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10/10/2013

Homework #3.

Problem 1a.

```
%Define constants;
R=8.314;
T=37+273.15;
F=96485;
z_K=1;
z_Ca=2;
z_Cl=-1;
z_Na=1;
%Define concentrations external and internal
K_ext=5;
K_int=100;
Na_ext=150;
Na_int=15;
Ca_ext=2;
Ca_int=0.0002;
Cl_ext=150;
Cl_int=13;
%compute the reversal potential for each ion
E_K=(R*T/(z_K*F))*log(K_ext/K_int);
E_Na=(R*T/(z_Na*F))*log(Na_ext/Na_int);
E_Ca=(R*T/(z_Ca*F))*log(Ca_ext/Ca_int);
E_Cl=(R*T/(z_Cl*F))*log(Cl_ext/Cl_int);

%===========================================RESULTS:=================================================
%                       E_K =   -0.0801 V
%                       E_Na =   0.0615 V
%                       E_Ca =   0.1231 V
%                       E_Cl =  -0.0654 V`
%====================================================================================================
```

Problem 1b.

```
syms Rm pK pNa K_in K_ext Na_ext Na_in R T F
pk=solve(Rm == R*T/F*log((pK*K_ext +pNa*Na_ext)/(pK*K_in +pNa*Na_in)),pK);

%Define constants;
R=8.314;
T=37+273.15;
F=96485;
Rm= -0.065;

%Define concentrations external and internal
K_ext=5;
K_int=100;
Na_ext=150;
Na_int=15;
%the formula for pK is as follows in terms of variables and constants...
-(Na_ext*pNa - Na_int*pNa*exp((F*Rm)/(R*T)))/(K_ext - K_int*exp((F*Rm)/(R*T)))
%============================RESULTS:==================================
% as a function of sodium permeability and concentrations of sodium and
% potassium, the formula for the permiability of K is as follows
% pk = (892807347126063155*pNa)/22726524804436992
% pk = 39.2848*pNa
%
%======================================================================
```

Problem 2:

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

$$\frac{dn}{dt} = \alpha_n - \alpha_n n - \beta_n n$$

$$\frac{dn}{dt} + (\alpha_n + \beta_n) n = \alpha_n$$

$a_1 = 1 \quad a_0 = \alpha_n + \beta_n$

$$1\frac{dKe^{st}}{dt} + (\alpha_n+\beta_n)Ke^{st} = 0$$

$1 Kse^{st} + (\alpha_n+\beta_n)Ke^{st} = 0$

$s + (\alpha_n+\beta_n) = 0 \rightarrow s = -\alpha_n - \beta_n$

$s = -(\alpha_n - \beta_n)$

$= -\left(\frac{1}{\tau_n}\right)$

$n_i = Ke^{-t/\tau}$

$$\frac{dn}{dt} + (\beta_n+\alpha_n)n = \alpha_n$$

$0 + (\beta_n+\alpha_n)n_f = \alpha_n$

$$n_f = \frac{\alpha_n}{\alpha_n+\beta_n}$$

Initial Cond

$n = n_0 \quad @ t=0$

$$n = n_i + n_f = Ke^{-t/\tau} + \frac{\alpha_n}{\alpha_n+\beta_n}$$

$@ t=0 \quad n(t=0) = K + \frac{\alpha_n}{\alpha_n+\beta_n} = n_0$

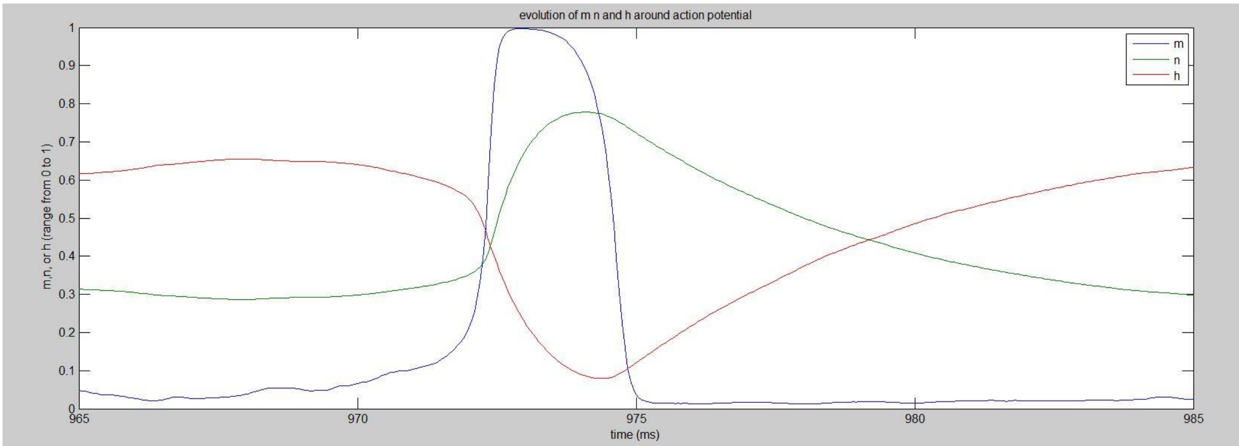
$$\therefore K = n_0 - \frac{\alpha_n}{\alpha_n+\beta_n} = n_0 - n_\infty$$

$$\boxed{n = (n_0 - n_\infty)e^{-t/\tau} + n_\infty}$$

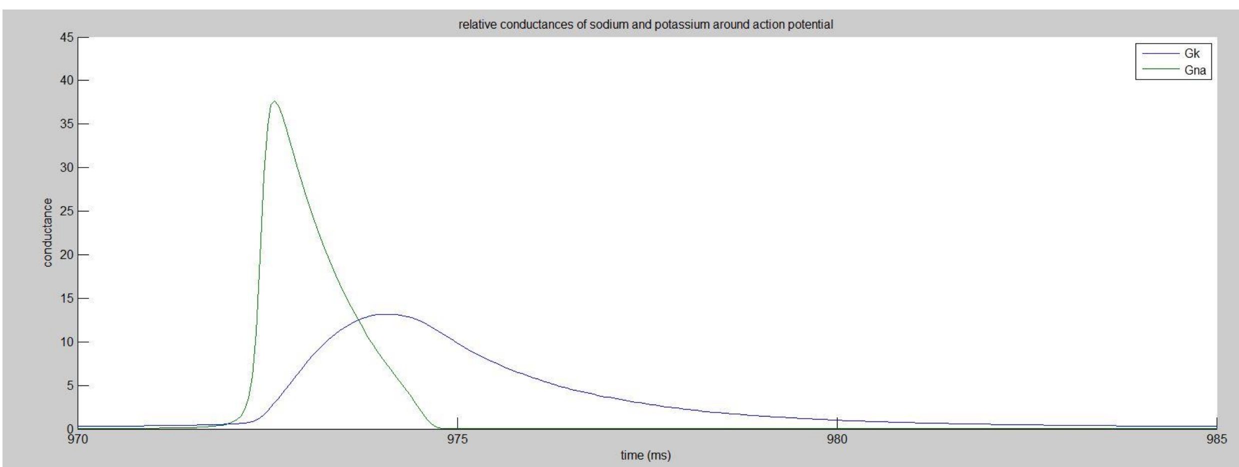
✓

Problem 3:

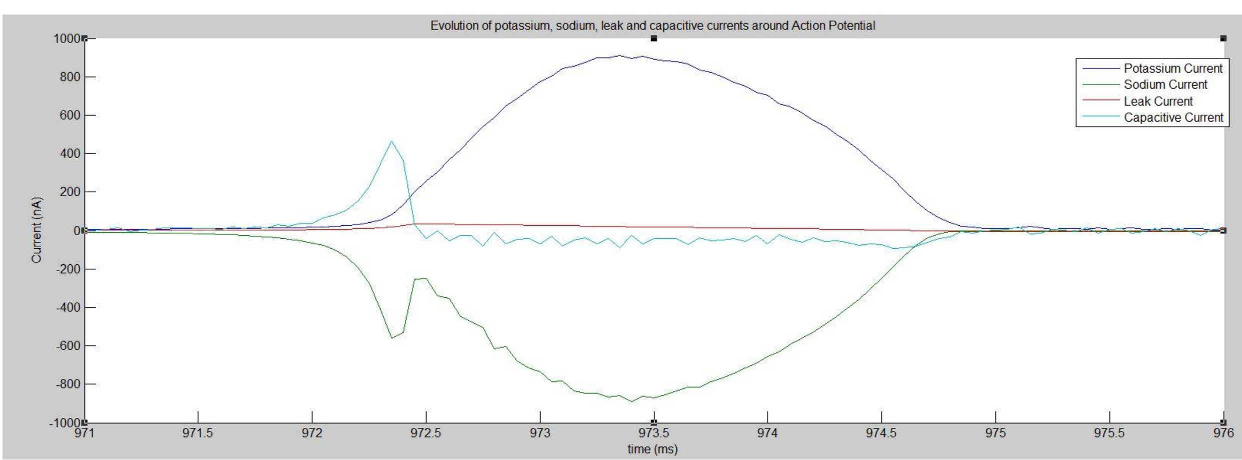
(i):



