BT6270 Computational Neuroscience Assignment 1

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Introduction:

The Hodgkin-Huxley model, a seminal achievement in computational neuroscience, provides a detailed mathematical framework for understanding the generation and propagation of electrical impulses, known as action potentials, in excitable cells. Developed by Alan Hodgkin and Andrew Huxley in the 1950s, this model is rooted in the behavior of ion channels within cell membranes. By characterizing the voltage-dependent conductance of sodium and potassium ions and introducing gating variables, the model accurately simulates the dynamics of membrane potential and action potential generation. This computational approach has profoundly influenced the field of neuroscience and serves as a cornerstone for studying the electrical properties of neurons and other excitable cells.

Assumptions:

- The model assumes a specific set of parameters for the Hodgkin-Huxley equations, including maximal conductance, reversal potentials, and capacitance values.
- The model operates assuming a single-compartment neuron with uniform properties across the membrane.
- The threshold value for action potential is set at 10 mV.
- The code simulates the Hodgkin-Huxley model under different external current stimuli incremented in steps of 0.01 μ A/mm^2.

Threshold values of External Current:

The threshold values **I1**, **I2**, and **I3** represent the points at which the neuron's behavior transitions:

- **I1 = 0.03 μ A/mm^2**: Below this current, no action potentials are observed.
- **I2 = 0.06 μ A/mm^2**: Between **I1** and **I2**, a finite number of action potentials are generated. Between **I2 and I3** Limit cycle behavior is observed.
- **I3 = 0.45 μ A/mm^2**: Beyond **I3** no more action potentials are observed.

[Note: The threshold values (in μ A/mm^2) were obtained using a current sampling interval of 0.01 μ A/mm^2, ranging from 0 to 0.6 μ A/mm^2.]

Plots:

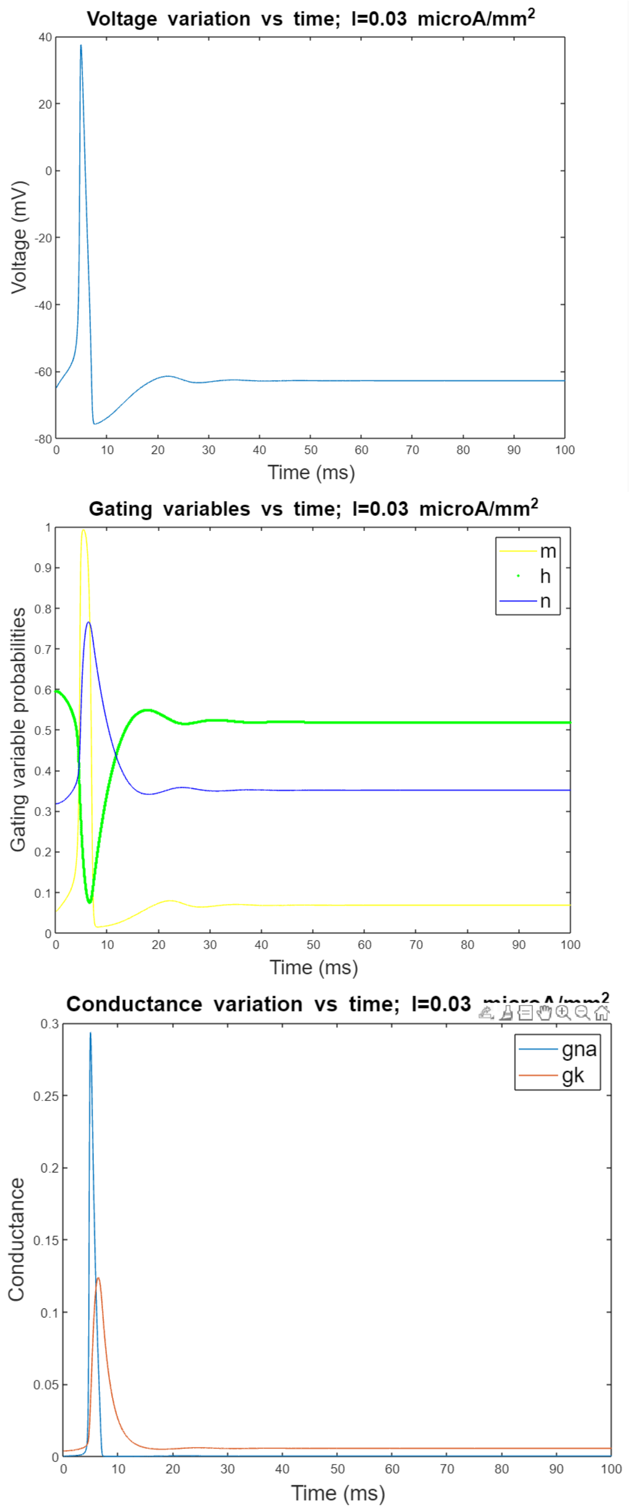
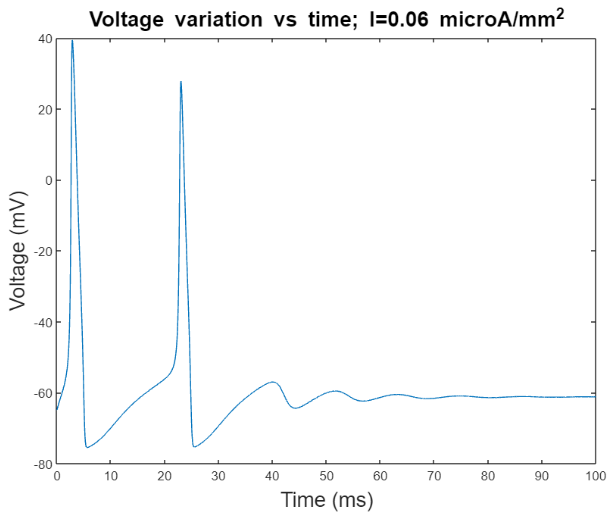
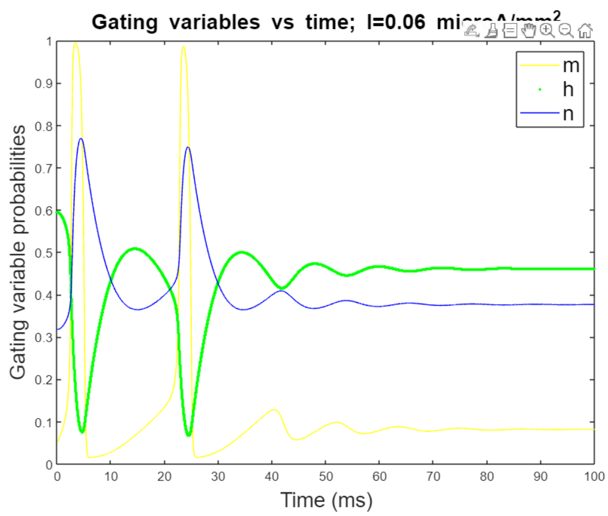


