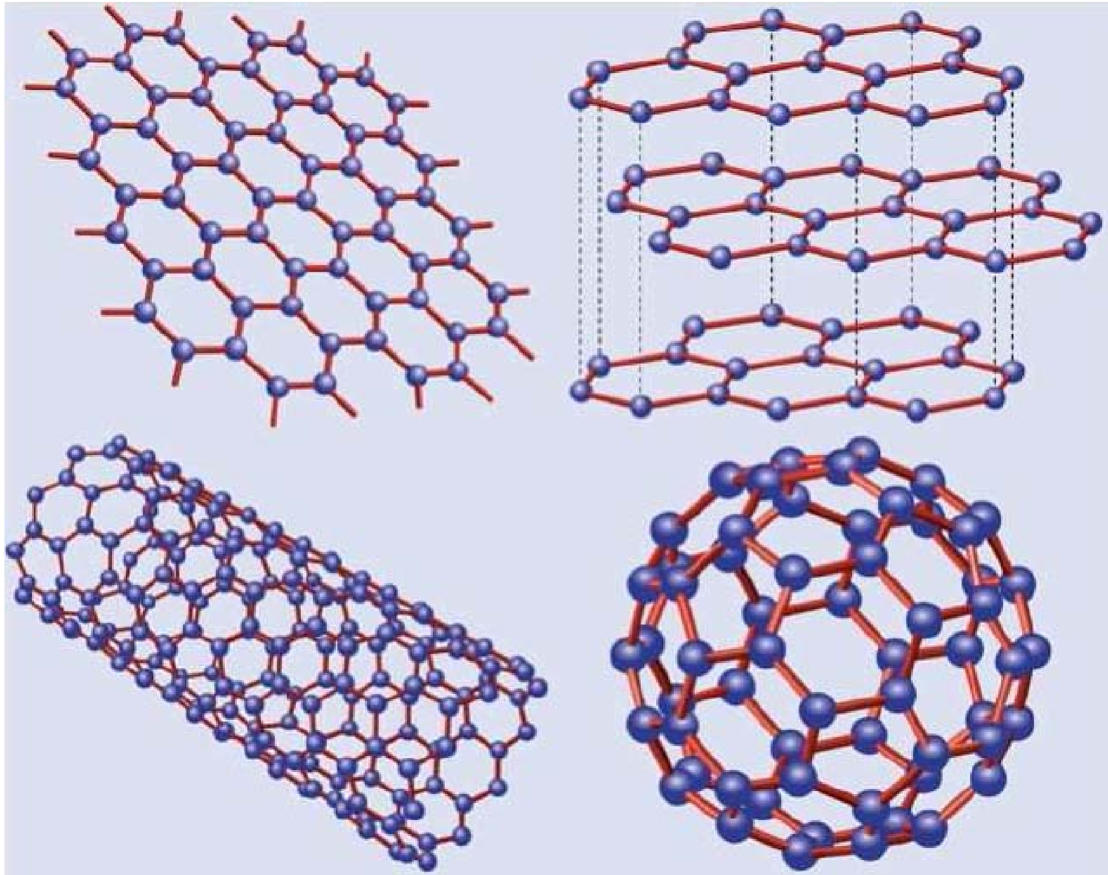
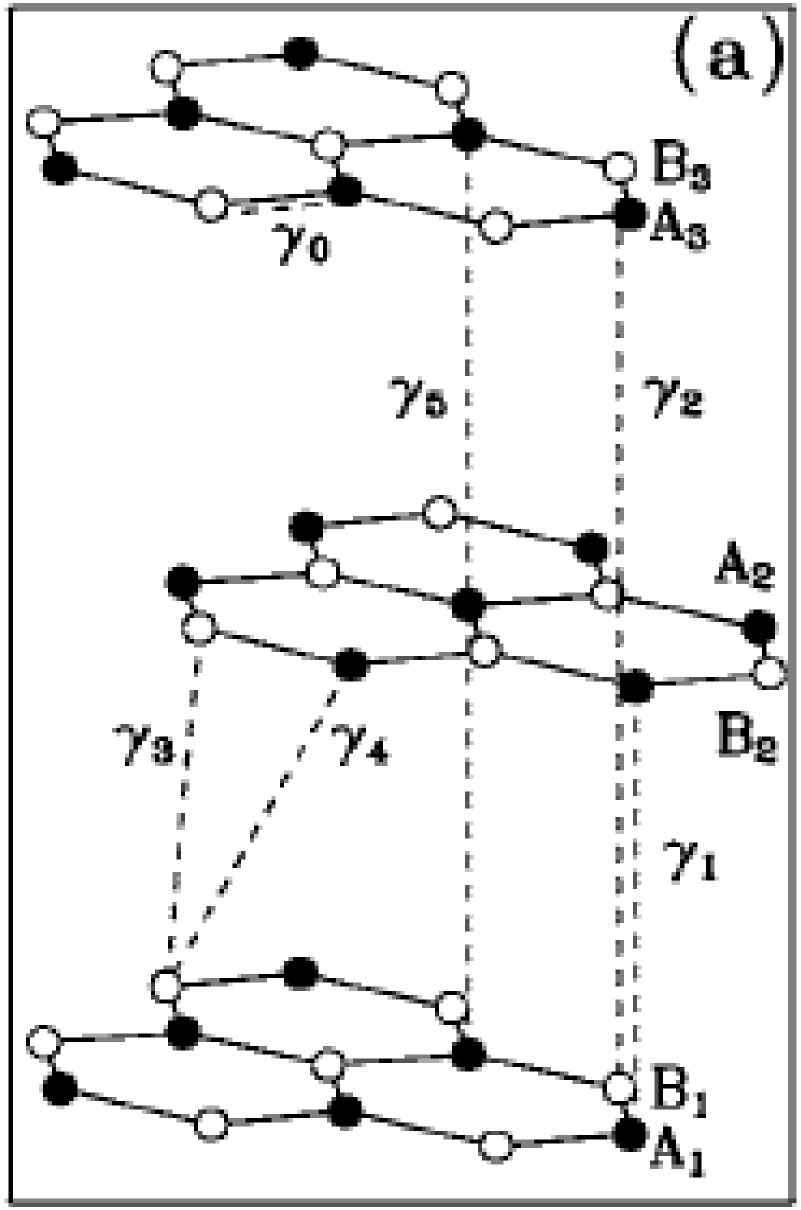
Universal infrared conductivity of graphite

