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Biological Psychology 10003

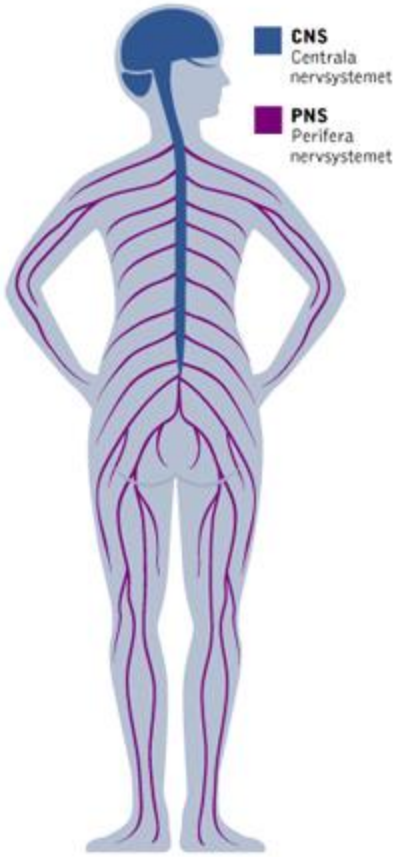
Lecture 2: Nerve Cells and Nerve Impulses

Overview:

- Central & peripheral nervous systems
- The blood-brain barrier (BBB)
- Types of cells that make up the nervous system: neurons and glia
- Types of neuron by function
- The basic structure of a neuron
- How a resting neuron differs from a stimulated neuron

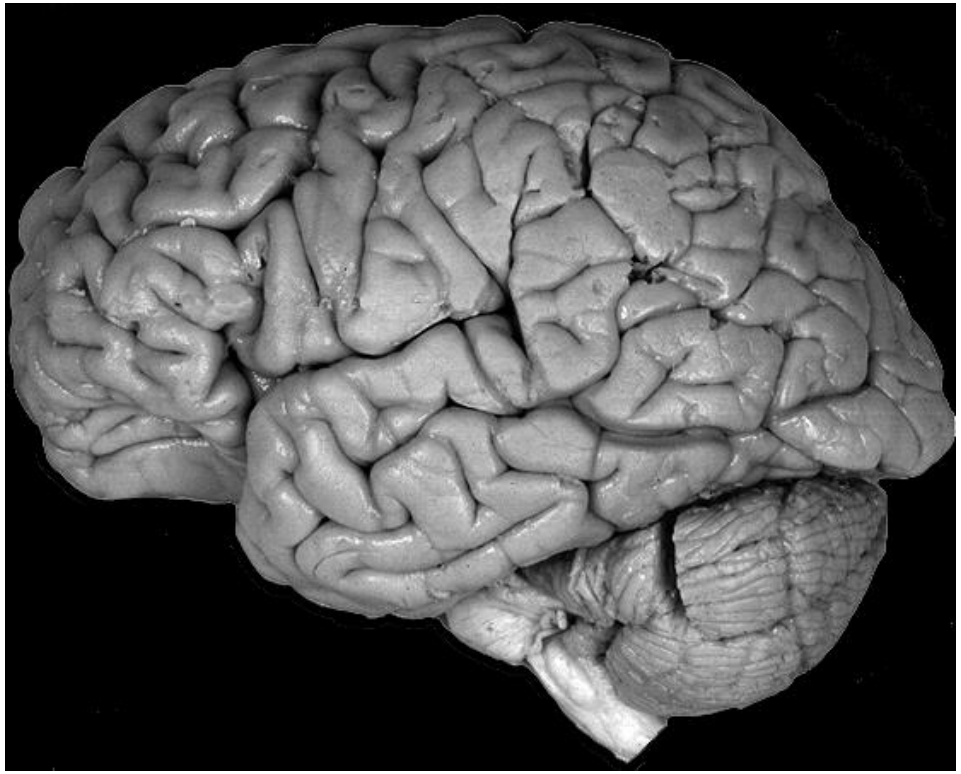
Nervous system

- Nervous system (NS)
  - Central nervous system (CNS) – the brain and the spinal cord
  - Peripheral nervous system (PNS) – NS other than brain and spinal cord (e.g., nerves from sense organs to the CNS)
- Nerve cells (=neurons) share the same basic architecture
- Neurons can be grouped in numerous ways and it is the neuronal network circuitry that complex behaviour



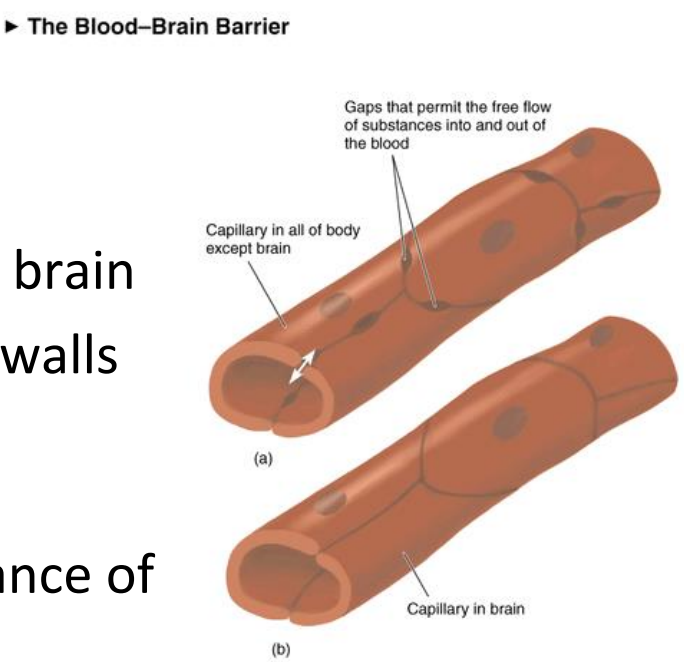
http://www.ms-guiden.se/MS-guiden/Om-MS/

The brain



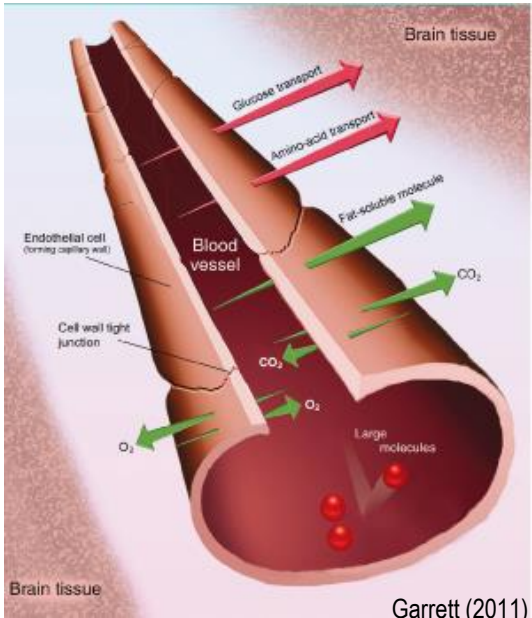
The brain

The Blood-Brain Barrier (BBB)



