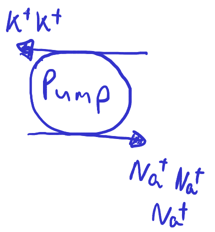
Contents

Ion Currents

Inside		Outside	
Na^+	(5–15 mM)	Na^+	(145 mM)
K^+	(140 mM)	K^+	(5 mM)
Cl^-	(4 mM)	Cl^-	(110 mM)
Ca^{2+}	(0.1 μM)	Ca^{2+}	(2.5–5 mM)
A^-	(147 mM)	A^-	(25 mM)



Equilibrium potential:

$$E_{ion} = \frac{RT}{zF} \ln \left[\frac{[Ion]_{out}}{[Ion]_{in}} \right]$$

Ionic current:

$$I_{ion} = g_{ion} (V - E_{ion})$$

$$E_K < E_{Cl} < V_{rest} < E_{Na} < E_{Ca}$$

Inward currents ($I_{Na}, I_{Ca} < 0$) increase the membrane potential (depolarization); Outward currents ($I_K, I_{Cl} > 0$) decrease it (hyperpolarization). I_{Cl} is called outward current even though the flow of Cl^- ions is inward; the ions bring negative charge inside the membrane, which is equivalent to positively charged ions leaving the cell, as in I_K.

$$C\dot{V} = I - I_{Na} - I_{Ca} - I_K - I_{Cl}$$

L, T, N, and P type Ca^{2+} channels

(Dayan & Abbott)

→ L-type Ca^{2+} currents are persistent as far as their voltage dependence is concerned, and they activate at a relatively high threshold. They inactivate due to a Ca^{2+}-dependent rather than voltage-dependent process, (Dayan & Abbott). Slowly inactivating, high-voltage activated (Suzuki et al 1989).

→ T-type Ca^{2+} currents have lower activation thresholds and are transient. (Dayan & Abbott). Rapidly inactivating, low-voltage activated. (Suzuki et al 1989)

→ N- and P-type Ca^{2+} conductances have intermediate thresholds and are transient and persistent, respectively. They may be responsible for the Ca^{2+} entry that causes the release of transmitter at presynaptic terminals (Dayan & Abbott). N-type channels are low-threshold, rapidly inactivating (Suzuki et al 1989).

Numerical Simulations

$$V(t+\Delta t) = V_\infty + (V(t) - V_\infty)\exp\left(-\frac{\Delta t}{\tau_V}\right) \qquad (1)$$

$$z(t+\Delta t) = z_\infty + (z(t) - z_\infty)\exp\left(-\frac{\Delta t}{\tau_z}\right) \qquad (2)$$

An efficient integration scheme for conductance-based models is to alternate using rule (1) to update the membrane potential and rule (2) to update all the gating variables. It is important to alternate the updating of V with that of the gating variables, rather than doing them all simultaneously, as this keeps the method accurate to second order in Δt. If Ca^{2+}-dependent conductances are included, the intracellular Ca^{2+} concentration should be computed simultaneously with the membrane potential. By alternating the updating, we mean that the membrane potential is computed at times $0, \Delta t, 2\Delta t, \ldots$ while the gating variables are computed at times $\Delta t/2, 3\Delta t/2, 5\Delta t/2, \ldots$ A discussion of the second-order accuracy of this scheme is given in Mascagni and Sherman (1998).

Fig. 9.12-13. Parameters (Izhikevich Book)

$$\overset{1}{C}\dot{V} = I - \overset{8}{g_L}(V - \overset{-80}{E_L}) - \overset{20}{g_{Na}}\, m_\infty(V)(V - \overset{60}{E_{Na}}) - \underbrace{\overset{\overset{9}{\cancel{10}}}{g_K}\, n\,(V - \overset{-90}{E_K})}_{\text{fast}} - \underbrace{\overset{5}{g_M}\, n_M (V - \overset{-90}{E_K})}_{\text{slow}}$$

$$\dot{n} = (n_\infty - n)/\tau(V) = \cancel{1}\ 0.152$$

$$\dot{n}_M = (n_{M,\infty} - n_M)/\tau_M(V) = 20$$

$$m_\infty = \frac{1}{1 + \exp[(\underset{-20}{V_{1/2}^{(m)}} - V)/\underset{15}{k^{(m)}}]} \qquad n_\infty = \frac{1}{1 + \exp[(\underset{-25}{V_{1/2}^{(n)}} - V)/\underset{5}{k^{(n)}}]}$$

$$n_{M,\infty} = \frac{1}{1 + \exp[(\underset{-20}{V_{1/2}^{(M)}} - V)/\underset{5}{k^{(M)}}]}$$