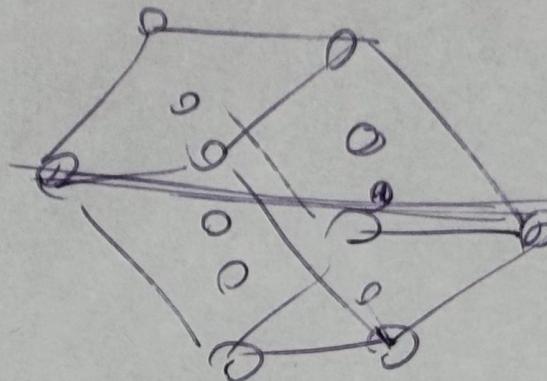
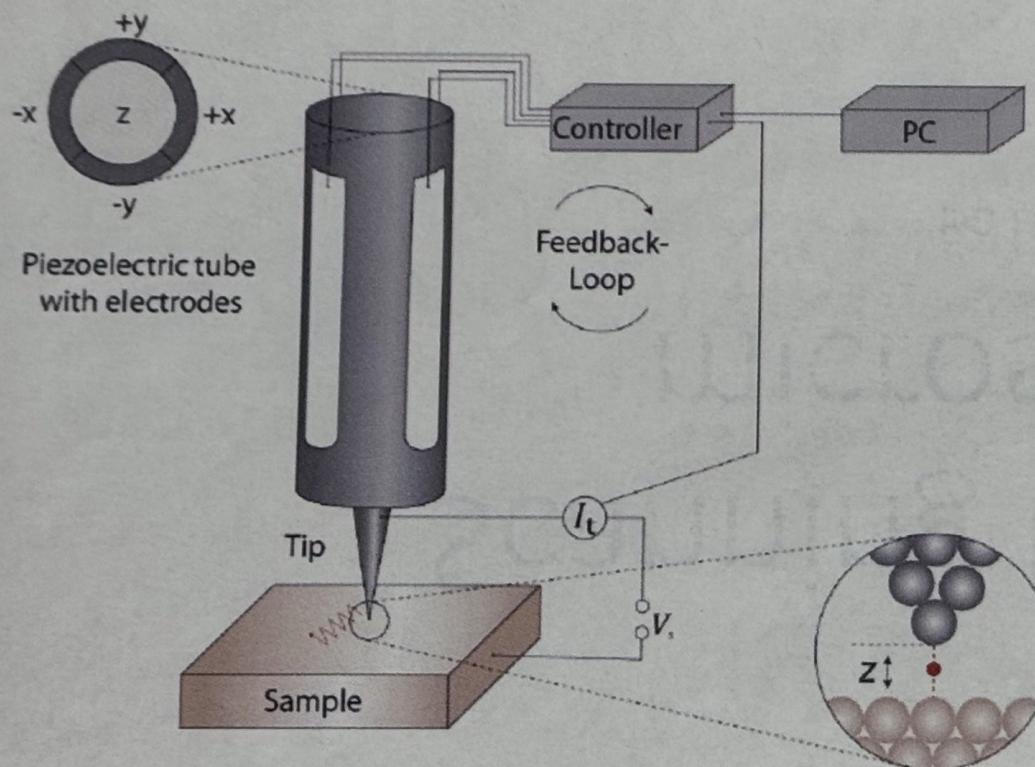
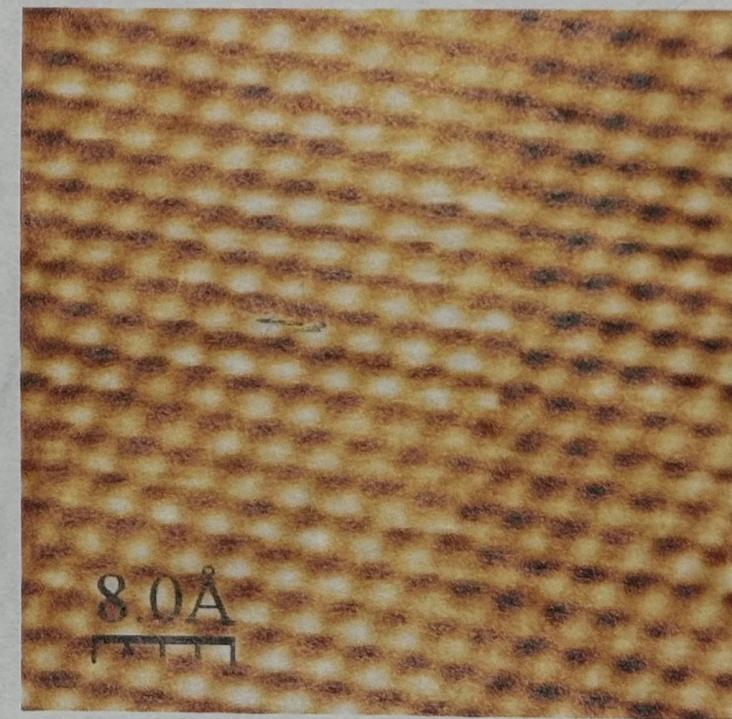


