanisms.

ADH is also known as **vasopressin** and reduces the amount of urine expelled. Osmoreceptors in the hypothalamus measure the osmolality of the blood. ADH is released when blood osmolality is high. As a result, distal and collecting tubules in the kidneys increase their permeability to water- allow for water to be reabsorbed to prevent further dehydration.

Alcohol can block the release of ADH, resulting in dangerous dehydration.

Anterior Lobe

Also known as the **adenohypophysis**, the anterior lobe releases many hormones. Unlike the posterior lobe composed of nervous tissue, the anterior tissue is composed of glandular tissue.

The hypothalamus produces a "releasing hormone" that stimulates the anterior pituitary to release hormones through negative feedback.

The most abundant hormone from the anterior lobe is the growth hormone (also known as **somatotropin**). The growth hormone is stimulated (causing release of GH) by **growth hormone release hormone**, also known as GHRH. It is inhibited by **growth hormone release inhibiting hormone,** also known as GHRIH.

GH is secreted most at night and during adolescence, and can be affected by exercise, glycaemia, etc.

Thyroid stimulating hormone stimulated the thyroid gland, which in turn release **thyroxine** and **triiodothyronine**. There is also a negative feedback system in place. For example, TSH secretion reduces when there is a high amount of thyroid hormones. Release of TSH is triggered by thyroid releasing hormone.
Prolactin is a hormone that promotes lactation; it is stimulated and reduced respectively by prolactin releasing hormone and prolactin inhibiting hormone.

Thyroid/Parathyroid Gland

This butterfly-shaped gland is located at the 5th-7th cervical and 1st thoracic vertebrae. It contains two lateral lobes joined by the **isthmus** in front of the trachea. There are also two **parathyroid glands** on the posterior of each lobe (meaning four in total).
The thyroid is made up of cuboidal epithelium called spherical **follicles**. The **lumen** stores **colloid**, a protein material, inside of the follicle. In between these follicles there are **parafollicular cells** (also known as **C-cells**) that produce a hormone called **calcitonin**.

Thyroid hormones from the thyroid glands affect all cells- allowing for metabolism, development, etc. It is formed from the previously mentioned colloid. Thyroid hormones enter target cells and interact with genes in order to start the transcription of mRNA, controlling protein synthesis.

Parathyroid Hormone is secreted by the parathyroid glands.

Adrenal Cortex

The adrenal cortex synthesizes many steroid hormones that are generally called **adrenocorticocoids/corticosteroids/corticoids.** They are separated into three main groups:

- **Glucocorticoids**
- **Mineralocorticoids**
- **Gondaocorticoids/Sex Hormones (Androgens)**

Glucocorticoids

Examples of glucocorticoid hormones include **cortisol/hydrocortisone, cortisone,** and **corticosterone.**

Cortisol is the main glucocorticoid hormone. Cortisol affects metabolism, responding to stress, gene activity, keeping glucose levels/blood pressure constant, etc. Cortisol levels are regulated by negative feedback.

Mineralocorticoids

The main mineralocorticoid is **aldosterone.** It regulates water reabsorption and electrolytes in your body. It targets the kidneys by reabsorbing Na+ and decreasing K+ levels by excreting it in urine. When Na+ is reabsorbed, water is retained- this affects blood volume and blood pressure (increases). Aldosterone is also regulated by negative feedback. Two factors affecting the amount of aldosterone are blood potassium levels and **angiotensin**. For an example of the negative feedback system, when there is a high amount of K+ in the blood, aldosterone is secreted (which in turn excrete K+, reducing the amount of K+ in the blood). After K+ is excreted and K+ levels in the blood get low, less aldosterone is secreted. This cycle continues to maintain aldosterone levels.

Gonadocorticoids/Sex Hormones

Gonadocorticoids mainly consist of weak androgens, which are male sex hormones. These weak androgens (including **androstenedione and dehydroepiandrosterone/DHEA**) are converted into stronger sex hormones like **testosterone** (male sex hormones) or **estrogens** (female sex hormones). However, the gonads produce much more sex hormones, especially during later stages of puberty and adulthood.

