Unit 21 · Nervous System

STUDY NOTES

WHAT NEB'S GRADE 12 EXAM ASKS

- **CDC's grid (2078):** Human Biology (Units 17–24 together): 16 of 75 marks; 4 MCQs (knowledge, understanding, application, higher ability), 1 short question (4 marks: knowledge 1, application 2, higher ability 1) and 1 long question (8 marks: understanding 2, application 2, higher ability 4)
- **The paper:** Botany 37 + Zoology 38; each part: MCQs × 1 (5 Botany, 6 Zoology) · 4 short × 4 · 2 long × 8; one OR in each short and long group; 3 hours; 1 mark per expected point
- **CDC's model paper:** MCQ on acetylcholine
- **Our model papers:** Paper 1's short question (synapse; time for an impulse over 1 m on each kind of fiber; how myelin speeds it); Paper 2 MCQ (unsteady walk, overshooting: cerebellum); Paper 3 MCQ (dog runs at you: sympathetic) and short OR question (why the resting inside is negative; most impulses a second from a 2 ms refractory period, what a stronger stimulus changes; acetylcholinesterase blocked by organophosphate)
- **MCQ (1 mark)**
  - irritability: protoplasm; 3 meninges, pia on the brain; inner → outer: pia, arachnoid, dura
  - 86 billion neurons; no corpus callosum in the platypus
  - Broca's area: speaking; right-handed writing: left hemisphere
  - cerebrum: intelligence; cerebellum: coordination
  - foramen of Monro: lateral ventricles → third
  - CN VIII auditory; 31 pairs spinal nerves
  - Na^+, K^+; impulse = wave of depolarization; resting −70 mV
  - parasympathetic ACh: slower heart; opposite actions: sympathetic and parasympathetic
  - axons over 1 m: spinal nerves; rhombencephalon not forebrain
- **Short and long (in parts)**
  - nervous vs endocrine; the meninges; the ventricles
  - label lobes, areas and functions; brain histologically
  - functions of the hypothalamus; of the medulla
  - sympathetic vs parasympathetic; their transmitters; synapse; brainstem
  - brain structure and functions (long); medulla and spinal cord (long)
  - cranial and spinal nerves (long); outflows of the ANS (long)
  - conduction of the impulse, with neurotransmitters (long)

Key terms

Irritability (sensitivity): sensing and answering a change; a property of **protoplasm**.

Neuron: structural and functional unit of the nervous system; from **ectoderm**.

Sensory (afferent): receptor → CNS; **motor (efferent)**: CNS → effector; **interneuron**: inside the CNS.

Gray matter: cell bodies; **white matter**: myelinated axons.

Nucleus: cell bodies **inside** the CNS; **ganglion**: **outside** it.

Nerve: bundle of axons in connective tissue; sensory, motor or mixed.

Stimulus: a change that can excite; **threshold** (adequate) or **subthreshold**.

All-or-none law (Bowditch, 1871): a full impulse or none.

Neural summation: subthreshold stimuli adding up: **temporal** (same source, fast), **spatial** (different sources, same moment).

Neural accommodation: a slowly rising stimulus fails to fire the neuron.

Refractory period: **absolute** (1–2 ms, no stimulus works), **relative** (a stronger one works).

Action potential: brief reversal of membrane charge; a **wave of depolarization**.

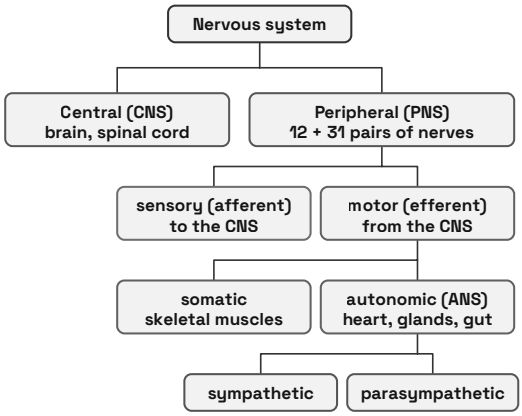
Synapse: where one neuron passes its signal to the next.