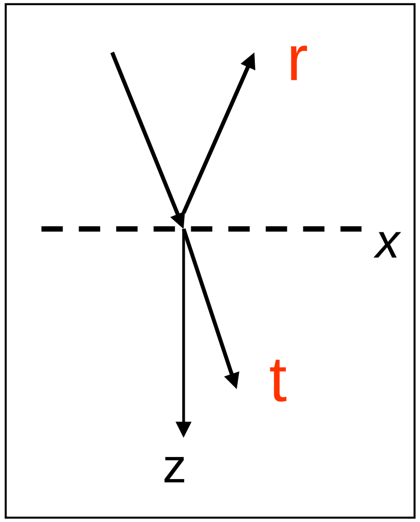
L. Falkovsky

Graphite
Wallace, PR 71, 622 (1947)
McClure, PR 108, 612 (1957)
Slonczewski, Weiss, PR 109 (1958)



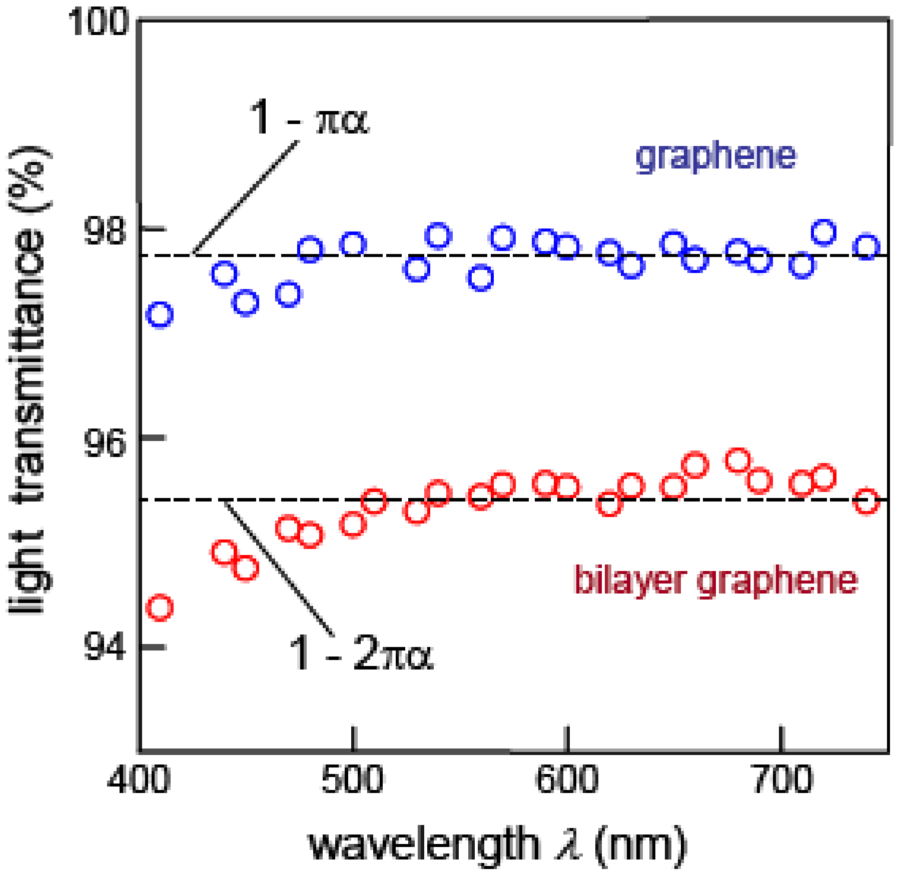


graphene transmittance



$$T = 1 - \pi \frac{e^2}{\hbar c}$$

fine structure constant



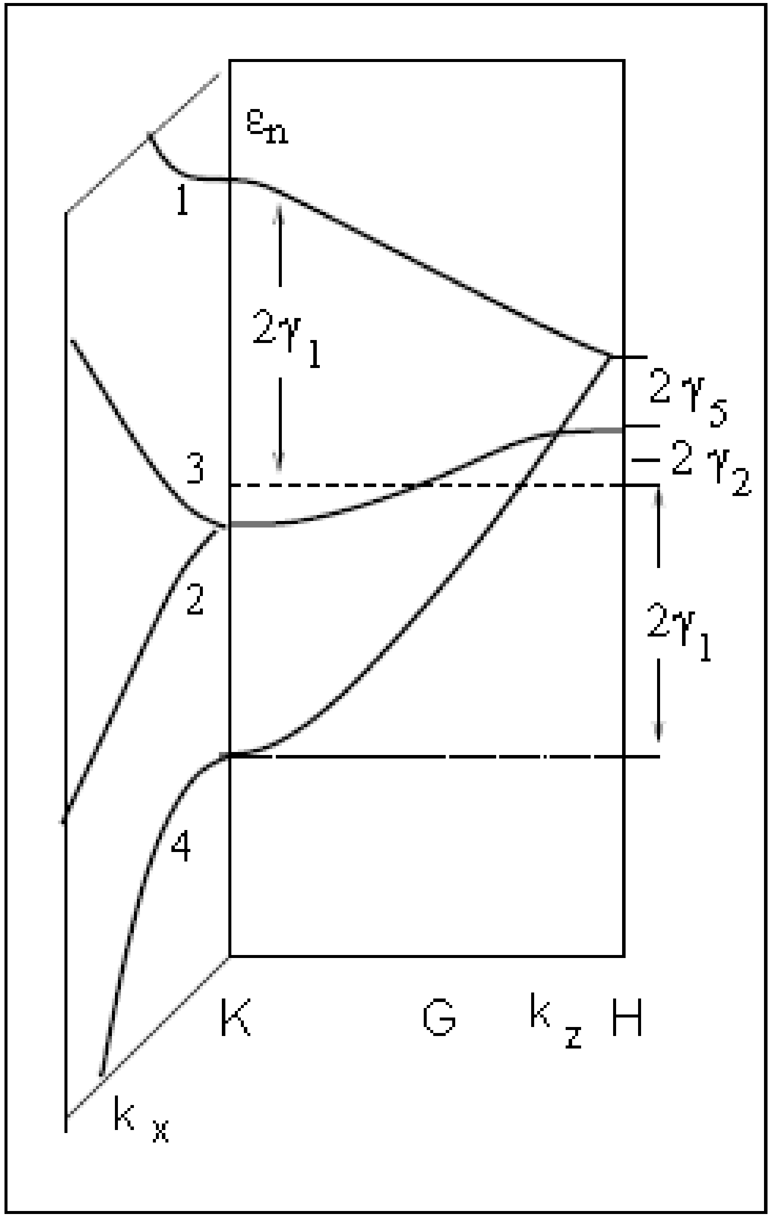
Conductance

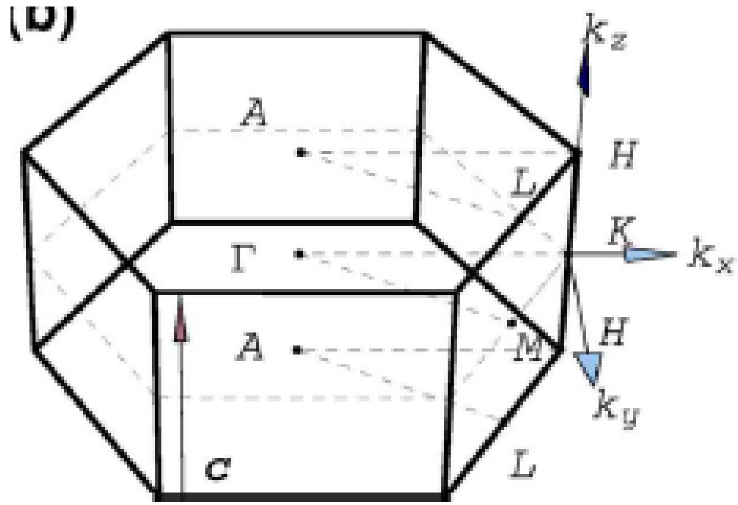
graphene $$G = \frac{e^2}{4\hbar}$$

graphite $$\sigma_0 = \frac{e^2}{4\hbar c_0}$$?

C_0 = 0.33 nm

Low energy bands in graphite





$$\gamma_0 = 3.1 \text{ eV}$$

$$v = 10^8 \text{ cm/s}$$

$$\gamma_1 = 0.4 \text{ eV}$$

$$\gamma_2, \gamma_5 \sim 0.02 \text{ eV}$$

Effective Hamiltonian

$$H(\mathbf{k}) = \begin{pmatrix} 0 & k_+ & \gamma(z) & 0 \\ k_- & 0 & 0 & 0 \\ \gamma(z) & 0 & 0 & k_- \\ 0 & 0 & k_+ & 0 \end{pmatrix}$$

$$\gamma(z) = 2\gamma_1 \cos z \qquad z = k_z c_0$$

$$k_\pm = v(\mp i k_x - k_y) \qquad 0 < z < \pi/2$$

$$v = 10^8 \text{ cm/s}$$

$$\varepsilon_n = \pm\frac{\gamma(z)}{2} \pm \sqrt{\frac{1}{4}\gamma^2(z) + k^2}$$

