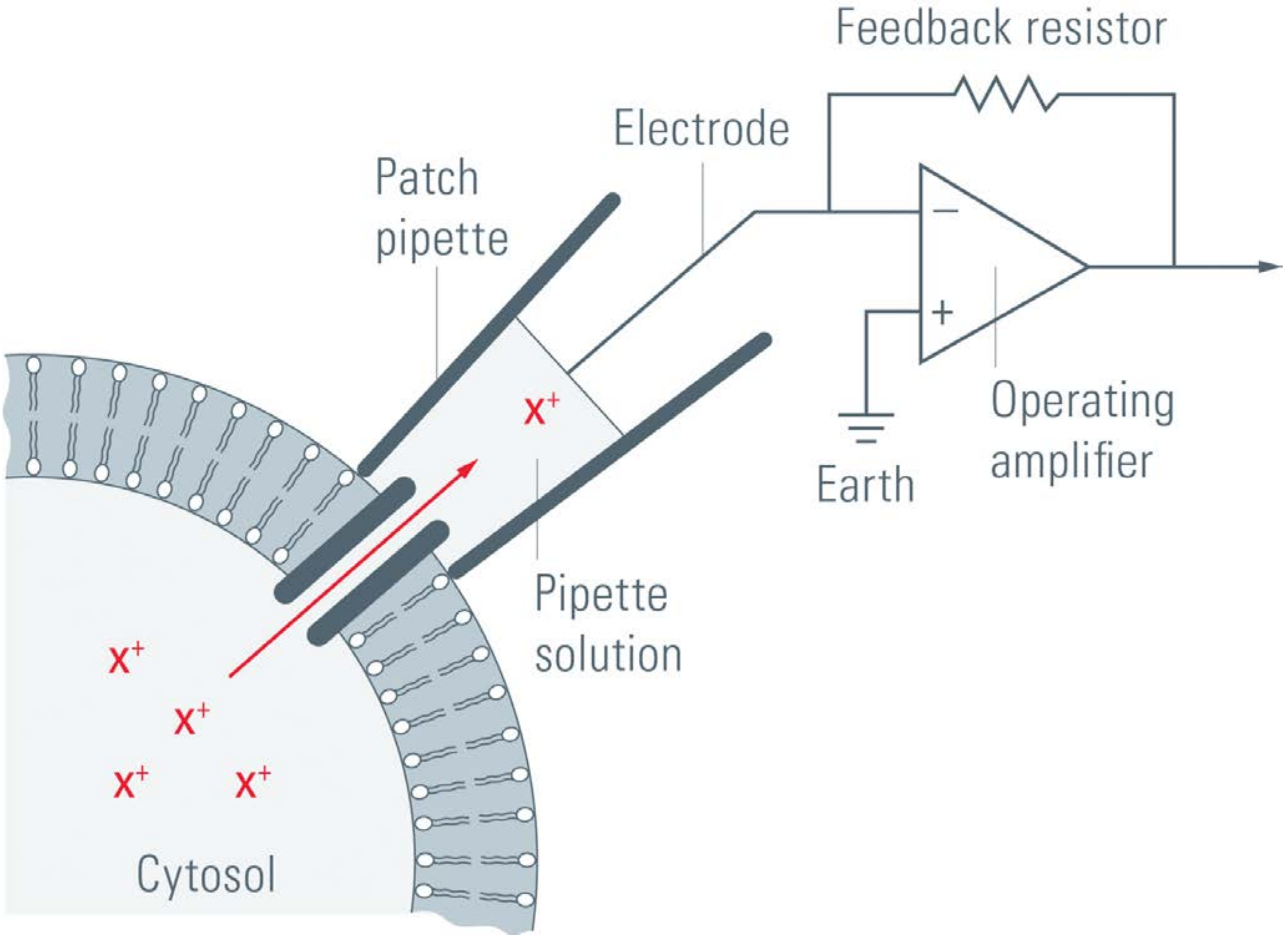
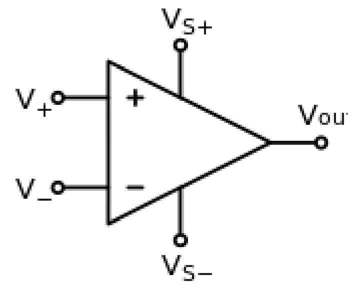
Electrophysiological Recording Techniques