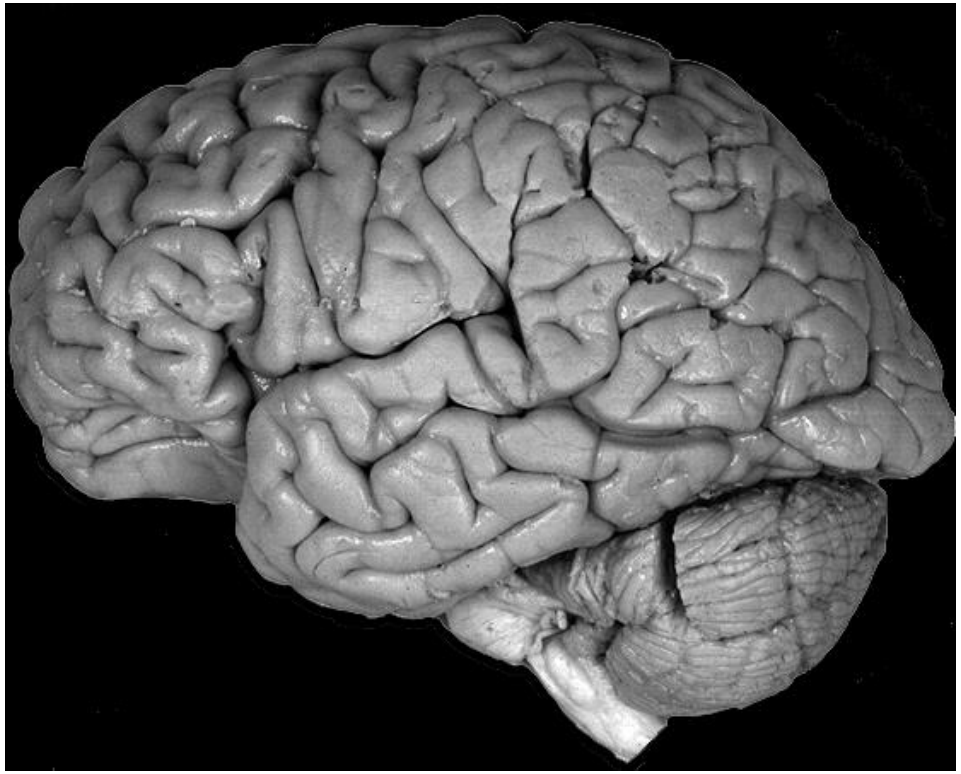
- A semi-permeable "barrier" between blood and brain
- Produced by tightly packed cells in the capillary walls of the brain

- Protects and helps to regulate the chemical balance of the brain
  - Passive (doesn't consume energy) crossing of the BBB:
    - small uncharged molecules (incl. oxygen & carbon dyoxide)
    - molecules that dissolve in the fats of the membrane, e.g. vitamins A&D, various drugs that affect the brain
  - Excludes most viruses, bacteria & toxins
- Necessary substances (e.g. glucose for energy & aminoacids to build proteins) access the brain via active transport systems



Garrett (2011)

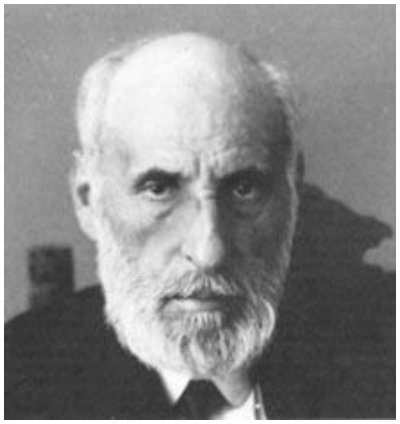
The brain

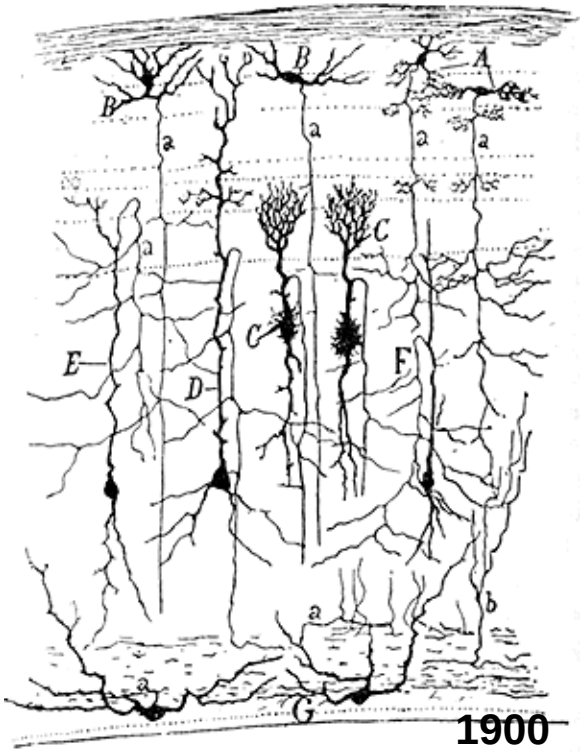


The Neuron Doctrine

- Santiago Ramón y Cajal (1852-1934)
- Used newly-developed staining techniques to show that **neurons are separable**, i.e., that there is a small gap between the tips of one neuron's fibers and the next neuron

- **=> the brain consists of individual neurons**





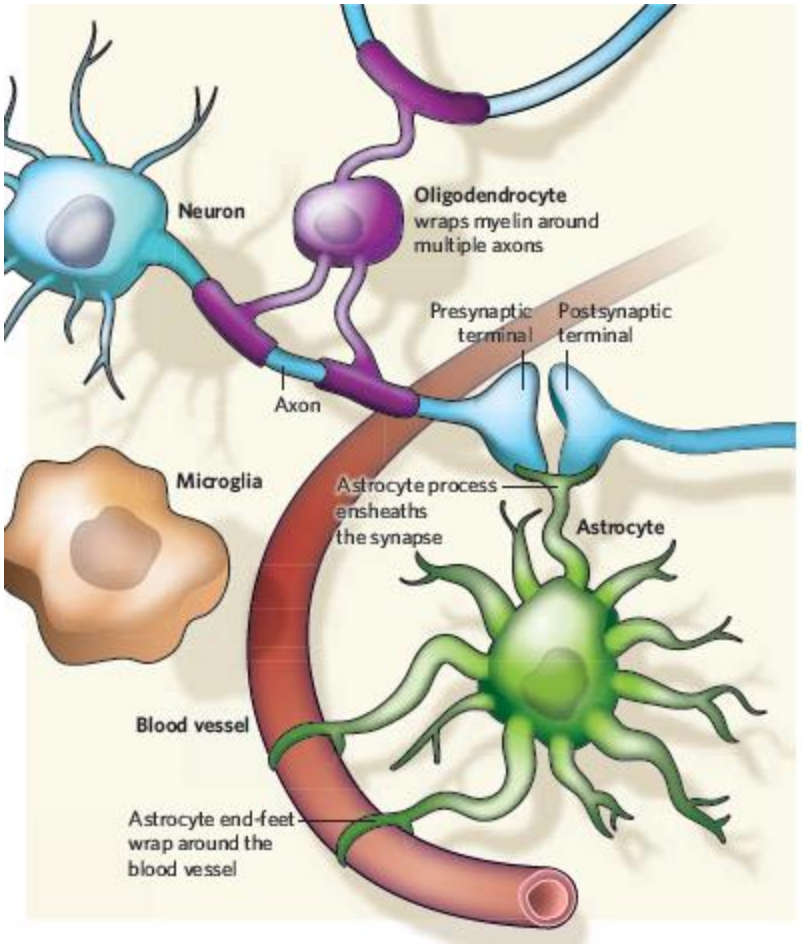
The brain

- Two main types of cells in the NS:
  - Nerve cells (neurons)
  - Glial cells (glia, neuroglia) - supporting cells
- **Neurons**
  - Cerebellum: 70 billion
  - Cerebral cortex: at least 12-15 billion
  - Spinal cord: 1 billion
- **Glia** (from Greek ‘glue’)
  - smaller than neurons but more numerous (approx 10 times as many as neurons)
  - most common glia: oligodendrocytes (76%), astrocytes (17%) and microglia (6%)

