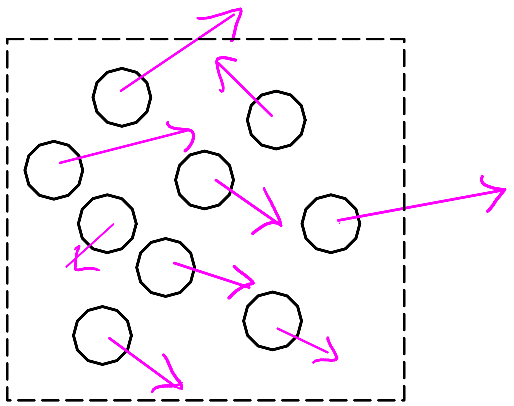
ELETTRICITÀ

Cariche elettriche → interazioni, dinamica → corrente elettrica stazionaria

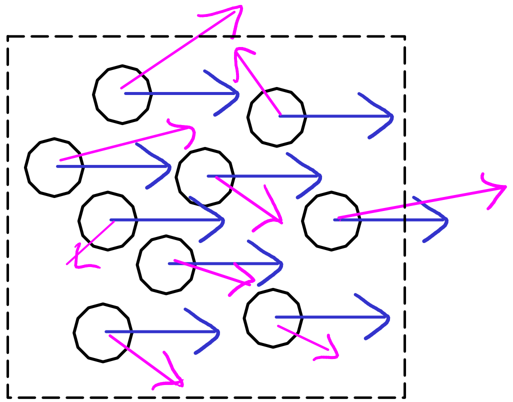
elettricità

termodinamica



equilibrio elettrostatico

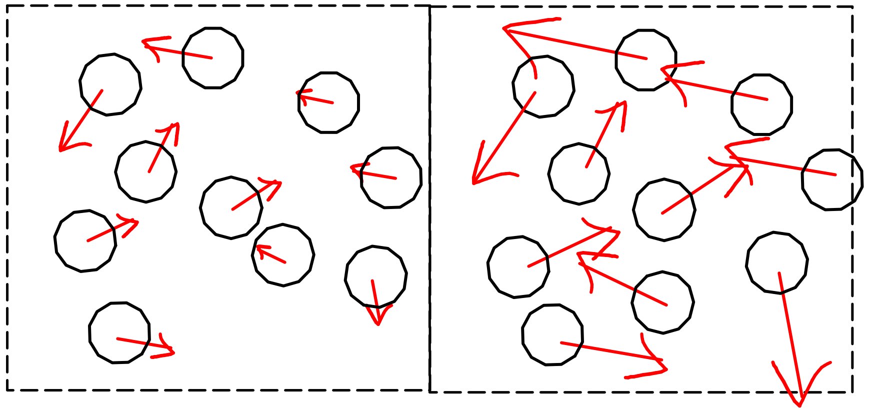
$\langle \vec{v} \rangle = \vec{0}$



conduzione elettrica

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

stazionario



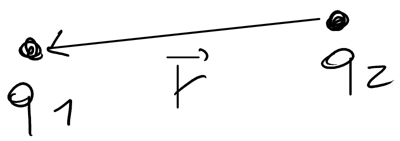
conduzione termica

↓

elettromagnetismo

Richiami

— Forza elettrostatica



$$\vec{F}_e^{\,12} = k_e \frac{q_1 q_2}{|\vec{r}|^2} \frac{\vec{r}}{|\vec{r}|} = -\vec{F}_e^{\,21}$$

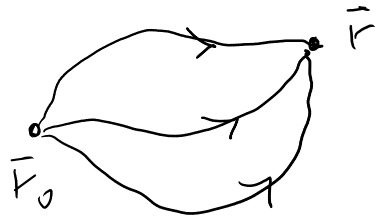
$$\vec{r} = \vec{r}_1 - \vec{r}_2$$

$$k_e \downarrow \frac{1}{4\pi\varepsilon_0}$$

costante dielettrica del vuoto

— Energia potenziale

$$\Delta E_p = -\int_{\vec{r}_0}^{\vec{r}} \vec{F}_e \cdot d\vec{r}$$



$$\vec{F}_e = -\vec{\nabla} E_p$$

— Campo elettrico

$$\vec{E} \equiv \frac{\vec{F}_e}{q} \qquad [|\vec{E}|] = \frac{[|\vec{F}|]}{[q]} \Rightarrow \text{SI}: \frac{N}{C}$$

$$\vec{F}_e \longrightarrow \vec{E} \equiv \frac{\vec{F}_e}{q}$$

$$\Delta E_p \longrightarrow \Delta V \equiv \frac{\Delta E_p}{q} \qquad (\rightarrow \phi_e)$$

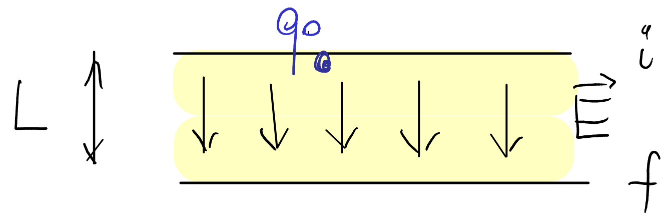
$$\Delta V = -\int_{\vec{r}_0}^{\vec{r}} \vec{E} \cdot d\vec{r}$$

differenza di potenziale elettrostatico

$$SI: \quad \frac{J}{C} \equiv V \quad (\text{Volt})$$

Voltmetro

Es.: particella carica in campo elettrico costante



q_0 = protone

$\Delta E_p = q_0 \Delta V = -q_0 E L$

$\Delta V = 12\ V$

$L = 0.3\ cm$

$q_0 > 0 \quad \Delta E_p < 0 \quad \Rightarrow \quad \Delta E_c > 0$

$q_0 < 0 \quad \Delta E_p > 0$

$q_0 = 1.6 \times 10^{-19}\ C$

elettronvolt : eV $\rightarrow$ energia!

$m = 1.67 \times 10^{-27}\ kg$

$v_f = \ ?$

Sistema: {carica, campo} isolato, $\vec{F}_e, \vec{E}$ conservativi

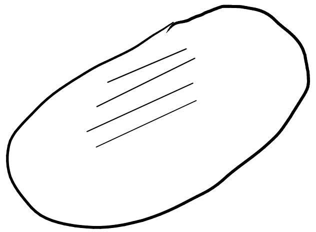
$$\Delta E_p + \Delta E_c = 0 \quad \Rightarrow \quad -q_0 E L + \left(\frac{1}{2} m v_f^2 - 0\right) = 0$$

$$v_f = \sqrt{\frac{2 q_0 E L}{m}} = \sqrt{\frac{2 \times 1.6 \times 10^{-19}\ C \times 12\ V}{1.67 \times 10^{-27}\ kg}} = 4.8 \times 10^{4}\ \frac{m}{s}$$

