Engineering Physics

(PHY1701)

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Scanning Tunneling Microscopy (STM)

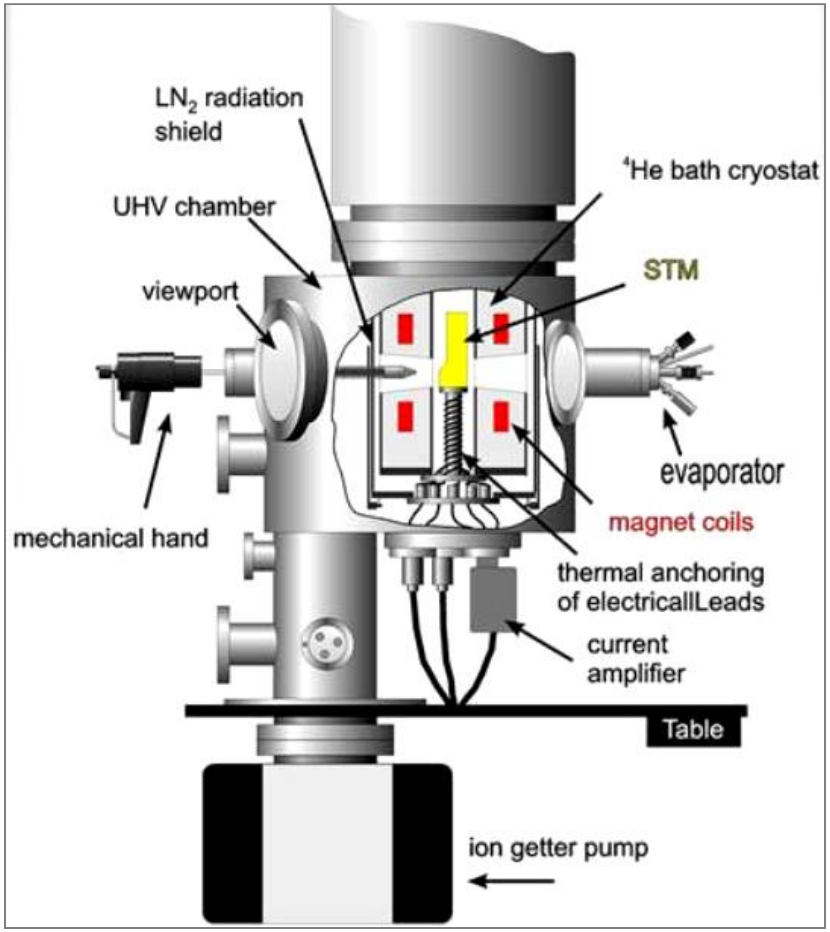
❖ History:

- A scanning tunneling microscope (STM) is an instrument for **imaging surfaces at the atomic level**.
- STM -Invented by **Binnig** and **Rohrer** at IBM in 1981 (*Nobel Prize in Physics in 1986*).

- ✓ Traditional microscopy or imaging techniques employ lenses to focus light, this results in diffraction.
- ✓ Due to diffraction effect, it is not possible to get a resolution better than half-wavelength of the radiation used.
- ✓ STM is an instrument which does not use radiations to image the objects and study of molecule of few Angstrom size with high resolution became possible.
- ✓ It is An electron microscope that uses a single atom tip to attain atomic resolution.
- ✓ It gives the **topographic** (*real space*) and **spectroscopic** (*electronic structure, density of states*) images.

Scanning Tunneling Microscopy (STM)

