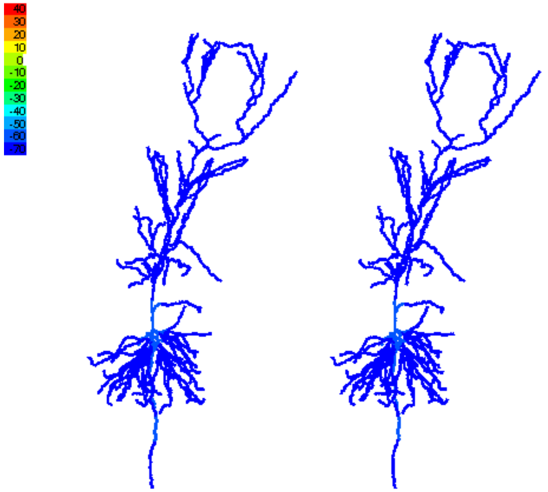
LASCON 2018

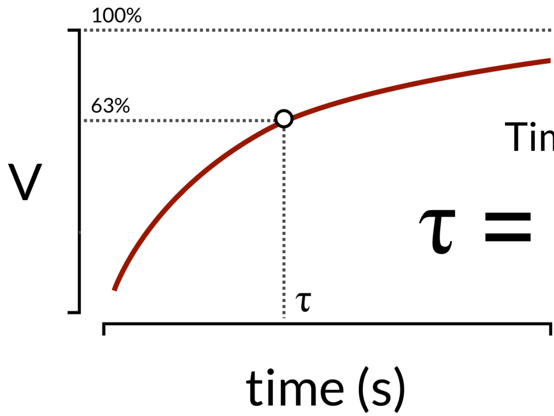
Tutorial 10
NEURON 6

NEURON
for empirically-based simulations of neurons and networks of neurons



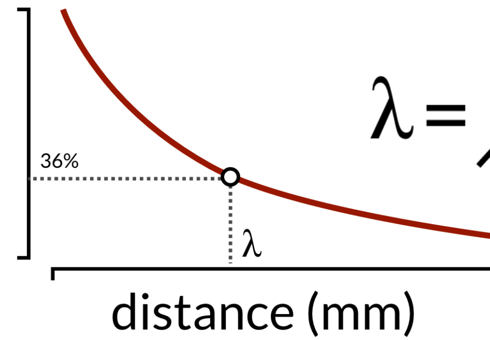
Instructors: Arnd Roth and Salvador Dura-Bernal

