DP Biology – C2.2 (HL extension)

Action potentials and synapses

- How do neurons produce electrical signals and pass them along?
- How do neurons affect other cells?

HL statements C2.2.8–16. Textbook pp. 479–489.

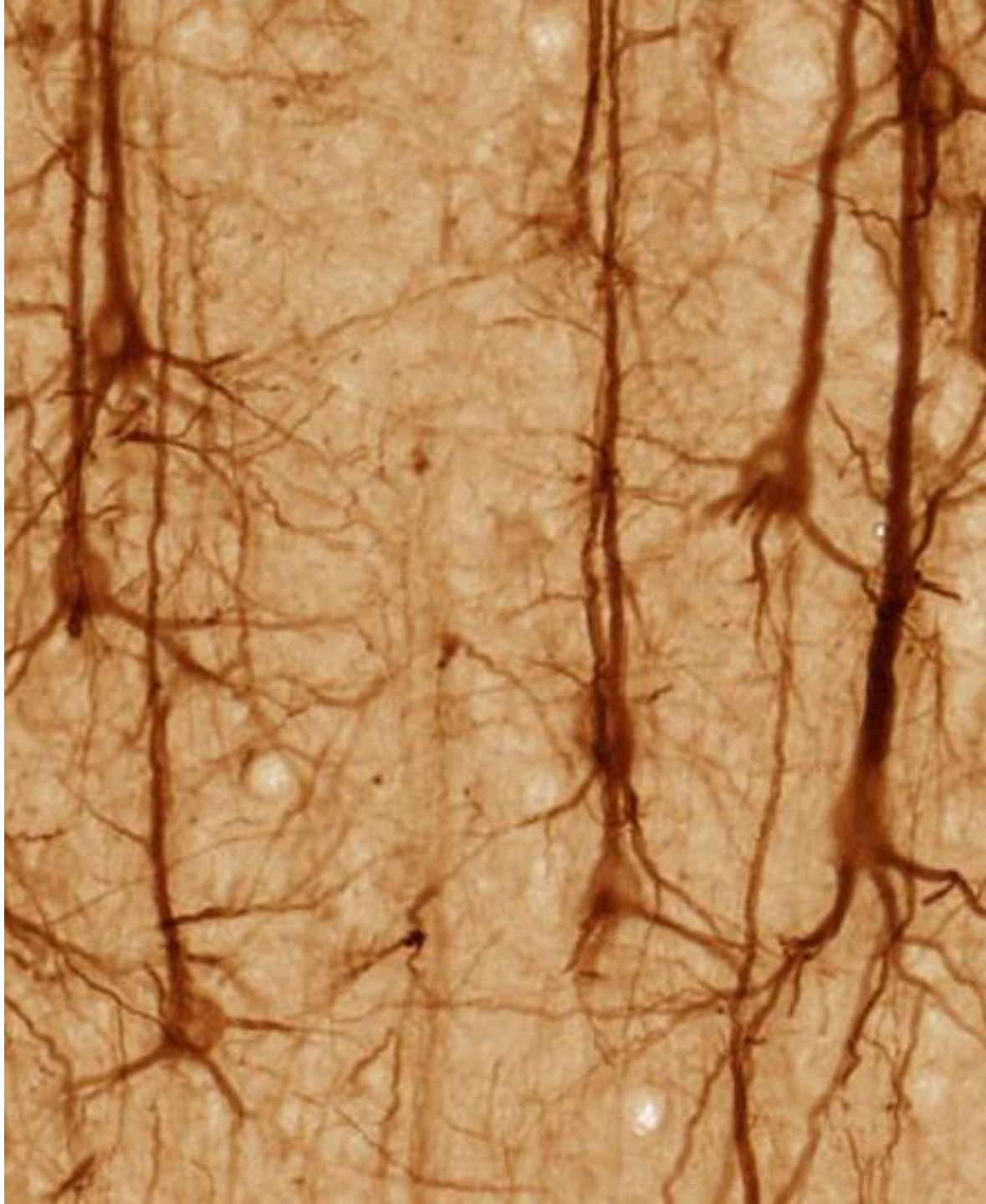


Image: neurons in the cerebral cortex, stained brown. UC Regents Davis campus, CC BY 3.0.

