MAGNETORESISTANCE AND MAGNETIC BREAKDOWN IN WHITE TIN*

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A preliminary study of the magnetoresistance of single crystals of white tin (resistivity ratios $\rho_{300°K}/\rho_{4.2°K}$ of about 30 000) at 4.2°K and in magnetic fields up to 100 kG has revealed structure in the anisotropy of the resistance not reported in previous work.[1] We show that the nearly free electron model[2] for the Fermi surface of white tin appears to account for the observations if modifications due to magnetic breakdown are allowed.

Resistance measurements were made by the conventional method, using a Magnion superconducting solenoid up to 50 kG, while a few runs at higher fields were made at the National Magnet Laboratory. A specimen was automatically rotated about its axis, plots of resistance versus angle of rotation being produced on an X-Y recorder. A range of magnetic-field directions was covered on each specimen by varying the angle between the magnetic-field direction and the axis of the specimen. The rotations in Fig. 1(a) are indexed by the angle of closest approach of the magnetic field to the c axis, the zero of rotation being when the field is in this position.

The general $H^2\cos^2\theta$ dependence of the resistance in Fig. 1(a) and the existence of the periodic open orbits, d, when the magnetic field is more than 45° from the c axis is in agreement with Alekseevskii et al.[1] The extra features observed in this work are the sharp spikes a, b which occur when the magnetic field is perpendicular to the [110] and [100] directions and the inner region c–c' which appears on rotations for which the magnetic field is less than 20° from the c axis. The spikes a, b were not observed within the region c–c'.

The development of these features with magnetic field is shown in Figs. 1(b) and 1(c) for a specimen with axis 78° from the c axis. The spikes a, b are large and broad at 4.8 kG but narrow and tend to disappear as the field is increased, spike a not being resolved at fields above 25 kG. The angle of rotation over which the region c–c' exists narrows from 37° at 10 kG to 24° at 50 kG. The spikes which oc-

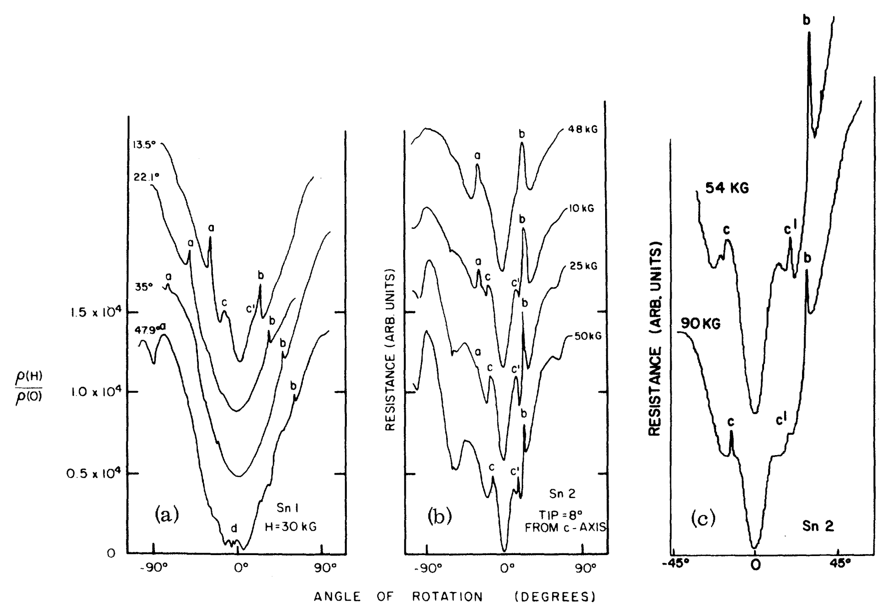

FIG. 1. Reproductions of recorder tracings of resistance versus angle of rotation of the specimen about its axis, relative to the direction of magnetic field: (a) for several angles of tip at 30 kG for a specimen with axis 55° from the c axis; (b) at various fields up to 50 kG for a specimen with axis 78° from the c axis (not to scale—the field dependence at 90° is H^2); (c) at 54 and 90 kG for the same specimen as (b), taken at the National Magnet Laboratory.

cur at the boundary of the region $c-c'$ at higher fields differ from the spikes a, b in that they do not have any particular relation to the crystal axes.

