Ionic Current

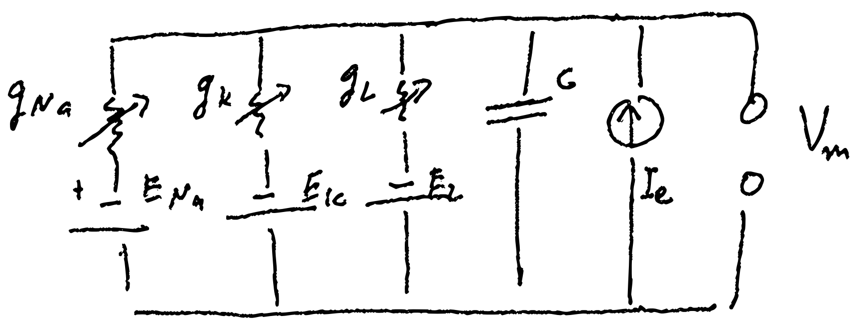
18th Nov 2020

Lecturer : Michale Fee

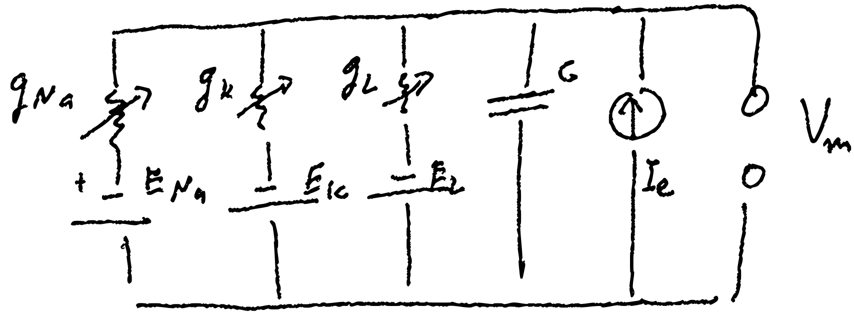
* Silicon neural pixels can record brain activities.
* How to find correlation in large datasets.

Song birds listen and imitate their parents. so they can memories and practice.

Math of neuron



- Neurons are very complicated
- Different neurons are defined by the genes that are expressed.
- Different neurons also have different morphology, the spacial properties also shape how a neuron behaves.



Ions flow by two methods:

- Diffusion
- Drift in an electric field

Thermal energy:

* Every way a particle come to equilibrium that is proportional to the temperature.

The constant is Boltzmann constant

$$\boxed{kT = 4 \times 10^{-21} \text{ Joules at } 300\,k}$$

kinetic energy: $\left\langle \frac{1}{2} m v_x^2 \right\rangle = \frac{1}{2} kT$

The mass of a sodium ion is 3.8×10^{-6} kg

$\rightarrow \bar{v}_x = 3.2 \times 10^2 \, m/s$

In a solution the particles are crashing into each other. A particle in a solution collides with a water molecule are 10^{13} times per second.

* an ion can diffuse across a cell body $10\mu m$ in 50ms
* to diffuse down a dendrite (1mm) takes around 10 mins.
* for 1m long motor neuron takes 10 years!!

<u>Random Walk 1D</u>

Consider a particle moving $\leftarrow$ or $\rightarrow$ at V_x for a time τ before a collision.

If we have N particle, the i^{th} particle position is $x_i(n)$. Let $\delta = \pm V_x \tau$

$n = t/\tau$

$$x_i(n) = x_i(n-1) \pm \delta$$

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$$\langle x_i(n) \rangle = \frac{1}{N} \sum_i x(n) \quad \text{average}$$

$$= \frac{1}{N} \sum_i x_i(n-1) + \frac{1}{N} \cancel{\sum_i (\pm\delta)}^{\,0}$$

$$\langle x_i(n) \rangle = \langle x_i(n-1) \rangle_i$$

or center of the distribution is the same.

$$\langle |x(n)| \rangle = \sqrt{\langle x^2(n) \rangle}$$

$$= \frac{1}{N} \sum_i x_i^{2}(n)$$

$$= \frac{1}{N} \sum_i x_i^2(n-1) \pm 2\delta x_i(n-1) + \delta^2$$

$$= \langle x^2(n-1) \rangle + \cancel{\langle \pm 2\delta x(n-1) \rangle}^{\,0} + \langle \delta^2 \rangle$$

$$= \langle x^2(n-1) \rangle + \delta^2$$

At each t the variance grows at δ^2.

