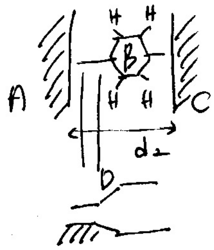
① V STM.

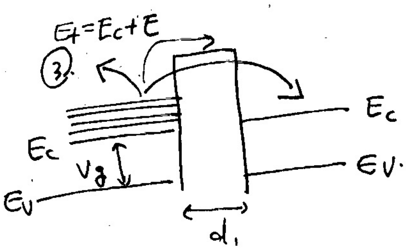
sample.

③

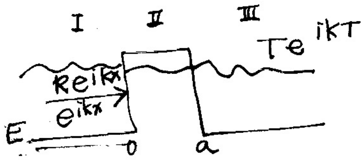


tunneling.

→ diode.



$d_1 << d_2$



$|T^2|$.

$$I: \psi_I = e^{ikx} + Re^{-ikx}, \quad \frac{\hbar^2 k_1^2}{2m} = E.$$

$$II: e^{k_2 x} + De^{-k_2 x}, \quad \frac{\hbar^2 k_2^2}{2m} = (V-E).$$

when, $E_I = E_{II}$ (golden rule).
tunneling 일어남.

$$\frac{\partial |\psi(r,t)|^2}{\partial t} = \frac{2e}{\hbar} |\langle a|V|b\rangle|^2 \delta(E_a - E_b$$

$$\begin{cases} \psi_I(0) = \psi_{II}(0) \\ \left.\frac{\partial \psi_I}{\partial x}\right|_{x=0} = \left.\frac{\partial \psi_{II}}{\partial x}\right|_{x=0} \\ \psi_{II}(d) = \psi_{III}(d) \\ \left.\frac{\partial \psi_{II}}{\partial x}\right|_{x=d} = \left.\frac{\partial \psi_{III}}{\partial x}\right|_{x=d} \end{cases}$$

$$T = \frac{2ip_1 k_2 \hbar}{2i\hbar p_1 k_2 \cosh(k_2 d) + (p_1^2 - k_2^2)\sinh(k_2 d)}$$

$$\cosh k_2 d = \frac{e^{k_2 d} + e^{-k_2 d}}{2}, \quad \sinh k_2 d = \frac{e^{k_2 d} - e^{-k_2 d}}{2}$$

$$\begin{bmatrix} R \\ C \\ D \\ T \end{bmatrix} = A^{-1} \begin{bmatrix} 1 \\ ip \\ 0 \\ 0 \end{bmatrix}$$

$$|T|^2 = \left[1 + \frac{\sinh^2(k_2 d)}{1 + 4(E/V)(1 - \frac{E}{V})}\right]^{-1} = TT^*$$

$$|T|_{\lambda << d} \overset{?}{=} \left[\frac{e^{2k_2 d}/4}{4(E/V)(1 - E/V)}\right]^{-1}$$

$$= 16(E/V)(1 - E/V)\exp^{-2k_2 d}$$

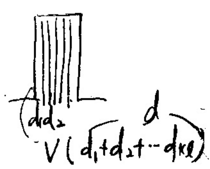
$$16(E/V)(1-E/V)\exp\left(-\frac{2}{\hbar}\int_0^d \sqrt{2m(E-V(x))}\,dx\right)$$

⇑

$$\frac{2}{\hbar}\int \sqrt{2m(V_1 - E)}\,(d_1 + d_2 \cdots)$$

⇑

$$\frac{2}{\hbar}\left(\int \sqrt{2m(Vd_1 - Ed)} + \int \sqrt{2m(Vd_2 - Ed_2} \cdots\right)$$

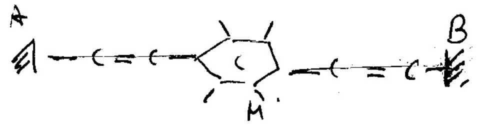


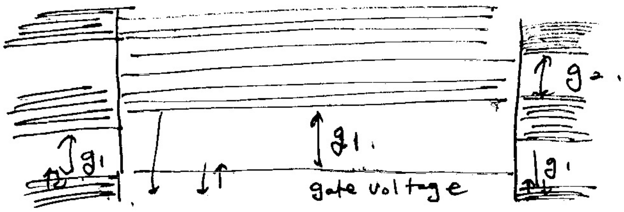
Tip. sample.

(+): sampled ground state 보냄

(−): 〃 excitation state 받음.

conduction.





s.D voltage - <tr.>.