Fundamentals of Nanoelectronics

ECE495 - Session 35, Nov 20, 2009

Non-coherent Transport

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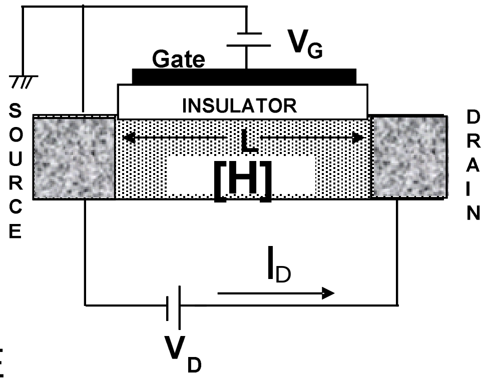
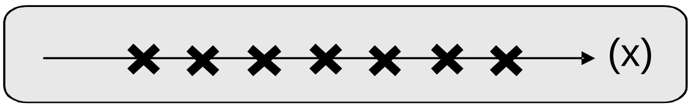
Review

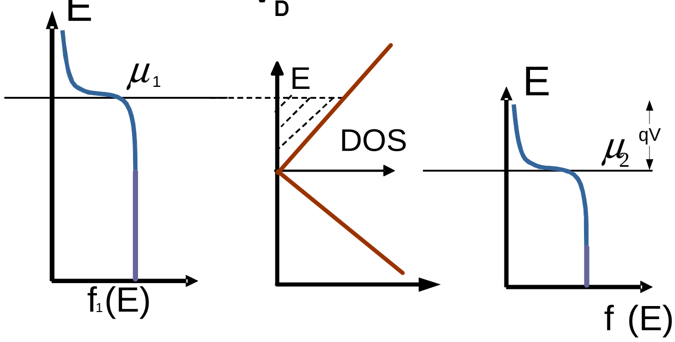


$[EI - H - \Sigma_1 - \Sigma_2]\{\Psi\} = \{S\}$

$\Psi\Psi^+ = ?$



$$I = \frac{q}{h}\int dE \quad * \quad (f_1 - f_2)$$

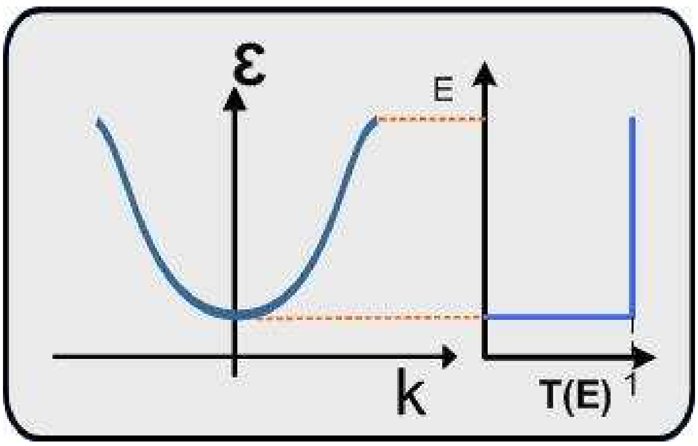


$$\Sigma_1 = \begin{bmatrix} -t_0 e^{ika} & 0 \\ 0 & 0 \end{bmatrix}$$

$$\Sigma_2 = \begin{bmatrix} 0 & 0 \\ 0 & -t_0 e^{ika} \end{bmatrix}$$

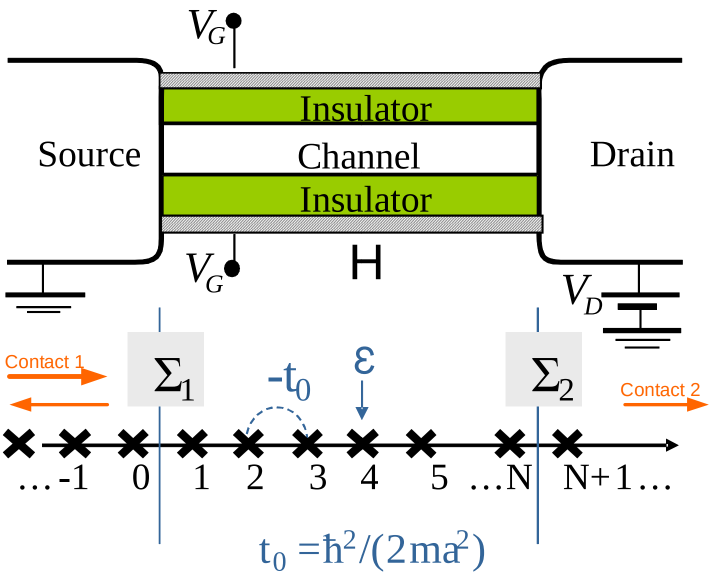
Just one element is non-zero in Σ. For Σ_1, the top left and for Σ_2 button right.

