Tutorial 4.1 The Hodgkin-Huxley Model as an Oscillator

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1 Overview

In this tutorial, the neuroscience goal is set to gain appreciation of the Type-II properties of the Hodgkin-Huxley model. We simulated a full four-variable model similar to the original Hodgkin-Huxley model. Following the requirements, we manipulated the applied current and initial conditions to different values and compared their membrane potential response. The observations we got from those comparisons could show us how those four variables attribute to the change of membrane potential and relate to the properties of Type-II neurons.

2 Tutorial Questions

2.1 Question a

In this part, we set up a simulation of 0.35s duration of the Hodgkin-Huxley model based on equation(1)-(4). The parameters are given in table 4.1 on the textbook (p149), time and rate constant of gating variables are given in table 4.2(p149). The applied current is set to 0.

$$C_m \frac{dV_m}{dt} = G_L(E_L - V_m) + G_{Na}^{(max)} m^3 h(E_{Na} - V_m) + G_K^{(max)} n^4 (E_k - V_m) + I_{app} \tag{1}$$

$$\frac{dm}{dt} = \alpha_m(1-m) - \beta_m \tag{2}$$

$$\frac{dh}{dt} = \alpha_m(1-m) - \beta_h h \tag{3}$$

$$\frac{dn}{dt} = \alpha_n(1-n) - \beta_n n \tag{4}$$

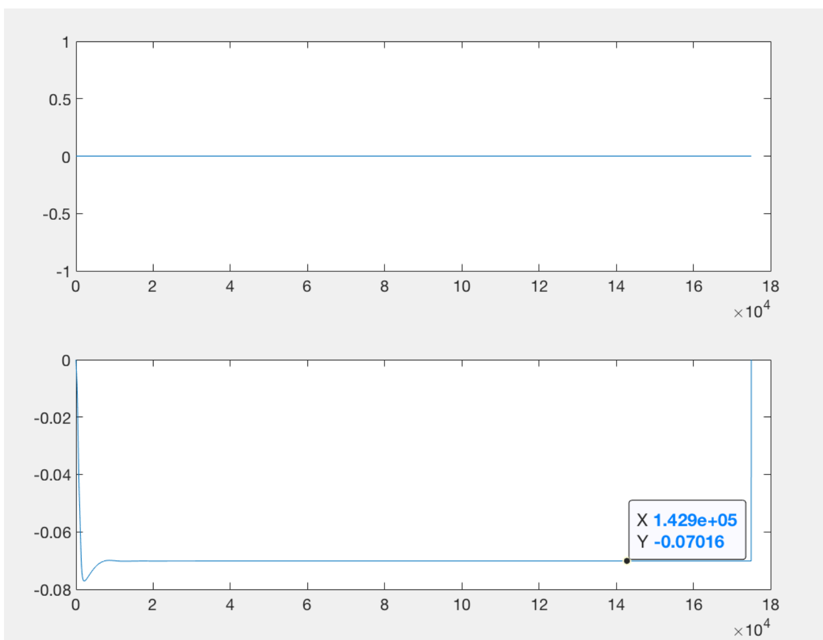

Fig 1.

The upper plot of Fig.1 indicates the applied current, while the lower plot show us the membrane potential response. We can see the membrane potential stabilizes at -0.07016V which is approximately -70.2mV as required in the text. We successfully simulate the Hodgkin-Huxley model.

2.2 Question b

We set the applied current with a baseline of zero and steps it up to 0.22nA for a duration of 100ms at a time a 100ms.