(ii):

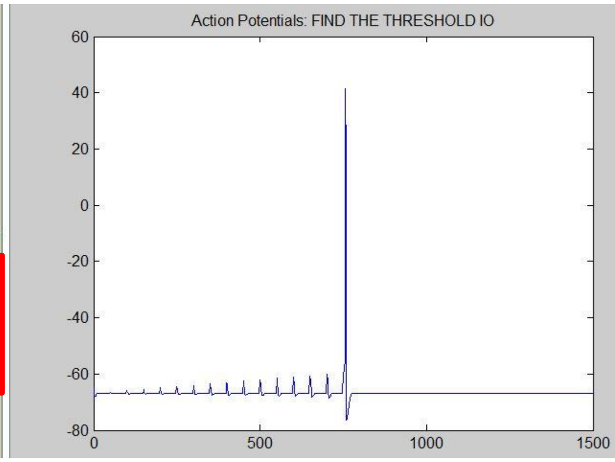


(iii):



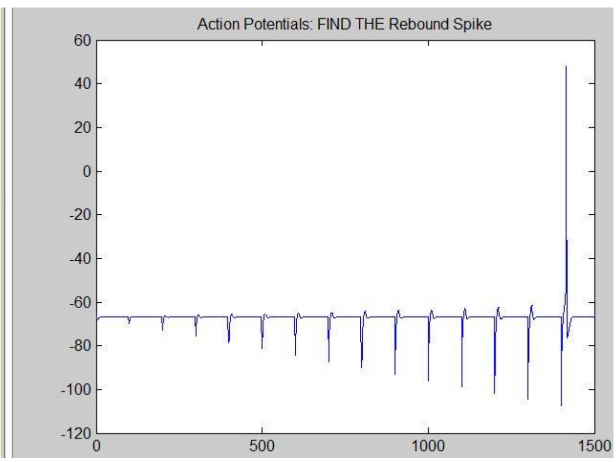
Threshold was determined by increasing the value of I0 at visible spacings on the graph until an AP presented itself, then narrowing the range down back and forth until a precise value was obtained.Here the value of threshold is I0= 9 .758*15 = 146.7705nA

```
clear
clc
T = 1500; dt = 0.05;
Tsteps = round(T/dt);
C = 1; % capacitance (microF/cm^2)
Vl = -77; % leak reversal potential (nV)
gl = 0.3; % leak conductance (mS/cm^2)
VNa = 55; % Na reversal potential
gNa = 120; % open Na conductance
VK = -77; % K reversal potential
Vl = -61; % leak reversal potential (nV)
gK = 36; % open K conductance
% input current:   sets length of applied current to 0 and randomizing
% current amplitude across 0-10   for 4 and 5 comment out the 2nd line and
% redefine current with a vector of currents to find the threshold current
I0 = zeros(1, Tsteps);
%I0 = I0 + 10*randn(1, Tsteps);
for i=1:15
    I0(1000*i)=9.785*i;
end
%the samllest I0 that created an action potential (so threshold I0) was
%9.785*15= 146.775
% initial conditions:
Volt(1) = -65;
n(1) = 0.318;
m(1) = 0.053;
```



A similar process was used to find the rebound spike inducing stimulus. The I0 required for a rebound spike was ~15*(-58)= - 870.