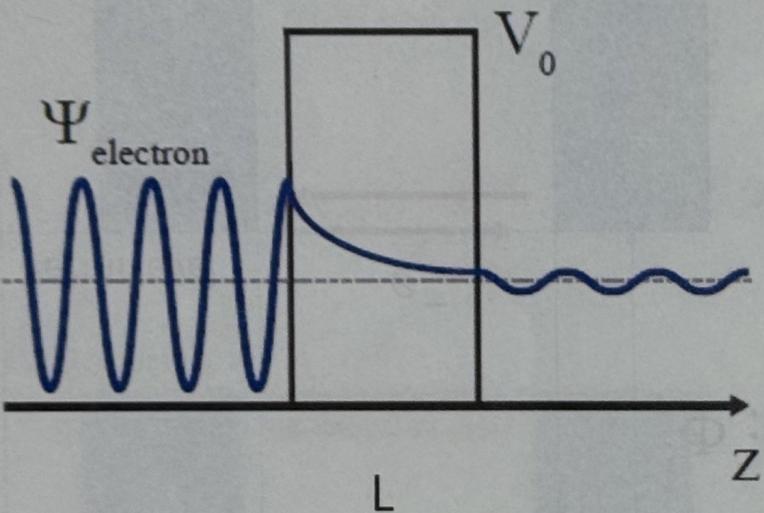
# STM principle



Au(111) surface



# Quantum tunneling



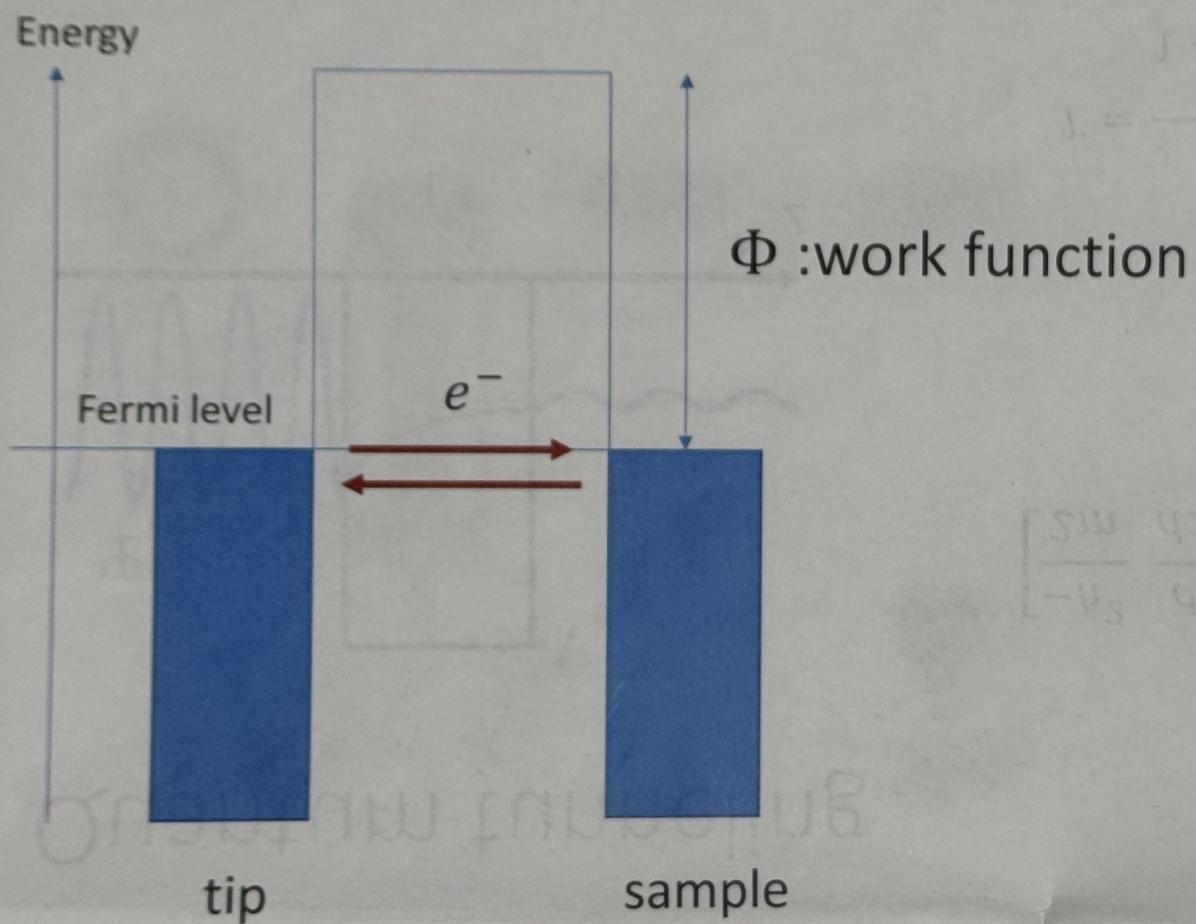
Schrodinger equation

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

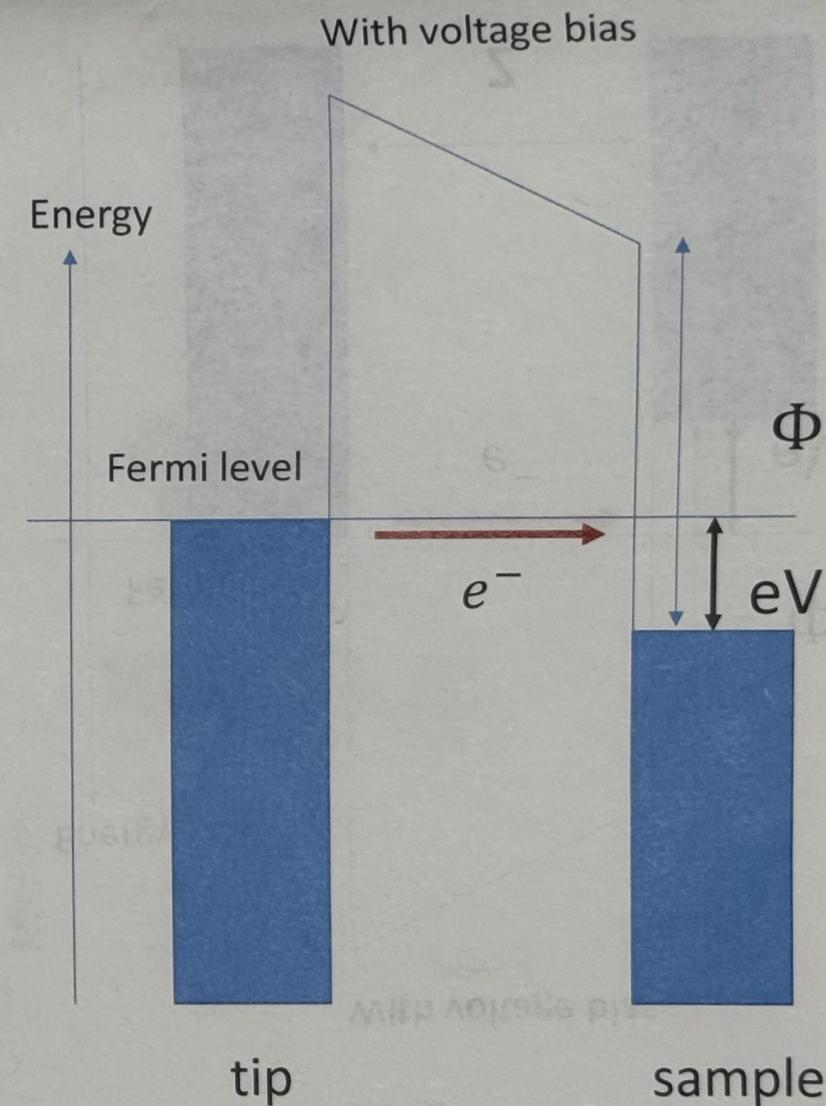
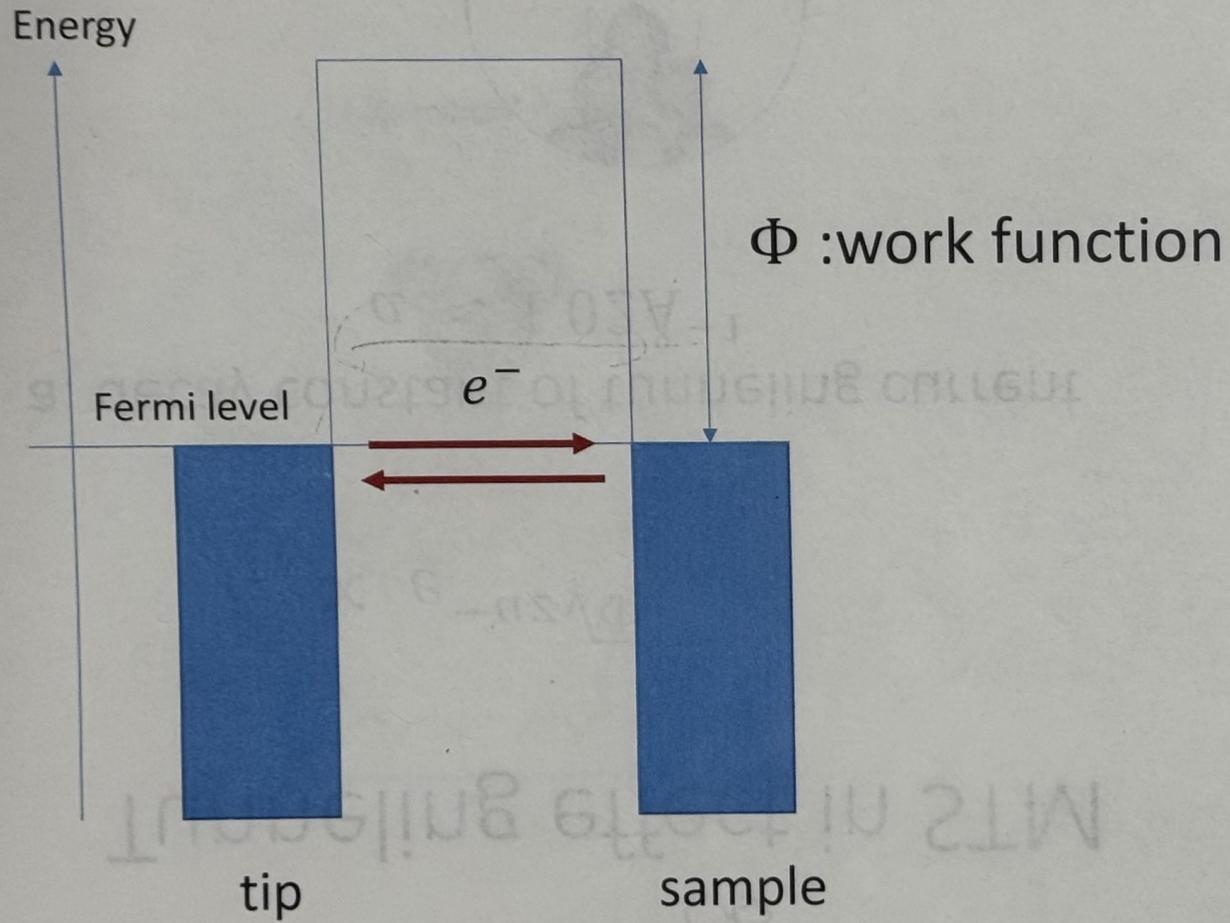
Tunneling transmission probability

$$T = \frac{1}{1 + \frac{V_0 \sinh^2(L \sqrt{2m(E - V_0)}/\hbar^2)}{4E(V_0 - E)}}$$

