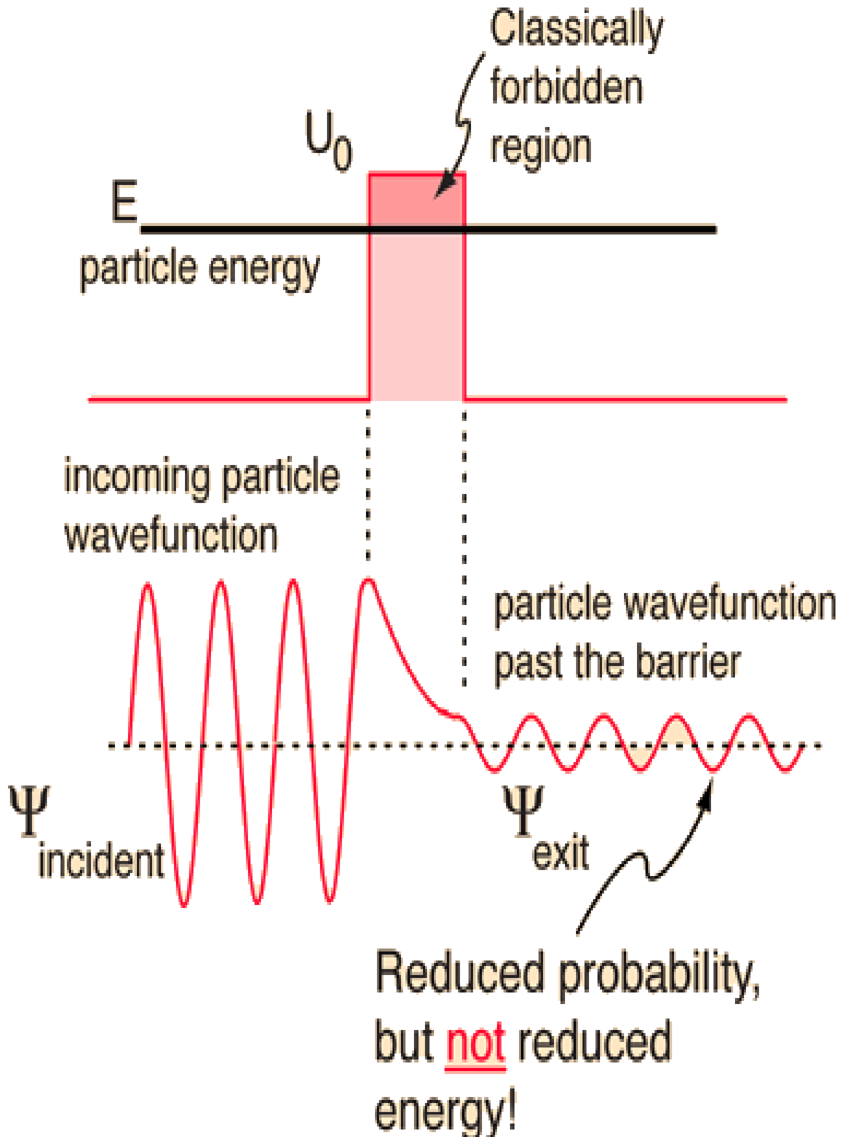
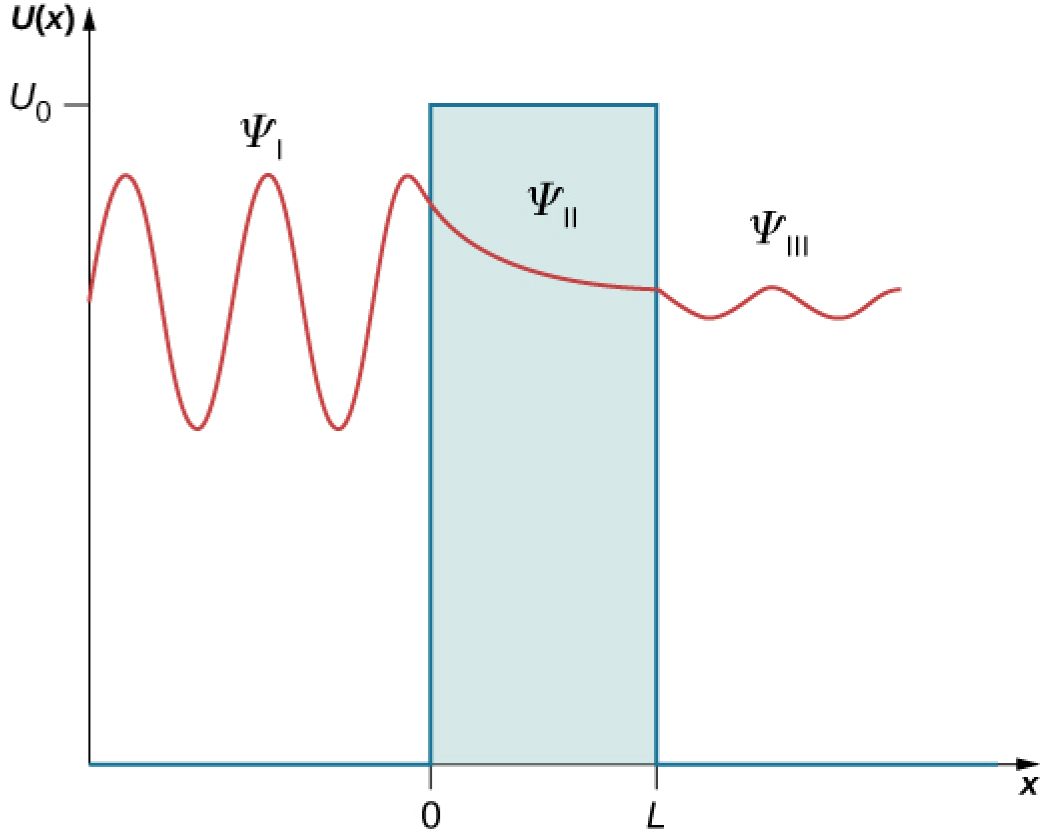
Tunneling