Neurotransmitter: chemical released at a nerve ending, carries the signal across.

Divisions

- **nervous system**: impulses; fast; aimed at particular muscles, glands
- **endocrine system**: **hormones** in blood; slower (seconds to days); every cell with a receptor
- together the **neuro-endocrine system** (center: **hypothalamus** + pituitary; also adrenal medulla): homeostasis
- irritability in steps: **excitability** → **reactivity** → **responsiveness** → **behavior**
- **CNS**: brain + spinal cord
- **PNS**: **12 pairs cranial** + **31 pairs spinal** nerves; link receptors, effectors
- **ANS**: organs without our will; **sympathetic** + **parasympathetic**; strictly the **visceral motor part of the PNS**

- motor neurons' cell bodies are in the CNS too (ventral horns, brainstem); sensory cell bodies in **dorsal root ganglia**



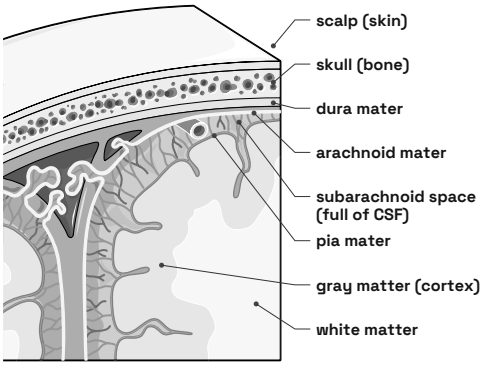
The divisions of the nervous system.

Meninges

- brain in the **cranium**, cord in the **neural canal**; three **meninges** (meninx = membrane)

1. **dura mater**: outer, thick, tough, fibrous; two layers round the brain (fixed to skull; **dural venous sinuses** between them), one round the cord; has blood vessels
2. **arachnoid mater**: middle, thin, **no blood vessels**; web-like threads
3. **pia mater**: inner, thin, transparent, **rich in blood vessels**; on the brain, in every fold

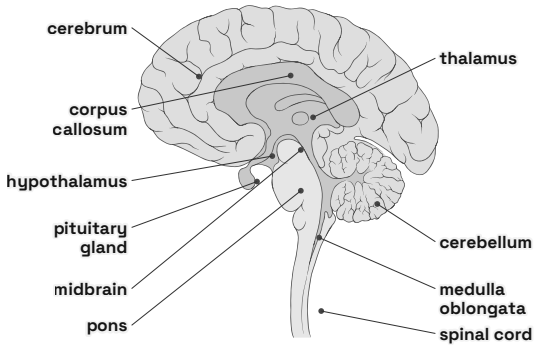
- **epidural space**: bone–dura; real only in the backbone (fat, veins; epidural anesthetic)
- **subdural space**: dura–arachnoid; a thin film
- **subarachnoid space**: arachnoid–pia; **CSF** (only this space)



The meninges under the skull.

The brain

- ~98% of CNS weight, ~2% of body: **~1.4 kg**; 90% adult size by ~6 years
- gets ~**15%** of the heart's blood, uses ~**20%** of O_2 (ion pumping)
- **86 billion neurons** (2009 count) + about as many **neuroglia** (support, nourish, insulate)
- **cerebrum, cerebellum**: gray **outside** (cortex); **spinal cord**: gray **inside**
- three parts from the neural tube: **forebrain**, **midbrain**, **hindbrain**



The brain cut down the middle, from the left.

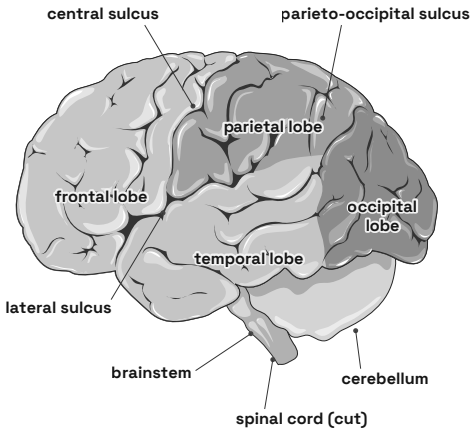
Forebrain (prosencephalon) = **cerebrum** (telencephalon) + **diencephalon**

