Batteries have internal resistance, so we write:

$$\Delta V - IR = \mathcal{E} - Ir - IR = 0.$$

Resistances in series:

$$R_{\text{tot}} = \sum_i R_i.$$

Resistances in parallel:

$$\frac{1}{R_{\text{tot}}} = \sum_i \frac{1}{R_i}.$$

Networks of resistors: Identify groups, combine, and continue to combine until you are left with one equivalent resistor.

Kirchhoff's Circuit Rules:

(1) At any circuit junction, $(\sum_i I_i)_{\text{in}} = (\sum_i I_i)_{\text{out}}$. **Charge is conserved.**

(2) Around any circuit loop, $(\sum_i \Delta V_i)_{\text{rises}} = (\sum_i \Delta V_i)_{\text{drops}}$. **Energy is conserved.**

Guess a current direction. Then, look at the various loops in the circuit.

• if you loop with the current, then $\Delta V < 0$ across any resistor.

• If you loop against the current, then $\Delta V > 0$ across any resistor.

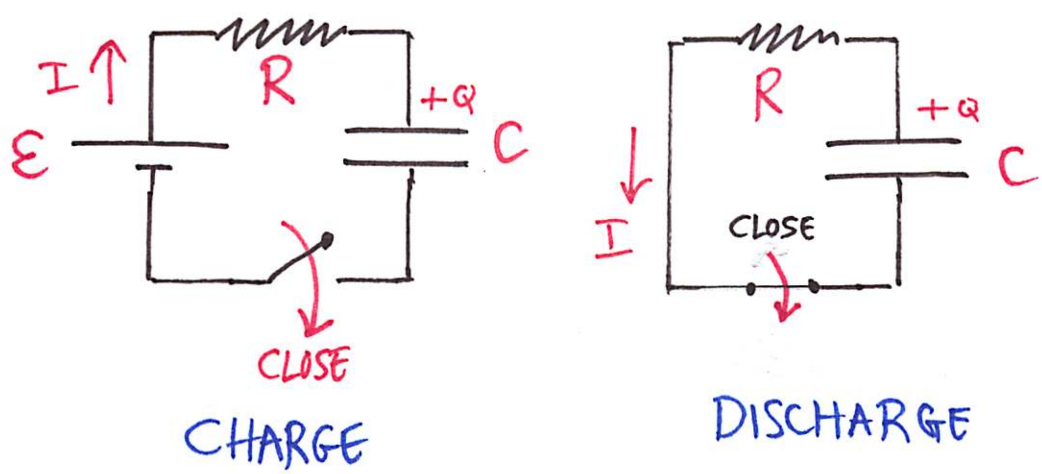
• If you loop with the current, then $\Delta V = \mathcal{E}$ across any battery.

• If you loop against the current, then $\Delta V = -\mathcal{E}$ across any battery.

RC Circuit:

Charging: $q(t) = Q[1-\exp(-t/RC)]$ where $Q = C\mathcal{E}$.

Discharging: $q(t) = Q\exp(-t/RC)$ where $Q = C\mathcal{E}$.



Charging capacitor in RC circuit:

$$V_C = \mathcal{E}\left[1 - \exp(-t/RC)\right] \text{ and } V_R = \mathcal{E}\exp(-t/RC).$$

Discharging capacitor across R:

$$V_C = \frac{Q}{C}\exp(-t/RC),\ I(t) = -\frac{Q}{RC}\exp(-t/RC)$$

$$\text{and } V_R = -\frac{Q}{C}\exp(-t/RC).$$