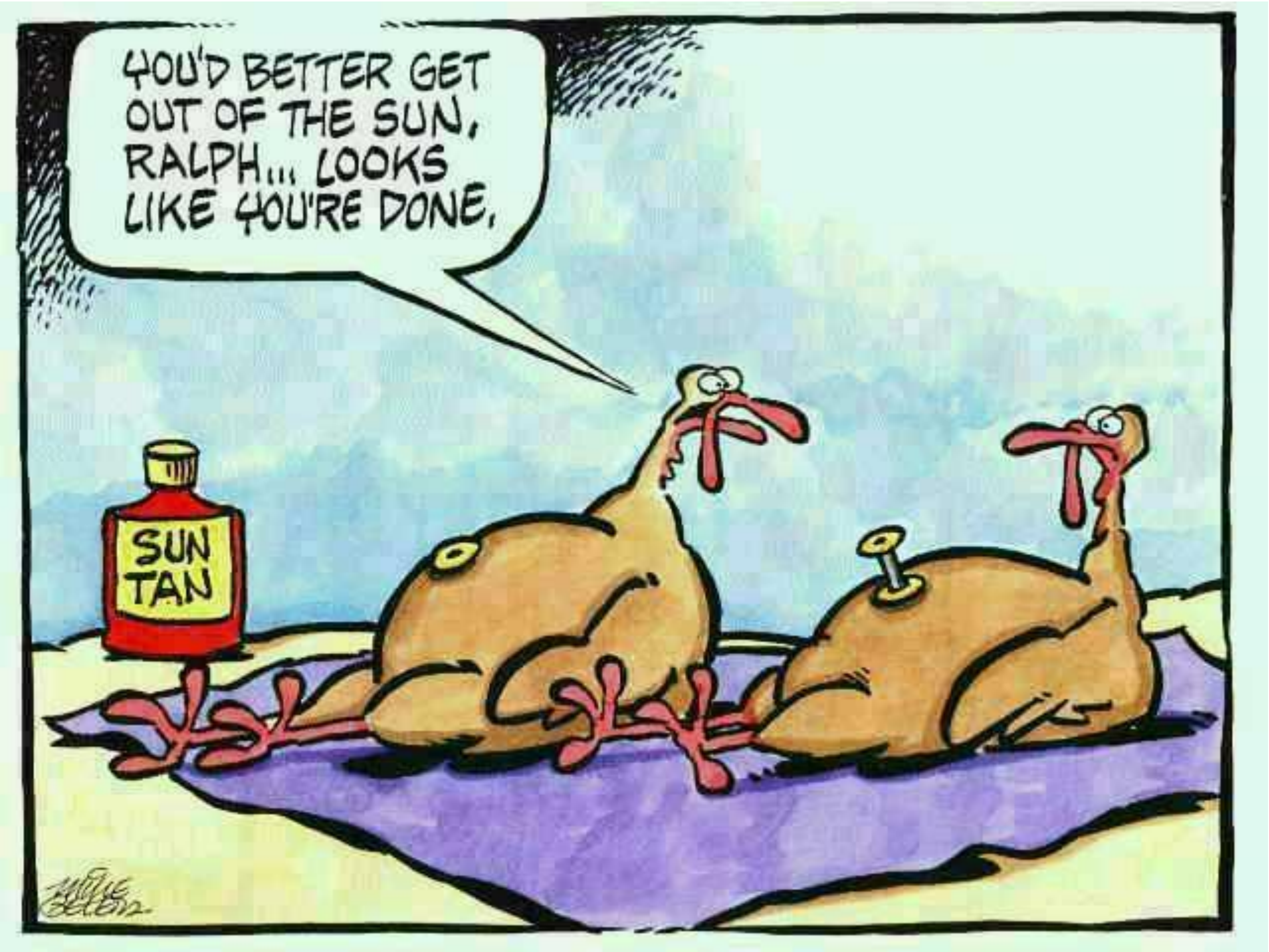
Geometrical Optics

Brewster's Angle

One exam: 11:30 to 12:20 pm (Monday, 12/07)

Last submission day for reports – Friday, (12/11/14).



About Exam

Open book and notes; bring calculator; Google is not allowed!

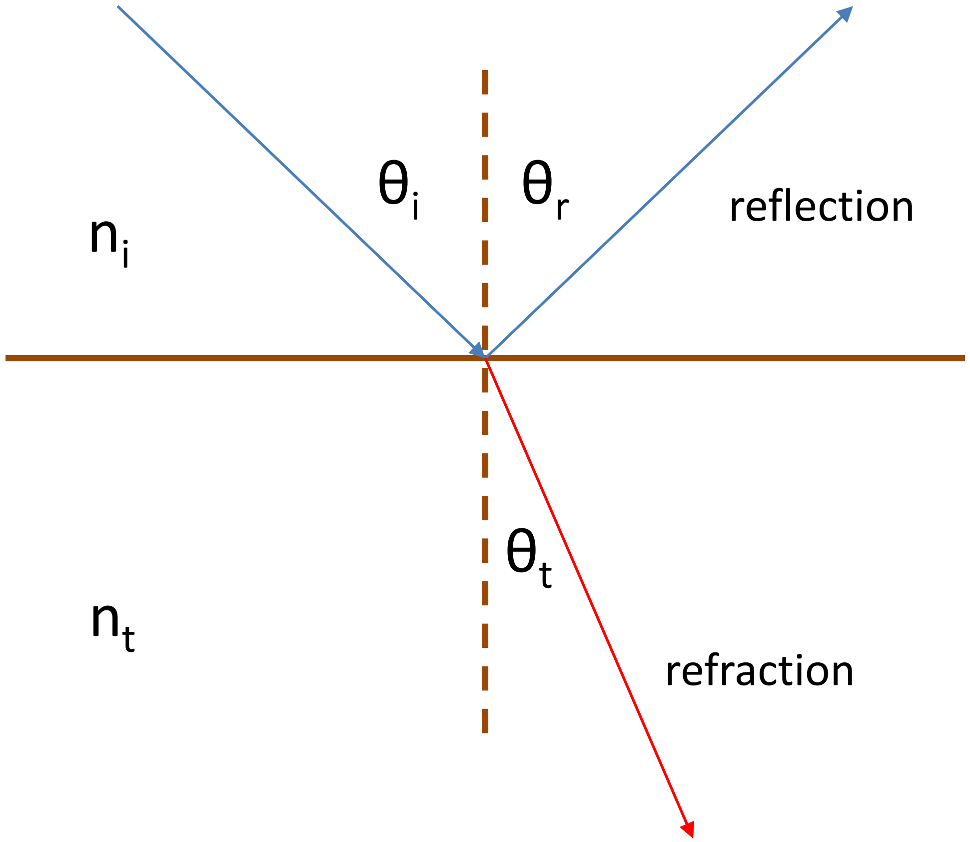
Five questions: (1) Uncertainties; Error propagation

(2) Fabry-Perot Interferometer (fineness, resolve power, free spectral range…)

(3) Michelson Interferometer (calculate coherence length, interference of frequency doublet…)

(4) Diffraction (Fraunhofer or Fresnel ? Grating equation ….)