# Tunneling effect in STM



# Tunneling effect in STM

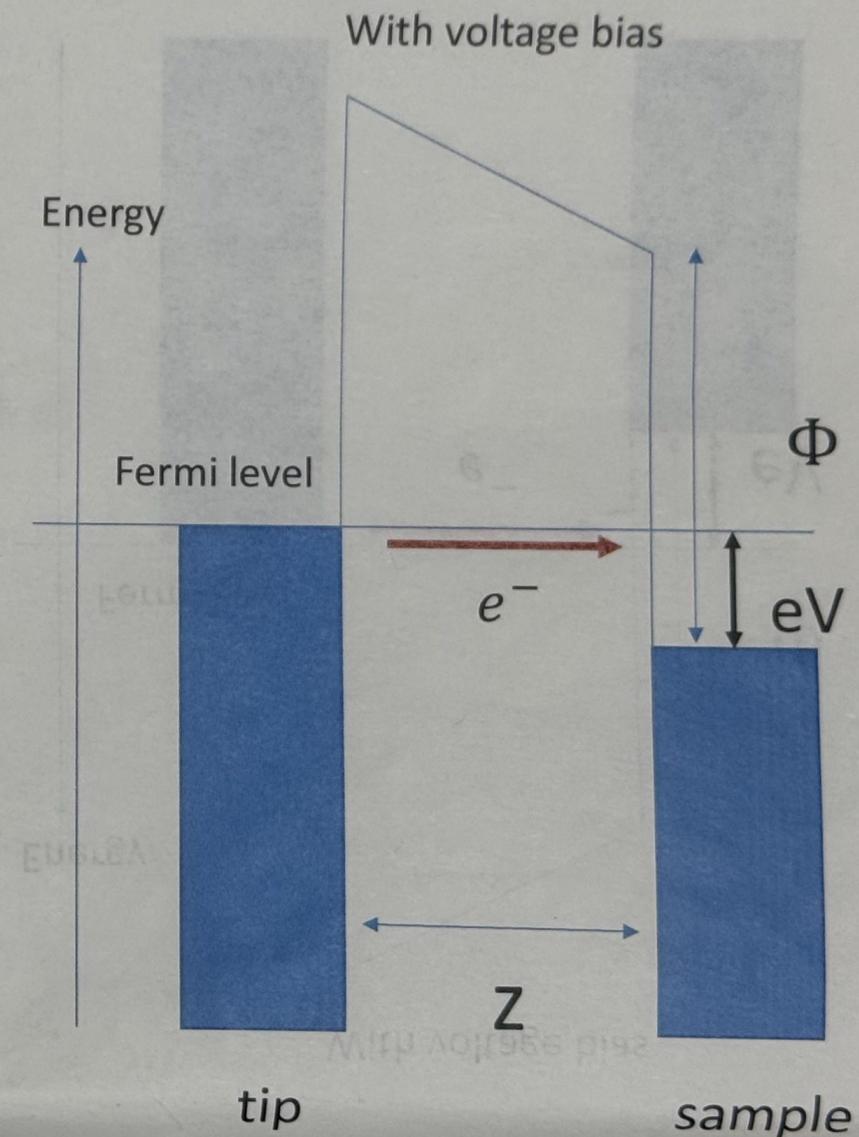
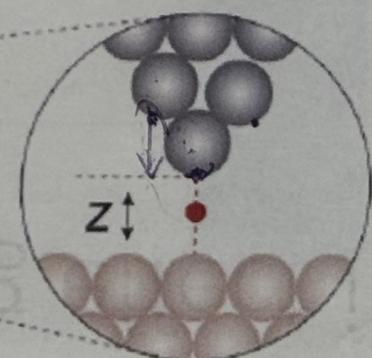


# Tunneling effect in STM

$$I_t \propto e^{-az\sqrt{\Phi}}$$

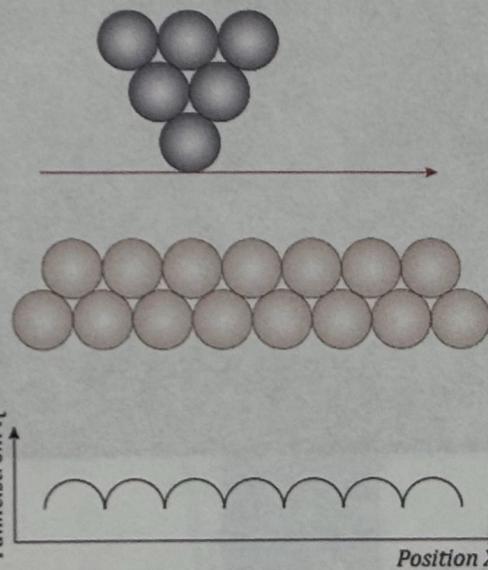
a: decay constant of tunneling current

$$a \approx 1.02 \text{ \AA}^{-1}$$

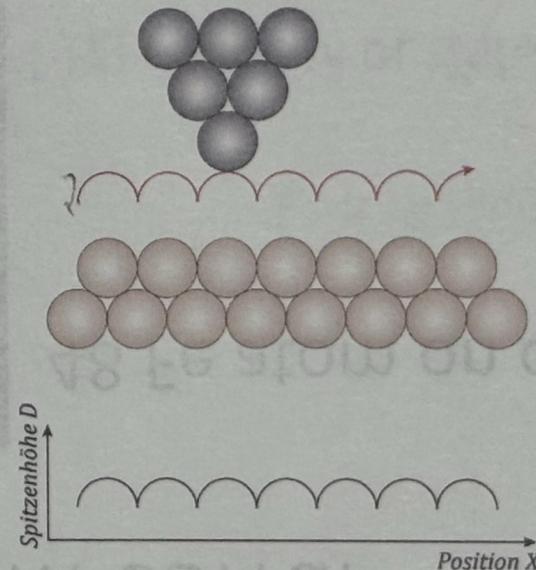


# Scanning mode

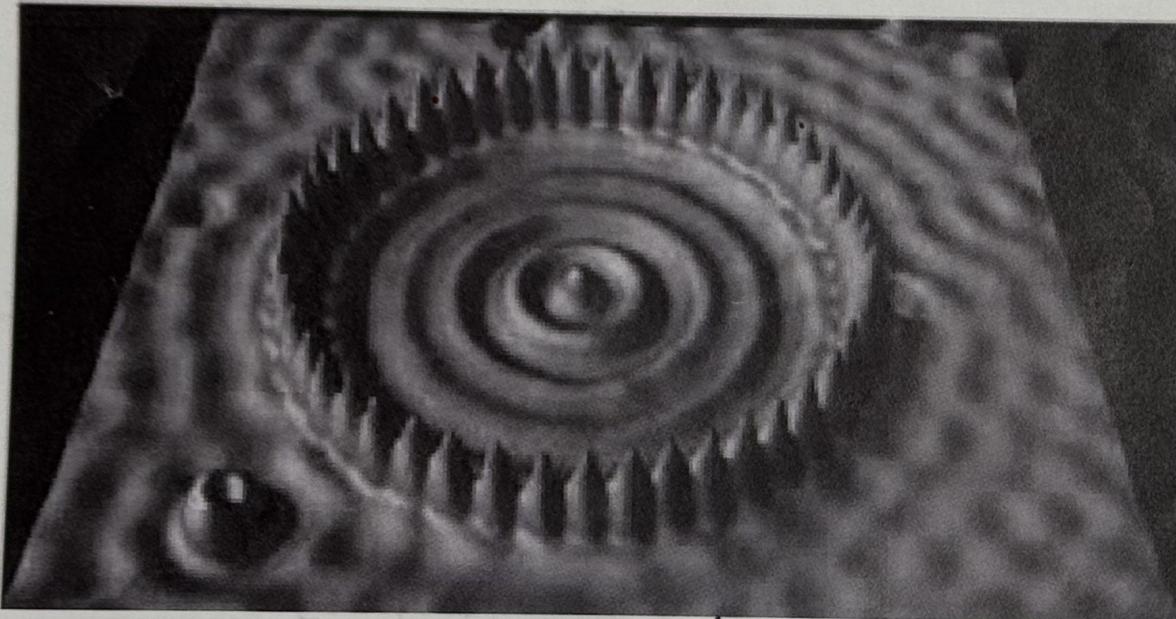
Constant height



Constant current



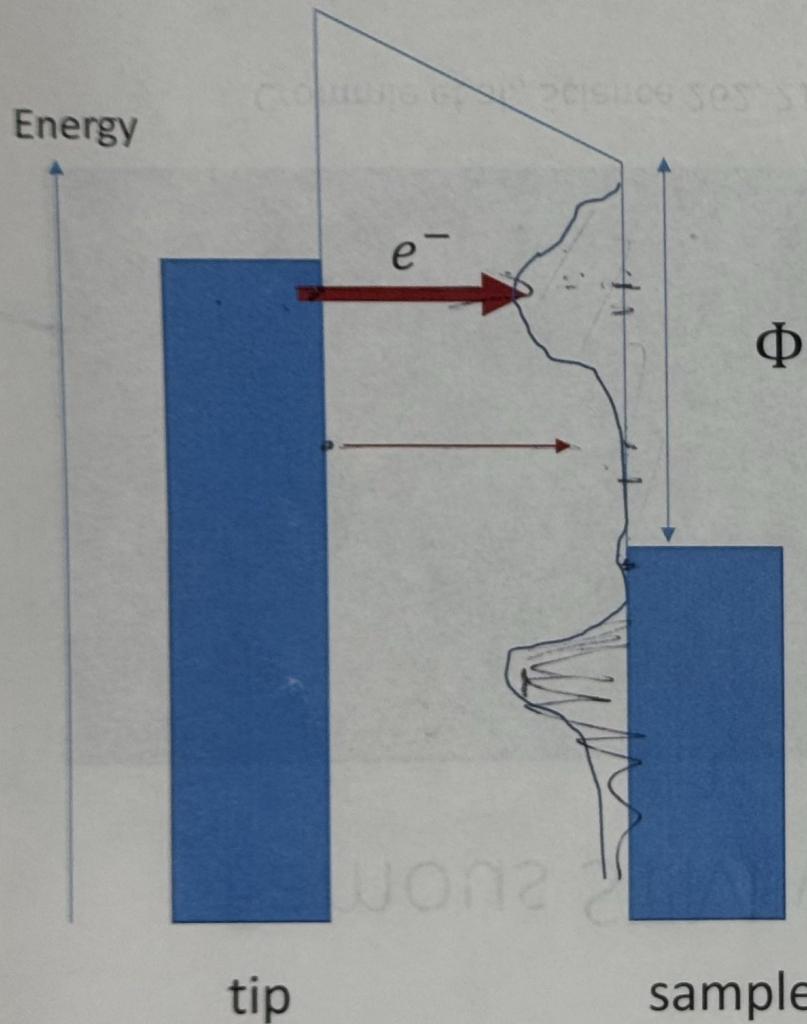
# Famous STM work: Quantum corral



48 Fe atom on copper surface

Crommie et al., Science 262, 218 (1993)

