Name: _____

Week 2 Question Set
The Hodgkin-Huxley model & Eyes

Summer 2023

1 CNS2.2 - Reversal potential and Nernst equation

Choose the most correct option for each question:

1. Circle the correct choice: At rest, the concentration of K+ is higher (inside/outside) the neuron, and the concentration of Na+ is higher (inside/outside) the neuron.

2. The video introduces a couple of formulas. Name them and give a brief description.

Formula	Name	Brief Description
$n \propto e^{-E/(kT)}$		
$E = q \cdot u$		
$\Delta u = u_{in} - u_{out} = \frac{-kT}{q} \ln \frac{n(u_{in})}{n(u_{out})}$		

3. Which of the following statements is correct regarding the Nernst equation and the membrane potential of a neuron? Select all that apply.

   a. The Nernst potential (a.k.a. reverse potential) describes the equilibrium potential for a single ionic species at a time.

   b. The Nernst potential, also referred to as the reversal potential, is the membrane potential at which the direction of the net flow of a particular ion species across the membrane will reverse.

   c. The total membrane potential of a neuron is simply a sum of the Nernst potentials for each ion species present.

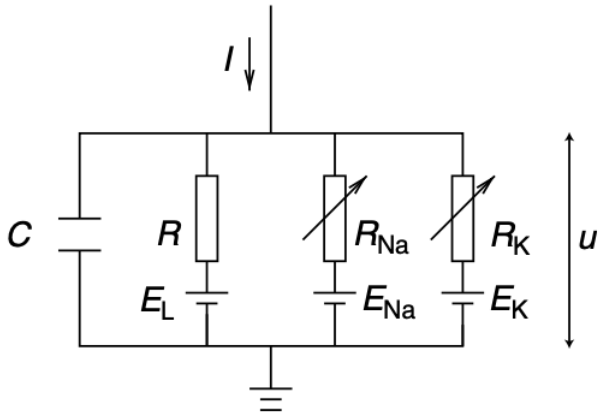
   d. The total membrane potential of a neuron at rest is most influenced by the Nernst potential for potassium and sodium, as the membrane is most permeable to those ions.

2 CNS2.3 - Hodgkin-Huxley Model

1. Let's derive the conversation equation of the Hodgkin-Huxley Model:

$$I_{stimulus} = C\frac{du}{dt} + g_{Na}\, m^3 h(u - E_{Na}) + g_K\, n^4(u - E_K) + g_L(u - E_L),$$

where g are the conductances/permeability of the membrane to the ions, E are the Nernst (equilibrium) potentials, and m, h, n are gating variables for the sodium and potassium channels.



(a) Start off by using Kirchhoff's Current Law: $I_{stimulus} = I_C + I_{Na} + I_K + I_L$. *Hint*: Feel free to use the following well-known differential equations to simplify the steps:

$$I_C = C\frac{du}{dt} \text{ and } I_n = \frac{u}{R_n}$$

(b) Then, replace each $1/R$ term with the appropriate conductance and the gating variables.

2. Which of the following statements correctly describe the gating variables in the Hodgkin-Huxley model? Select all that apply.

   a. The gating variables m, h, and n represent the probabilities that a particular type of voltage-gated ion channel is open.

   b. The gating variables do not depend on the membrane potential and remain constant over time.

   c. Each gating variable has an associated rate equation, given by $\frac{dx}{dt} = -\frac{x-x_0(u)}{\tau(u)}$, where x is the gating variable.

   d. In this model, $x_0(u)$ is the steady-state value of the gating variable at a given membrane potential, and $\tau(u)$ is the time constant which determines how quickly the gating variable approaches its steady-state value.

3. As the membrane potential u changes, how do the activation and inactivation gating variables typically respond? Please fill in the blanks.

   (a) An activation gating variable typically (increases/decreases) with an increase in u.

   (b) An inactivation gating variable typically (increases/decreases) with an increase in u.

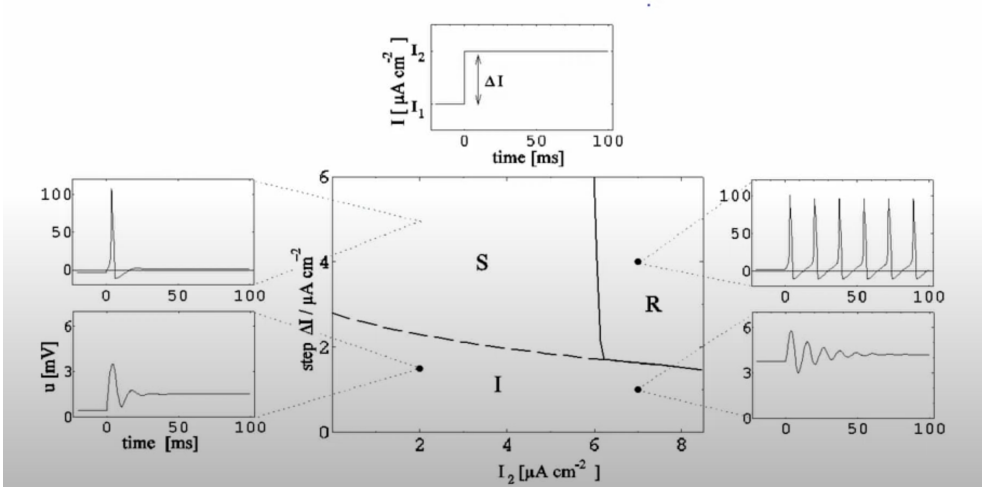
3 CNS2.4 - Threshold in the Hodgkin Huxley Model

1. Please fill in the blanks.

   (a) (m_0/h_0) is an activation gating variable that has a (fast/slow) response.

   (b) (m_0/h_0) is an inactivation gating variable that has a (fast/slow) response.

2. The Hodgkin-Huxley Model does not explicitly define a clear voltage or current threshold for action potential initiation. However, the concept of a threshold is still useful. For different types of input, we can characterize regions of different firing behaviors—Repetitive firing (R), Single spike (S), and Inactivity (I)—within a defined parameter space. Consider the case of a step current input, represented by a certain plot:



   (a) What do the horizontal axis (I_2) and the vertical axis (step ΔI) represent in this plot?

   (b) Based on this parameter space, what shape does the current step function need to have to cause a neuron to fire repetitively?

4 CNS2.5 - Detailed Biophysical Models

1. The lecture introduces two sources of adaptation that can lead to an elongation of inter-spike intervals. Provide a concise summary of each adaptation source:

   (a) I_M Slow potassium current:

   (b) I_{NaP} Persistent sodium current:

5 V&B Chapter 2 - Eyes

1. The evolution of the eye into a cup shape has significant implications for visual perception. Why is this morphological development crucial?

    a. The cup shape allows the eye to store more light, enabling brighter vision.
    b. The cup shape provides the eye a larger surface area, allowing for a wider field of vision.
    c. The cup shape allows the eye to better determine the direction of incoming light, enhancing the animal's ability to sense the direction of light sources.
    d. The cup shape enhances the eye's ability to change focus between near and distant objects.

2. Which of the following statements about a pinhole camera is true?

    a. The smaller the pinhole, the better the image clarity in all circumstances.
    b. Shrinking the pinhole too much can lead to the appearance of diffraction patterns that can degrade the image quality.
    c. The quality of the image in a pinhole camera is primarily determined by the focal length.
    d. The larger the pinhole, the brighter the image without any degradation in its sharpness.

3. The orientation of human photoreceptors, facing towards the back of the retina, with other neurons like ganglion cells situated closer to incoming light, is a unique arrangement. The author does not provide a reason for this orientation. Conduct some research or consult ChatGPT. What are some possible explanations for this photoreceptor arrangement in humans? Provide a brief summary of your findings.

4. We humans often perceive green as being brighter than blue even when the two colors are equally bright. What might be the reason for this?

    a. The human eye has more green cones than blue cones.
    b. The wavelength of green light is longer than that of blue light, making it appear brighter.
    c. Our perception of brightness is influenced by the distribution of cones in our retina, which is optimized for daylight conditions where green is the most prevalent color.
    d. Blue light is absorbed more by the atmosphere, making it appear less bright to us.

5. In Figure 2.12, the author uses degrees as the unit of retinal eccentricity. This measure is essentially referring to a concept known as visual angle. What does the visual angle represent in this context?

    a. It represents the angle formed by the lens of the eye as it adjusts to focus light on the retina.
    b. It refers to the angle subtended at the eye by an object in the visual field, indicating the size of the object's image on the retina.
    c. It represents the angle of deviation of the eyes when looking at objects in the peripheral field of view.
    d. It corresponds to the angle of incidence of light as it strikes the cornea.