$$\vec{J} = -e N_e \vec{v}$$

N_e: must decrease to compensate, when $\frac{\partial \rho}{\partial t} = 0$.

$\vec{v}$: increases as one goes accross

Ohm's Law

Empirically, in many substances,

$$\vec{J} \propto \vec{E}, \quad \vec{J} = \sigma \vec{E} = \frac{1}{\rho} \vec{E}$$

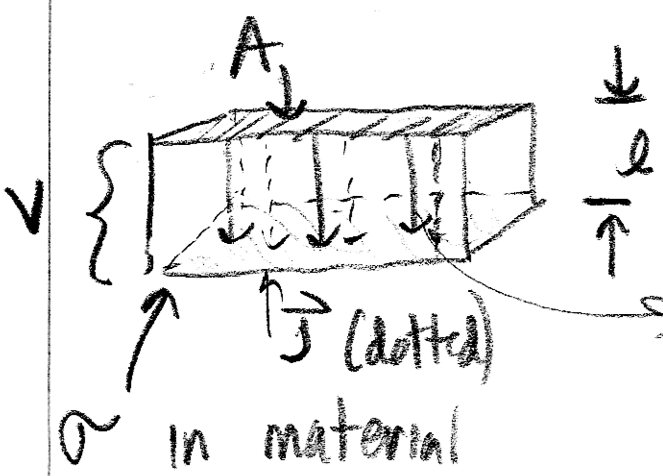
σ: a constant known as conductivity; ρ: resistivity

the larger σ, the more current density for a given $\vec{E}$ applied.

$$\vec{J} = \sigma \vec{E} \quad \text{"intrinsic quantities"}$$

leads to

$$V = IR. \quad \text{"extrinsic"}$$



$$E = \frac{V}{l}, \quad J = \sigma E = \frac{\sigma V}{l}$$

$$I = J \cdot A = \frac{\sigma V A}{L}$$

$$V = \left(\frac{L}{\sigma A}\right) \cdot I \qquad \boxed{R = \frac{L}{\sigma A}}$$

$$\rho \left(\text{new quantity, not charge density}\right) \equiv \frac{1}{\sigma}$$

$$\boxed{R = \frac{L}{A} \cdot \rho = \frac{L}{A} \frac{1}{\sigma}}$$

units:

CGS

$$\underbrace{\vec{J}}_{\frac{esu}{cm^2 \cdot s}} = \underbrace{\sigma}_{\frac{1}{s}} \underbrace{\vec{E}}_{\frac{esu}{cm^2}}$$

(!!!!)

SI/MKS

$$\underbrace{R}_{\text{ohms } (\Omega)} = \underbrace{\frac{L}{A}}_{\frac{m}{m^2}} \cdot \underbrace{\rho}_{(\text{ohm-m}) \text{ or } (\text{ohm-cm})}$$

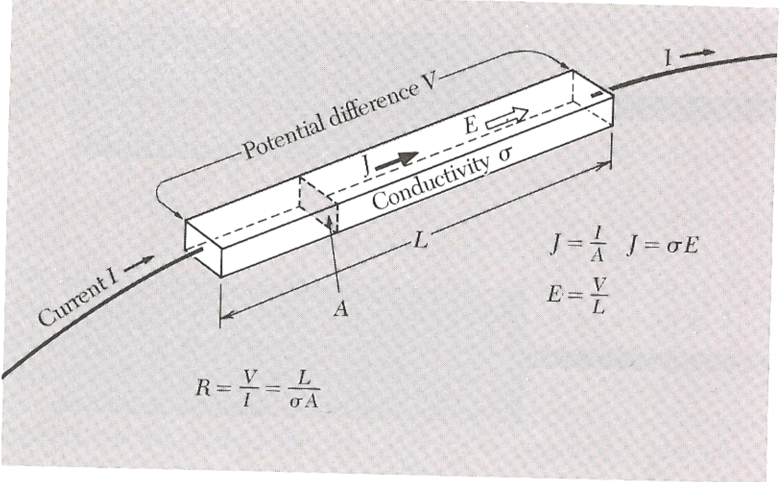
There are some conditions for ohm's law... see text