# STM and density of states

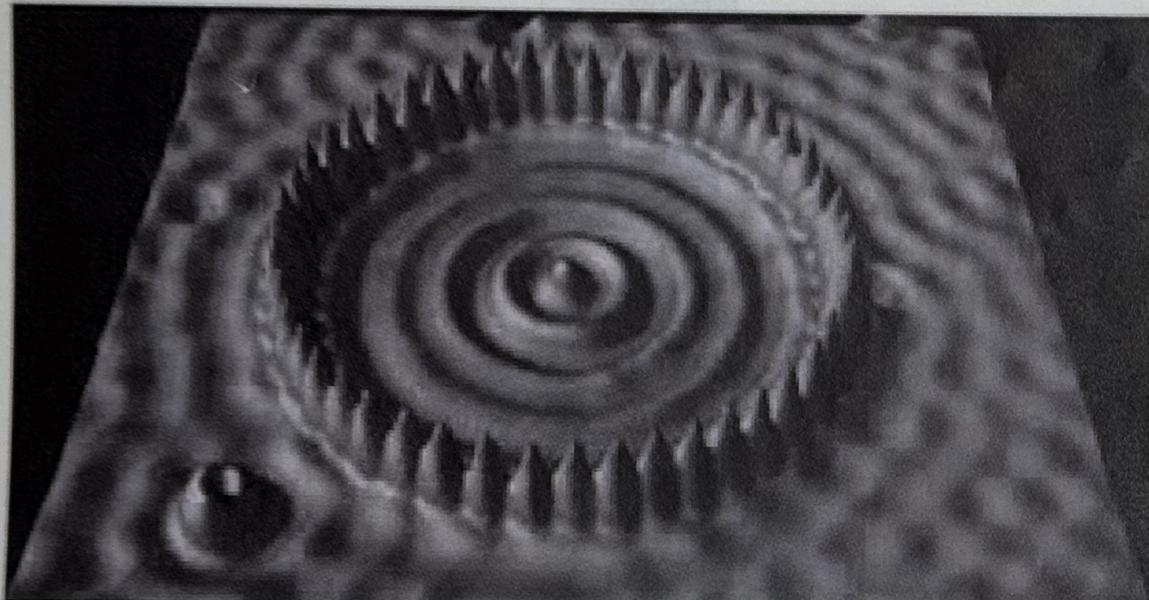


$$I_{\text{tunneling}}(V) \propto \int \rho_s(E) \cdot \rho_t(E - eV) \cdot [f_t(E - eV) - f_s(E)] \cdot T(E, eV) dE$$

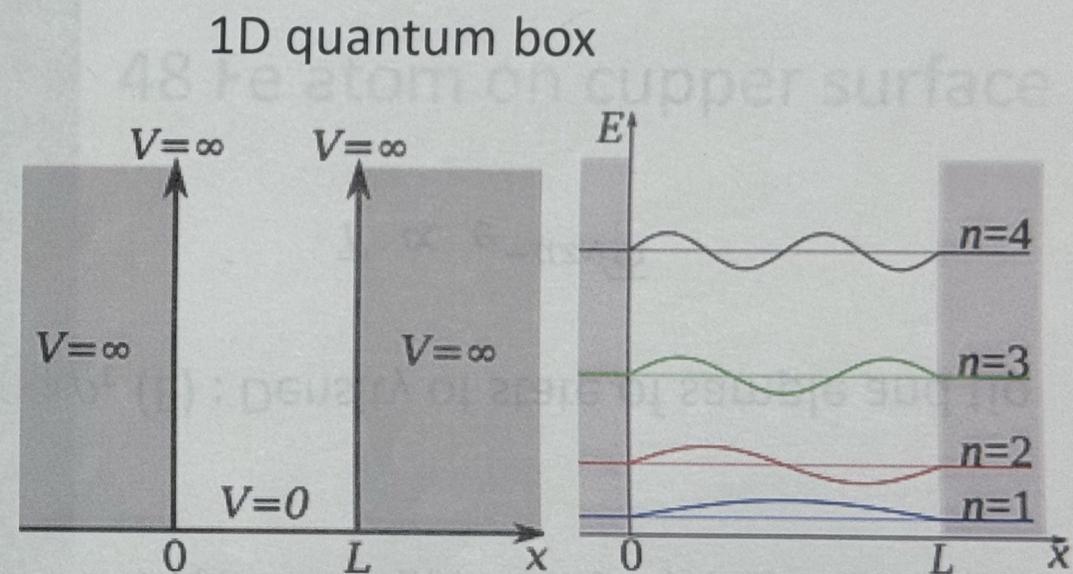
$\rho_s(E)$  and  $\rho_t(E)$  : Density of state of sample and tip

$$T \propto e^{-az\sqrt{\Phi}}$$

# Famous STM work: Quantum corral

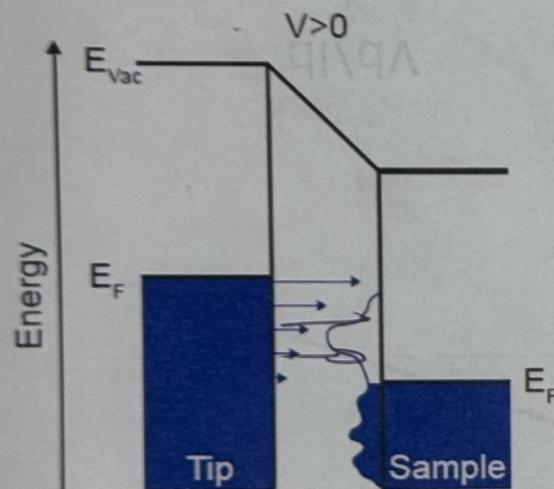


Crommie et al., Science 262, 218 (1993)

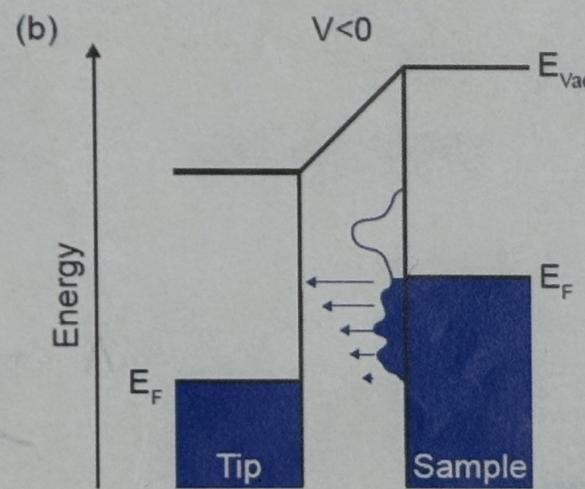


# STM and spectroscopy

$$I_{\text{tunneling}}(V) \propto \int \rho_s(E) \cdot \rho_t(E - eV) \cdot [f_t(E - eV) - f_s(E)] \cdot T(E, eV) dE$$



