

Hodgkin Huxley Current Injection Report

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Method

The Hodgkin-Huxley model used in this simulation using original parameters for sodium and potassium channels by Hodgkin and Huxley, which are based on the squid giant axon with the following values:

- $C_m = 1 \mu F/cm^2$
- $E_{Na} = 50 \text{ mV}$
- $g_{max,Na} = 120 \text{ mS/cm}^2$
- $E_K = -77 \text{ mV}$
- $g_{max,K} = 36 \text{ mS/cm}^2$
- $E_L = -54.387 \text{ mV}$
- $g_{max,L} = 0.3 \text{ mS/cm}^2$

To determine the injecting current required to trigger an action potential in the axon, but with minimum amount of total absolute charges, we use the following equation to calculate the total absolute charges:

$$Q = \int |I(t)| dt \quad (1)$$

where:

- Q is the total absolute charges
- $I(t)$ is the injecting current at time t

To make sure that the injecting current is charge balance, we use the following equation:

$$\text{Net Charge} = \int_{t_0}^{t_1} I(t) dt = 0 \quad (2)$$

where:

- t_0 is the start time of the simulation
- t_1 is the end time of the simulation

From the above equations, we can see that the total absolute charges is the product of the injecting current and the time duration of the simulation, and independent of the frequency. Therefore, for our simulation, we will keep the duration constant, and change the amplitude, frequency and the waveform of the injecting current.

- Duration: $200ms$
- Waveforms: Step, Sinusoidal, Square, Triangle, Bi-phasic
- Frequency: $30Hz$, $40Hz$, $50Hz$, $100Hz$
- Amplitude: From $1\mu A/cm^2$ to $5\mu A/cm^2$ with a step of $0.2\mu A/cm^2$
- Delta time: $0.001ms$
- Delay: $100ms$

The codes for sweeping different pairs of frequency and intensity and for generating this report are available in the following Github repository: <https://github.com/samsam2610/Sim4Life-Sweeping>

Result

The following tables show the combinations of each waveform, amplitude, and frequency at which the lowest total absolute charges were required to produce an action potential with charge balanced.

Waveform	Freq(Hz)	Amp($\mu\text{A}/\text{cm}^2$)	AbsQ
sine	30	2.2	0.28
square	30	1.4	0.28
triangle	30	3.0	0.30
biphasic	30	2.4	0.48
sine	40	1.8	0.23
square	40	1.2	0.24
triangle	40	2.4	0.24
biphasic	40	2.4	0.48

Table 1: Outputs of 30Hz and 40Hz

Waveform	Freq(Hz)	Amp($\mu\text{A}/\text{cm}^2$)	AbsQ
sine	50	1.6	0.20
square	50	1.2	0.24
triangle	50	2.0	0.20
biphasic	50	2.4	0.48
sine	100	2.4	0.30
square	100	1.8	0.36
triangle	100	2.8	0.28
biphasic	100	2.4	0.48

Table 2: Outputs of 50Hz and 100Hz

From the results, we can see that the sine and triangle waveforms at 50Hz required the lowest total absolute charges to produce an action potential. The following figures show the resulting waveforms of the injecting current at the amplitude with the lowest total absolute charges to produce an action potential and another similar figure at 1 step ($0.2 \mu\text{A}/\text{cm}^2$) lower without producing action potential (AP).

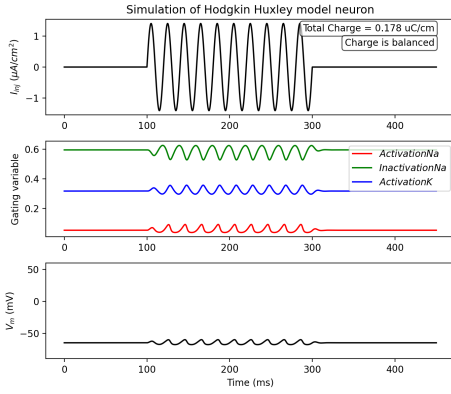


Figure 1: Sine Wave at 50Hz and $1.4 \mu\text{A}/\text{cm}^2$ without AP

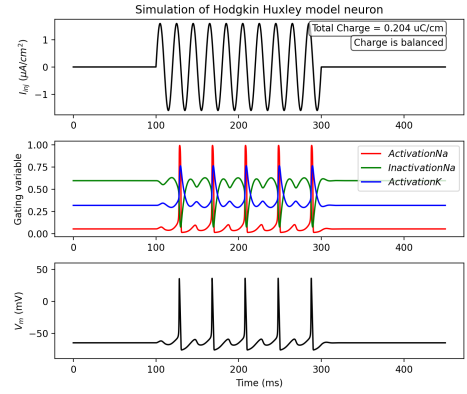


Figure 2: Sine Wave at 50Hz and $1.6 \mu\text{A}/\text{cm}^2$ with AP

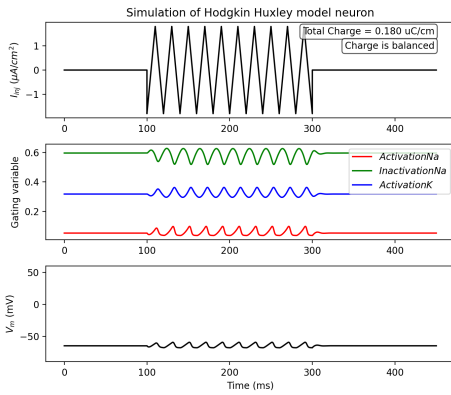


Figure 3: Triangle Wave at 50Hz and $1.8 \mu\text{A}/\text{cm}^2$ without AP

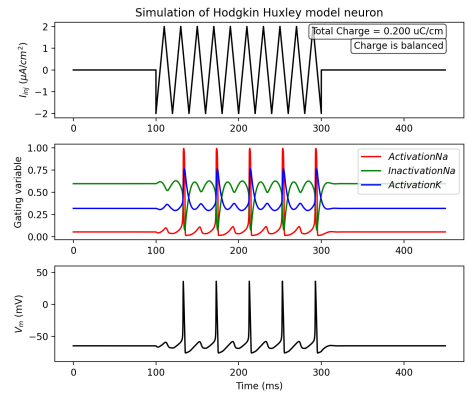


Figure 4: Triangle Wave at 50Hz and $2.0 \mu\text{A}/\text{cm}^2$ with AP