I. Before coming to lab

- Read this handout. Also review the background supplemental for Lab 3:Digital Circuits–especially the sections on breadboard layout, transistors, and LEDs.
- Carefully study the circuit presented in lecture for modeling a neuron ("The Neuron")

II. Learning Objectives

Using transistors, resistors, capacitors, and LEDs, you will model a part of the axon, with Na and K ion channels. You will show that your circuit works, and then connect it with the circuits built by your lab mates. Ultimately, you should be able to create an action potential that propagates from one circuit to the next.

III. Materials

You will be using the same basic circuit elements that you have used in previous labs. Consult the lab handouts for the previous labs for detailed information about these components; we have given a brief review below.

Box of loose wires
These are all various colors and lengths. We'll have a special use for the long yellow and green wires, so don't use those for your regular circuit connections.

Brand new breadboard
Make sure you use short wires to connect the top two rows and the bottom two rows. The columns are numbered; orient the board so that column 10 is on the left and column 60 is on the right.

Spare breadboard from Lab 3:Digital Circuits
Use this only as a spare board to test your transistors. DO NOT REMOVE THE IC CHIP!

Power supply
This should always be the last thing you connect and the first thing you disconnect.

LEDs
There are two kinds of LEDs, yellow and green. You can't tell which is which until you plug it in, so please try to keep them separate in the storage boxes. An LED will only light up if the current is flowing in the correct direction. With the LEDs we're using, the legs should be oriented so that positive current is flowing into the longer leg and out of the shorter one.

Capacitors
There is only one kind of capacitor. It's value is 1 microfarad (1 μF). It can be wired in either direction.

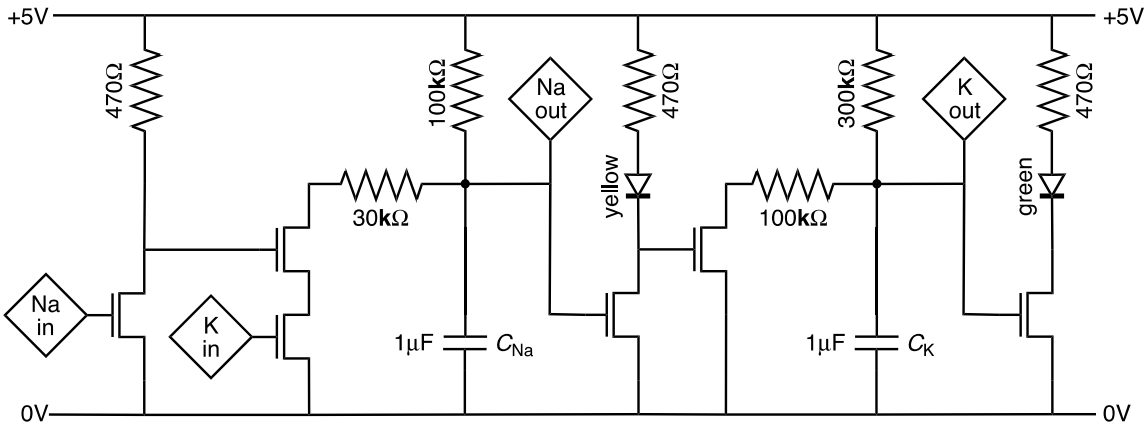
Vernier voltage probe
You will have two voltage probes, each with a red clip lead and a black clip lead. The black leads will typically be connected to the ground rail in your circuit, while the red clip leads will be connected wherever you wish to measure the voltage.

Resistors
You will be using four different resistors in this lab. They should be located in the correct boxes at your lab bench, but you should double-check the color codes.

value (Ohms)	colors
470	Yellow Purple Brown Gold
30k	Orange Black Orange Gold
100k	Brown Black Yellow Gold
300k	Orange Black Yellow Gold

Transistors
You will be using the same type of transistors that you used in Lab 3. These are fragile and can give confusing results when they malfunction. Stay away from the mangled old ones and always try to use fresh new ones. You will build a simple circuit on the spare breadboard so that you can test each transistor. Fan the drain and source legs out to the sides and bring the gate leg back to form a tripod.

Goal: Your goal in this lab is to build the complete neuron circuit shown below. Don't worry we'll do this in stages and test it as you go!

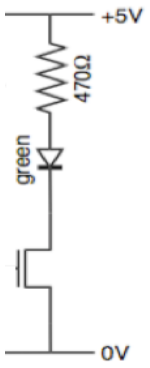


IV. Procedure
Tell us who you are. (photos and names!)
A:

Test the transistors

You will need a total of six transistors for the complete circuit. We will use the **spare breadboard** from Lab 3 to construct a simple circuit that can be used to test each transistor to make sure it is functioning properly.

With the power supply unplugged, construct the circuit below.