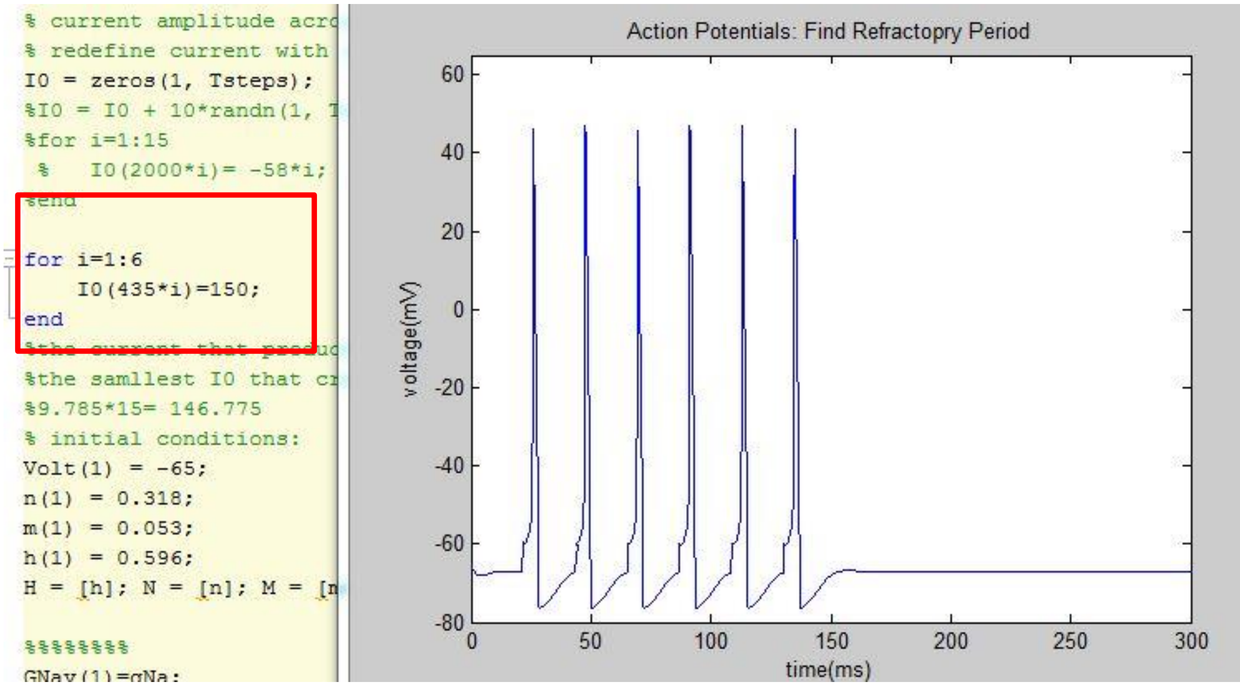
```
T = 1500; dt = 0.05;
Tsteps = round(T/dt);
C = 1; % capacitance (microF/cm^2)
Vl = -77; % leak reversal potential (nV)
gl = 0.3; % leak conductance (mS/cm^2)
VNa = 55; % Na reversal potential
gNa = 120; % open Na conductance
VK = -77; % K reversal potential
Vl = -61; % leak reversal potential (nV)
gK = 36; % open K conductance
% input current:   sets length of applied current to 0 and randomizing
% current amplitude across 0-10   for 4 and 5 comment out the 2nd line and
% redefine current with a vector of currents to find the threshold current.
I0 = zeros(1, Tsteps);
%I0 = I0 + 10*randn(1, Tsteps);
for i=1:15
    I0(2000*i)= -58*i;
end
%the current that produced a rebound spike was ~15*-58= -870
%the samllest I0 that created an action potential (so threshold I0) was
%9.785*15= 146.775
% initial conditions:
Volt(1) = -65;
n(1) = 0.318;
m(1) = 0.053;
h(1) = 0.596;
```