Cerebrum: largest; ~82% of the brain's mass

- **cerebral cortex**: gray, **1–4.5 mm** (avg 2.5); ~90% **neocortex**, **6 layers**; **gyri**, **sulci**, **fissures**; ~2,500 cm^2; **pyramidal** and **stellate** cells
- areas: **sensory** (interpret senses) · **motor** (voluntary movement) · **association** (personality, intelligence, memory, reasoning, will, emotion, judgment)
- **cerebral medulla**: white matter + basal ganglia + limbic parts + **lateral ventricles**

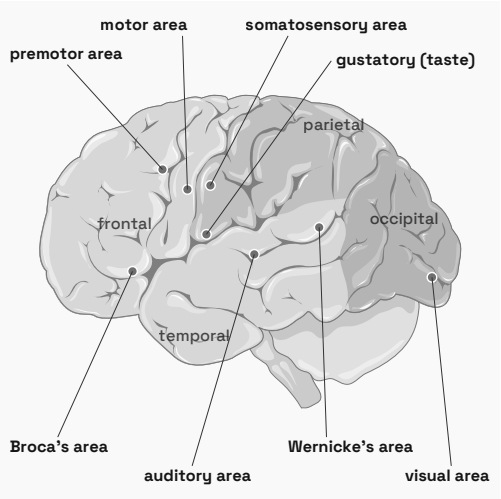
Cerebral hemispheres

- left and right; **longitudinal fissure**; joined by **corpus callosum** (~200 million axons; front **genu**, back **splenium**); **fornix** under it
- **cross over**: left hemisphere → right side (left stroke: right limbs, speech)
- four lobes; grooves: **central sulcus** (frontal | parietal) · **lateral sulcus** (Sylvius; temporal below) · **parieto-occipital sulcus**



The lobes and grooves of the left hemisphere.

Lobe	Area	Function
frontal	**premotor**	plans **voluntary**, learned movements (writing)
	primary motor (front of central sulcus)	voluntary movement of skeletal muscles
	Broca's (usually left)	**speaking**
	(whole lobe)	planning, judgment, self-control, personality
parietal	**somatosensory** (behind central sulcus)	touch, pressure, heat, cold, pain, body position
	gustatory	taste
	(whole lobe)	where things are: maps, clock hands
temporal	**auditory**	hearing
	olfactory (inner surface)	smell
	Wernicke's (usually left)	**understanding** speech, writing; memory
occipital	**visual**	seeing



The main functional areas of the left hemisphere.

- **olfactory bulbs** under the frontal lobes → **olfactory tracts** → smell areas, **amygdala**; = **rhinencephalon**; smell skips the thalamus
- **basal ganglia** (strictly basal **nuclei**): **caudate**, **putamen**, **globus pallidus**; **corpus striatum**; with subthalamic nucleus, substantia nigra: **start, stop, smooth movements**, muscle tone; Parkinson's (too few), Huntington's (too many)
- **limbic system** ("**emotional brain**"), ring round corpus callosum and thalamus:
  - **amygdala**: danger, **fear**, aggression
  - **hippocampus**: new experiences → lasting **memories**; finding the way
  - **fornix** → mammillary bodies; **cingulate gyrus**
  - pain, pleasure, affection, anger, memory, smell

Diencephalon: round the **third ventricle**; choroid plexus on its roof

- **epithalamus**: roof; **pineal gland** (**melatonin**, sleep rhythm), habenular nuclei
- **thalamus**: ~⅘ of the diencephalon; walls of the 3rd ventricle; **gateway to the cortex**: every sense **except smell** sorted here; motor relay; memory, emotion, sleep
- **hypothalamus**: **floor** of the 3rd ventricle; pituitary hangs below; ~4 g; **neuro-hormonal**:
  - nervous: **temperature**, **water balance**, **hunger**, **satiety**, **thirst**, sleep, heartbeat, blood pressure, breathing, **ANS**; feeding, fighting, fleeing, mating; anger, fear, pleasure
  - hormonal: **releasing** (GnRH, GHRH) and **inhibiting** hormones → front pituitary; **oxytocin**, **ADH** → back pituitary
- **subthalamus**: subthalamic nucleus, movement with basal ganglia