Conductivity for collisionless electrons in a band metal

$$\sigma^{ij}(\omega) = \frac{2ie^2}{(2\pi)^3}\int d^3k \sum_{k,n\geq m}\left\{-\frac{df}{d\varepsilon_n}\frac{v_n^i v_n^j}{\omega + i\nu}\right.$$

$$\left. +2\omega\frac{v_{nm}^i v_{mn}^j\{f[\varepsilon_n(\mathbf{k})] - f[\varepsilon_m(\mathbf{k})]\}}{[\varepsilon_m(\mathbf{k}) - \varepsilon_n(\mathbf{k})]\{(\omega + i\nu)^2 - [\varepsilon_n(\mathbf{k}) - \varepsilon_m(\mathbf{k})]^2\}}\right\}$$

$$\mathbf{v} = \frac{\partial H(\mathbf{k})}{\partial \mathbf{k}} \longrightarrow U^{-1}\mathbf{v}U$$

Contributions of electron transitions in conductivity

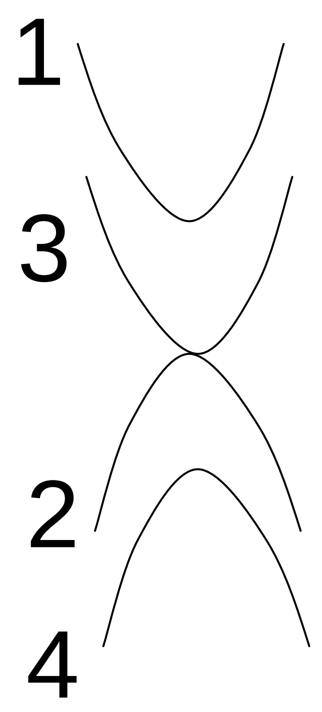
$$\gamma_2, \gamma_5 < \omega < \gamma_0$$

$$\mathrm{Re}\ \sigma_{23} = \frac{e^2}{4\pi\hbar c_0}\int_0^{\pi/2} dz \frac{2\gamma(z)+\omega}{\gamma(z)+\omega}\,,$$

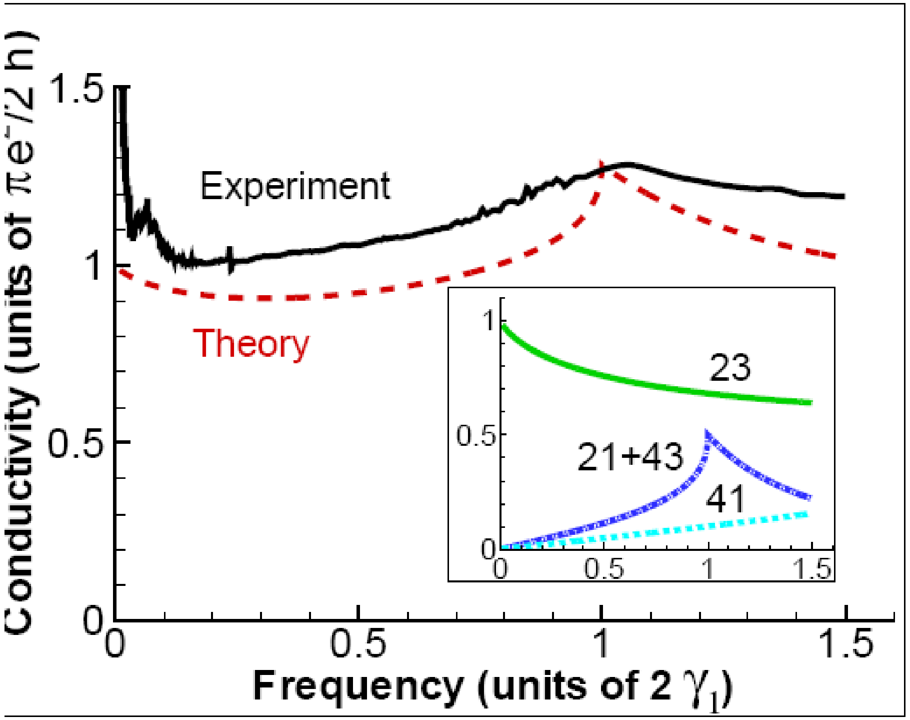
$$\mathrm{Re}\ \sigma_{21} = \frac{e^2}{4\pi\hbar c_0}\int_0^{\pi/2} dz \frac{\gamma^2(z)}{\omega^2}\theta[\omega-\gamma(z)]\,,$$