Empty states of surface

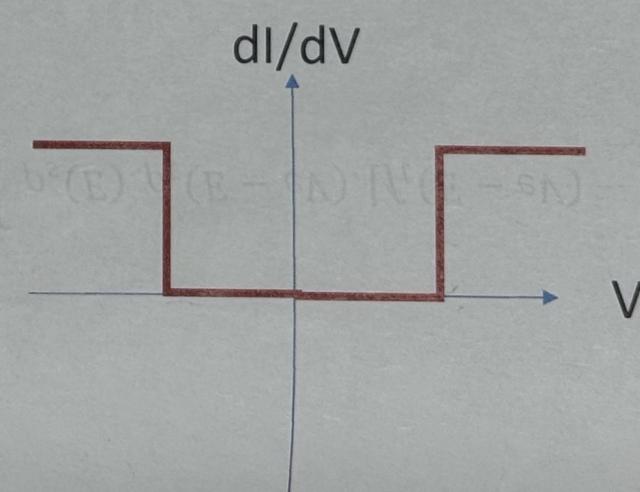
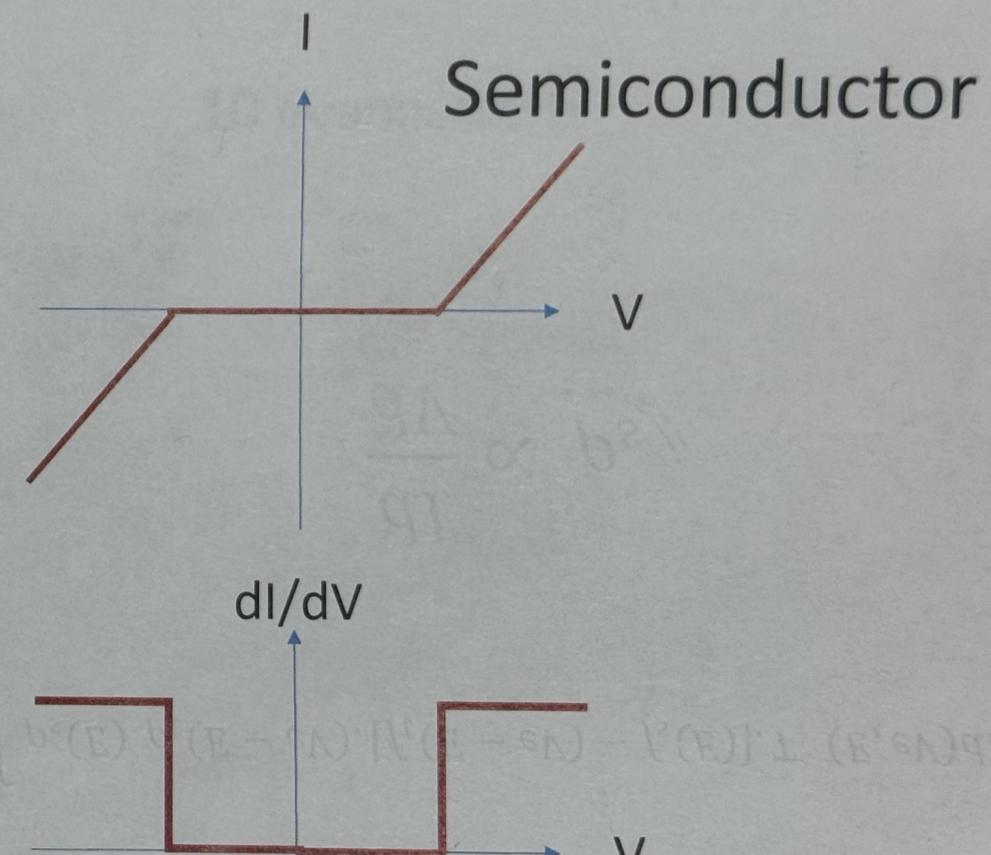
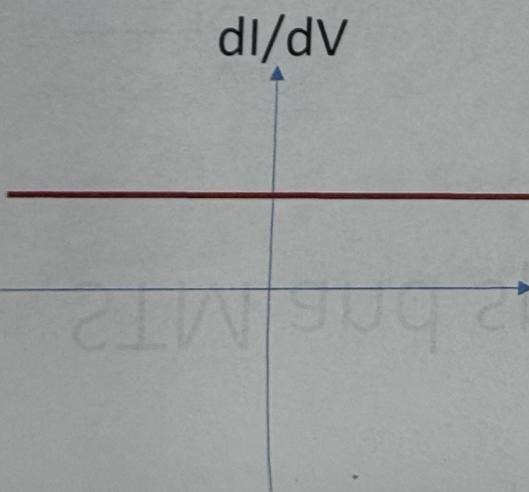
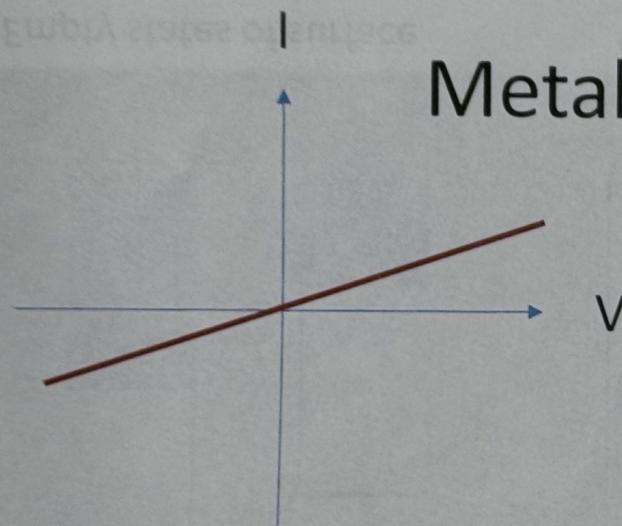


