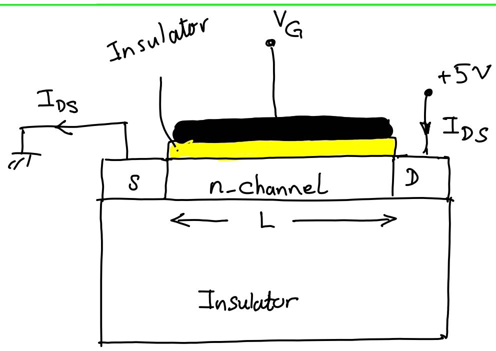
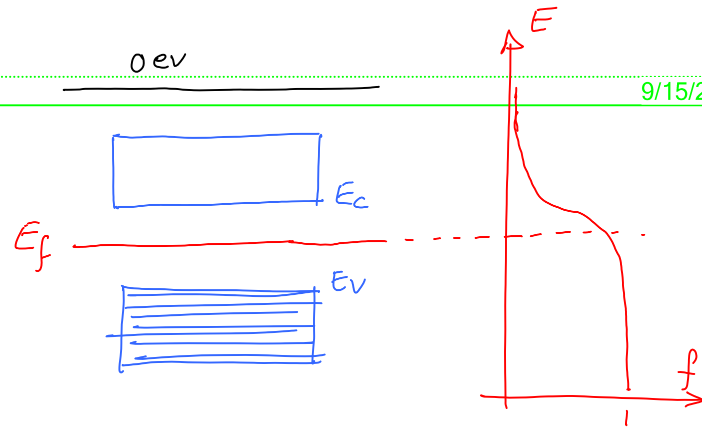
Session 3

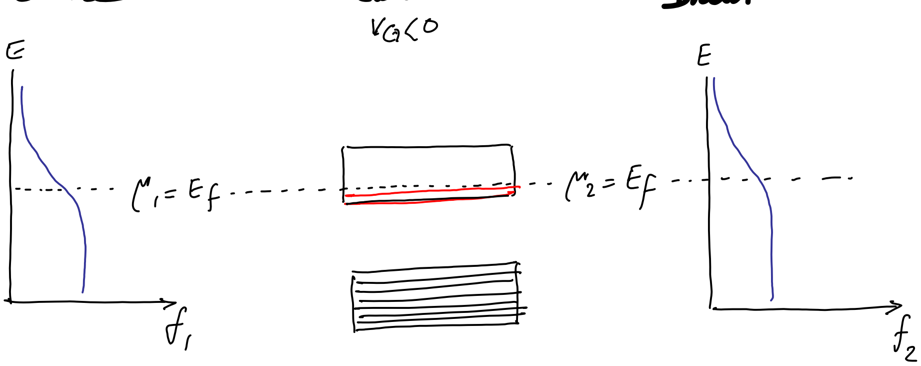
Note Title 9/15/2008





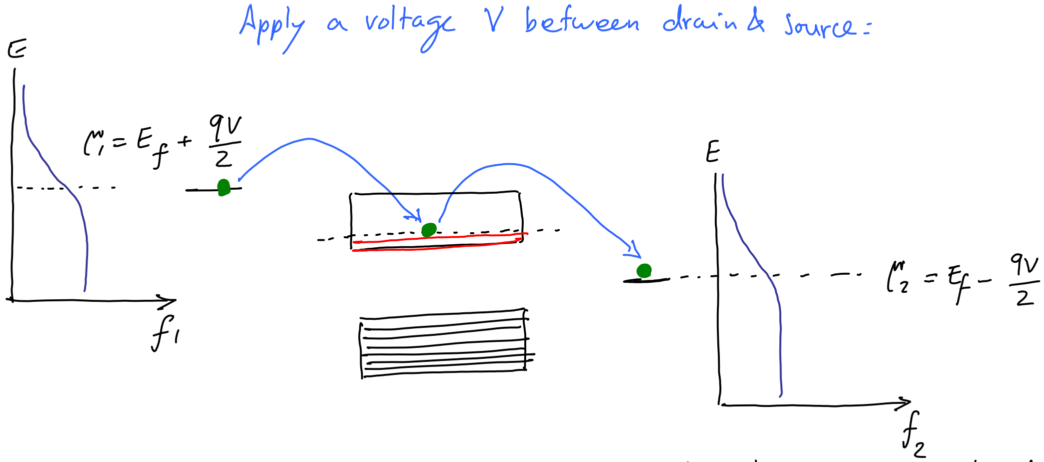
Current depends on number of states around fermi energy, not on number electrons.

