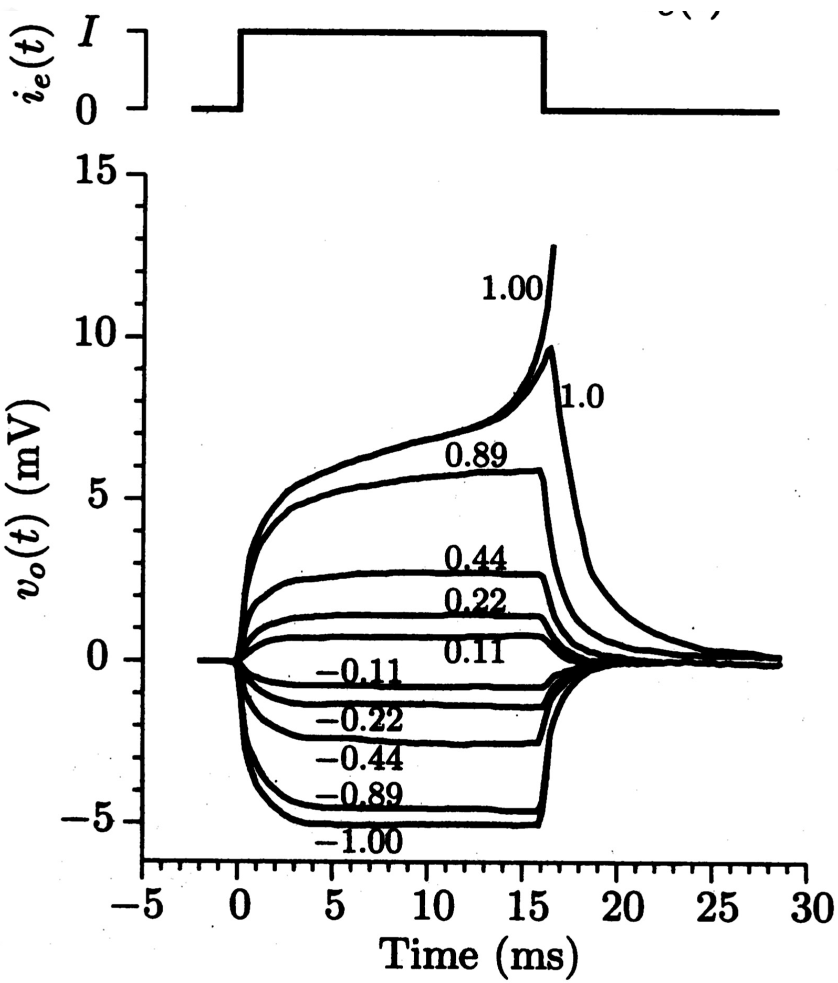
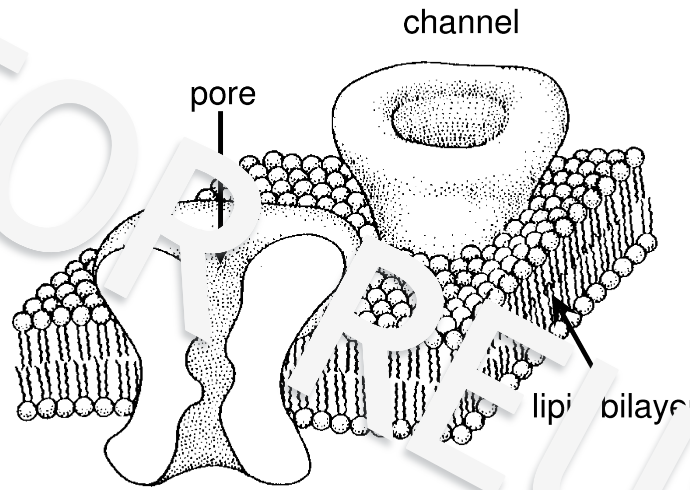
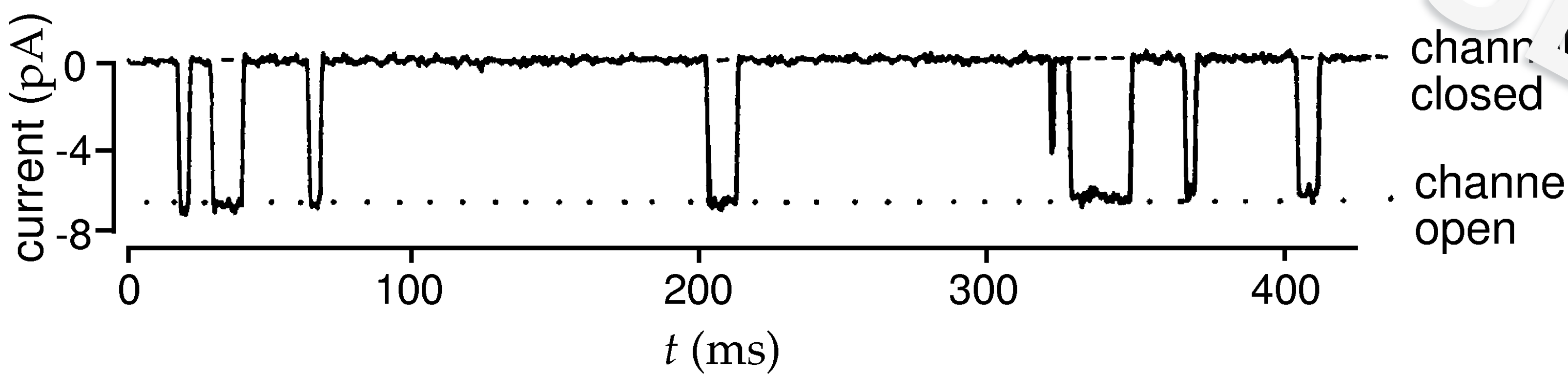
But what makes a neuron *compute*?