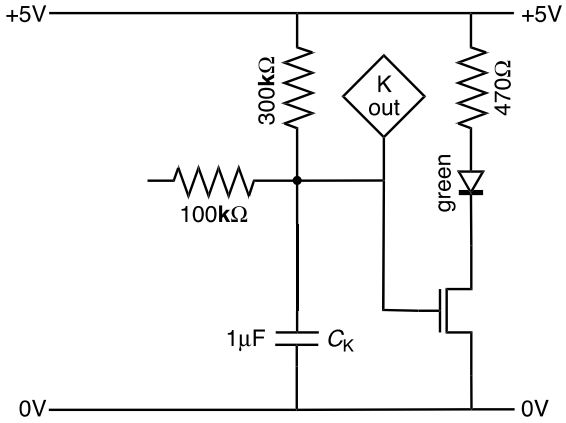


Take a long orange wire and connect one end to the gate of the transistor and the other end to the +5V rail. Plug in the power supply. The LED should be on–if it is not on then unplug the power supply and check your wiring (make sure the LED is oriented properly, with the long leg connected to the resistor).

Next, take the orange wire out of +5V and connect it to ground. The LED should be **completely** off–if it is not completely off then unplug the power supply, twist up the legs of the transistor, and throw it in the trash.

Build the K channel

On the rightmost third of the **new breadboard**–between the 40th and 60th columns–construct the following circuit (with the power unplugged):



Test the K channel

With the left end of the 100k resistor unconnected to the board, plug in the power. If you wired everything correctly, the green LED should light up. If you then connect the left end of the 100k to ground, the LED should go completely out.

Take K channel data

Take one of the voltage probes and connect the black lead to a wire sticking out of ground, and connect the red lead to a long green wire sticking out of the point labeled "K out" in the diagram. Start up Logger Pro and set Data Collection to collect 1000 data points per second for a total of 15 seconds.

Plug in the power and start collecting data. While you are collecting, connect the end of the 100k resistor to ground, hold it there for a few seconds, and then release it so it is no longer grounded.

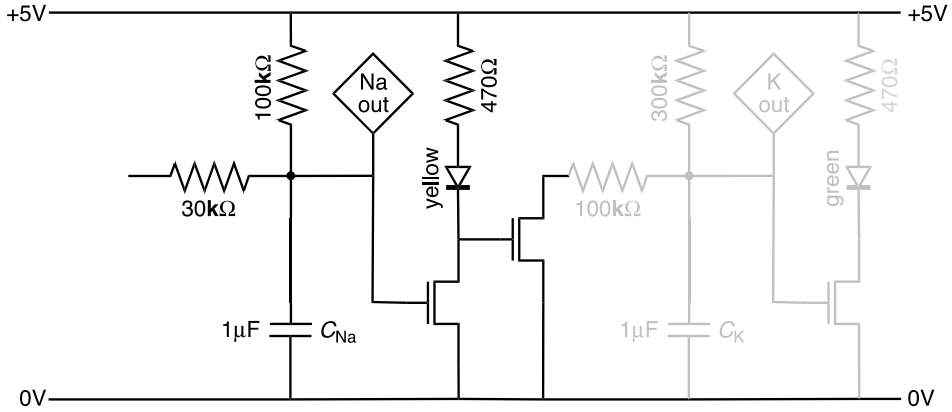
Take a screenshot of your Logger Pro graph and paste it here:
A:

You should have seen that the voltage started off at about +5V, dropped smoothly down to about +1.5V when you grounded the resistor, and then increased smoothly again towards +5V when you released it.

What happened to the LED when you grounded the resistor and released it?
A:

How does that correspond to what you saw in the voltage graph?
A:

Build the Na channel
Unplug the power, disconnect the voltage probe, and remove the green wire from "K out." The Na channel is very similar to the K channel you just made. Add the circuit elements shown below to build the Na channel. Use the center third of the board between the 20th and 40th columns. The new elements are shown below in black, while the previous K channel elements are shown in gray:



Be careful to note the different resistor values!

Test the Na channel by itself
Disconnect the K channel's 100k resistor from the Na channel (you can just connect it to ground for now).

With the left end of the Na channel's 30k resistor unconnected to the board, plug in the power. If you wired everything correctly, the yellow LED should light up. If you then connect the left end of the 30k resistor to ground, the yellow LED should go completely out.

Test the Na and K channels together
Unplug the power supply. Connect the K channel's 100k resistor to the Na channel. With the left end of the Na channel's 30k resistor connected to ground, plug in the power supply. The yellow and green LEDs should both be completely off.

Take K and Na channel data
Connect the black leads from **both** voltage probes to your circuit ground. Connect one of the red probes to a long yellow wire sticking out of the point labeled "Na out" in the diagram. Connect the other red probe to a long green wire sticking out of "K out." **Make a note of which probe is which (e.g. K is "Potential 1" and Na is "Potential 2").**

Start collecting data. While you are collecting, connect the end of the 30k resistor to ground, hold it there for a few seconds, and then release it so it is no longer grounded.