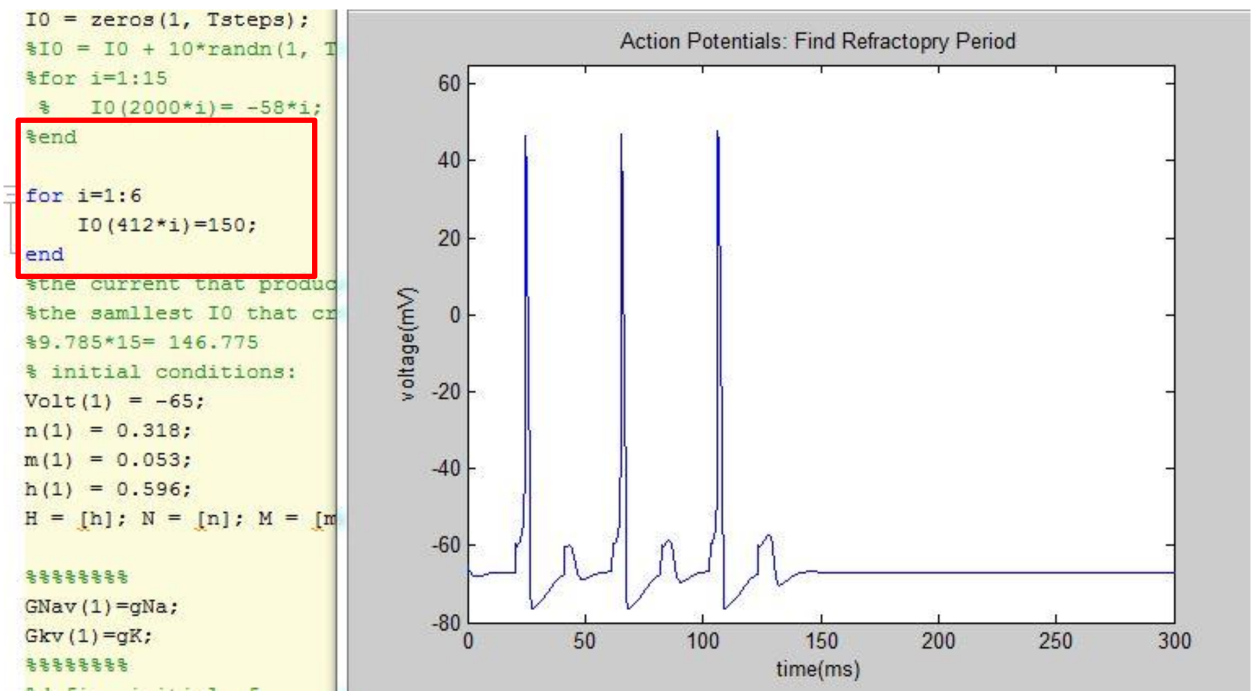
The refractory periods were determined using threshold and an extremely high stimulus current at evenly spaced points in time, and then decreasing the spacing between them. Note that the conversion from time steps (used to vary the period between stimuli) to time in milli seconds is time=0.05*timesteps.

First a value of stimulus current, just above the threshold value that was determined previously, was used (I=150 slightly greater than 146.7705). The stimulus was applied 6 times with decreasing period until every other action potential dropped out.