$\langle x^2(0) \rangle = 0$, $\langle x^2(1) \rangle = \delta^2$, $\langle x^2(2) \rangle = 2\delta^2$

$$\rightarrow \langle x^2(n) \rangle = \cancel{\langle\delta^2} \; n\,\delta^2$$

$$\langle x^2(t) \rangle = \frac{t}{\tau} \delta^2$$

$$\langle x_i^2 \rangle = 2Dt \qquad D = \frac{\delta^2}{2\tau} \quad \text{diffusion coefficient.}$$

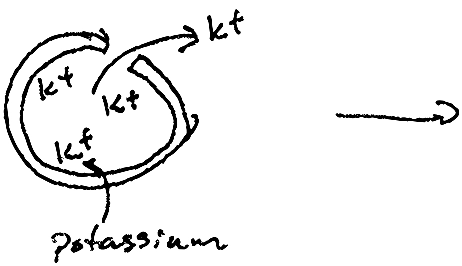
Spatial and t scales

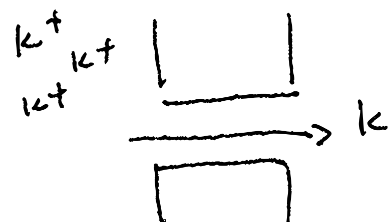
Diffusion at short distances is fast but slow at large distances.

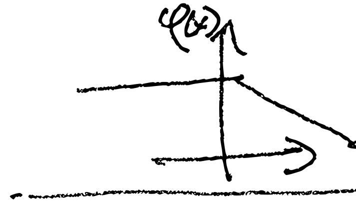
Fick's first law

- Produces a net flow from area of high concentration to lower.

$$\boxed{J_x = -D \frac{\partial c}{\partial x}}$$ concentration

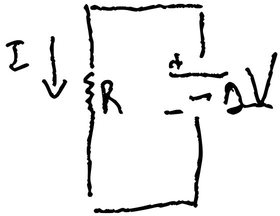




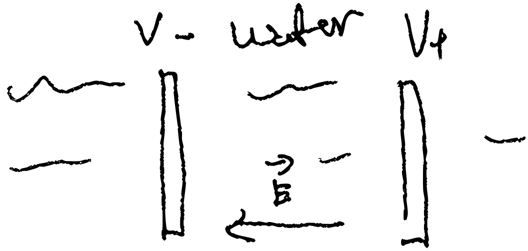


$J_x = -D \frac{\partial c}{\partial x}$

In a circuit current is $\propto$ to voltage diff^n.



$$\Delta V = I R$$
$$\rightarrow I = \frac{\Delta V}{R}$$



$$E = \frac{\Delta V}{L}$$

- $\vec{F} = q\vec{E}$ is going to drag the particle through the liquid.

- $\vec{F} = f\vec{v}_d$ $\qquad f = k\frac{T}{D}$ frictional coefficient

The drift velocity $\vec{v}_d = \frac{D}{kT}\vec{F} = \frac{D}{kT}\vec{E}$

- $I \propto v_d A$ and $I \propto E A = \frac{\Delta V}{L} A$

$\rightarrow \quad I \propto \left(\frac{1}{\rho}\right)\frac{\Delta V}{L} A \qquad \rho =$ resistivity (Ωm).

$$\boxed{I = \left(\frac{A}{\rho L}\right)\Delta V \rightarrow R = \frac{\rho L}{A}.}$$

$\rho = 1.6\,\mu\Omega\,cm$ copper

$\rho = 60\,\Omega\,cm$ for mammalian saline.

→ Need huge Voltage to diffuse a small current. Thats why the brain ~~cave~~ created the axon.