FUNDAMENTALS OF NANOELECTRONICS

Basic Concepts

1. The New Perspective
2. Energy Band Model
3. What and Where is the Voltage?

Heat & Electricity: Second Law & Information

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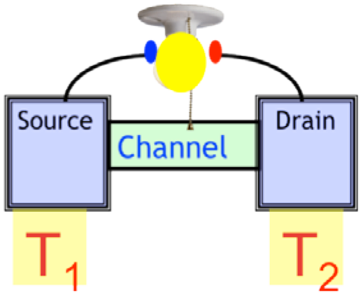
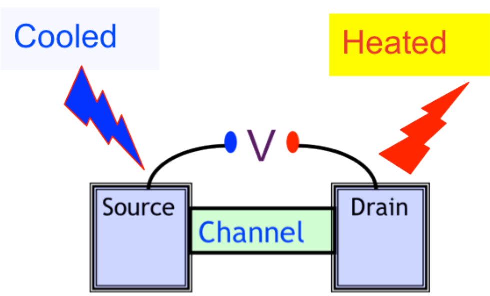
http://nanohub.org/groups/lnebook

4.5a Second law

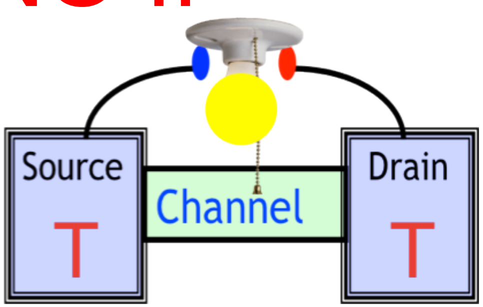
4.2. Seebeck Effect



4.3. Peltier Effect

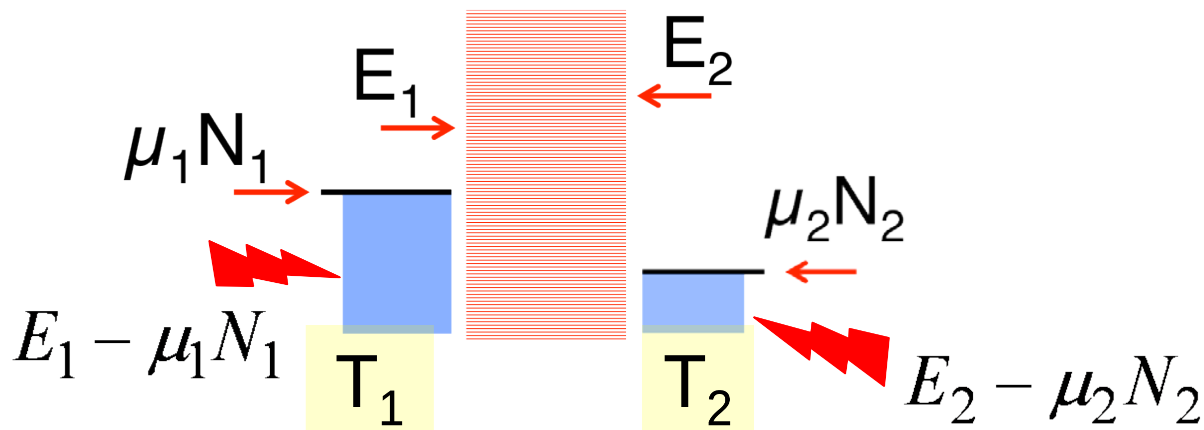


NO !!

