Graphene and Quantum Mechanics

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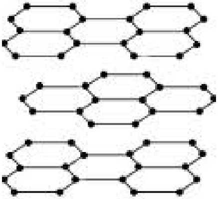
Carbon structures

Graphite

- 3 strong bonds/atom
- layer of 2D sheets
- weak bonding normal to the plane
- black
- conducting



Graphene

Graphene

A single layer of graphite

- The thinnest 2D material
- 97% transparent
- conducting

Graphene

Graphene was first studied in theory by P.R. Wallace in 1947 as a starting point for understanding the property of graphite. However, nothing thinner than 50 to 100 layers was produced in practice before 2004.

Andre Geim and Konstantin Novoselov at University of Mandhester succeeded to extract a single layer of graphite using the "Scotch tape method." They won the Nobel Prize in Physics in 2010.

Figure: Graphite and a tape dispenser. Donated to the Nobel Museum in Stockholm by Andre Geim and Konstantin Novoselov in 2010.

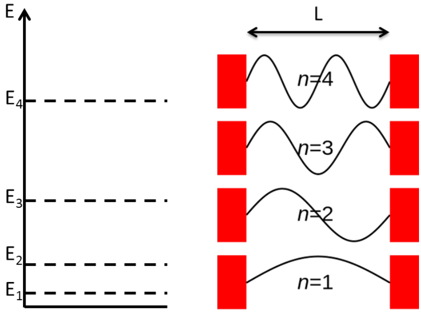
Wave properties of Electrons

Electron in a box

Due to the particle-wave duality, electrons behave as wave on a microscopic scale. For example, an electron in a box with L sufficiently small can be considered as a string vibrating between two walls. Then we observe the discrete mode and energy corresponding to each standing wave.

$$E_n \propto \frac{n^2}{mL^2}$$

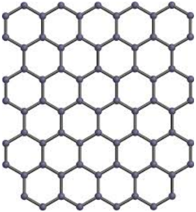
$$m = \text{mass}, \quad n = 1, 2, 3, \cdots$$



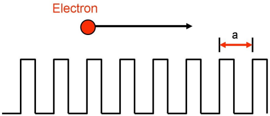
Electron in a crystal

Crystals have periodic atomic structures.

3D: Diamond



2D: Graphene



1D: Kronig-Penney model

When the electron is in a periodic structure, the allowed energy levels form a band structure which determines the electronic/optical property of the material.

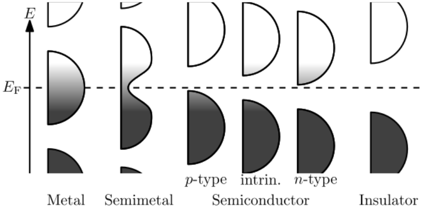


Figure: Various types of energy level

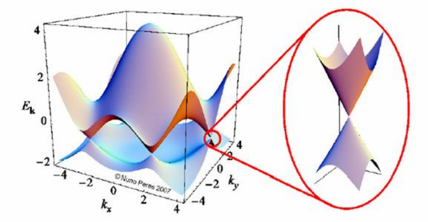


Figure: Energy level of graphene

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