Objectives for each class

Class	Statements	By the end of the class, you can...
1	C2.2.8	Explain depolarization and repolarization by voltage-gated channels and a threshold
2	C2.2.9–10	Explain how local currents propagate an action potential, and read oscilloscope traces
3	C2.2.11–12	Explain saltatory conduction, and how neonicotinoids and cocaine affect synapses
4	C2.2.13–14	Explain inhibitory postsynaptic potentials and summation
5	C2.2.15–16	Explain how pain is detected, and consciousness as an emergent property

An action potential, step by step

C2.2.8



Threshold

Below threshold, too few Na^+ channels open and the membrane returns to rest. At threshold, each opening channel depolarizes the membrane further, opening more: the action potential is all-or-nothing.

After the spike

K^+ channels close slowly, so the potential briefly dips below −70 mV. The sodium-potassium pump then restores the ion gradients. Each action potential moves only a tiny fraction of the ions.

Two voltage-gated channels

C2.2.8

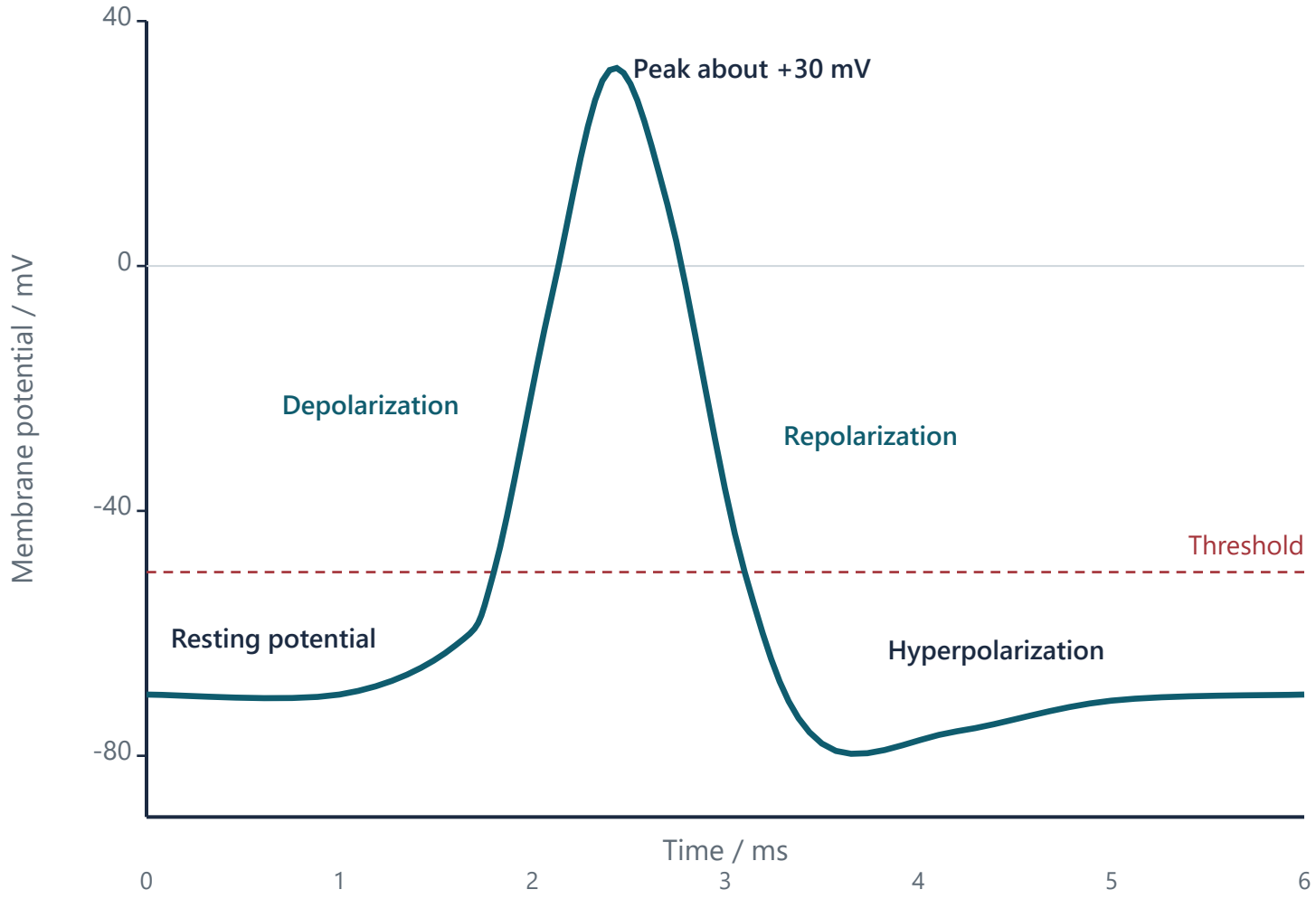
	Voltage-gated Na^+ channel	Voltage-gated K^+ channel
Opens when	Potential reaches threshold (about -50 mV)	Potential reaches its peak (about +30 mV)
Ions move	Na^+ diffuses in	K^+ diffuses out
Effect	Depolarization: inside becomes positive	Repolarization: inside becomes negative again
Closes	Quickly, at the peak	Slowly, after a slight overshoot