Operational Amplifier – The Heart of Electrophysiological Amplifier



$V_{out} = Gain * (V_+ - V_-)$
Gain is very large, therefore
$V_+ - V_- = 0$
$V_+ = V_-$

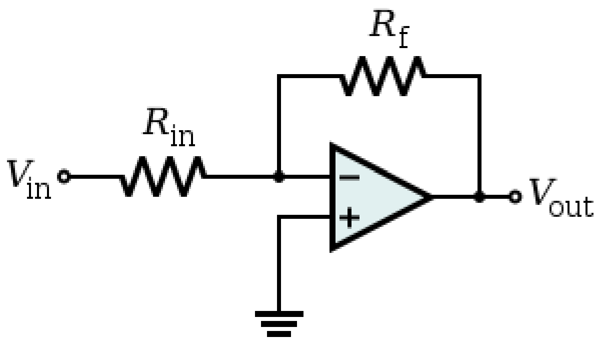
***V_+*: non-inverting input**
***V_-*: inverting input**
***V_{out}*: output**
V_{S+}: positive power supply
V_{S-}: negative power supply

The golden rules of op-amp:

1. Voltage difference between inputs is zero.
2. The inputs draw no current.

Operational Amplifier

Inverting Amplifier

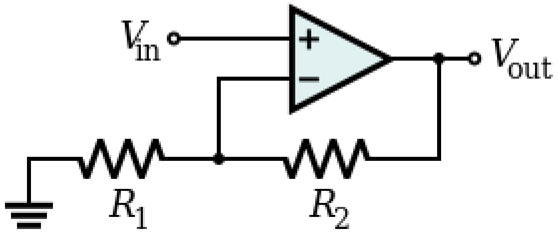


$$V_- = V_+ = 0$$

$$\frac{V_{out}}{R_f} = -\frac{V_{in}}{R_{in}}$$

$$V_{out} = -V_{in}\frac{R_f}{R_{in}}$$

Non-inverting Amplifier

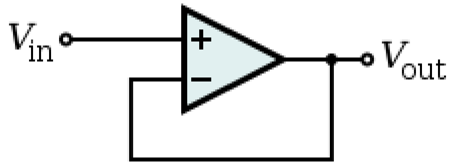


$$V_- = V_+ = V_{in}$$

$$\frac{V_{out}}{R_1 + R_2} = \frac{V_{in}}{R_1}$$

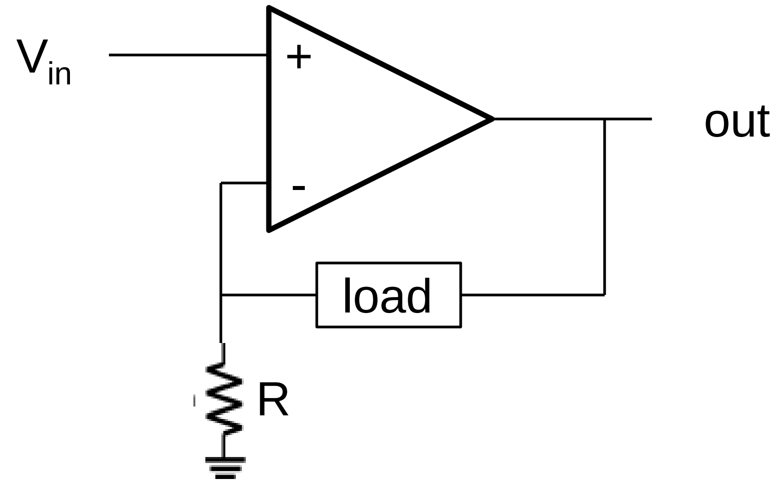
$$V_{out} = V_{in}\frac{R_1 + R_2}{R_1}$$

Voltage Follower



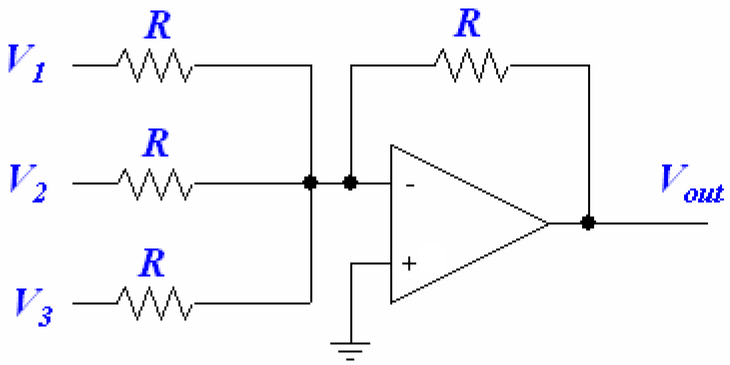
- The op-amp has an input resistance many orders of magnitude greater than that of the micropipette and the cell.
- The output voltage follows what is at the tip of the micropipette.
- The current through the micropipette is “clamped” at zero.