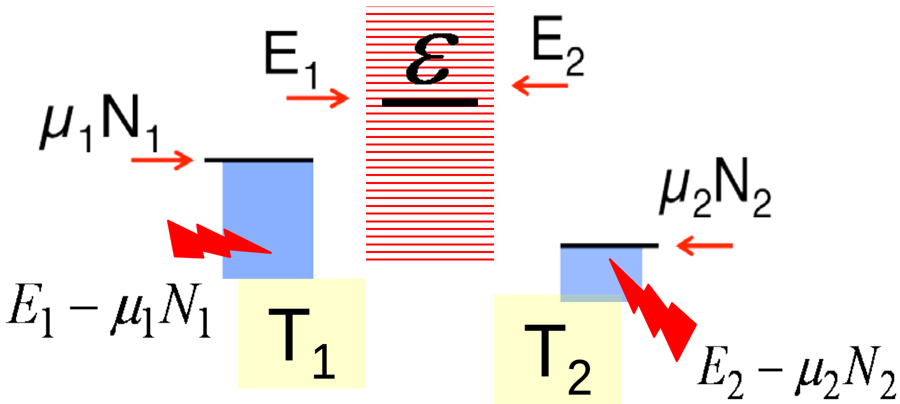


$$N_1 + N_2 = 0$$

First Law $$E_1 + E_2 = 0$$



Second Law $$\frac{E_1 - \mu_1 N_1}{T_1} + \frac{E_2 - \mu_2 N_2}{T_2} \le 0$$



Fermi function

$$f(\varepsilon,\mu,T) = \frac{1}{1+e^{x}} \qquad x \equiv \frac{\varepsilon-\mu}{kT}$$

$$E_1 = \varepsilon N_1$$

$$E_2 = \varepsilon N_2$$

Second Law

$$\frac{E_1-\mu_1 N_1}{T_1} + \frac{E_2-\mu_2 N_2}{T_2} \le 0$$

$$\frac{\varepsilon-\mu_1}{T_1} N_1 + \frac{\varepsilon-\mu_2}{T_2} N_2 \le 0$$

$$N_1 \left(\frac{\varepsilon-\mu_1}{T_1} - \frac{\varepsilon-\mu_2}{T_2} \right) \le 0$$

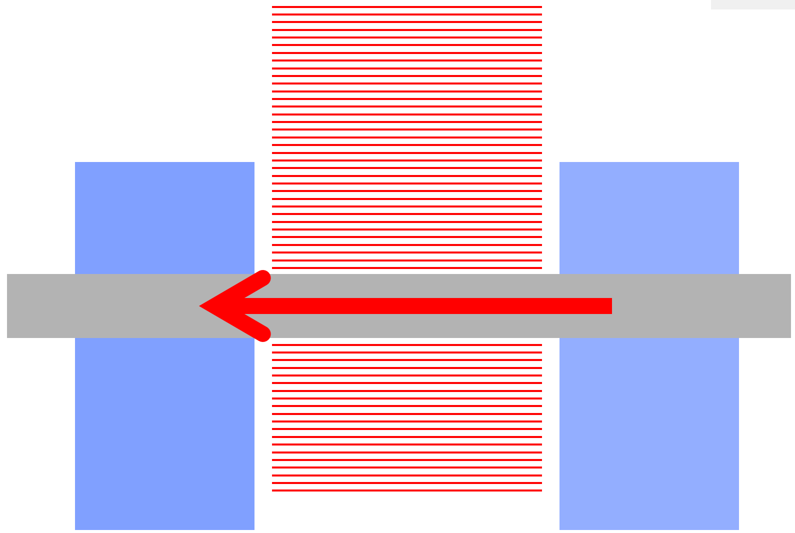
$$N_1 \left(f_1(\varepsilon) - f_2(\varepsilon) \right) \ge 0$$