Key idea

Both ions move by facilitated diffusion down gradients set up earlier by the pump (C2.2.2).

Reading an oscilloscope trace

C2.2.10



Schematic trace from one point on an axon.

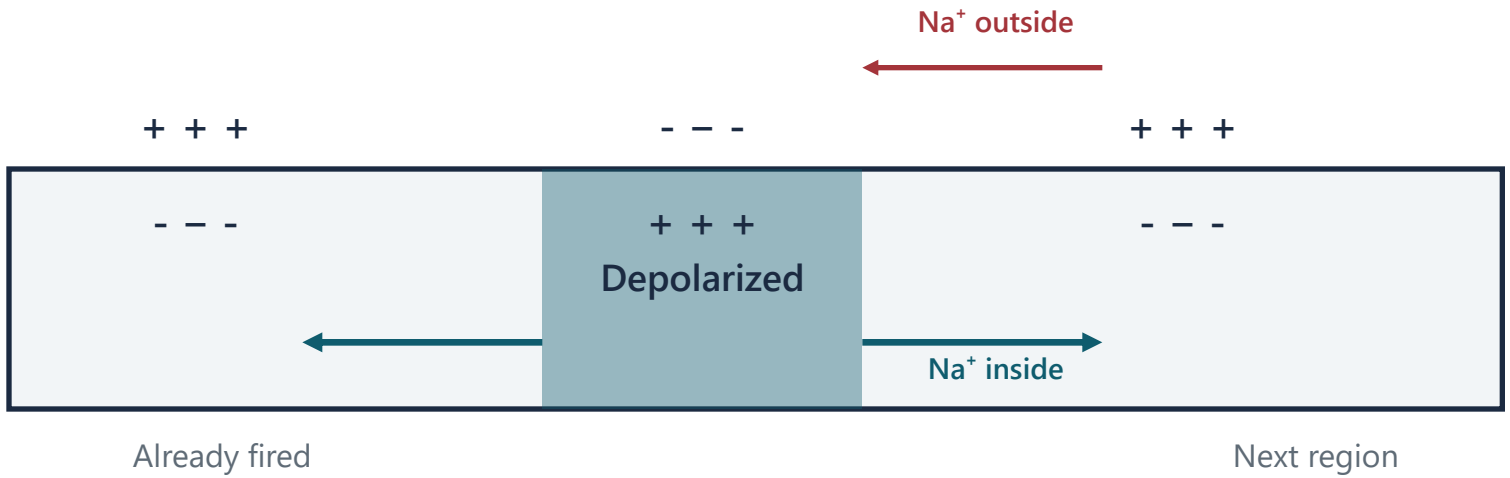
- Microelectrodes inside and outside the axon measure the potential difference
- The oscilloscope plots it against time
- A whole action potential takes about 2 to 3 ms

Try it

Label when Na^+ channels open, when K^+ channels open, and when the pump restores rest.