TABLE 4.1

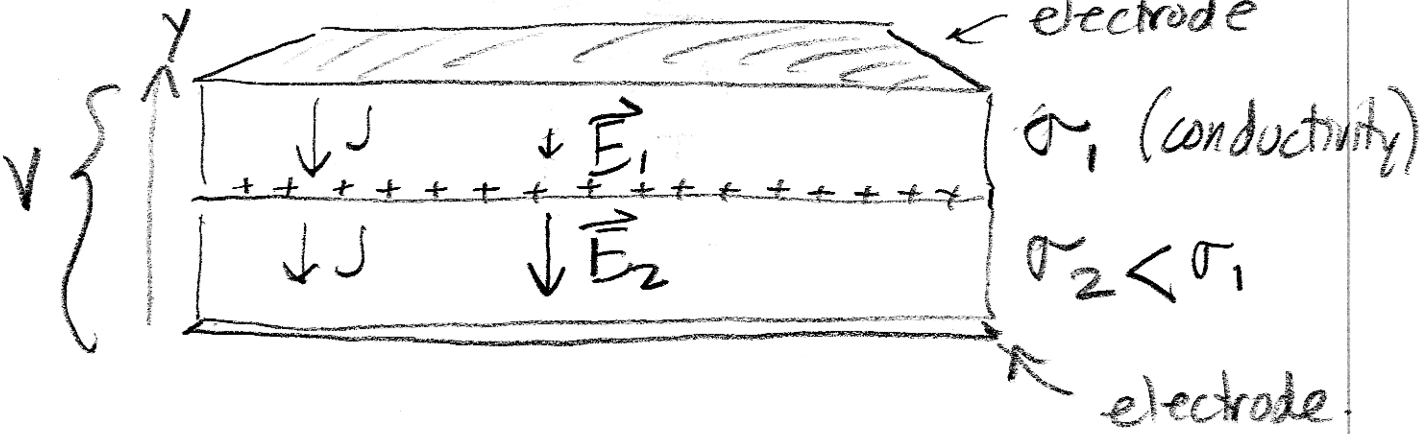
Resistivity and its reciprocal, conductivity, for a few materials

Material	Resistivity ρ	Conductivity σ
Pure copper, 273 K	1.56×10^{-6} ohm-cm 1.73×10^{-18} sec	6.4×10^{5} (ohm-cm)$^{-1}$ 5.8×10^{17} sec^{-1}
Pure copper, 373 K	2.24×10^{-6} ohm-cm 2.47×10^{-18} sec	4.5×10^{5} (ohm-cm)$^{-1}$ 4.0×10^{17} sec^{-1}
Pure germanium, 273 K	200 ohm-cm 2.2×10^{-10} sec	0.005 (ohm-cm)$^{-1}$ 4.5×10^{9} sec^{-1}
Pure germanium, 500 K	0.12 ohm-cm 1.3×10^{-13} sec	8.3 (ohm-cm)$^{-1}$ 7.7×10^{12} sec^{-1}
Pure water, 291 K	2.5×10^{7} ohm-cm 2.8×10^{-5} sec	4.0×10^{-8} (ohm-cm)$^{-1}$ 3.6×10^{4} sec^{-1}
Seawater (varies with salinity)	25 ohm-cm 2.8×10^{-11} sec	0.04 (ohm-cm)$^{-1}$ 3.6×10^{10} sec^{-1}

Note: 1 ohm-meter = 100 ohm-cm = 1.11×10^{-10} sec.


Potential difference V
I
E
J
Conductivity σ
L
A
Current I
$J = \frac{I}{A}$ $J = \sigma E$
$E = \frac{V}{L}$
$R = \frac{V}{I} = \frac{L}{\sigma A}$

One interesting example:



What is the same? $\vec{J}$, when steady state.

$$\vec{\nabla}\cdot\vec{J} = \frac{\partial J_x}{\partial x} + \frac{\partial J_y}{\partial y} + \frac{\partial J_z}{\partial z} = -\frac{\partial \rho}{\partial t}$$

0 (∞ in those directions) 0

0 in steady state.

$$\frac{\partial J_y}{\partial y} = 0 \rightarrow J_y \text{ is constant}$$

What is different? $\vec{E}_1 = \left(\frac{1}{\sigma_1}\right)\vec{J} < \left(\frac{1}{\sigma_2}\right)\vec{J}$

$< \vec{E}_2$

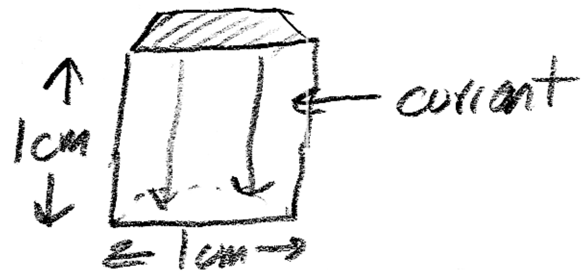
(new field lines must start)

Must be some positive charge at the interface... in steady state. Initially not (then, $\frac{\partial \rho}{\partial t} \neq 0$), but it builds up.