Midbrain (mesencephalon): **cerebral aqueduct** (3rd → 4th ventricle)

- **substantia nigra**: dark (neuromelanin); **dopamine** to basal ganglia
- **red nuclei**: iron, blood vessels; cerebellum ↔ motor paths
- **reticular formation** (whole brainstem): keeps the cortex **awake**
- **cerebral peduncles** (crura cerebri): ventral; tracts up and down
- **corpora quadrigemina** (dorsal, tectum): **superior colliculi** (**visual reflexes**) · **inferior colliculi** (**hearing** path, turning to a sound)

Hindbrain (rhombencephalon): cerebellum, pons (metencephalon), medulla (myelencephalon)

- **brainstem** = midbrain + pons + medulla

Cerebellum ("little brain")

- second largest; behind pons and medulla, **4th ventricle** between; solid
- ~10% of weight but **69 of 86 billion** neurons (granule cells)
- cortex: **3 layers** (molecular, **Purkinje cells**, granular), **folia**; medulla: **arbor vitae**
- **vermis** + two **hemispheres**; anterior, posterior, **flocculonodular** lobes (balance, with the inner ear)
- peduncles: **superior** (midbrain) · **middle** (largest; pons) · **inferior** (medulla, cord)
- **coordinates**, does not start: when and how much each muscle pulls; **posture**, **balance**; **learns** movements
- damage: unsteady walk, sway, overshooting

Pons varolii: bridge, up–down and across to the cerebellum; **pontine nuclei** (cortex → cerebellum); **pneumotaxic** (shortens breath in) and **apneustic** (lengthens) areas

Medulla oblongata: pons → cord at the **foramen magnum**

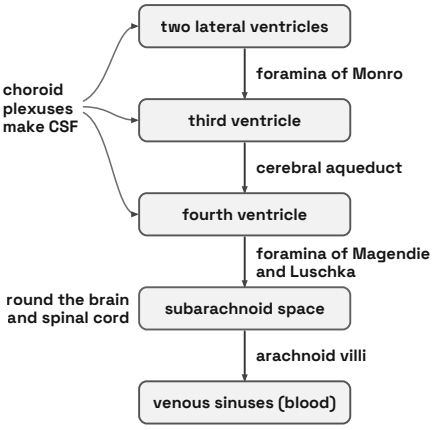
- **pyramids**: motor fibers; most **cross** here
- 4th ventricle with choroid plexus over it; white + gray matter
- vital centers: **cardiac** (heart rate, force) · **vasomotor** (vessel diameter → **blood pressure**) · **respiratory** (rate, depth)
- swallowing, coughing, sneezing, vomiting, saliva, gastric juice

Ventricles and CSF

- hollow of the **neural tube** = **neurocoel**: ventricles + **central canal**; all hold **CSF**

1. **first** = **left lateral** ventricle (paracoel)
2. **second** = **right lateral** ventricle; lateral ventricles split by **septum pellucidum**; each → 3rd by **foramen of Monro** (interventricular foramen)
3. **third** (**diocoel**): diencephalon; → 4th by **cerebral aqueduct** (aqueduct of **Sylvius**, iter)
4. **fourth** (**metacoel**): pons, medulla in front, cerebellum behind; **foramen of Magendie** (median) + two **foramina of Luschka** (lateral) → subarachnoid space; → central canal

- "one-two-three-four, Monro–aqueduct–out the door"



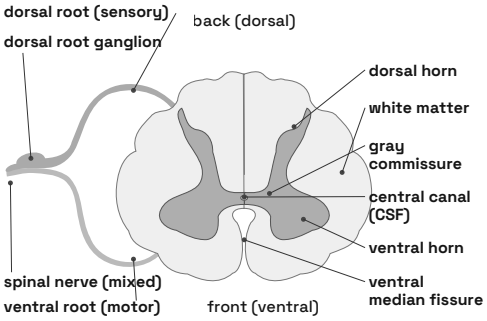
Where the cerebrospinal fluid goes.