Passive Propagation



Time Constant

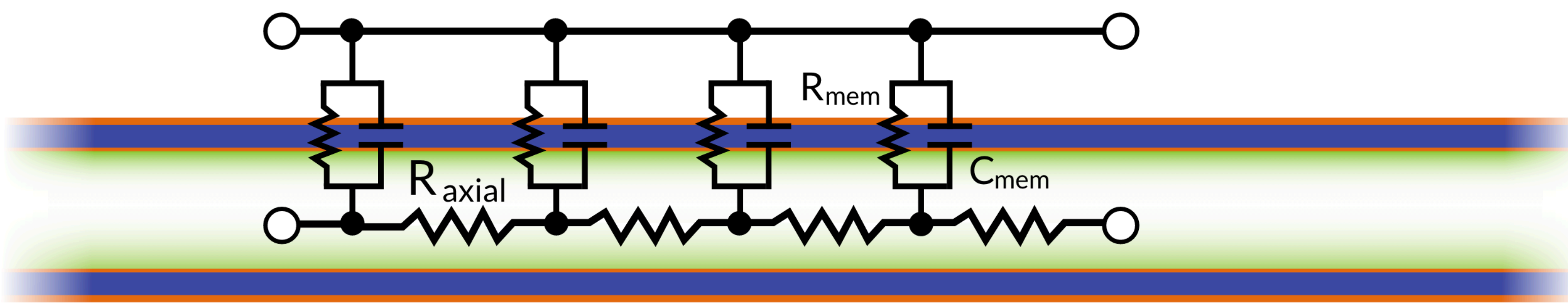
$$\tau = R_{mem} C_{mem}$$

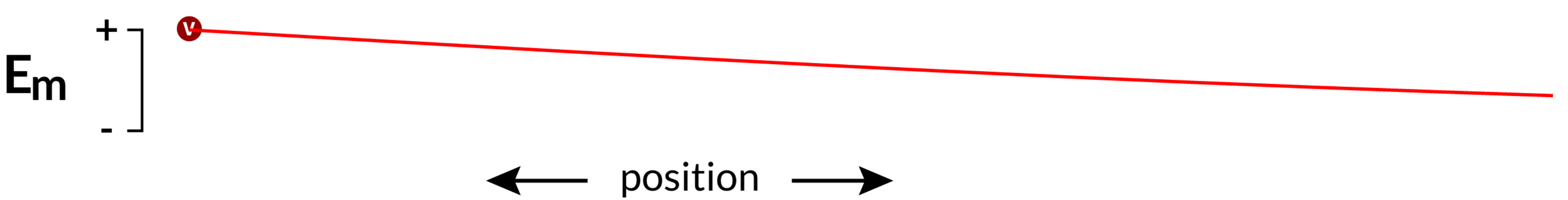