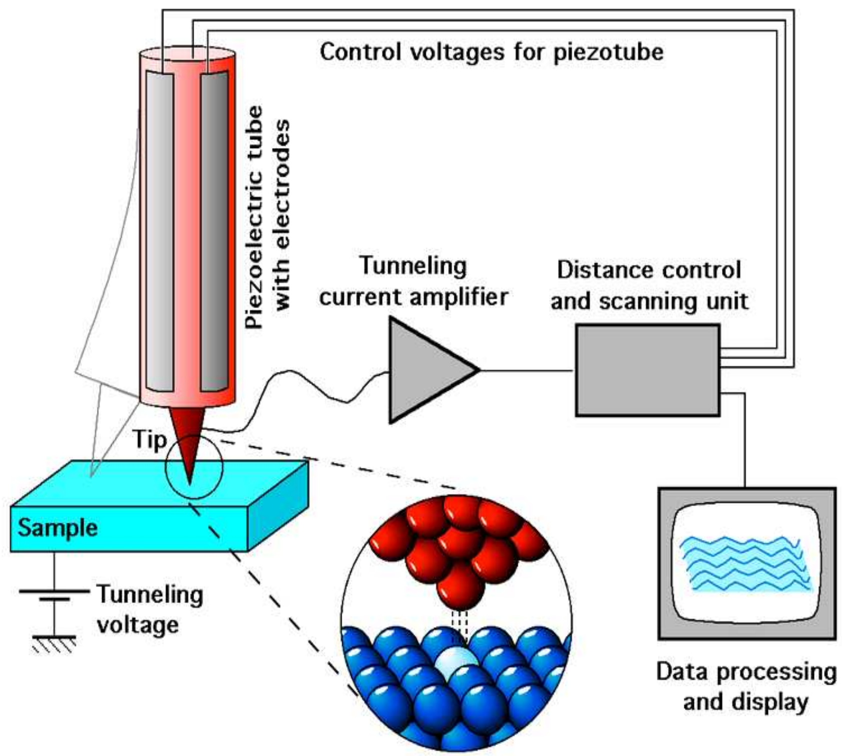
Instrumentation



Scanning Tunneling Microscopy (STM)

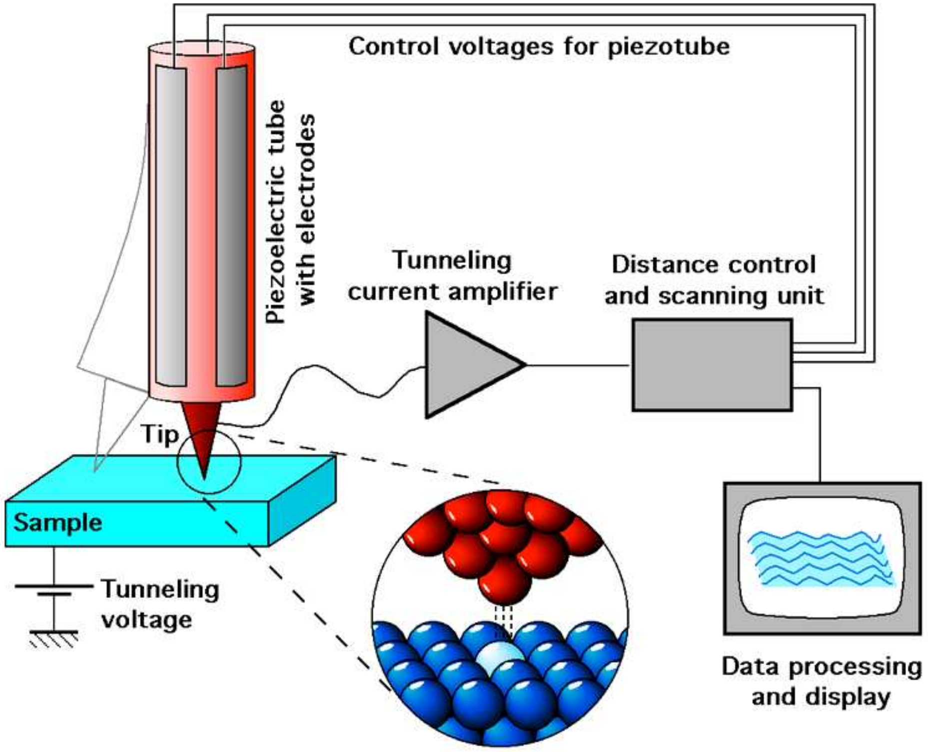
Working Principle

- ✓ Scanning Tunneling Microscope works on the basis of **tunneling effect**.
- ✓ **Tunneling effect:** It is a phenomenon where a **particle tunnels through a barrier** that it classically could not support.
- ✓ The electrons can tunnel from tip to the sample (or vice versa) through a nano gap maintained between them.
- ✓ The tunneling current is measured and converted to surface profile of the sample using image processing technique.
- ✓ As shown in the magnified image of the tip, the sharpness is up to a single atomic dimension so that the resolution tunneling current signal and the images are also up to atomic dimensions.



Scanning Tunneling Microscopy (STM)

- ✓ Tip is connected to a electrically controlled piezo-electric tube, which moves along all the three axes to adjust the position of the tip while scanning over the sample.
- ✓ The sample is supplied with a bias voltage (usually in the range of 5 mV) to maintain the direction of the tunneling current.
- ✓ As the tunneling current will be in the range of micro amperes, it is amplified by tunneling current amplifier.