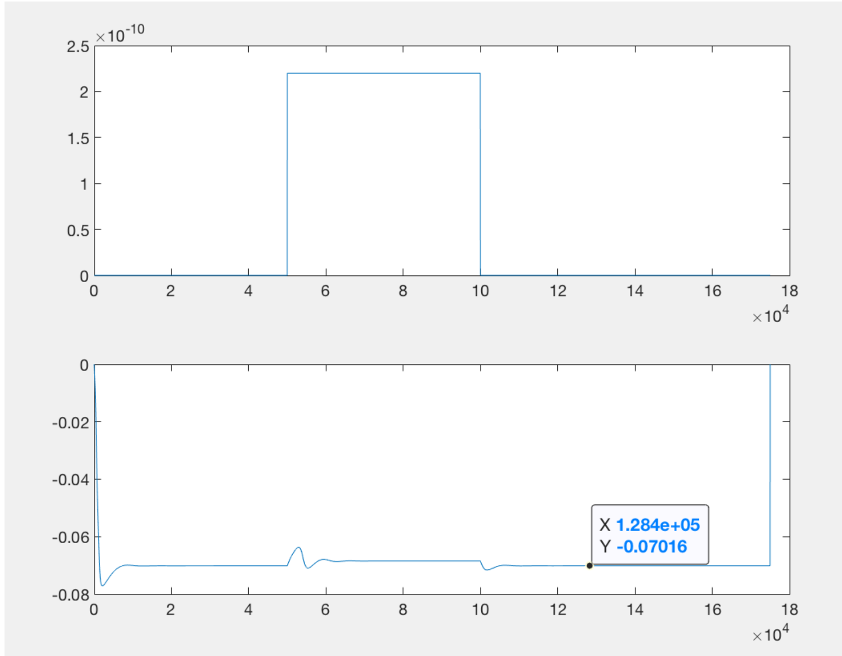

Fig. 2

We could see subthreshold oscillations in the membrane potential reponse. It is an oscillation in the membrane potential, but with insufficient amplitude to produce a spike.

2.3 Question c

In this part, the applied current is a set of 10 pulses, each of 5ms duration and 0.22nA amplitude. A parameter τ is created which defines the delay from the onset of one pulse to the onset of next pulse. In the following three figures, the τ is set to 6ms, 12ms, 23ms respectively.