CSF

- made by **choroid plexuses** in all four ventricles; **blood–CSF barrier** (tight lining cells)
- → subarachnoid space → back into venous sinuses by **arachnoid granulations**
- clear, colorless; < 5 lymphocytes per μL
- **~80–150 mL**; **~500 mL** made a day
- vs plasma: much less protein, ~⅔ glucose, more Cl^-, Mg^{2+}, less K^+, Ca^{2+}, same Na^+
- jobs: **shock absorber** · **floats** the brain (1.4 kg → ~50 g) · nutrients, hormones in, wastes out · even pressure in the skull
- brain's blood: internal carotids + vertebrals (→ basilar) → **circle of Willis**

Spinal cord

- foramen magnum → **L1–L2**; **42–45 cm**; ~1 cm thick
- **cervical** and **lumbar enlargements** (arms, legs)
- **conus medullaris**; **filum terminale** (pia) → coccyx; **cauda equina** (roots below the cord)
- ~200 million neurons
- **gray inside**, **H**/butterfly: **dorsal horn** (sensory fibers end) · **ventral horn** (motor neurons) · **lateral horn** T1–L2 (sympathetic) · **gray commissure**
- **central canal**: ependymal cells, CSF
- **white outside**: dorsal, lateral, ventral **funiculi**; ascending, descending tracts
- reflex center



The spinal cord cut across.

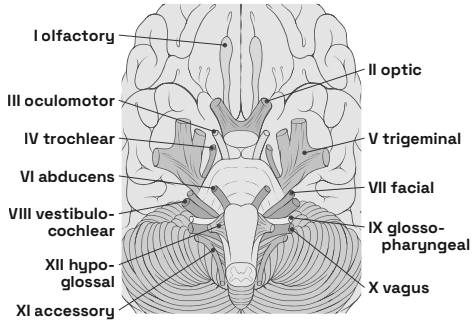
Peripheral nervous system

Cranial nerves: 12 pairs, CN I–XII front to back; I, II from the forebrain, rest from the brainstem; III, VII, IX, X carry **parasympathetic** fibers

No.	Name	Type	Supplies
I	olfactory	S	smell (cribriform plate → olfactory bulb)
II	optic	S	sight (crossing at the **optic chiasma**)
III	oculomotor	M	superior, inferior, medial rectus, inferior oblique; eyelid; pupil narrows, lens focuses
IV	trochlear	M	**superior oblique**; **smallest**; only one from the **back** of the brainstem
V	trigeminal	mixed	**largest**; ophthalmic (forehead, eye, nose), maxillary (cheek, upper teeth), mandibular (mixed: lower jaw, teeth; **chewing**); face's touch, pain, heat
VI	abducens	M	**lateral rectus** (eye outwards)
VII	facial	mixed	**facial expression**; **taste front ⅔** of tongue (chorda tympani); tears, submandibular and sublingual saliva
VIII	vestibulocochlear (auditory)	S	**hearing** (cochlear) and **balance** (vestibular)
IX	glossopharyngeal	mixed	taste, touch **back ⅓** of tongue, pharynx; swallowing; **parotid**
X	vagus	mixed	**longest**, widest; pharynx, larynx, **heart** (slows), lungs, gut; ~¾ of parasympathetic fibers
XI	accessory	M	turning head, shrugging (sternocleidomastoid, trapezius)
XII	hypoglossal	M	**tongue** movement

- order: Oh Oh Oh To Touch And Feel Very Good Velvet, Ah Heaven

- types: Some Say Marry Money, But My Brother Says Big Brains Matter More
- one side of the face droops: **Bell's palsy** (facial nerve)



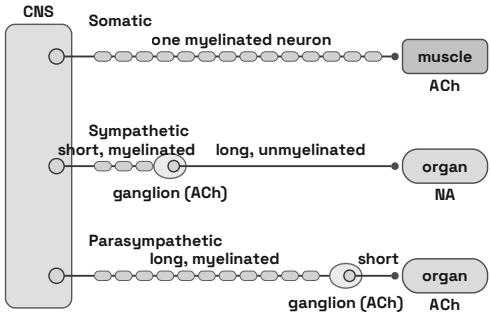
The twelve pairs of cranial nerves, underside of the brain.

Spinal nerves: 31 pairs, through **intervertebral foramina**; all **mixed**

- **dorsal root**: sensory, **dorsal root ganglion**; **ventral root**: motor, no ganglion
- **C_8 T_{12} L_5 S_5 Co_1 (Cd1)** = 31; 8 cervical nerves, 7 cervical vertebrae
- cervical: neck, arms (C3–C5 diaphragm) · thoracic: trunk · lumbar: lower abdomen, legs · sacral: buttocks, pelvis, legs · coccygeal: skin round coccyx

Autonomic nervous system

- involuntary; **smooth muscle**, **heart**, **glands**; reflexes
- centers: **hypothalamus** (highest), **medulla**, cortex, limbic system (blushing)
- usually counted as **motor**
- **two neurons** in a row, meeting in a **ganglion**: **preganglionic** (thin, **myelinated**) → **postganglionic** (**unmyelinated**)
- **cholinergic** (acetylcholine): **all preganglionic**; parasympathetic postganglionic; sympathetic to sweat glands
- **adrenergic** (noradrenaline, "sympathin"): most sympathetic postganglionic



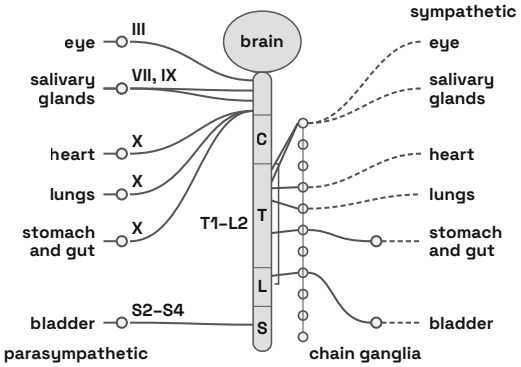
One somatic motor neuron, two autonomic neurons.

Sympathetic (**thoracolumbar**, **T1–L2**, 14 segments)

- lateral horns → ventral root → **white ramus** → **sympathetic chain** (**paravertebral ganglia**, ~22–23 a side)
- in the chain: synapse (→ **gray ramus** → skin) · run up or down (head, legs) · pass through in **splanchnic nerves** → **prevertebral (collateral) ganglia** (gut, pelvis)
- some go straight to the **adrenal medulla** → adrenaline
- "**fight or flight**": stress, pain, fear, anger, exercise

Parasympathetic (**craniosacral**: CN **III, VII, IX, X + S2–S4**, pelvic splanchnic nerves)

- **long** preganglionic fibers → **terminal ganglia** near or in the organs; short postganglionic
- head ganglia: ciliary (III), pterygopalatine and submandibular (VII), otic (IX)
- **acetylcholine** at both synapses
- "**rest and digest**"; saves and restores energy



The sympathetic and parasympathetic outflows.

Feature	Sympathetic	Parasympathetic
outflow	thoracolumbar T1–L2	craniosacral III, VII, IX, X, S2–S4
preganglionic cell bodies	lateral horns T1–L2	brainstem nuclei; sacral cord
preganglionic fibers	**short**	**long**
ganglia	chain beside cord (+ prevertebral)	near or in organs
effect	**widespread**	**local**
postganglionic fibers	**long**	**short**
transmitter at organ	**noradrenaline** (not sweat glands)	**acetylcholine**

Organ	Sympathetic	Parasympathetic
pupil	dilates	constricts
ciliary muscle	relaxes (far)	contracts (near)
salivary glands	little, thick saliva	much, watery
heart	faster, stronger	slower, weaker
bronchi	widen	narrow
stomach, intestine; pancreas	less movement, secretion	more
liver	releases glucose	stores glycogen
gall bladder	relaxes	contracts
adrenal medulla	adrenaline	—
urinary bladder	wall relaxes, sphincter shuts	wall contracts, empties
skin, gut vessels; muscle vessels	narrow; widen	—
sweat glands	sweating	—
sex organs	ejaculation	erection

