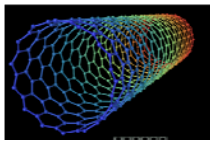
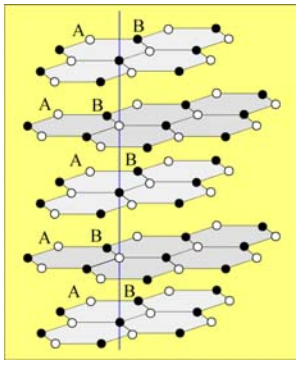
Lecture 22

Carbon nanotubes



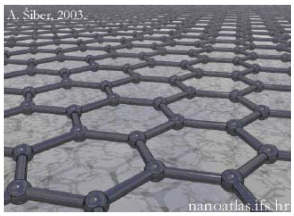
Physical Properties of Carbon Nanotubes
Saitoh, Dresselhau, Dresselhaus, Imperial College Press 1998

Graphite



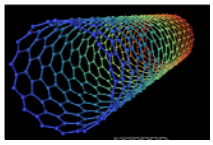
Layered poorly conducting semimetal used in pencils, fuses and nuclear fusion moderators

Graphene



Nanotubes

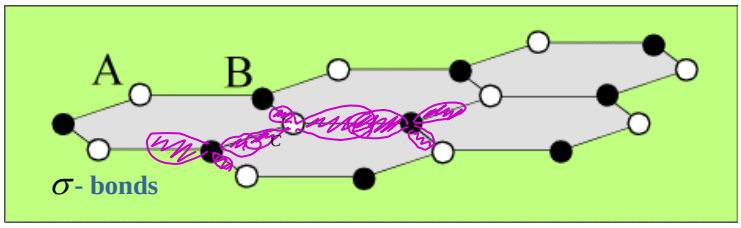
Iijima 1991
Smalley 1993

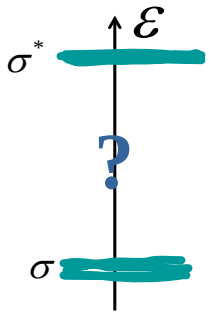


Physical Properties of Carbon Nanotubes
Saitoh, Dresselhau, Dresselhaus, Imperial College Press 1998

Carbon has 4 electrons in the outer s-p shell

sp^2 hybridisation forms strong directed bonds which determine a honeycomb lattice structure.

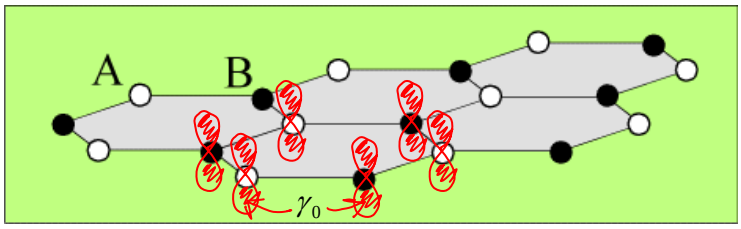




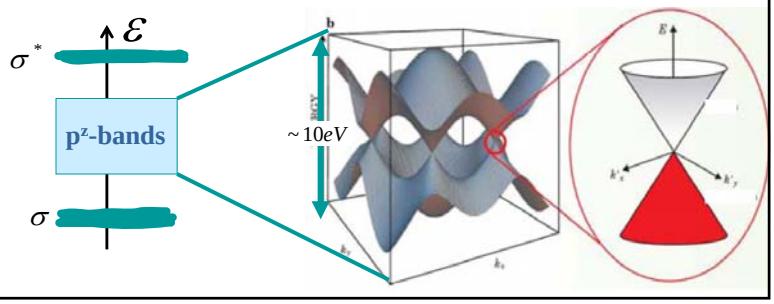
Covalent bonds

Carbon has 4 electrons in the outer s-p shell

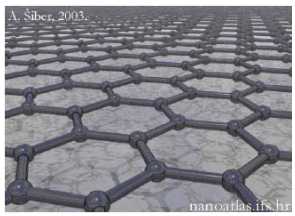
sp^2 hybridisation forms strong directed bonds which determine a honeycomb lattice structure.



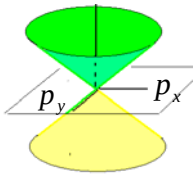
$p^z(\pi)$ orbitals determine conduction properties of graphite



Graphene (monolayer of graphite) is a truly two-dimensional zero-gap semiconductor with linear dispersion of band electrons near the Fermi level

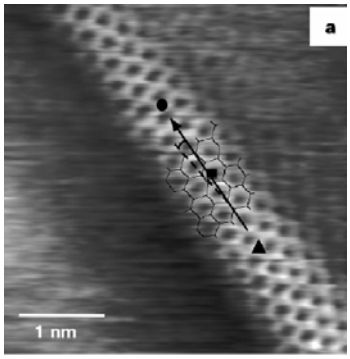


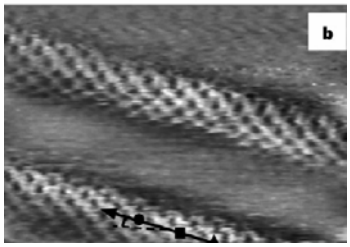
$$\varepsilon^{cond} = vp = v\sqrt{p_x^2 + p_y^2}$$

