Comment on "Consistent Interpretation of the Low-Temperature Magnetotransport in Graphite Using the Slonczewski-Weiss-McClure 3D Band-Structure Calculations"

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In [1, 2] we have shown that substantial part of conductivity in graphite is provided by holes (h) with massless linear spectrum \(\varepsilon(p) = |p|_{\perp}\) - Dirac Fermions (DF) that coexist with massive normal carriers (NC) - electrons (e) with \(\varepsilon(p) = p^2/2m^*\). Existence of such quantity of DF does not follow from the classical Slonczewski Weiss and McClure (SWM) band model and can signify that at least part of carbon layers behaves like independent grahenes.

In a recent Letter [3] Schneider et al. revised our conclusion pointed that both types of carriers are massive and are described by SWM model. Since both [1, 2] and [3] use the same method of phase determination of Shubnikov de Haas (SdH) oscillation we comment here that the controversy originates from the improper treatment of experimental results in [3].

The sense of the method is to extract the phase \(\varphi_1\) from the quantum oscillation of conductivity:

\[
\sigma_{xx}(B) = \sum_{l=1}^{\infty} a_l \cos[2\pi l \frac{\mu}{|\omega_c|} + \varphi(l)],
\]

by noting that \(\varphi_1 = \pi\) for NC and 0 for DF (\(\mu\) is the chemical potential, \(|\omega_c| = eB/m^*\) for NC and \(|\omega_c^*|B\) for DF).

Note first that presented in Fig. 1 method to find \(\varphi_1\) shows the remarkable coincidence between our [2] and Schneider et al. results. The lower line corresponds to carriers with higher frequency (HF). From its extrapolation to \(B^{-1} = 0\) we clearly see that at \(B \rightarrow \infty\) the lowest LL \((n = 0)\) is placed exactly at \(E = 0\) and that \(\varphi = 0\), as it follows for DF. Similarly the low frequency (LF) carriers with \(\varphi_1 \sim \pi\) are attributed to NC.

Schneider et al. argue that these data can not be used because "in the quantum limit the Fermi energy \([\mu \text{ in [1]}\] is no longer constant as carriers are transferred between the electron and holes".

To verify this doubt we present in Fig. 1 the calculated within SWM model diagram of \(B_n^{-1}\) at which SdH oscillation exhibits maxima:

\[
B_n^{-1} = \sqrt{n(n+1)} \left[ 1 - \frac{N_{\mu n}}{N_{\mu 0}} \right] B_0^{-1}
\]

The first (band) factor [4] generalizes the used in [1, 2] quasi-classical \(n + \frac{1}{2}\) quantization. The taken from [3] correction to \(\mu\) is due to electron-hole cross-talk.

Next, we trace the differential phase \(\varphi_1(B^{-1}) = -2\pi \left[ n(B^{-1}) - B^{-1}(dn/dB^{-1}) \right]\) for HF carriers (smoothed by 2-point moving average) and observe that the SWM curve, as was mentioned in [3], has the strong nonlinear deviation from \(-\pi\) at \(B > 2T\). Our data don’t demonstrate such non-linearity whereas Schneider et al. stay close to \(\phi_1 = 0\) and don’t drop together with SWM curve to \(\varphi_1 = -\pi\) at \(2T > B > 0.7T\). Contradiction with SWM model and closeness of \(\varphi_1\) to 0 confirms the existence of DF in graphite.

Note that proposed in [3] extrapolation of \(\varphi_1\) from fields \(B < 0.7 \text{T}\) is not reliable. Thus, for the presented in Fig. 2e of [3] phase-frequency analysis of HF carriers one gets \(\varphi_1 \approx (0.56 \pm 0.6)\pi\). This value and error-bar, determined as FWHM of 2D Gaussian projected on phase-axis are insufficient to discriminate between the DF and NC.

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