Excitability arises from ion channel nonlinearity

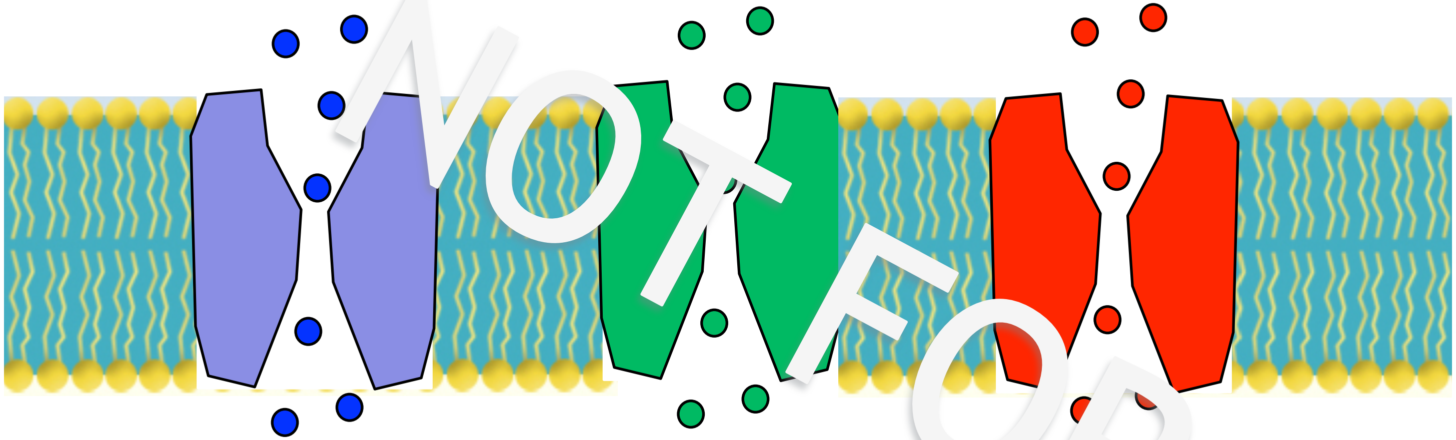
- voltage dependent
- transmitter dependent (synaptic)
- Ca dependent
- mechanosensitive



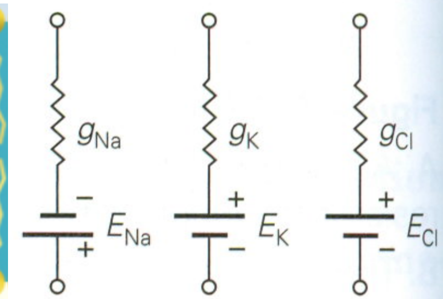


Best pics are all from Dayan and Abbott, *Theoretical Neuroscience*

Parallel paths for different ions to cross membrane

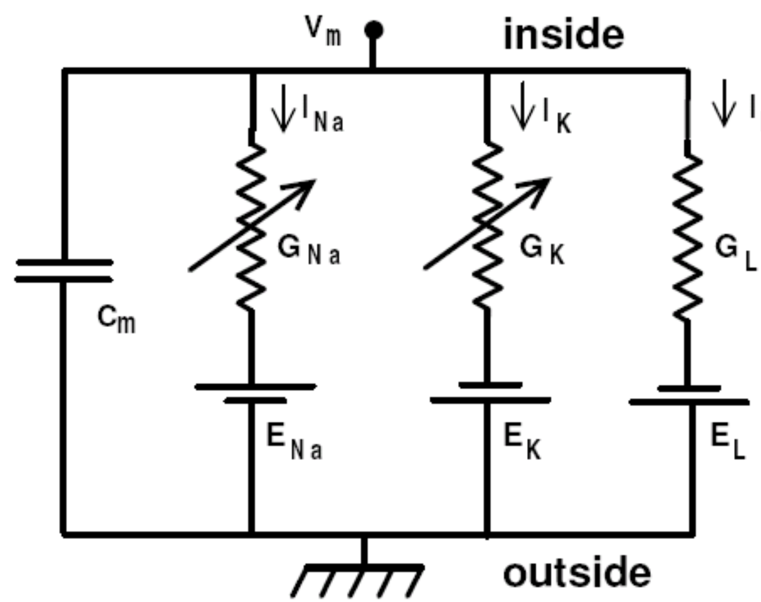


$$I_i = g_i\,(V\text{-}E_i)$$



New equivalent circuit:

Variable conductance

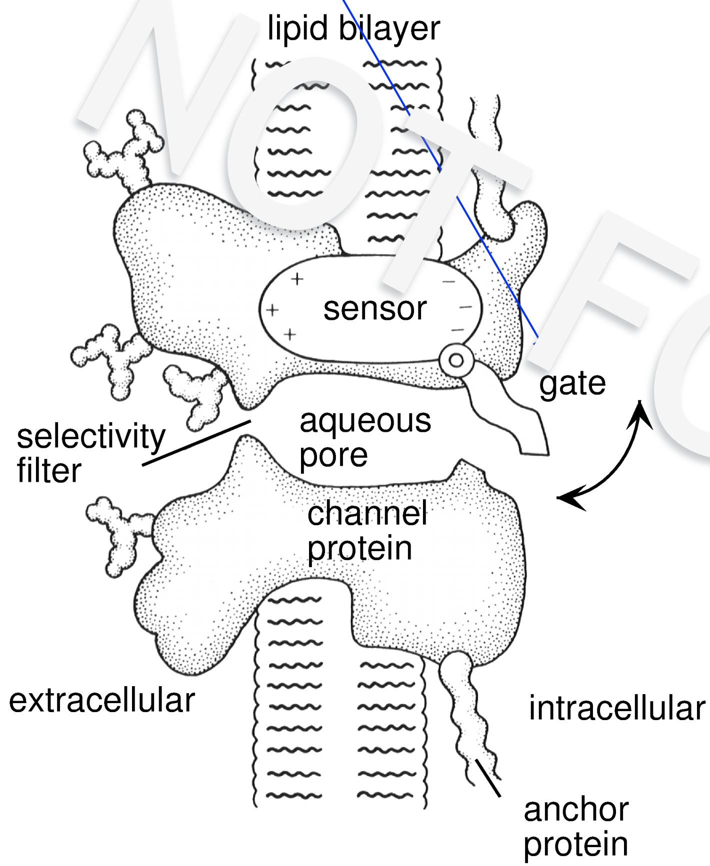


The ion channel is a cool molecular machine

K channel: open probability increases when depolarized

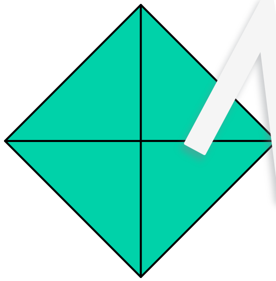
Gating depends on subunit state

$\boxed{P_K \sim n^4}$



Persistent conductance

The ion channel is a cool molecular machine

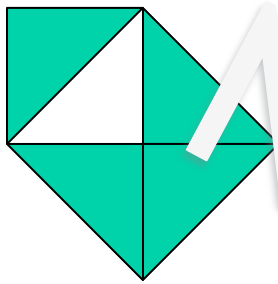


n describes a subunit

n	is open probability
$1 - n$	is closed probability

This picture is not from Dayan and Abbott, for instance

The ion channel is a cool molecular machine



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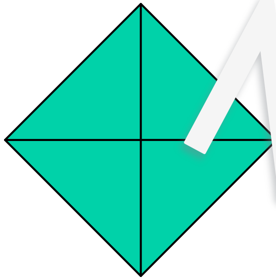

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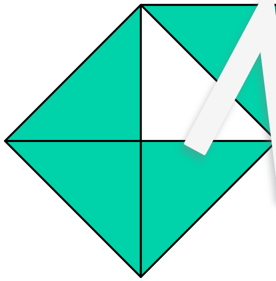
The ion channel is a cool molecular machine



n describes a subunit

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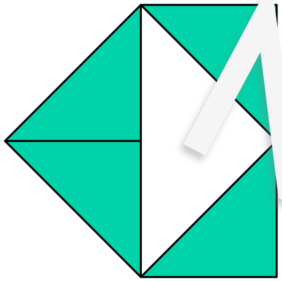
The ion channel is a cool molecular machine



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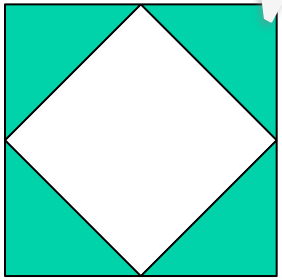
The ion channel is a cool molecular machine