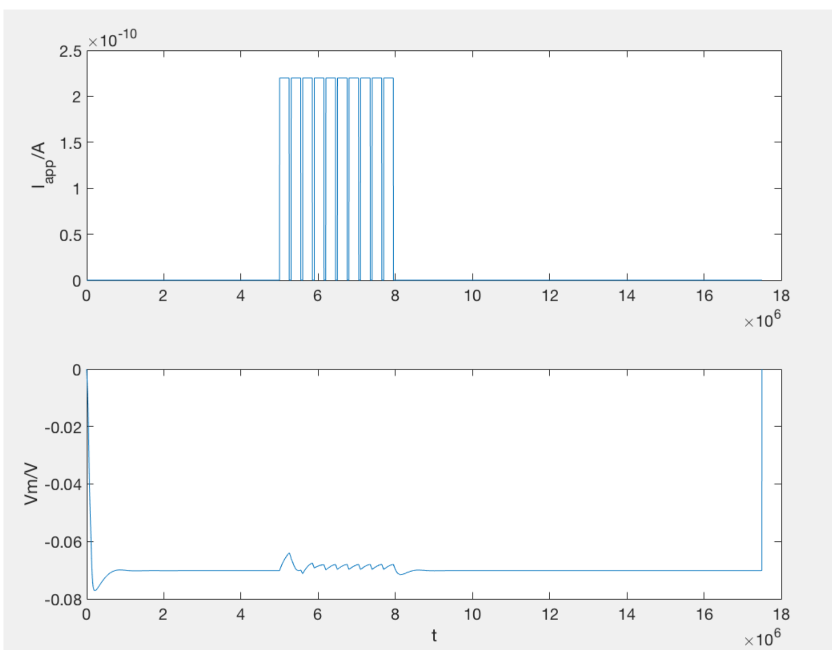

Fig. 3

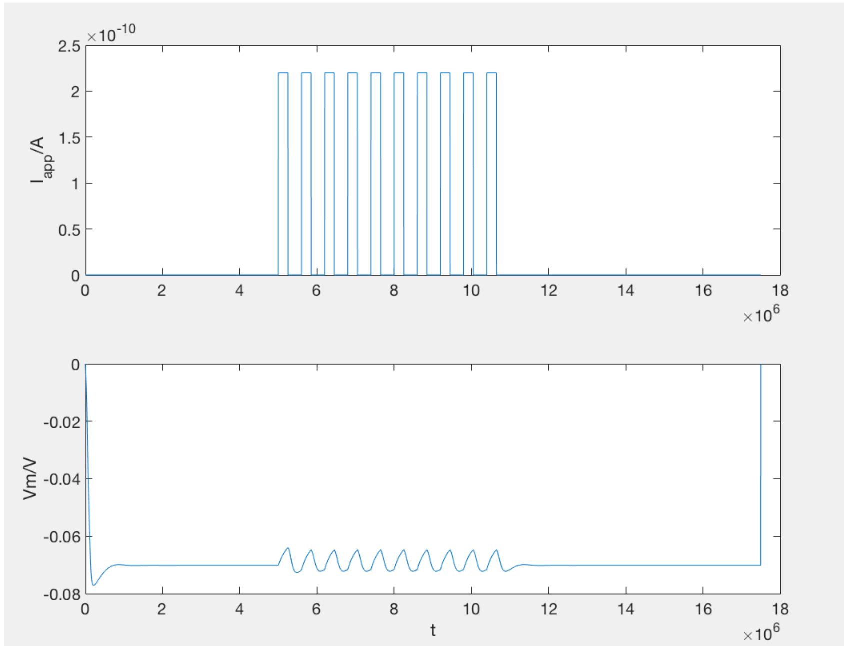

Fig. 4

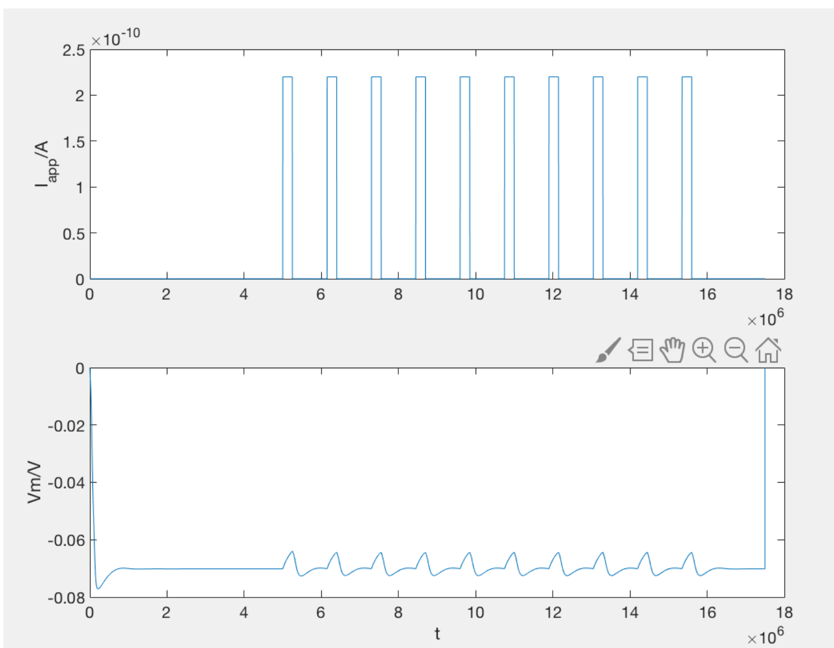

Fig. 5

As we cans see, subthreshold oscillations could be found following step changes but no spikes. The result is similar to subsection b's.

2.4 Question d

We set the baseline current to 0.65nA. Set the initial conditions as $V_m(0) = -0.065V, m(0) = 0.05, h(0) = 0.5, n(0) = 0.35$. And applied a series of 10 inhibitory pulses to bring the applied current to 0 for a duration of 5ms.

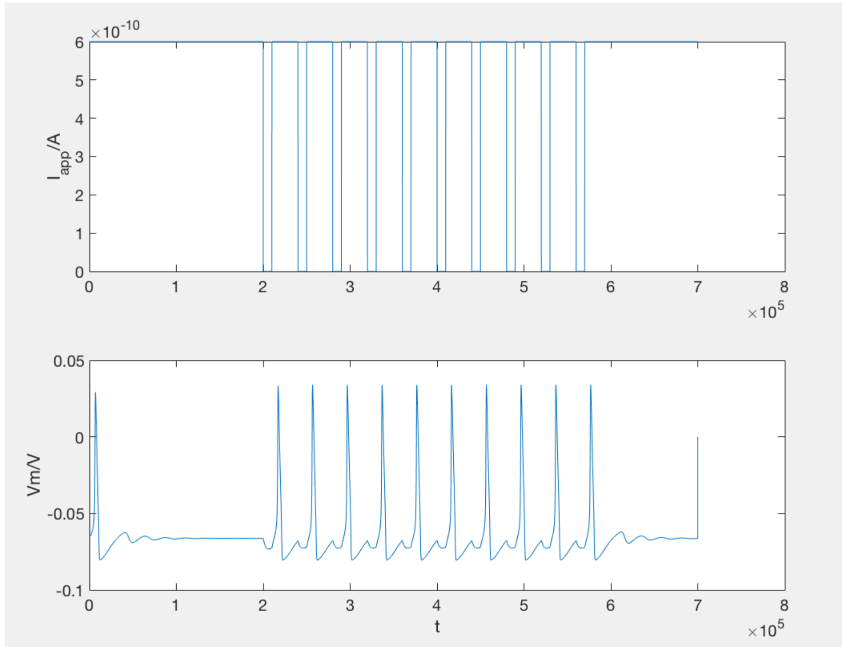

Fig. 6

Anode break could be observed in Fig.6. Set the applied current to negative for a period of time could be reckoned as an approximation of hyperpolarization. When the applied current is released to the baseline 0, an spike is produced.