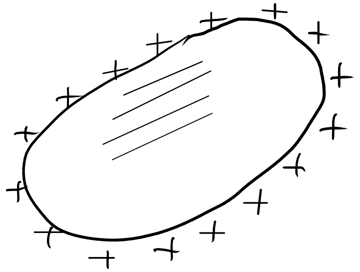
Conduttori elettrici

↗ **conduttori**: una frazione delle cariche (e^-) può spostarsi liberamente

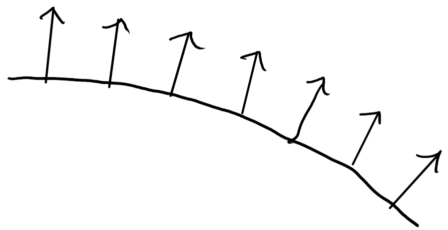
↘ isolanti: tutte le cariche sono legate → non possono spostarsi



1. chiuso
equilibrio elettrostatico
$\vec{E} = \vec{0}$



2. carica aggiuntiva
si distribuisce sulla
superficie

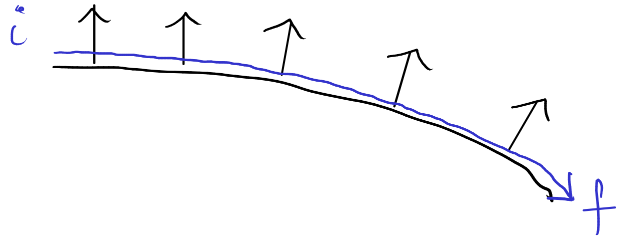


3. $\vec{E} \perp$ superficie

$$|\vec{E}| = \frac{\sigma}{\varepsilon_0}$$

teor. Gauss

$\sigma \equiv$ densità di carica per unità di superficie

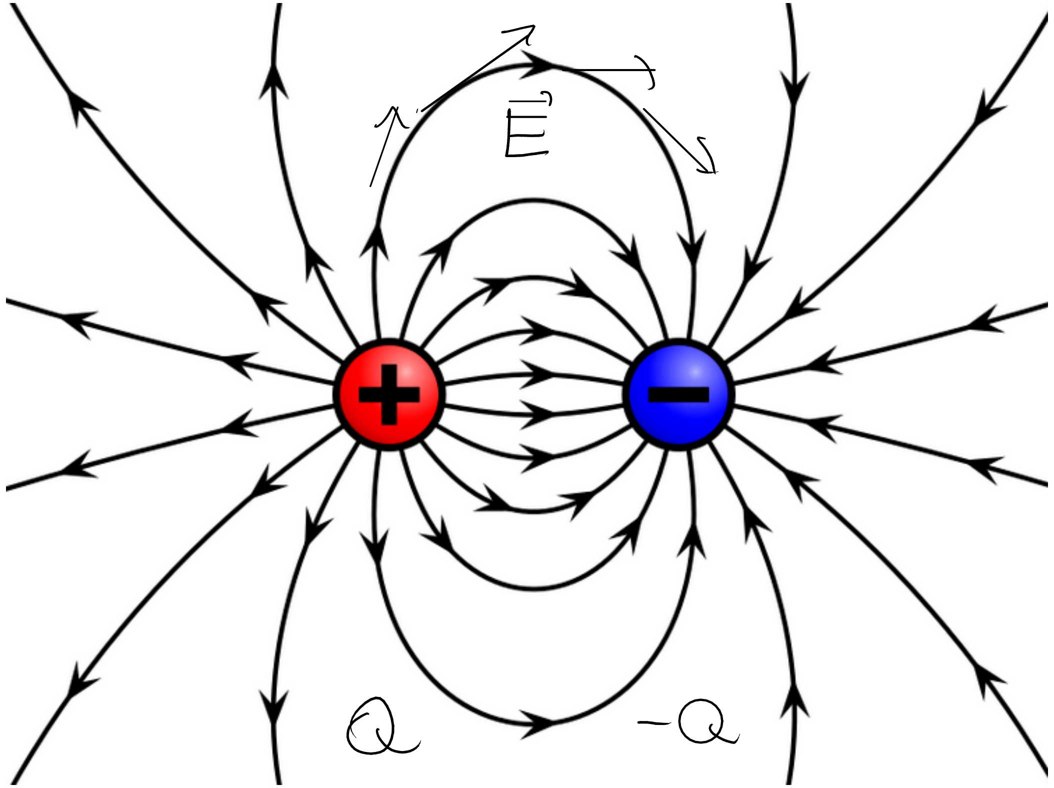


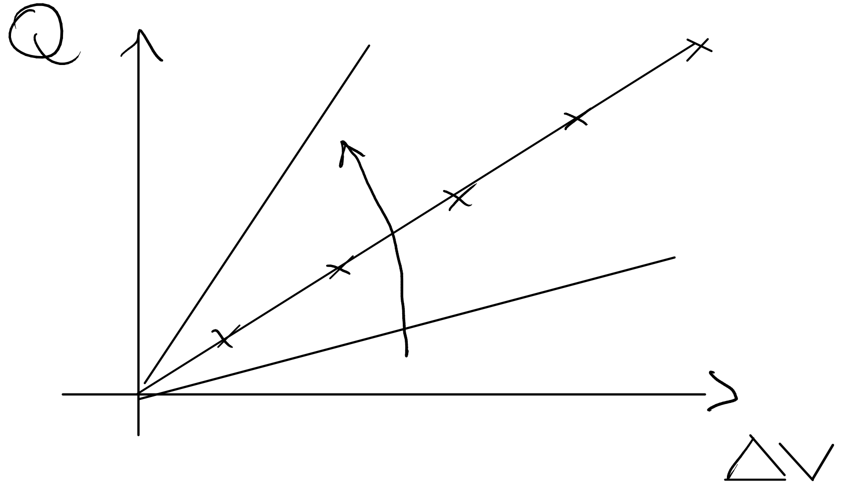
$$\Delta V = -\int_i^f \vec{E} \cdot d\vec{r} = 0$$

V è costante sulla superficie

$\Rightarrow$ V = cost in tutto il conduttore

Condensatore: dispositivo capace di accumulare cariche elettriche





$$Q \sim \Delta V$$

$$C \equiv \frac{Q}{\Delta V}$$

capacità elettrica

$$SI : \frac{C}{V} \equiv F$$

Farad

(pF ...)