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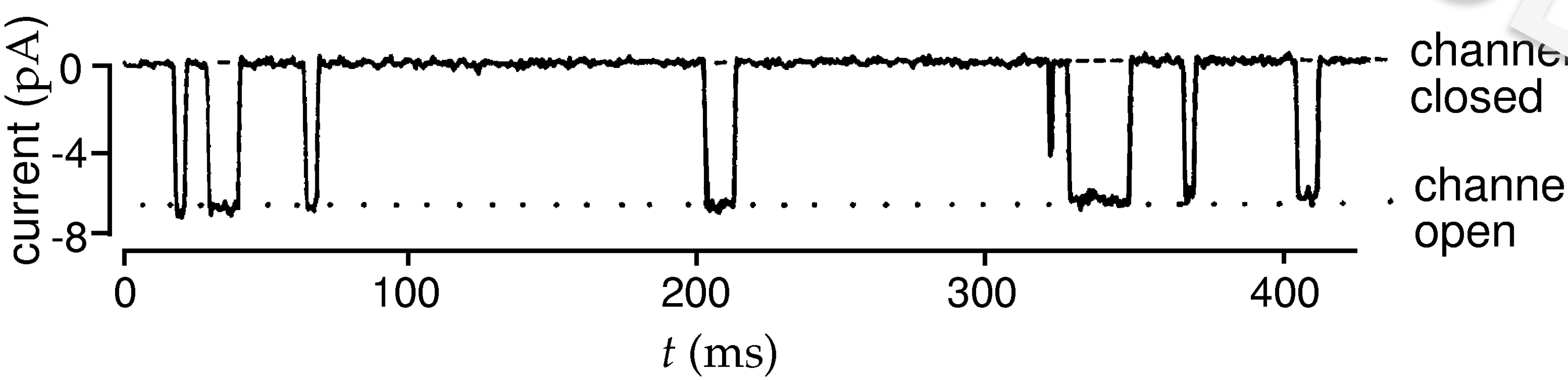
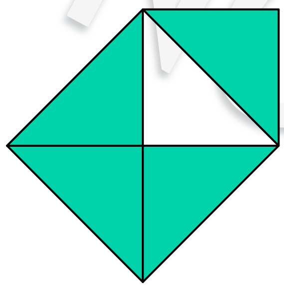
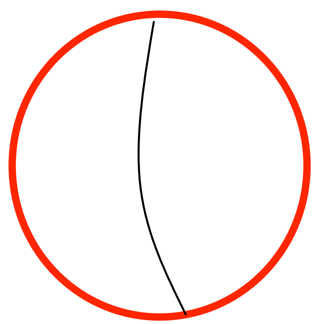
$\boxed{P_K \sim n^4}$



The ion channel is a cool molecular machine





n describes a subunit

n	is open probability
$1 - n$	is closed probability

Transitions between states occur at voltage dependent rates

$\alpha_n(V)$	C → O
$\beta_n(V)$	O → C

$$\boxed{\frac{dn}{dt} = \alpha_n(V)(1-n) - \beta_n(V)n}$$

Dynamics of activation: persistent conductance

$$\frac{dn}{dt} = \alpha_n(V)(1-n) - \beta_n(V)n$$

We can rewrite:

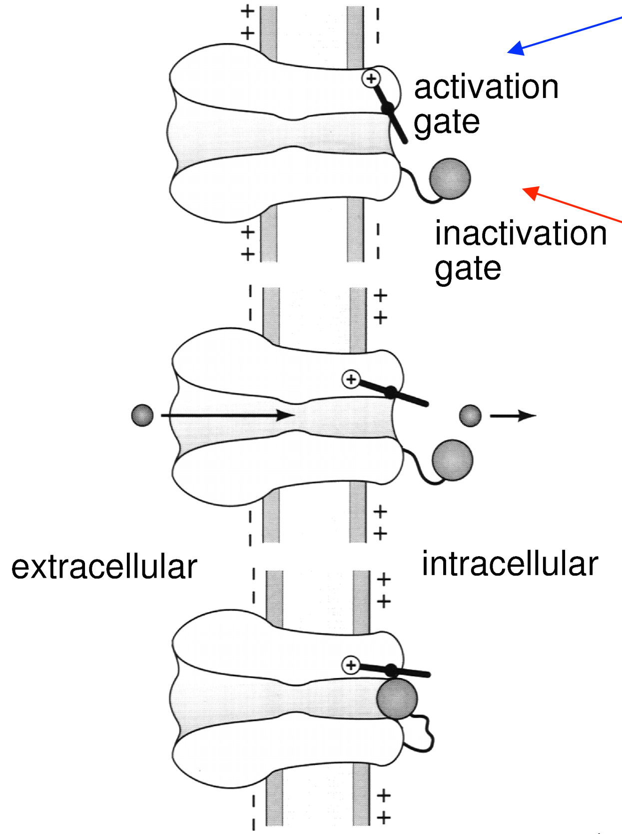
$$\tau_n(V)\frac{dn}{dt} = n_\infty(V) - n$$

where

$$\tau_n(V) = \frac{1}{\alpha_n(V) + \beta_n(V)}$$

$$n_\infty(V) = \frac{\alpha_n(V)}{\alpha_n(V) + \beta_n(V)}$$

Transient conductances



Gate acts as in previous case

Additional gate can block channel when open

$P_{Na} \sim m^3 h$

m is activation variable
h is inactivation variable

m and *h* have opposite voltage dependences:
depolarization increases *m*, activation
hyperpolarization increases *h*, deinactivation

