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TEMPERATURE DEPENDENCE OF RELAXATION TIMES OF QUASIPARTICLES IN GRAPHENE

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INTRODUCTION

The temperature dependence of relaxation times of quasiparticles (electrons and phonons) is analyzed in graphene from the first principles. In the transport processes the various mechanisms of relaxations are essential (electron and phonon scatterings on impurities, phonons, vacancies...). Therefore, relaxation times are found for several characteristic and mostly involved scattering mechanisms of quasiparticles in graphene. This is of fundamental importance for any method applied in further studying of the transport characteristics (solving Boltzmann's equation, using Green's functions...). In particular, the role of relaxation times is important in finding temperature dependence of the coefficients of electronic and thermal conductivities in graphene, as measurable macroscopic transport properties.

RELAXATION TIME

Boltzmann's equation is solved in the approximation of relaxation time, which depends on scatterings of quasiparticles on different imperfections of graphene crystal lattice. These processes of scatterings are analyzed either via Born's approximation or via phase shift (scatterings on vacancies).

Relaxation times are essentially important for finding transport coefficients:

$$\sigma = \frac{e^2 v_F^2}{2}\int_0^\infty D(\varepsilon)\tau(\varepsilon)\left(-\frac{\partial f_0}{\partial \varepsilon}\right)d\varepsilon \qquad \kappa = \frac{1}{4\pi L_z k_B T^2}\int_{\omega_{\min}}^{\omega_{\max}} (\hbar\omega_s)^2 \frac{e^{\frac{\hbar\omega_s}{k_B T}}}{\left(e^{\frac{\hbar\omega_s}{k_B T}}-1\right)^2}\tau(\omega_s)\frac{v}{u}\omega_s d\omega_s$$

Mean energy per quasiparticle as a function of temperature is:

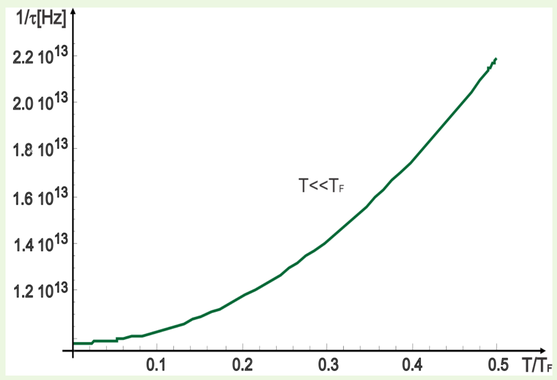
$$\bar{\varepsilon}(T) = \frac{4}{3}\varepsilon_F\left(1+\frac{\pi^2}{2}\left(\frac{T}{T_F}\right)^2\right) \quad \text{za } T \ll T_F; \qquad \bar{\varepsilon}(T) = \frac{\pi^2}{48(\ln 2)^3}\varepsilon_F\frac{T_F}{T} \quad \text{za } T \gg T_F$$

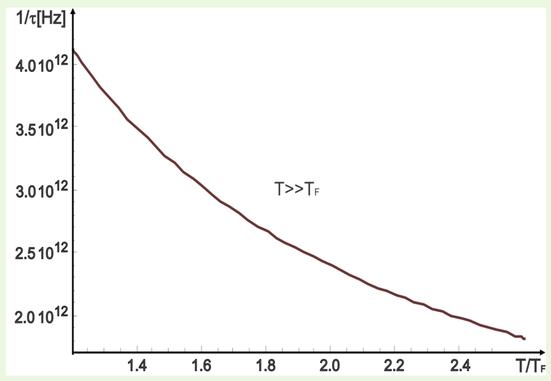
SCATTERING MECHANISMS OF QUASIPARTICLES

1. Scattering on short-range delta-potential;
2. Scattering on screened potential of charged impurities;
3. Scattering on phonons;
4. Scattering on vacancies.

