1) Match these cellular elements to their equivalent circuit elements:

- Resistor: Lipid bilayer
- Capacitor: Ionic concentration gradient
- Battery: Ion channel
- Voltage source: Transmembrane voltage

2) Imagine this circuit. There is a switch that can be flipped to connect or disconnect the voltage source to the rest of the circuit. What is the total current flow across the “membrane” right after the switch is thrown? What about 1 year after the switch is thrown? Can you write the full equation for the current flow as a function of time?

Right after the switch is flipped, the total membrane current is:

\[ I_m = C \frac{dV}{dt} + g_{Na^+} V + g_{K^+} V \]

After one year, probably all the charge is dissipated from the capacitor. Then:

\[ I_m = (g_{Na^+} + g_{K^+}) V \]
3) What could you ever hope to understand by voltage-clamping a cell?

One thing you can tell is the magnitude and time course of currents that are active when the cell is at a certain voltage. If you think about what we learn from voltage clamp experiments of a cell, the current measured reflects the currents that flow when the cell is going through voltages similar to the one at which you clamped the cell. In other words, if you clamp to voltages like 0mV, you’ll measure an initial inward current followed by a slow, long lasting outward current. This in fact is what goes on during an action potential when the voltage crosses 0mV.

4) The current voltage relationship for a sodium ion channel is:

\[ I_{Na^+} = g_{Na^+} (V - E_{Na^+}) \]

The I-V curve of a sodium ion channel generated by a series of voltage-clamp experiments is below:

Try to think about five things:

a) Are there many sodium channels open when the voltage is very negative? 
No

b) When are about all of the sodium channels open? 
Maybe at voltage clamps to around –20mV or so

c) Why is the current negative for part of the curve?
Because for those voltages, the current flow for voltage is clamped to a voltage more negative than the sodium reversal potential so the direction of current flow will be into the cell, hence a negative current.

d) What is the reversal potential for sodium channels?
   About +40mV

e) For voltage clamps between about –10 mV and +40 mV, why does the current get progressively smaller?
   At those voltage clamps, even though the sodium conductance is at a maximum (all the sodium voltage-gated channels are open), V-E\textsubscript{Na} is getting progressively smaller. There is less and less of a driving force for the sodium current.