Dynamics of activation and inactivation

$$\frac{dn}{dt} = \alpha_n(V)(1-n) - \beta_n(V)n$$

$$\frac{dm}{dt} = \alpha_m(V)(1-m) - \beta_m(V)m$$

$$\frac{dh}{dt} = \alpha_h(V)(1-h) - \beta_h(V)h$$

So will get equivalent forms as for *n*…

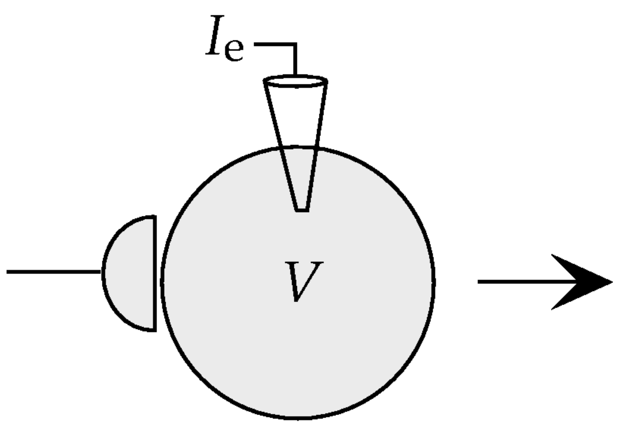
$$\tau_n(V)\frac{dn}{dt} = n_\infty(V) - n$$

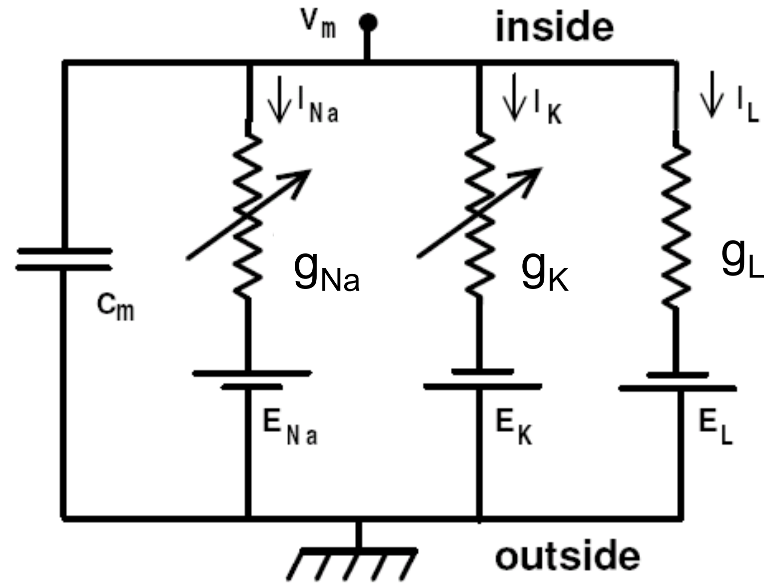
V-dependent conductances

$$g_K(V) = \bar{g}_K\, n^4$$

$$g_{Na}(V) = \bar{g}_{Na}\, m^3h$$

Putting it together





Ohm's law: $V = IR$ and Kirchhoff's law

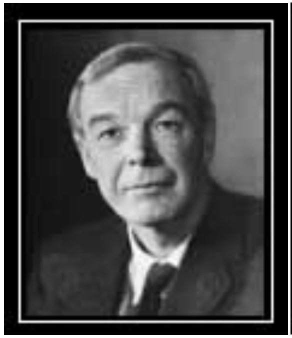
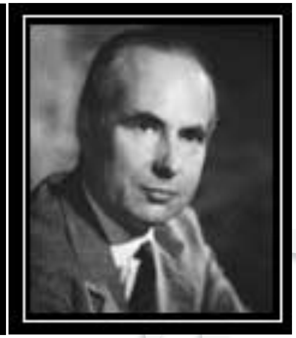
$$\boxed{C_m \frac{dV}{dt}} = \boxed{-\sum_i g_i(V - E_i)} + \boxed{I_e}$$

Capacitative current

Ionic currents

Externally applied current

Hodgkin and Huxley's Nobel equation

$$C_m \frac{dV}{dt} = -\sum_i g_i (V - E_i) + I_e$$

$$-C_m \frac{dV}{dt} = g_L(V - E_L) + \bar{g}_{\mathrm{K}} n^4 (V - E_{\mathrm{K}}) + \bar{g}_{\mathrm{Na}} m^3 h (V - E_{\mathrm{Na}}) - I_e$$