SCATTERING ON SHORT-RANGE DELTA POTENTIAL

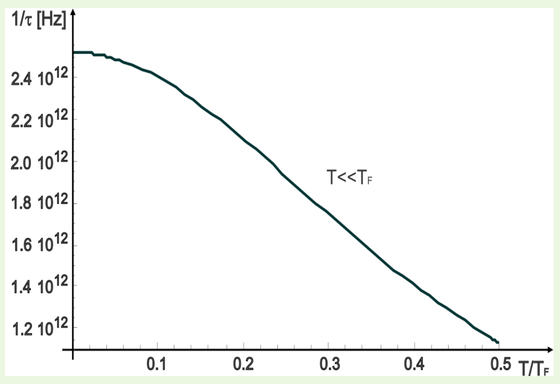
$$\frac{1}{\tau(T)} = \frac{n_i U_0^2 \varepsilon_F}{3\hbar^3 v_F^2}\left(1+\frac{\pi^2}{2}\left(\frac{T}{T_F}\right)^2\right) \quad \text{za } T \ll T_F; \qquad \frac{1}{\tau(T)} = \frac{n_i U_0^2}{4\hbar^3 v_F^2}\frac{\pi^2\varepsilon_F}{48(\ln 2)^3}\frac{T_F}{T} \quad \text{za } T \gg T_F$$

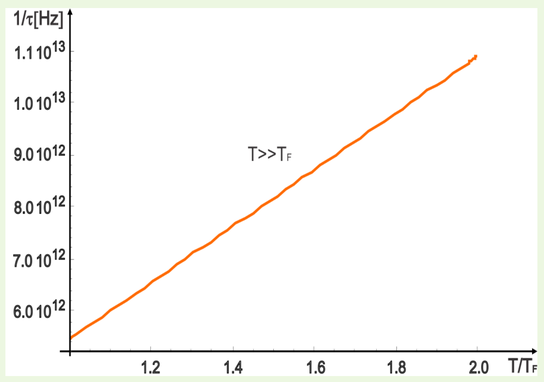




SCATTERING ON LONG-RANGE COULOMB POTENTIAL

$$\frac{1}{\tau(T)} = \frac{1}{\tau_1}\frac{3}{4\left(1+\frac{\pi^2}{2}\left(\frac{T}{T_F}\right)^2\right)}; \quad \text{za} \quad T \ll T_F; \qquad \frac{1}{\tau(T)} = \frac{48(\ln 2)^3}{\pi^2\tau_1}\frac{T}{T_F}; \quad \text{za} \quad T \gg T_F$$





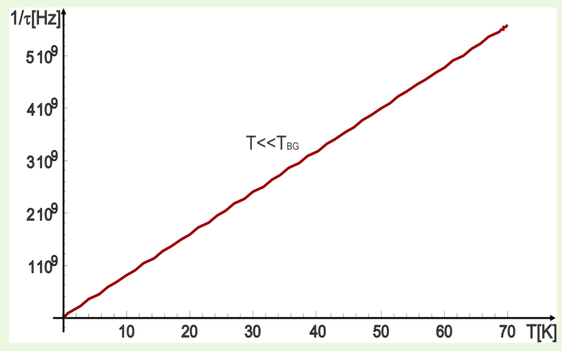
SCATTERING ON SCREENED POTENTIAL

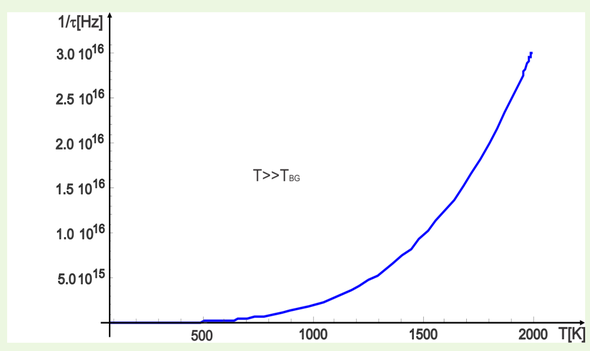
$$\frac{1}{\tau(T)} = \frac{1}{\tau_0}\left[1+2r_s\frac{\pi^2}{3}\left(\frac{T}{T_F}\right)^2\frac{I_1}{I_0}\right] \qquad \frac{1}{\tau(T)} = \frac{1}{\tau_0}\frac{\pi}{16 I_0}\frac{1}{(4r_s\ln 2)^2}\left(\frac{T_F}{T}\right)^2$$

$$\frac{1}{\tau_0} = \frac{n_i}{2\pi\hbar}\left(\frac{e^2}{2\varepsilon_0\varepsilon_r}\right)^2\frac{2}{\varepsilon_F}\int_0^1 \frac{x^2\sqrt{1-x^2}}{\left[x+2r_s\left(1-\frac{\pi^2}{6}\left(\frac{T}{T_F}\right)^2\right)\right]^2}dx$$

