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

4.1. Introduction

4.2. Seebeck Coefficient

4.3. Heat Current

4.4. One-level Device

4.5. Second Law

4.6. Entropy

4.7. Law of Equilibrium

4.8. Shannon Entropy

4.9. Fuel Value of Information

4.10. Summing up ..

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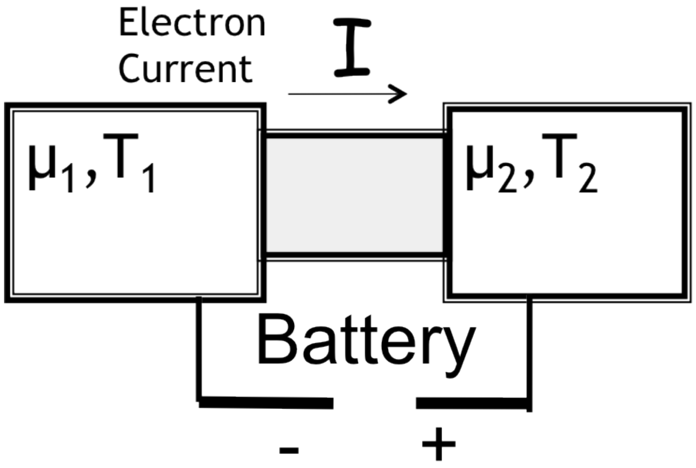
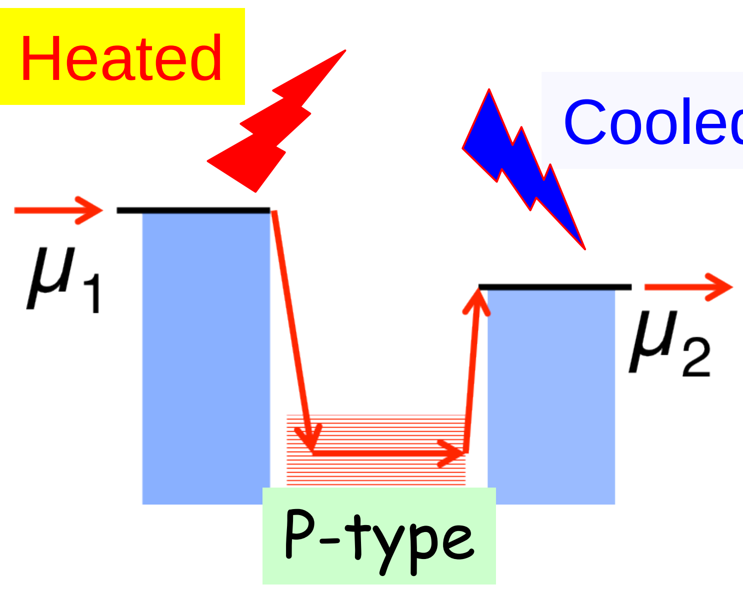
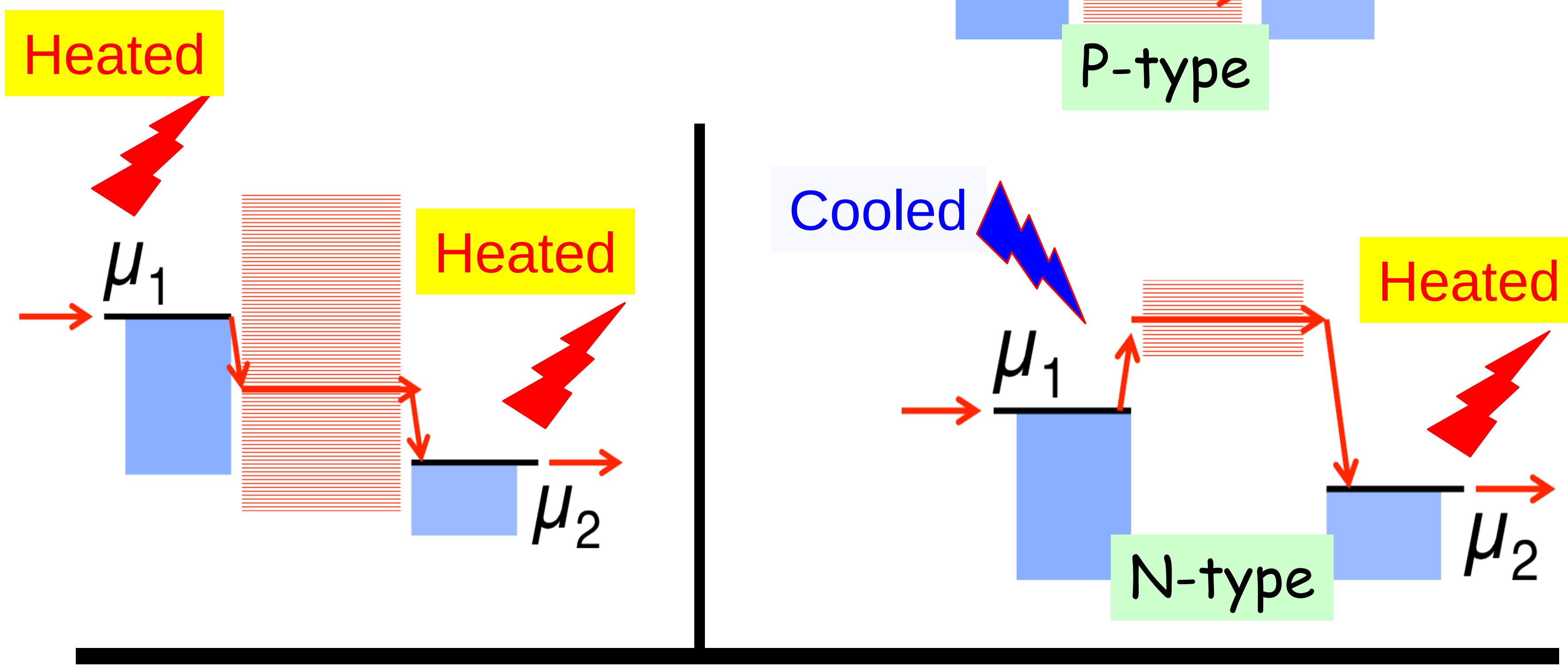
http://nanohub.org/groups/lnebook

