Introduction to Computational Neuroscience (Spring 2018)

Modeling the Effects of Temperature

Increasing the temperature of a neuron has a big impact on its kinetics. All the kinetic rates are larger, and the ion conductance through channels is greater. In this exercise we will explore the effects of these changes on the dynamics of action potentials.

The Q_{10} **temperature coefficient** is a quantity that describes how something changes when the temperature is changed by 10^oC. With regard to kinetic rates, it is defined as

$$Q_{10} = \frac{\text{rate at } (\text{T} + 10^o\text{C})}{\text{rate at T}}$$

Activation, deactivation, and inactivation of ion channels all happen faster at higher temperatures, so for each of these $Q_{10} > 1$. In fact, typically $Q_{10} \approx 3$ for each of these processes. If $\alpha(V, T_1)$ is a V-dependent kinetic rate at temperature T_1, then the rate at temperature T_2 is then

$$\alpha(V, T_2) = \alpha(V, T_1) Q_{10}^{\frac{\Delta T}{10}}$$

where $\Delta T = T_2 - T_1$. In terms of a time constant, which is the inverse of rate, one must divide by the temperature factor, rather than multiply. If $\tau(V, T_1)$ is a voltage-dependent time constant at temperature T_1, then the time constant at temperature T_2 is then

$$\tau(V, T_2) = \tau(V, T_1) / Q_{10}^{\frac{\Delta T}{10}}$$

so that if T_2 is a higher temperature, then the time constant will be reduced.

The conductance of an ion channel has also been shown to increase at higher temperatures, but the temperature effect here is much smaller than with kinetic rates: $Q_{10} \approx 1.2$ typically. Still, this can be an important effect. If $\bar{g}_x(T_1)$ is the maximal conductance of ion channel x at temperature T_1, then at temperature T_2,

$$\bar{g}_x(T_2) = \bar{g}_x(T_1) Q_{10}^{\frac{\Delta T}{10}}$$

with the appropriate value for Q_{10}.

Exploration

(1) Copy your HH.ode file to a new one, call this Q10.ode. Add in the effects of temperature described above (modify the time constant functions and the ionic current functions) . Make sure that the two Q_{10}s and the two temperatures

are parameters. You could initially set $T_1 = T_2 = 18^o$C and with the total integration time to 50 ms. Define an auxiliary variable dvdt as the right hand side of the voltage ODE. This variable will tell you the speed of the voltage change at each time point. Also define the Na^+ current as an auxiliary variable. Make sure that the code runs.

(2) Run the XPP code with $T_2 = 18^o$C, freeze the voltage trace, and run again with $T_2 = 22^o$C. How did the action potential change? Why?

(3) A nice way to view the dynamics is through a **phase plot**, where you plot V on the x-axis and $\frac{dV}{dt}$ on the y-axis using your auxiliary variable. Open up a new window and make a phase plot for both temperatures. Does this help explain the changes you observed in the V time course?

(4) Run the code with the two temperatures again, but this time plot the Na^+ current in a new window. What change was there in response to the temperature increase? Superimpose a third curve, this time with the effect of temperature on the conductances removed. What does the current look like now at the higher temperature? What effect does removing this component have on the T_2 action potential?

(5) Put the temperature effect on conductance back. Now raise the temperature T_2 in increments of 2^oC. At what temperature does action potential production stop? Is the temperature effect on conductance responsible for this? Is the model neuron incapable firing at this temperature or can it be made to fire?

(6) Now increase the total integration time to 100 ms and run. With the lower temperature $T_2 = 18^o$C what is the interspike interval? What is the firing rate? What is the firing rate when the temperature is increased to $T_2 = 26^o$C?

(7) In one sentence, what does increasing temperature due to the voltage response to depolarizing current?