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Fermi-surface radii in gold: Radio frequency size effect

C. A. Steele* and R. G. Goodrich
Department of Physics and Astronomy, Louisiana State University, Baton Rouge, Louisiana 70803
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Fermi-surface dimensions for electron orbits in the (110) plane of gold have been measured to a precision of 0.2%. The measured dimensions are found to deviate from the accepted values of Halse by as great as 1.6%.

Since 1969 the analytical expressions for the Fermi surfaces of copper, silver, and gold given by Halse[1] have been used in many investigations. The expressions which give these Fermi surfaces are symmetrized Fourier series expansions of the form

$$C_0=\sum_{lmn} C_{lmn} \sum \cos\left[\frac{lak_x}{2}\right] \cos\left[\frac{mak_y}{2}\right] \times \cos\left[\frac{nak_z}{2}\right], \qquad (1)$$

where the second sum denotes permutation of x, y, and z, a is the lattice constant, and $l^2+m^2+n^2=0,2,4,\ldots$ for an fcc lattice. By fitting de Haas–van Alphen data Halse determined the values of C_0 and C_{lmn} up to $l^2+m^2+n^2=14$ for copper and silver and up to 10 for gold. Given these constants the Fermi surface is determined to be any value of $\vec{k}=\hat{i}k_x+\hat{j}k_y+\hat{k}k_z$ which satisfies Eq. (1).

It generally has been believed that Fermi radius vectors obtained using the coefficients given by Halse are accurate to within 0.2%.[2] In previous radio-frequency size-effect (RFSE) measurements[3] on copper and silver we have been unable to determine any deviation of points on the Fermi surface of these two metals from the values given by Eq. (1) with Halse's coefficients to within our experimental uncertainty of 0.5%. We wish to report here on high-precision caliper measurements on gold in which deviations greater than 0.2% from the Fermi surface of Eq. (1) are observed.

Experimentally the RFSE involves the detection of changes in the surface impedance of a thin single-crystal slab of metal placed in a magnetic field applied parallel to the crystal surface. At magnetic field values such that an extremal cyclotron orbit of a carrier exactly spans the sample thickness, an abrupt change in the surface impedance of the sample is observed. For a sample of known thickness, the magnitude of the magnetic field at which the change occurs is directly proportional to an extremal dimension of the Fermi surface.

The sample used for these measurements was cut by spark erosion from a single crystal that was grown by the Bridgeman technique. It was in the form of a disk of approximately 1-cm diameter with the [110] direction perpendicular to the faces of the disk. The thickness was 1.051 ± 0.001 mm at room temperature. The sample thickness at 4.2 K was corrected for contraction in the [110] direction using the ratio of lattice constants between 300 and 4.2 K.[1] The resulting thickness at 4.2 K for the sample was 1.049 ± 0.001 mm. After cutting and polishing, the sample was annealed in air at 975 C for 12 h prior to making the measurements.

A standard rf detection apparatus was used for the measurements.[4] The magnetic field was provided by a pair of air core coils in the Helmholtz configuration. These coils were surrounded by earth field cancelling coils which reduced the ambient field to less than 0.01 Oe. Calibration of the applied field was made using proton NMR between 150 and 175 Oe where the RFSE signals occurred and is accurate to 0.05 Oe.

Signals from the belly orbits for this sample were very narrow with a width $\Delta H/H=8\times10^{-3}$. The noncentral belly orbit was completely separated in field from the central belly orbit at all angles. This fact allowed high-precision calipers to be determined. The overall fractional uncertainty in calipers obtained from these measurements is 0.2%.

In Table I the measured Fermi radii along with those obtained from Eq. (1) using the Halse coefficient are given. As can be seen the Halse values

TABLE I. Fermi radii in the (110) plane for gold in units of the free-electron Fermi radius of 1.2080×10^{8} cm^{-1}.

Direction of k from (110)	Present results	Halse	% difference
0°	0.946(2)	0.942	0.43
5°	0.949(2)	0.946	0.32
10°	0.960(2)	0.958	0.21
15°	0.988(2)	0.979	0.92
20°	1.022(3)	1.014	0.79
21°	1.032(3)	1.023	0.88
22°	1.045(3)	1.033	1.16
23°	1.054(3)	1.045	0.86
24°	1.070(3)	1.059	1.04
25°	1.096(3)	1.078	1.67
neck			
48°	1.060(3)	1.042	1.63
50°	1.040(3)	1.023	1.56
55°	1.008(2)	0.994	1.41
60°	0.995(2)	0.981	1.43
65°	1.000(2)	0.982	1.83
70°	1.009(2)	0.995	1.41
72°	1.017(2)	1.004	1.30
73°	1.022(3)	1.010	1.19

give good agreement for directions near [110], but deviations greater than 1% occur near the neck and in the [100] direction. A reevaluation of the coefficients for Eq. (1) cannot be done reliably on the basis of these eighteen Fermi radii in the (110) plane. If higher precision is to be obtained from Eq. (1) a reanalysis of high-precision de Haas—van Alphen data for gold should be performed.

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*Present address: Laser-Scan Laboratories, Cambridge CB4 4BO England.

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