Glia (1)

- Many different types but essentially are supportive cells of the NS and have many vital roles:

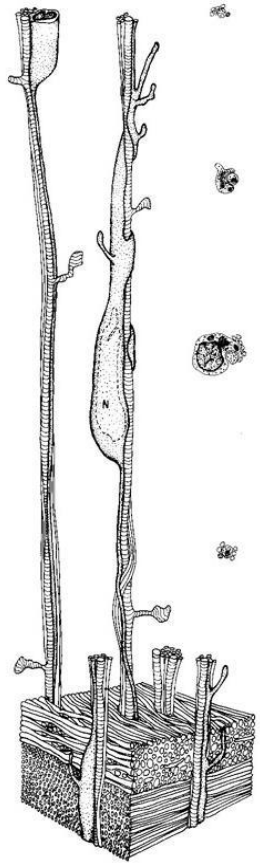
1. Provide structure, i.e., surround neurons and hold them in place (astrocytes)
2. Insulate nerve cells with myelin sheaths (oligodendrocytes in the CNS, Schwann cells in the PNS)



Allen & Barres (2009) *Nature*

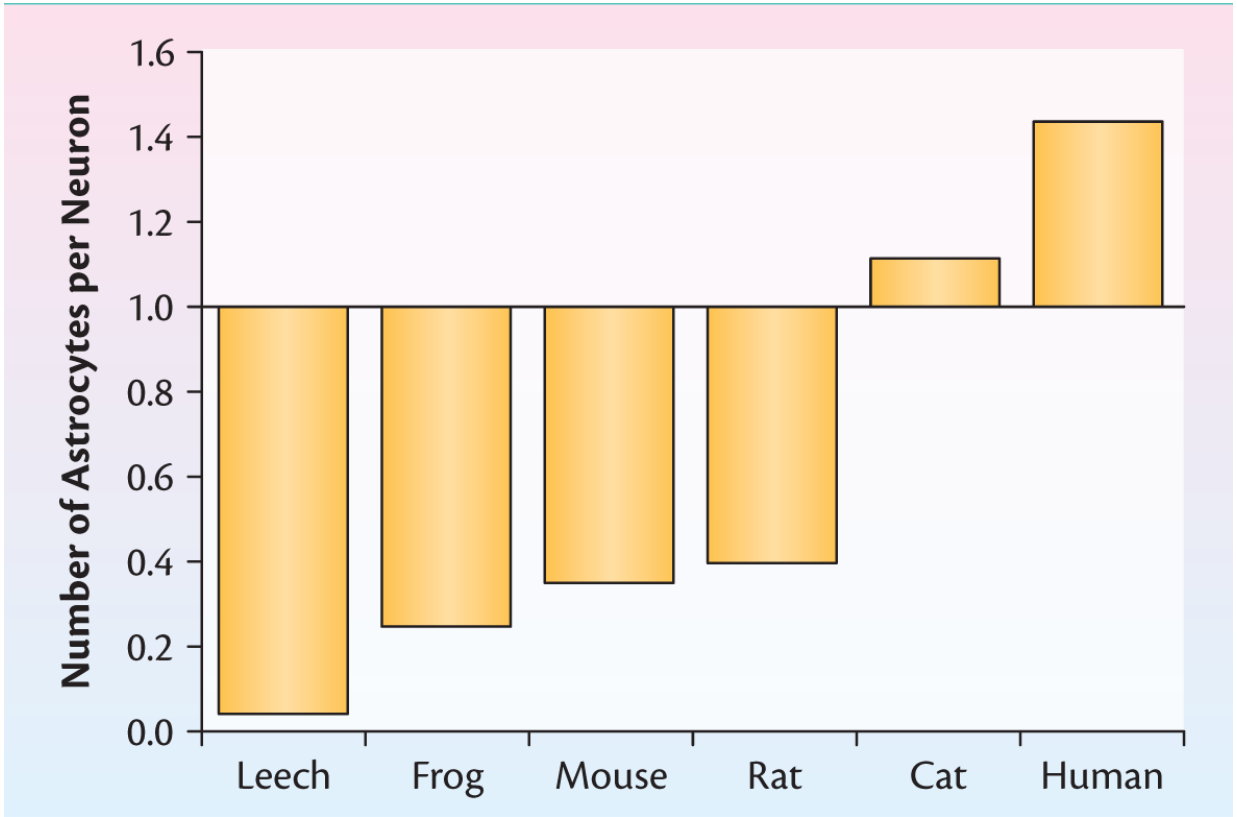
Glia (2)

3. Supply nutrients and oxygen to neuron (astrocytes)
4. Removal of dead neuronal tissue & immune defence of the CNS (microglia: phagocytes)
5. During development, glial cells provide scaffolds for neurons to migrate to their final destinations (radial glia)
6. Modulate neurotransmission (astrocytes: clear neurotransmitter from within the synaptic cleft, hence prevent toxic build-up of certain neurotransmitters, see the lecture on *Neurotransmission*)



Rakic (1972) radial glia-guided migration

Astrocyte to Neuron Ratio in Various Species



As behavioral complexity increases, the ratio of astrocytes to neurons also increases.

(Garrett, 2011; based on Nedergaard et al, 2003)