$$C_V = \left.\frac{\partial U}{\partial T}\right|_V$$

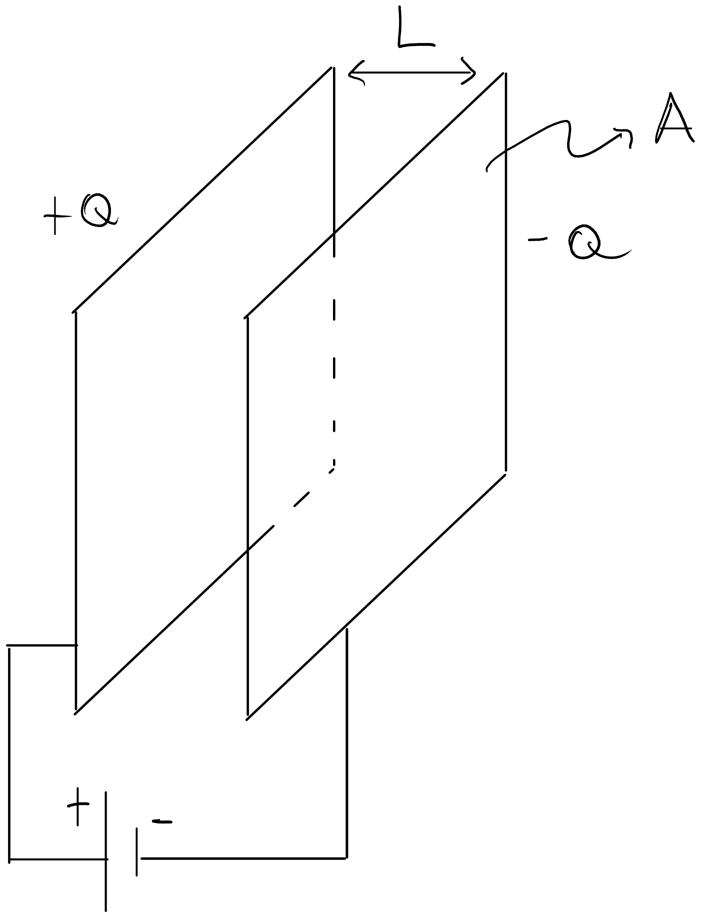
$$= \frac{\Delta U}{\Delta T}$$

$$U = C_V T$$

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

$$Q = \frac{1}{\tilde{C}} \Delta V \qquad \Delta V = \tilde{C} \, Q$$

Es.: condensatore a facce piane



$$\Delta V = \left| - \int_i^f \vec{E} \cdot d\vec{r} \right| = E \cdot L = \frac{\sigma}{\varepsilon_0} \cdot L = \frac{QL}{\varepsilon_0 A}$$

$$Q = C \Delta V$$

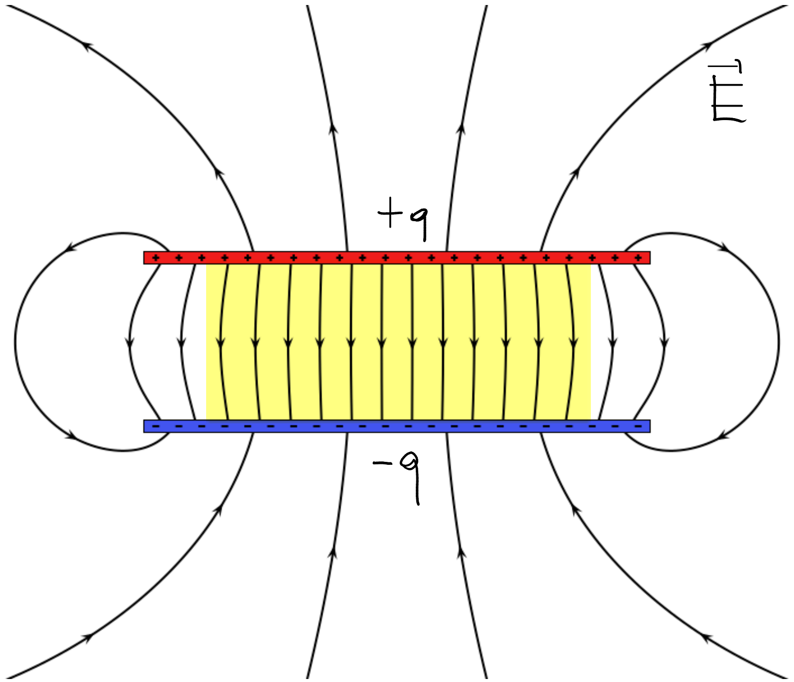
$$Q = \frac{\varepsilon_0 A}{L} \Delta V$$

$$\Rightarrow \quad C = \frac{\varepsilon_0 A}{L} \sim A \sim \frac{1}{L}$$

$$\tilde{C} = \frac{L}{\varepsilon_0 A}$$

"incapacità elettrica"

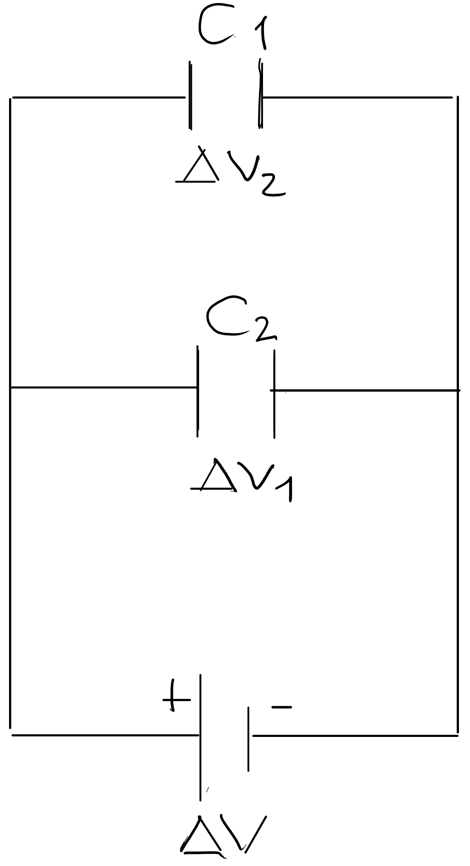
$$\begin{cases} \vec{E} = \text{cost} & \text{all'interno} \\ \vec{E} = \vec{0} & \text{al di fuori} \end{cases}$$



Associazione di condensatori

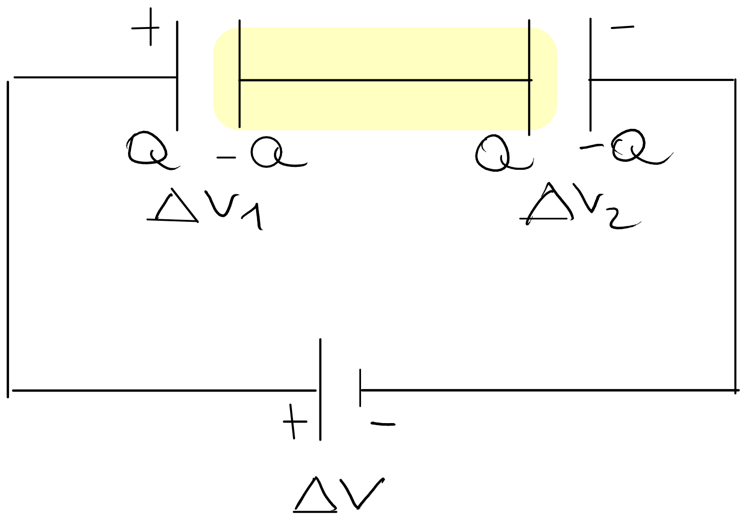
filo conduttore   condensatore   batteria