filled states of surface

$$\frac{dI}{dV} \propto \rho_s$$

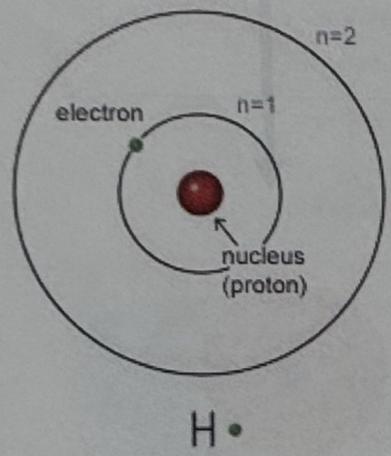
# STM and spectroscopy

$$\frac{dI}{dV} \propto \rho_s \text{ corr}$$

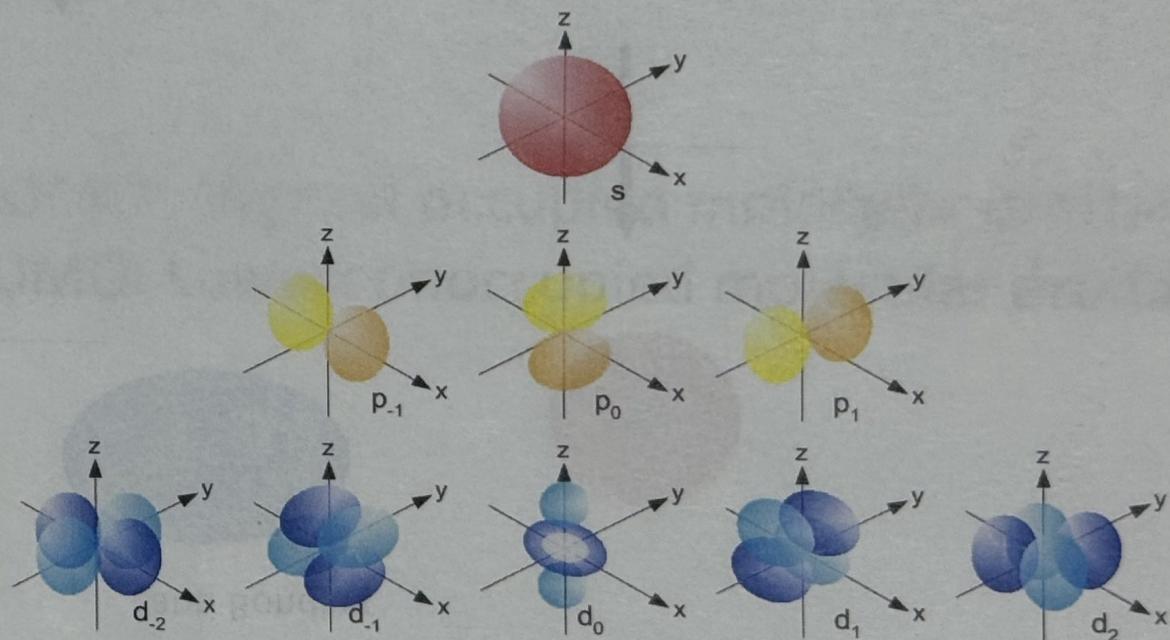


# Molecular orbital – dihydrogen model

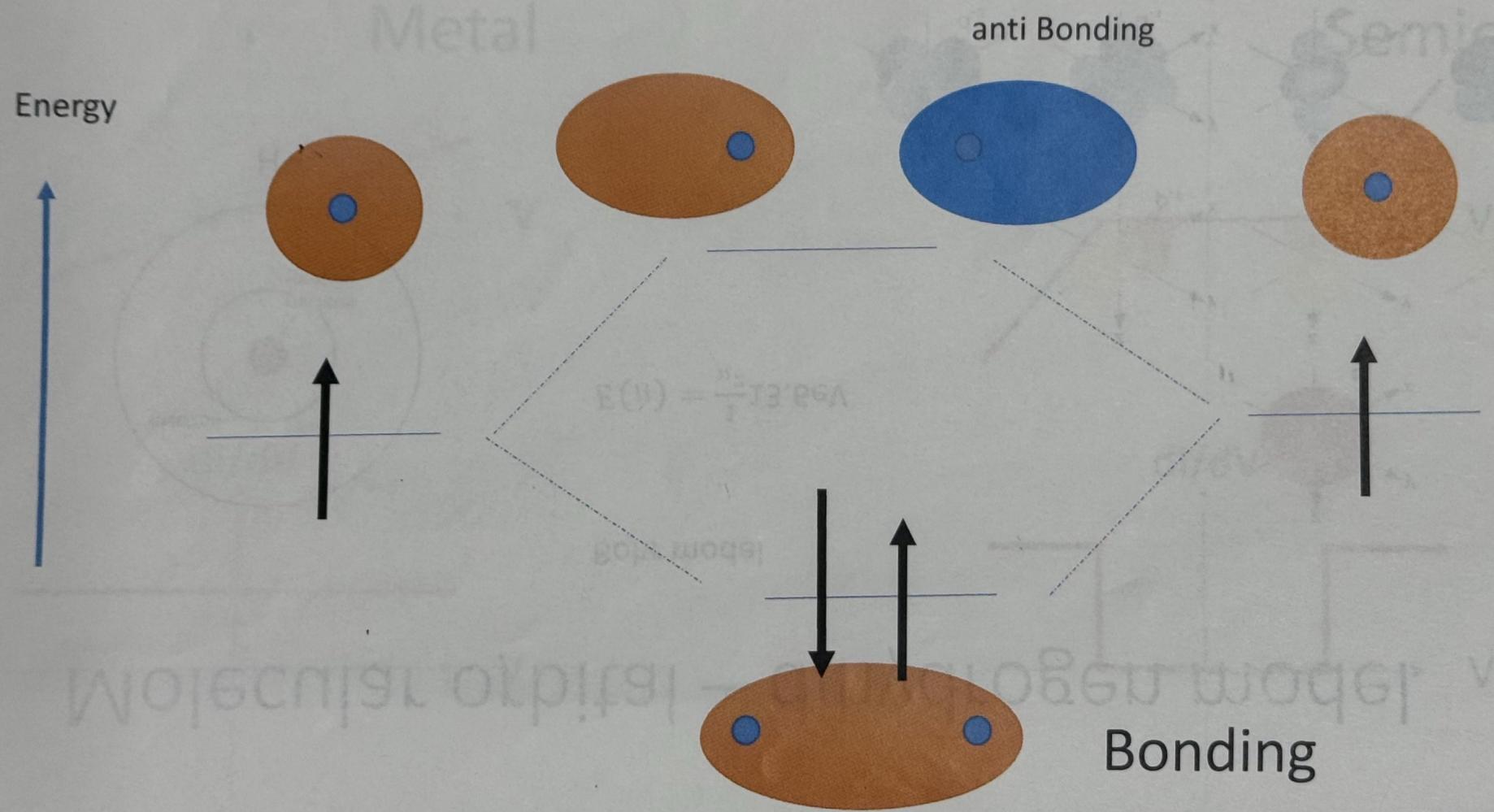
Bohr model

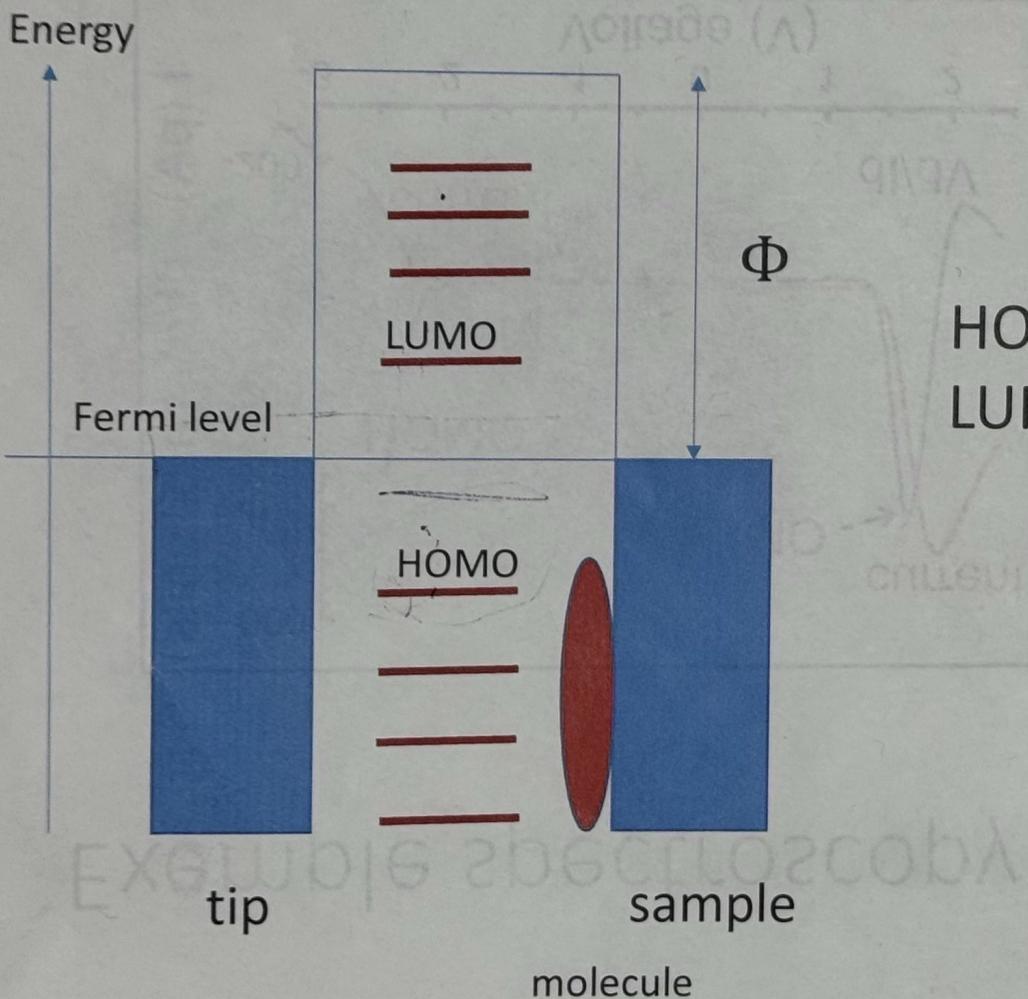


$$E(n) = \frac{1}{n^2} 13.6 \text{ eV}$$



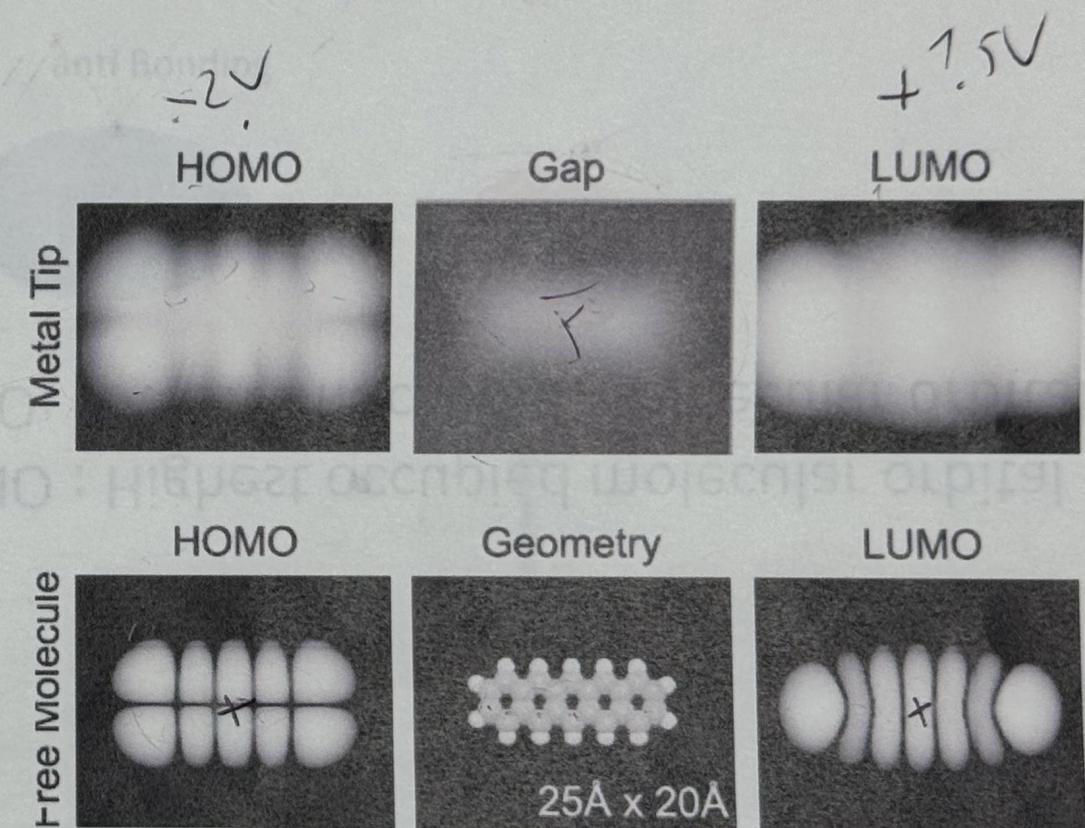
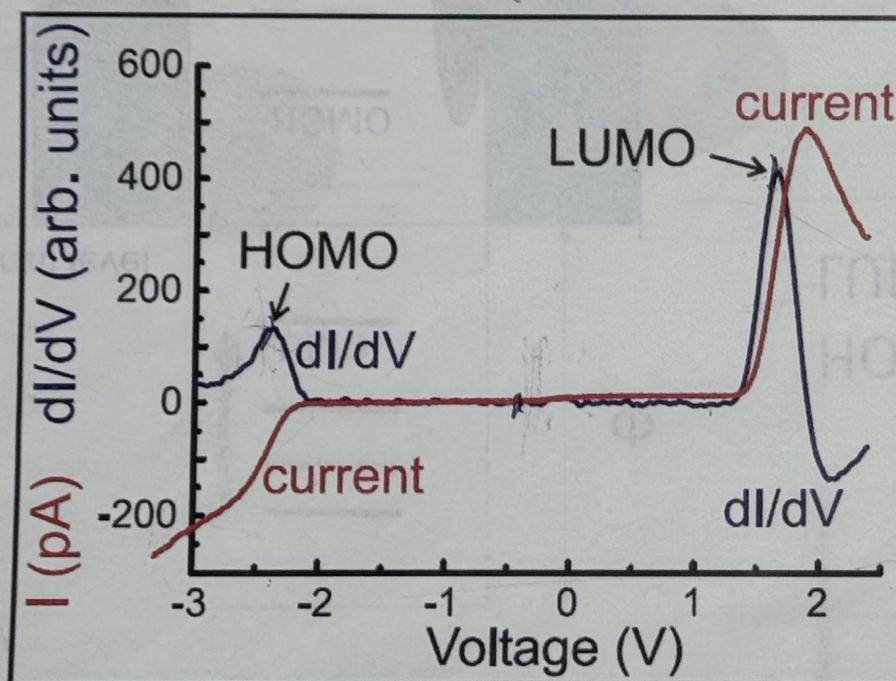
# Molecular orbital – dihydrogen model