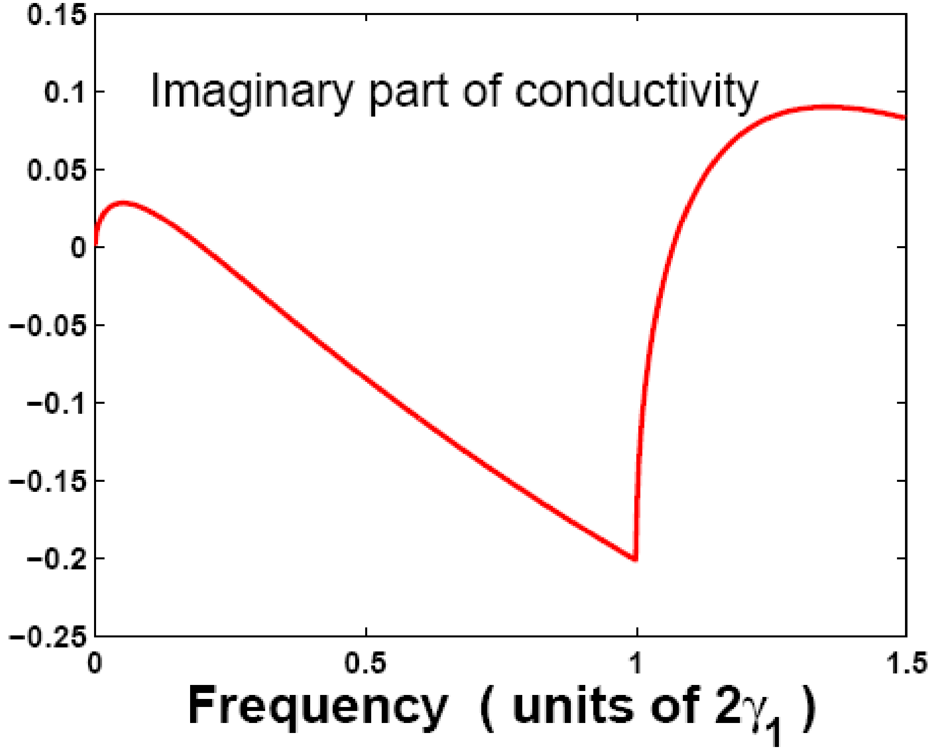
$$\mathrm{Re}\ \sigma_{41} = \frac{e^2}{4\pi\hbar c_0}\int_0^{\pi/2} dz \frac{2\gamma(z)-\omega}{\gamma(z)-\omega}\theta[\omega-2\gamma(z)]$$