2.5 Question e

Set the baseline current to 0.65nA. The initial conditions are the same as in subsection d.

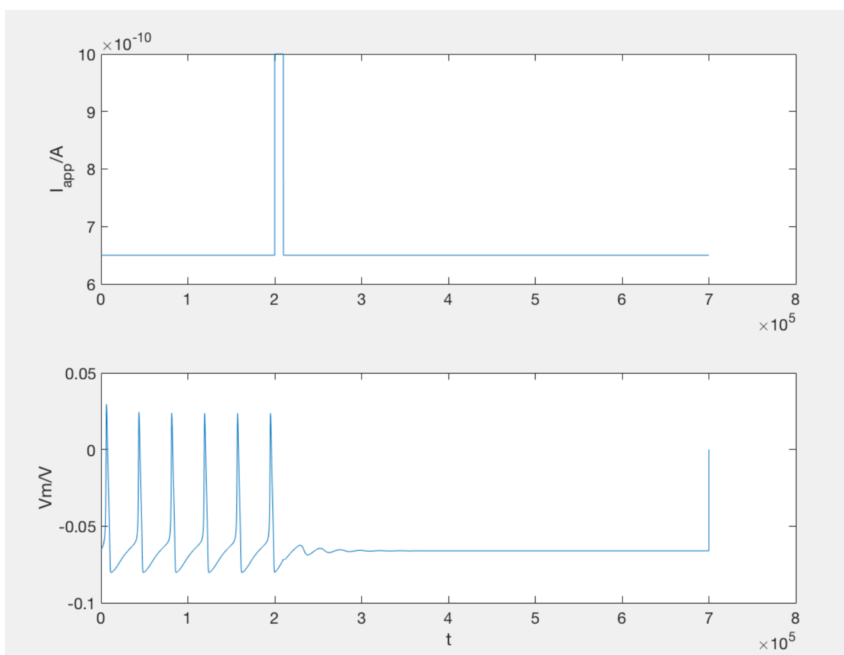

Fig. 7

Bistability can be observed in Fig. 7. Initially with a stable firing rate, the neuron turns into quiescent(zero firing rate) in response to a current step.

2.6 Question f

Repeat (e) with the baseline current of 0.7nA, but set the initial conditions as $V_m(0) = -0.065V, m(0) = 0, h(0) = 0, n(0) = 0$.

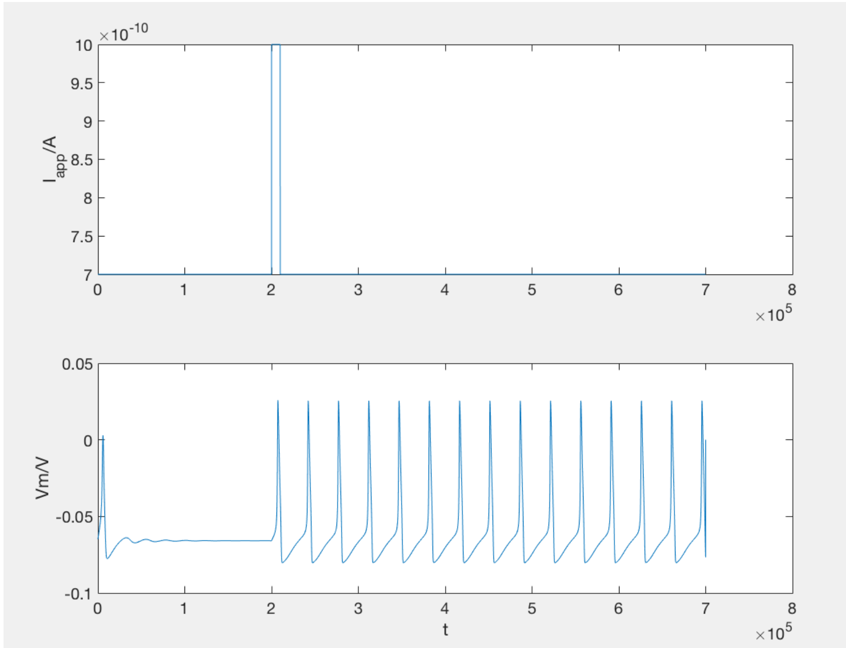

Fig. 8

We can also obeserve bistability in Fig. 8. Initially in quiescent, the neuron starts firing steadily in response to a current step.