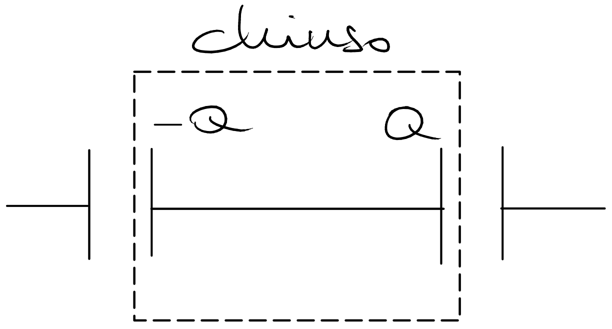
Parallelo



$$\Delta V_1 = \Delta V_2 = \Delta V$$
$$Q_{tot} = Q_1 + Q_2$$

Serie



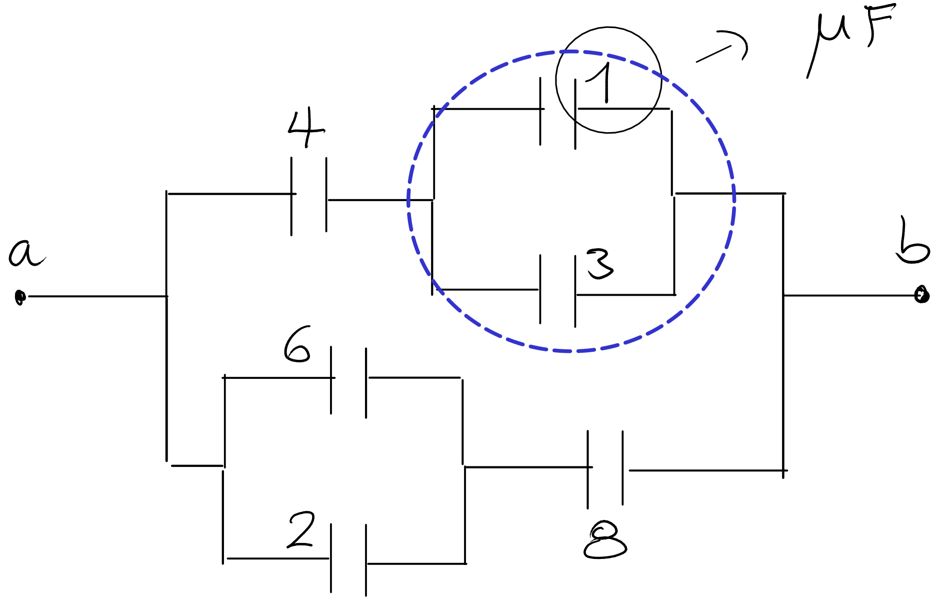


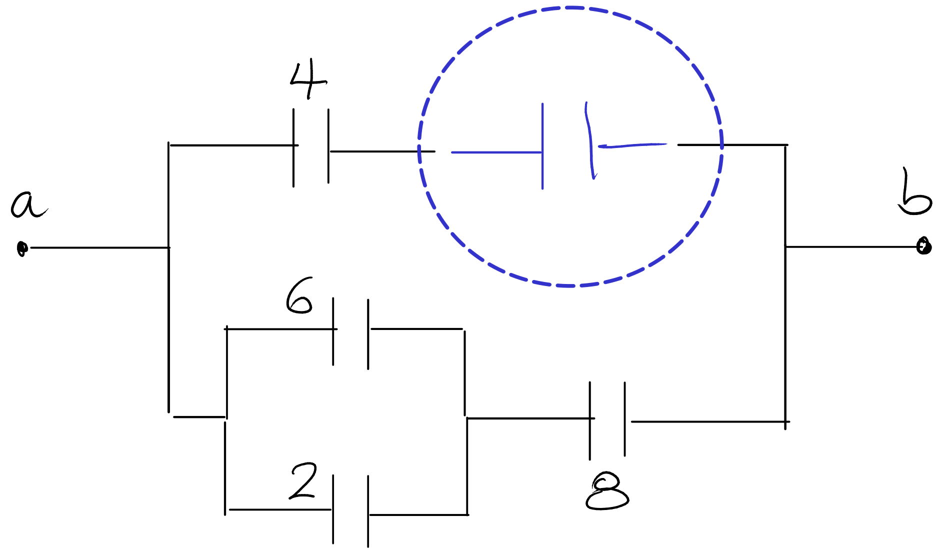
$$Q_1 = Q_2 = Q$$
$$\Delta V = \Delta V_1 + \Delta V_2 = \frac{Q}{C_1} + \frac{Q}{C_2} = \frac{Q}{C_{tot}} \Rightarrow \frac{1}{C_{tot}} = \frac{1}{C_1} + \frac{1}{C_2}$$
$$\frac{1}{C_{tot}} = \sum_{i=1}^{n} \frac{1}{C_i}$$

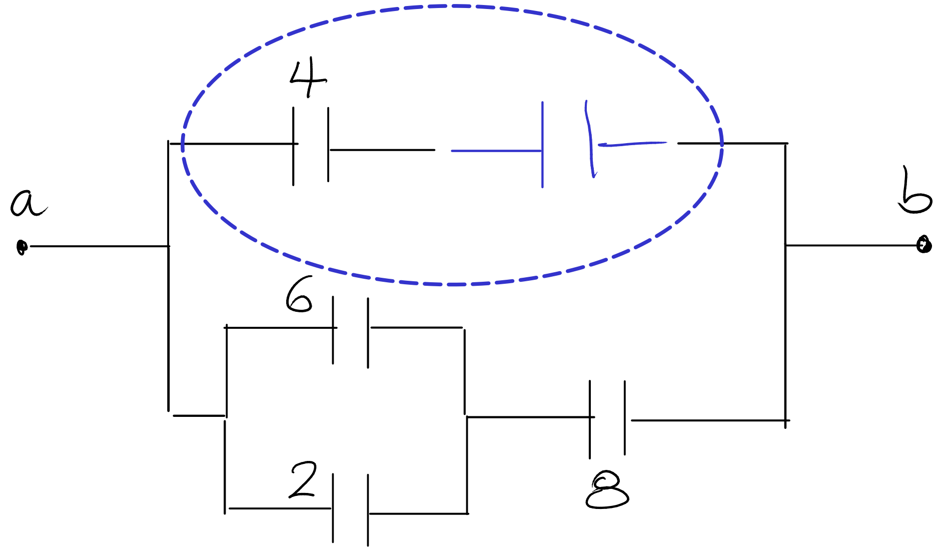
$$\left.\begin{aligned} Q_{tot} &= C_1 \Delta V + C_2 \Delta V = (C_1 + C_2)\Delta V \\ Q_{tot} &= C_{tot} \Delta V \end{aligned}\right\} \Rightarrow \begin{aligned} C_{tot} &= C_1 + C_2 \\ C_{tot} &= \sum_{i=1}^{n} C_i \end{aligned}$$

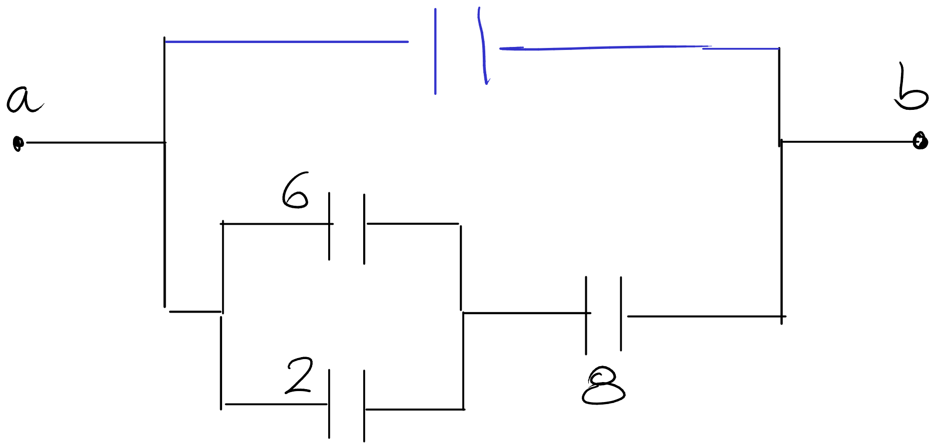
Es.: SJ esempio 20.8

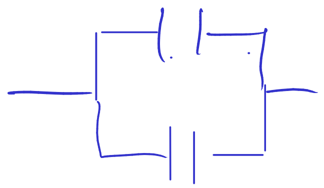
Capacità equivalente (totale) del dispositivo?