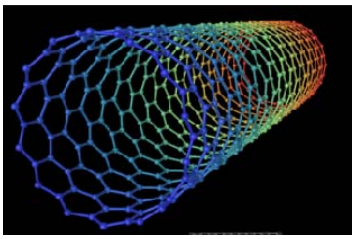


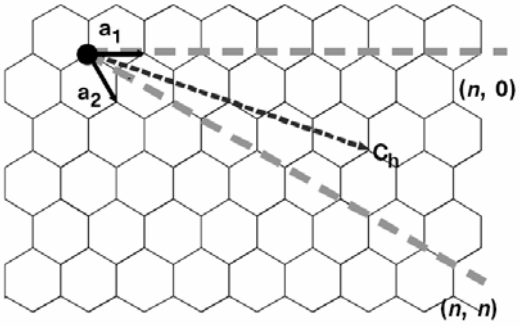
$$\varepsilon^{val} = -vp = -v\sqrt{p_x^2 + p_y^2}$$

Carbon nanotubes









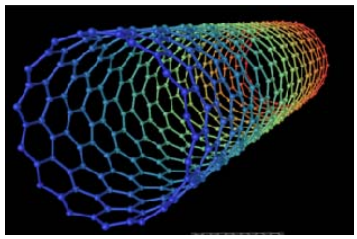
STM images of carbon nanotubes
T.W. Odom, J.-L. Huang, P.Kim, C.Lieber, Nature 391 (1998)

$$\psi(y=0)=\psi(y=L_\perp)$$

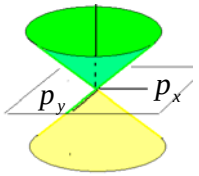
$$\psi \sim \frac{1}{\sqrt{L_\perp}} e^{i2\pi y/L_\perp}$$

$$p_y = \frac{2\pi\hbar}{L_\perp} n$$

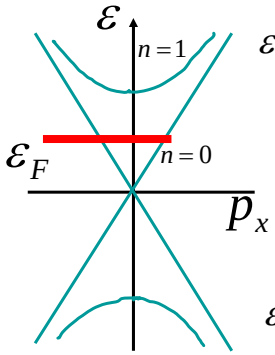
Metallic nanotubes



$$\varepsilon^{cond} = v\sqrt{p_x^2 + p_y^2}$$



$$\varepsilon^{val} = -v\sqrt{p_x^2 + p_y^2}$$

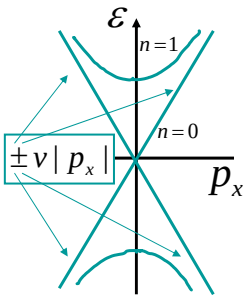


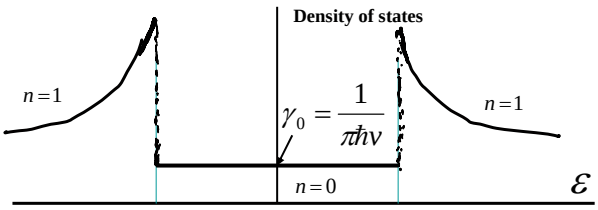
$$\varepsilon_n^{cond} = v\sqrt{p_x^2 + \frac{h^2 n^2}{L_\perp^2}}$$

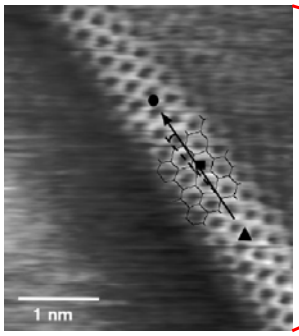
$$n = 0,1,2,3,....$$

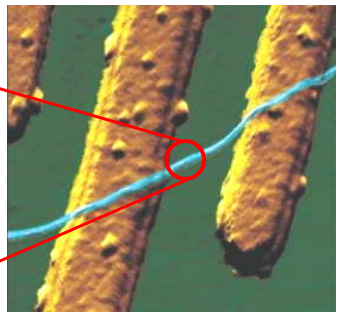
$$\varepsilon_n^{val} = -v\sqrt{p_x^2 + \frac{h^2 n^2}{L_\perp^2}}$$

Metallic nanotubes – truly 1D conductors

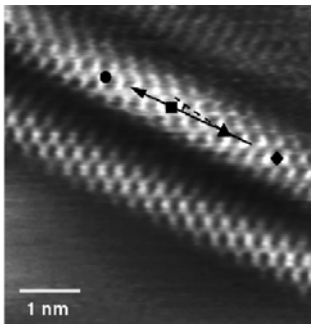


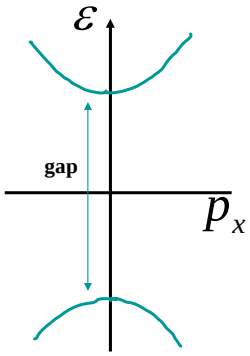






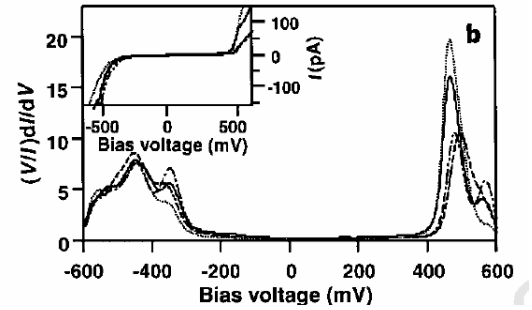
Yao *et al* 1999





Semicondutor-type nanotubes

Depending on how the carbon sheet is rolled into a nanotube, the resulting nanotube nay have gap in the electron spectrum.



STM current

T.W. Odom, J.-L. Huang, P.Kim, C.Lieber, Nature 391 (1998)

Promising applications of carbon nanotubes:

In surface tunnelling microscopy – used as a tip.

Make excellent tips for for field-effect electron emitters (SONY).

For surface force microscopy – used as a tip.