$$\lambda = \sqrt{\frac{R_{membrane}}{R_{axial}}}$$

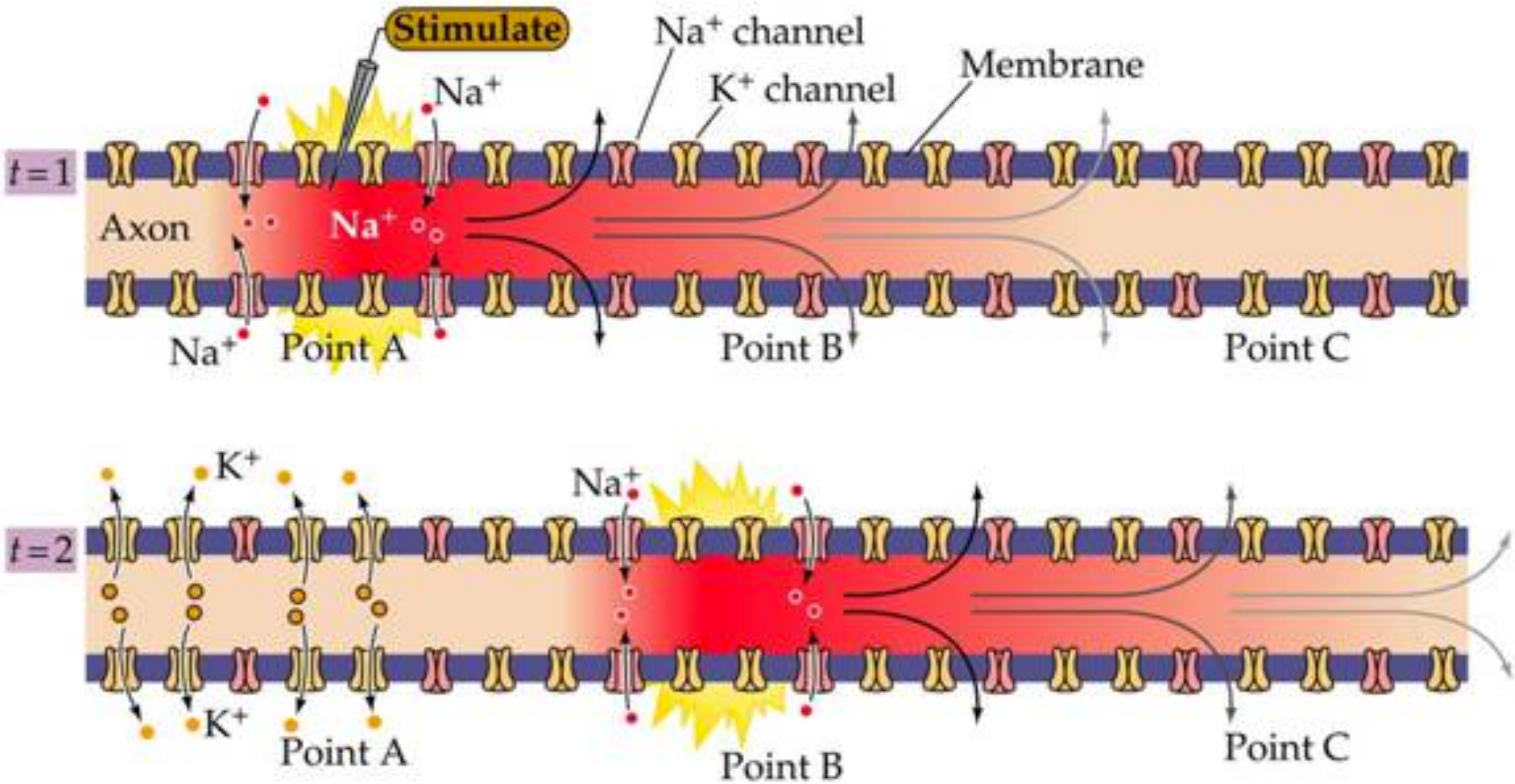
Ohm · cm

Ohm / cm

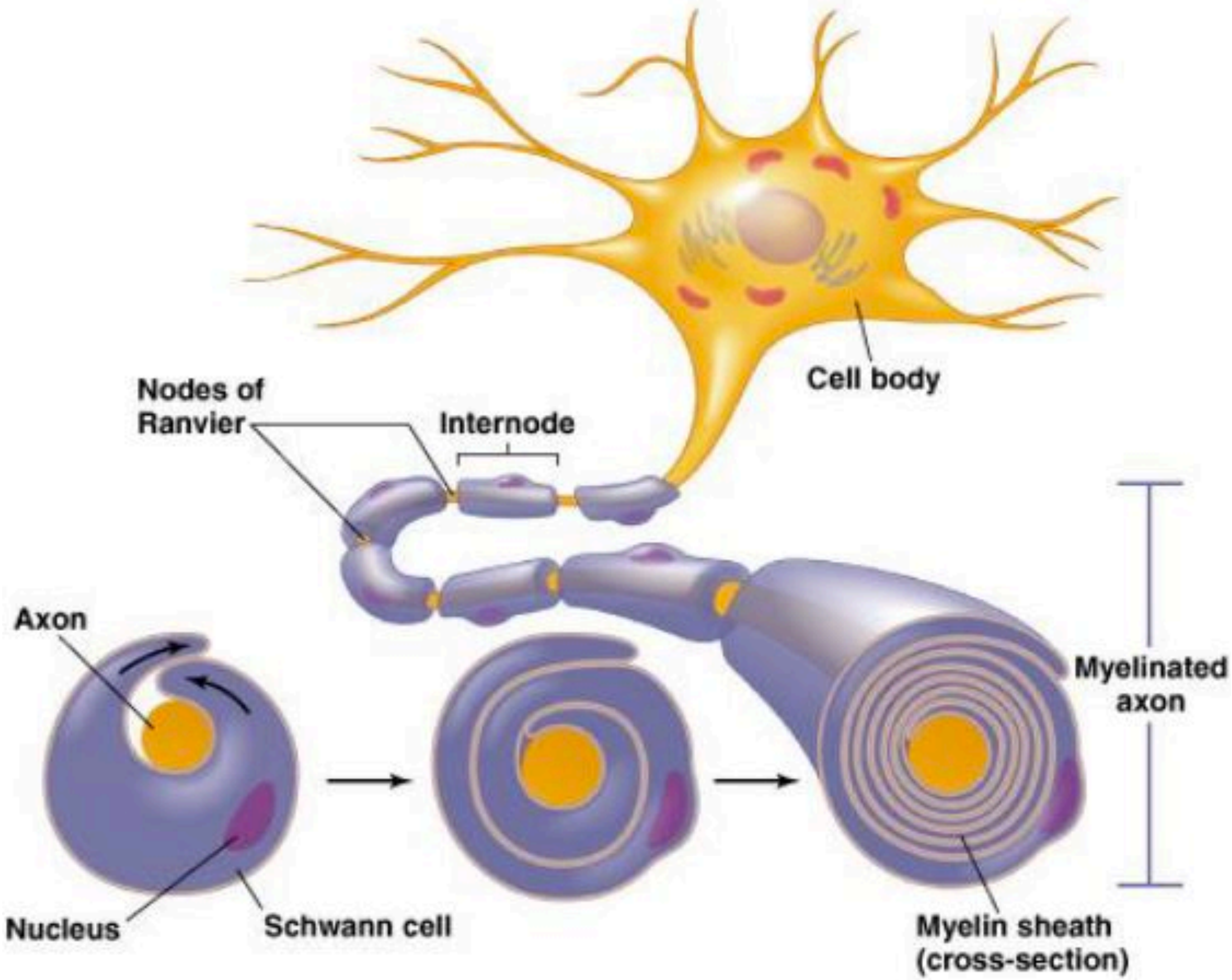




Unmyelinated Axon