Interesting Table - p. 133

$\rho = \frac{1}{\sigma}$: Pure Copper .. $1.56 \cdot 10^{-6}$ ohm-cm

$1.56 \cdot 10^{-6}\ \Omega$



Pure Water : $25 \cdot 10^{6}$ ohm-cm

25 MΩ above.

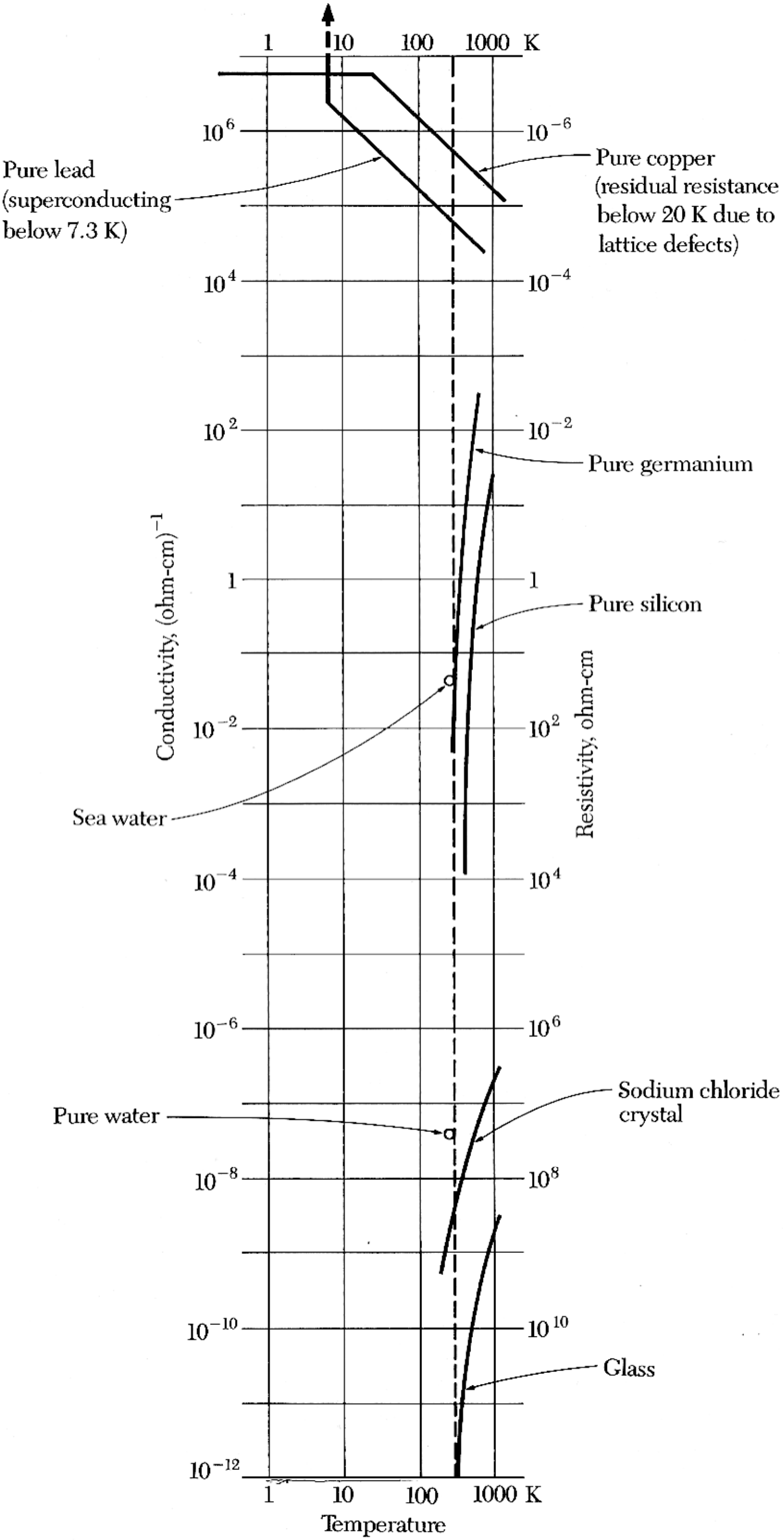
Sea Water : 25 ohm-cm
(Bath Water)

purity matters a lot!