The energy bands for tin are degenerate along the lines XL and XP [Fig. 2(a)] on the (110) face of the Brillouin zone,[3] but spin-orbit coupling splits this degeneracy except at the point X in the center of the face. In the absence of breakdown, aperiodic open orbits are found on the fourth-zone hole surface of the nearly free electron model for all field directions for which the closed orbit ζ exists. Magnetic breakdown connects orbit ζ on the fourth-zone hole surface to orbit δ on the third-zone hole surface [Fig. 2(b)]. By breakdown an aperiodic open orbit ζ which passes near X on the fourth-zone surface is able to tunnel via the third-zone surface to the fourth-zone surface ζ' in the next repeated zone. If ζ' is closed, the electron will return to ζ, merely causing more convolution in the aperiodic open orbit. For field directions of more than about 20° from the c axis, ζ' can be part of an aperiodic open orbit on the bottom of the fourth-zone sheet, thus reversing the direction of the electron's original path.

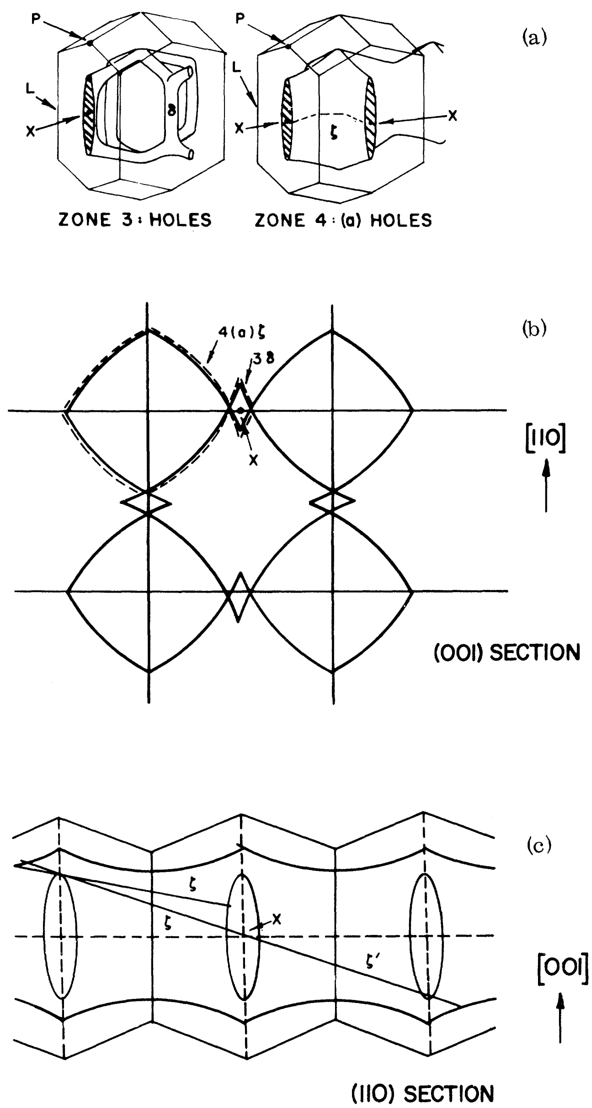

FIG. 2. (a) The third-zone hole surface and the fourth-zone hole surface on the free electron model for tin (after Gold and Priestley, 1960). (b) A (001) central section showing the relation of the orbits ζ and δ. (c) A (110) section of the fourth-zone hole surface showing how orbits ζ and ζ' become linked by breakdown.

The experimental observations will now be compared to the predictions of this model. A region of aperiodic open orbits exists until breakdown starts to close them—marked by the feature $c-c'$ of the results. The observed narrowing of the region with field appears to be due to breakdown occurring further from X as the field is increased. The spikes a, b occur because it is always possible to find [100] and [110] open orbits which do not pass near X. The magnetic-field dependence of the resistivity just outside region $c-c'$, neither H^2 nor saturating, reflects the mixture of open, closed, and extended orbits possible on the model. The observations are thus in general agreement with the predictions of the nearly free electron model with magnetic breakdown.

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