- most organs get both, opposite (accelerator and brake); hypothalamus coordinates

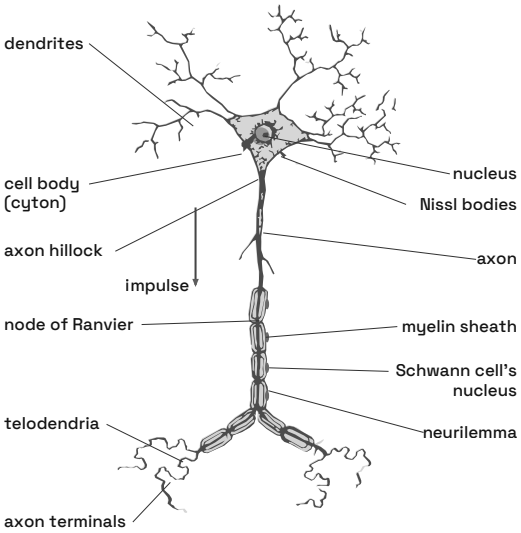
- transplanted heart, nerves cut: beats ~100/min (vagus normally holds it ~70)

The nerve impulse

- impulse = **action potential**: electrochemical; a **wave of depolarization**; passed on at **synapses**
- stronger stimulus → **more impulses per second** and **more neurons**, not bigger impulses (all-or-none for one fiber)

Neuron

- **dendrites** (towards the cell body) · **cell body** (soma, cyton; **Nissl granules**) · **axon** from the **axon hillock** (impulses start), **myelin** (**Schwann cells** in PNS, oligodendrocytes in CNS), **nodes of Ranvier**, **synaptic knobs**
- endings: **synapse** · **neuromuscular junction** (motor end plate), neuroglandular · **sensory nerve endings**
- outside (**ISF**): Na^+, Cl^-, HCO_3^-; inside (**ICF**): K^+, negative proteins, phosphates
- properties: **excitability**, **conductivity**



A motor neuron.

Speed: faster with **myelin**, **thicker** fiber, **warmer**; vertebrates > invertebrates

- unmyelinated **~0.5–2 m/s**; thick myelinated **~70–120 m/s**
- e.g. 1 m toe to cord: 1 ÷ 100 = 0.01 s; 1 ÷ 1 = 1 s
- **continuous** conduction (unmyelinated, slow) · **saltatory** (myelinated; only at **nodes**, leaps; ~20 × faster, less energy)

Refractory period: **absolute** ~1–2 ms (Na^+ channels inactivated) · **relative** (undershoot; stronger stimulus)

- impulse goes **one way**; at most a few hundred a second (1 ÷ 0.002 s = 500)

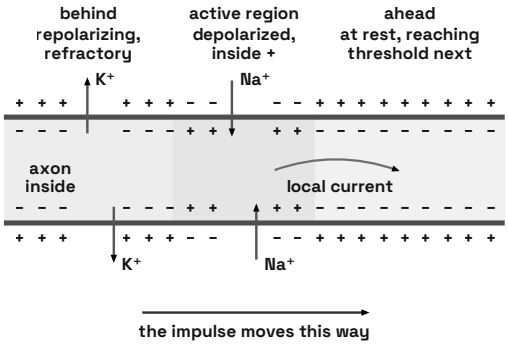
Resting potential (Hodgkin and Huxley, squid giant axon, **1952**: **ionic theory**)

- Na^+ ~10–14 × higher **outside**; K^+ ~30 × higher **inside**; big negative proteins can't leave
- **Na^+/K^+ pump** (ATP): **3 Na^+ out, 2 K^+ in**; active
- **K^+ leak channels**: K^+ leaks out, negatives stay
- outside **+**, inside **−**: **−70 mV**; **polarized**