Barrier Tunneling



http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/barr.html

Barrier Tunneling



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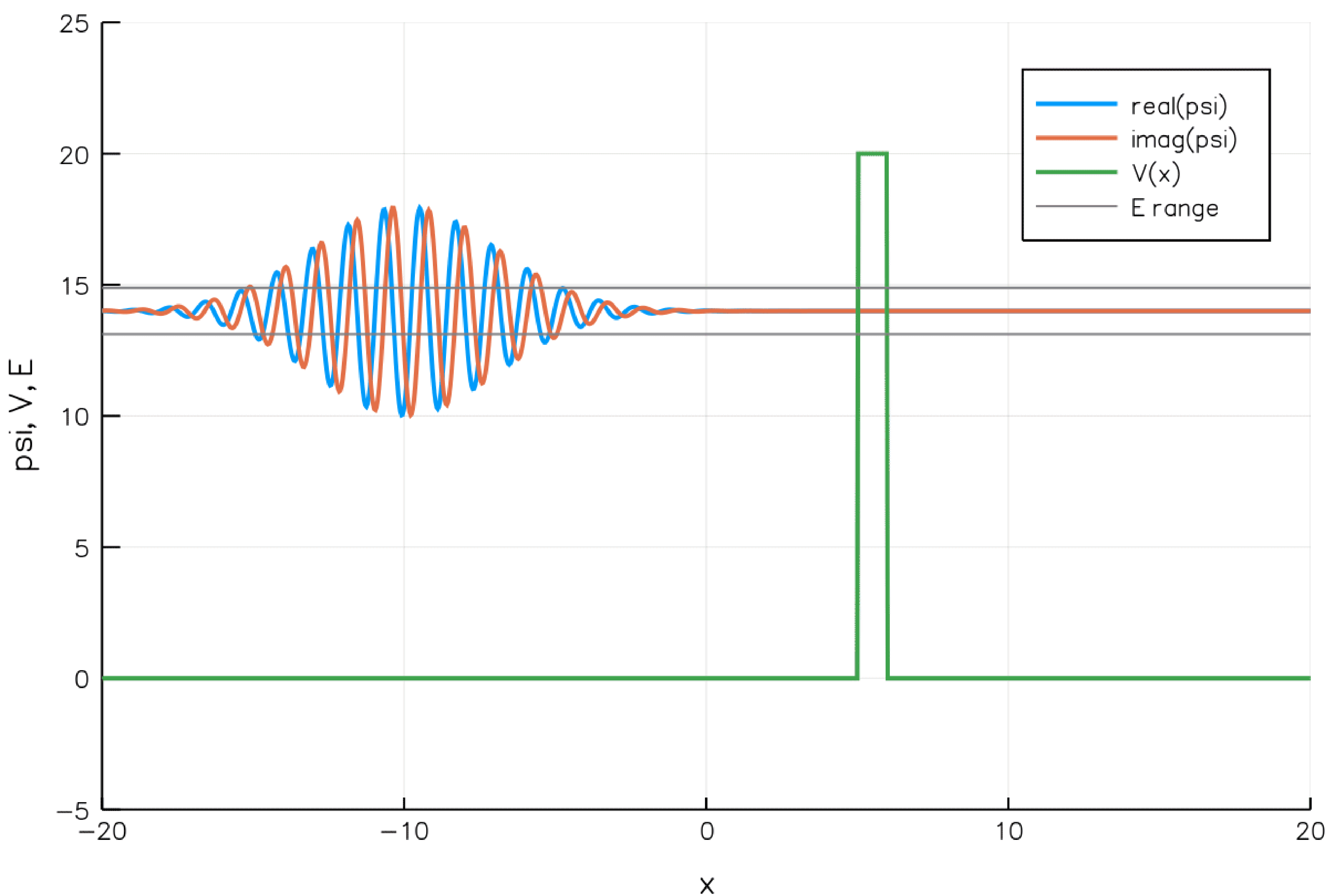
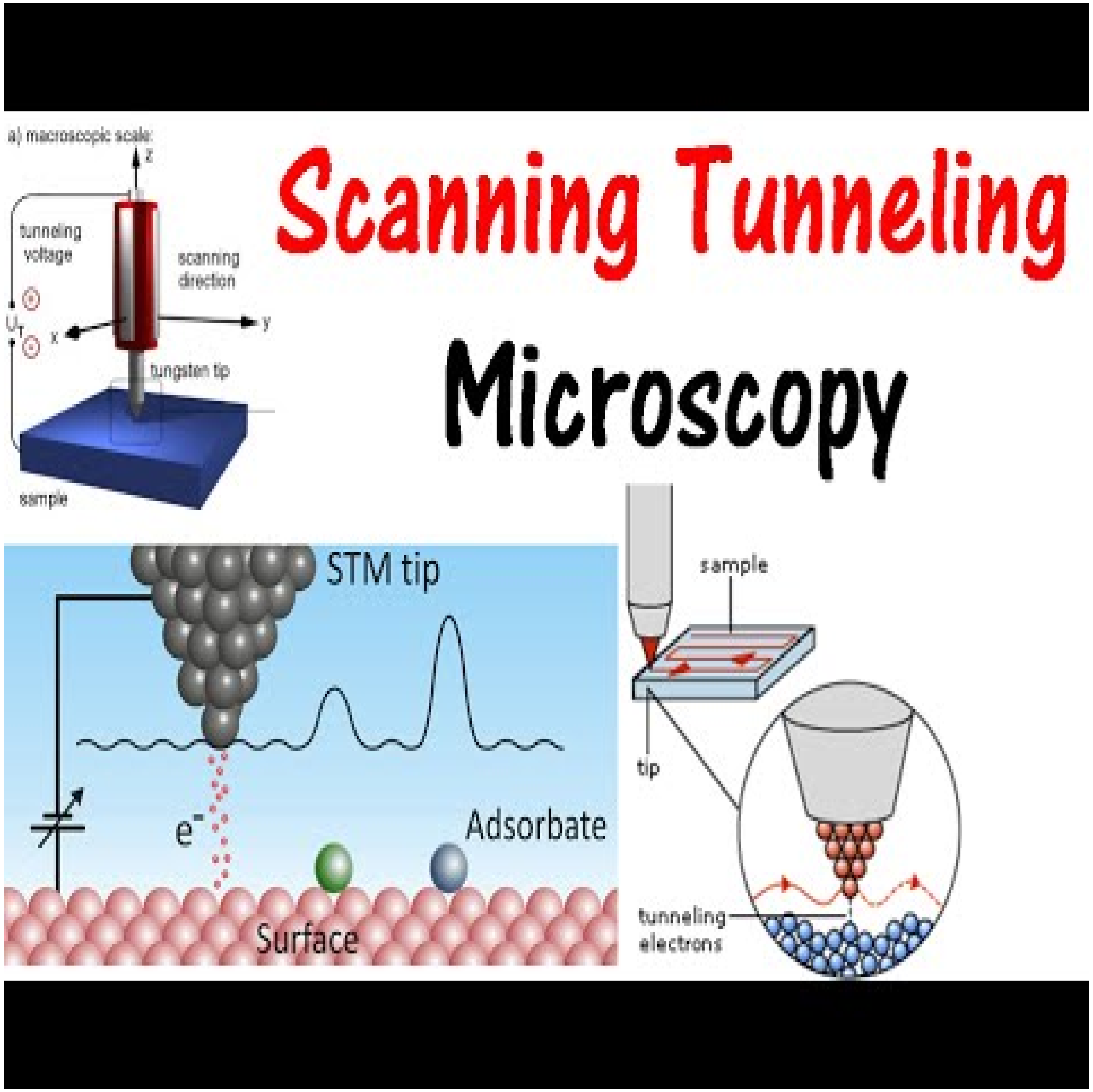
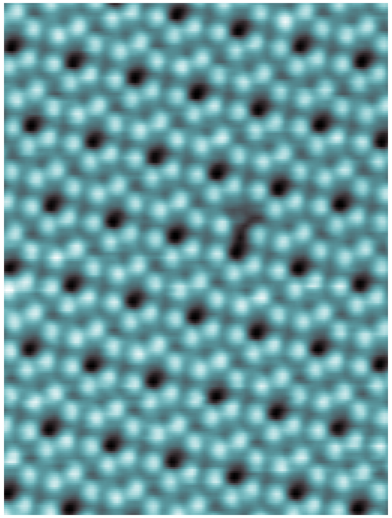
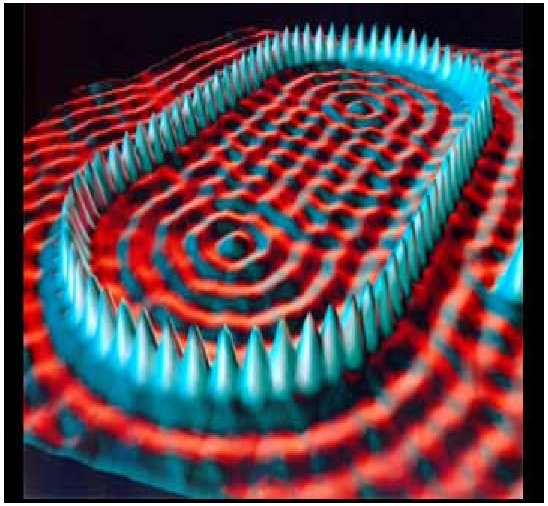


