1. If the extracellular concentration of potassium gets reduced, what do you expect to happen to the resting membrane potential of a neuron, and why?

If the extracellular concentration of potassium gets reduced, then the potassium gradient across the cell membrane increases. Due to the increased potassium gradient, more potassium ions tend to leak out of the cell. The loss of positive charge from the inside makes the resting membrane potential more negative, which is called as hyperpolarization. This implies the cell becomes less excitable and requires a stronger stimulus to fire an action potential.

2. Consider an LIF neuron (equation 2.9) with parameters: $E_L = -75$ mV, $G_L = 400$nS, $C_m = 2$nF, $V_{th} = -50$ mV and $V_{reset} = -70$ mV.

a. If it receives an applied current of 6 nA, what is its steady state membrane potential?

b. If it receives an applied current of 15 nA, what is its firing rate?

$$C_m \frac{dV_m}{dt} = G_L(E_L - V_{th}) + I_{app}; \;\; if\ V_m > V_{th}\ then\ V_m \to V_{reset}$$

a) When the membrane potential is in steady state it means that it has a constant value. Therefore its derivative will be zero.

$$G_L(E_L - V_m) + I_{app} = 0$$

$$400e^{-9}(-75e^{-3} - V_m) + 6e^{-9} = 0$$

$$V_m = -60mv$$

the steady state is below threshold then the model neuron does not reset.

b) the firing rate of the neuron can be calculated from

$$f(I_{app}) = \frac{1}{\tau_m \ln\left(\frac{E_L + I_{app}/G_L - V_{reset}}{E_L + \frac{I_{app}}{G_L} - V_{th}}\right)} = \frac{1}{\frac{2\text{nF}}{400\text{nS}} \ln\left(\frac{-75\text{ mV} + 15\frac{\text{nA}}{400\text{nS}} + 70\text{ mV}}{-75\text{ mV} + \frac{15\text{ nA}}{400\text{nS}} + 50\text{ mV}}\right)} = 209Hz$$

3. Explain two similarities and two differences between how you incorporate a refractory period and how you incorporate an adaptation conductance into a simulation of an LIF neuron.

Similarities:

- Both refractory periods and adaptation ultimately aim to regulate the neuron's firing rate and prevent runaway excitation. By introducing constraints on firing, they contribute to orderly and efficient communication within the nervous system. Both mechanisms tend to decrease the neuron's responsiveness to stimuli that persist for a long time. The refractory period completely pauses firing initially, while adaptation often leads to a gradual decline in firing rate. This allows neurons to focus on transient changes in their environment and avoid getting overwhelmed by constant input.
- Both involve changes that happen over time. The refractory period has a fixed duration, while adaptation conductances exhibit gradual decay or more complex time dependencies. However, they both modify the neuron's response to subsequent stimuli based on past activit.

Differences:

- Refractory periods directly blocks specific channels or mechanisms, preventing action potential generation for a fixed duration whereas adaptation conductances modulates membrane potential indirectly by altering leak currents, making it harder or easier to reach the firing threshold.
- A refractory period is implemented as a brief time window of unresponsiveness to stimuli, often modeled as a membrane potential reset and subsequent refractory period. Adaptation conductance is implemented as a dynamic variable evolving over time based on spiking activity, contributing to membrane potential dynamics in order to either increase or decrease the likelihood of firing, depending on the type of adaptation.

4. In the models of spike-rate adaptation which we have produced, is there any possibility that the model neuron can respond to a prolonged current step with a small number of spikes followed by complete quiescence (an absence of spiking) while the applied current remains, because of the adaption current? Explain your reasoning.

Yes, adaptation increases the neuron's threshold for firing after an action potential, making it harder to fire again for a short period Due to the hyperpolarization caused by adaptation currents, a stronger input is required to surpass this increased threshold and trigger another spike. If the applied current is not strong enough to overcome the increased threshold, the neuron may become quiescent, exhibiting a lack of spiking activity even though the current input persists.