Law of Reflection and Refraction



$$\theta_i = \theta_r$$

$$n_i \sin\theta_i = n_t \sin\theta_t$$

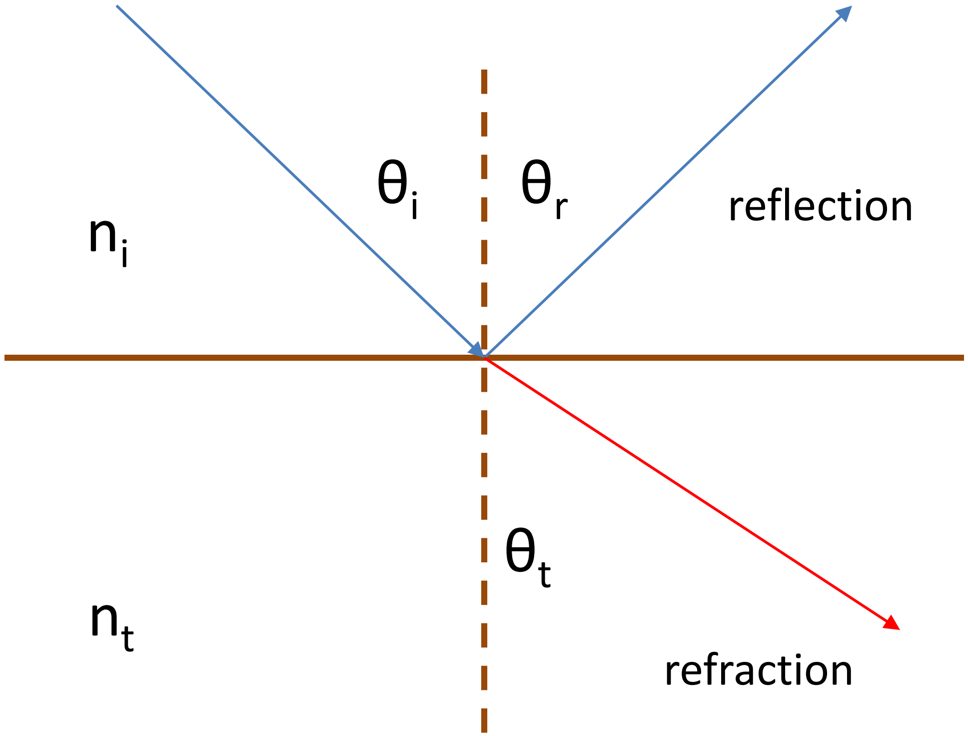
$$\sin(\theta_t) = \frac{n_i}{n_t}\sin(\theta_i)$$