Figure 1: Variation of Voltage, Gating variables and Conductance at current instant I1. A single voltage spike is observed. Number of iterations performed: 10^4


Voltage variation vs time; I=0.06 microA/mm2
Voltage (mV)
40
20
0
-20
-40
-60
-80
0
10
20
30
40
50
60
70
80
90
100
Time (ms)


Gating variables vs time; I=0.06 microA/mm2
Gating variable probabilities
m
h
n
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
100
Time (ms)

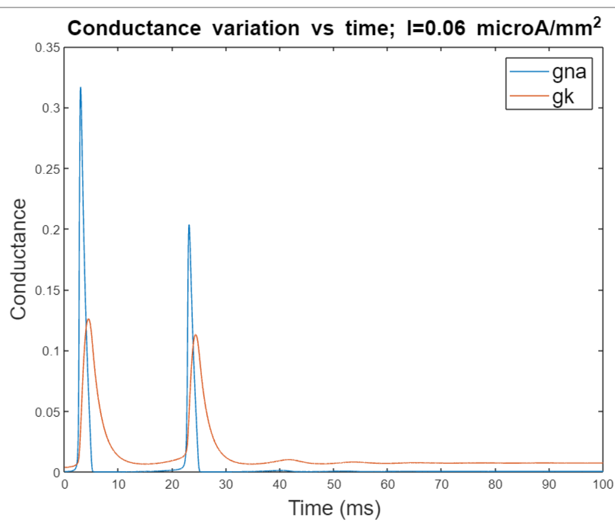

Conductance variation vs time; I=0.06 microA/mm2
Conductance
gna
gk
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
10
20
30
40
50
60
70
80
90
100
Time (ms)

Figure 2: Variation of Voltage, Gating variables and Conductance at current instant I2. A finite number of voltage spikes are observed. Number of iterations performed: 10^4