$$\gamma(z) = 2\gamma_1 \cos z$$



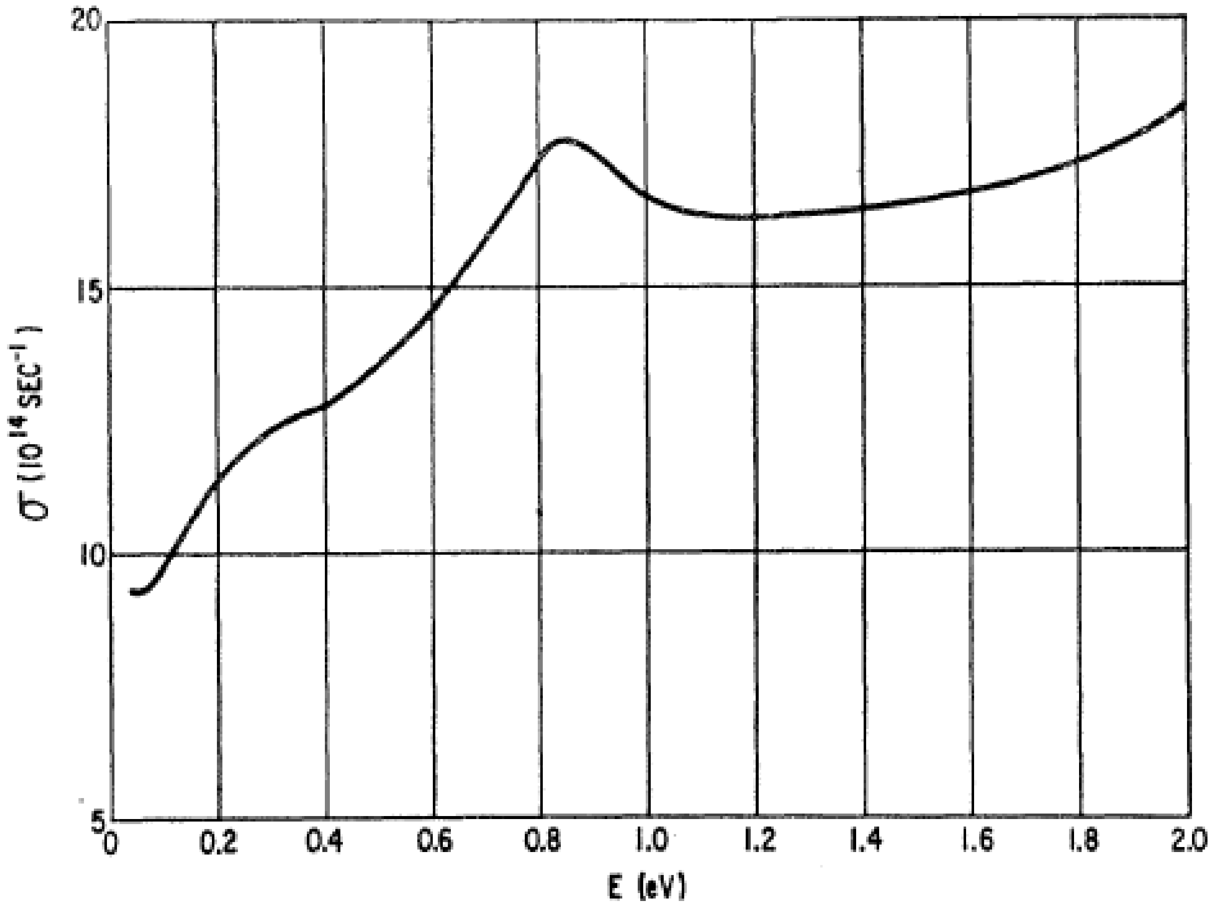
Real and imaginary parts of conductivity in graphite