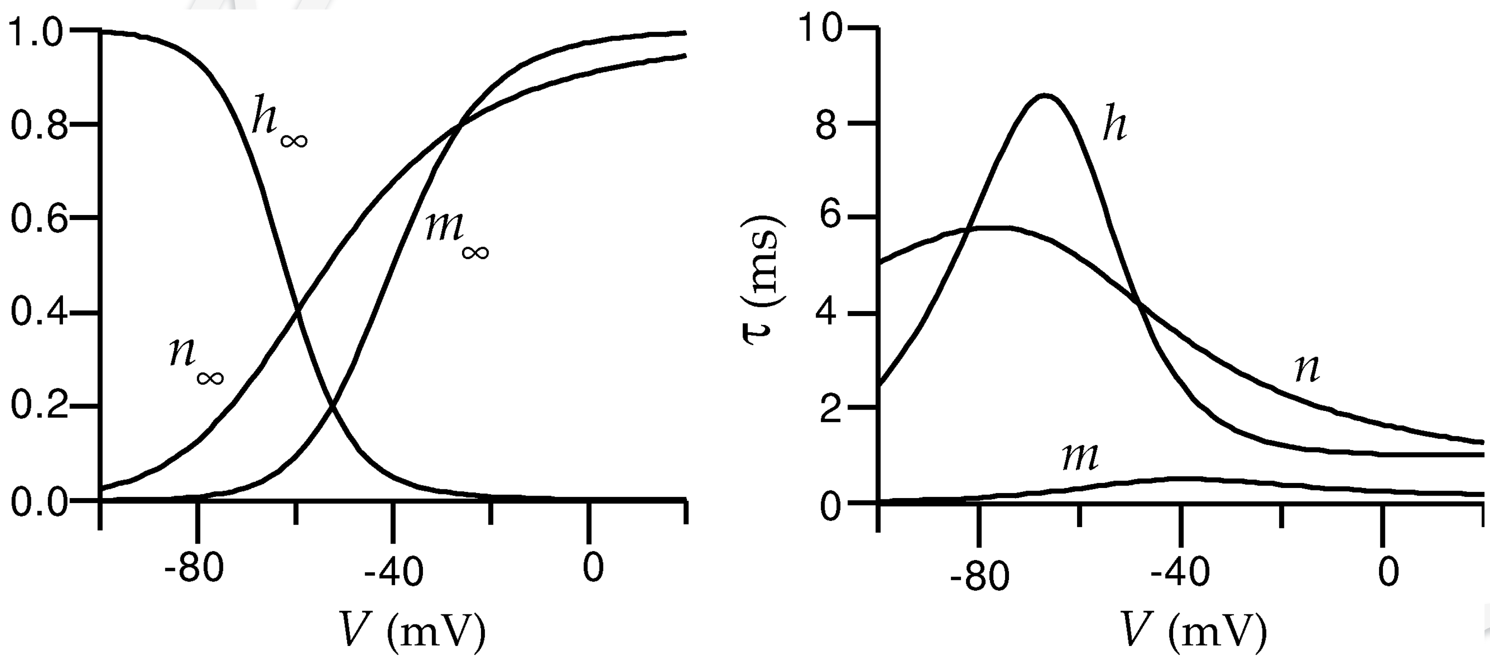
$$\frac{dn}{dt} = \alpha_n(V)(1 - n) - \beta_n(V) n$$