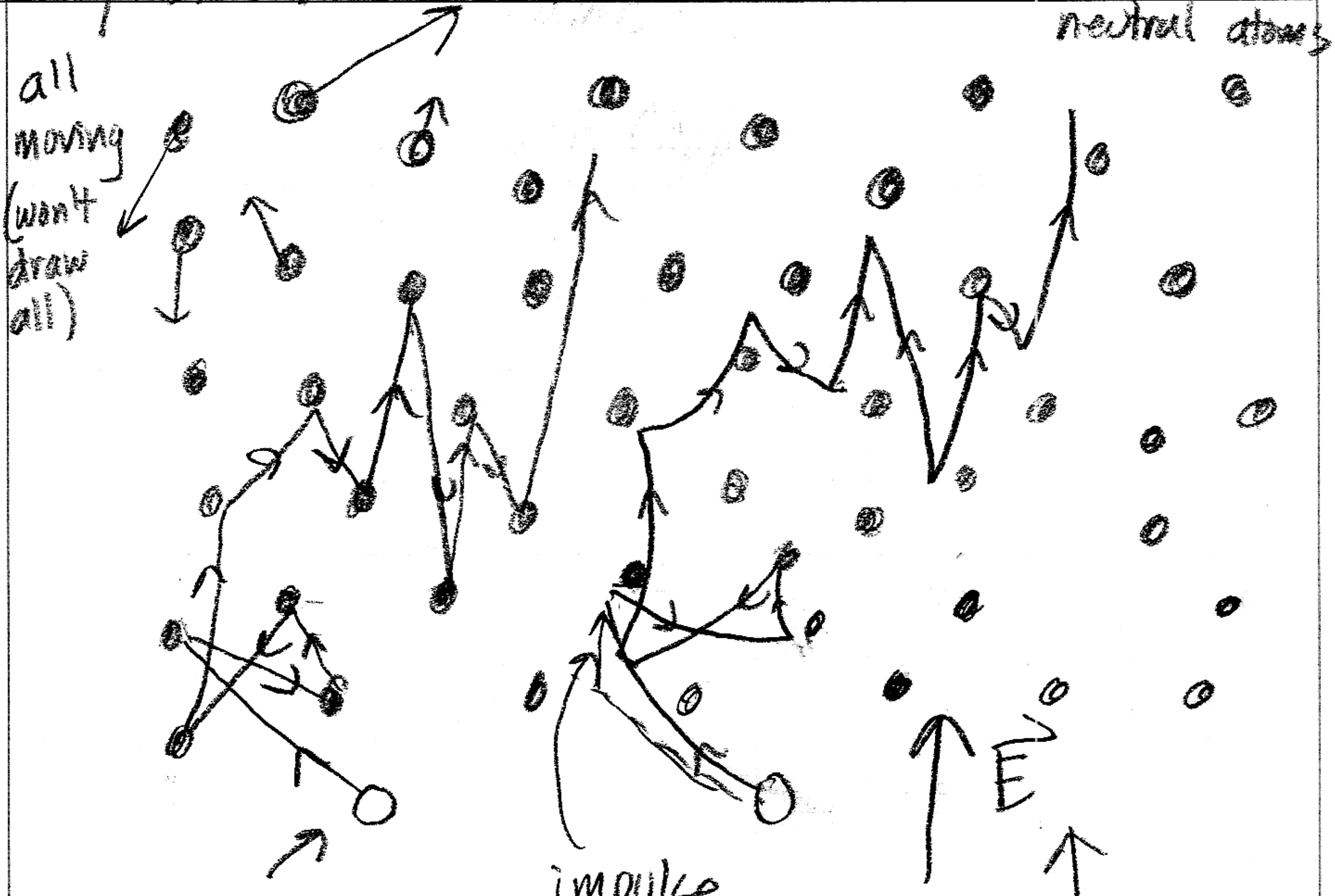
Conductivity / Resistivity are <u>very</u> sensitive to temperature... look at plot on page 140.

<u>Reason</u> : dominant motion (usually) in condensed matter is <u>thermal motion</u>, even when electric field is present.

Electric field is a <u>minor</u> effect. Usually.



1
10
100
1000 K
10^6
10^{-6}
Pure lead (superconducting below 7.3 K)
Pure copper (residual resistance below 20 K due to lattice defects)
10^4
10^{-4}
10^2
10^{-2}
Pure germanium
1
1
Pure silicon
Conductivity, $(\text{ohm-cm})^{-1}$
Resistivity, ohm-cm
10^{-2}
10^2
Sea water
10^{-4}
10^4
10^{-6}
10^6
Sodium chloride crystal
Pure water
10^{-8}
10^8
10^{-10}
10^{10}
Glass
10^{-12}
1
10
100
1000 K
Temperature



$$\Delta\vec{p} = q\vec{E}\Delta t$$

$$M\Delta\vec{v} = q\vec{E}\Delta t$$

$$\Delta\vec{v} = \frac{q\vec{E}}{M}\Delta t$$

$$\langle\Delta\vec{v}\rangle = \frac{q\vec{E}}{M}\langle\Delta t\rangle$$

$$\langle\vec{v}\rangle = \langle\Delta\vec{v}\rangle$$

$$\langle\vec{v}\rangle = 0$$

$$\frac{1}{2}m\langle v^2\rangle = \frac{3}{2}kT$$

$$\langle v^2\rangle = \frac{3kT}{m}$$

$$\langle v^2\rangle^{1/2} = \sqrt{\frac{3RT}{M}}$$

suppose: $T \sim 300\,K$, $M \sim .030\,\frac{kg}{mole}$

$$\langle v^2\rangle^{1/2} = \sqrt{\frac{3\cdot 8.3\cdot 300}{0.030}} = 500\,\frac{m}{s}$$

big!