Exp: Kuzmenko et al

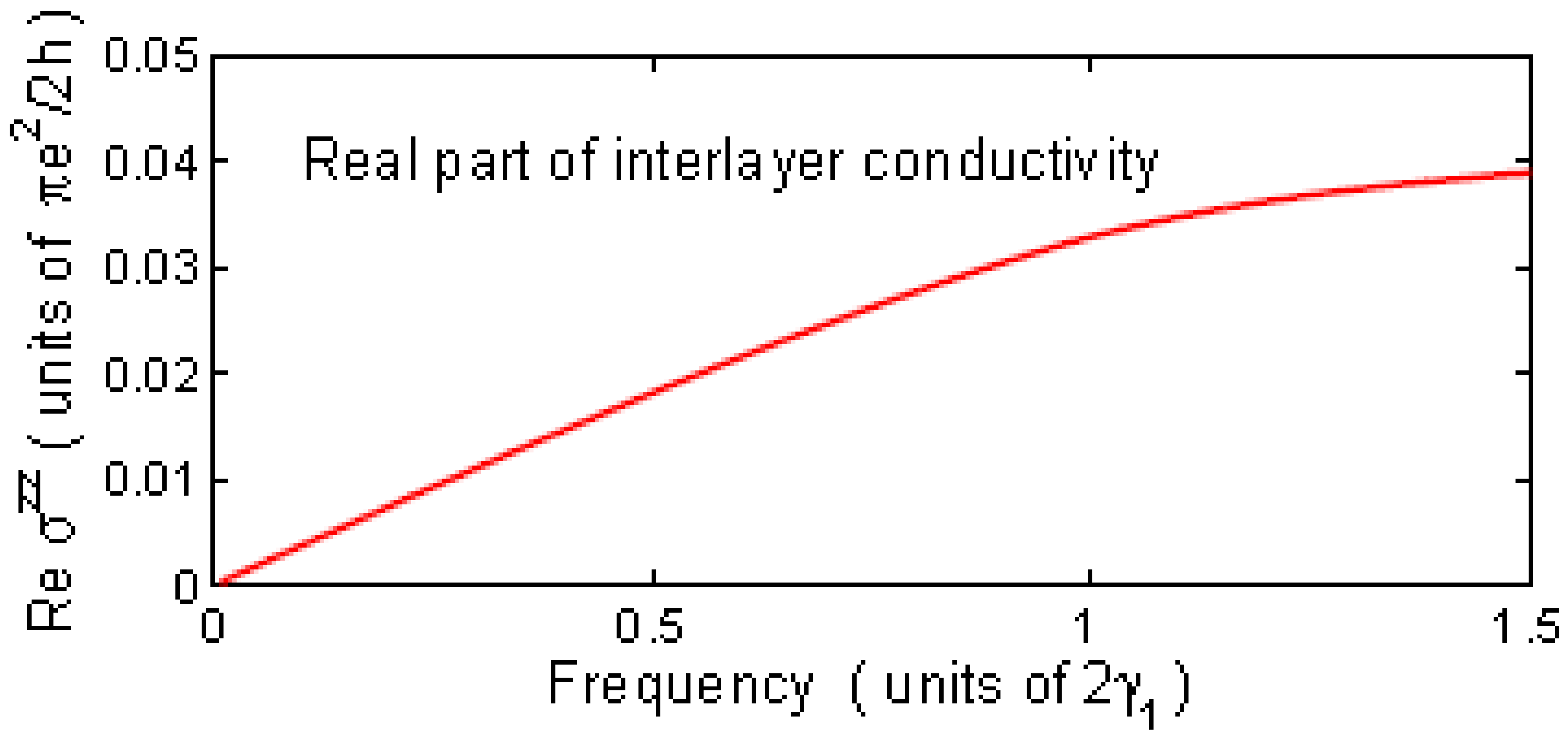
Taft and Philipp



in-z conductivity

$$v_z = \frac{\partial \varepsilon_3}{\partial k_z} \sim \gamma_1 c_0 \sin(k_z c_0)$$

$$\sigma_z / \sigma_0 \sim (\gamma_1 c_0 / \hbar v)^2 / 2 \sim 0.05$$



$$\mathrm{Re}\,\frac{\sigma_{21}^{zz}}{\sigma_0} = \frac{2}{\pi}\left(\frac{\gamma_1 c_0}{\hbar v}\right)^2 I(t)$$

$$I(t) = \int_0^{\pi/2} dz \sin^2 z \left(1 - \frac{\cos^2 z}{t^2}\right)\theta(t - \cos z)$$

$$t = \omega/2\gamma_1$$

$$I(t) = \frac{\pi}{4}\left(1 - \frac{1}{4t^2}\right), \quad t > 1$$