Source **Gate** **Drain**



No current since $\mu_1 = \mu_2$

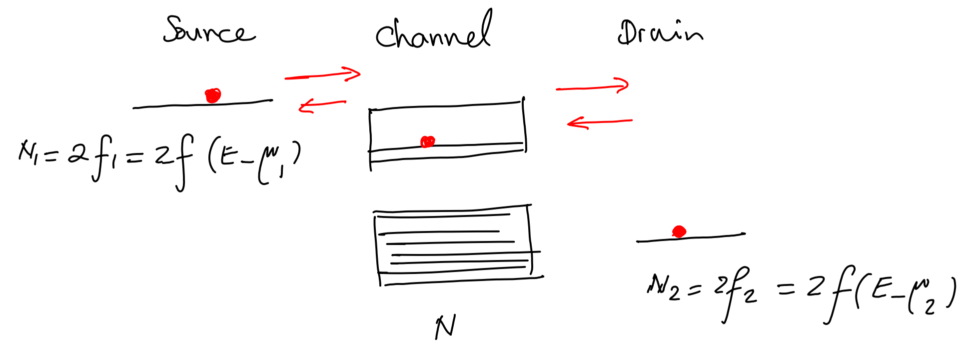
Apply a voltage V between drain & source:



Current flows between source & Drain through the energy level between them. Left side at μ_1 keeps filling the channel's states and the right side at μ_2 keeps emptying the channel's states.

If there was no state between μ_1 & μ_2 in the channel, there would be no current.

Let's calculate the current for a one level model for Source & Drain:



Current from left side:

$I_1 = e$ (transition rate from μ_1 to the channel − transition rate from channel to μ_1)

$$= e\left(\frac{\gamma_1}{\hbar} N_1 - \frac{\gamma_1}{\hbar} N\right) = e\frac{\gamma_1}{\hbar}(N_1 - N)$$

rate × number of electrons in the Source

number of electrons in the Channel

$$\hbar = \frac{h}{2\pi} = \frac{6.626\times10^{-34}}{2\pi} = 1.06\times10^{-34}\ j.s$$

$$I_2 = e\frac{\gamma_2}{\hbar}(N - N_2)$$

$$\frac{\gamma_1}{\hbar} \quad \left[\frac{\gamma_1}{j.s}\right]\left[\frac{1}{s}\right] \rightarrow \gamma_1\,[j]$$

Say $\gamma_1 = 1\ \text{meV} \rightarrow \frac{\gamma_1}{\hbar} = \frac{10^{-3}\times1.6\times10^{-19}}{1.06\times10^{-34}} \simeq 10^{12}\ s^{-1} \rightarrow$ it takes ~ 1 ps for the electron to escape into channel.

Equating $I_1 = I_2 \Rightarrow$

$$e\frac{\gamma_1}{\hbar}(N_1 - N) = e\frac{\gamma_2}{\hbar}(N - N_2)$$

$$(\gamma_1 + \gamma_2)N = \gamma_1 N_1 + \gamma_2 N_2 \rightarrow N = \frac{\gamma_1 N_1 + \gamma_2 N_2}{\gamma_1 + \gamma_2}$$

$$\Rightarrow I = I_1 = I_2 = \frac{e\gamma_1}{\hbar}\left(N_1 - \frac{\gamma_1 N_1 + \gamma_2 N_2}{\gamma_1 + \gamma_2}\right) = \frac{e\gamma_1}{\hbar}\,\frac{\gamma_2(N_1 - N_2)}{\gamma_1 + \gamma_2}$$

$$= \frac{e}{\hbar}\,\frac{\gamma_1\gamma_2}{\gamma_1+\gamma_2}\left(2f_1(\varepsilon) - 2f_2(\varepsilon)\right)$$

$$I = \frac{2e}{\hbar}\,\frac{\gamma_1\gamma_2}{\gamma_1+\gamma_2}\left(f_1(\varepsilon) - f_2(\varepsilon)\right)$$

So if $f_1(\varepsilon) = f_2(\varepsilon) \Rightarrow I = 0$ as expected.

$$f_1(\varepsilon) \downarrow f(\varepsilon - \mu_1) \qquad f_2(\varepsilon) \downarrow f(\varepsilon - \mu_2)$$

Let's Taylor expand to get the expression at small voltage:

$$f_1(\varepsilon) - f_2(\varepsilon) = f(\varepsilon - \mu_1) - f(\varepsilon - \mu_2)$$

$$= \left[f(\varepsilon) - \frac{df}{d\varepsilon}\mu_1 \right] - \left[f(\varepsilon) - \frac{df}{d\varepsilon}\mu_2 \right]$$

$$= \frac{df}{d\varepsilon}\underbrace{(\mu_2 - \mu_1)}_{-qV_D} = -\frac{df}{d\varepsilon} eV_D$$

So for **small voltage** V_D:

$$I = \frac{2e}{\hbar}\frac{\gamma_1\gamma_2}{\gamma_1+\gamma_2}\overbrace{\left(-\frac{df}{d\varepsilon}eV_D\right)}^{f_1 - f_2}$$

$$I = V \underbrace{\frac{2e^2}{\hbar}}_{\substack{\text{dimension of} \\ \text{Conductance} \\ [S] \to 1/\Omega}} \underbrace{\frac{\gamma_1\gamma_2}{\gamma_1+\gamma_2}}_{\substack{\text{dimension of} \\ \text{energy} \\ [j]}} \underbrace{\left(-\frac{df}{d\varepsilon}\right)}_{\substack{\text{dimension of} \\ \text{inverse energy} \\ [1/j]}}$$

How does it look?