$$\Gamma_1 = \begin{bmatrix} \frac{\hbar v / a}{2t_0 \sin ka} & 0 \\ 0 & 0 \end{bmatrix} \qquad \varepsilon = 2t_0(1 - \cos ka) \Rightarrow \frac{d\varepsilon}{dk} = 2at_0 \sin ka = \hbar v$$



Wire without Scattering

For a one dimensional lead:



The important point to notice is that unlike H, Sigma is complex. The imaginary part indicates a finite lifetime and tells us how easily an electron can escape into the contact.

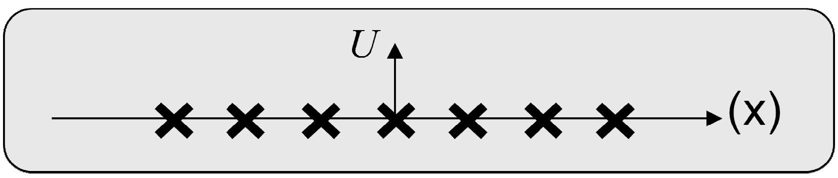
We've been discussing coherent transport where electrons go through the channel without losing energy or dissipating heat. Using the general form, current can be calculated as follows:

$$G(E) = (EI - H - \Sigma_1 - \Sigma_2)^{-1}, \quad A = i(G - G^+)$$

$$\Gamma_1 = i(\Sigma_1 - \Sigma_1^+) \quad and \quad \Gamma_2 = i(\Sigma_2 - \Sigma_2^+)$$

$$I = \frac{2q}{h}\int dE\bar{T}(E)\left(f_1(E) - f_2(E)\right) \text{ where } \bar{T}(E) = Trace\left(\Gamma_1 G \Gamma_2 G^+\right)$$

Wire with One Impurity



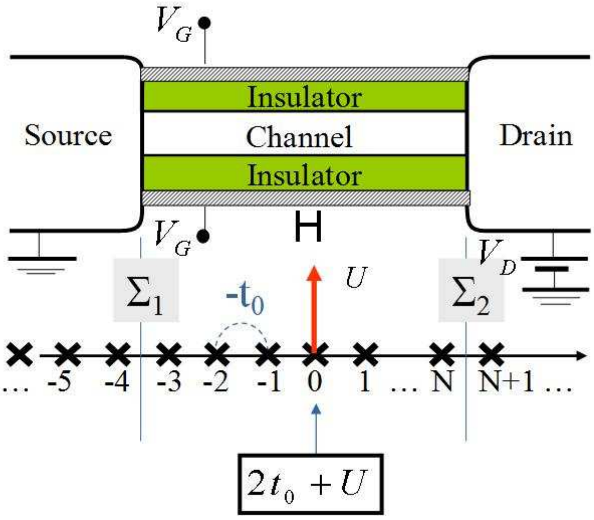
For a uniform 1-D wire we have:

$$\left[E_c - \frac{\hbar^2}{2m_c}\frac{d^2}{dx^2} + U(x)\right]\psi(x) = E\psi(x)$$

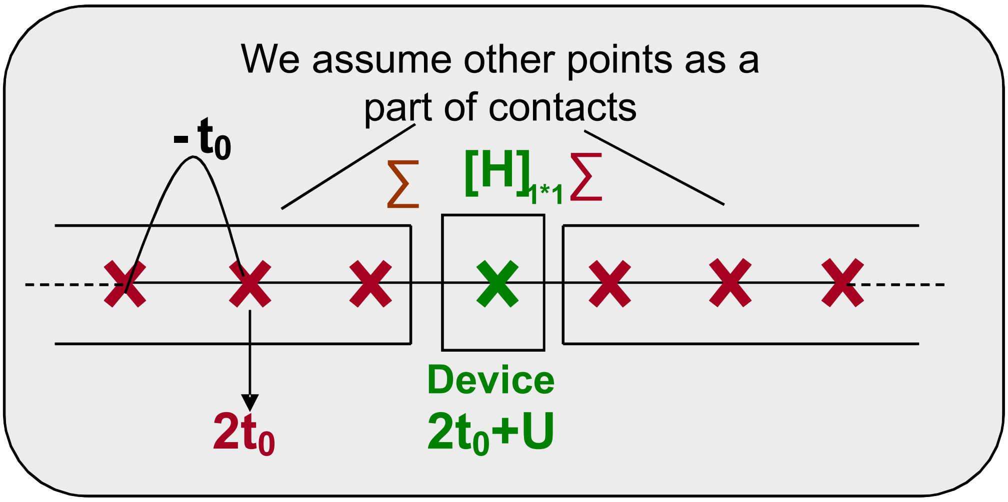
Based on the discrete lattice above Schrödinger equation becomes a matrix equation:

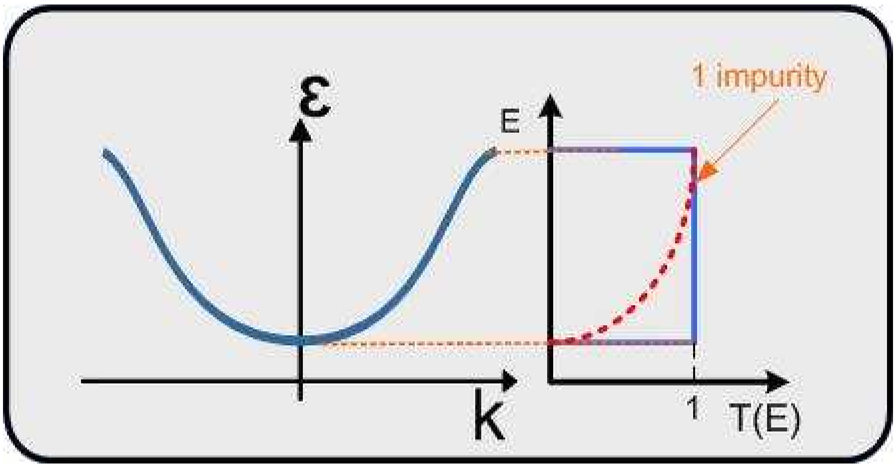
The Hamiltonian is tri diagonal:

$$H=\begin{bmatrix} 2t_0 & -t_0 & 0 & \cdots & \cdots & \\ -t_0 & 2t_0 & -t_0 & 0 & \cdots & \vdots \\ 0 & -t_0 & \ddots & \ddots & & \vdots \\ \vdots & 0 & \ddots & 2t_0+U & & \vdots \\ \vdots & \vdots & & & \ddots & -t_0 \\ & \cdots & \cdots & \cdots & -t_0 & 2t_0 \end{bmatrix}$$

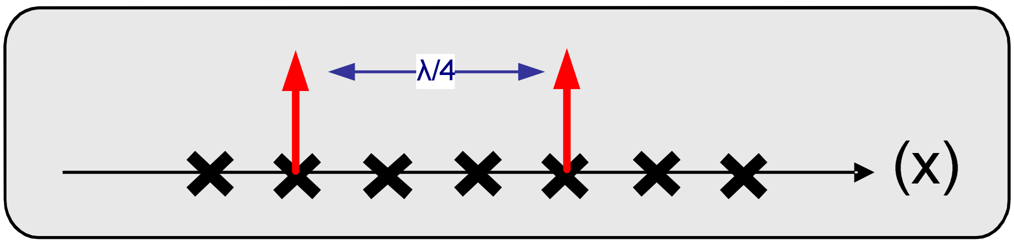


We can solve it just by assuming the device with only one lattice point:

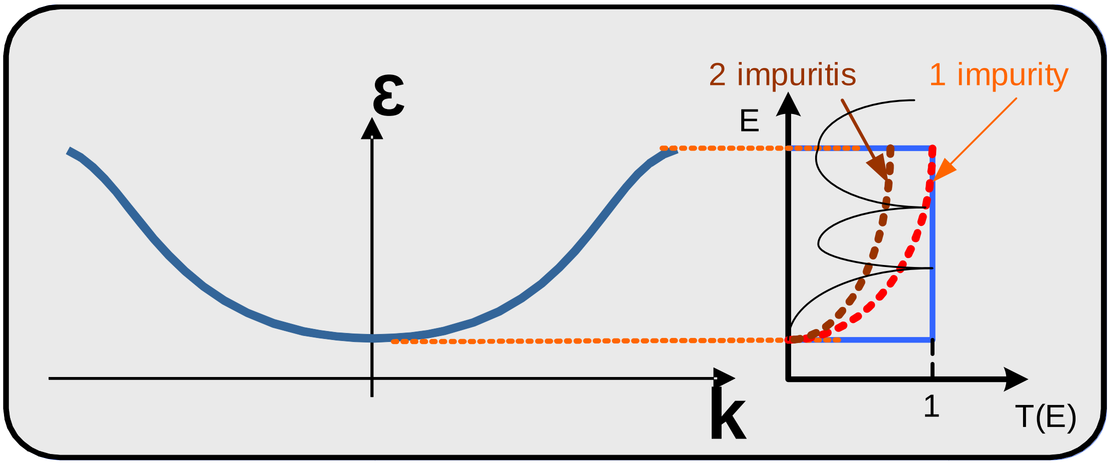




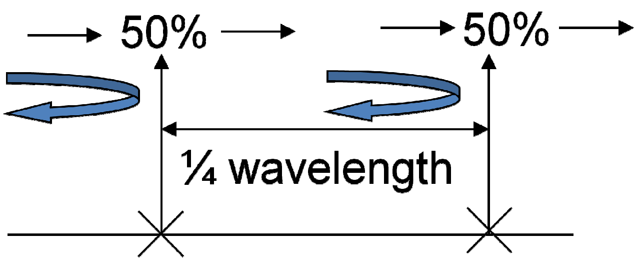
Wire with Two Impurities



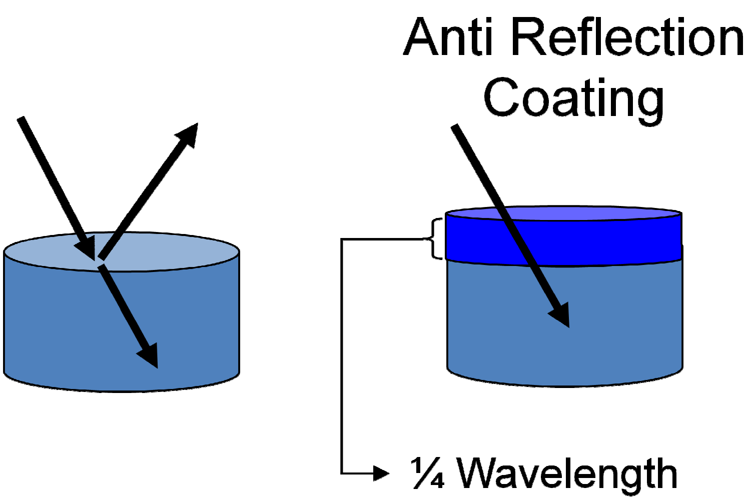
At some energy the distance between two particles is exactly λ/4 and it is due to wave property of electron. In practice, due to noise people may not be able to see this behavior in room temperature.



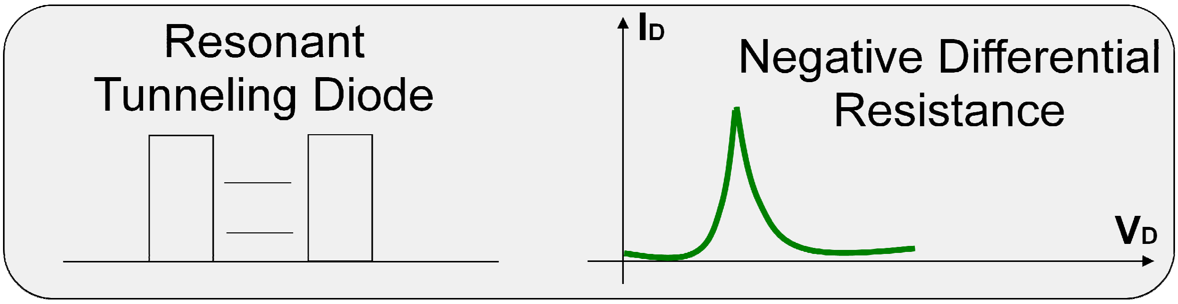
The below picture is not as easy if we think of electrons as waves and our relationship will not compensate for all the physics that is inherent in the problem.



Looking at the problem Quantum mechanically, it is interference between the waves that changes the picture. For example if the distance between the two scatterers is quarter of a wavelength, the two reflections cancel each other and this way we can even get more transmission (Constructive interference). In this case, transmission will be 100% and there would be no reflection. This technique has been used to eliminate reflection from lenses:



Resonant Tunnelling Devices



Why does negative differential resistance happen?

A voltage is applied to the two barrier device, the barrier and the Fermi level on the right start going down. Initially, current increases for higher voltages. But there comes a point where the allowed energy levels in between the two barriers falls under the bottom edge of the allowed energy levels in the left contact. In this case since there is no energy level available for the electron coming from the left contact, current will drop to 0.