$$\frac{dm}{dt} = \alpha_m(V)(1 - m) - \beta_m(V) m$$

$$\frac{dh}{dt} = \alpha_h(V)(1 - h) - \beta_h(V) h$$

Dynamics of activation and inactivation

$$\tau_n(V)\frac{dn}{dt} = n_\infty(V) - n$$

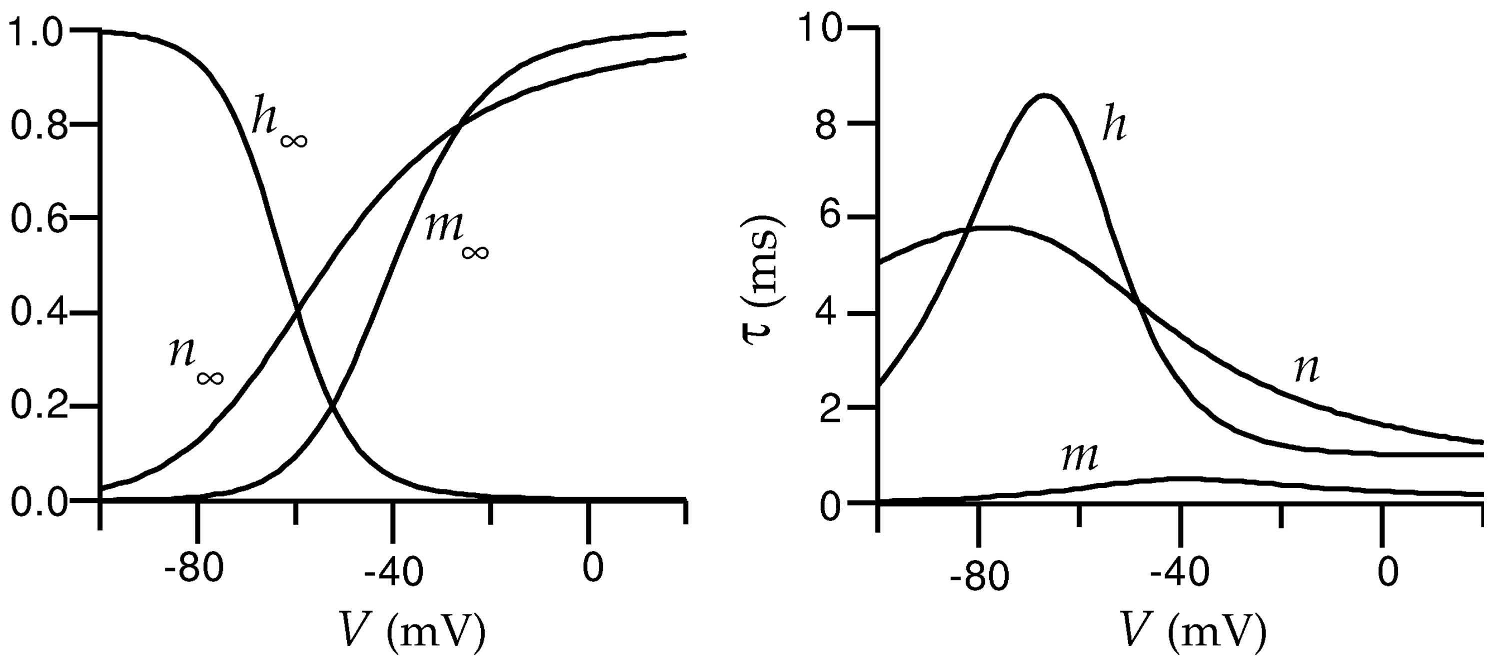


This is where each variable is going

This is how fast it gets there

Dynamics of activation and inactivation