$$n_i < n_t$$

$$\sin(\theta_t) < \sin(\theta_i)$$

The ray entering a higher-index medium bends toward the normal

Total Internal Reflection



$\theta_i = \theta_r$

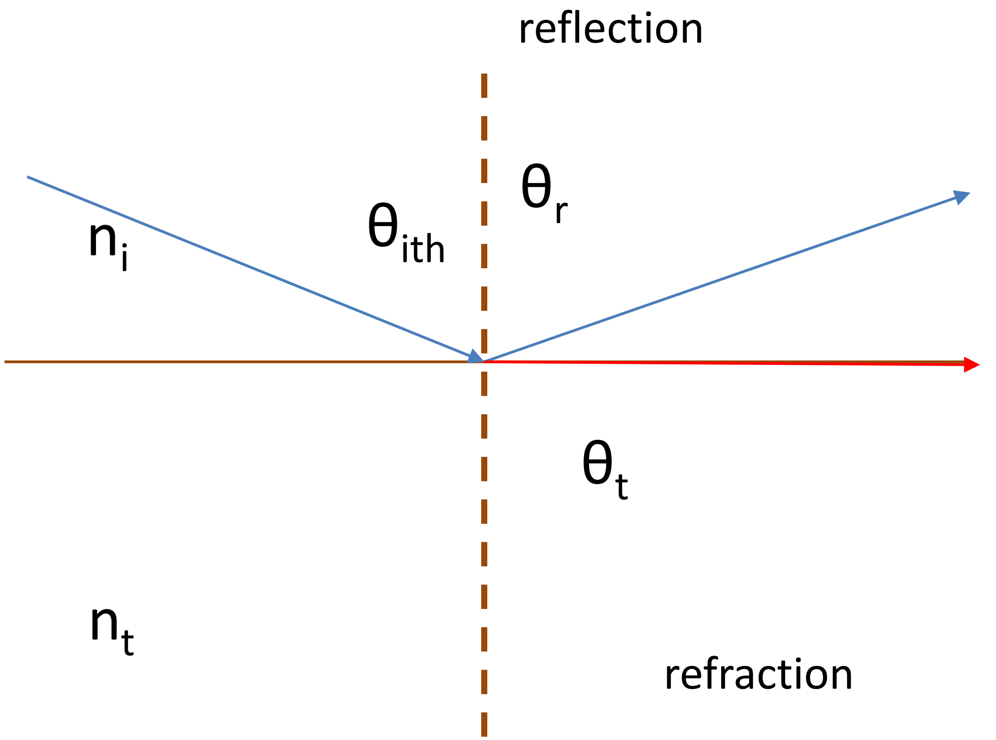
$$n_i \sin\theta_i = n_t \sin\theta_t$$

$$\sin(\theta_t) = \frac{n_i}{n_t}\sin(\theta_i)$$

$$n_i > n_t$$

$$\sin(\theta_t) > \sin(\theta_i)$$

Total Internal Reflection



$$\theta_i = \theta_r$$

$$n_i \sin\theta_i = n_t \sin\theta_t$$

$$\sin(\theta_t) = \frac{n_i}{n_t}\sin(\theta_i)$$

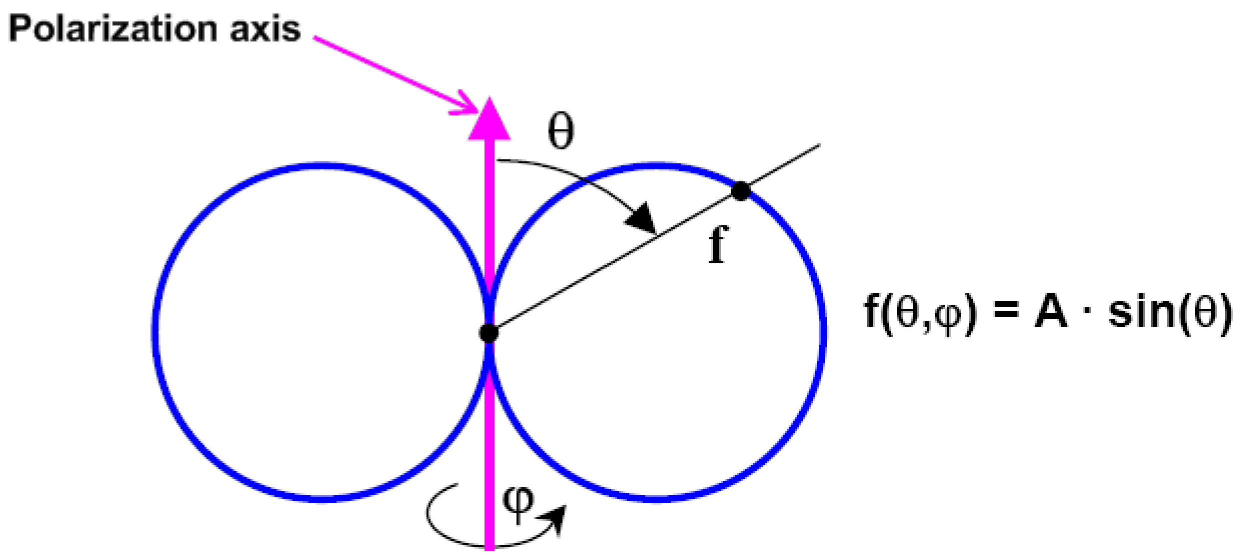
$$n_i > n_t$$

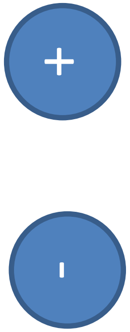
$$\sin(\theta_t) > \sin(\theta_i)$$

$$\theta_t = 90;$$

$$\theta_{ith} = Arc\sin(\frac{n_t}{n_i});$$

Dipole radiation pattern





Dipole oscillation is in the same direction of light polarization, which is perpendicular to the light propagation direction.

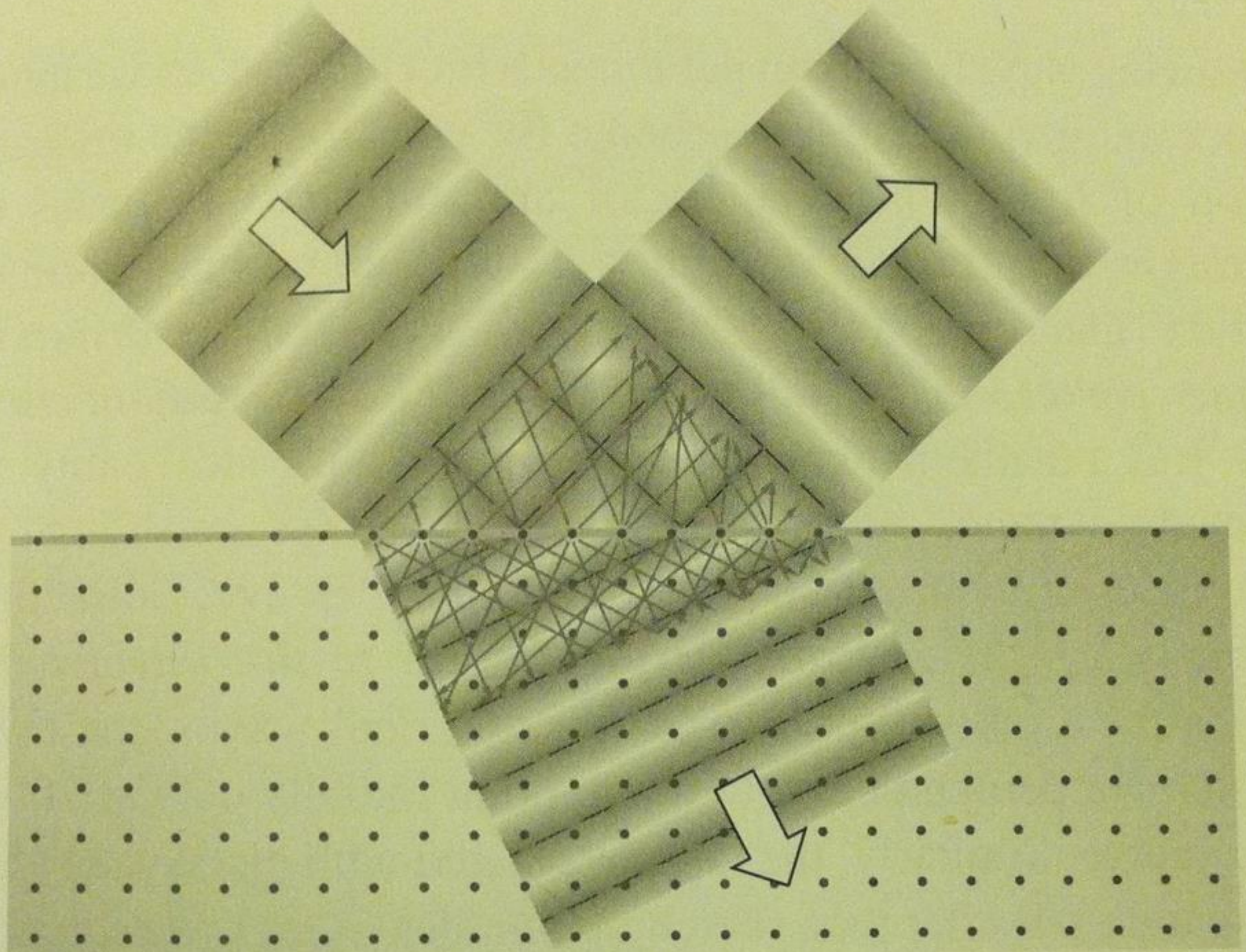


Figure 4.14 A plane wave sweeps in stimulating atoms across the interface. These radiate and reradiate, thereby giving rise to both the reflected and transmitted waves.

Polarization of Light

$$\vec{E}$$

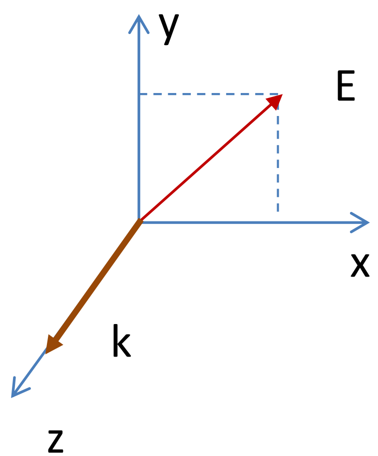
Polarized electric field

$$\vec{k}$$

Wave-vector

$$\vec{E} \bullet \vec{k} = 0$$

Transverse wave



$$\overrightarrow{E_x}(z,t) = \hat{x}E_x \cos(k.z - \omega t)$$

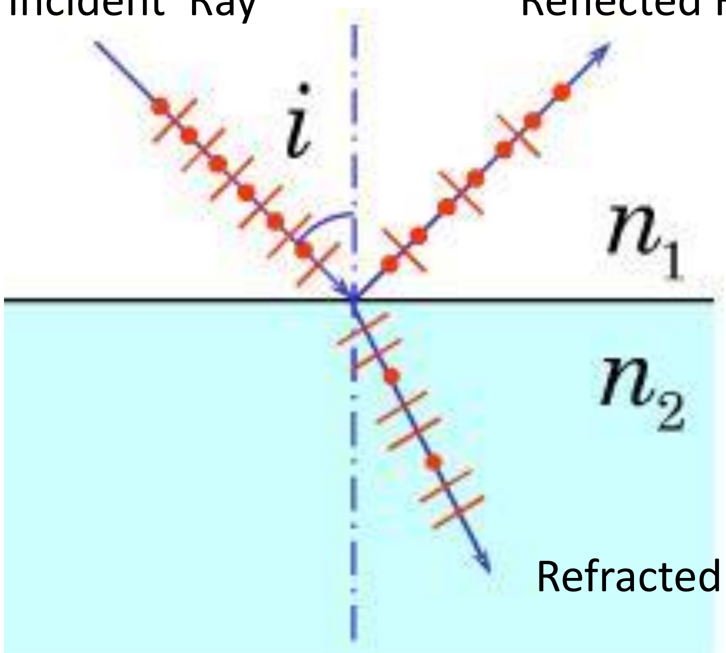
$$\overrightarrow{E_y}(z,t) = \hat{y}E_y \cos(k.z - \omega t + \xi)$$