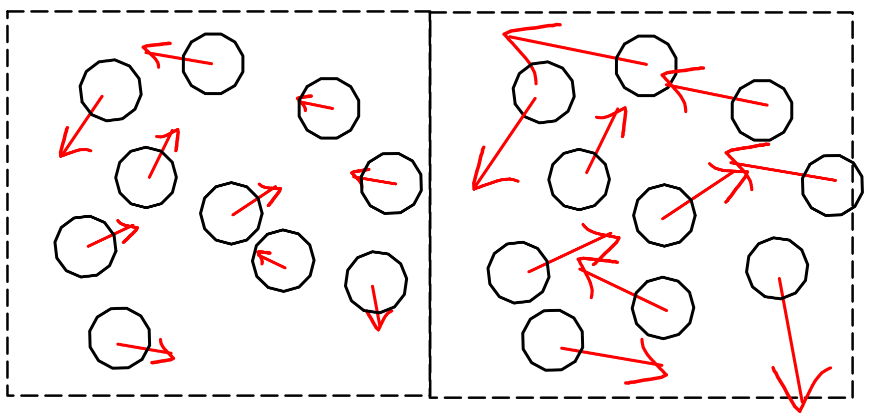


$\Rightarrow C_{tot}$

$\Delta V = V_b - V_a$

CONDUZIONE ELETTRICA

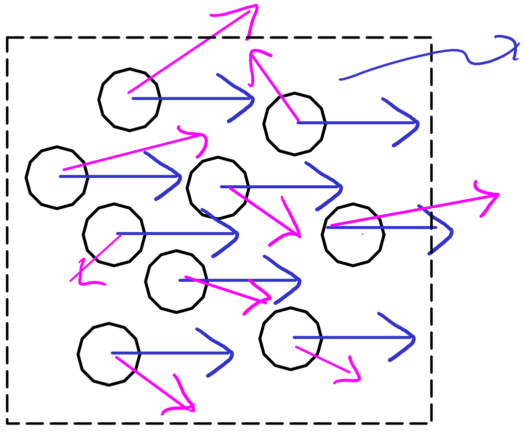
$\vec{\nabla} T$



conduzione termica

$\vec{J}_t$

$\vec{E} = -\vec{\nabla} V$

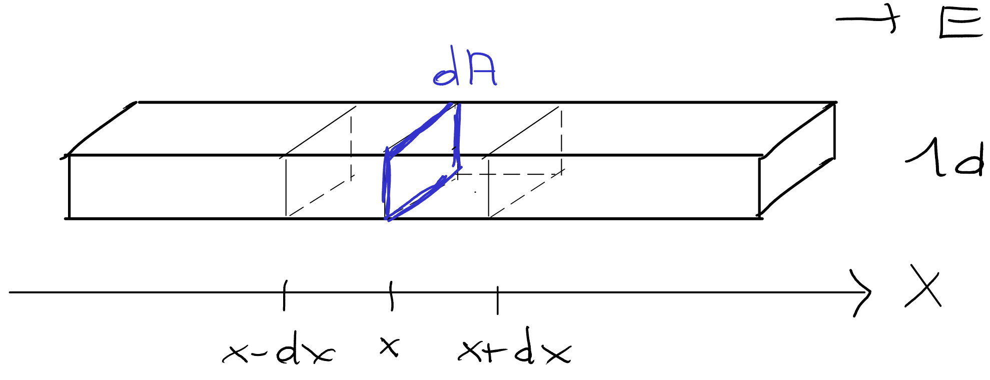


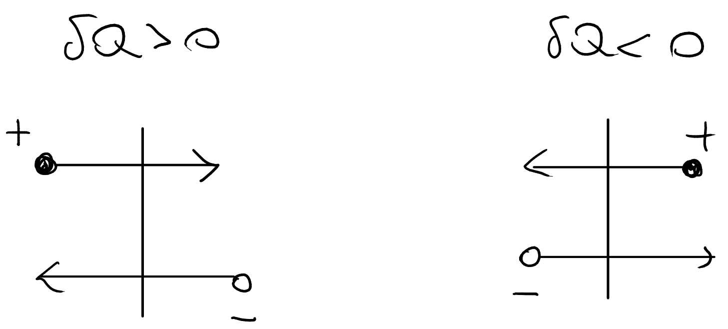
$q < 0$

conduzione elettrica

$\vec{J}_e$

Legge di Ohm : conduzione elettrica





$\delta q \equiv$ carica elettrica che attraversa la superficie dA del sottosistema in x durante l'intervallo di tempo dt, proveniente dal sottosistema in x-dx

