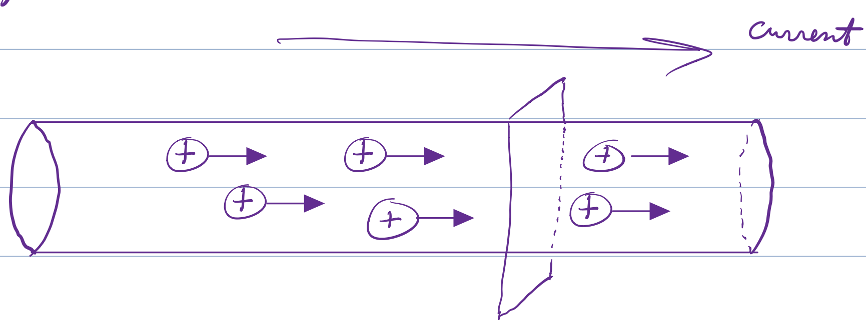
22.1 A Model of Current & 22.2 Defining and Describing Current (review)

We now consider systems out of equilibrium.
What happens to charge carriers if you apply an electric field? They tend to move.
e.g. consider a wire



Count how many charges ΔQ pass through this surface in a time Δt

Define current $I \equiv \dfrac{\Delta Q}{\Delta t}$

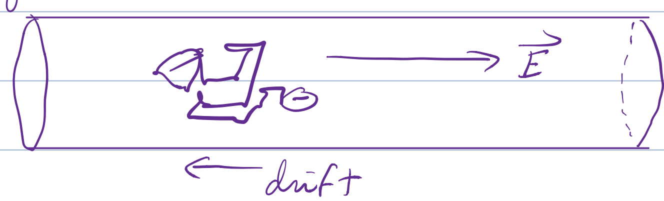
Units: $\dfrac{\text{Coulombs}}{\text{second}} \equiv$ Amperes = Amps = A.

Common units: $1\,mA = 10^{-3}\,A$.
Household circuits $\lesssim 20\,A$ or $30\,A$.

22.4 Connecting Potential and Current

Moving charges typically encounter resistance – impurities & imperfections

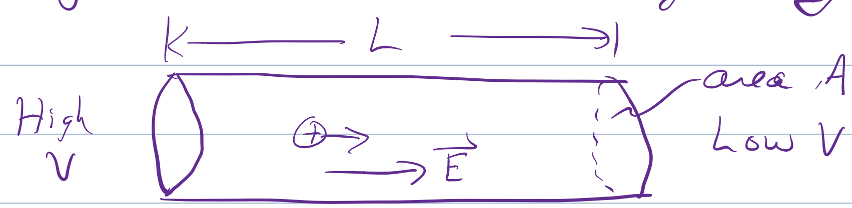
Net effect



average speed $\sim 10^6$ m/s, <u>But</u> many collisions / stop & starts

Drift speed $\sim$ 0.1 mm/s

Quantify that resistance. Two main factors: material and geometry.



I = current through device

A = cross-sectional area

j = current density = I/A $\left(\frac{\text{Amps}}{m^2}\right)$

(a local, microscopic property)

ΔV = applied voltage difference

L = length

E = electric field

What sets $\vec{j}$? Applied $\vec{E}$ and the material's resistivity ρ

$$j = \frac{1}{\rho} E$$

ρ = resistivity

Units: $\rho = \frac{E}{\bar{j}}$

$$[\rho] = \frac{V/m}{A/m^2} = \frac{V}{A} \cdot m = \Omega \cdot m$$

ρ is a property of a material.
If ρ = constant (i.e. independent of E) then we say the material is "ohmic." It obeys the microscopic version of Ohm's Law

$$\bar{j} = \frac{1}{\rho} E.$$

Tables:

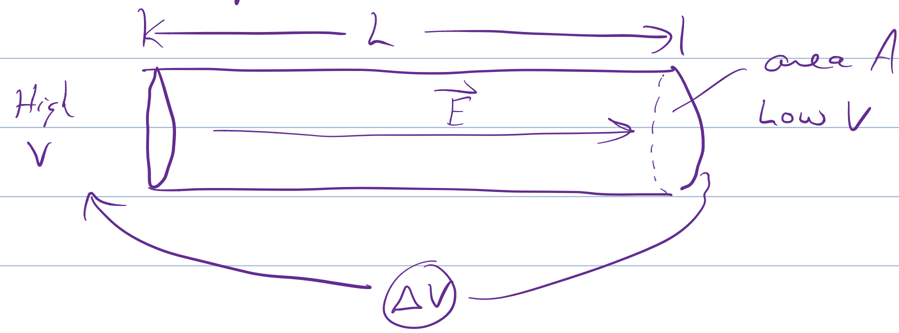
Table 25.1 Resistivities at Room Temperature (20 °C)