Polarization by Reflection

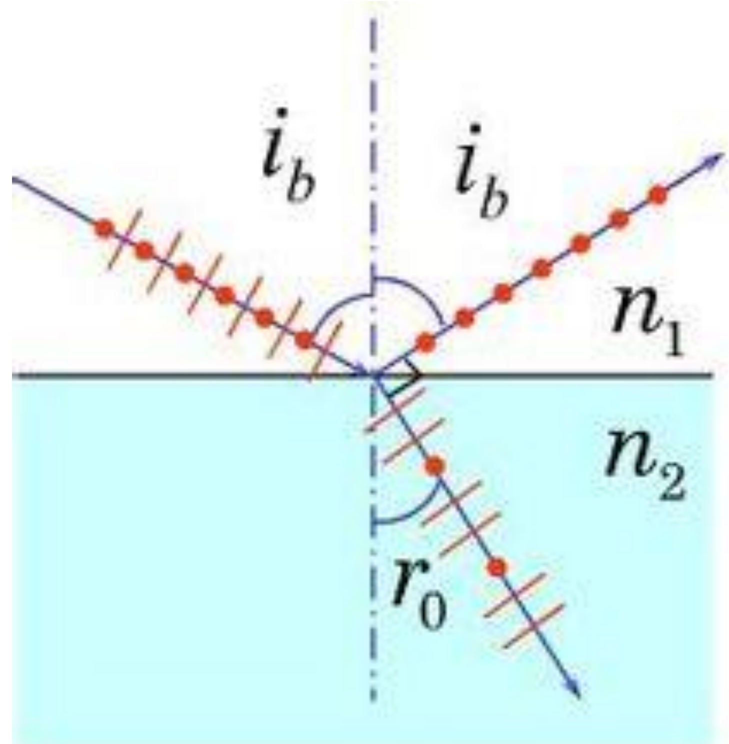
E is perpendicular to k.

Incident Ray

Reflected Ray



Refracted Ray

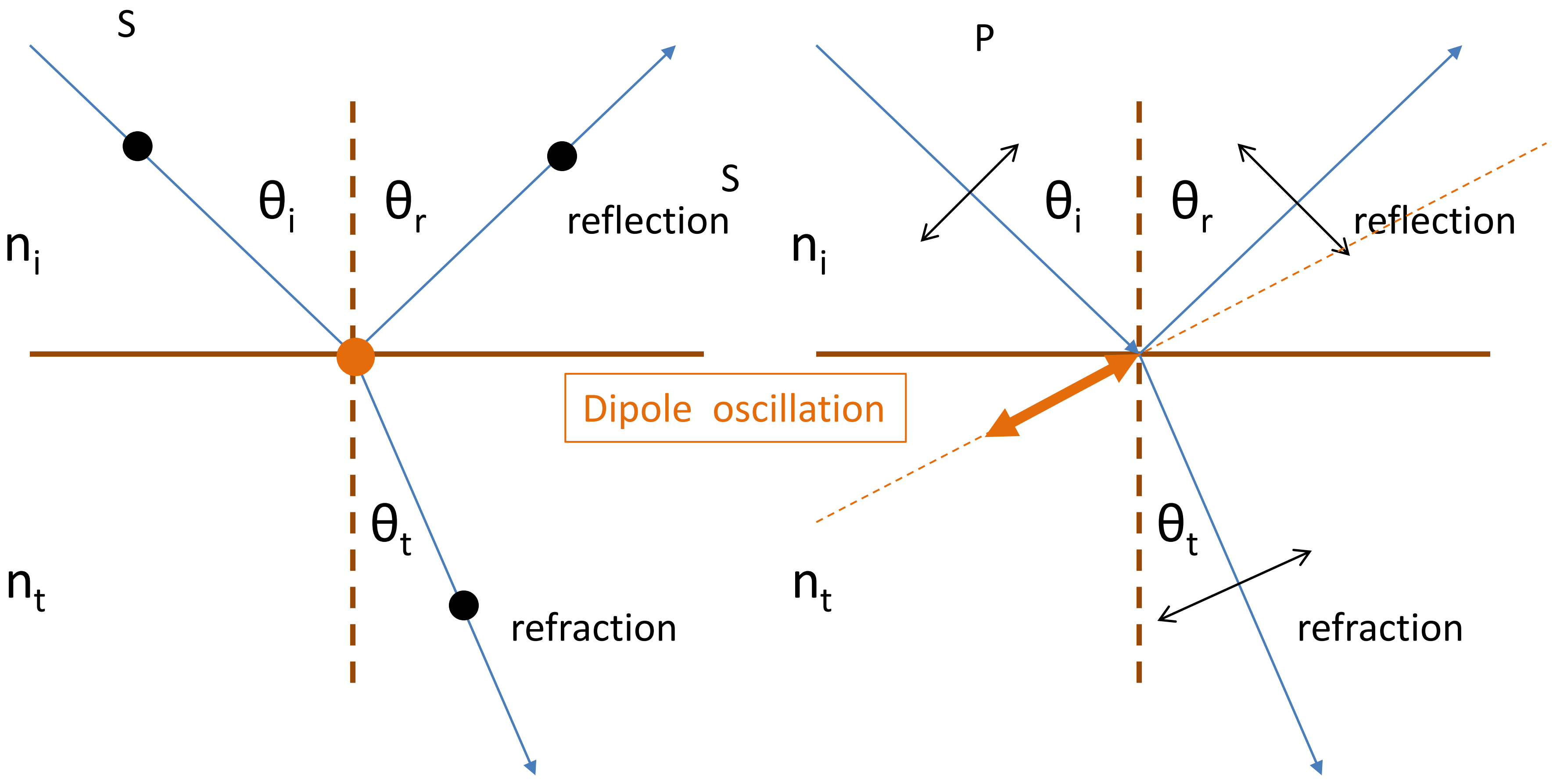


General

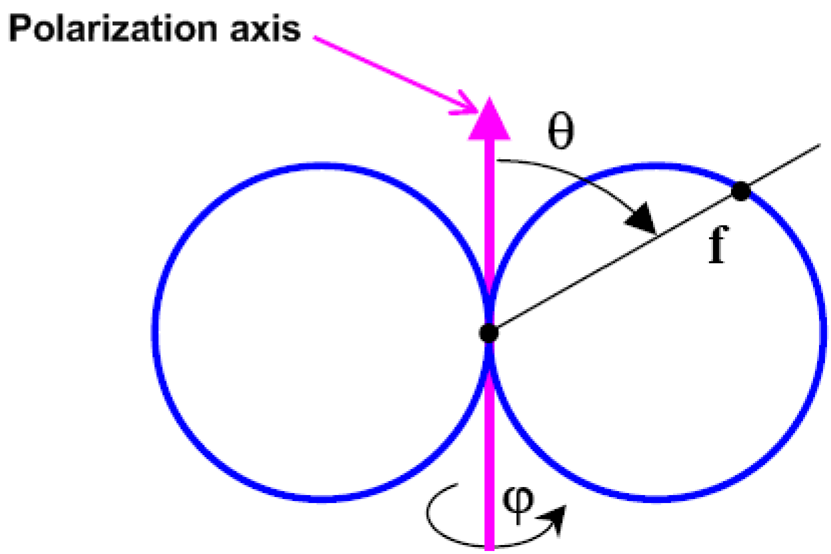
Brewster's Angle

Sun Glass: Polarized glass

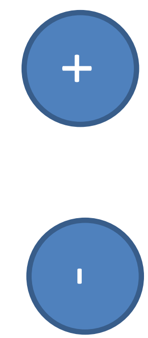
Polarized Reflection: Electron-Oscillator Model



Dipole radiation pattern

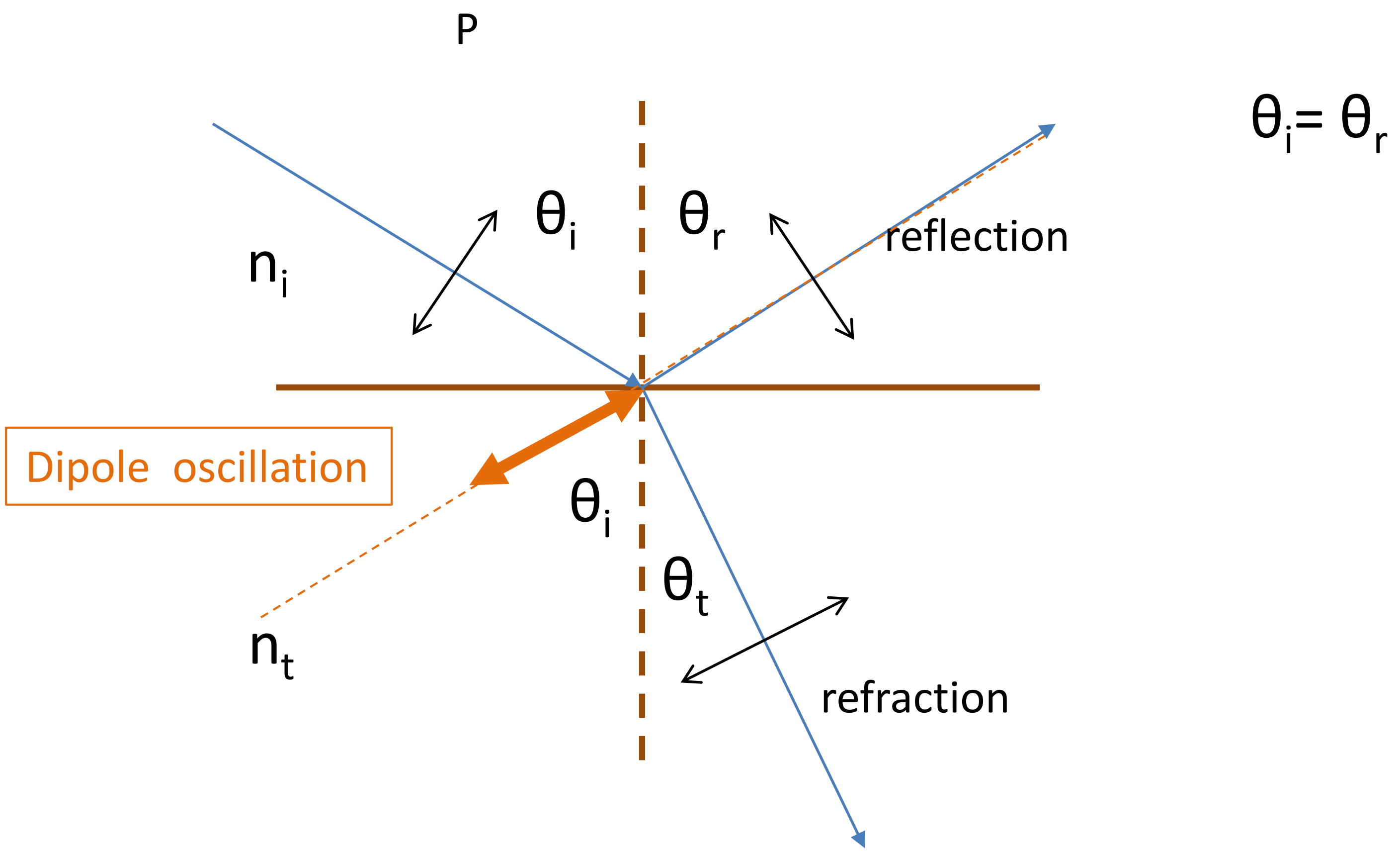


$$f(\theta,\varphi) = A \cdot \sin(\theta)$$

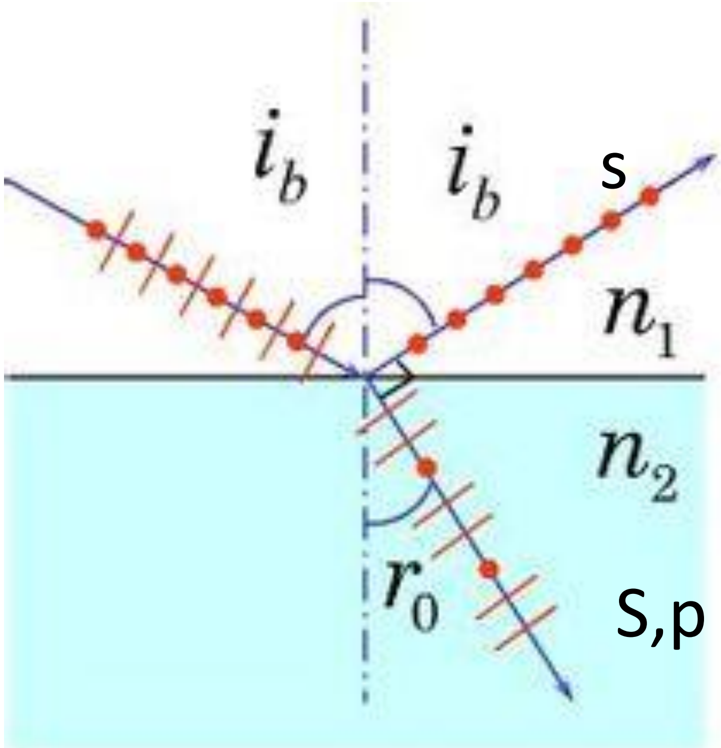


Dipole oscillation is in the same direction of light polarization, which is perpendicular to the light propagation direction.

E is perpendicular to k.



$$\theta_i + \theta_t = \frac{\pi}{2}$$



Brewster's Angle

$$n_i \sin\theta_i = n_t \sin\theta_t$$

$$\Theta_i + \Theta_t = 90$$

$$\theta_i = Arc\tan\left(\frac{n_t}{n_i}\right)$$

Implementation: Electrical transport measurements of graphene

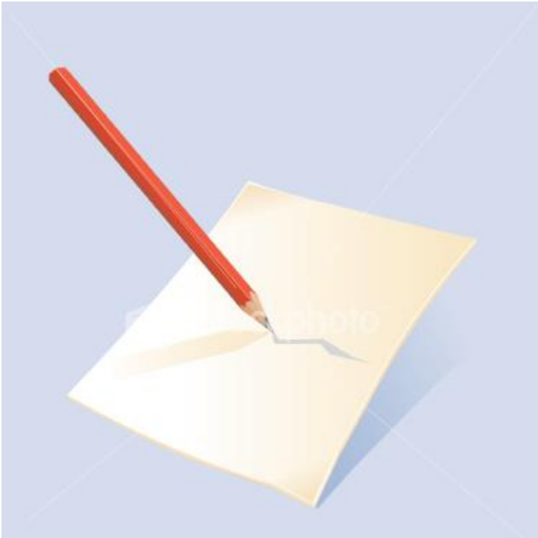
- Task: Repeat the first experiment done by the Manchester's team -> Nobel Prize in 2010
- Objective: Electronics, optics, condensed matter physics
- Spirit: Simple experiment -> Beautiful Science

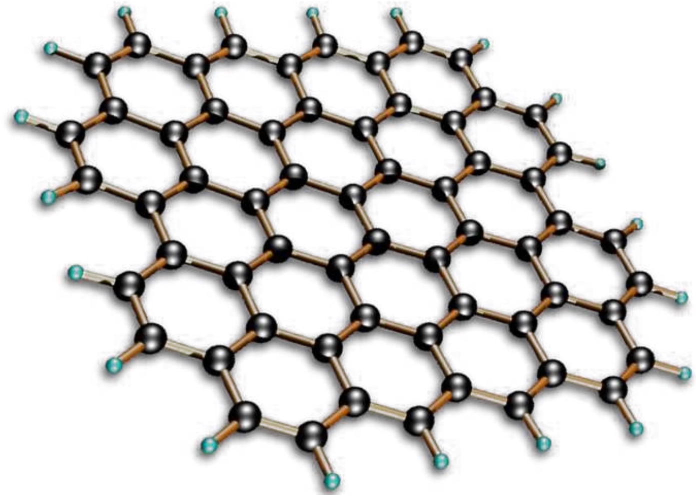
Electric Field Effect in Atomically Thin Carbon Films

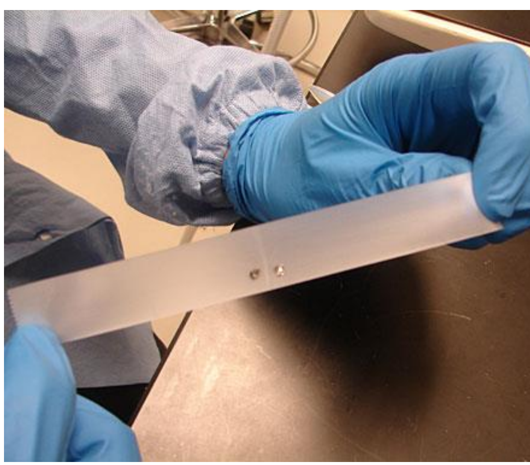
K. S. Novoselov,[1] A. K. Geim,[1*] S. V. Morozov,[2] D. Jiang,[1] Y. Zhang,[1] S. V. Dubonos,[2] I. V. Grigorieva,[1] A. A. Firsov[2]

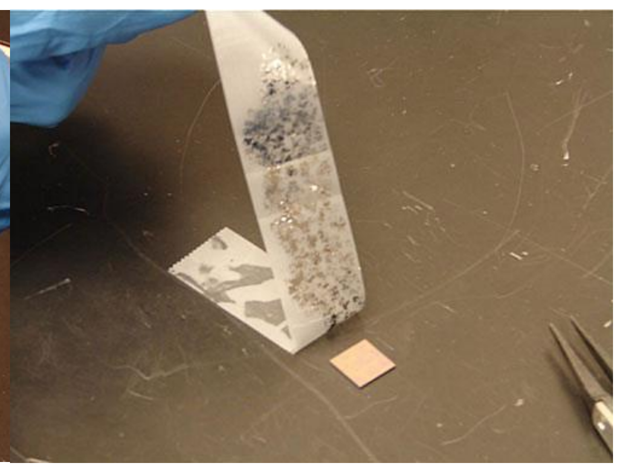
We describe monocrystalline graphitic films, which are a few atoms thick but are nonetheless stable under ambient conditions, metallic, and of remarkably high quality. The films are found to be a two-dimensional semimetal with a tiny overlap between valence and conductance bands, and they exhibit a strong ambipolar electric field effect such that electrons and holes in concentrations up to 10^{13} per square centimeter and with room-temperature mobilities of $\sim$10,000 square centimeters per volt-second can be induced by applying gate voltage.