Local currents carry the impulse

C2.2.9



Simplified axon. + and − show the charge outside (top) and inside (lower row).

- Na^+ that entered diffuses along **inside** the axon to the next region
- Outside, Na^+ diffuses towards the region that lost it
- This raises the next region to **threshold**, so its Na^+ channels open

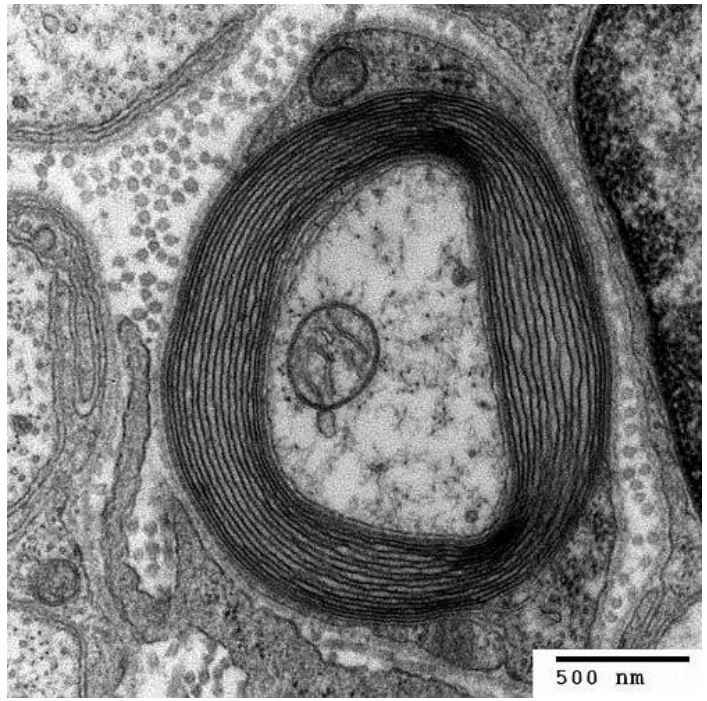
Why one way?

The region that has just fired cannot fire again at once: its Na^+ channels are briefly inactive (the refractory period). So the wave of depolarization, then repolarization, travels only away from the cell body.

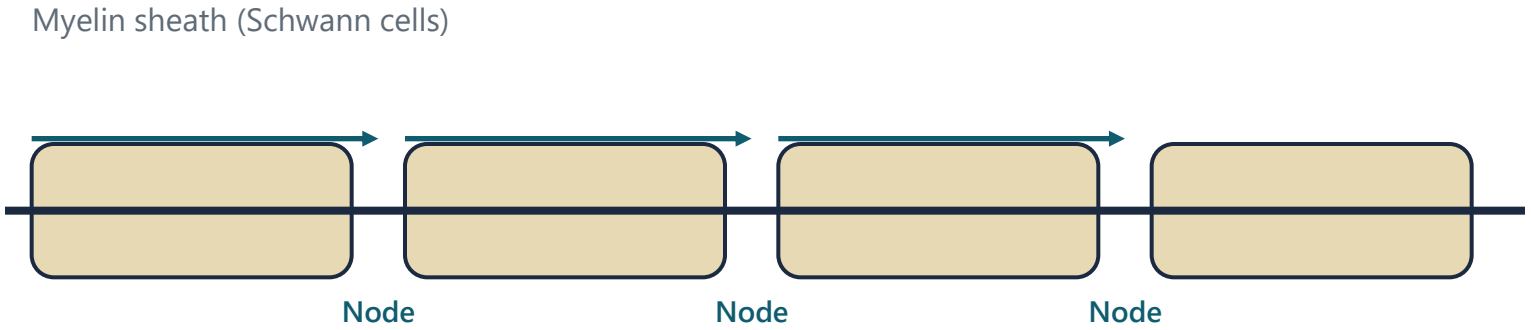
Link

Diffusion (B2.1) explains the spread.

Saltatory conduction



A myelinated axon in section, electron micrograph.
Roadnottaken, CC BY-SA 3.0.



- Myelin insulates the axon, so ions cannot cross the membrane under it
- Pumps and voltage-gated channels are **clustered at the nodes of Ranvier**
- The action potential jumps from node to node: **saltatory** conduction

Axon	Typical speed	Example
Unmyelinated, narrow	About 1 m s^{-1}	Pain fibres (slow ache)
Myelinated, wide	Up to about 100 m s^{-1}	Motor neurons

Neonicotinoids: blocking transmission

C2.2.12



A honey bee feeding. Andreas Trepte, CC BY-SA 2.5.

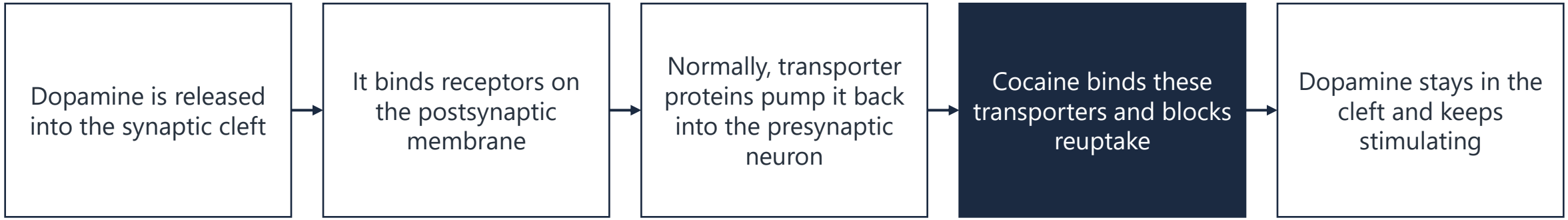
- **Exogenous** chemicals come from outside the body
- Neonicotinoids are pesticides that bind **nicotinic acetylcholine receptors** in insect synapses
- Acetylcholinesterase cannot break them down, so they stay bound
- Receptors are blocked for acetylcholine: transmission fails, causing paralysis and death
- Insect receptors bind them far more strongly than mammal receptors

Debate

Neonicotinoids protect crops, but bees and other pollinators are harmed even by small doses carried in pollen and nectar. Several countries now restrict their outdoor use.