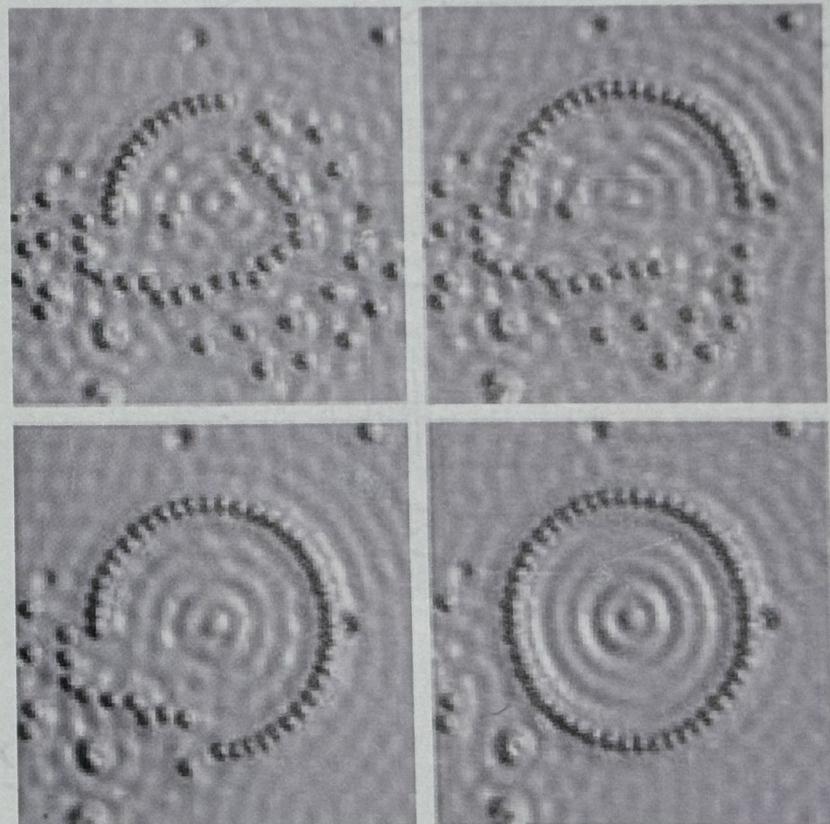
HOMO : Highest occupied molecular orbital  
LUMO: Lowest unoccupied molecular orbital

# Exemple spectroscopy – molecular orbital

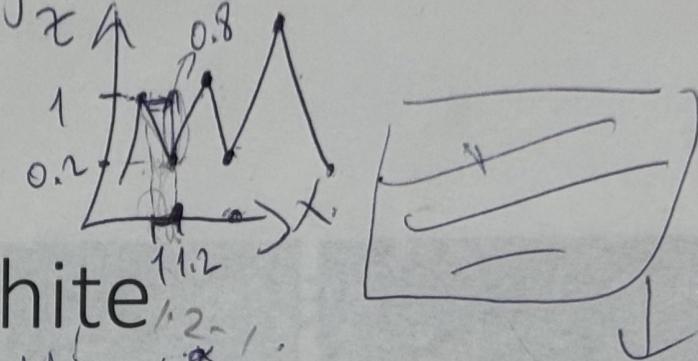


Repp et al. Physical review letters, 94, 026803 (2005)

# STM and atomic manipulation

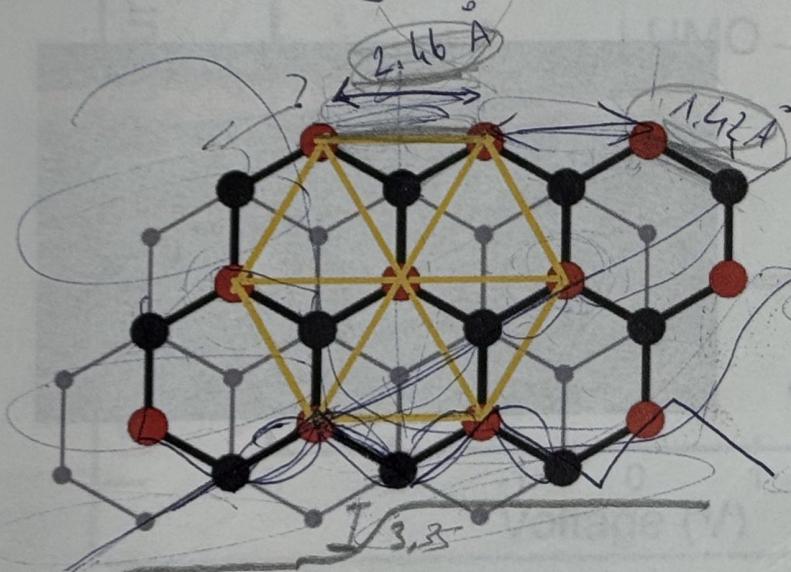
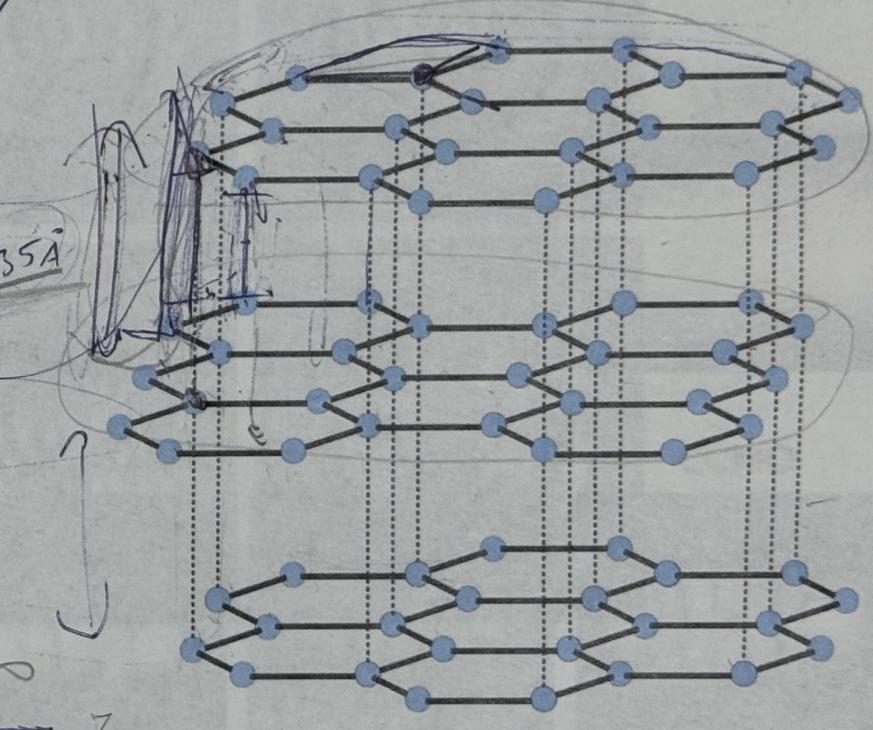
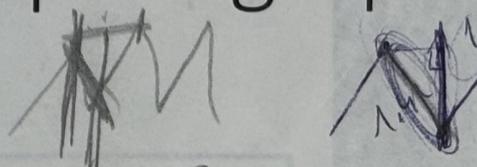
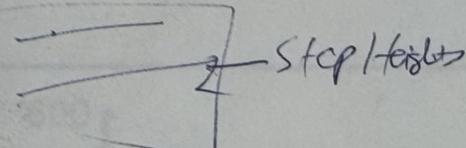
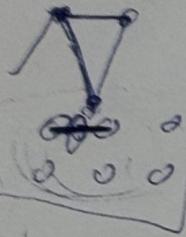