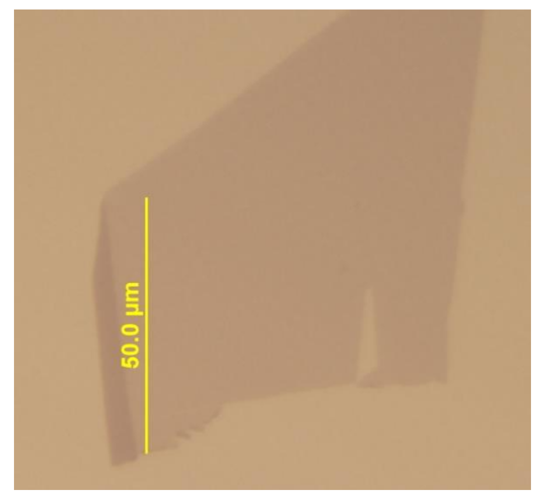
Graphene Preparation









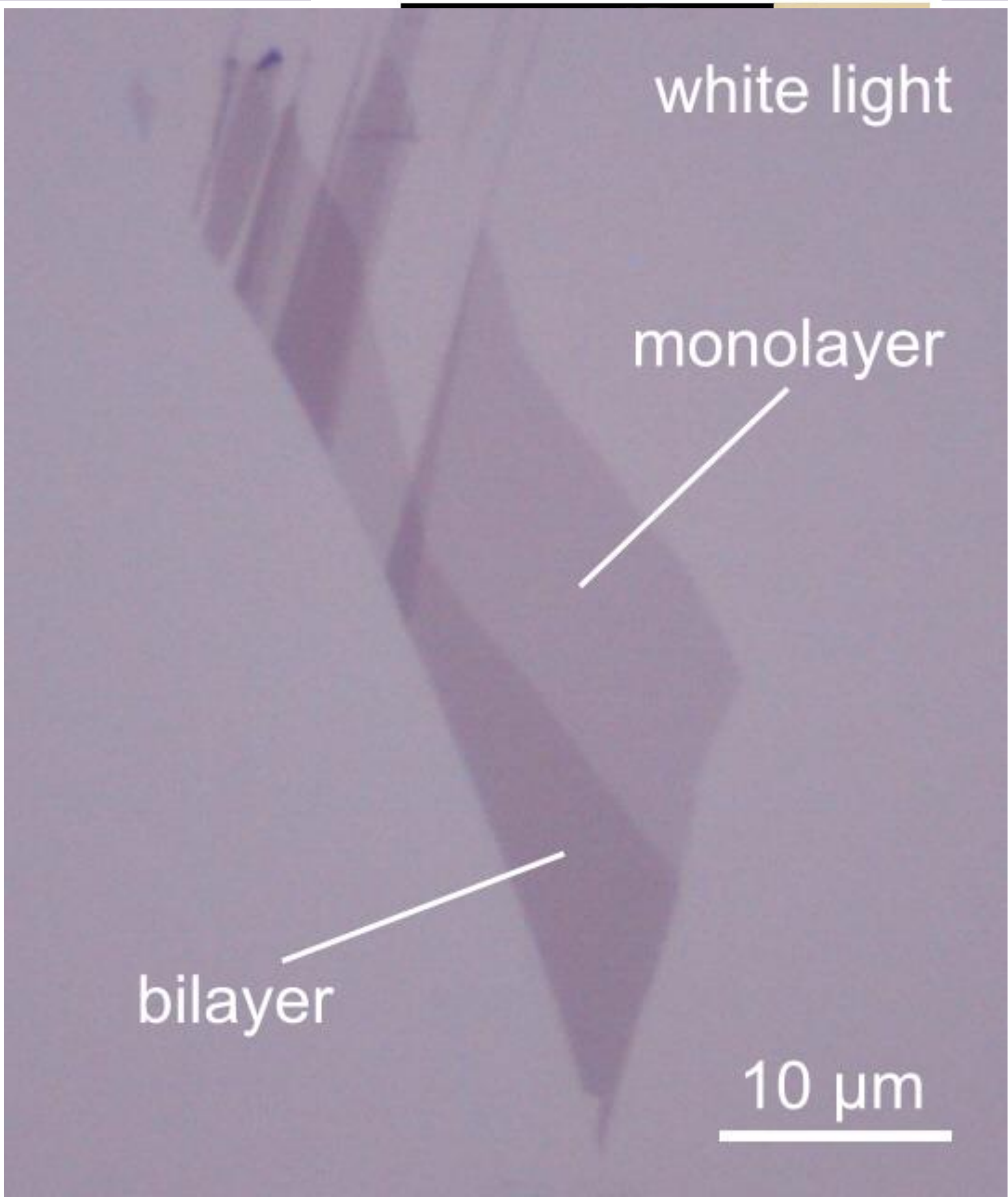


Microscope Image of monolayer graphene

Analysis of Optical Properties of Graphene

First task: Calculate Optical Interference Effect

Ref: Blake et al., Making Graphene visible, APL, 91, 063124 (2007)



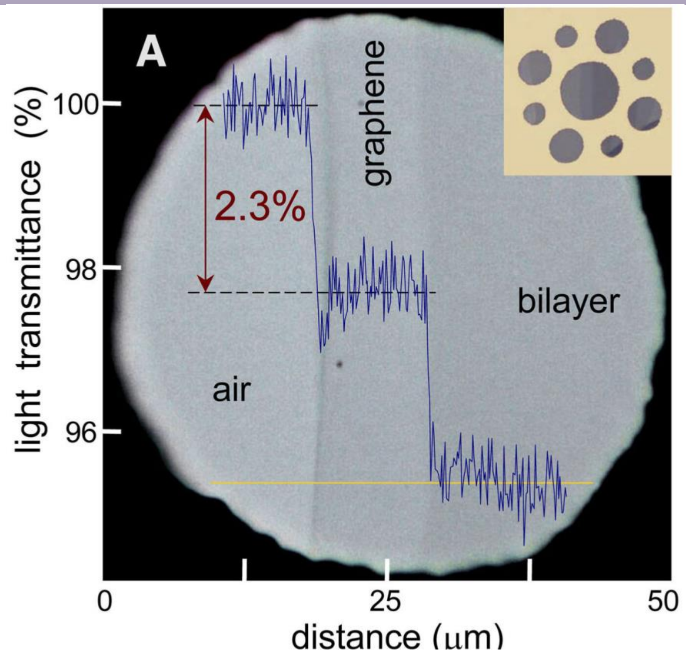
Implementation: Electrical transport measurements of graphene

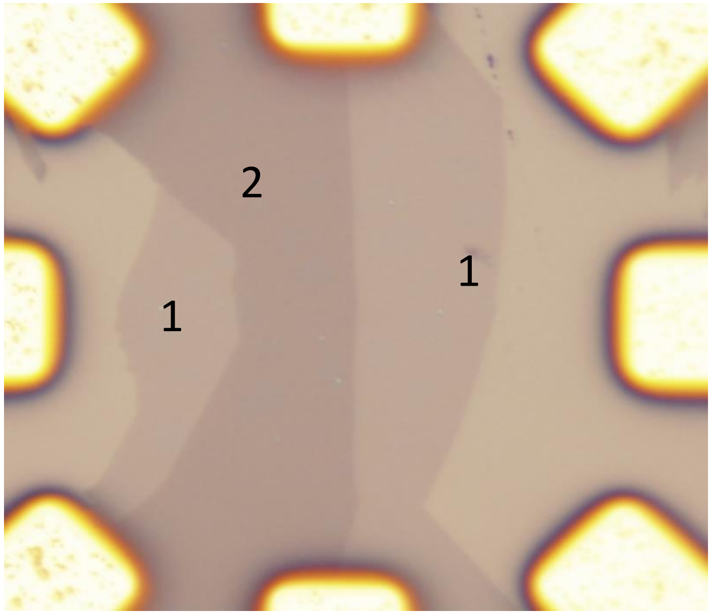
First task: Calculate Optical Interference Effect

Ref: Blake et al., Making Graphene visible, APL, 91, 063124 (2007)

Second Task: Using image processing in Mathematica/Matlab to analyze the optical contrast (2.3% for each layer ~ $\pi * fine\ structure\ constant$)