$$\delta Q \sim dt\, dA\, E$$

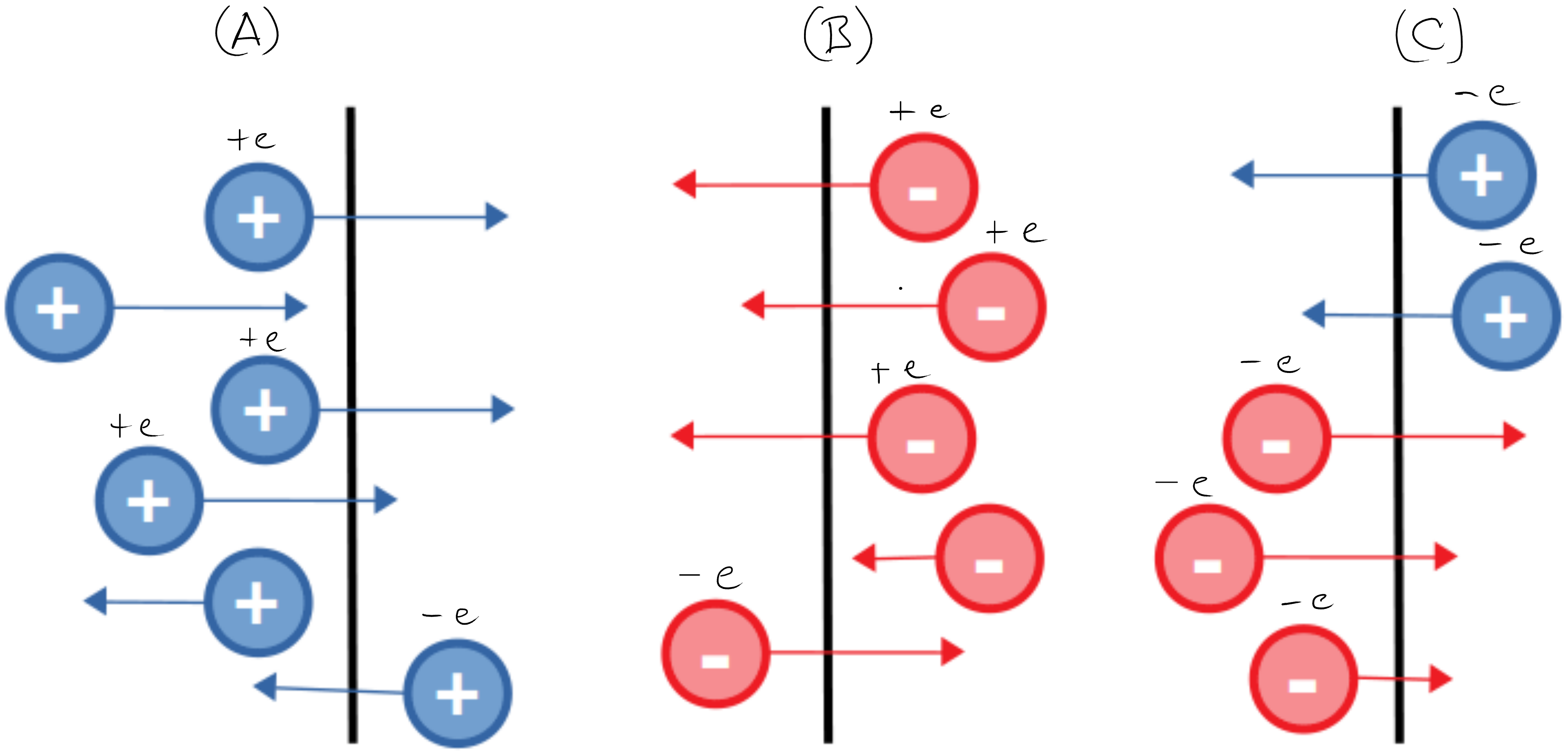
$$\delta Q \sim -dt\, dA \frac{dV}{dx}$$ → empirica

$$I_e = \frac{\delta Q}{dt}$$ **corrente elettrica** SI : $\frac{C}{s} = A$ (Ampère)

$$J_e = \frac{\delta Q}{dt\, dA}$$ **densità di corrente elettrica** SI : $\frac{C}{m^2 s} = \frac{A}{m^2}$

Es: intervallo di tempo $dt = 10^{-14}\,s$, cariche elementari $\pm e = \pm 1.6 \times 10^{-19}\,C$

Calcola la corrente elettrica I_e attraverso la superficie in ciascun caso.

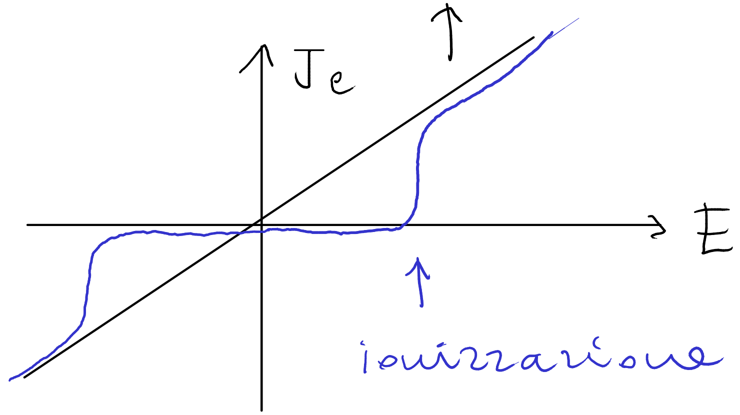


$$I_e = \frac{\delta Q}{dt} \qquad \frac{+2 \times 1.6 \times 10^{-19}\,C}{10^{-14}} = 3.2 \times 10^{-5}\,A \qquad 3.2 \times 10^{-5}\,A \qquad \frac{-5 \times 1.6 \times 10^{-19}\,C}{10^{-14}}$$

$J_e \sim E \qquad J_e \sim -\frac{dV}{dx} \qquad J_e = \sigma E = -\sigma \frac{dV}{dx}$ legge di Ohm

σ: conducibilità elettrica

ohmici

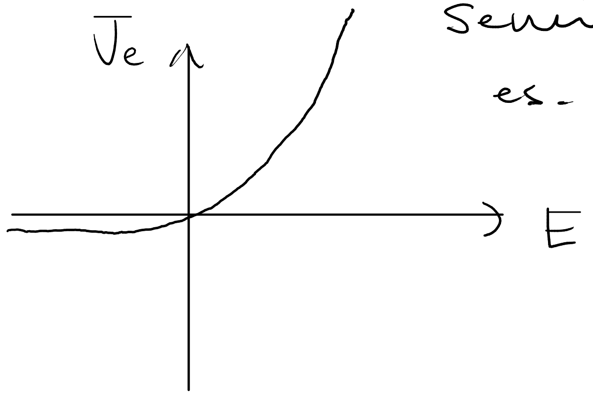


ionizzazione

$\vec{J}_e \rightarrow \vec{J}_e = \sigma \vec{E}$

$= -\sigma \vec{\nabla} V$

3d

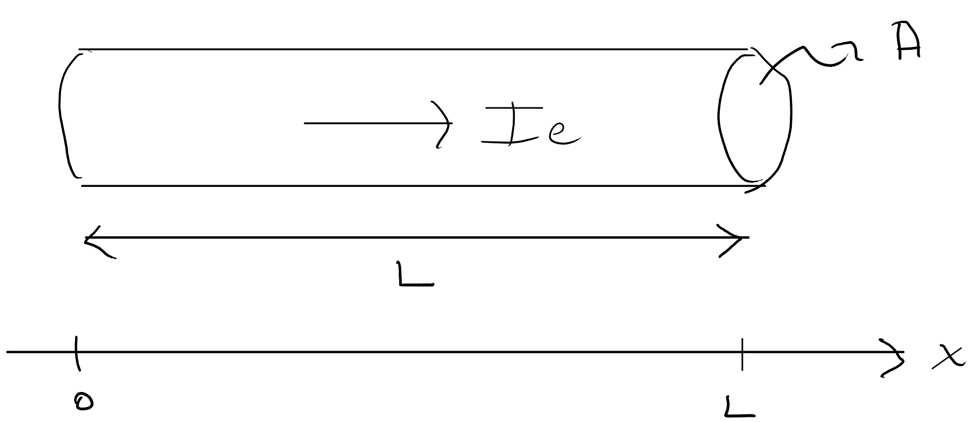


Semiconduttori
es. diodi

Analogia tra conduzione termica ed elettrica

Legge di Fourier	Legge di Ohm
$\vec{J}_t = -\lambda \vec{\nabla} T$	$\vec{J}_e = -\sigma \vec{\nabla} V$
$\Delta T = R_t I_t$	$\Delta V = R_e I_e$
$R_t = \frac{L}{\lambda A}$	$R_e = \frac{L}{\sigma A}$