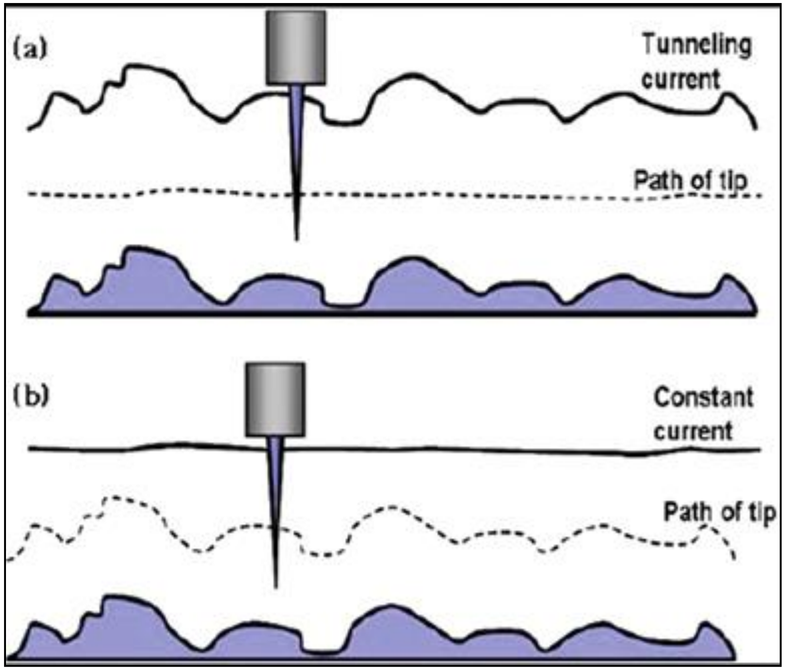


Scanning Tunneling Microscopy (STM)

✓ STM operates in two different modes;

1. Constant height mode and
2. Constant current mode.

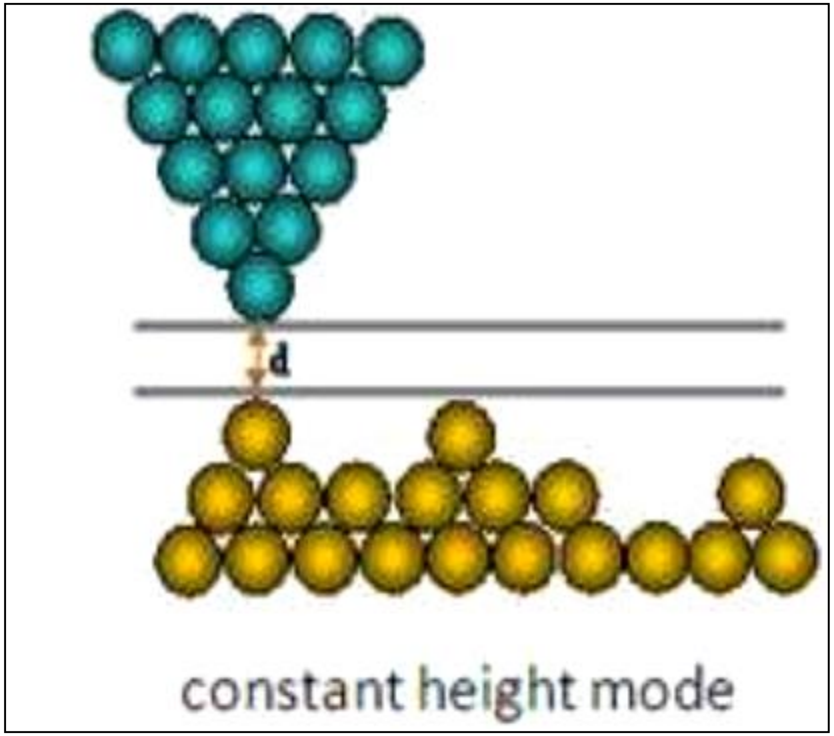
These are explained as shown in the schematic diagram below:



Scanning Tunneling Microscopy (STM)