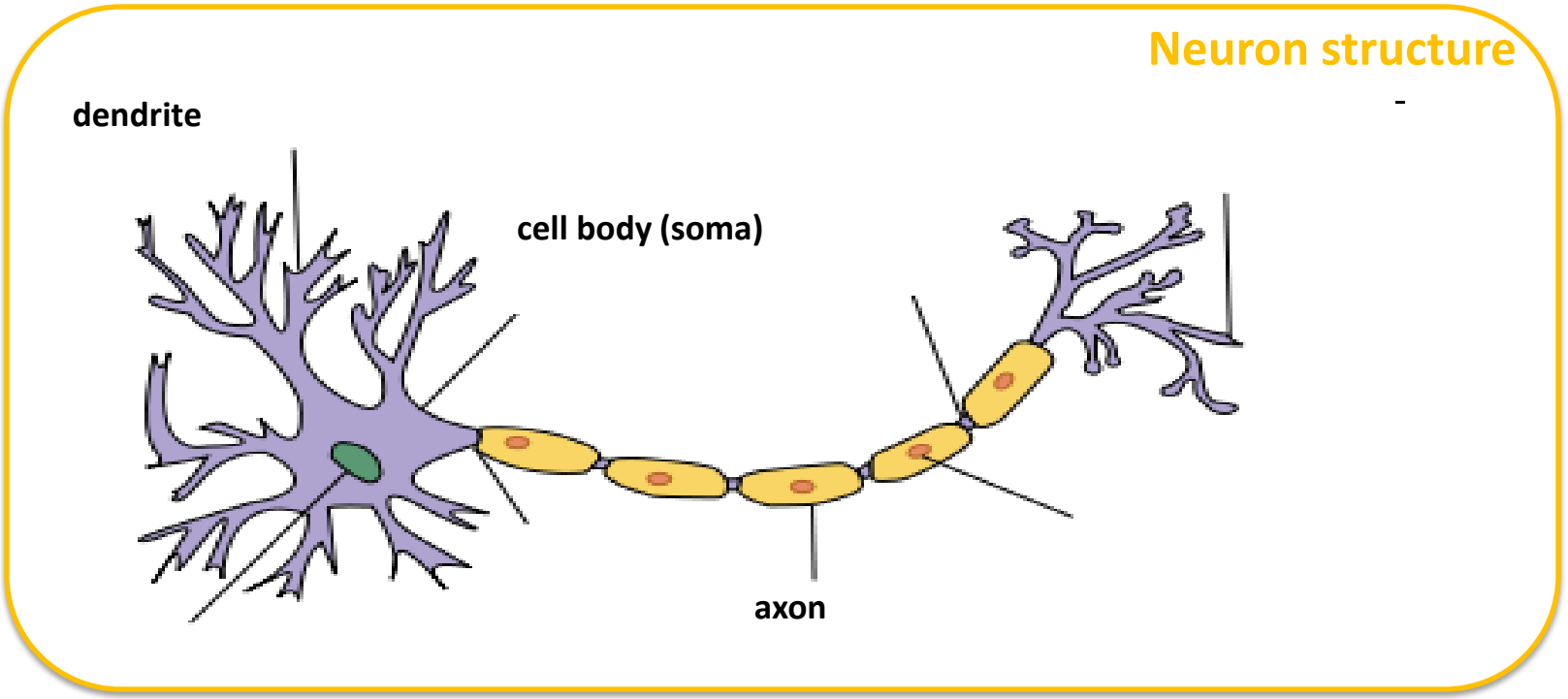
Rett Syndrome

- Strikes little girls (under 2 years) almost exclusively
- Loss of speech, motor control & functional hand use, seizures, orthopedic and severe digestive problems, breathing, anxiety, etc
  - caused by mutations in the MeCP2 protein present in neurons and astrocytes
  - re-expression of MeCP2 in neurons or astrocytes in mouse models dramatically reversed Rett symptoms

rett syndrome research trust

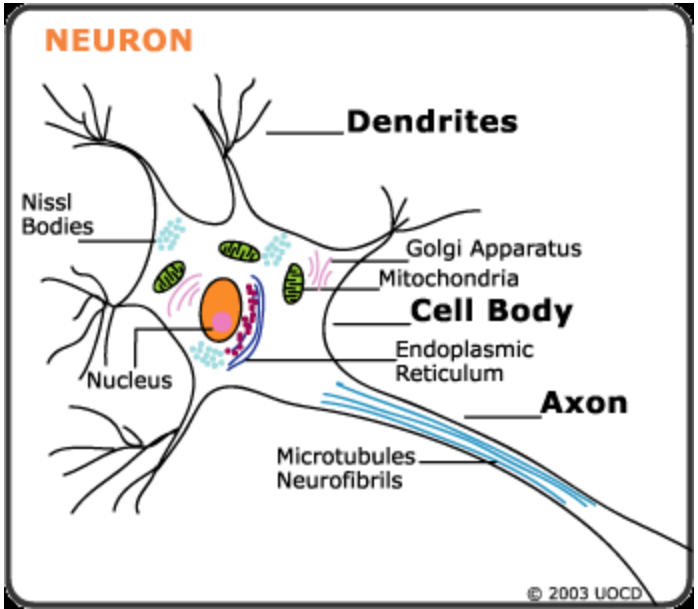
Neurons

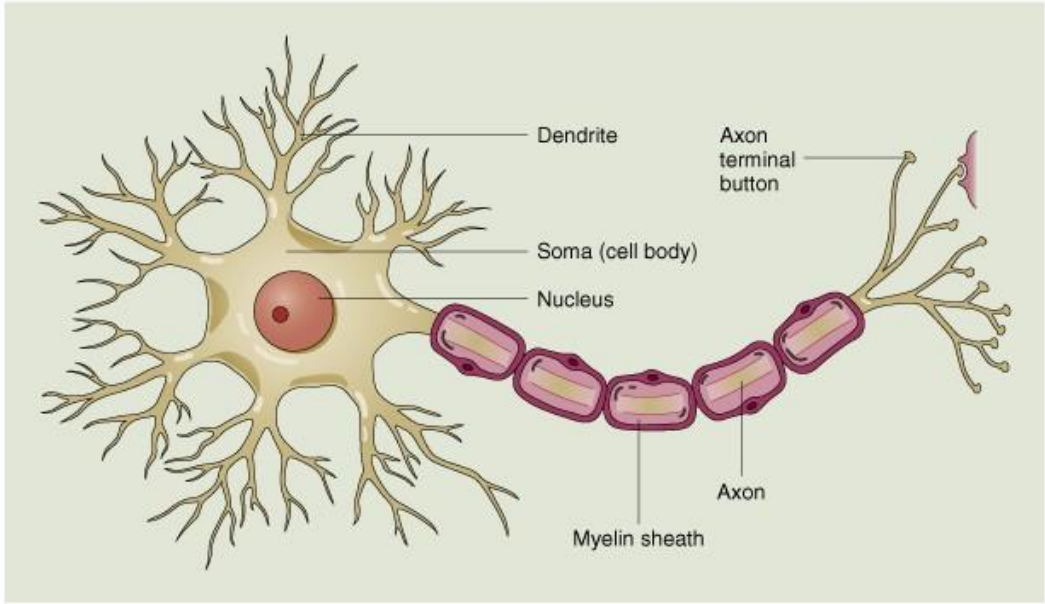
Neurons - cells in the nervous system that specialise in performing information-processing tasks



Neuron structure: Soma (cell body)

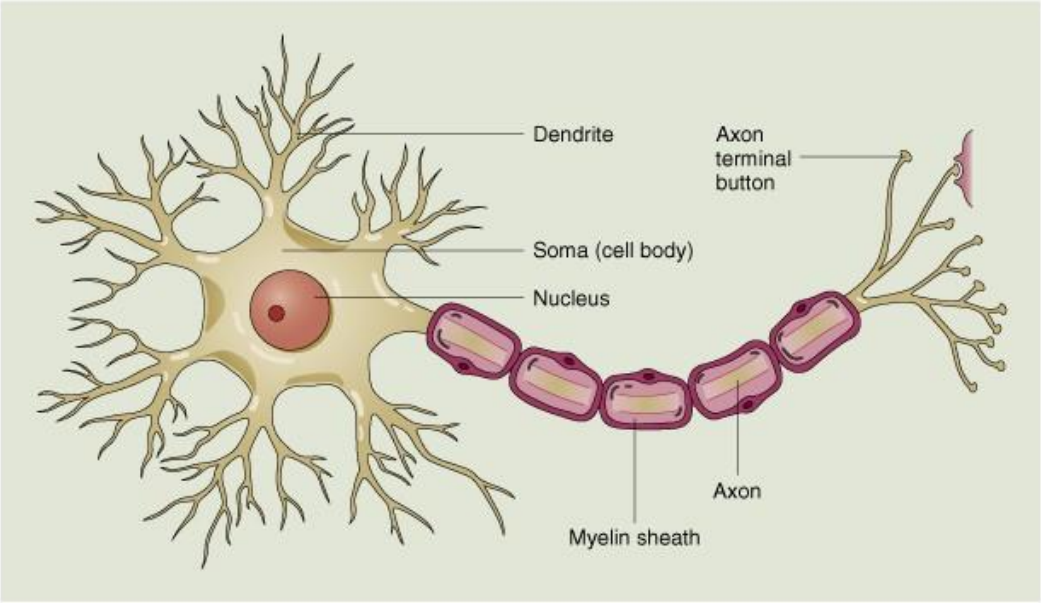
- **Cell nucleus** - contains most of the cell's genetic material organized as DNA molecules
- Cell "machinery"
  - ribosomes - protein production
  - mitochondria – performs metabolic activities, extracts energy from nutrients
  - endoplasmic reticulum – transports newly made proteins to other locations





