Interplane transport effects in layered organic conductors

J.A. Symington a,1, J. Singleton a, N. Harrison b, N. Clayton c, J. Schlueter d, M. Kurmoo, P. Day e

a Department of Physics, University of Oxford, the Clarendon Laboratory, Parks Road, Oxford, OX1 4AW, UK.
b National High Magnetic Field Laboratory, LANL Los Alamos, New Mexico 87545, USA.
c H.H. Wills Physics Laboratory, Tyndall Avenue, Bristol, BS8 1TL, UK.
d Argonne National Laboratory, 9700 south Class Avenue, Argonne, IL 60439, USA.
e The Royal Institution, 21 Albemarle Street, London, W1X 4BG, UK.

Abstract

Detailed studies of the magnetic field orientation on magnetic quantum oscillations in two charge transfer salts of the molecule ET have been carried out. After all conventional mechanisms affecting quantum oscillations have been accounted for, we find that the amplitude of the oscillations has an underlying dependence \( \exp(-a \tan \theta) \), where \( \theta \) is the angle between the normal to the highly-conducting layers and the magnetic field, and \( a \) is a constant.

Key words: Organic superconductor, Transport measurements, magnetotransport, Magnetic measurements

Whether layered organic metals possess true three dimensional (3D) Fermi surfaces, or whether the interlayer transport is incoherent, has excited considerable recent interest (see e.g. [1,2]). As the temperature is raised, the resistivity in the interlayer direction rapidly passes the size at which the mean-free-path is smaller than the layer separation. McKenzie and Moses have thus proposed that the Fermi surface of ET salts are not necessarily extended in the interlayer direction [1]. They show that phenomena such as angle-dependent magnetoresistance oscillations [3] do not necessarily imply Fermi surfaces that are extended in the interlayer direction; “weakly incoherent interlayer transport”, in which a quasiparticle tunnels coherently between adjacent layers, but is scattered before subsequent tunneling processes, can give rise to similar phenomena. This paper reports quantum oscillation experiments carried out to detect any change in quantum oscillation behaviour at different field orientations. We find an anomalous angle dependence of the quantum oscillation amplitude which was observed in two very different ET charge-transfer salts and we tentatively interpret this in terms of interplane tunnelling effects.

The samples studied were single crystals of \( \alpha-(ET)_{2}NH_{4}Hg(SCN)_{4} \) and \( \beta''-(ET)_{2}SF_{2}CH_{2}CF_{2}SO_{3} \), of approximate size \( 1 \times 1 \times 0.5 \text{ mm}^{3} \). Both materials possess Fermi surfaces consisting of a quasi-two-dimensional (Q2D) pocket plus a pair of Q1D sheets [5]. De Haas-van Alphen oscillations were measured using standard field-modulation methods [5]. Temperatures down to 20 mK were provided by a dilution refrigerator, and magnetic fields were generated by a 13.5 T superconductive solenoid. Shubnikov-de Haas oscillations were studied at fields of up to 33 T in a Bitter magnet at NHMFL, Tallahassee, using low-frequency AC techniques described elsewhere [6]. In this configuration, the measured resistance is proportional to \( \rho_{xx} \) [6]. The samples were mounted in a cryostat which provided temperatures between 1.35 K and 4.2 K, and allowed the sample to be rotated around two mutually perpendicular axes [6]. The amplitude \( A \) of magnetic quantum oscillations of frequency \( F \) caused by a Q2D Fermi surface should be described by the following variant of the Lifshitz-Kosevich formula [8]:

1 E-mail: j.symington1@physics.ox.ac.uk
Table 1

<table>
<thead>
<tr>
<th>Material</th>
<th>Expt. (m^* (m_e))</th>
<th>(g^*)</th>
<th>(T_D (K))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\alpha-(ET)_2(NH_4)Hg(SCN)_4)</td>
<td>2.7</td>
<td>2.25</td>
<td>2.0</td>
</tr>
<tr>
<td>(\alpha-(ET)_2(NH_4)Hg(SCN)_4)</td>
<td>2.7</td>
<td>2.25</td>
<td>1.0</td>
</tr>
<tr>
<td>(\beta''-(ET)_2SF_2CH_2CF_2SO_3)</td>
<td>2.0</td>
<td>2.05</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Fig. 2. Natural logarithm of the ratio of experimental quantum oscillation amplitude to the prediction of Eqn. 1 versus \(\tan \theta\). The lines are straight-line fits to the data.

Magnetic quantum oscillations includes a term proportional to \(\exp(-\alpha \tan \theta)\), where \(\alpha\) is a constant.

The cause of this extra damping term is unclear, but one possibility is an interlayer, inter-Landau level coupling caused by the in-plane component of the field [9]. This could lead to an apparent broadening of the Landau levels scaling as \(\tan \theta\). Simulations are being carried out to investigate this possibility.

In summary, we have demonstrated a new damping term \(\exp(-\alpha \tan \theta)\) in the angle dependence of the amplitude of the quantum oscillations of two quite different ET salts. The effect occurs in both magnetisation and magnetoresistance, suggesting that it might be a very general phenomenon in Q2D organic conductors.

This work is supported by EPSRC (UK). NHMFL is supported by the Department of Energy, the National Science Foundation and the State of Florida.

References

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