Cocaine: blocking reuptake

C2.2.12



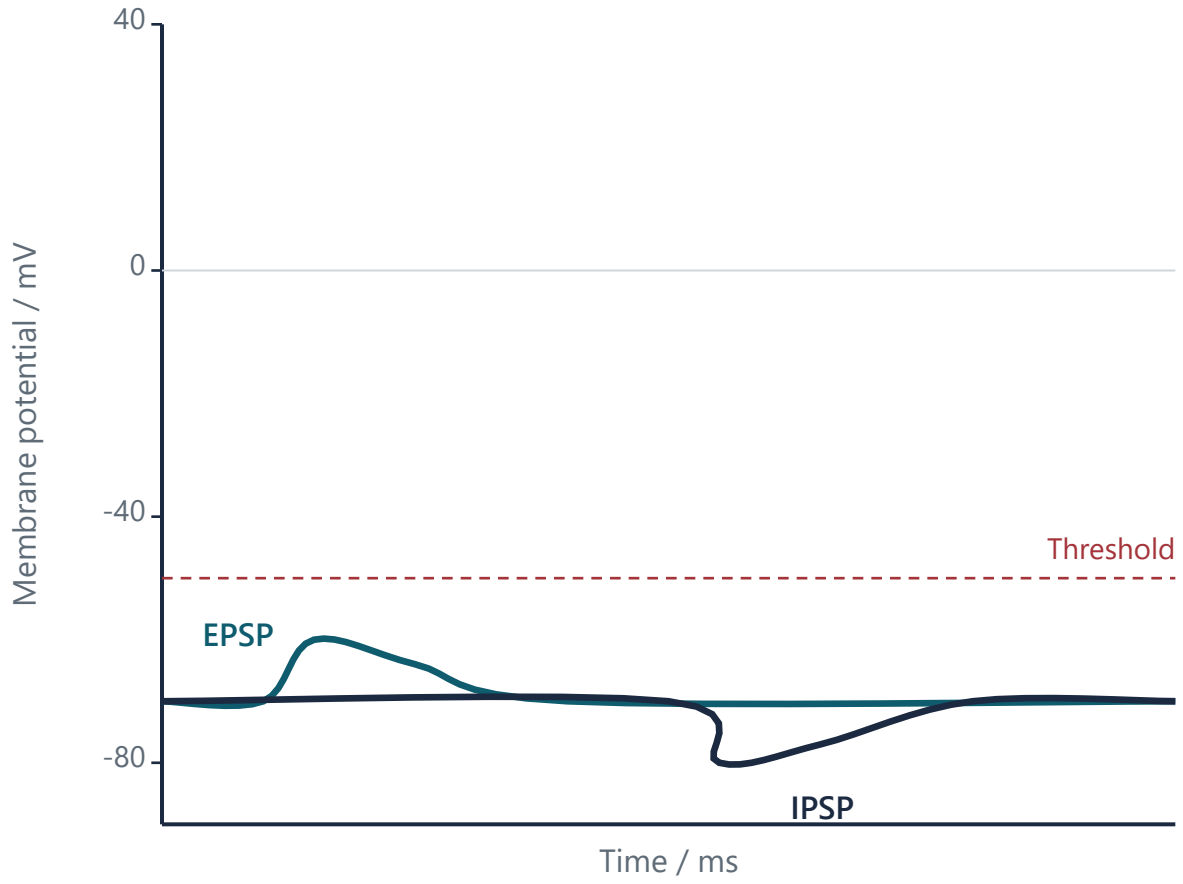
Effects

Strong feelings of pleasure, energy and alertness. Over time, the brain makes fewer dopamine receptors, so more drug is needed and normal pleasures feel flat: this helps explain addiction.

Compare

Neonicotinoids act on the receptor; cocaine acts on reuptake. Both change how strongly and how long a synapse signals. Make a table of the two.