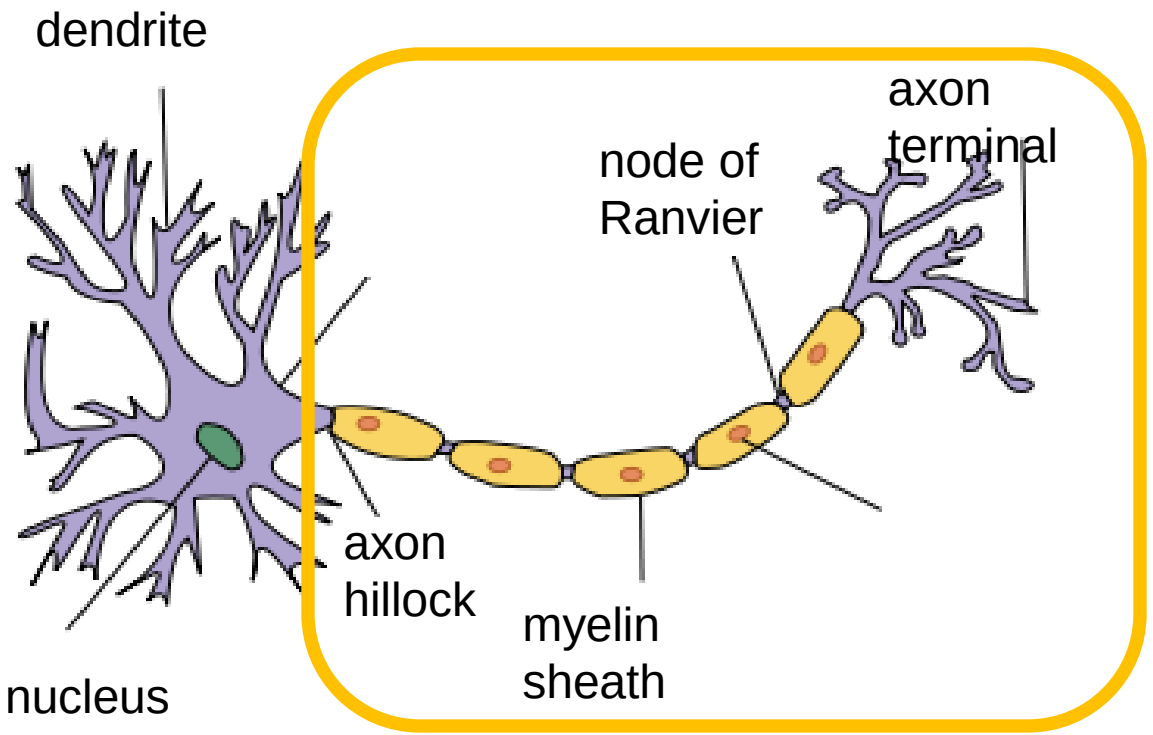
Neuron structure: Dendrites

- **Dendrites** (from Greek ‘tree’) – branching fibers that get narrower at the end
- Dendrites receive information from other neurons via synaptic receptors
- The greater the surface area of a dendrite the more information it can receive



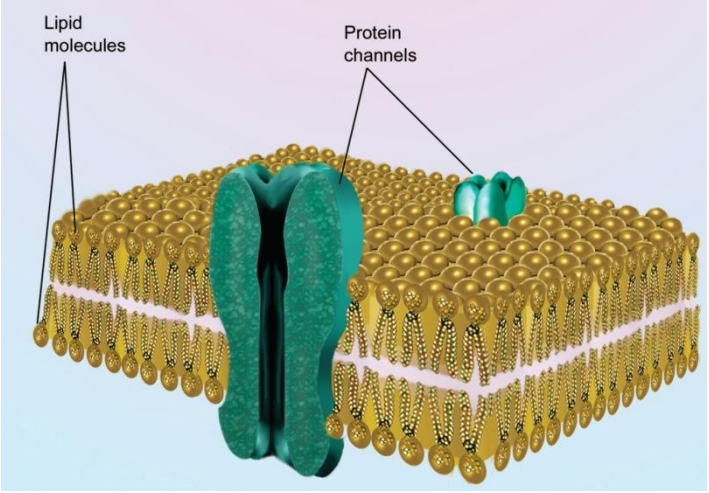
Neuron structure: Axon

- **Axon** – a thin fiber of constant diameter that extends away from the soma and transmits information from the soma to other neurons
  - Main conduction apparatus for carrying signals to other neurons
- Most (vertebrate) axons are covered in **myelin sheaths**



Neuron structure: the edge

- The neuron's edge, **the membrane** (~8 nm thick, made up of lipid molecules and proteins), holds the cell together and separates the neuron form the outside environment