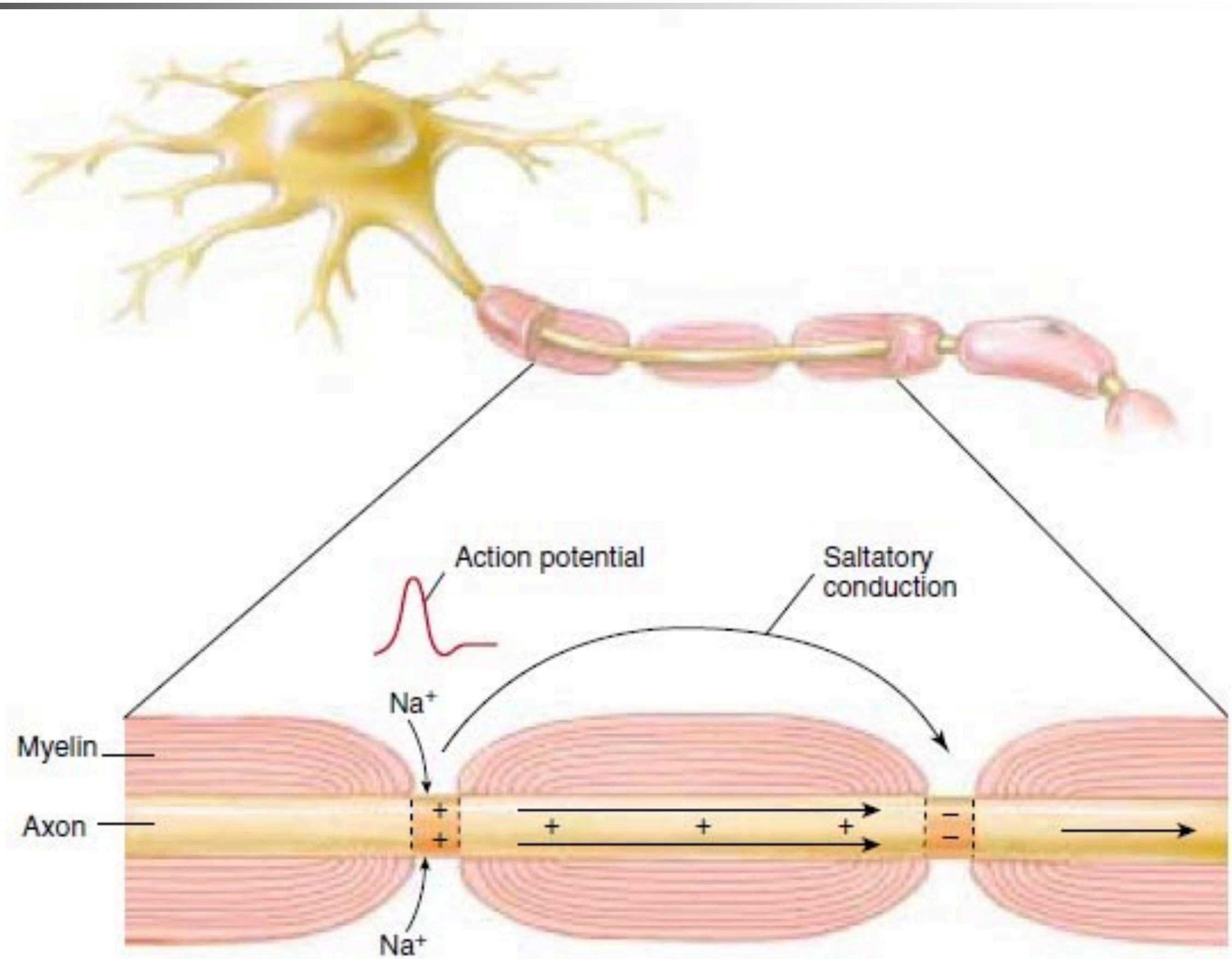


Action Potential Propagation



https://www.mcb80x.org/course/electrical_properties/action_potential_propagation/myelination_in_depth