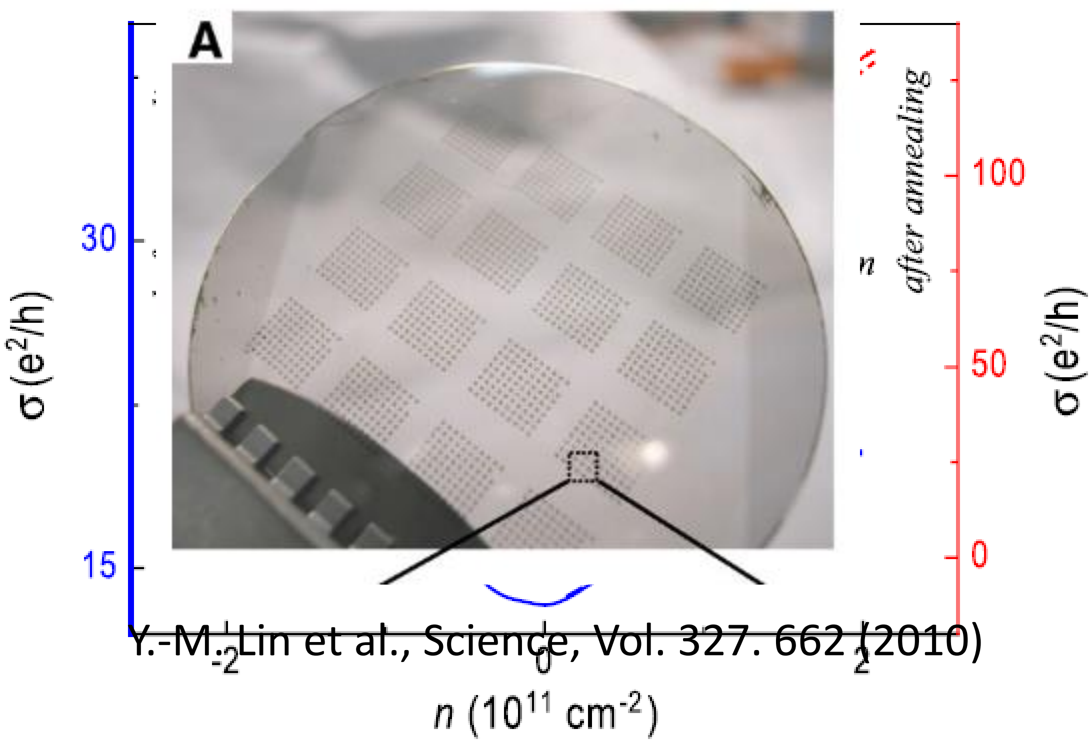
Ref: Nair *et al.*, Fine structure constant defines visual transparency of graphene, Science (2008)





Fundamental Physical Properties of Graphene Atomic Membrane

Electron mobility ~200,000 cm^2 /v.s

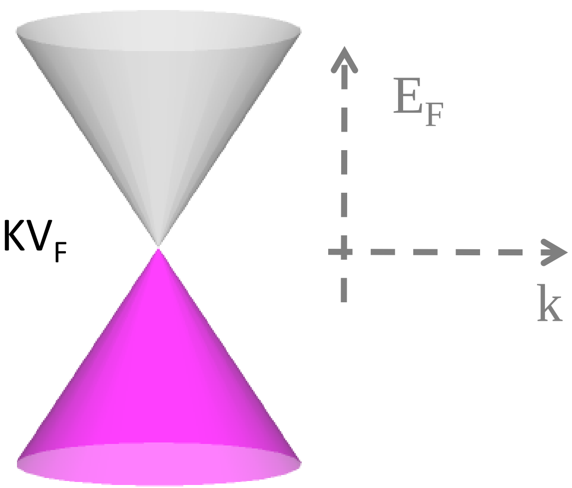


Y.-M. Lin et al., Science, Vol. 327. 662 (2010)

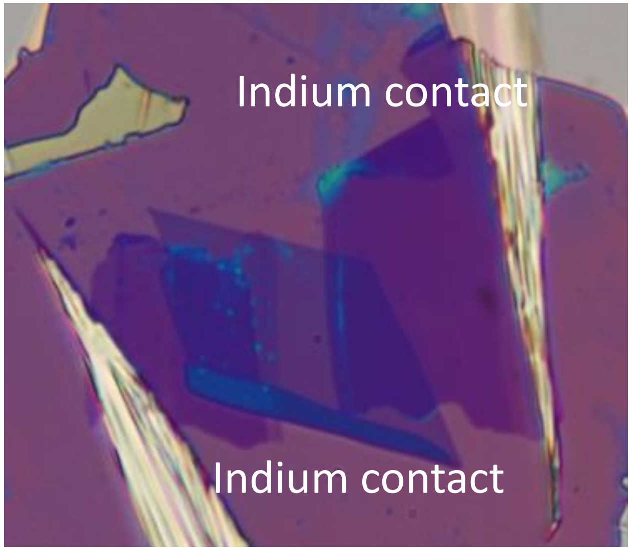
K. I. Bolotin et al., PRL 101, 096802 (2008)

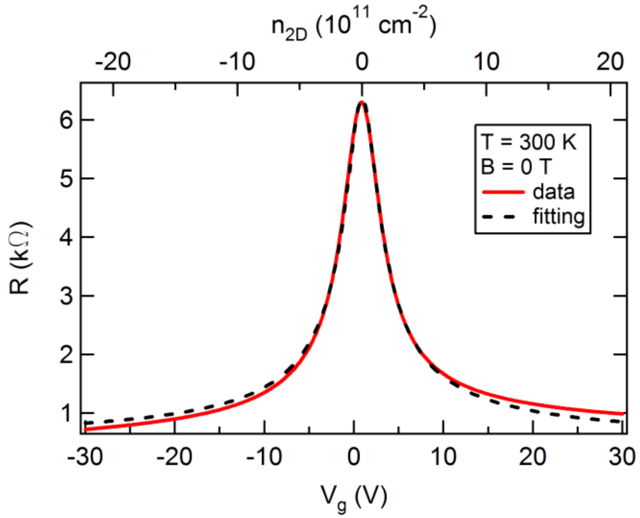
Dirac Cone Electronic Structure

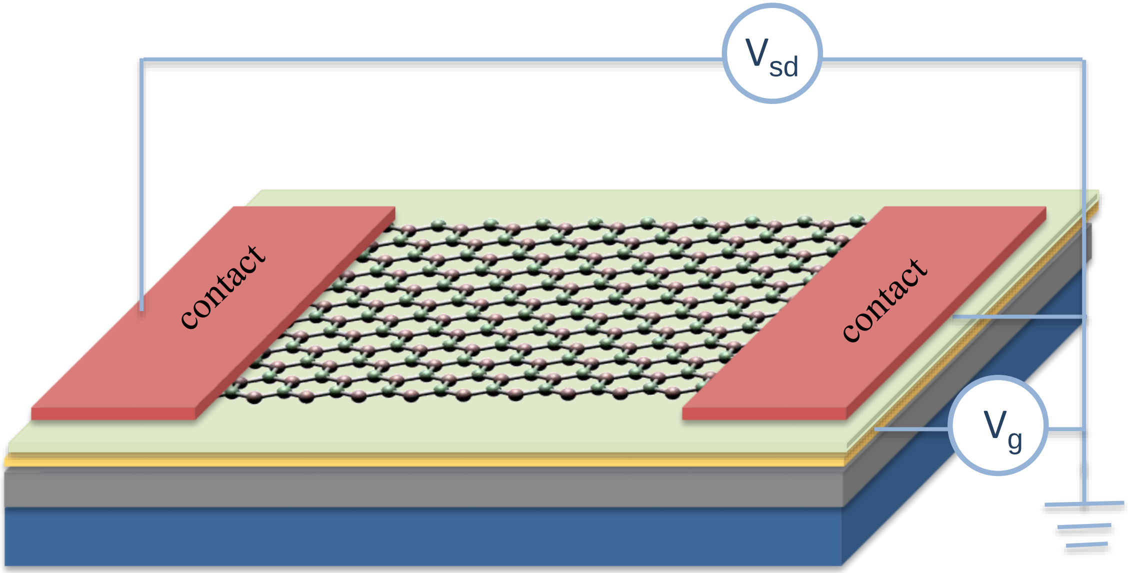
$E=hKV_F$



Electrical transport measurements of graphene







(1) Understand electron and hole transport of massless Dirac Fermion
(2) Calculate fundamental electronic properties, such as mobility calculation