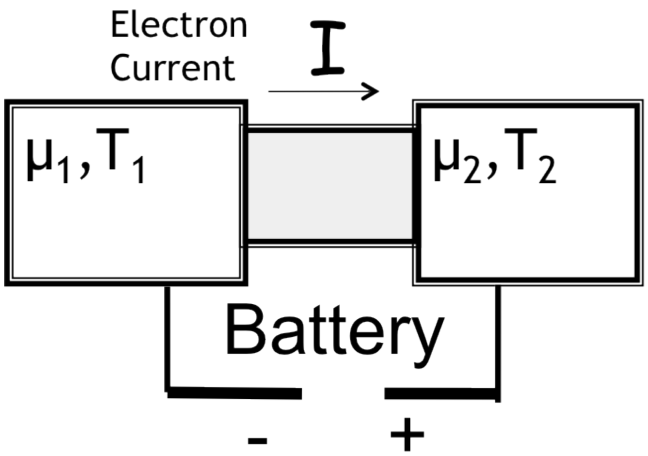
4.3a Heat current

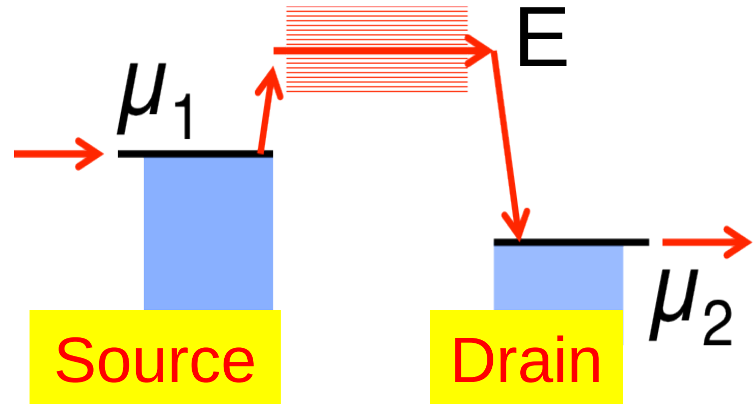






4.3b Heat current





Energy from source
$$I_{Q1} = \frac{1}{q}\int_{-\infty}^{+\infty} dE\ G(E)\big(f_1(E) - f_2(E)\big) \times \frac{E-\mu_1}{q}$$