Current Source



$$I = \frac{V_{in}}{R}$$

Summing Amplifier



$$\frac{V_{out}}{R} = \frac{V_1}{R} + \frac{V_2}{R} + \frac{V_3}{R}$$

$$V_{out} = V_1 + V_2 + V_3$$

Bridge Balance Technique

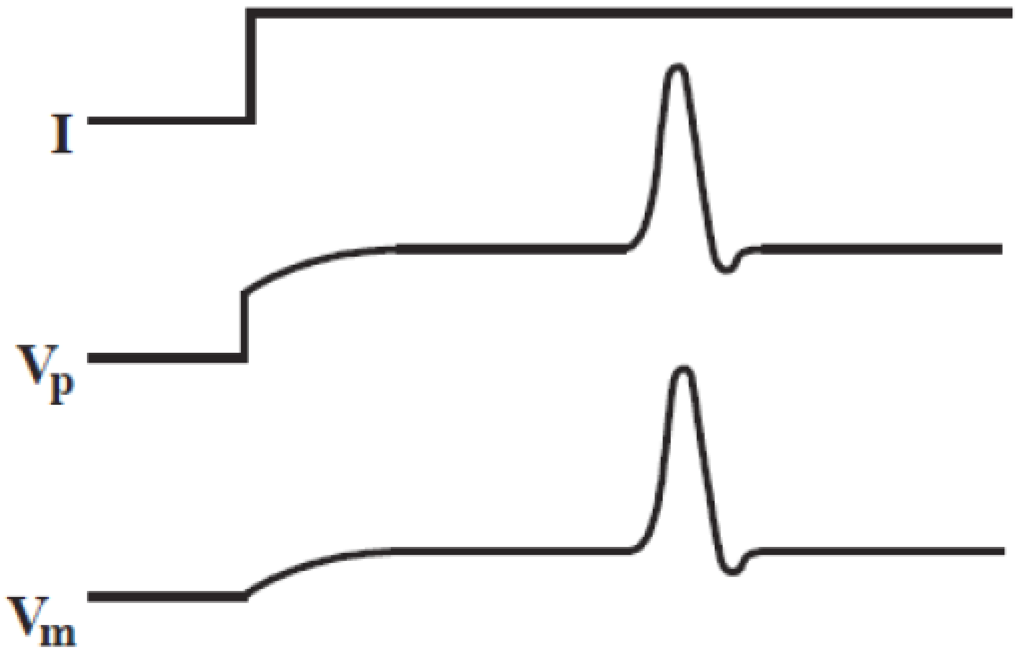
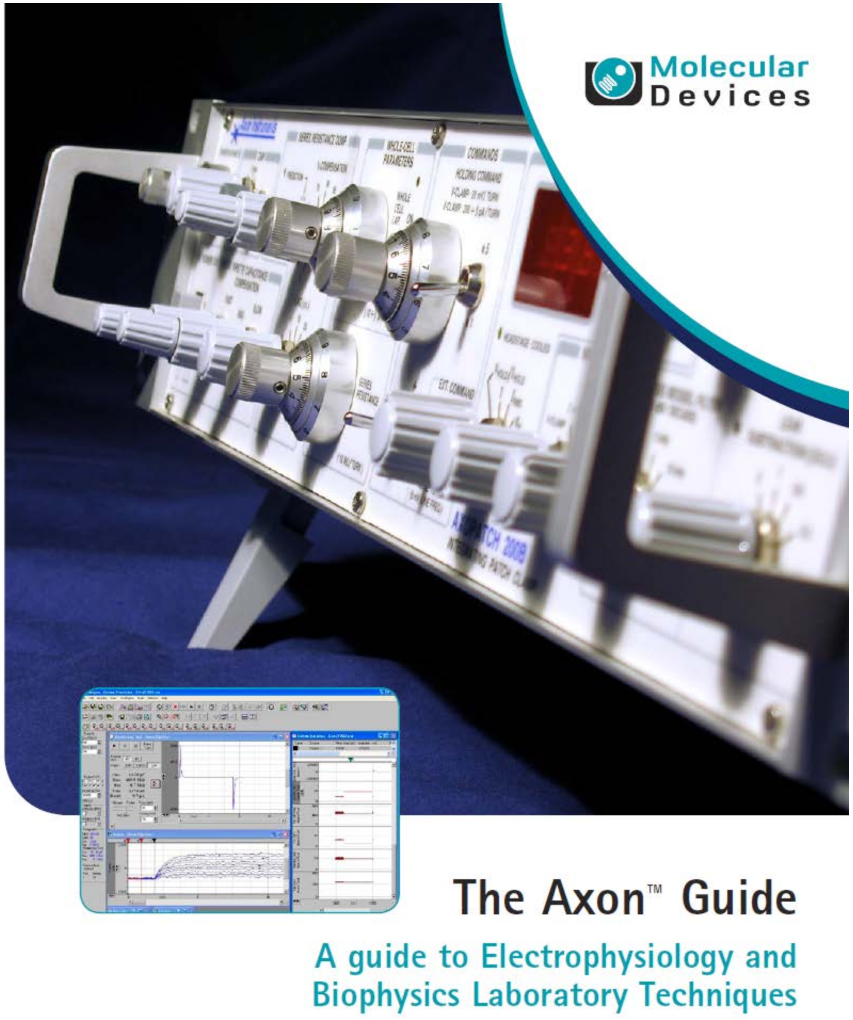
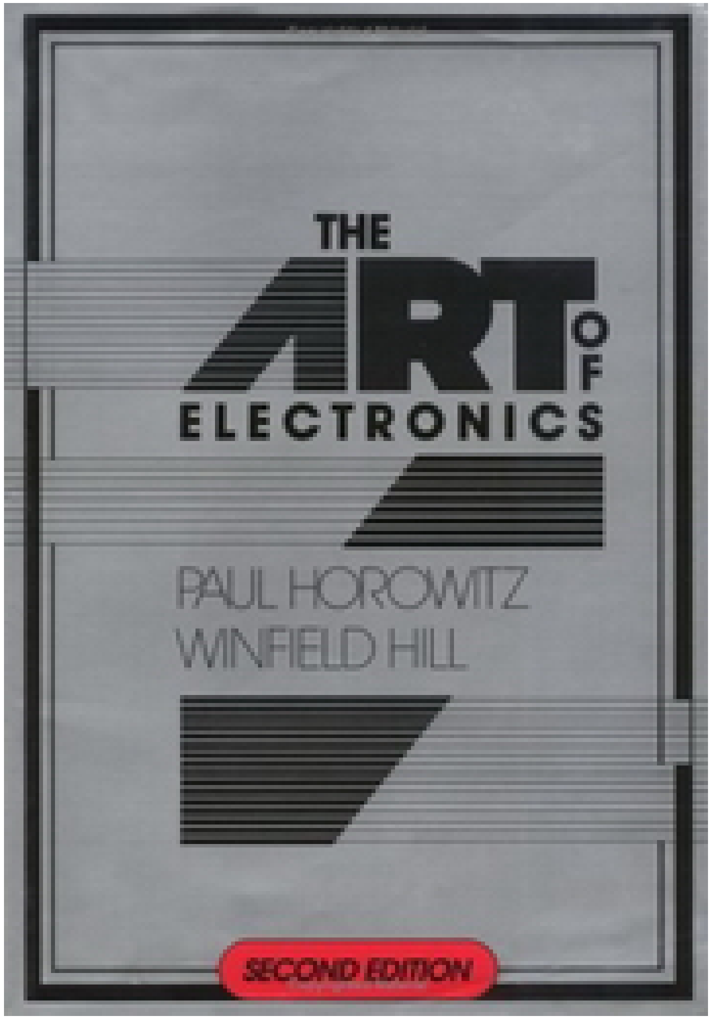


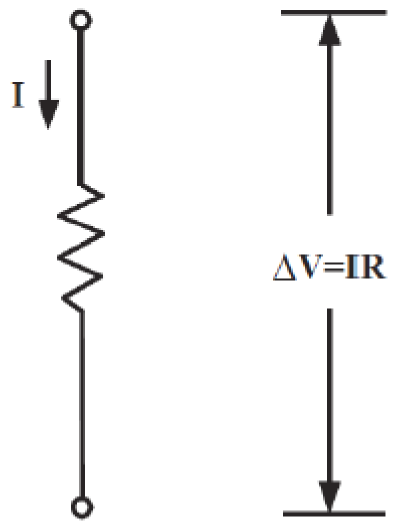
Figure 3-3 The "Bridge Balance" technique.

Two Excellent Sources of Electronics and Amplifiers





Ohm’s Law

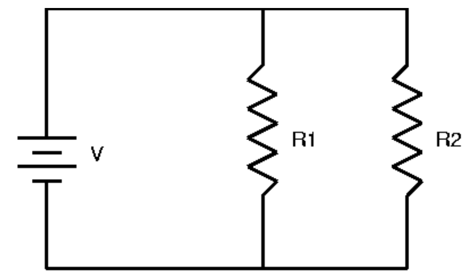


Kirchhoff's Laws

Kirchhoff's current law:
The sum of currents into a node equals the sum of currents out.

$$I_1 + I_2 = I$$

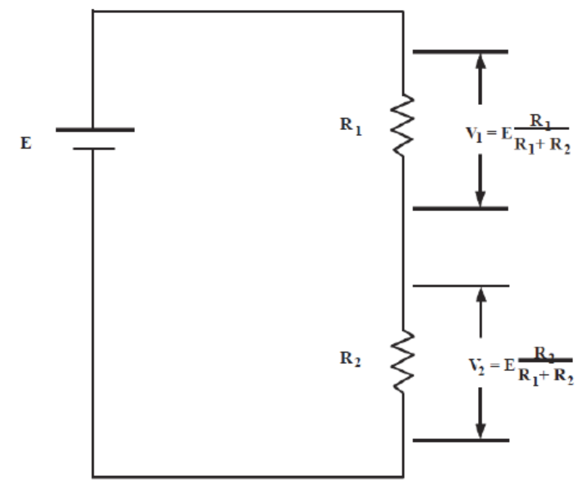
$$\frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{R}$$



Kirchhoff's voltage law:
The sum of the voltage drops around a closed circuit is zero.

$$\Delta V_1 + \Delta V_2 = E$$

$$R_1 + R_2 = R$$



Axon Guide, 2012

Capacitor – two conductive surfaces separated by a nonconductive material

Biological membrane is a capacitor

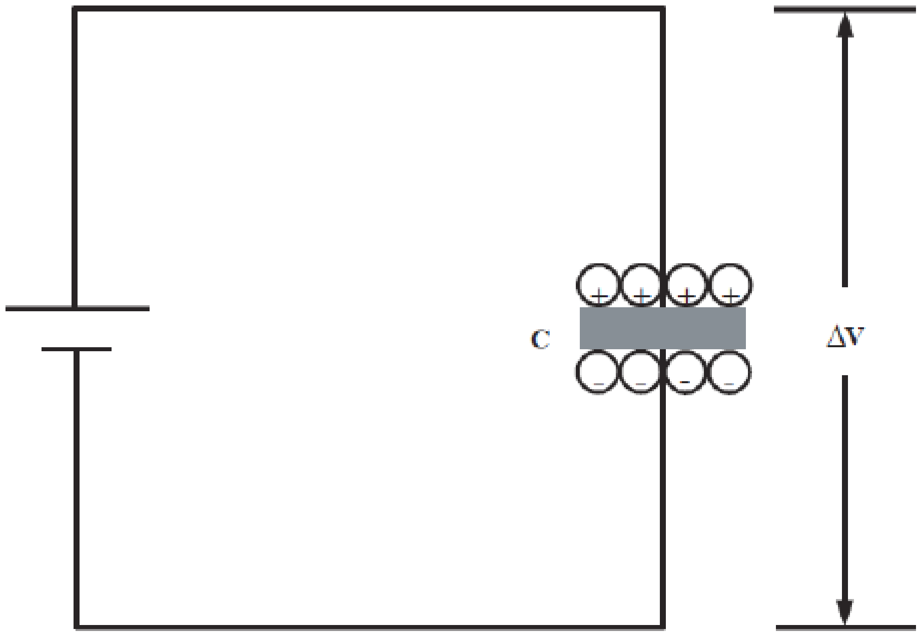


Figure 1-11 Capacitance. A charge Q is stored in a capacitor of value C held at a potential ΔV.

$$Q = C\,\Delta V$$

Charge = Capacitance x Potential

Capacitor is proportional to the area and inversely proportional to the distance between the two conductive layers. Biological membrane: 1 μF/cm^2

- Resistors consume energy. V = IR. P = IV.
- Capacitors store energy. Q = CV.
- Current passing through a resistor is proportional to the voltage drop.
- Current passing through a capacitor is proportional to the rate of voltage change. $I = \frac{dQ}{dt} = C\frac{dV}{dt}$

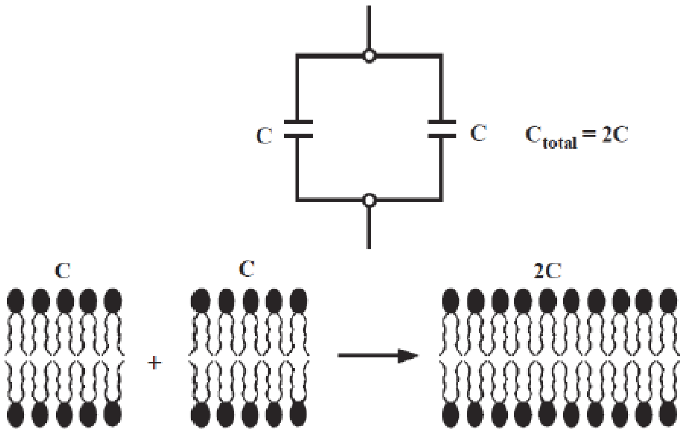


Figure 1-12 Capacitors in parallel add their values.

Capacitors in parallel

$$Q = Q_1 + Q_2$$
$$CV = C_1V + C_2V$$
$$C = C_1 + C_2$$

Capacitors in series

$$V = V_1 + V_2$$
$$\frac{Q}{C} = \frac{Q}{C_1} + \frac{Q}{C_2}$$
$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

Neuron as an RC Circuit

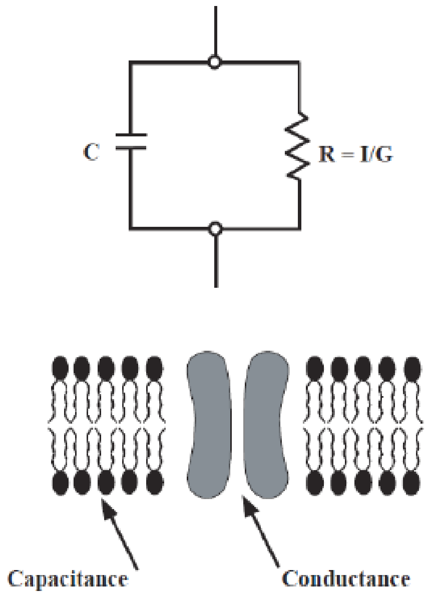
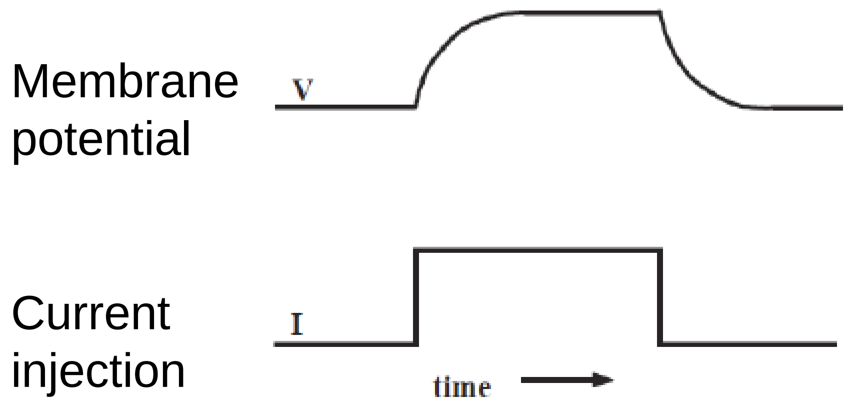


Figure 1-13 Membrane behavior compared with an electrical current. A membrane behaves electrically like a capacitance in parallel with a resistance.



$$V = I_R R = R(I - C\frac{dV}{dt})$$

$$V(t) = V_{inf}\ (1\ -\ e^{-t/\tau})$$

$$V_{inf} = I\ R$$

$$\tau = R\ C$$