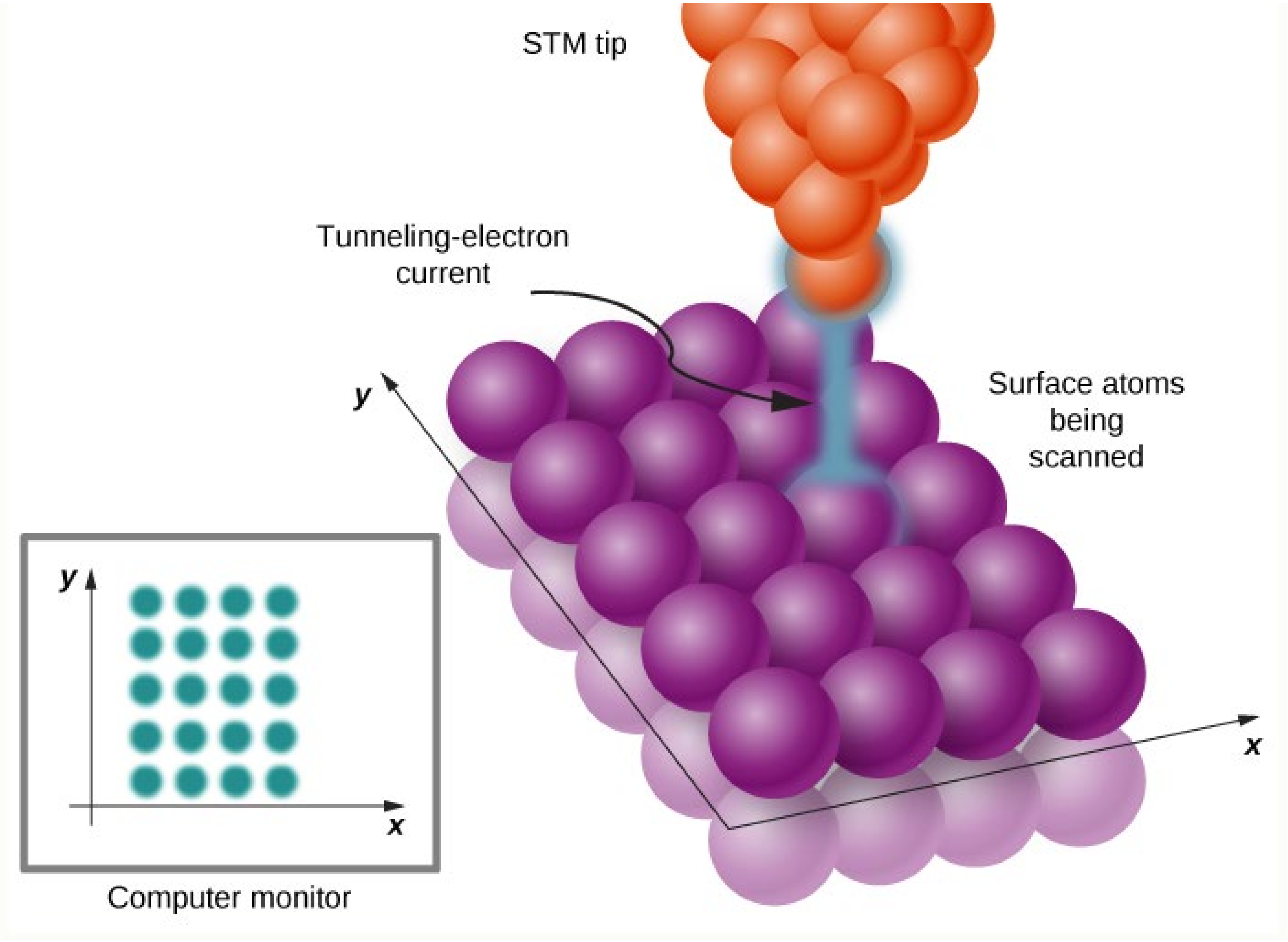
25
20
15
10
5
0
−5
psi, V, E
−20
−10
0
10
20
x
real(psi)
imag(psi)
V(x)
E range


Scanning Tunneling
Microscopy
a) macroscopic scale:
z
tunneling
voltage
scanning
direction
x
y
tungsten tip
sample
STM tip
e⁻
Adsorbate
Surface
sample
tip
tunneling
electrons





Scanning Tunneling Microscopy



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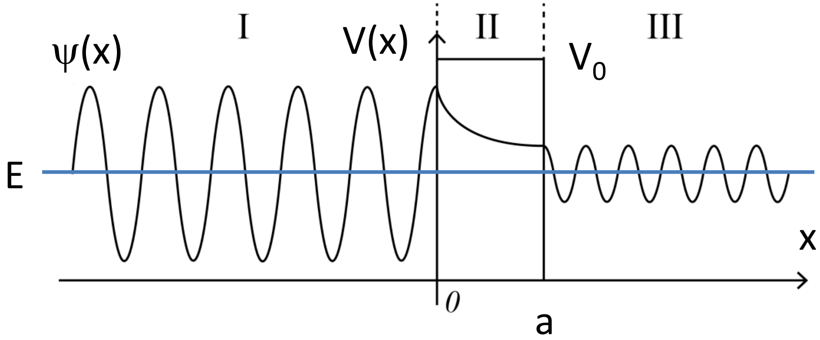
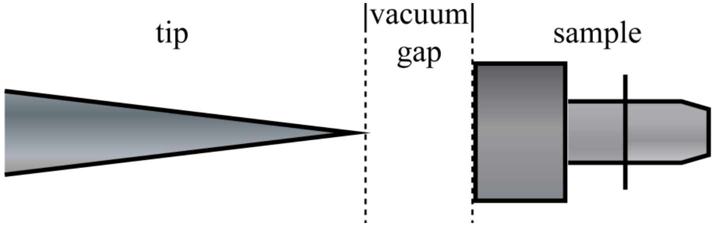
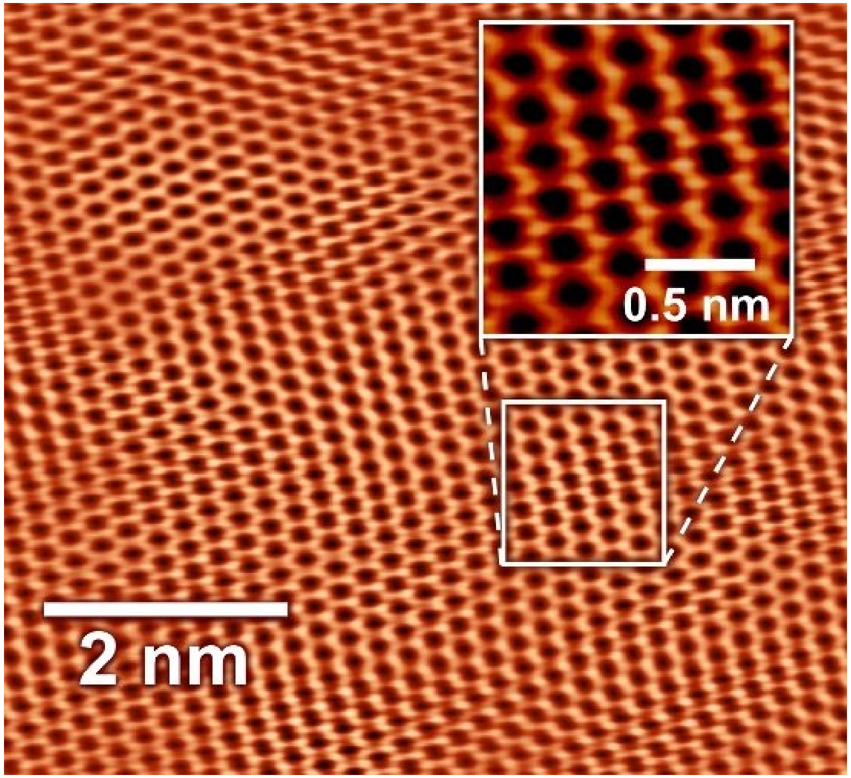
Scanning Tunneling Microscopy



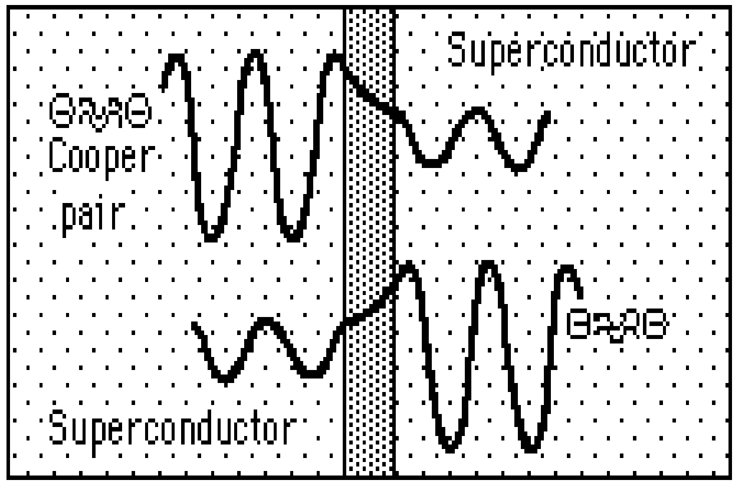


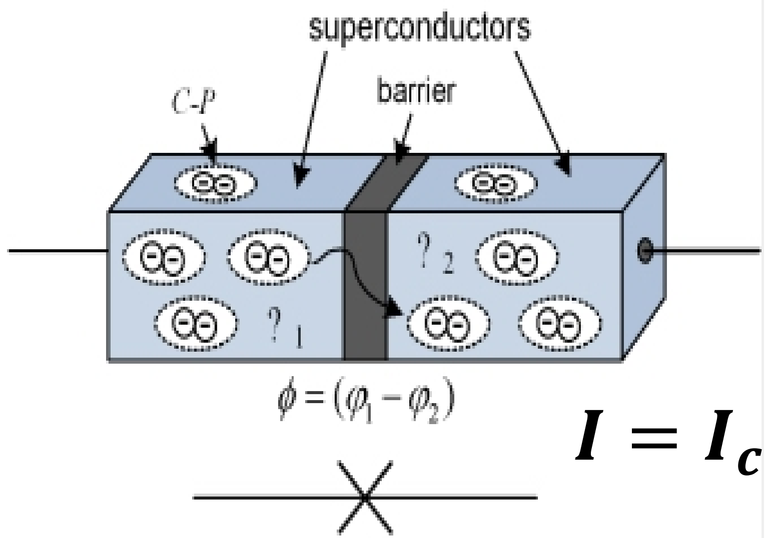
Atomic-Resolution Images of Graphite



https://nanomat.as.wm.edu/wiki/public/news/blog/2006-2009/2009-01-23_atomic-resolution-stm

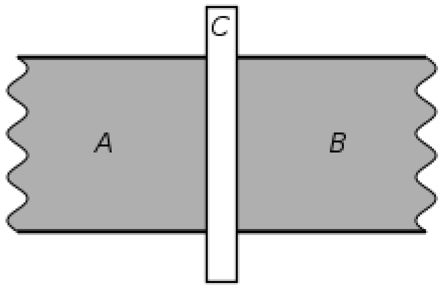
Josephson Tunneling of Cooper Pairs Between Two Superconductors

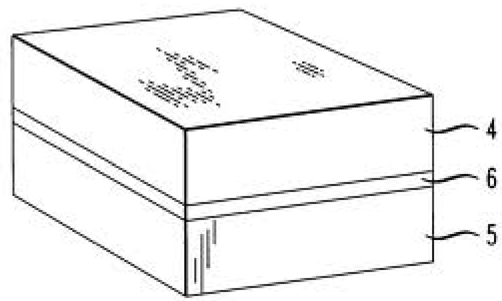


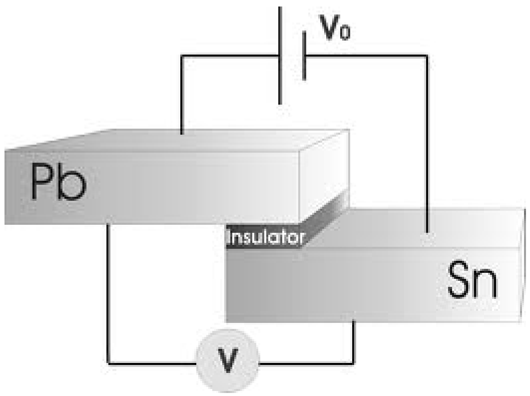


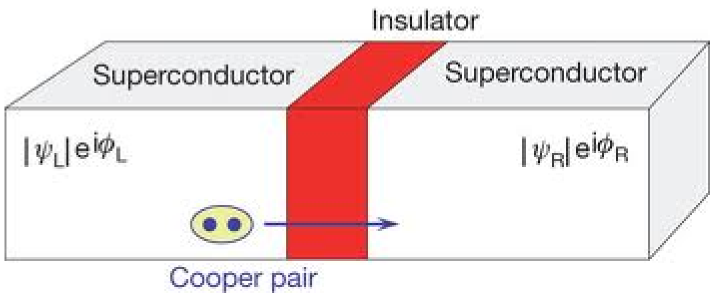
$$I = I_c \sin\phi$$

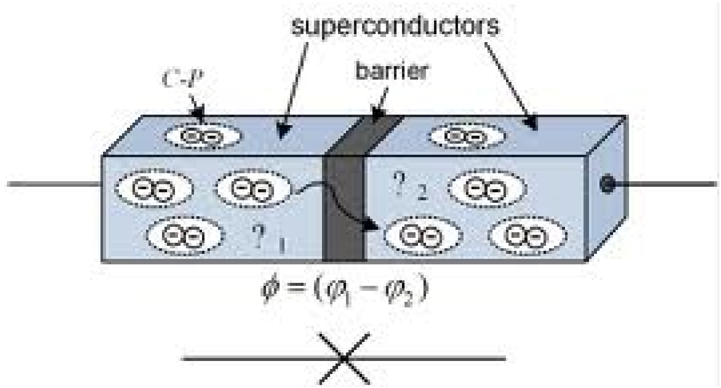
Tunnel Junctions

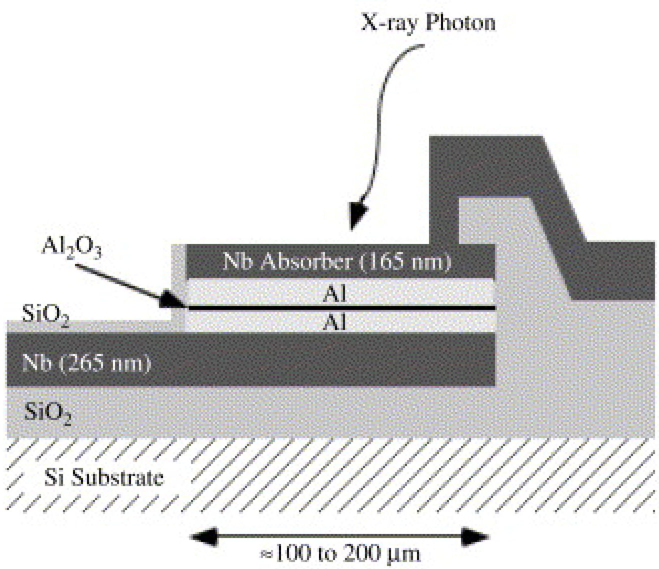




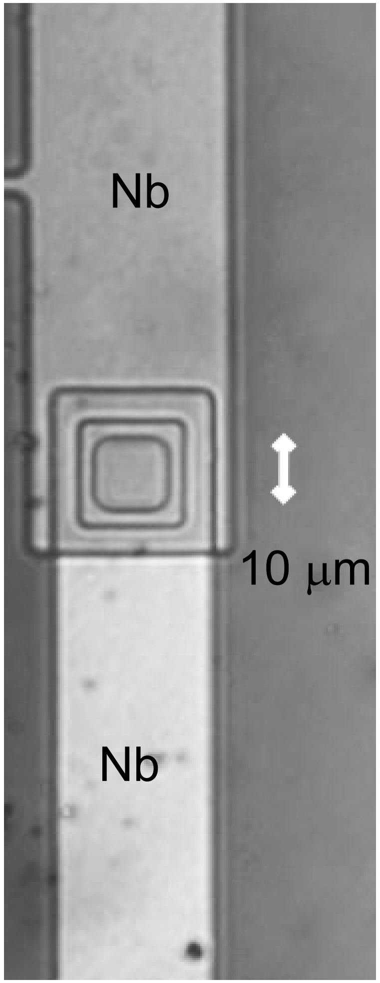




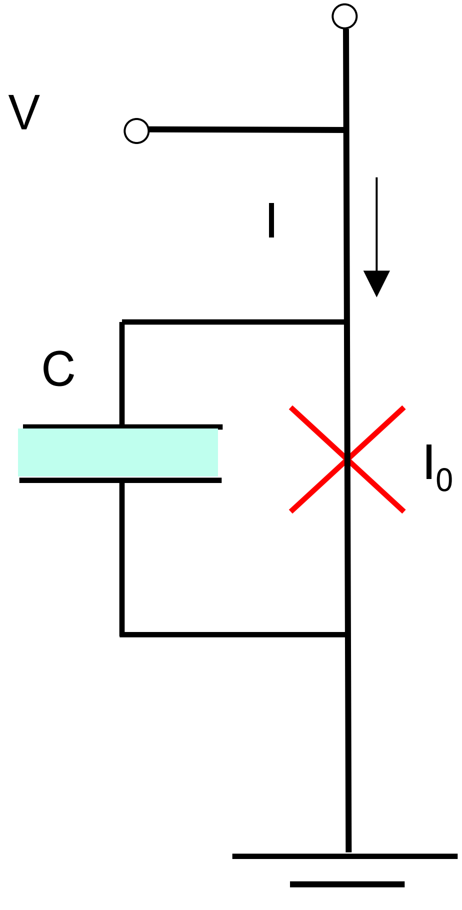




Josephson tunnel junctions



Nb/Al_2O_3/Nb tri-layer junction



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Josephson relations

$$I_j = I_o \sin(\gamma)$$

$$2eV = \hbar \frac{d\gamma}{dt}$$

Junction Hamiltonian

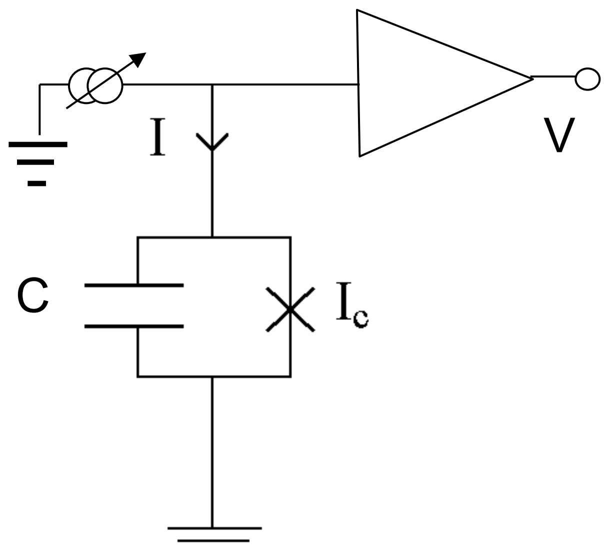
$$H = \frac{Q^2}{2C} - \frac{I_0 \Phi_0}{2\pi} \cos(\gamma) - I\gamma \frac{\Phi_0}{2\pi}$$

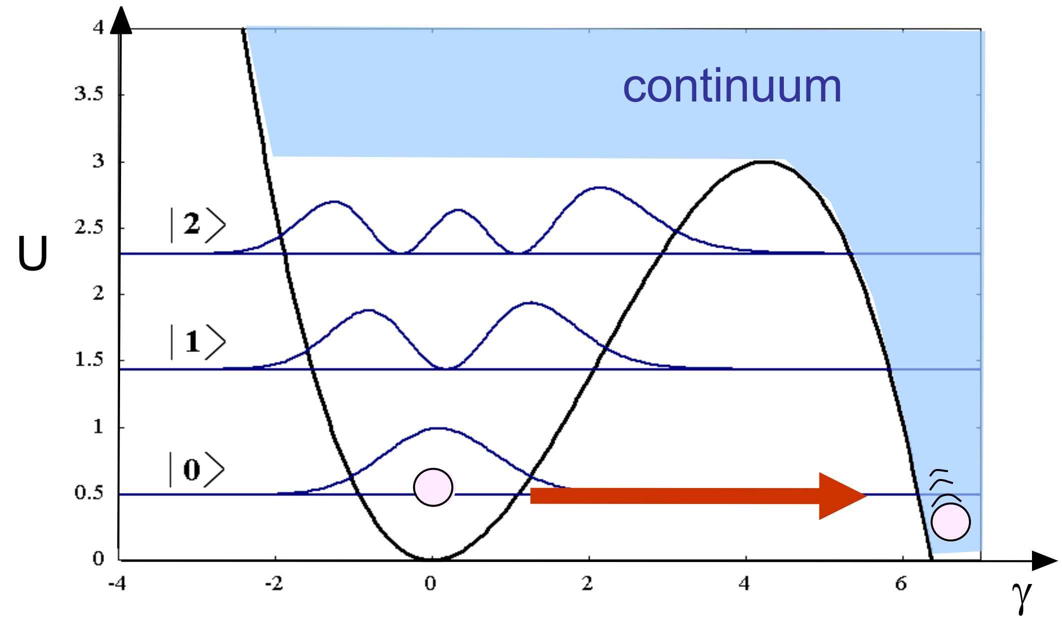
$$\frac{p^2}{2m} = \frac{Q^2}{2C}$$

$$p = m\dot{\gamma}$$

$$m = C\left(\Phi_0 / 2\pi\right)^2$$

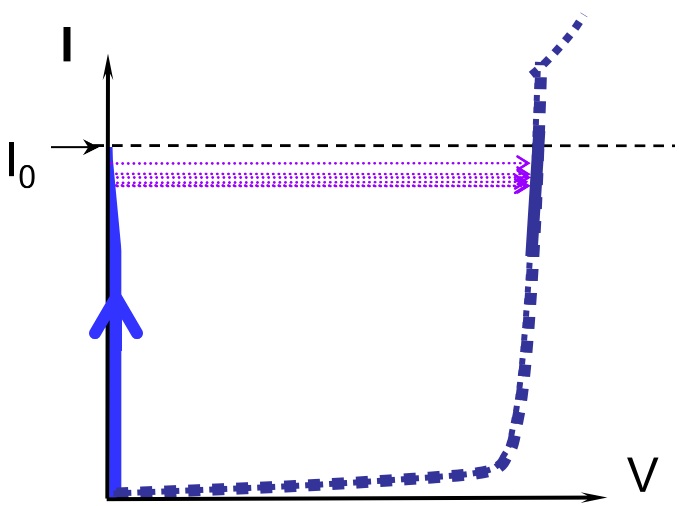
Measuring the state by tunneling



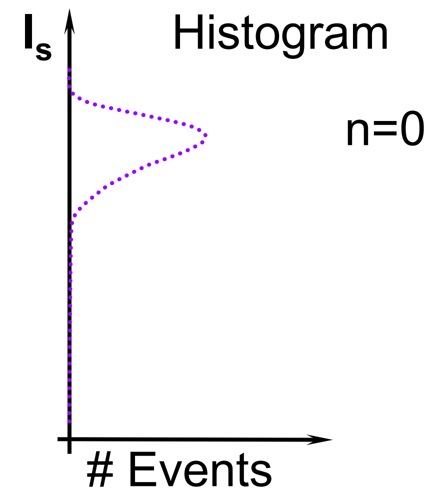


ramp current and record I_{switch}

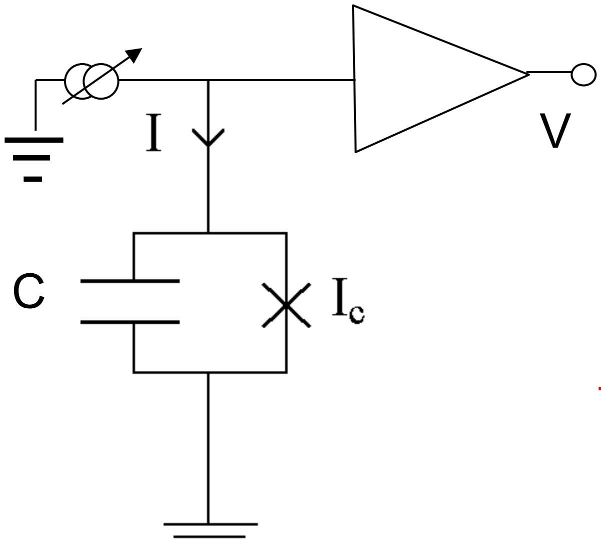
Applying current I “tilts” the U(γ) potential