Conduttore omogeneo in regime stazionario $\quad I_e = \text{cost}$



$$I_e = J_e \cdot A = -\sigma A \frac{dV}{dx}$$

ohm

$$I_e\, dx = -\sigma A\, dV$$

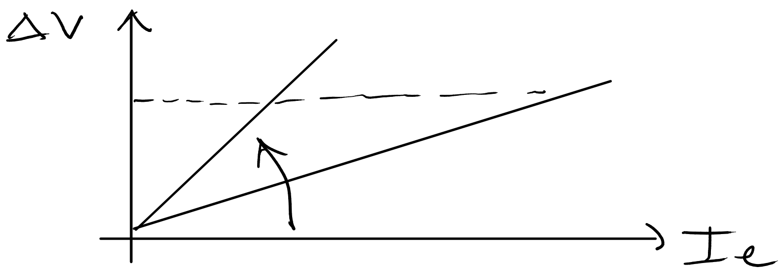
$$\int_0^L I_e\, dx = -\int_{V(0)}^{V(L)} \sigma A\, dV$$

SI : $\frac{\cancel{L}}{[\sigma]\, L^{\cancel{2}}} = [R] \Rightarrow \sigma : \frac{1}{\Omega\, m}$

$$I_e L = -\sigma A\,[V(L) - V(0)] = \sigma A\, \Delta V$$

$\Delta V = V(0) - V(L)$

$\Delta V \sim I_e$

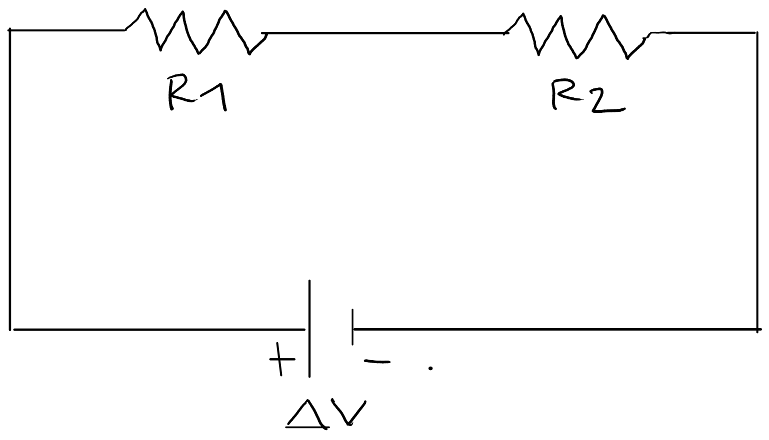


$$\Delta V = \underbrace{\frac{L}{\sigma A}}\, I_e \qquad (R = R_e) \qquad \boxed{\Delta V = R I_e}$$

R_e = resistenza elettrica

SI : $\frac{V}{A} = \Omega$ (Ohm)

1) Resistenze in serie



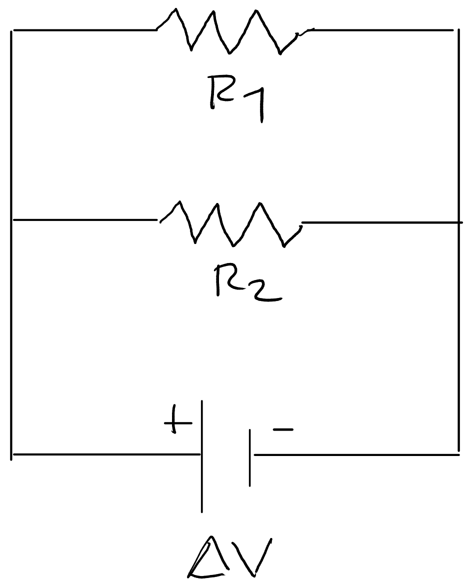
conduttore stazionario

$$I_1 = I_2 = I$$

$$\begin{cases} \Delta V = \Delta V_1 + \Delta V_2 = I R_1 + I R_2 = (R_1 + R_2) I \\ \Delta V = R_{tot} I \end{cases}$$

$$\Rightarrow R_{tot} = R_1 + R_2 \qquad R_{tot} = \sum_{i=1}^{N} R_i$$

2) Resistenze in parallelo

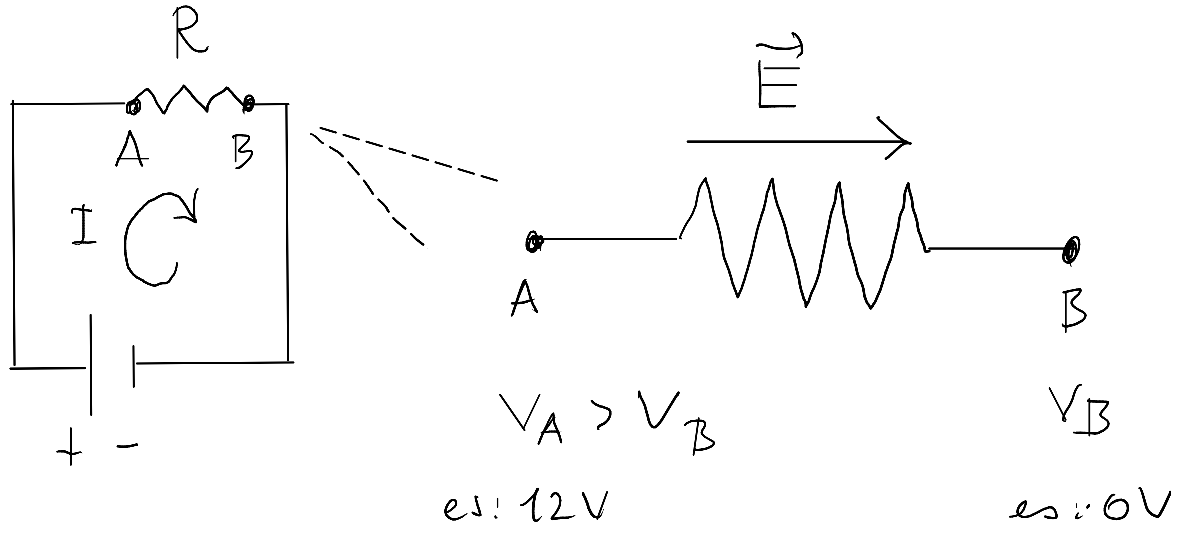


$$\Delta V_1 = \Delta V_2 = \Delta V$$

$$\begin{cases} I = I_1 + I_2 = \frac{\Delta V}{R_1} + \frac{\Delta V}{R_2} = \left(\frac{1}{R_1} + \frac{1}{R_2}\right) \Delta V \\ I = \frac{\Delta V}{R_{tot}} \end{cases}$$

$$\Rightarrow \frac{1}{R_{tot}} = \frac{1}{R_1} + \frac{1}{R_2} \qquad \frac{1}{R_{tot}} = \sum_{i=1}^{N} \frac{1}{R_i}$$