1. Constant height mode:

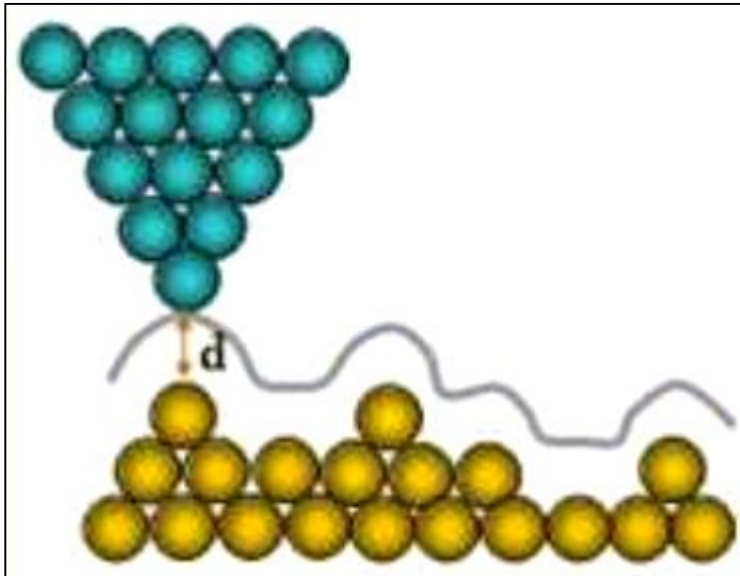
- ✓ The voltage and height are constant, while the current changes to keep the voltage from changing this leads to an image made of **current changes** over the surface, which can be related to **charge density**.
- ✓ In constant height mode scanner will move the tip in **plane**.
- ✓ The benefit to using constant height mode is faster as the piezoelectric movements require more **time to register the height change in constant current mode**.
- ✓ Generally less preferred due to the risk of damaging the tip.



Scanning Tunneling Microscopy (STM)

2. Constant current mode:

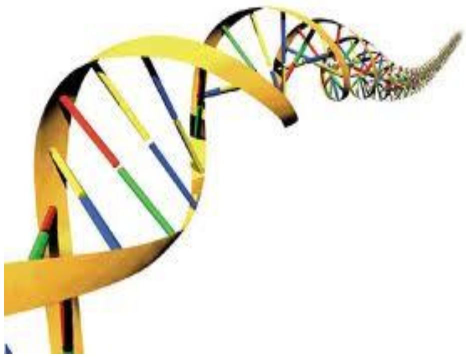
- ✓ Feedback electronics adjust the **height** by a voltage to the **piezoelectric height control mechanism**.
- ✓ This leads to a height variation and thus the image comes from the tip topography across the sample and gives a **constant charge density surface**, this means contrast on the image is due to variation in charge density.
- ✓ It is a **time consuming methods** compared to the constant height mode as the **feed back control has to adjust the current constant** according height as the tip moves along the specimen surface.



constant current mode

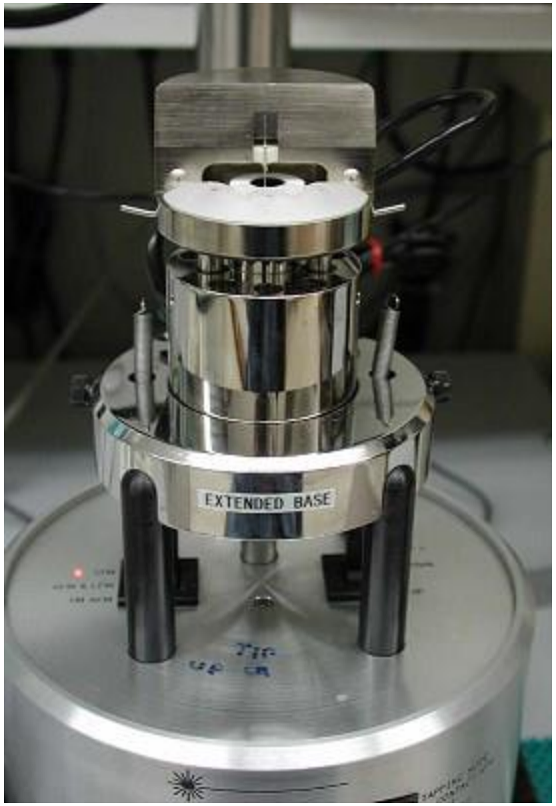
Scanning Tunneling Microscopy (STM)

Wide Applications:



- ✓ Physics, semiconductor physics and microelectronics
- ✓ Chemistry, surface reaction catalysis
- ✓ Biology, in the study of DNA molecules
- ✓ Nanoscale chemistry labs, synthetic chemical compounds

Scanning Tunneling Microscopy (STM)



Advantages:

- ✓ Conceptually simple but complexities in use
- ✓ Can even move atoms
- ✓ Can be used in variety of temperatures
- ✓ Perform in different environments(air, water etc.)