Inhibitory postsynaptic potentials

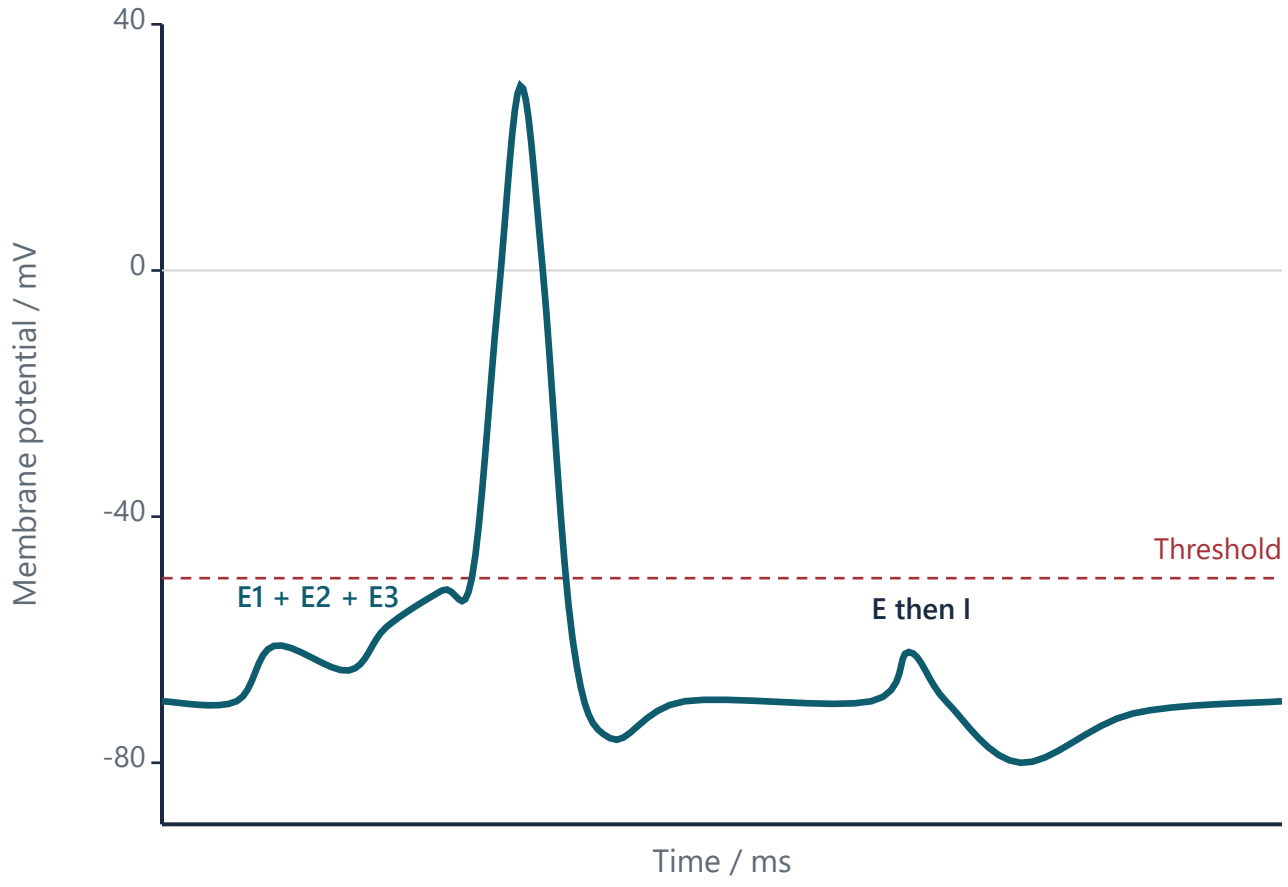


Schematic traces from the postsynaptic membrane.

- Some neurotransmitters, such as **GABA**, are inhibitory
- They open channels that let chloride ions in or K^+ out
- The inside becomes **more negative**: the membrane is **hyperpolarized**
- This is an inhibitory postsynaptic potential (IPSP)
- It moves the membrane further from threshold, so an action potential is less likely

Summation

C2.2.14



Schematic trace at the start of a postsynaptic axon. E: excitatory input. I: inhibitory input.

- One neuron receives inputs from many presynaptic neurons
- EPSPs and IPSPs are added together where the axon begins
- Many EPSPs close together reach threshold: an action potential fires
- IPSPs cancel EPSPs, so no action potential
- The output is all-or-nothing

Why it matters

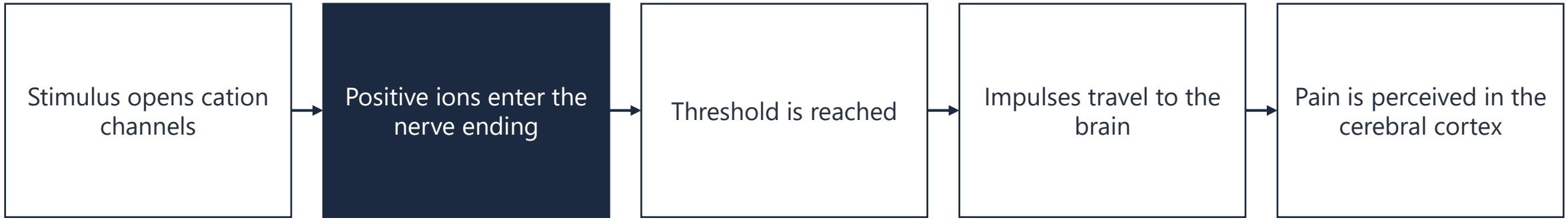
Summation lets neurons integrate information and make decisions.