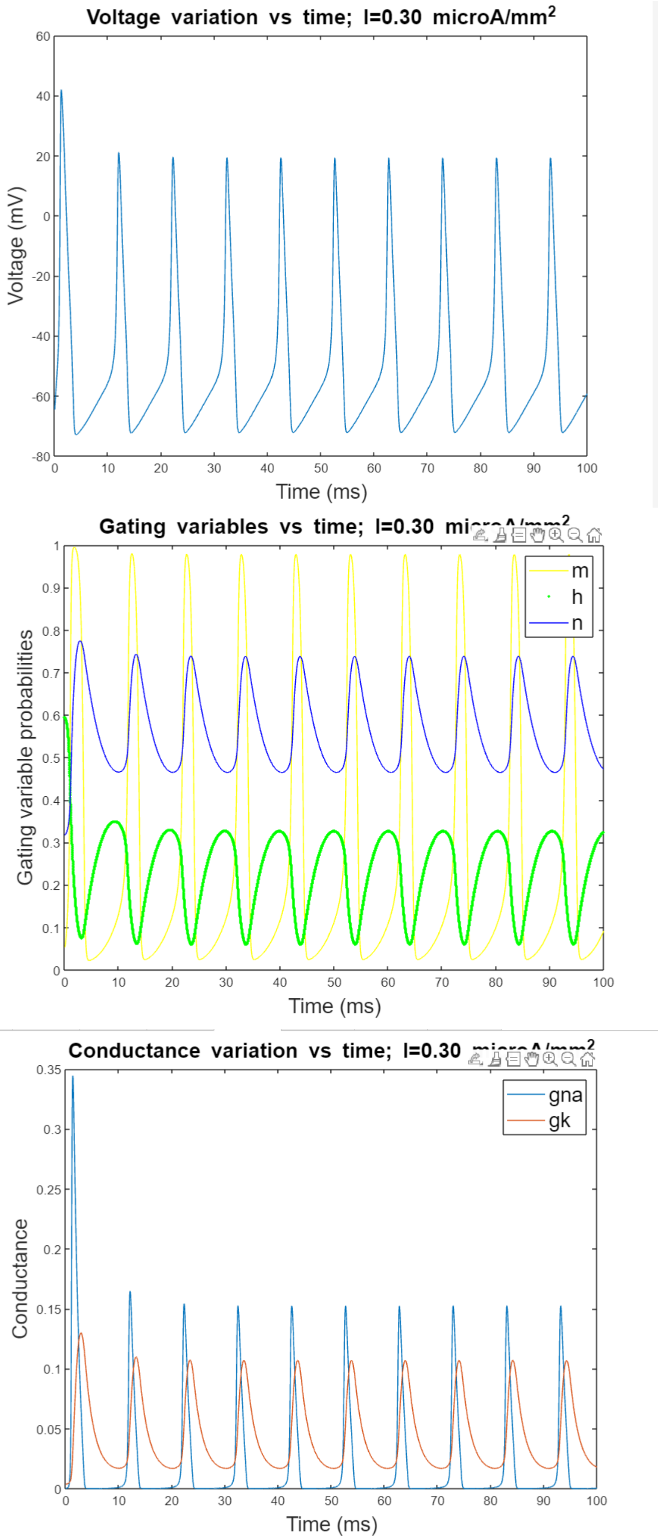
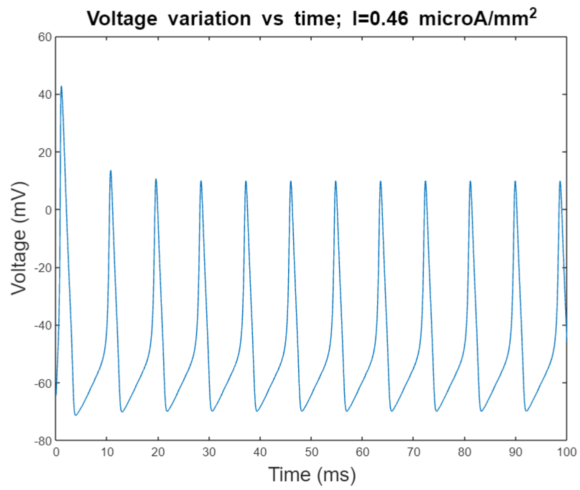
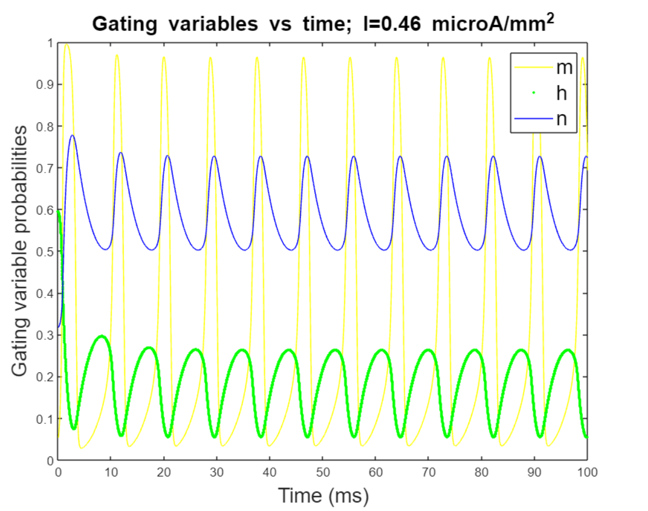


Figure 3: Variation of Voltage, Gating variables and Conductance at current instant

I3=0.30μ A/mm^2. Limit cycle behavior in voltage spikes is observed. Number of iterations performed: 10^4





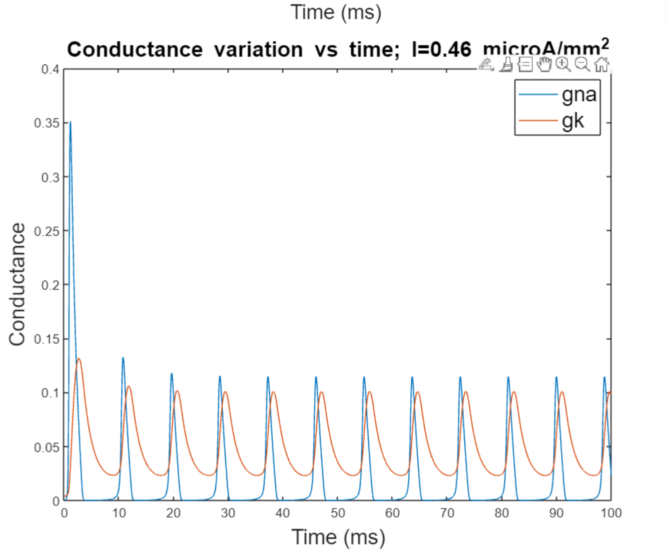


Figure 4 Variation of Voltage, Gating variables and Conductance at current instant after I3. A significant reduction in the number of spikes with amplitude greater than 10mV is observed. Number of iterations performed: 104

Important observation:

We observe a significant increase in the gating variables 'm' for Sodium ions and 'n' for Potassium ions, representing the activation gates. Additionally, there is a decrease in the variable 'h' (representing the inactivation gate for Sodium ions). Concurrently, we notice a rise in the conductance of Sodium and Potassium ions whenever an action potential is generated.

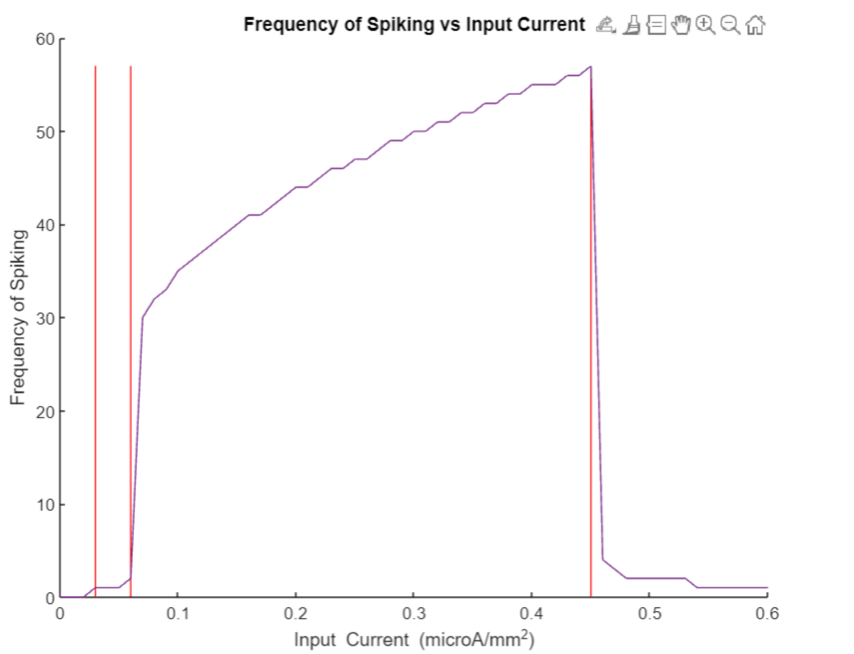


Figure 5: The change in frequency of firing as a function of Input current. The number of iterations performed for each current instance: 5*10^4. The red vertical lines indicate the current thresholds - I1, I2 & I3 respectively.