Disadvantages:

- ✓ It is very expensive
- ✓ It need specific training to operate effectively
- ✓ Mainly used to analyze conducting materials
- ✓ The best results from STM can be obtained only in vacuum conditions, hence it may not be the best tool to inspect and analyse biological samples

Problems

1) **The average kinetic energy of neutrons, atoms and molecules is also expressed in terms of temperature through the equipartition law E = 3/2 *k*T. Write down the de-Broglie formula for such particles whose energy corresponds to temperature T. Hence determine the wavelength of thermal neutron; Rest mass of the neutron is 1.67×10^{-27} kg.(T=300 K say)**

$$E = \frac{p^2}{2m_0} = \frac{3}{2}kT \qquad \Rightarrow p = \sqrt{3m_0kT}$$

According to de-Broglie,

$$\lambda = \frac{h}{mv} = \frac{h}{p} = \frac{h}{\sqrt{3m_0kT}} = \frac{6.6\times10^{-34}}{\sqrt{3\times1.67\times10^{-27}\times1.38\times10^{-23}\times300}}$$

Non-relativistic formula for K.E is used, as it is valid for 'T' not very high

$$\lambda = 1.46\times10^{-10}\,m$$

Problems

2) **A beam of mono-energetic neutrons corresponding to 27°C is allowed to fall on a crystal. A first order reflection is observed at a glancing angle 30. Calculate the interplanar spacing of the crystal.**

According to Bragg's law

$$2d\sin\theta = n\lambda$$

$$2d\sin 30^o = 1\times\lambda \Rightarrow d = \lambda$$

The energy of neutron

$$E = kT = 1.38\times10^{-23}\times300 = 4.14\times10^{-21}\,J$$

Now, $p = \sqrt{2m_n E} = \sqrt{2\times1.67\times10^{-27}\times4.14\times10^{-21}}$

$$\therefore d = \lambda = \frac{h}{p} = \frac{6.62\times10^{-34}}{\sqrt{2\times1.67\times10^{-27}\times4.14\times10^{-21}}}$$

$$= 1.78\times10^{-10}\,m$$

3) **10 kV electrons are passed through a thin film of a metal for which the atomic spacing is 5.5×10^{-11}m.What is the angle of deviation of the first order diffraction maximum?**

Wavelength of the electron

$$\lambda = \frac{h}{\sqrt{2.m.eV}} = \frac{6.6\times10^{-34}}{\sqrt{2\times9.11\times10^{-31}\times10^{4}\times1.602\times10^{-19}}}$$

$$=1.227\times10^{-11}m$$

Applying Bragg's formula for diffraction at the atomic planes,

$$n\lambda = 2d\sin\theta \Rightarrow 1\times1.227\times10^{-11} = 2\times5.5\times10^{-11}\sin\theta$$

$$\sin\theta = 0.1115$$

$$\therefore \theta = 6^{o}24'$$

Angle through which electron is deviated =$2\theta = 12^{o}48'$

4) **At what scattering angle will incident 100 keV X-rays leave a target with an energy of 90 kev.**

$$[\frac{1}{E'}-\frac{1}{E}]=\frac{1}{m_0c^2}(1-\cos\theta)$$

$$m_0c^2[\frac{1}{E'}-\frac{1}{E}]=(1-\cos\theta)$$

We get,

$$\cos\theta = 0.4428$$

$$\therefore \theta = 64^{\circ}$$

Problems

5) **In an experiment of Compton scattering, the incident radiation has wavelength 2A°. Calculate the energy of recoil electron which scatters radiation through 60°.**

Change in wavelength in Compton scattering

$$\lambda' - \lambda = \frac{h}{m_0 c}(1 - \cos\theta)$$

$$\lambda' = 2\times10^{-10}\, m + 2.426\times10^{-12}\, m(1 - \cos 60^{\circ})$$

$$\lambda' = 2.012\times10^{-10}\, m$$

Hence the energy of recoil electron which scatters radiation through 60°, is given by

$$E = h\nu - h\nu' = \mathrm{hc}[\frac{1}{\lambda} - \frac{1}{\lambda'}]$$

$$E = 37 eV$$