First Law

$$E_1 + E_2 = 0$$

$$N_1 + N_2 = 0$$

$$I \sim f_1(\varepsilon) - f_2(\varepsilon)$$



First Law

$$E_1 + E_2 = 0$$

Second Law

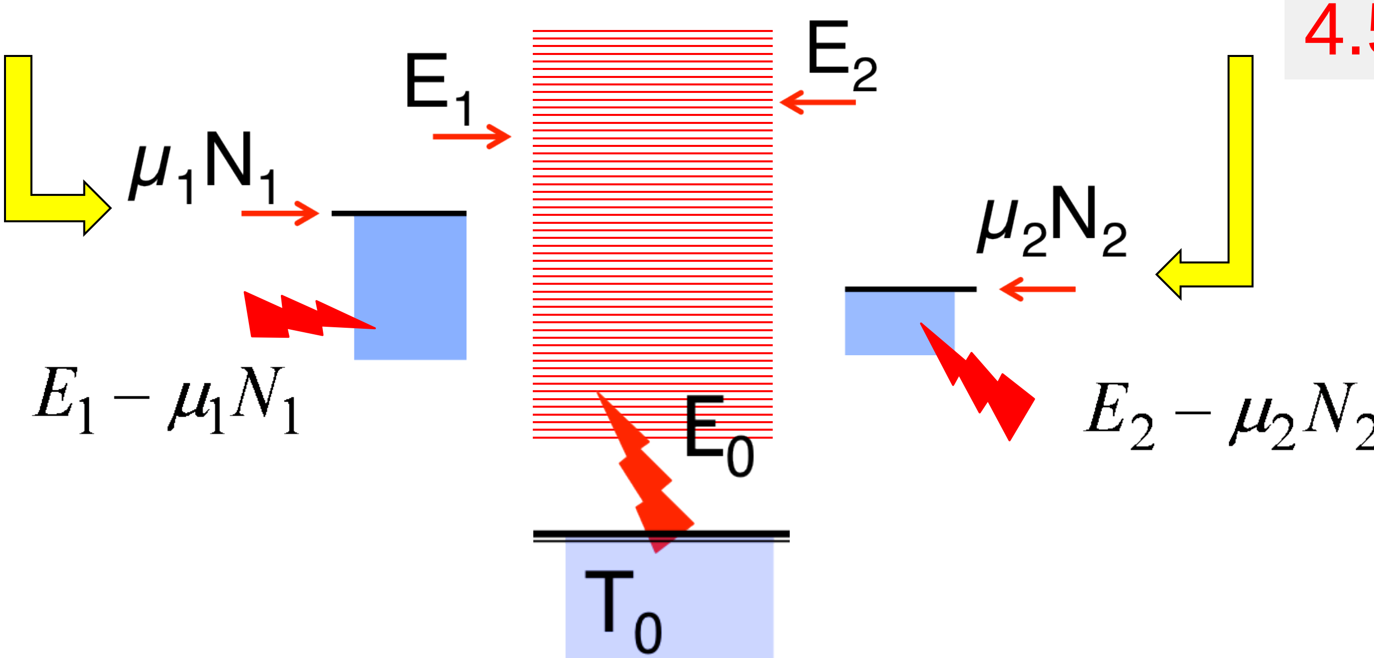
$$\frac{E_1 - \mu_1 N_1}{T_1} + \frac{E_2 - \mu_2 N_2}{T_2} \leq 0$$