Homeostatic Imbalances

Addison's disease results when there is a lack of glucocorticoids and mineralocorticoids. Symptoms include weight loss, low sodium and glucose levels, and high potassium levels.

Adrenogenital syndrome, also known as **masculinization**, that is due to hypersecretion of gonadocorticoids. The effects do not show in adult males but evident symptoms show up in females and males that have not yet gone through puberty.

Pineal Gland

The pineal gland resembles a pinecone and hangs from the roof of the third ventricle, connected by a stalk of nerves.
The secretory cells of the pineal gland are called **pinealocytes**.
After puberty, the pineal gland atrophies and later becomes calcified.

Melatonin

The pineal gland secretes a hormone called **melatonin**. Melatonin is affected by factors like your body's circadian rhythm (an internal 24 hour clock). The amount of melatonin is highest at nighttime and lowest during noon/midday. Even though the effects of melatonin are not certain, it is associated with coordinating circadian rhythms (possibly with the **suprachiasmatic nucleus** of the hypothalamus, which contains many melatonin secretion). It also is associated with the growth and development of sex organs (before puberty).

Other Tissues

As mentioned previously, other organs can partially contain endocrine tissue. The ones we will talk about are the **pancreas, gonads,** and **placenta.**

Pancreas

The pancreas has a triangular shape and is made up of mostly **acinar cells**. Irregular clusters are found in the pancreas that are called **pancreatic islets** (also known as **islets of Langerhans**). Pancreatic hormones are produced here and are secreted into the bloodstream.
The three main types of cells present in the pancreatic islets are **alpha cells, beta cells,** and **delta cells**. Know the corresponding letters in the Greek alphabet.
Alpha cells secrete **glucagon**; beta cells secrete **insulin**; delta cells secrete **somatostatin/GHRIH**. As mentioned before, insulin and glucagon are antagonistic. Insulin, which lowers blood glucose levels, is known as a **hypoglycemic** hormone while glucagon, which increases blood glucose levels, is known as a **hyperglycemic** hormone.
As a fact (to possibly add to your cheatsheet), normal blood glucose levels vary between 3.5-8 mmol/liter (or 63-144 mg/100mL).
Somatostatin/GHRIH acts to inhibit the secretion of insulin and glucagon as well as the secretion of growth hormone (GH) from the anterior pituitary.

The pancreas is associated with major disorders like **type I diabetes mellitus** and **type II diabetes mellitus**. Diabetes mellitus is a result of the deficiency/absence of insulin- and sometimes alterations/impediments in insulin activity. This prevents carbohydrates and fats to be metabolized correctly.
Type I diabetes is also known as **insulin-dependent diabetes mellitus/IDDM**. It mainly occurs in children and young adults. Beta cells in the pancreas islets (which as previously mentioned, secrete insulin) are destroyed, causing the deficiency/absence in insulin. Although the exact cause in unknown, it is suspected that autoantibodies that destroy the insulin-secreting beta cells, possibly due to genetics or the environment.
Type II diabetes, also known as **non-insulin-dependent diabetes mellitus/NIDDM**, are the most prevalent form of diabetes (making up 90% of cases). Some possible causes are obesity, lack of exercise, age, genetics, etc. Insulin secretion can either be abnormally high or low, and low glucose levels can still occur.
Diabetes mellitus over time can result in severe problems like cardiovascular disorders, increased susceptibility to infections, renal failure, blindness, etc.

Gonads

Gonads produce the same steroid sex hormones that are produced by the previously mentioned adrenal cells. However, gonads produce larger amounts of sex hormones in a different corresponding location.
Female gonads are **ovaries**, which are responsible for producing eggs/ova. They also produce hormones like estrogens and progesterone.

Male gonads are known as **testes**, which produce sperm. They also produce hormones- mainly testosterone.

Placenta

The placenta is only temporary and nourishes the fetus during pregnancy. It also secretes hormones including estrogen, progesterone, and human chorionic gonadotropin (also known as hCG).