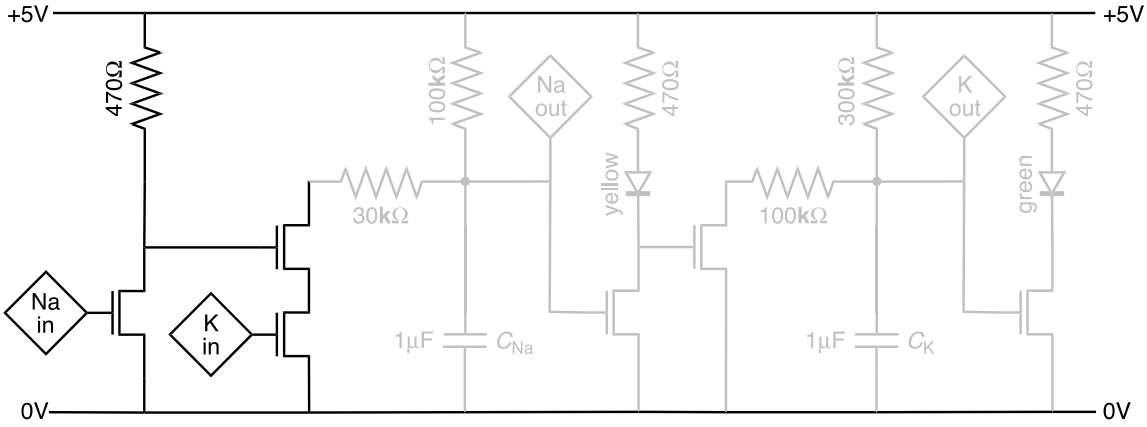
Take a screenshot of your Logger Pro graph and paste it here:
A:

You should have seen that **both** voltages started off at about +1.5V, increased smoothly to about +5V when you grounded the resistor, and then decreased smoothly again to +1.5V when you released it from ground. You should also note that the changes in the Na voltage **precede** the changes in the K voltage. The Na voltage **drops first and falls faster** than the K voltage. Then, when you release the resistor from ground, the Na voltage **rises first and increases faster**. This is an important part of the model: in the axon, the opening and closing of the Na channels precedes the K channels. If you are not sure if your circuit is working correctly, please consult with your TF.

What happened to the LEDs when you grounded the resistor and released it?
A:

How does that correspond to what you saw in the voltage graph?
A:

Build the input logic
Unplug the power supply and disconnect the voltage probe leads. Add the circuit elements shown below to build the input logic elements, which determine when this circuit should "fire" based on the input from the neighboring circuit. The new elements are shown below in black, while the previously-built Na and K channel elements are shown in gray:



The point labeled "Na in" should have a long **yellow** wire sticking up out of the board, while the point labeled "K in" should have a long **green** wire sticking up out of the board.

Test the input logic
The "Na in" and "K in" are inputs to a digital logic gate. Test that the digital logic works correctly by constructing a "truth table" for each of the possible input combinations. Connect the yellow "Na in" and green "K in" wires to ground (0V) or +5V in each possible combination below, and note what happens to the LEDs.

Fill out the results of your truth table here:

Na in	**K in**	**LEDs (on or off)?**
0V	0V	A:
0V	5V	A:
5V	0V	A:
5V	5V	A:

You should have found that **only one combination** of inputs will turn the LEDs off.

Take your final circuit board and hold it up to the Photo Booth camera, and **paste a picture of your final circuit below:**
A:

Modeling the action potential
To measure the action potential, take one of the Logger Pro probes. Connect the **red** lead to the **green** "K out" wire and the **black** lead to the **yellow** "Na out" wire. The other probe will not be connected.

Connect the green "K in" wire to +5V.

Take your non-dominant hand (for most folks, your left hand) and hold one of the exposed **resistor** leads that is connected to the +5V rail. Keep holding on to that lead.

Take your dominant hand, and hold the metal end of the **yellow** "Na in" wire. You should see both LEDs light up. (We are using **you** as a resistor here!)

While still holding the metal end of the yellow "Na in" wire, briefly touch that wire to one of the exposed **capacitor** leads that is connected to the **ground rail**. You should see the LEDs flicker off briefly as you bring the wire in contact with ground.

Start collecting data in Logger Pro, and while collecting, **very briefly** touch the **yellow** "Na in" wire to one of the exposed grounded capacitor leads. Repeat this a few times. You should see "action potentials" in your Logger Pro graph each time you bring the "Na in" wire in contact with ground. **Take a screenshot of your Logger Pro graph and paste it here:**
A:

Connecting your circuit to the other circuits
Once you have confirmed that your axon circuit is working properly, disconnect the Logger Pro leads and remove the power supply leads from your circuit.

Bring your circuit up to your TF and wire it in with the other circuits built by your lab mates. You will have to connect **four wires** between each pair of neighboring circuits:

Red:	+5V to +5V
Black:	ground to ground (0V)
Yellow:	"Na out" to "Na in"
Green:	"K out" to "K in"

Confirm with your TF that you can get a signal to propagate from one circuit to the next.

Cleaning up
Before leaving, please clean up your lab station and **return any unused wires and components** to the proper locations in the storage boxes.

V. Conclusion

What is the most important thing you learned in lab today?
A: