**Recap**

- **Electrical Resistance**: 
  
  \[ R = \frac{\Delta V}{\text{over resistor}} \]
  
  \[ \text{Resistance: } R = \frac{\Delta V}{\text{current } i} \]

- **Resistivity/conductivity**: 
  
  \[ \sigma = \frac{1}{\rho} \]
  
  Conductivity \( \sim \) Resistivity

- TEMPERATURE DEPENDENCE:
  
  \[ \rho(T) = \rho(T_0)[1 + \alpha DT] \]
  
  Temperature coefficient of resistivity

- For wire:
  
  \[ R_{\text{wire}} = \frac{\rho L}{A} \]

**Lecture 12**

- **High Pot.** \( q > 0 \)
  
  \[ \Delta V = q \]

- **Low Pot.** \( q < 0 \)
  
  \[ \Delta V = -q \]

- **Energy for** \( \Delta V = q \)
  
  \[ \text{Energy for } \Delta V = q \]
  
  \[ q > 0 \]

- **Electric Potential Energy is Transformed to Other Forms of Energy**
  
  \[ P_{\text{el}} = i \Delta V = iR^2 = \frac{\Delta V^2}{R} \]
  
  Current
Today:

- “Pumping charges”: emf
- RC circuits
What should be the value of $R_{\text{eff}}$ in terms of $R_1$, $R_2$, & $R_3$ so that the same current flows in both circuits?

**Current:**  $i = i_1 = i_2 = i_3$

**Add Voltage:**  $\Delta V_{\text{bat}} = \Delta V_1 + \Delta V_2 + \Delta V_3$

with

$$ R_{\text{eff}} = \sum_{i=1}^{\sum} R_i $$ for resistors in series

$$ i = R_{\text{eff}} \ i $$
Which resistor has the greater current going through it?

\[ i = \frac{\Delta V}{R} \propto \frac{1}{R} \]

\[ R_1 > R_2 \]

\[ \Rightarrow i_1 < i_2 \]

A. \( R_1 \)  
B. \( R_2 \)  
C. The current through both resistors is the same
What should be the value of $R_{\text{eff}}$ in terms of $R_1$, $R_2$, & $R_3$ so that the same current flows in both circuits?

Same: voltage $\Delta V_{\text{bat}} = \Delta V_1 = \Delta V_2 = \Delta V_3$

Add: current $i = i_1 + i_2 + i_3 = \frac{\Delta V_{\text{bat}}}{R_1} + \frac{\Delta V_{\text{bat}}}{R_2} + \frac{\Delta V_{\text{bat}}}{R_3}$

with $\frac{1}{R_{\text{eff}}} = \sum_{i=1}^{n} \frac{1}{R_i}$ for resistors in parallel

$R_{\text{eff}} = \sum_{i=1}^{n} \frac{1}{R_i}$
Which resistors are in series?

Two resistors are in series if the same charge carrier must go through both resistors.

A. A and B  
B. A and C  
C. A and E  
D. B and D  
E. Both answers C and D above
Which resistors are in parallel?

Two resistors are in parallel, if same potential difference \( V \) is applied across both resistors!

A. A and B
B. A and C
C. A and E
D. C and D
E. No pair listed above
**Circuits**

- **Emf device** (outdated name: "electromotive force")
  - produces a steady flow of charge by "pumping" them to a higher electric potential energy
  - maintains a potential difference $V_+ - V_-$ between its terminals
  - converts some form of energy (chemical, sunlight...) into electrical energy

Define: not $E_0$?

$$\text{emf} = \mathcal{E} = \frac{\Delta W}{\Delta Q} = \frac{dW}{dQ} = \left(\frac{\text{Work per unit charge done by the emf device to move charge from low to high potential energy terminal}}{\text{Charge}}\right)$$

$L \in J = \text{volts}$
Potential electric energy is “used” (converted to other forms of energy) in the devices of the circuit.

Potential energy

Emf device “pumps” charges to higher potential energy

$q$

$q$
\[ E = \frac{dW}{dq} \Rightarrow \left( \text{work done by emf \ (device \ by \ pump)} \right) = \frac{dW}{dq} \cdot dq = dW \]

\[ = \text{Power delivered by emf device:} \]

\[ P_{\text{emf}} = \frac{dW}{dt} = E \frac{dq}{dt} = Ei \]

\[ \text{delivers energy in form of electric potential energy} \]

\[ = \] This energy is "used"/converted into another form of energy in the electric circuit, i.e. by the circuit device: since \( V_a > V_b \)

Energy "used" in device = \( \Delta q \cdot (V_a - V_b) = \Delta q \cdot OV \text{ over device} \)

\[ = \left( \text{Power \ "used \ by circuit device"} \right) = P_{\text{device}} = \frac{\text{Energy used}}{\text{time \ interval}} = \frac{\Delta q \cdot OV}{\Delta t} = i \cdot OV \text{ over device} \]

\[ \Sigma P_j = \frac{2}{5} \cdot \frac{2}{5} = \frac{2}{5} = \text{Watt} \]
Kirchhoff’s circuit rules:

(a) Loop rule:

for closed loop:

\[ V_A + \varepsilon + 0V_1 + 0V_2 + 0V_3 = V_A \]

\[ \sum_{i=1}^{N} \Delta V_i = 0 \]

for sum of potential change in closed circuit loop; watch out for correct sign of \( \Delta V \).

(b) Junction rule:

at junction: \( i_0 = i_1 + i_2 \)

\[ \sum i_{\text{in}} = \sum i_{\text{out}} \]  \[ \text{charge is conserved} \]
Ideal emf device – Has no internal resistance.

Real emf device – Has internal resistance \( r \).

\[ \mathcal{E} + \Delta V_R = 0 = \mathcal{E} - \mathcal{I}R \Rightarrow \mathcal{I} = \frac{\mathcal{E}}{R} \]

When a load resistance \( R \) is connected to the real emf device, what is the potential difference across its terminals?

For real emf:

\[ \mathcal{E} + \Delta V_R + \Delta V_R = 0 = \mathcal{E} - \mathcal{I}r - \mathcal{I}R = \mathcal{E} - \mathcal{I}(r + R) \]

\[ \Rightarrow \quad \mathcal{I} = \frac{\mathcal{E}}{r + R} \]

\[ \Delta V_{\text{real emf}} = \mathcal{E} + \Delta V_R = \mathcal{E} - \mathcal{I}r = \mathcal{E} - \frac{\mathcal{E}r}{r + R} = \frac{\mathcal{E}R}{r + R} = -\Delta V_R \]

A. \( \mathcal{E} \)  
B. 0  
C. \( \mathcal{E} \left( \frac{r}{R} \right) \)  
D. \( \mathcal{E} \left( \frac{R}{r + R} \right) \)  
E. \( \mathcal{E} \left( \frac{r}{r + R} \right) \)
Standard Alkaline Batteries:

- Converts chemical energy into electrical energy
- Anode (negative terminal) is made of zinc powder
- Cathode (positive terminal) is composed of manganese dioxide
- Electrolyte is potassium hydroxide

\[ \text{Zn} + 2 \text{OH}^- \rightarrow \text{ZnO} + \text{H}_2\text{O} + 2 \text{e}^- \]  
\[ 2 \text{MnO}_2 + \text{H}_2\text{O} + 2 \text{e}^- \rightarrow \text{Mn}_2\text{O}_3 + 2 \text{OH}^- \]

At potential \( V \approx 1.5\text{V} \)  
At potential \( V \approx 0\text{V} \)
**RC circuit: Charging and discharging of a capacitor**

- At time \( t = 0 \) move the switch to position \( a \).
- Current \( i \) begins to flow to **charge** the capacitor.
- \( i \) into the upper plate of the capacitor always equals \( i \) out of the lower plate even though no charge flows across the gap between the plates.

\[ \epsilon \quad \begin{array}{c}
\text{---}
\end{array} \quad b \quad a
\]

\[ R \quad \begin{array}{c}
\text{---}
\end{array} \quad C
\]

\[ i \quad +q \quad -q \quad \text{initial}: q = 0 \]

\[ \Rightarrow \Delta V_c = \frac{q}{C} \quad \text{initial} \]

\[ = 0 \]
At time $t = 0$ the switch is moved to position a.

After a very long time what will be the voltage on the capacitor?

- A. 0
- B. $iR$
- C. $\mathcal{E}$
- D. $\rightarrow \infty$ V, the voltage will keep increasing as long as the switch is at position a.

Loop rule: $\mathcal{E} + \Delta V_R + \Delta V_C = 0$