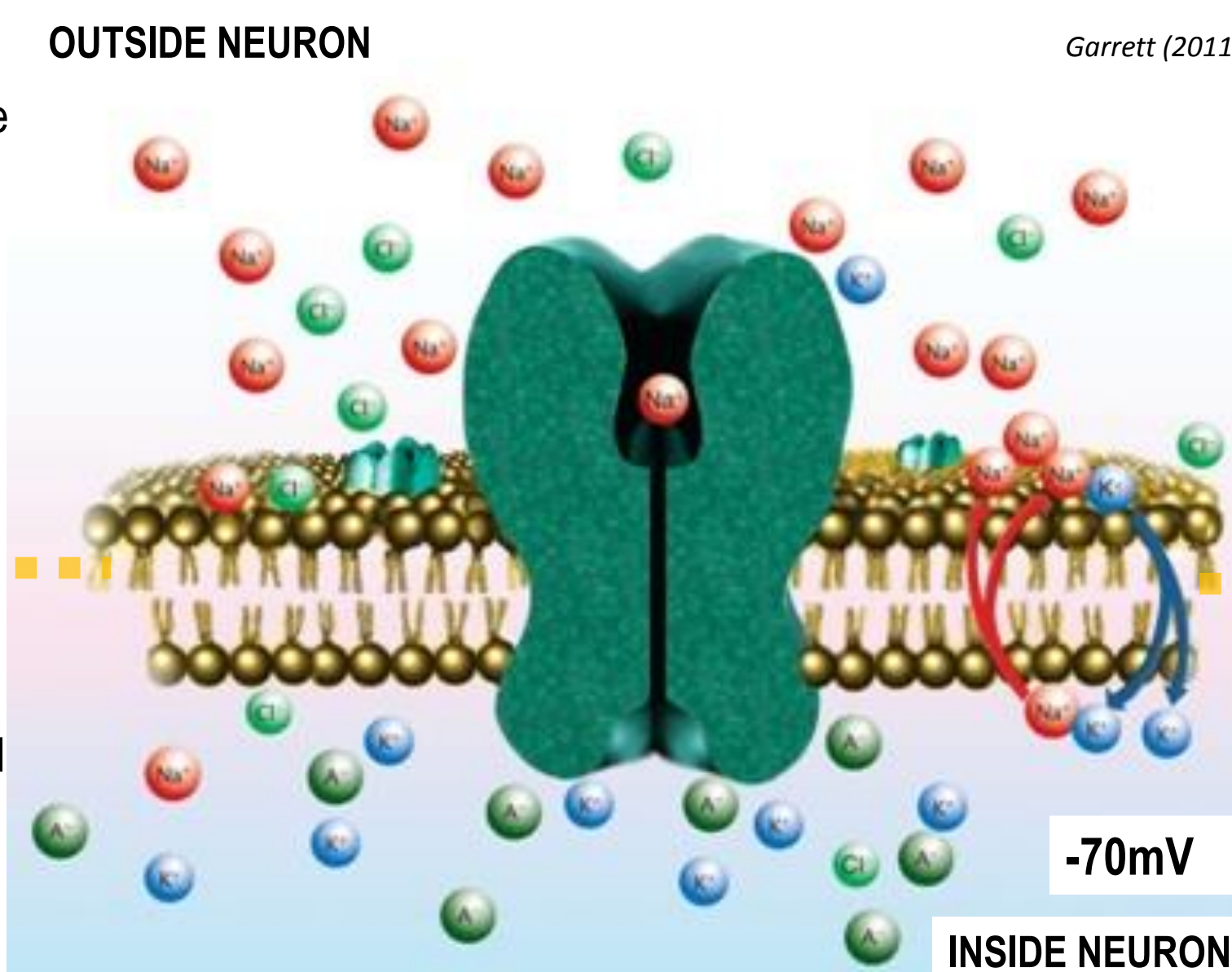


- The membrane is penetrable for small uncharged molecules (water H_2O, oxygen O_2, carbon dioxide CO_2)
- Some charged ions (sodium Na+, potassium K+, calcium Ca+, cloride Cl-) can cross through specialized **protein channels**, e.g. Na+ channels

- Concentration & electrical gradients: Na+ strongly dragged into the cell; K+ more-or-less in balance
- Sodium-potassium pump: 3 Na+ out, 2 K+ in

more Na+ & Cl- outside than inside

- more K+ inside than outside
- **resting potential inside the neuron: -70 mV**



Forces acting on Na+ and K+ ions: summary

- **Force of diffusion** (aka **concentration gradient**): ions move from area of high to low concentration
  - Sodium Na+ is dragged into the cell (little Na+ inside, so Na+ is more likely to enter the cell than to leave it)
  - Potassium K+ is dragged out of the cell
- **Electrostatic pressure** (aka **electrical gradient**): positively-charged ions are dragged to the negative charge (and vice versa)
  - Both sodium Na+ and potassium K+ are dragged into the cell

→ Both gradients want to move Na+ ions into the cell

→ The two gradients almost balance each other out for K+ ions

→ The sodium-potassium pump (3 Na+ out, 2 K+ in) : helps to maintain high concentration of Na+ outside/Ka+ inside

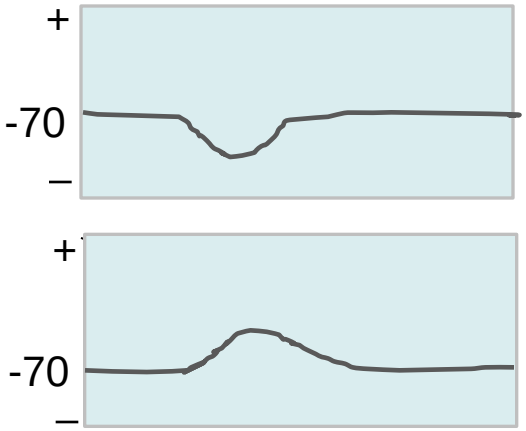
Neuron's resting potential

- The neuron inside the membrane has a more negative electric potential with respect to the outside: **the resting potential** of an unstimulated neuron - approx. **-70 mV** (millivolts)

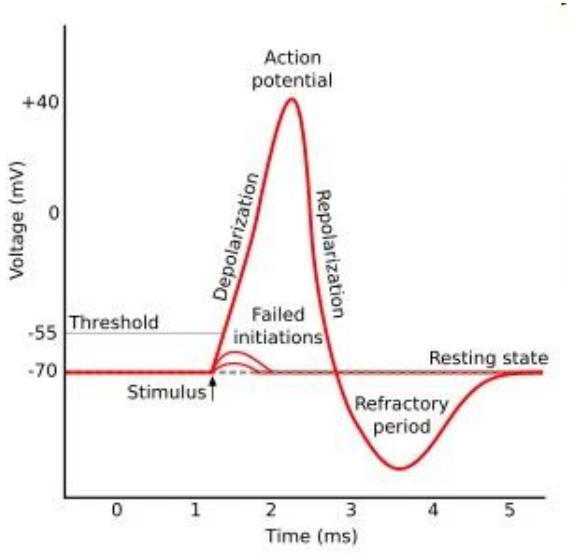
- Q: *Why does a neuron have a resting potential of -70mV (rather than 0)?*
  A: It makes it possible for the neuron to respond quickly and actively to a stimulus (via **an action potential**)

What happens if a neuron is stimulated?

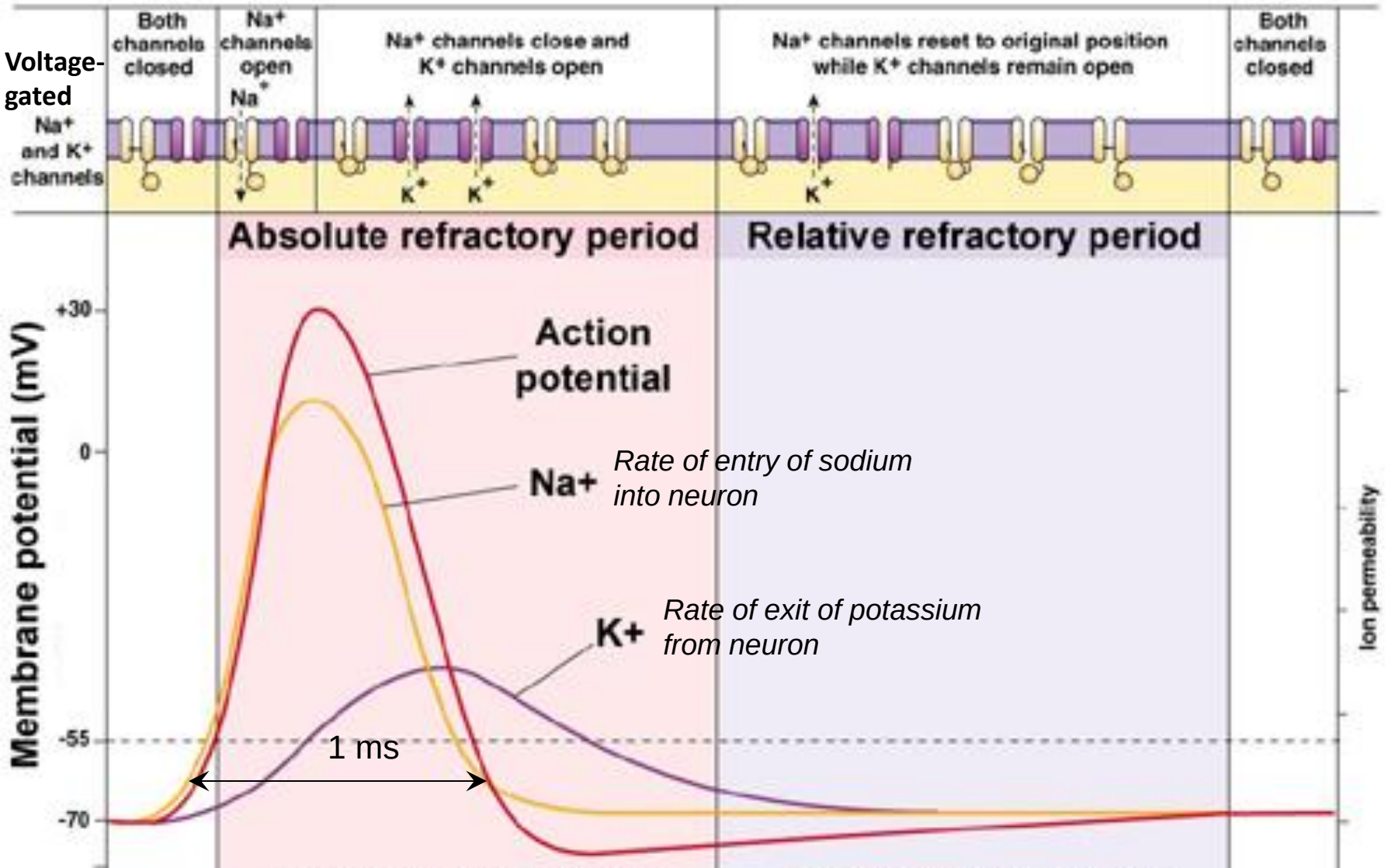
- Stimulation: change of the neuron's membrane potential (in labs – applying current via an electrode; naturally – via synapses)
  - **Hyperpolarization** – increased (even more negative) polarization of the neuron
  - **Depolarization** – reduction of the neuron's polarization towards zero