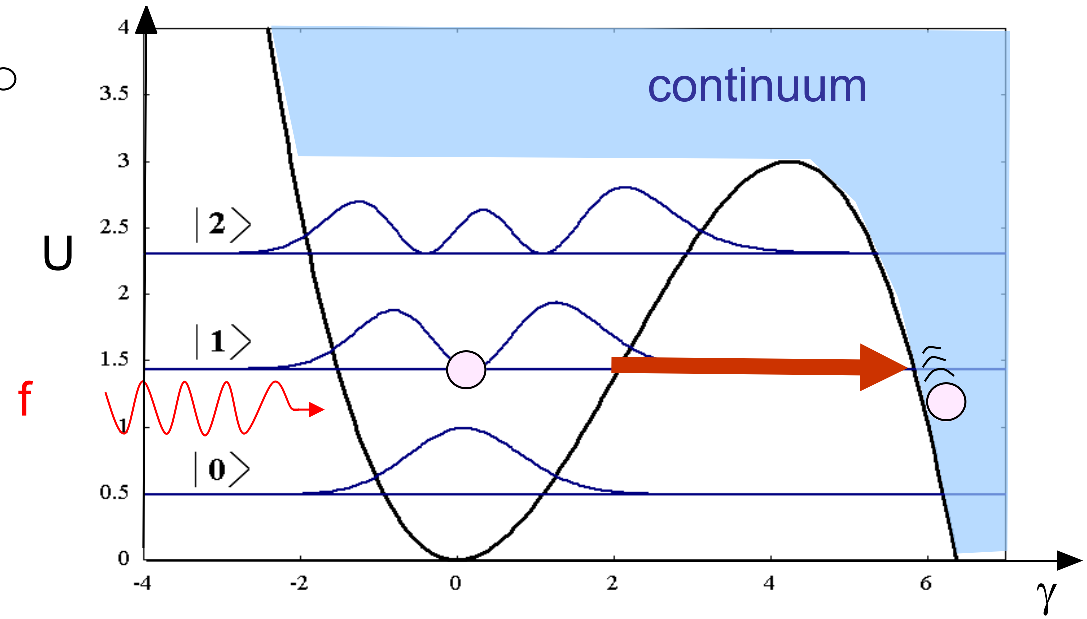


repeat
10^6 times

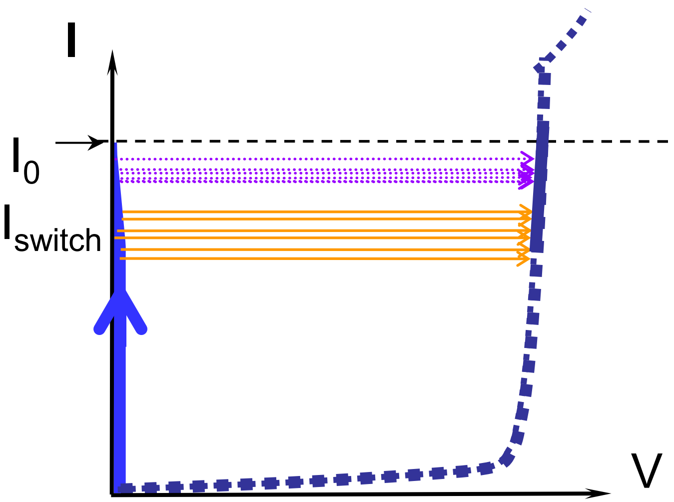


Measuring the state by tunneling

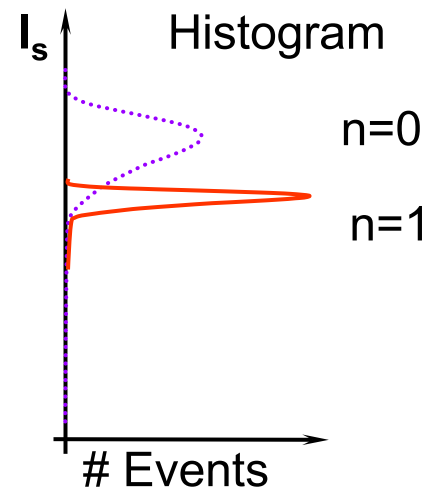




ramp current and record I_{switch}



repeat
10^6 times



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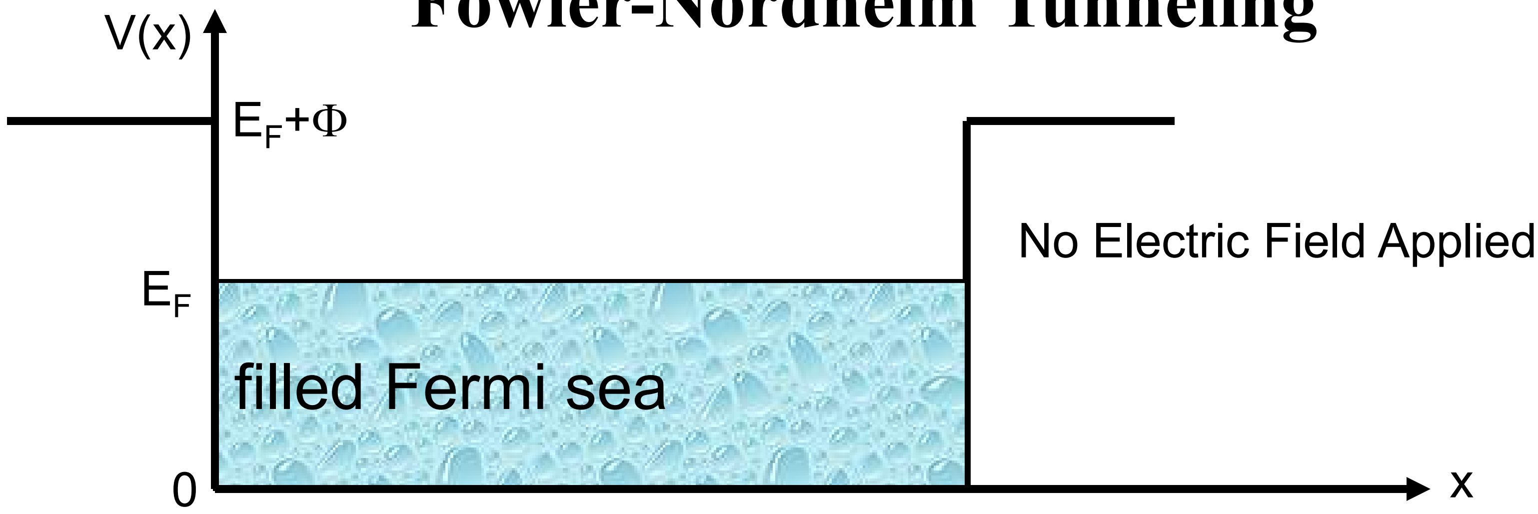
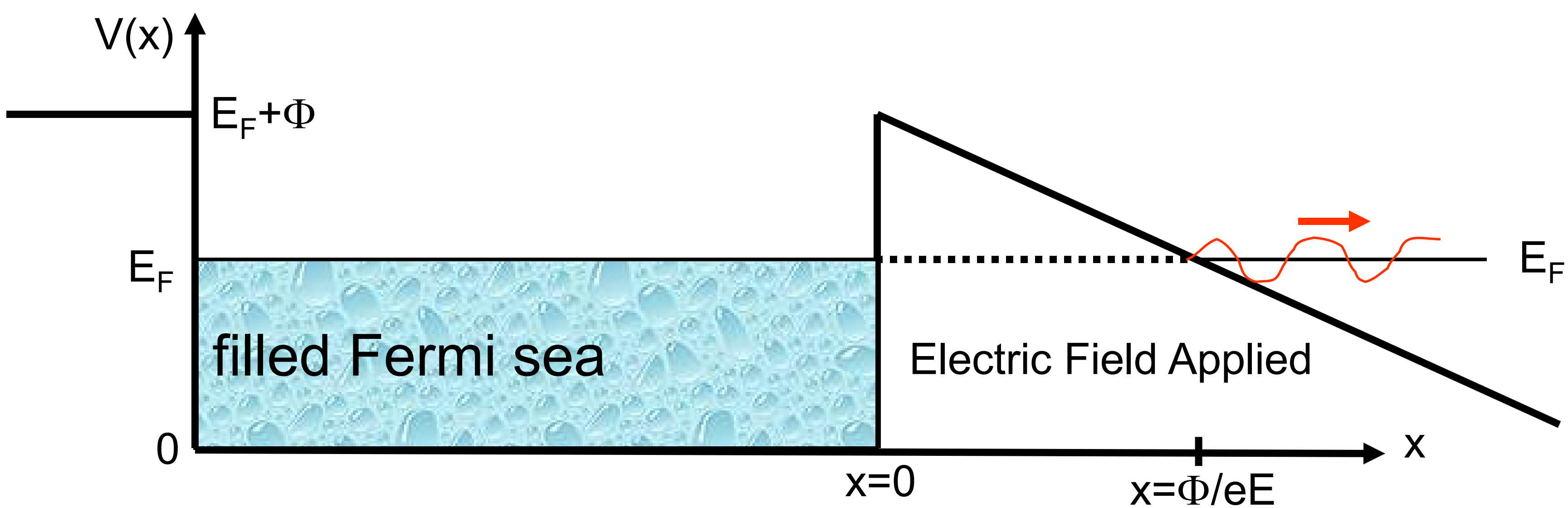
Fowler-Nordheim Tunneling