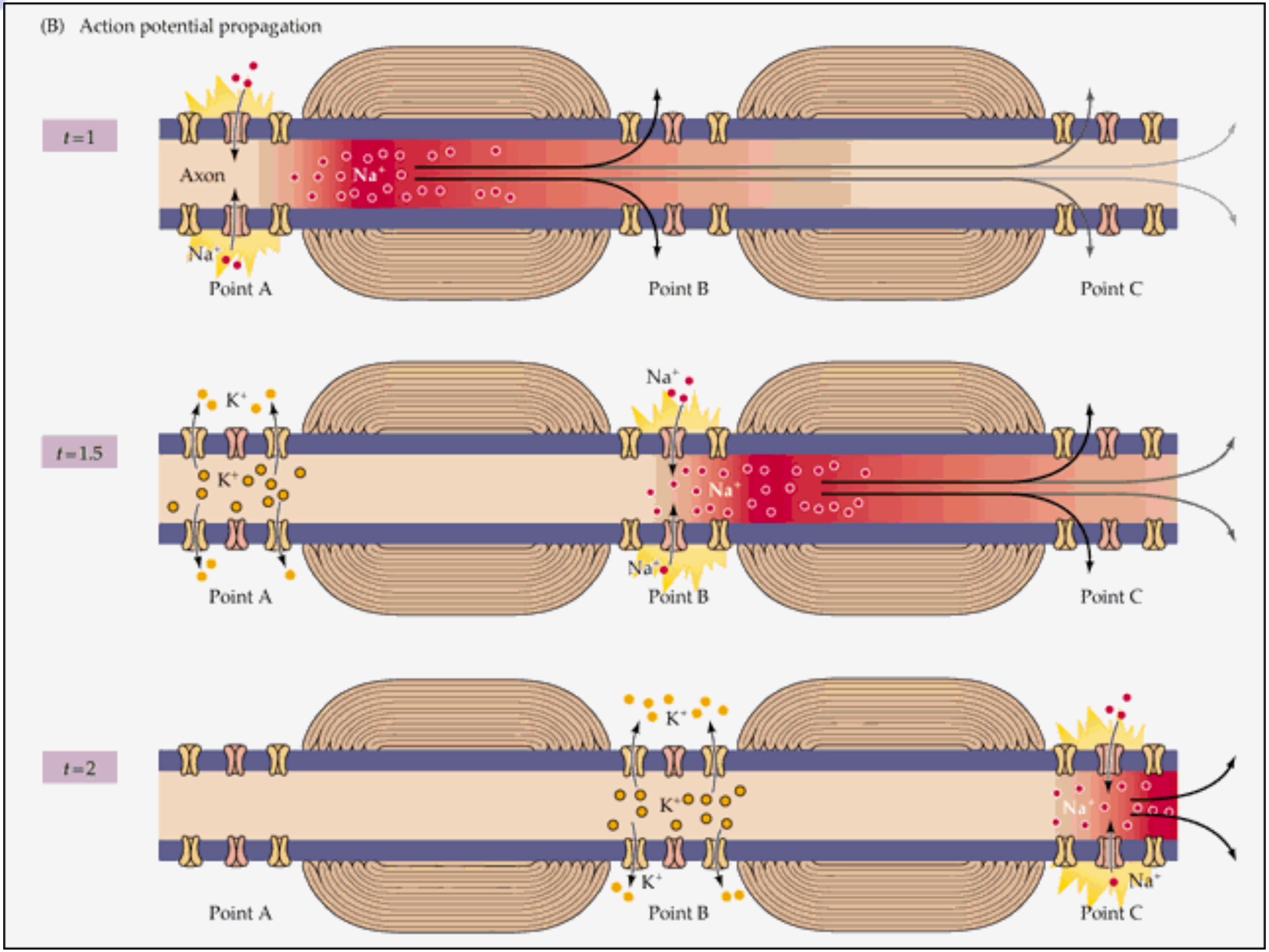
Myelinated Axon



0.2-2 mm
passive
high r_m
low c_m

1–2 μm
active

Myelinated Axon



Myelinated Axon

Axon: passive propagation

1. Start with tut3.py, but change the dendrite to an *axon*.
2. Keep its diameter at 1um, but increase its length to 1cm (axons can be as long as 1 meter!). axon.nseg = 1000
3. Keep only the current clamp stimulation, but change its parameters to: delay = 5ms, duration = 1ms, amplitude = 10nA at soma(0.1).
4. Replace the plotting code with the following code. Here we want to record the voltage at different spatial location of the axon to see how it propagates. So we create a list with the locations to record (0 to 0.1 in steps of 0.01), and another list to store the recorded vectors:

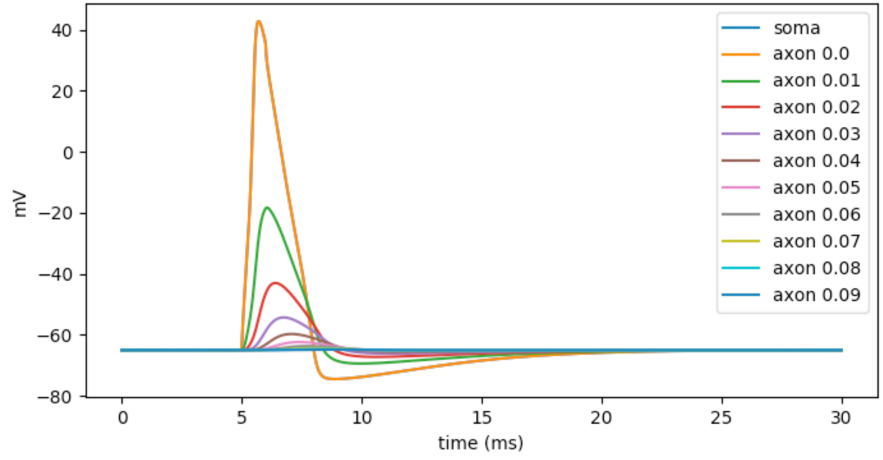
```
import numpy as np


t_vec = h.Vector() # record time
t_vec.record(h._ref_t)

v_vec_soma = h.Vector() # record soma
v_vec_soma.record(soma(1.0)._ref_v)

axon_locs = np.arange(0,0.1,0.01) # set axon recording times
v_vec_axon=[]
for loc in axon_locs:
     v_vec_axon.append(h.Vector())
     v_vec_axon[-1].record(axon(loc)._ref_v)
```

Axon: passive propagation

6. Change the simulation duration to 30 ms.
7. Replace the plotting code with the one below, which plots the soma and all the dendrite voltages recorded.

```
# plot voltage traces
pyplot.figure(figsize = (8,4))
pyplot.plot(t_vec, v_vec_soma, label = 'soma') # plot soma
for i,v_vec in enumerate(v_vec_axon): # plot axon
     pyplot.plot(t_vec, v_vec, label = 'axon '+str(axon_locs[i]))
pyplot.legend()
pyplot.xlabel('time (ms)')
pyplot.ylabel('mV')
pyplot.show()
```