	Substance	$\rho(\Omega \cdot m)$		Substance	$\rho(\Omega \cdot m)$
Conductors			**Semiconductors**		
Metals	Silver	1.47×10^{-8}		Pure carbon (graphite)	3.5×10^{-5}
	Copper	1.72×10^{-8}		Pure germanium	0.60
	Gold	2.44×10^{-8}		Pure silicon	2300
	Aluminum	2.75×10^{-8}	**Insulators**		
	Tungsten	5.25×10^{-8}		Amber	5×10^{14}
	Steel	20×10^{-8}		Glass	10^{10}–10^{14}
	Lead	22×10^{-8}		Lucite	$>10^{13}$
	Mercury	95×10^{-8}		Mica	10^{11}–10^{15}
Alloys	Manganin (Cu 84%, Mn 12%, Ni 4%)	44×10^{-8}		Quartz (fused)	75×10^{16}
	Constantan (Cu 60%, Ni 40%)	49×10^{-8}		Sulfur	10^{15}
	Nichrome	100×10^{-8}		Teflon	$>10^{13}$
				Wood	10^{8}–10^{11}

TABLE 22.1 Resistivities of materials

Material	Resistivity ($\Omega \cdot m$)
Copper	1.7×10^{-8}
Aluminum	2.7×10^{-8}
Tungsten (20°C)	5.6×10^{-8}
Tungsten (1500°C)	5.0×10^{-7}
Iron	9.7×10^{-8}
Nichrome	1.5×10^{-6}
Seawater	0.22
Blood (average)	1.6
Muscle	13
Fat	25
Pure water	2.4×10^{5}
Cell membrane	3.6×10^{7}

Macroscopic Ohm's Law:



$$j = \frac{1}{\rho} E$$

$$\frac{I}{A} = \frac{1}{\rho}\left(\frac{\Delta V}{L}\right)$$

$$I = \left(\frac{A}{\rho L}\right)(\Delta V) \quad \text{or} \quad \Delta V = I\left(\frac{\rho L}{A}\right)$$

compare to

$$I = \frac{1}{R}\Delta V \quad \text{or} \quad \Delta V = I R$$

for a cylinder $R = \frac{\rho L}{A}$

units $[R] = \frac{[\Omega \cdot m] \cdot m}{m^2} = \Omega$.

Macroscopic form of Ohm's Law

$$\boxed{\Delta V = I R}$$

units $R = \frac{\Delta V}{I} \Rightarrow \frac{V}{A} = \text{ohms} = \Omega$.

common units: $10^3 \Omega = 1 k\Omega$

common voltages ~ V

common currents $10^{-3} A = 1 mA$

symbol 

Cool application: Example 22.16

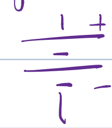
Body composition: muscle and fat have different resistivities.

Measurements of ρ for a fixed geometry can tell about the relative composition.

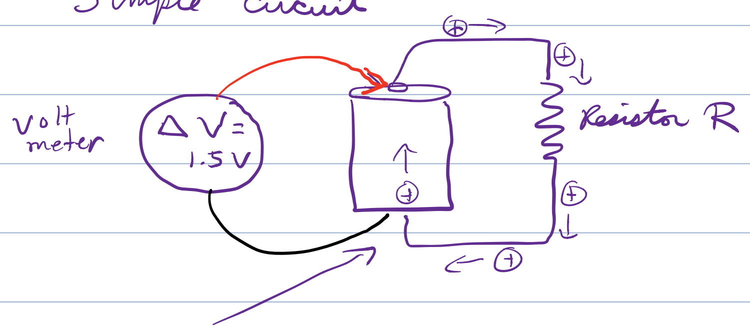
22.3 Batteries and emf

emf = electromotive force — a terrible name!

emf = $\mathcal{E}$ = a device in a circuit that makes current flow from a low potential to a high potential.
(e.g. a battery) Text talks of a "charge escalator." (Read)

Symbol 

Simple circuit



follow a charge q_0 on its journey around the circuit

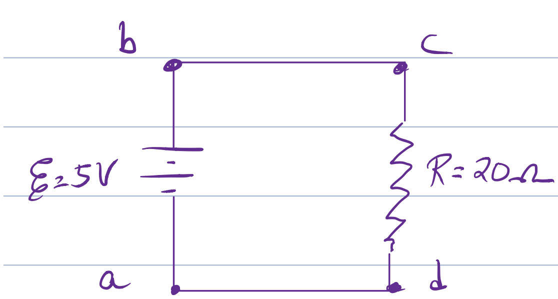
Start — 0 potential energy

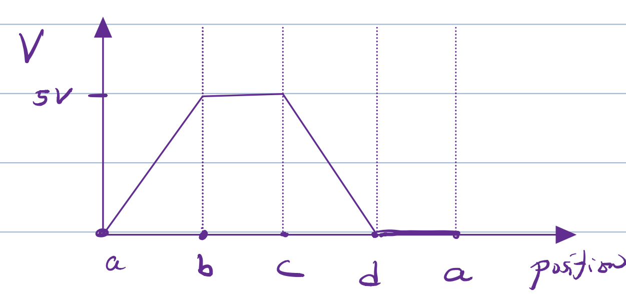
battery boosts energy by $\Delta U = q_0 \Delta V = q_0 (1.5\,V)$

charge moves easily through wire

charge loses energy / it takes work to move through resistor

charge arrives back at battery at low energy





Look at resistor and apply Ohm's Law

$$\Delta V = IR$$

$$5V = I(20\Omega)$$

$$I = \frac{5V}{20\Omega} = 0.25A$$