Detecting pain

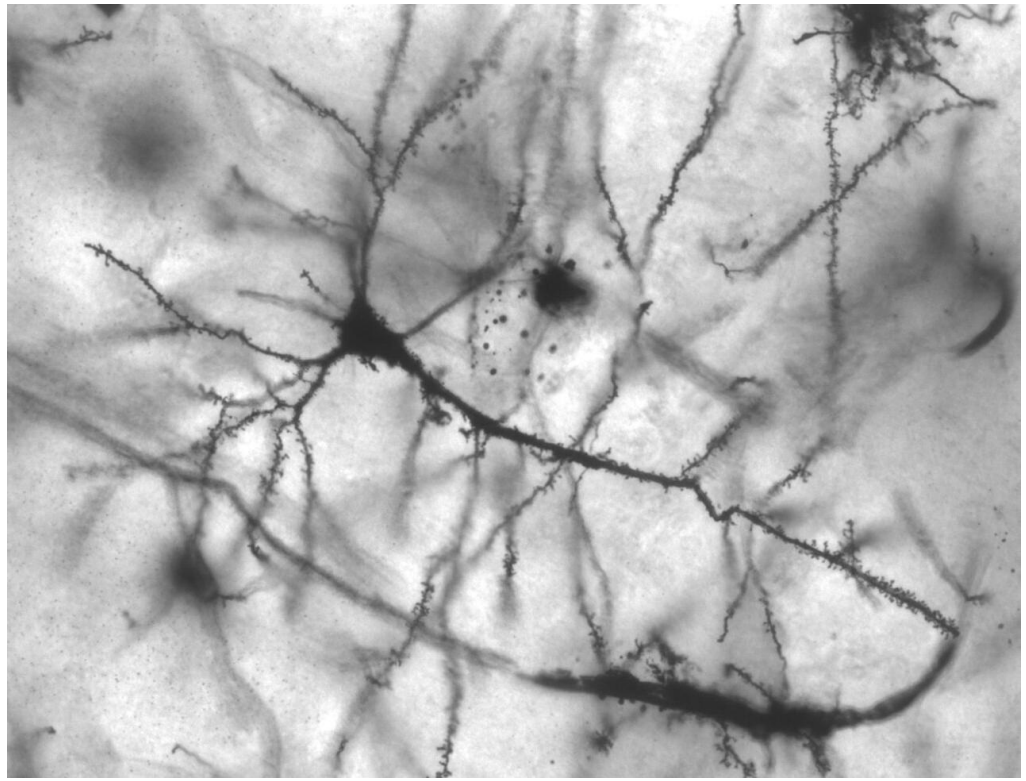


Chilli peppers contain capsaicin. Daniel Risacher, CC BY-SA 3.0.

- Pain receptors are **free nerve endings** of sensory neurons in the skin
- Their membranes have channels for positive ions
- The channels open in response to high temperature, acid, or chemicals such as **capsaicin**
- One channel protein responds both to heat and to capsaicin: that is why chilli feels hot



Consciousness as an emergent property



Pyramidal neurons, light micrograph. MethoxyRoxy, CC BY-SA 2.5.

- Consciousness is awareness of ourselves and our surroundings
- No single neuron is conscious
- It **emerges** from the interactions of billions of neurons linked by trillions of synapses
- Emergent properties appear at one level of organization that are absent from the parts

Think about it

Other emergent properties: a beating heart from cardiac cells, the behaviour of an ant colony. How could anyone test whether an animal, or a machine, is conscious?

Check that you can explain

1. How voltage-gated Na^+ and K^+ channels cause depolarization and repolarization
2. Why a threshold must be reached
3. How local currents propagate an action potential
4. How to read an oscilloscope trace
5. Why saltatory conduction is faster
6. How neonicotinoids and cocaine affect synapses
7. How inhibitory neurotransmitters hyperpolarize the membrane, and how summation works
8. How free nerve endings detect pain, and why consciousness is an emergent property

Exit activity: 5 minutes

On your own and without notes. Hand this in as you leave.

1. State the effect of opening voltage-gated K^+ channels.
2. Explain why impulses travel faster in myelinated axons.
3. Explain how cocaine affects a dopamine synapse.

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