Effetti termici della conduzione elettrica



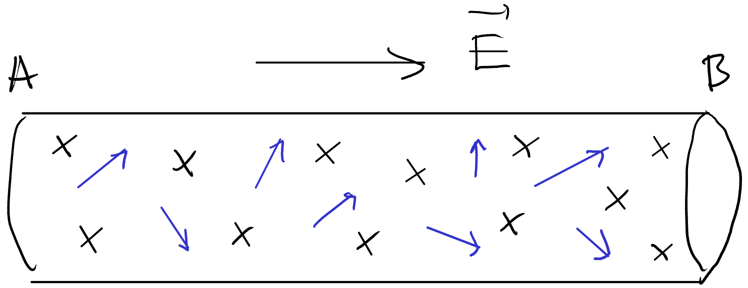
Lavoro compiuto dal campo

$$|\delta q|\,|\Delta V| \rightarrow \delta q\,\Delta V > 0$$

fornito al sistema

$$\underset{=0}{dE_c} + dU = \underset{\delta q \Delta V}{\delta W} + \delta Q$$

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



$$T = \text{cost} \Rightarrow dU = 0$$

$$U = C_V T$$

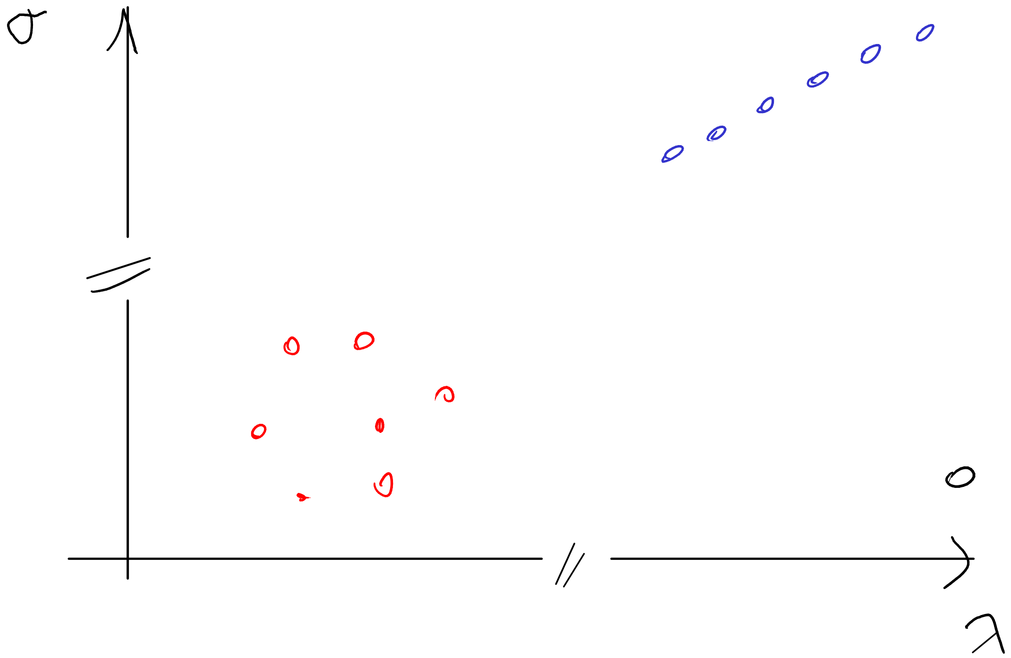
Energia per unità di tempo fornita dal campo elettrico al sistema, P_e

$$\delta Q = -|\delta q|\,|\Delta V| < 0$$

effetto Joule

$$P_e = \frac{|\delta q|\,|\Delta V|}{dt} = I_e\,|\Delta V| \xrightarrow{\text{ohm}} I_e^2 / R$$

Conducibilità elettrica e conducibilità termica



metalli : $\sigma \sim \lambda$

alta σ, alta λ

non metalli : bassa σ, bassa λ

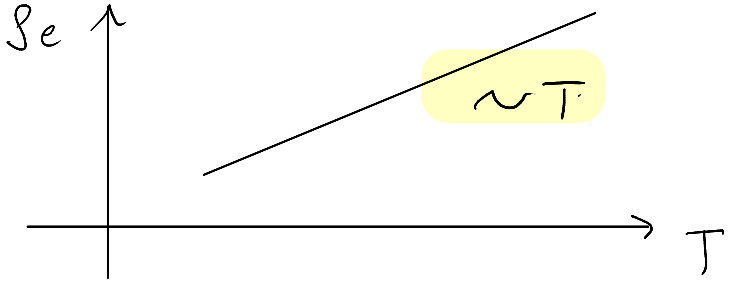
diamante : alta λ, bassa σ (es.)

Resistività elettrica : $\rho_e = \dfrac{1}{\sigma}$ SI : Ωm

Dipendenza della resistività ρ_e dalla temperatura

Materiali conduttori: Cu, Ag, ...

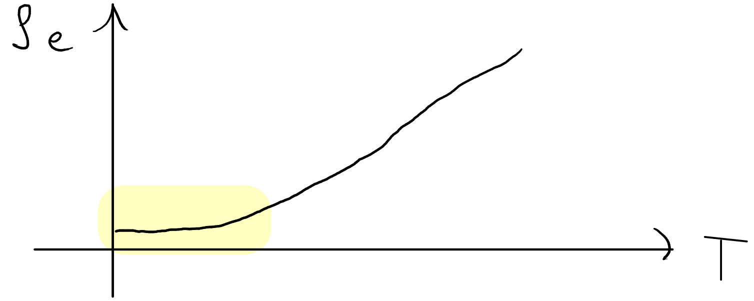
alta T



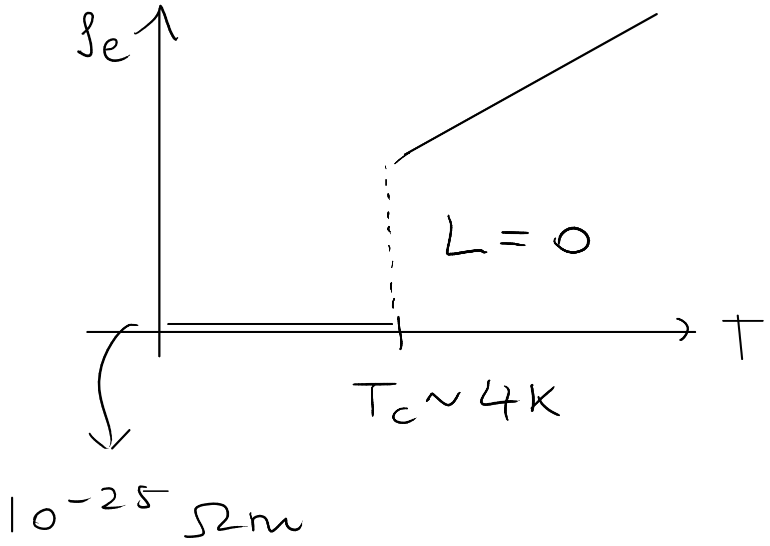
$\rho_e \sim \sqrt{T}$

bassa T

$\Rightarrow$ QM



Superconduttività



Onnes 1911

Hg

ceramici: $T_c \approx$ 100 K - 200 K

transizione di fase continua (II ordine)