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Fermi surface spectroscopy: a magnetic resonance approach

J.M. Schrama[a], S.O. Hill[b], J. Singleton[a,*], A. Ardavan[a], E. Rzepniewski[a], R. Edwards[a]

[a]*Department of Physics, University of Oxford, The Clarendon Laboratory, Parks Road, Oxford OX1 3PU, UK*
[b]*Department of Physics, Montana State University, Bozeman MT 59717, USA*

Abstract

We describe recently-developed GHz magneto-optical techniques which measure the Fermi-surface topologies and superconducting order parameter symmetry in organic molecular metals.

Keywords: Fermiology; Magneto-optics; Organic molecular metals

Quasi-two-dimensional (Q2D) organic molecular metals have attracted enormous attention in recent years, as they exhibit a wide range of low-temperature ground states and yet possess Q2D Fermi surfaces (FSs) which may be accurately represented using tractable analytical models [1]. Here we review recently derived methods for establishing the FS topology of these systems which involve GHz magneto-optical techniques.

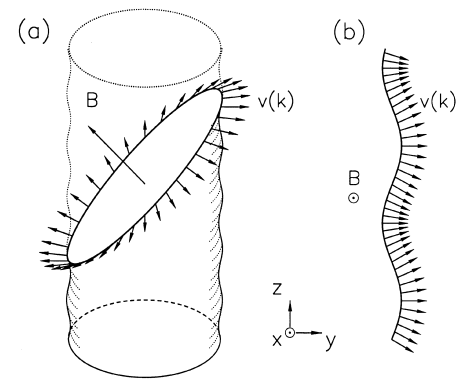

Fig. 1. Schematic view of two types of orbit on the Fermi surfaces (FSs) of organic metals in a magnetic field $\boldsymbol{B}$. (a) closed orbit around warped Q2D FS section. (b) open orbit along Q1D FS section. The arrows indicate the quasiparticle velocities.

* Corresponding author.
E-mail address: j.singleton1@physics.ox.ac.uk (J. Singleton)

The path of a quasiparticle of energy $E(\boldsymbol{k})$ and velocity $\boldsymbol{v}$ in a magnetic field $\boldsymbol{B}$ is determined by the equations $\hbar\boldsymbol{v} = \nabla_k E(\boldsymbol{k})$ and $\hbar\partial\boldsymbol{k}/\partial t = -e\boldsymbol{v}\times\boldsymbol{B}$, where ∇_k is the gradient operator in k-space. Quasiparticles at the FS

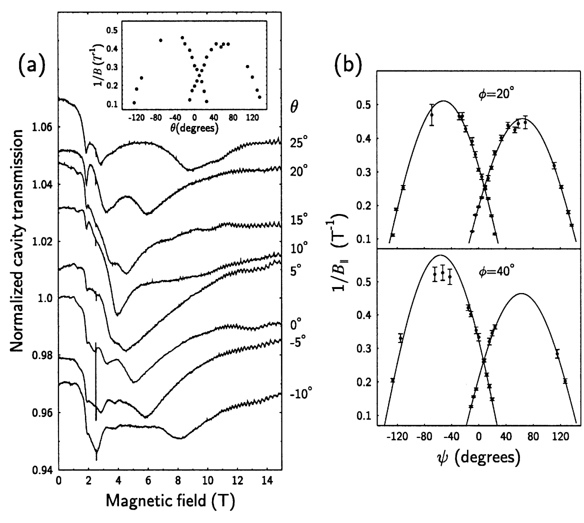

Fig. 2. (a) FTRs in α-$(ET)_2KHg(SCN)_4$ at $T = 1.4$ K and 70 GHz using a rectangular cavity tilted to angles θ in the field. FTR fields are plotted versus θ (inset) and ψ (b), where ψ is the angle between $\boldsymbol{B}$ and the warping direction of the Q1D FS. Data are shown in (b) for two orientations of the sample within the cavity. The ψ dependence in (b) unambiguously identifies FTRs [4].