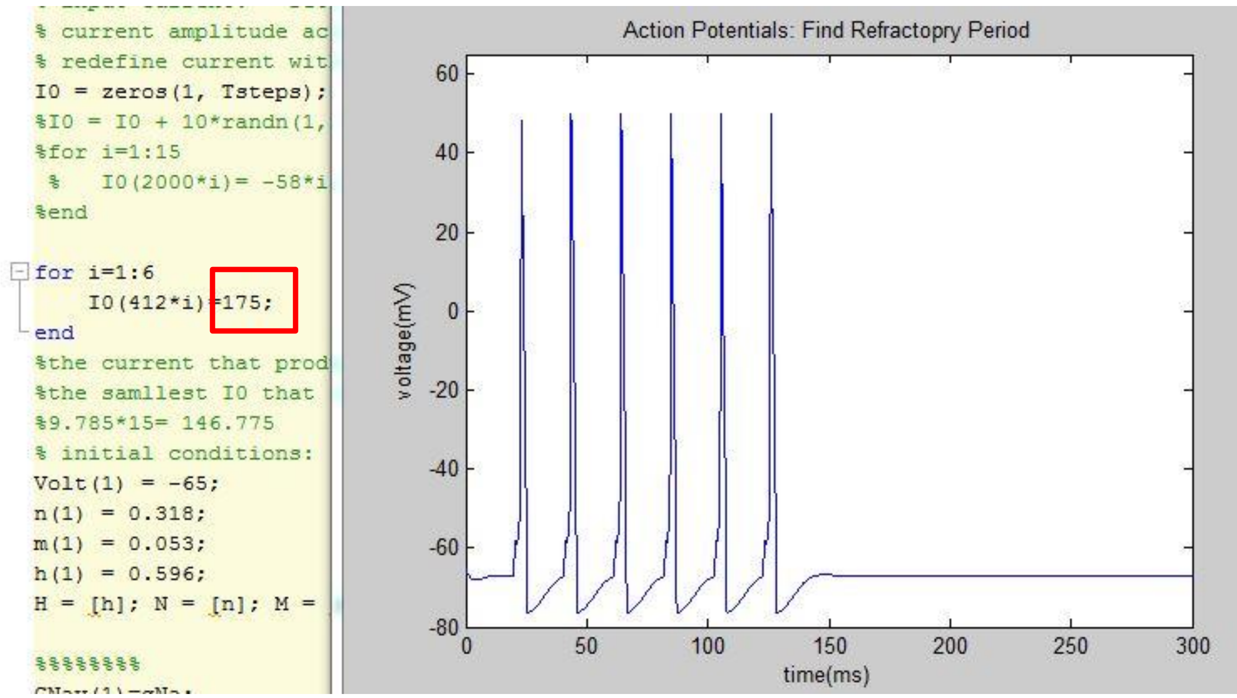
Here all APs are present with period between stimuli being 435 timesteps and stimuli being 150



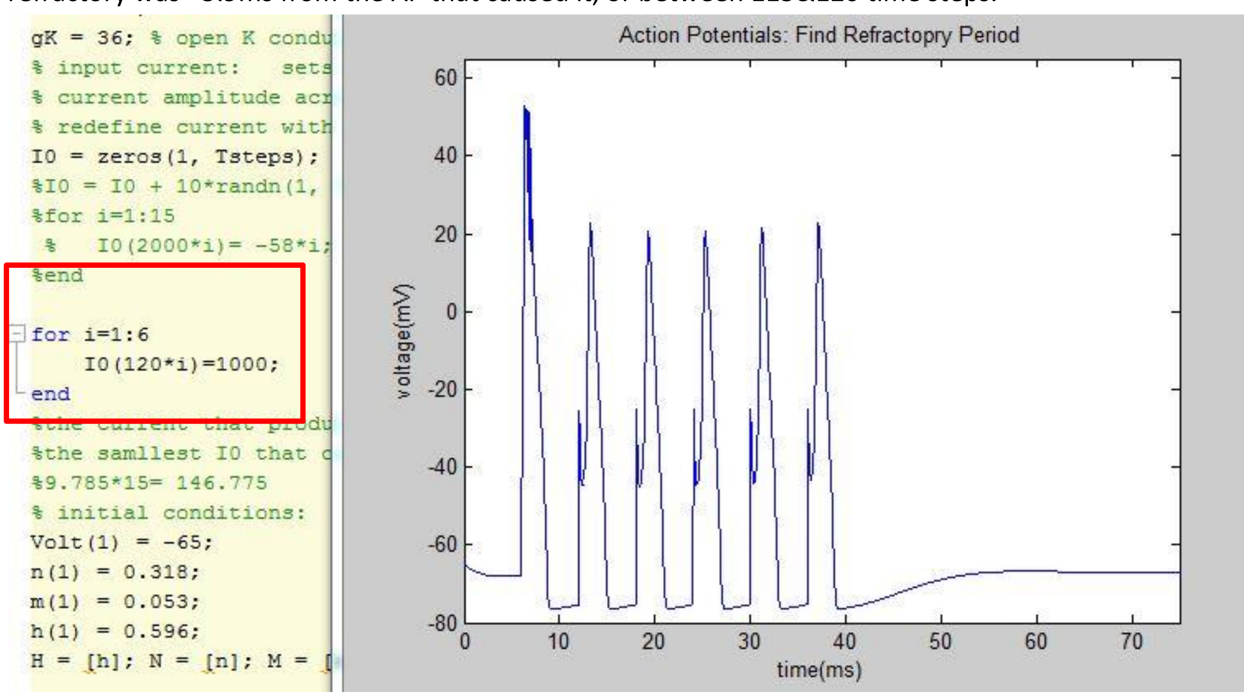
Here they have dropped out when the period between stimuli was dropped to 412 timesteps from 435 timesteps