- If stimulation exceed a certain level – the threshold of excitation (here -55mV) – it produces a sudden, massive depolarization of the membrane (the potential shoots <u>beyond</u> the strength of the stimulus) – **an action potential**



Action potential



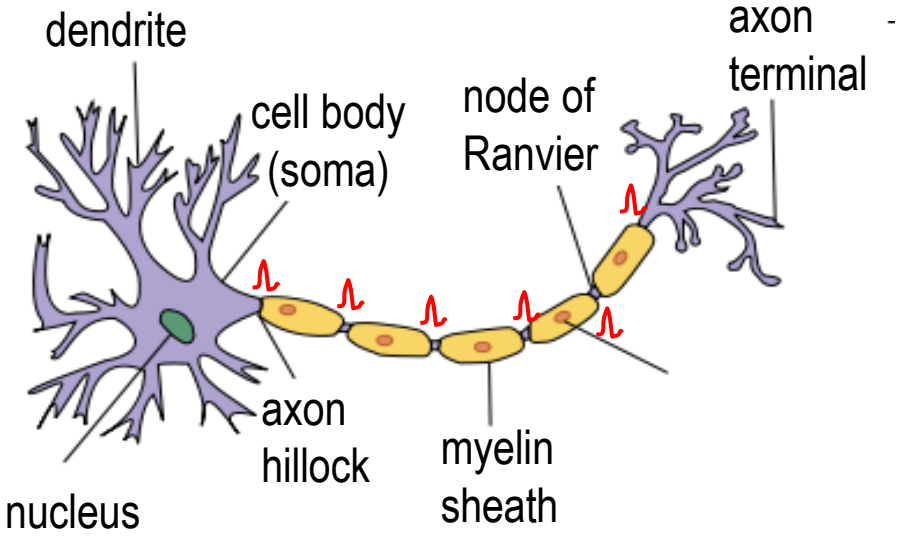
Action potential: “All-or-none” principle

- The amplitude of an action potential is **independent** of the amount of current which produced it, i.e. larger currents do not create larger action potentials
  - The amplitude of an action potential is constant for a given axon (e.g., +40 mV)
- Therefore action potentials are said to be **all-or-none**: they either occur fully or do not occur at all

- How is the intensity of neuron’s stimulation encoded? – *Answer in the lecture on Audition*

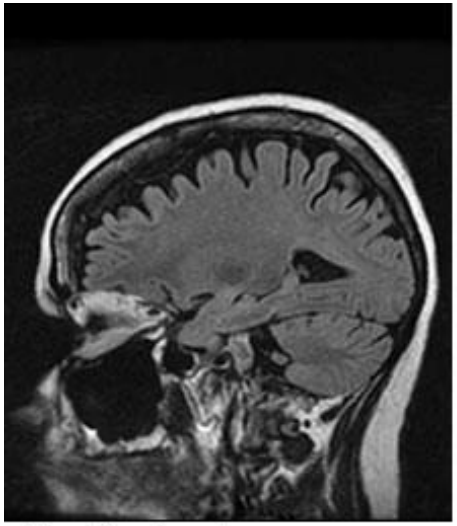
Propagation of action potential

- First action potential – on the axon hillock
- (in a myelinated axon) Action potentials move down an axon towards another cell using **saltatory conduction**
  - action potentials hop along the axon and recur at successive nodes of Ranvier (and thus travel faster)
  - myelin prevents any charge leakage through the axon

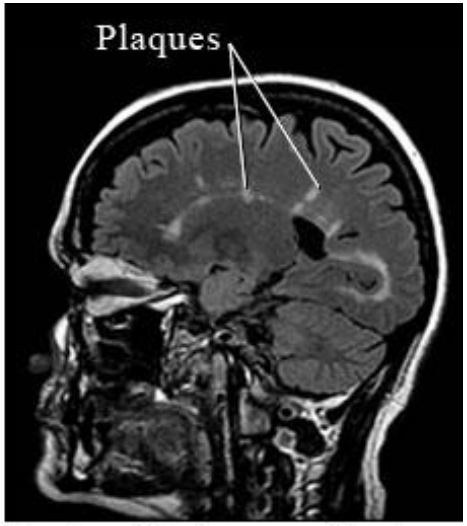


Multiple Sclerosis (MS)

- MS is a neurological condition which affects around 100,000 people in the UK
- Common symptoms: fatigue, vision problems and difficulties with walking
  - Most people are diagnosed between the ages of 20-40
  - More common in women than men (~2:1 ratio)
- Cause: demyelination of axons in the brain and spinal cord



Healthy brain



Brain with damage (lesions or plaques) caused by MS

Multiple Sclerosis Society

Summary

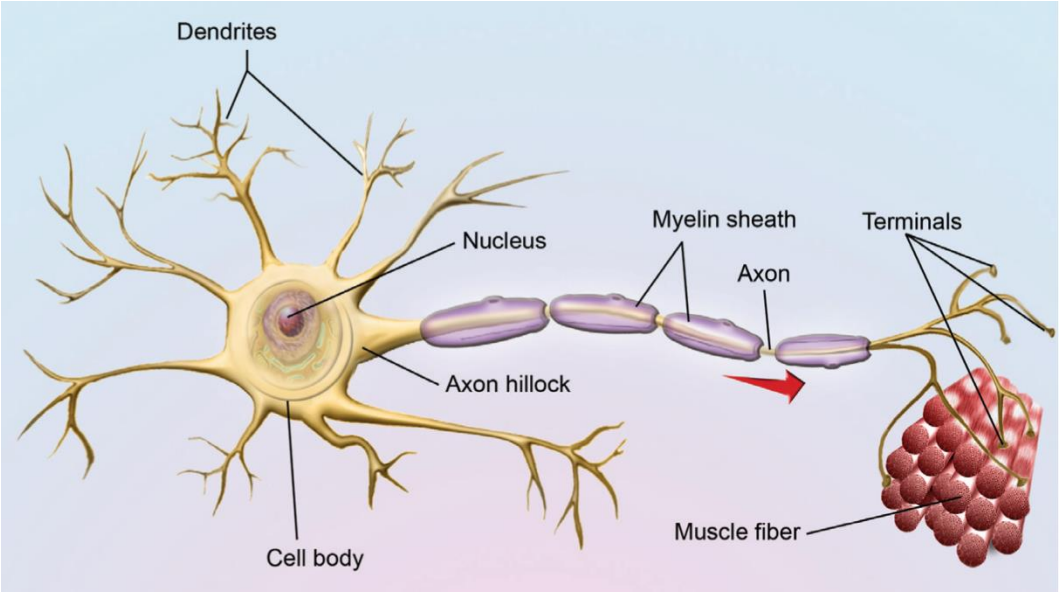
- The nervous system: central nervous system (brain + spinal cord) & peripheral nervous system (the rest)
- The blood-brain barrier (BBB): protects the brain from chemicals carried by the blood
- Two main types of cells in the nervous system: neurons and glia
- Glia perform many important functions
- 3 types of neurons: sensory, motor and interneurons
  - basic structure of a neuron: soma + dendrites + axon
- A stimulated neuron fires an action potential that starts at the axon hillock and propagates along the axon via saltatory conduction