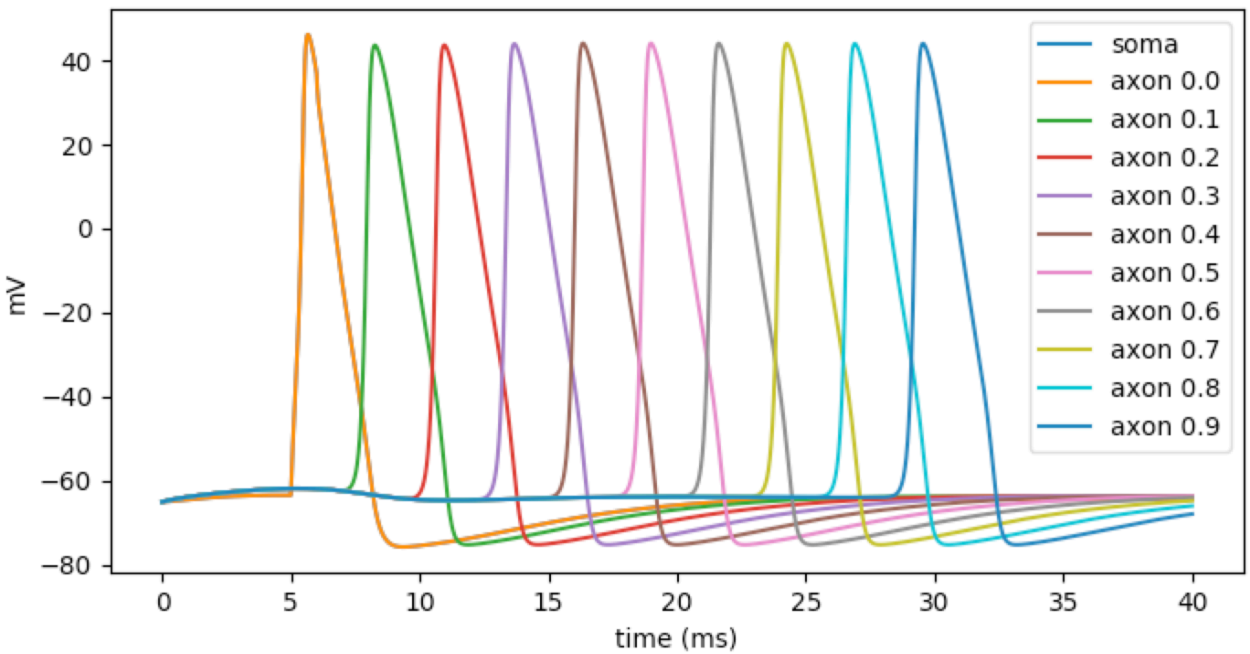
8. Run the simulation for passive propagation (no active channels in axon), and you should get this:



Axon: active propagation

Add the following code at the end of the code you already have:

1. Add active channels (hh) to the axon with the same values as for the soma.
2. Add again the code to record voltage, but this time record at axon locations from 0 to 1.0 at intervals of 0.1.
3. Add the code to run simulation and increase simulation duration to 40 ms
4. Add the same code as before to plot the voltages.
5. Run the simulation of an unmyelinated axon, you should get this:
6. Whats are we seeing??



Axon: myelinated propagation

Add the following code at the end of the code you already have.
Now we are going to add myelination and nodes of Ranvier to the axon.

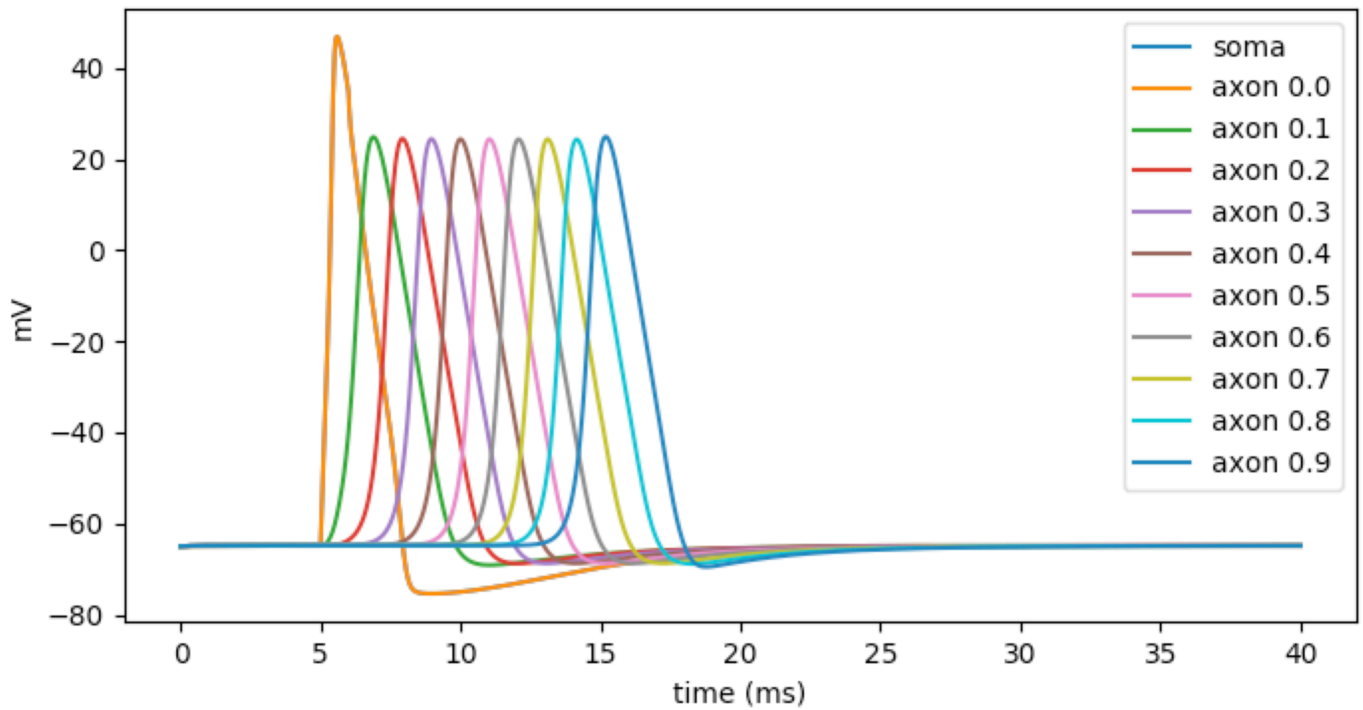
1. The first thing is to make the number of segments of the axon 10000, so that each segment is 1um in size.
2. Now make the whole axon myelinated. That means:
   - Setting the active (hh) channel conductances to 0.
   - Increasing the membrane resistance (decreasing membrane conductance)
   - Decreasing the membrane capacitance.

3. Now create nodes of Ranvier. We want to set them at intervals of 100 um. The Node of Ranvier is simply a segment with the original active channel properties. Use this code to implement them (try to understand it):

```
ranvierNodeInterval = 100 # interval to place Nodes of Ranvier (in um)
for segIndex in range(1, axon.nseg, ranvierNodeInterval):
    segIndexNorm = float(segIndex)/float(axon.nseg)
    axon(segIndexNorm).hh.gnabar = 0.3
    axon(segIndexNorm).hh.gkbar = 0.036
    axon(segIndexNorm).hh.gl = 0.0003
    axon(segIndexNorm).pas.g = 0.001
    axon(segIndexNorm).cm = 3
```

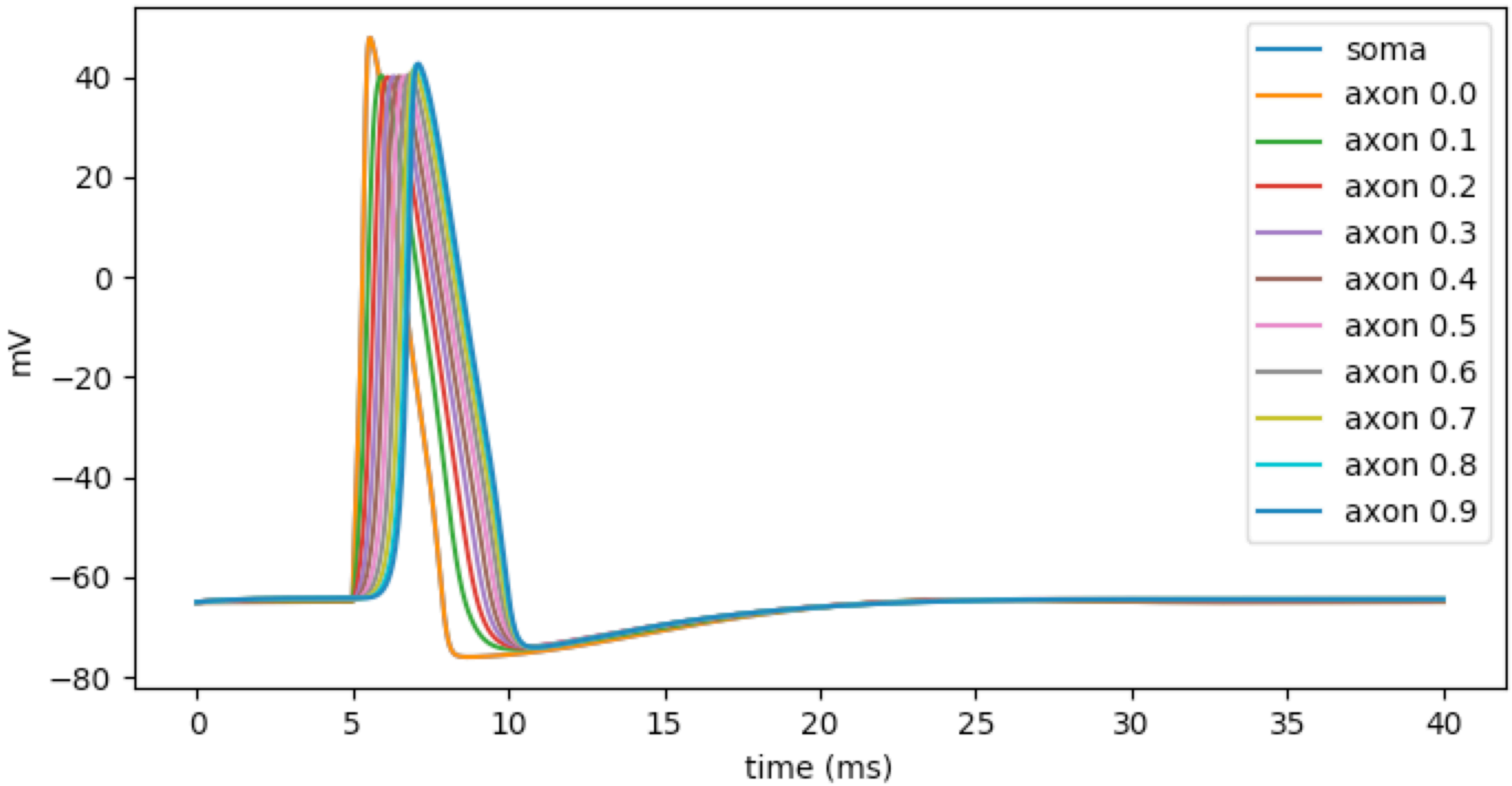
Axon: myelinated propagation

4. Add again the code to record voltage, and record at axon locations from 0 to 1.0 at intervals of 0.1.
5. Add the code to run simulation and increase simulation duration to 40 ms
6. Add the same code as before to plot the voltages.
7. Run the simulation of an myelinated axon, and with the correct values for mebrane resistance and capacitance of the myelinated sections, you should get this:
8. How does it compare to the unmyelinated spike propagation?