The lattice constant of graphite is  $2.46 \text{ \AA}$



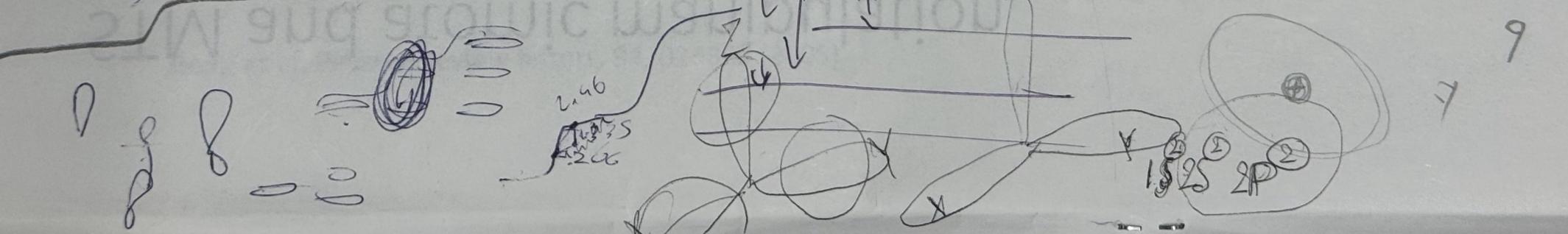
ED

## Task to do : sample - graphite



$3.35 \text{ \AA}$

$2.46$   
 $3.35$   
 $2.46$

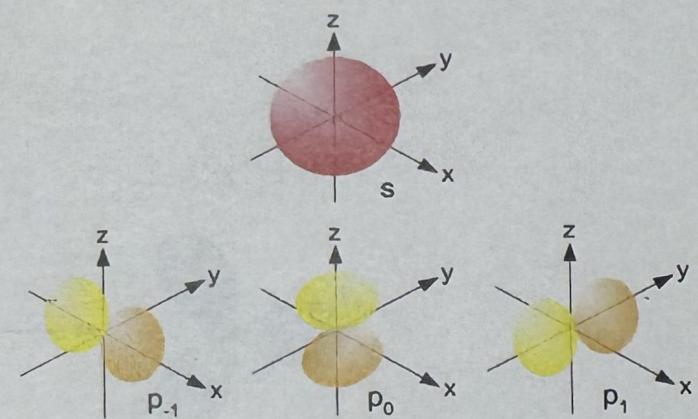
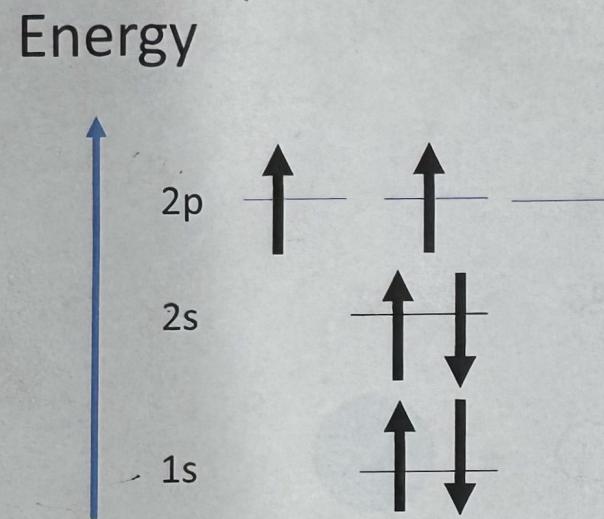


$1.525$   
 $2P$

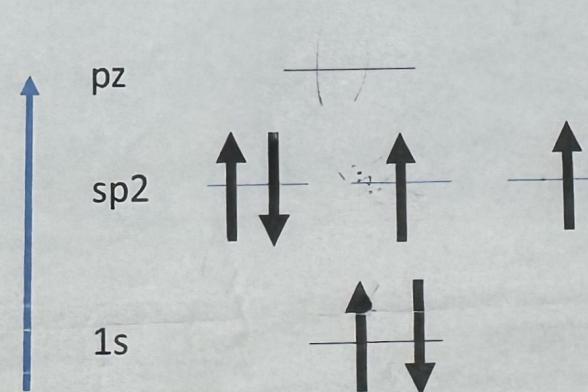
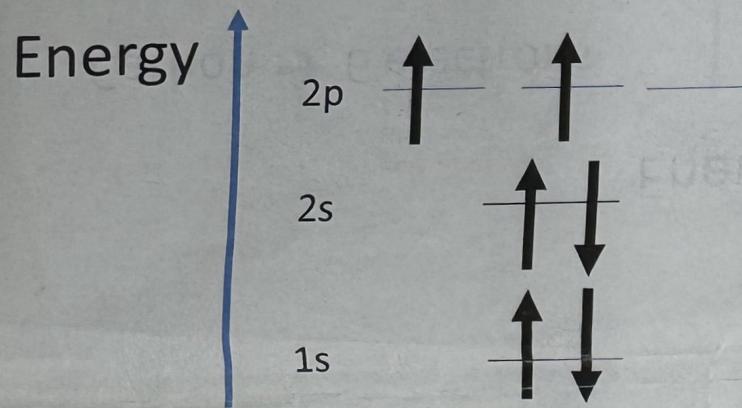
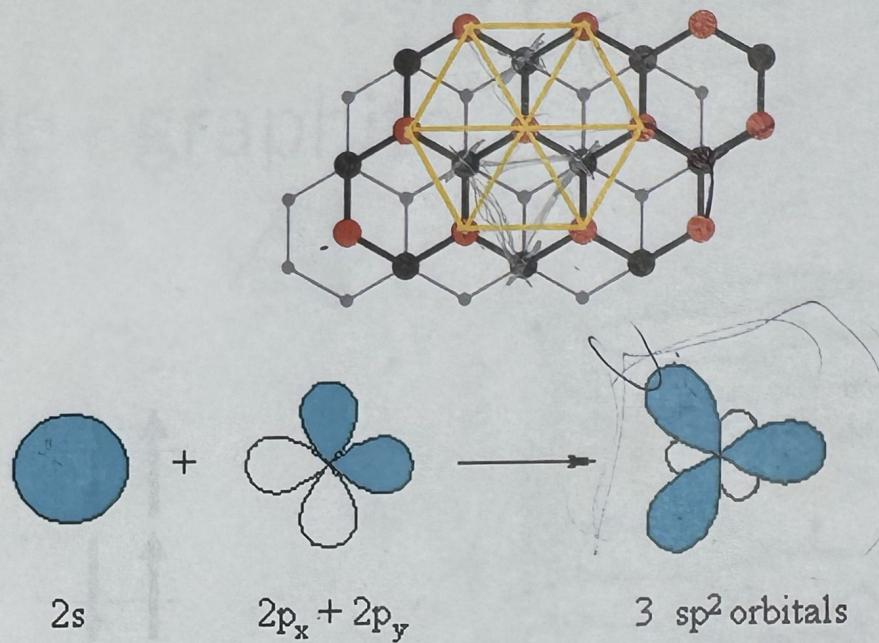
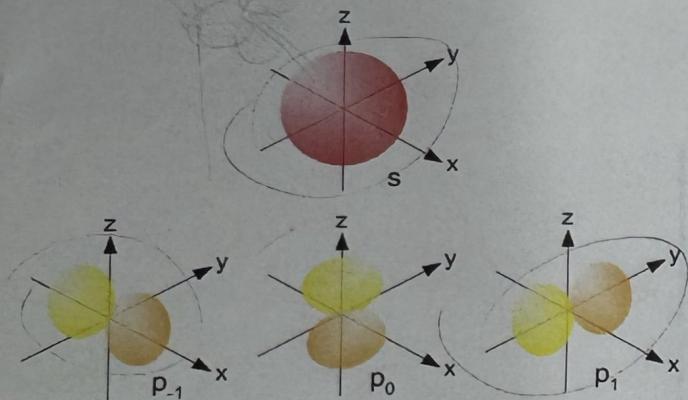
9

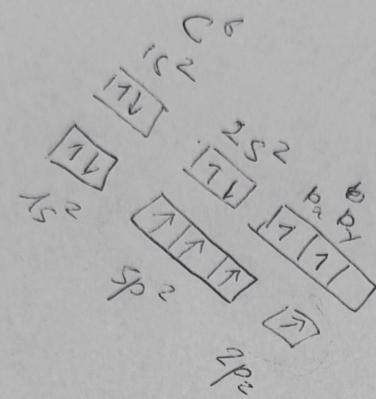
7

Carbon → 6 electrons

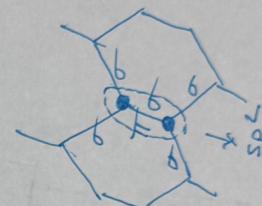


# Hybridized orbital



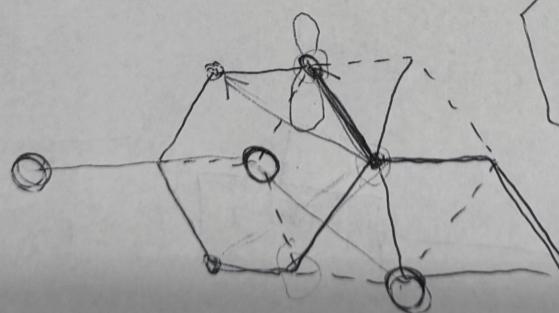


O O



O

O



O

O

O

