Study of a Simple Neuron Circuit Model

ECE 5730 Foundations of Neural Networks

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Consider the simple LINEAR neuron circuit model of Figure 1 [1].

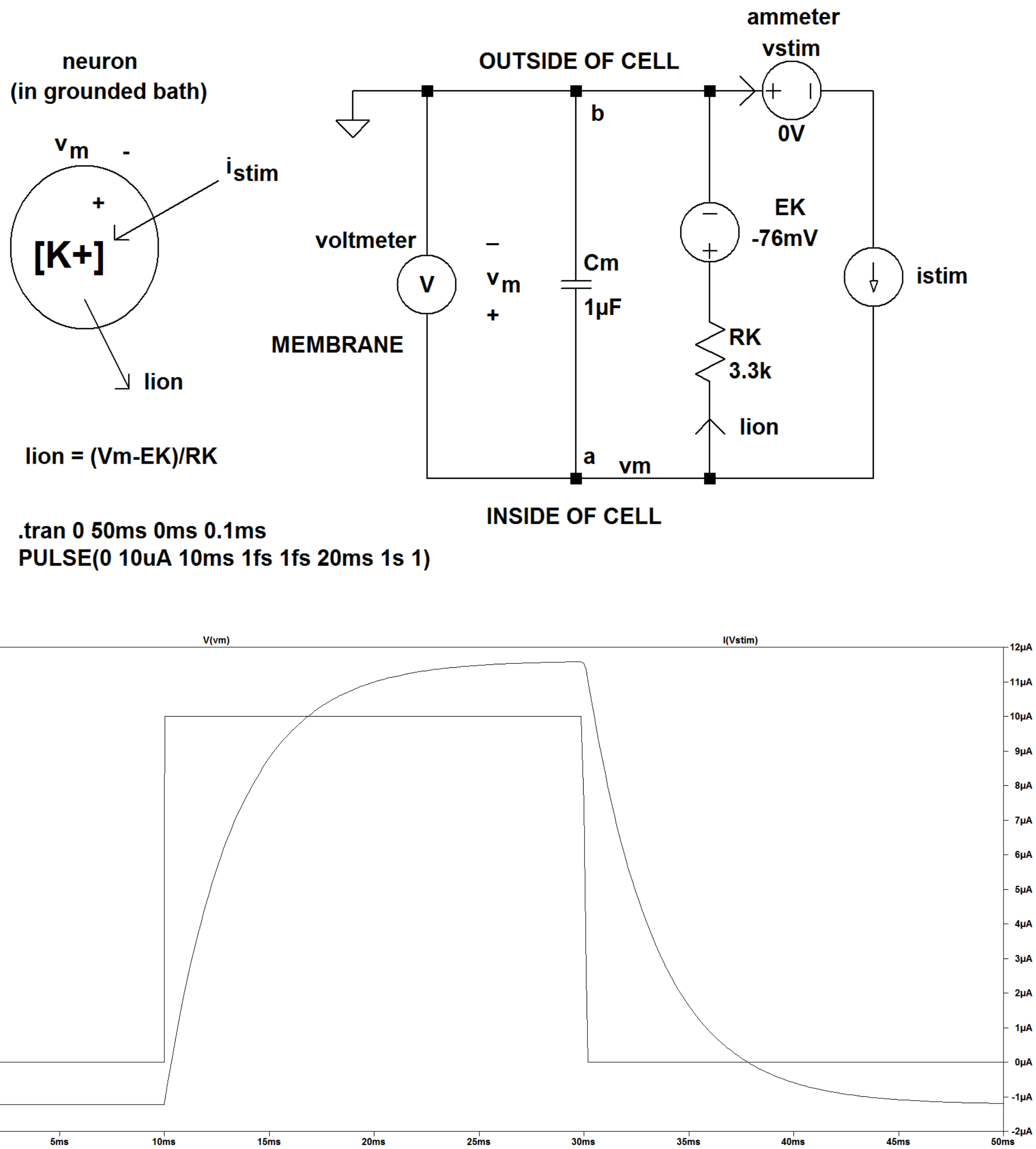

Figure 1. Simple circuit neuron model (adapted from Figure I.1-9 of [1] and created using LTspice) and example waveforms.

The voltmeter measures the membrane voltage $v_m(t)$ (across the neuron membrane). In electrophysiology experiments the neuron is usually in a bath which is grounded, thus the reference polarity direction for $v_m(t)$. In LTspice® (www.linear.com) a voltage source with value zero can be used to measure the stimulation current $i_{stim}(t)$ applied by an experimenter as shown. Cm corresponds to the membrane capacitance and RK is the inverse of the ionic channel conductance, assumed to be potassium ions having a positive charge. Note the potassium concentration is higher inside the cell; this concentration gradient acts to push ions out of the cell. But as potassium ions exit the cell, the membrane voltage decreases, creating an electric potential that opposes further movement of ions out of the cell. The Nernst potential EK is the voltage that balances the electric and concentration gradient resulting $i_{ion}(t)$=0.

1. Derive the differential equation that describes the neuron membrane voltage $v_m(t)$ in terms of EK, RK, Cm, and $i_{stim}(t)$.
2. Solve the differential equation of part (1) by hand using the indicated values. Note: $i_{stim}(t)$ is discontinuous but piecewise linear. One approach to solving the differential equation is to solve a slightly different differential equation in each linear region noting that the membrane voltage must be continuous (**WHY?**). Plot your solutions using MATLAB®.
3. Solve the differential equation of (1) using MATLAB®.
4. Compare results from parts (2), (3), and LTspice®.
5. Investigate the effects of Cm and RK on the shape of the membrane voltage $v_m(t)$.

References

[1] W. Otto Friesen and J. A. Friesen, *NeuroDynamix II: Concepts of Neurophysiology Illustrated by Computer Simulations*, Oxford University Press, 2010.