$$\tau_n(V)\frac{dn}{dt} = n_\infty(V) - n$$

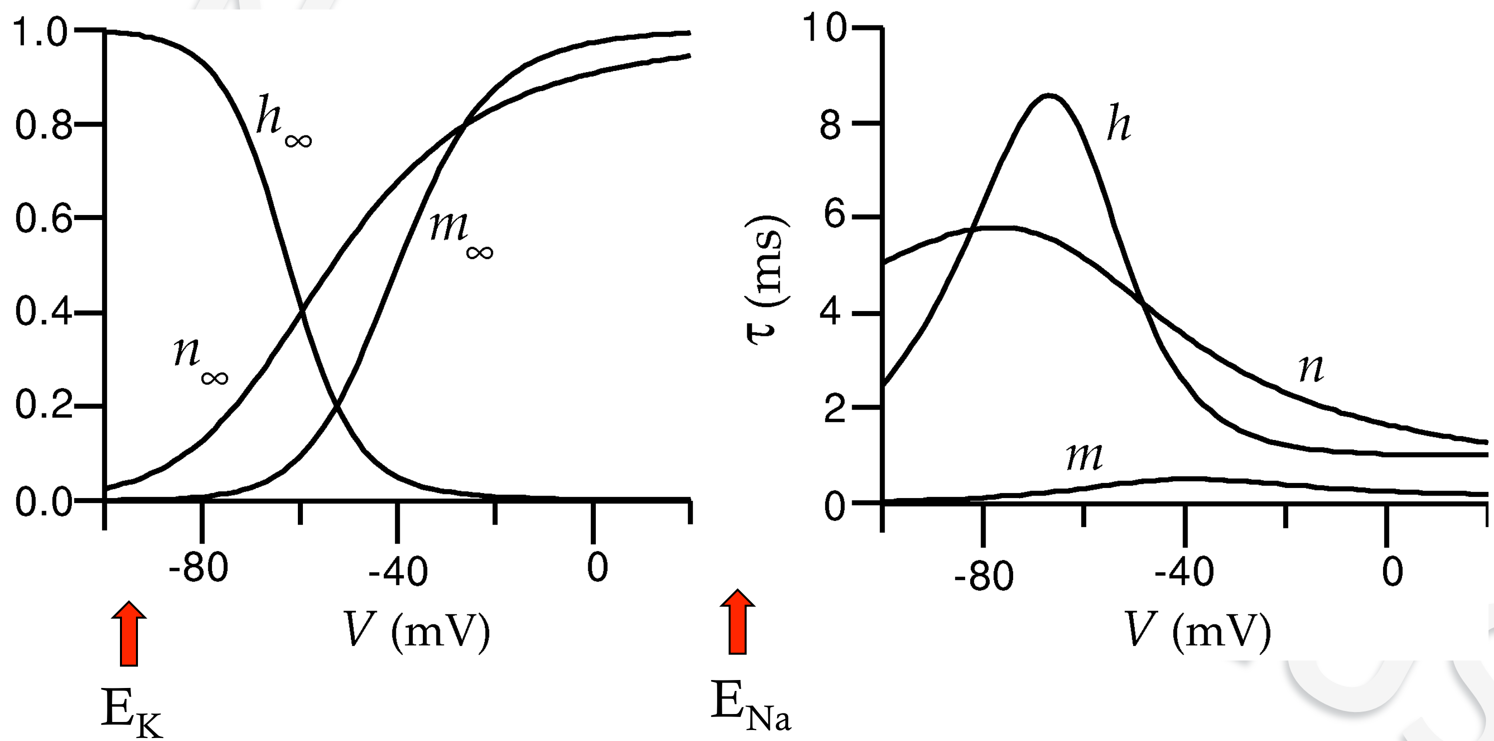


This is where each variable is going

This is how fast it gets there

Anatomy of a spike

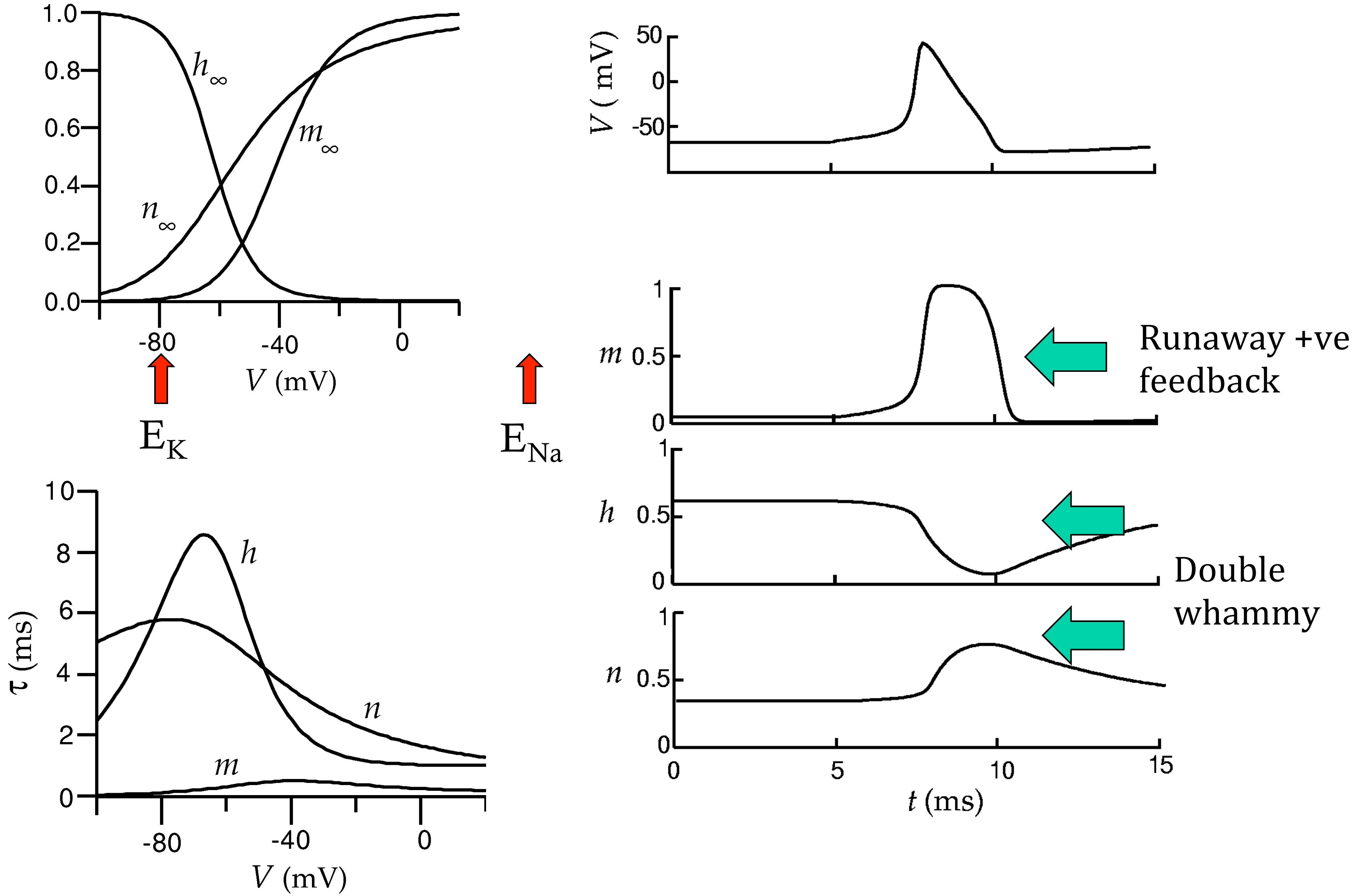
Steady state | Time constant



$$g_K(V) = \bar{g}_K\, n^4$$

$$g_{Na}(V) = \bar{g}_{Na}\, m^3 h$$

Anatomy of a spike



Where to from here?