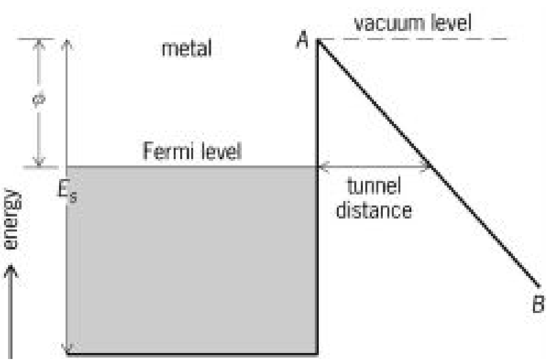


Fowler-Nordheim Tunneling

$$I \sim Log(T) \sim \mathbf{1}/\mathcal{E}$$

I = current

$\mathcal{E}$ = electric field



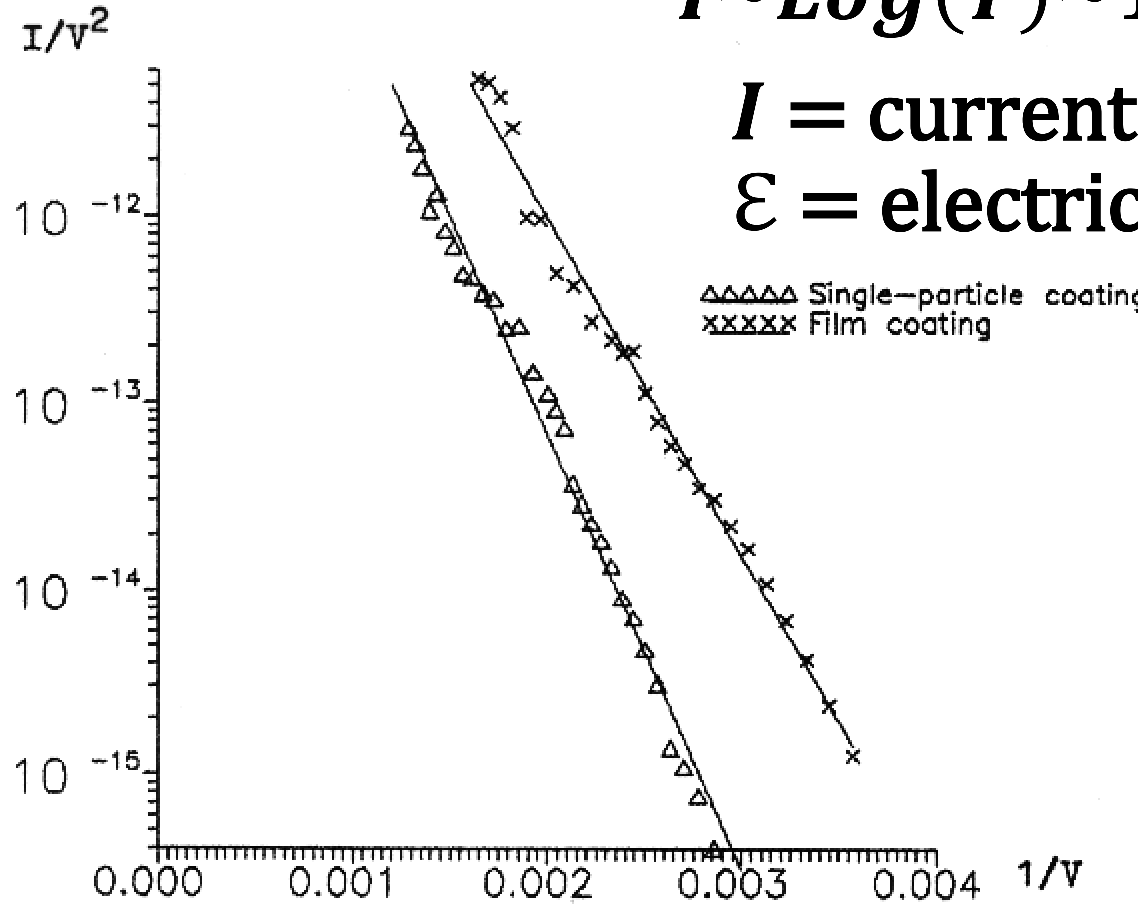
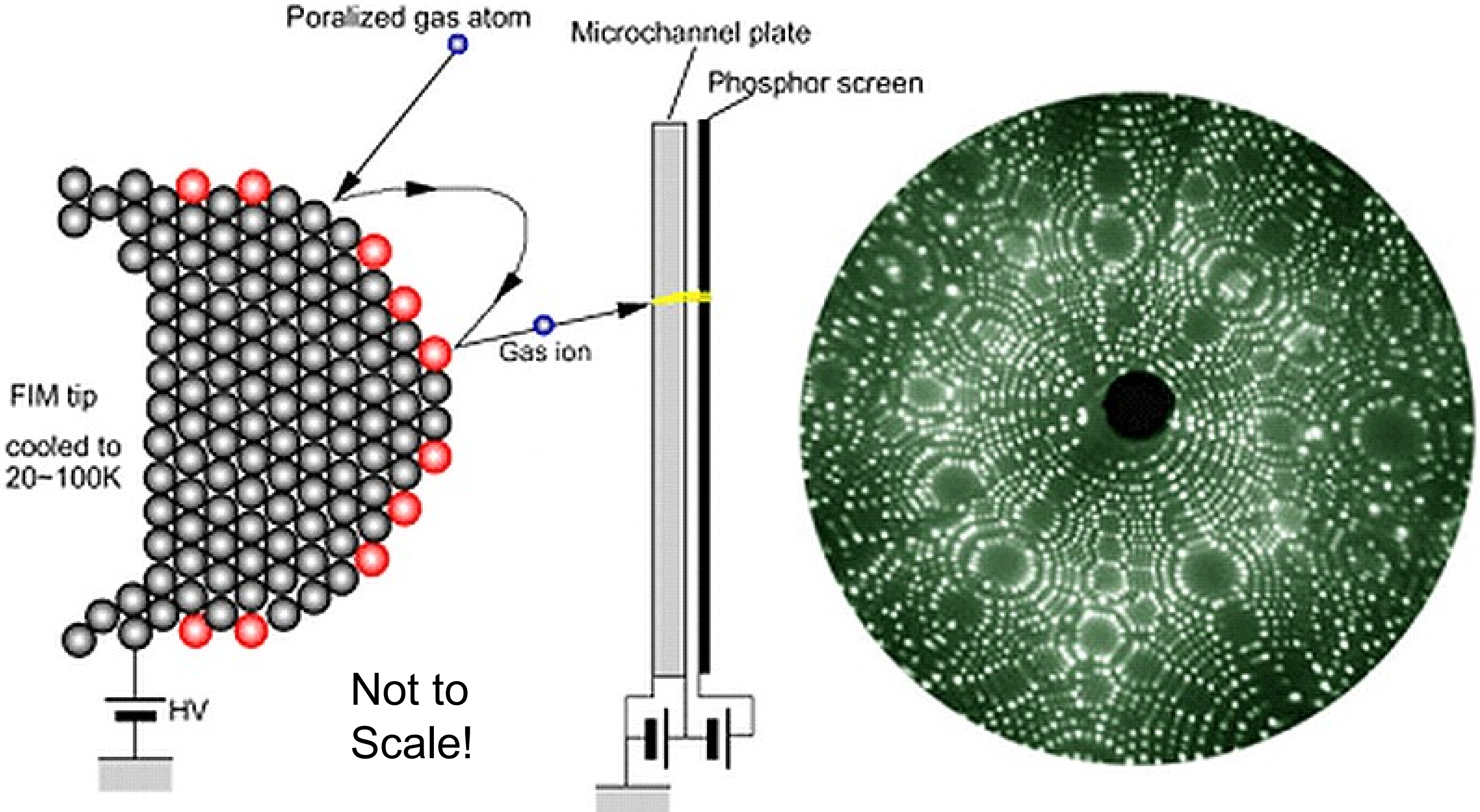


Figure 4.5. Field emission (Fowler-Nordheim) plots for diamond-coated silicon tips.

Field Ion Microscopy



Principle of the method

In the Field Ion Microscope (FIM) gas ions are formed by field ionisation in the high electric field applied to the fine needle shaped specimen tip. The gas ions are accelerated in the strong inhomogeneous field and are forming an enlarged direct projection of the surface on the screen. If the specimen tip is kept on very low temperatures the imaging gas ions are keeping almost on the field trajectories and atomic resolution can be obtained.

www.if.tugraz.at/Surface/images/fimschem.jpg

Motorola's prototype flat panel display based on the Fowler-Nordheim field emission principle. The display is 14 cm in diagonal and 3.5 mm thick with a viewing angle of 160�. Each pixel (325 micron) in size uses field emission of electrons from microscopic sharp point sources (icebergs). Emitted electrons impinge on colored phosphors on a screen and cause light emission by cathodoluminescence. There are millions of these microscopic field emitters to constitute the image. (Photograph courtesy of Dr. Babu Chalamala, Flat Panel Display Division, Motorola.).