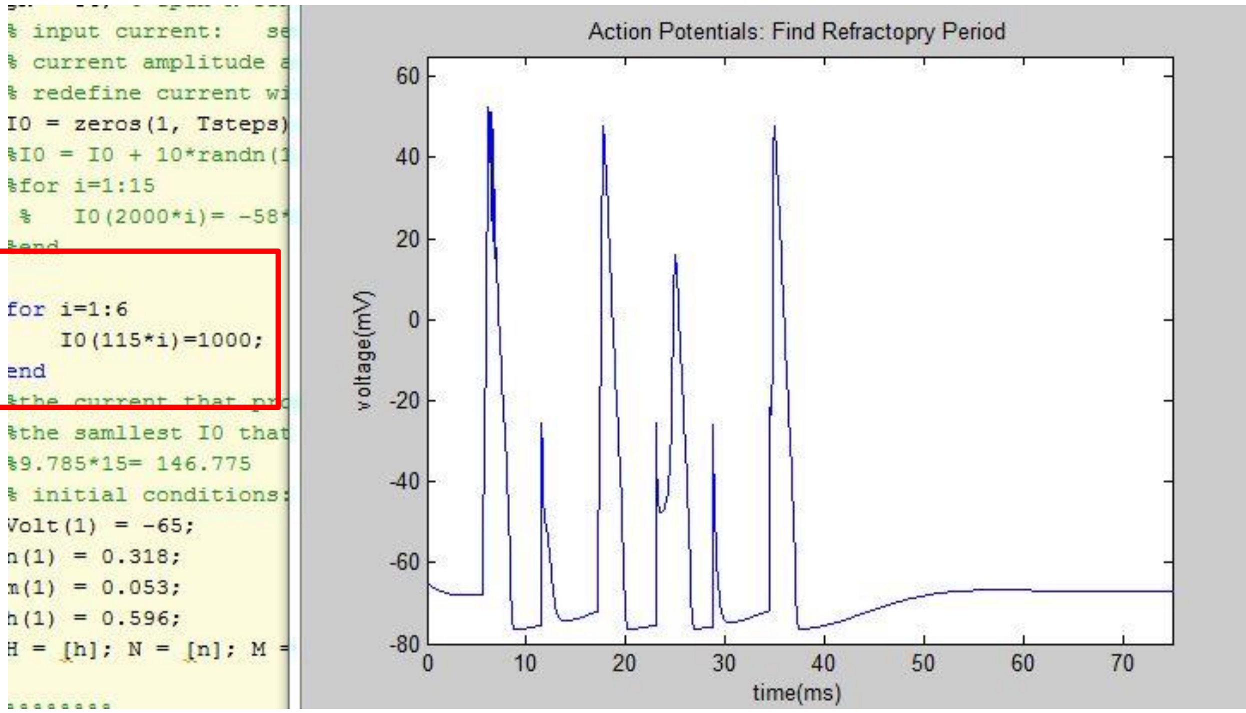


The end of the relative refractory period was ~21ms from the AP that caused it, or between 412&435 time steps. At that refractory period, where every other AP dropped out, increasing the current to 175 brought back the APs that had dropped out, showing that the period was relative refractory, not absolute. This is shown below.



To handle the determination of the absolute refractory period, a much much higher current stimulus was used (1000) to find the absolute refractory period by the same method. This time the absolute refractory was ~5.9ms from the AP that caused it, or between 115&120 time steps.





The two graphs above show the crossing of the absolute refractory period where even an extremely high stimulus of 1000nA isn't producing full secondary AP because the period between stimuli sinks into the range of the absolute refractory period. The change from being in the relative to being in the absolute refractory periods wasn't an on/off switch. It was fast acting, but showed changes in amplitude as it approached the border.

Discussants: Paras Vora, Jordan Nick, Maeve Woeltje, Matt Everett, Jodi Small, Professor Widder,

References:

1. http://aries.ucsd.edu/najmabadi/CLASS/MAE140/NOTES/dynamic-2.pdf%E2%80%8E
2. Koch Chapter 6