Four stages at one patch

1. **polarization**: −70 mV
2. **depolarization**: threshold **~−55 mV** → **voltage-gated Na^+ channels** open → Na^+ rushes **in** (positive feedback) → **+30 to +40 mV**
3. **repolarization**: Na^+ channels close and lock; **voltage-gated K^+ channels** open → K^+ **out** → back towards −70 (absolute refractory)
4. **hyperpolarization** (undershoot): −80 to −90 mV (relative refractory); then the pump restores the few ions

- ions move by **diffusion** through channels; the pump never reverses
- **local currents** depolarize the patch ahead; the patch behind is refractory → **forwards**, **no loss in size**
- hyperpolarized = more negative (harder to fire); depolarized = less negative (easier)



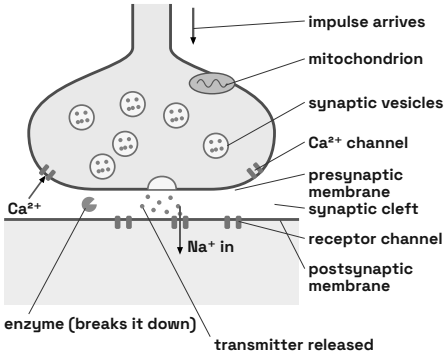
An impulse moving along an unmyelinated axon.

Synapse and transmitters

- axodendritic, axosomatic, axoaxonic
- **presynaptic knob** (mitochondria, **synaptic vesicles** of transmitter) · **synaptic cleft ~20 nm** · **postsynaptic membrane** (receptor proteins, ion channels)
- **electrical**: **gap junctions** (~3.5 nm); instant, both ways; heart, gut smooth muscle, lens
- **chemical**: one way, ~0.5 ms delay, can change strength (learning); most common

How a chemical synapse works

1. impulse reaches the knob
2. **voltage-gated Ca^{2+} channels** open; **Ca^{2+} in**
3. vesicles fuse with the **presynaptic** membrane → **exocytosis**
4. transmitter diffuses, binds receptors
5. **ligand-gated** channels: Na^+ in → **EPSP**; Cl^- in or K^+ out → **IPSP**
6. sum at the **axon hillock** → fires if threshold
7. removal: ACh split by **acetylcholinesterase** (acetate + choline); noradrenaline pumped back



A chemical synapse.

Neurotransmitters

- **acetylcholine**: all **neuromuscular junctions**, all autonomic **ganglia**, parasympathetic endings, brain; excites skeletal muscle, **slows heart**
- **noradrenaline**: most sympathetic postganglionic; alertness
- **GABA**: main **inhibitory** (Cl^- channels)
- **glutamate** (main excitatory), **dopamine** (movement, reward; Parkinson's), **serotonin** (mood, sleep), **glycine** (inhibitory, cord), **endorphins**
- **organophosphate** (pesticide) blocks acetylcholinesterase → ACh piles up → sweating, drooling, small pupils, slow heart, twitching → muscles weaken; breathing muscles fail → death

COMMON MISTAKES

✗ The ANS is wholly separate from the PNS
✓ it is the PNS's **visceral motor** part.

✗ All three meningeal spaces hold CSF
✓ only the **subarachnoid** space (and ventricles, central canal).

✗ The premotor area controls involuntary movement
✓ it plans **voluntary**, skilled movement; hypothalamus and medulla rule the ANS.

✗ The cardiac center sets blood vessel size
✓ **cardiac** = heartbeat; **vasomotor** = vessels.

✗ The cerebellum starts movements
✓ it **coordinates** them; the motor cortex starts them.

✗ The trigeminal's mandibular branch is purely motor
✓ **mixed** (lower jaw sense, chewing muscles).

✗ The parasympathetic system inhibits release of acetylcholine
✓ it **releases** acetylcholine.

✗ Synaptic vesicles fuse with the postsynaptic membrane
✓ with the **presynaptic** membrane.

✗ During an impulse the Na^+/K^+ pump reverses
✓ **voltage-gated channels** open; ions **diffuse**; the pump keeps going.

✗ A stronger stimulus gives a bigger impulse
✓ same size; **more impulses** per second, **more fibers**.

✗ Hyperpolarization means less negative
✓ **more** negative than rest.