The Membrane Voltage

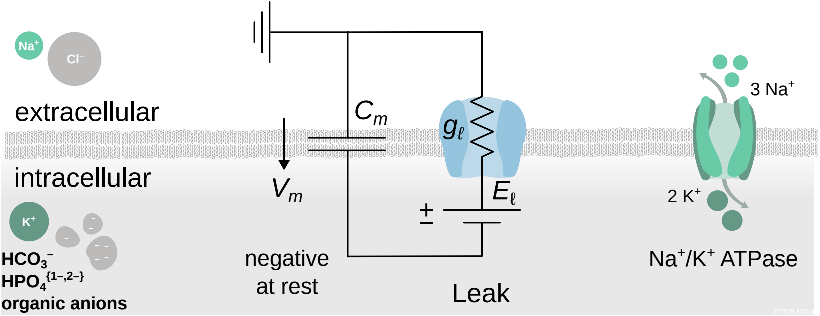
Neurons are excitable cells

Computational Neuroscience
University of Bristol

M Rule

Learning outcomes:

- The effective RC circuit for passive membrane



Na^+
Cl^-
extracellular
intracellular
K^+
HCO_3^-
$HPO_4^{\{1-,2-\}}$
organic anions
C_m
V_m
negative
at rest
g_ℓ
E_ℓ
±
Leak
3 Na^+
2 K^+
Na^+/K^+ ATPase

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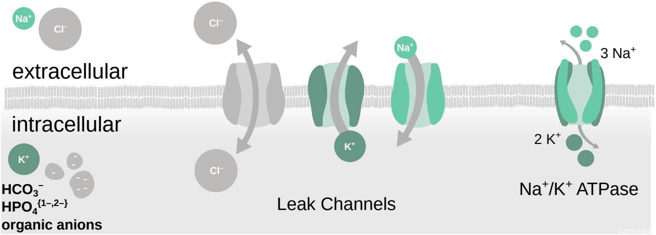
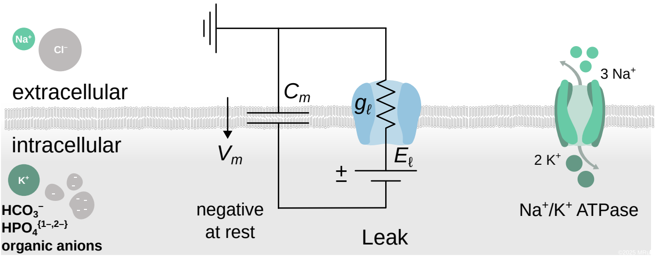
Remember these?

$V = IR$	Ohm's law
$I = gV$	Ohm's law, conductance form
$I = C\dot{v}(t)$	Definition of capacitence



$$C_m \dot{v} = g_\ell (E_\ell - v)$$

$C_m =$	100×10^{-12}	Farads	(100 picofarads)	**cell membrane capacitance**
$E_\ell =$	-70×10^{-3}	Volts	(-70 millivolts)	**resting potential**
$g_\ell =$	10×10^{-9}	Siemens	(10 nanosiemens)	**leak conductance**



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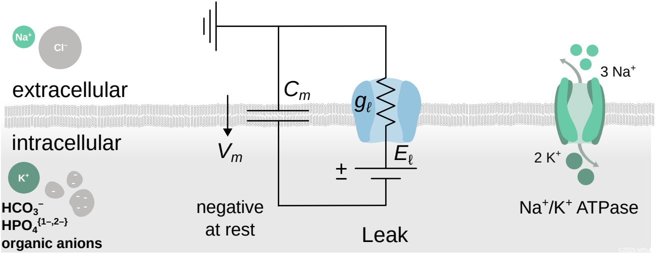
Plausible (albeit invented) numbers for a cortical pyramidal cell neuron

ΔV: arrow tip − arrow base



$$C_m \dot{v} = g_\ell (E_\ell - v)$$

$$\tau_m \dot{v} = E_\ell - v$$

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$R_m = 1/g_\ell = 100\times 10^{6}$	Ohms	(100 megaohms)	**membrane resistance**
$\tau_m = r_m C_m = 10\times 10^{-3}$	seconds	(10 milliseconds)	**membrane time constant**

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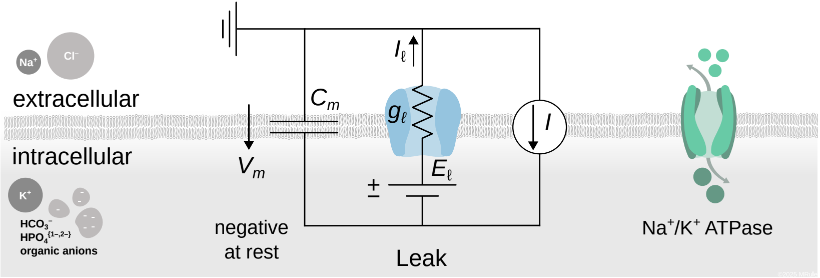
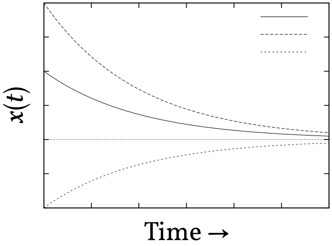
Model: A neuron with applied current



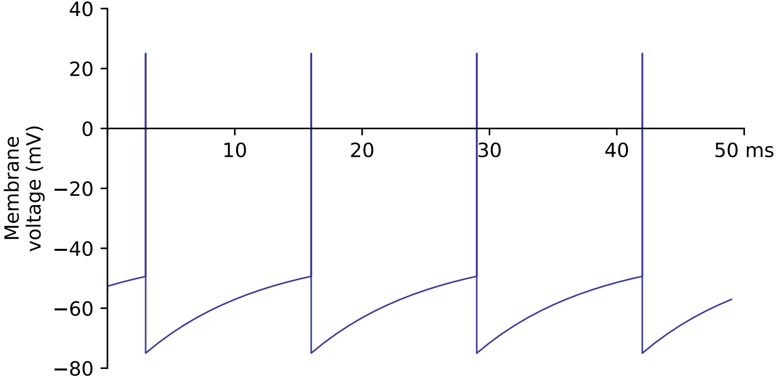
$$\tau_m \dot{v} = E_\ell - v + I$$

When is the previous model good? When is it bad?

Manually plot and solve some examples



$x(t)$
Time →



40
20
0
−20
−40
−60
−80
Membrane voltage (mV)
10
20
30
40
50 ms

Jargon

depolarize v_m increases

repolarize v_m decreases towards resting potential

hyperpolarize v_m is driven below resting potential

Sign conventions

Let $v_m = v_{\text{interior}} - v_{\text{exterior}}$ denote a neuron's membrane voltage

A positive current applied to a neuron makes v_m _____?

- ***Engineer:*** increase
- ***Electrophysiologst:*** decrease!

Compromise:

- **inward current** makes the voltage inside the cell more positive, relative to the outside
- **outward current** makes the voltage inside the cell more negative, relative to the outside

remind them that inward flux of negative, e.g. Cl^-, ions makes a outward current *end*