$$I \sim \quad f_1(\varepsilon) - f_2(\varepsilon)$$

Fermi function

$$f(E,\mu,T) = \frac{1}{1+e^x} \qquad x \equiv \frac{E-\mu}{kT}$$

4.5d Second law



$$\mu_1 N_1 + \mu_2 N_2 \geq 0$$

First Law

$$E_0 + E_1 + E_2 = 0$$

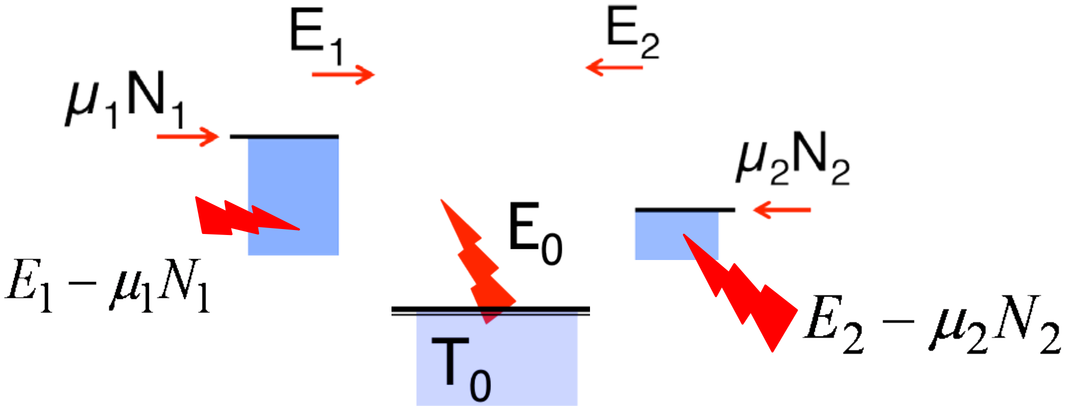
$$E_0 + (E_1 - \mu_1 N_1) + (E_2 - \mu_2 N_2) \leq 0$$

Second Law

$$\frac{E_0}{T_0} + \frac{E_1 - \mu_1 N_1}{T_1} + \frac{E_2 - \mu_2 N_2}{T_2} \leq 0$$

If $T_1 = T_2 = T_0$

4.5e Second law

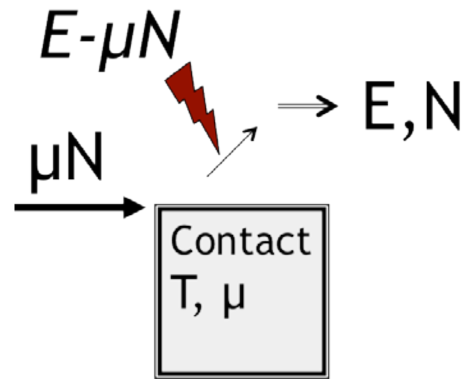


$$\frac{P(E_1,N_1)}{P_r(E_1,N_1)} \times \frac{P(E_2,N_2)}{P_r(E_2,N_2)} \times \frac{P(E_0)}{P_r(E_0)} \geq 1$$

$$\exp\left(-\frac{E_1-\mu_1 N_1}{T_1} - \frac{E_2-\mu_2 N_2}{T_1} - \frac{E_0}{T_0}\right) \geq 1$$

$$-\frac{E_1-\mu_1 N_1}{T_1} - \frac{E_2-\mu_2 N_2}{T_1} - \frac{E_0}{T_0} \geq 0$$

$$\boxed{\frac{E_1-\mu_1 N_1}{T_1} + \frac{E_2-\mu_2 N_2}{T_1} + \frac{E_0}{T_0} \leq 0}$$



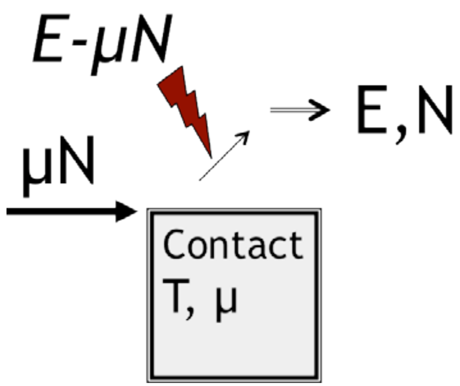
$$\frac{P(E,N)}{P_r(E,N)} = \exp\left(-\frac{E-\mu N}{kT}\right)$$

If N=0

$$\frac{P(E)}{P_r(E)} = \exp\left(-\frac{E}{kT}\right)$$

Harder to take than to give

Coming up next ..



$$\frac{P(E,N)}{P_r(E,N)} = \exp\left(-\frac{E-\mu N}{kT}\right)$$

If N=0

$$\frac{P(E)}{P_r(E)} = \exp\left(-\frac{E}{kT}\right)$$

Why is it harder to take than to give