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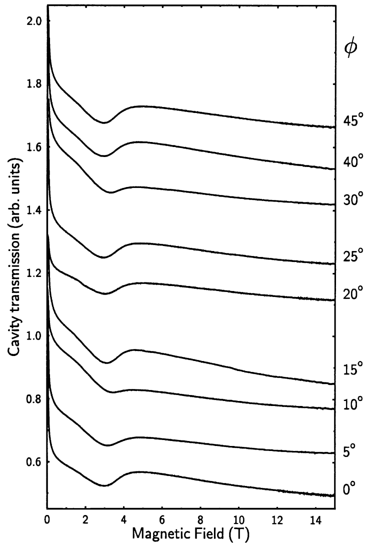

Fig. 3. Transmission of a cavity containing a κ-$(ET)_2Cu(NCS)_2$ crystal (70 GHz, 1.4 K); the Q2D planes are parallel to $\tilde{\boldsymbol{H}}$ and normal to $\boldsymbol{B}$, but $\tilde{\boldsymbol{H}}$ is rotated in the Q2D plane by angles ϕ; the induced in-plane current thus varies in direction. The dip at ~ 3 T marks the change in dissipation at H_{c2}; its size varies with ϕ, reflecting the angular variation of the order parameter [5].

will move on orbits of constant energy in the plane perpendicular to $\boldsymbol{B}$. Fig. 1 shows two classes of orbit important in organic molecular metals; (a) is a closed orbit about a Q2D FS section and (b) is an open orbit along a quasi-one-dimensional (Q1D) FS sheet. Note that the velocities of the quasiparticles (indicated by arrows in Fig. 1) oscillate up and down (a) or from side to side (b); the Boltzmann transport equation has been used to show that these oscillations contribute resonantly to the bulk ac conductivity [2,3]. As the corrugations of real FSs will not in general be sinusoidal, the conductivity will also contain a series of harmonics of the fundamental frequency which in effect represent a "Fourier analysis" of the shape of the Fermi-surface section [2,3]. Resonances from Q2D sections of FS are termed "periodic orbit resonances" (PORs) [2]; those from the Q1D FS sections are called Fermi-surface traversal resonances (FTRs) [4]. The high-frequency bulk conductivity is measured using the transmission of a rectangular [4] or cylindrical [2] resonant cavity loaded with a sample. The oscillating H-field $\tilde{\boldsymbol{H}}$ in the cavity is parallel to the sample's highly conducting Q2D planes; induced currents flow in the low-conductivity interplane direction, so that the skin-depth $\gg$ the sample size [4]. FTRs have a characteristic dependence on the direction of $\boldsymbol{B}$; hence, experiments are done using rectangular cavities which tilt in the static field [4]. FTRs observed in the organic metal α-$(ET)_2KHg(SCN)_4$ are seen in Fig. 2 as broad absorptions above ~ 4 T [4].

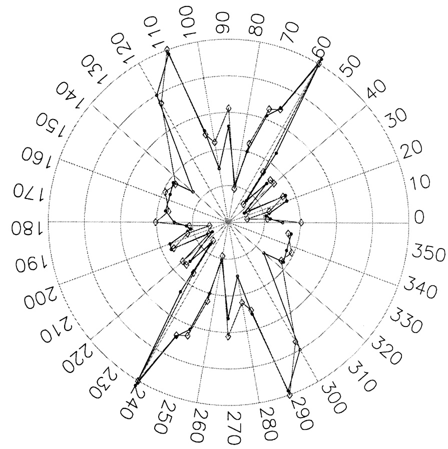

Fig. 4. The normalised amplitude of the dip in Fig. 3 versus ϕ; The underlying d-like symmetry of the order parameter can clearly be seen [1,5].

The bulk GHz conductivity is also affected by the presence of superconductivity. GHz conductivity measurements have been used to identify the presence of an anisotropic (d-wave-like) order parameter in the organic superconductor κ-$(ET)_2Cu(NCS)_2$ (see Figs. 3 and 4) [5].

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