Energy from drain
$$I_{Q2} = \frac{1}{q}\int_{-\infty}^{+\infty} dE\ G(E)\big(f_1(E) - f_2(E)\big) \times \frac{\mu_2 - E}{q}$$

Energy from battery
$$I_E = \frac{1}{q}\int_{-\infty}^{+\infty} dE\ G(E)\big(f_1(E) - f_2(E)\big) \times \frac{\mu_1 - \mu_2}{q}$$

4.3c Heat current

$$I_Q = \frac{1}{q}\int_{-\infty}^{+\infty} dE\ \frac{E-\mu_0}{q} G(E)\big(f_1(E)-f_2(E)\big)$$

$$\approx \quad G_P(V_1-V_2)+G_Q(T_1-T_2)$$

$$G_P = \int_{-\infty}^{+\infty} dE\left(-\frac{\partial f_0}{\partial E}\right)\frac{E-\mu_0}{q}G(E)$$

$$f_1-f_2 \approx \left(-\frac{\partial f_0}{\partial E}\right)\times$$

$$\left(\Delta\mu + \frac{E-\mu_0}{T_0}\Delta T\right)$$

$$G_Q = \int_{-\infty}^{+\infty} dE\left(-\frac{\partial f_0}{\partial E}\right)\frac{(E-\mu_0)^2}{q^2T_0}G(E)$$

Energy from source $$I_{Q1} = \frac{1}{q}\int_{-\infty}^{+\infty} dE\ G(E)\big(f_1(E)-f_2(E)\big)\times\frac{E-\mu_1}{q}$$

Energy from drain $$I_{Q2} = \frac{1}{q}\int_{-\infty}^{+\infty} dE\ G(E)\big(f_1(E)-f_2(E)\big)\times\frac{\mu_2-E}{q}$$

4.3d Heat current

$$I = \frac{1}{q}\int_{-\infty}^{+\infty} dE\, G(E)\,\big(f_1(E) - f_2(E)\big)$$

$$I \approx G_0\,\Delta V + G_S\,\Delta T$$

$$I_Q \approx G_P\,\Delta V + G_Q\,\Delta T$$

$$G_0 = \int_{-\infty}^{+\infty} dE\left(-\frac{\partial f_0}{\partial E}\right) G(E)$$

$$G_S = \int_{-\infty}^{+\infty} dE\left(-\frac{\partial f_0}{\partial E}\right) \frac{E-\mu_0}{qT_0}\, G(E)$$

$$G_P = \int_{-\infty}^{+\infty} dE\left(-\frac{\partial f_0}{\partial E}\right) \frac{E-\mu_0}{q}\, G(E)$$

$$G_Q = \int_{-\infty}^{+\infty} dE\left(-\frac{\partial f_0}{\partial E}\right) \frac{(E-\mu_0)^2}{q^2 T_0}\, G(E)$$

Kelvin Relation

$$G_P = T_0 G_S$$

$$I_Q = \frac{1}{q}\int_{-\infty}^{+\infty} dE\, \frac{E-\mu_0}{kT_0}\, G(E)\big(f_1(E) - f_2(E)\big)$$

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$$I \approx G_0 \, \Delta V + G_S \, \Delta T$$

$$I_Q \approx G_P \, \Delta V + G_Q \, \Delta T$$

$$\Delta V \approx \overbrace{\frac{1}{G_0}}^{R} I \; \overbrace{-\frac{G_S}{G_0}}^{S} \Delta T$$

Heat conductance

G_Q : *Short ckt*

G_K : *Open ckt*

$$I_Q \approx \underbrace{\frac{G_P}{G_0}}_{-\Pi} I + \underbrace{\left(G_Q - \frac{G_P G_S}{G_0} \right)}_{G_K} \Delta T$$

Coming up next ..