Axon: myelinated propagation

9. Change any values you want to try to increase the propagation speed of the action potential… see how fast you can get it! (it should be possible to reach values <5ms!



Passive Propagation

$$V_0 = I \cdot r_{in}$$

$$r_m(ohm) = \frac{R_m(ohm \cdot m)}{l(m)} = \frac{R_M(ohm \cdot m^2)}{\pi \cdot d(m) \cdot l(m)}$$

$$c_m(F) = C_m(F/m) \cdot l(m) = C_M(F/m^2) \cdot \pi \cdot d(m) \cdot l(m)$$

$$r_a(ohm) = R_a(ohm/m) \cdot l(m) = \frac{R_A(ohm \cdot m) \cdot 4 \cdot l(m)}{\pi \cdot d^2(m^2)}$$

r_m = membrane resistance in cylinder of diameter *d* and length *l* (ohm)

R_m = membrane resistance in section of diameter *d* (ohm·m)

R_M = specific membrane resistance (ohm·m^2)

r_a = axial resistance in cylinder of diameter *d* and length *l* (ohm)

R_a = axial resistance in section of diameter *d* (ohm/m)

R_A = specific axial resistance (ohm·m)

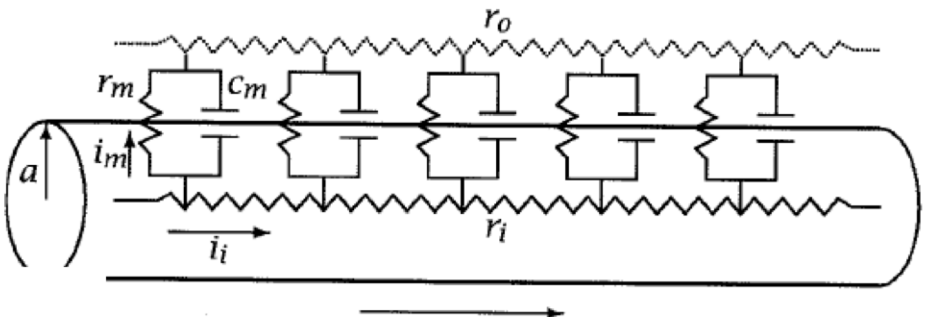
$$V(x) = V_0 \cdot e^{-x/\lambda}$$

$$\lambda = \sqrt{\frac{R_m(ohm \cdot m)}{R_a(ohm/m)}} = \sqrt{\frac{d(m)}{4} \cdot \frac{R_M(ohm \cdot m^2)}{R_A(ohm \cdot m)}}$$

$$V(t) = V_0 \cdot (1 - e^{-t/\tau})$$

$$\tau = R_m(ohm \cdot m) \cdot C_m(F/m)$$

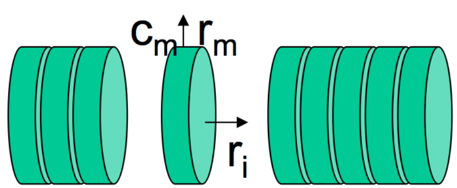
Passive Propagation



$$C_m = c_m l = \pi d l C_M,$$

$$R_m = r_m / l = \frac{R_M}{\pi d l}$$

$$R_a = r_i l = \frac{4 l R_A}{\pi d^2}.$$



e space constant,

$$\lambda = \sqrt{r_m / r_i} = \sqrt{(d/4) R_M / R_A}$$

ime constant,

$$\tau_m = r_m c_m = R_M C_M = R_m C_m.$$

	Unmyelinated Axon (UA)	Myelinated Axon (MA)
axoplasm resistivity	$\rho_{axoplasm} = 2.0\ \Omega{\cdot}m$	$\rho_{axoplasm} = 2.0\ \Omega{\cdot}m$
wall resistivity	$\rho_{UA} = 0.20\ \Omega{\cdot}m^2$	$\rho_{MA} = 40.0\ \Omega{\cdot}m^2$
wall capacitance/area	$C/A = 10^{-2}\ F/m^2$	$C/A = 5{\cdot}10^{-5}\ F/m^2$

Table 1. Useful constants.

Axon Propagation

	Unmyelinated Axon (UA)	Myelinated Axon (MA)
axoplasm resistivity	$\rho_{axoplasm} = 2.0\ \Omega\cdot m$	$\rho_{axoplasm} = 2.0\ \Omega\cdot m$
wall resistivity	$\rho_{UA} = 0.20\ \Omega\cdot m^2$	$\rho_{MA} = 40.0\ \Omega\cdot m^2$
wall capacitance/area	$C/A = 10^{-2}\ F/m^2$	$C/A = 5\cdot 10^{-5}\ F/m^2$

Table 1. Useful constants.