Reading material

- Schacter et al., chapter 3 – **REQUIRED!**
- Kalat, chapter 2
- Further readings:
  - Allen, N. J., & Barres, B. A. (2009). Neuroscience: glia—more than just brain glue. *Nature*, 457(7230), 675-677.
  - Breedlove, S.M., Rosenzweig, M.R., & Watson, N.V. (2009) *Biological Psychology (5th ed.)* Chapter 3 gives much detail on communication within the neuron (see also chapters 2&4)
  - Bear, M.F., Connors, B.W., & Paradiso, M.A. (2006). *Neuroscience: exploring the brain* (3rd edition). Baltimore, MA.
  - Garrett, B. L. (2011). Brain & Behavior: An Introduction to Biological Psychology. Sage. (2nd edition would do too) QP360 GAR

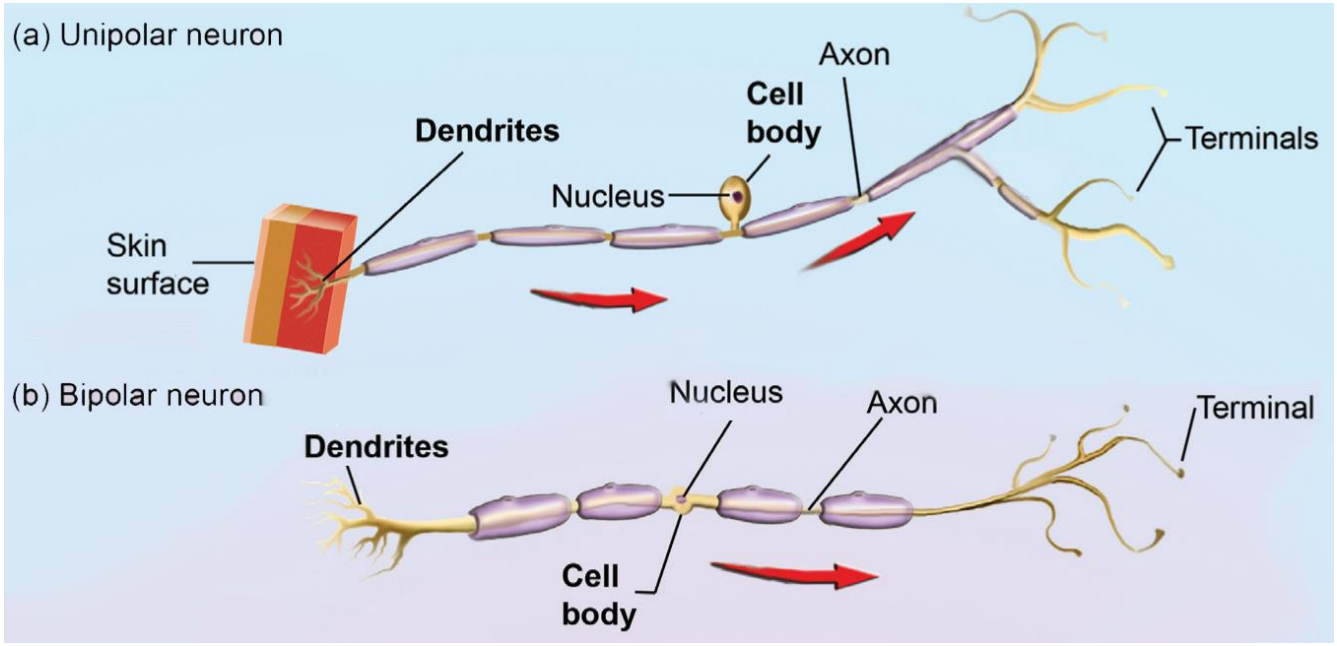
Major types of neurons by function (1)

- 3 major types of neurons by function: motor neurons, sensory neurons & interneurons
- **Motor neurons** – carry signals **away** from the brain/spinal cord to the muscles to produce movement



Major types of neurons by function (2)

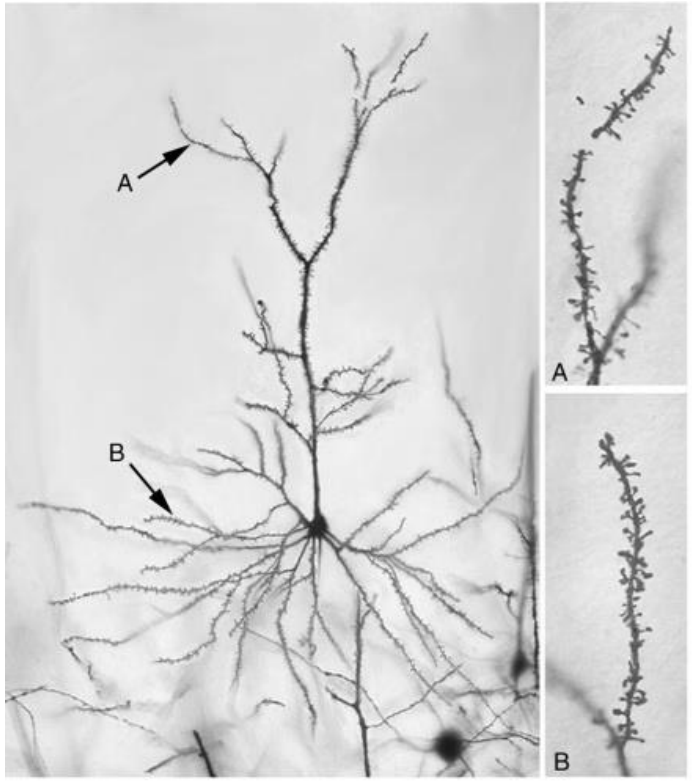
- **Sensory neurons** – carry information from the outside world **into** the brain via the spinal cord
  - Specialised sensory neurons according to 5 senses: light, touch, sound, taste & smell



Major types of neurons by function (3)

- **Interneurons** (most numerous type) – connect sensory neurons, motor neurons or other neurons

Purkinje cell (cerebellum)
Microscope view from http://www.astralgia.com/webportfolio/omnimoment/live_science/purkwrld/index.html)



Pyramidal cell (hippocampus)
Photo from Terry E. Robinson's lab site, Umich
(A,B – dendritic spines)