Basic Neurophysiology

1. Define the terms: (definitions taken from Seeley, Stephens and Tate glossary)
   Neuron: A cell which is the morphologic and functional unit of the nervous system.
   Dendrite: Branching processes of a neuron that receive stimuli and conduct potentials toward cell body
   Soma: Neuron Cell body
   Synapse: Functional membrane-to-membrane contact of a nerve cell with another nerve cell, muscle cell, gland cell or sensory receptor; functions in the transmission of action potentials from one cell to another.
   Myelin: Envelope surrounding most axons; formed by oligodendrocytes in the Central Nervous System, and Schwann cells in the Peripheral Nervous System.
   Node of Ranvier: Interruptions in the myelin sheath.
   Voltage-gated ion channel – ion channels that open or close in response to small voltage changes across the plasma membrane.

2. Define the terms:
   Resting membrane potential: the voltage of a neuron at rest measured inside with respect to outside; usually about –60 mV.
   Nernst potential: the steady-state potential across a permeable membrane with different ionic concentrations on either side.
   Graded potential: a change in membrane potential that can vary from small to large; also called a local potential. Occur in dendrites and in axon before action potential is triggered.
   Action potential: a large change in membrane potential that propagates, without changing its magnitude, over long distances along a cell membrane. Obey an all or nothing principle.
   Depolarization: change in membrane potential toward zero; also phase of action potential in which the membrane potential becomes more positive.
   Repolarization: phase of the action potential in which the membrane potential moves from its maximum degree of depolarization toward the value of the resting membrane potential.
   Hyperpolarization: phase of action potential in which membrane voltage becomes more negative than resting potential.

3. Diagram how different divisions of the nervous system talk to each other when a person sees a bear and runs. Your diagram should have the labels: peripheral nervous system, central nervous system, sensory division (afferent nerves), motor division (efferent nerves), somatic nervous system, autonomic nervous system, skeletal muscle, cardiac muscle, smooth muscle, glands.
4. Briefly outline the ionic flows and their consequences during an action potential.
Na\(^+\) ions rush in transiently – causes membrane potential to depolarize
K\(^+\) ions flow out more slowly – causes membrane potential to repolarize

5. Briefly outline the basic steps of synaptic communication.
Action potentials arriving at presynaptic terminal causes voltage-gated Ca\(^++\) channels to open;
Ca\(^++\) diffuse into the cell and cause synaptic vesicles to release a neurotransmitter molecule into
synaptic cleft.
Neurotransmitter molecule diffuses across synaptic cleft and binds to receptor on post-synaptic
terminal, causing specific ion channels (e.g. Na\(^+\) or K\(^+\)) to open.
Ion flow in post-synaptic cell causes graded potential (plus or minus) in the cell.

Core Engineering Skills
6. Write the equations that describe how a resistor, conductance, capacitor, voltage source, and
current source behave.
\[ V = IR \quad I = GV \quad I = \frac{dV}{dt} \quad I \text{ anything to achieve } V \quad V \text{ anything to achieve } I \]

7. Write down Kirchoff's current and voltage laws and apply them to a simple circuit that you devise.
KCL: sum of currents into node = sum of currents out of node
KVL: sum of voltage drops around a loop = 0
For circuit below: KCL: \( I_r = I_c \). KVL: \(-V_m + V_r + V_{out} = 0\)

8. Find the time constant for \( V_{out} \) for the following circuit, assuming a step change in \( V_{in} \)
Using KCL, and KVL above, \( I_c = C \frac{dV_{out}}{dt} = \frac{V_r}{R} = V_{in} - V_{out} \)

General solution to homogenous equation: \( V_g = C e^{-t/\tau} \quad \tau = RC \)

Particular solution: \( V_p = V_{in} \)

Total solution: \( V = C e^{-t/\tau} + V_{in}; \) assume \( V(0) = 0; \) then \( V = V_{in}(1-e^{-t/\tau}) \)

Time constant = \( \tau = RC \)

**Circuit Models of Neurons**

9. What is the Nernst Potential for sodium?

\[
E_{Na} = \frac{RT}{ZF} \ln \left( \frac{[Na^+]_0}{[Na^+]_i} \right) = \left( \frac{8.314 \times 298}{5.69} \right) \ln \left( \frac{0.1}{0.04} \right) \approx 60.25 \text{ mV}
\]

10. Using the Hodgkin-Huxley circuit model, show that the membrane resting potential tends toward the Nernst Potential of an ion that has a very large associated conductance.

11. Derive an expression for the strength-duration relationship of a neuron assuming a pulse of current as input and that the cell membrane acts as a resistance and capacitance.
Neural simulations (Problems 3–7) (Note: in each case you had to perform several simulations while varying the input parameters)

12. Problem 3: Find the minimum current for eliciting a single action potential ($I \approx 0.01764 \mu A$)
   There should be no “half height.” That is, the response is “all or none.”
13. Problem 4: Find the minimum current that will elicit repetitive firing ($I \approx 0.0491 \mu A$). Find the current that generates 2 action potentials ($I \approx 0.047 \mu A$)
14. Problem 5: Construct a plot of firing frequency vs. injected current

![Firing frequency vs Injected current graph](image1)

15. Problem 6: Construct a plot of single spike threshold current vs. pulse duration for pulse widths between 0.1 and 2.0 ms.

![Threshold current vs Pulse duration graph](image2)

$$y = 0.0555x^{0.9459}$$
$$R^2 = 0.999$$

16. Problem 7: Find the absolute (~5 – 6 msec) and relative refractory period (~10 msec) following an action potential generated by a pulse of 1 ms.

![Threshold amplitude vs Latency graph](image3)