SCATTERING ON PHONONS

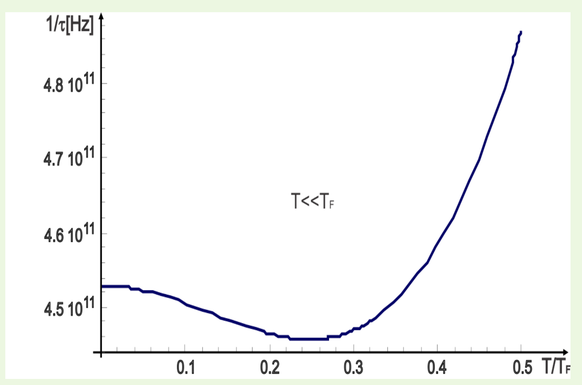
$$\frac{1}{\tau(T)} = \frac{D^2 k_B T \varepsilon_F\left(1+\frac{\pi^2}{2}\left(\frac{T}{T_F}\right)^2\right)}{3\rho\hbar^3 v_F^2 v_p^2} \qquad \frac{1}{\tau(T)} = \frac{D^2 4!\zeta(4)}{2\pi\rho\varepsilon_F k_F v_p}\left(\frac{k_B T}{\hbar v_p}\right)^4$$

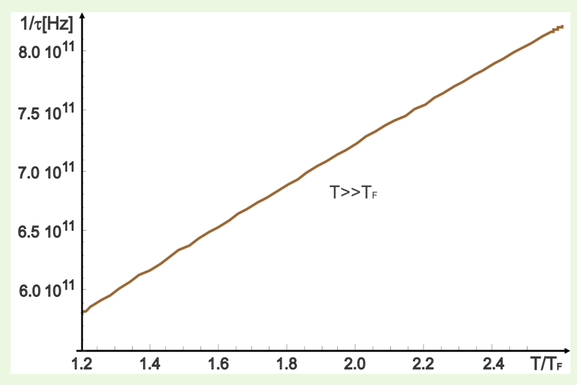




SCATTERING ON VACANCIES

$$\frac{1}{\tau(T)} = \frac{3n_i\pi^2\hbar v_F^2}{4\varepsilon_F\left(1+\frac{\pi^2}{2}\left(\frac{T}{T_F}\right)^2\right)\ln^2\frac{4R\varepsilon_F\left(1+\frac{\pi^2}{2}\left(\frac{T}{T_F}\right)^2\right)}{3\hbar v_F}} \qquad \frac{1}{\tau(T)} = \frac{n_i\pi^2\hbar v_F^2}{\frac{\pi^2}{48(\ln 2)^3}\varepsilon_F\frac{T_F}{T}\ln^2\frac{R\frac{\pi^2}{48(\ln 2)^3}\varepsilon_F\frac{T_F}{T}}{\hbar v_F}}$$





T_F [K]	v_F [m/s]	k_F [1/m]	v_p [m/s]	n_i [1/m^2]	r_s
3710	$8,73\cdot10^5$	$4,8\cdot10^8$	$2,0\cdot10^4$	$2,0\cdot10^{14}$	0,88
T_{BG} [K]	D [J]	ρ [kg/m^3]	R [m]	U_0 [J]	ε_r
76,58	$30,4\cdot10^{-19}$	$7,6\cdot10^{-5}$	$1,4\cdot10^{-10}$	$1,6\cdot10^{-36}$	2,4

CONCLUSION

Temperature dependance of relaxation times of quasiparticles in graphene is explored, which enable finding expressions for temperature dependance of transport coefficients, that can be then experimentally tested relatively easily.

Analytical expressions for relaxation times were found in two extreme cases: for $T \ll T_F$ and $T \gg T_F$, or in case of scattering of quasiparticles on phonons for $T \ll T_{BG}$ and $T \gg T_{BG}$. In other cases transport coefficients could be found numerically, which was not considered in this presentation.

For each case considered, graphical presentations of temperature dependances of relaxation times were provided for two extreme temperature ranges in graphene.

By analysis of transport coefficients and application of Matthiessen rule for calculated relaxation times the following conclusions could be drawn:

1. At low temperatures, the least influence on transport coefficients in graphene is exerted by phonons, point impurities with screened potential and vacancies, followed by impurities with long-range Coulomb potential, while the greatest influence is exerted by impurities with short-range delta potential;
2. At high temperatures, the least influence on transport coefficients in graphene is exerted by impurities with screened potential and vacancies, followed by impurities with short-range delta potential and by impurities with long-range Coulomb potential, while the greatest influence is exerted by phonons.

It is interesting to note that point impurities with screened potential and vacancies have similar contributions to transport coefficients in graphene at both low and high temperatures.