9d. Properties of Metals

JULIUS BABISKIN

U.S. Naval Research Laboratory

J. ROBERT ANDERSON

University of Maryland

9d-1. Electrical Resistivity and Hall Coefficient. The temperature-dependent ideal resistivity values ρ_i for very pure metals are listed in Table 9d-1 at 0 and 22°C where these ρ_i values are closely equal to the measured resistivity values ρ of pure metals. ρ_i was obtained either by subtracting ρ_0, the residual resistivity at very low temperatures due to impurities and imperfections, from ρ or by choosing the lowest reported values of ρ for high-purity metals. The ratio of the resistivity at 100,000 kg/cm² (ρ_p) to that at zero pressure (ρ) at 20°C and the Hall coefficient (R) at 20°C are also listed in Table 9d-1.

9d-2. Ideal Electrical Resistivity at Low Temperatures. *Matthiessen's rule* states that the *measured resistivity* ρ at a given temperature T is composed of the temperature-dependent *ideal resistivity* ρ_i due to electron scattering by lattice vibrations and the temperature-independent *residual resistivity* ρ_0 caused by impurities and imperfections; that is, $\rho = \rho_i + \rho_0$. At higher temperatures, $\rho_i \propto T$ for $T \gtrsim 0.25\theta$, where θ is the Debye characteristic temperature. At very low temperatures, $\rho_i \propto T^n$ where $n = 5$ for a free-electron metal. For many transition metals, $n \cong 2$ to 3 at low T owing to electron-electron interactions. Tables 9d-2a and 9d-2b list values for ρ_i at various temperatures below 273 K, while Table 9d-1 lists values for ρ_i at

TABLE 9d-1. SOME ELECTRICAL PROPERTIES OF PURE METALS

Metal	ρ_i,* microhm-cm 0°C	ρ_i,* microhm-cm 22°C	ρ_p/ρ,† at 100,000 kg/cm²	R,‡ cm³/coul × 10⁴
Aluminum	2.50, 2.44[a]	2.74	0.770	−0.30
Antimony	37.6	41.3	0.605	
Arsenic	26	29	0.928	
Barium	36	39	2.618	
Beryllium	2.71	3.25	0.876	+2.44
Bismuth	105	116	0.474	
Cadmium	6.73	7.27	0.658	+0.60
Calcium	3.08[b]	3.35[b]	4.399	
Cerium	79, 76.7[c]	81	.....	+0.181
Cesium	18.0	10.06	5.33	−7.8
Chromium	12.1[d]	12.9[d]	0.558	
Cobalt	5.15[d]	5.80[d]	0.951	−1.33
Copper	1.55[d], 1.545[a]	1.70[d]	0.866	−0.55
Dysprosium	87.5, 56[c]	90	.....	−1.3
Erbium	77	81	.....	−0.34
Europium	86	89		
Gadolinium	127.5	134.1	.....	−0.95
Gallium	13.65	14.85		
Gold	2.01[d]	2.20[d]	0.816	−0.72
Hafnium	28.0[d]	30.6[d]		
Holmium	74.5	77.7		
Indium	8.0	8.75	0.493	−0.07
Iridium	4.65[d]	5.07[d]	0.886	
Iron	8.7[d]	9.8[d]	0.841	+0.245
Lanthanum	75, 62.4[c]	79	.....	−0.8
Lead	19.3, 19.2[a]	21.0	0.487	+0.09
Lithium	8.494	9.32	1.704	−1.7
Lutecium	49	53		
Magnesium	3.94	4.30	0.767	−0.94
Manganese	136[d], 91[e]	136[a]	.....	−0.93
Mercury (liq.)	94.1	95.9	0.555	
Molybdenum	4.84[d]	5.33[d]	0.892	+1.26
Neodymium	56.5	59	.....	+0.97
Neptunium	116	118.5		
Nickel	6.20[d]	7.04[d]	0.858	−0.611
Niobium	13.5[d]	14.5[d]	0.894	
Osmium	8.35[d]	9.13[d]		
Palladium	9.70[d]	10.55[d]	0.847	−0.68
Platinum	9.59[d]	10.42[d]	.861	−0.24
Plutonium	144	143		
Polonium	42	46		
Potassium	6.447, 6.1[e]	7.19	0.596	−4.2
Praseodymium	64	67	.....	−0.71
Rhenium	16.9[d]	18.6[d]		
Rhodium	4.36[d]	4.78[d]	0.872	370
Rubidium	11.25	12.51	2.95	
Ruthenium	6.69[d]	7.37[d]		
Samarium	95, 88[c]	99		
Scandium	42.9	46.8		
Silver	1.47[d]	1.61[d]	0.802	−0.84
Sodium	4.289	4.75	0.479	−2.5
Strontium	19.8	21.5	1.810	
Tantalum	12.1[d]	13.1[d]	0.882	+1.01
Terbium	109	111		
Thallium	15	16.4	0.265	+0.24
Thorium	14.0, 13[e]	15.	0.821	
Thulium	58	62		

TABLE 9d-1. SOME ELECTRICAL PROPERTIES OF PURE METALS (*Continued*)

Metal	ρ_i,* microhm-cm 0°C	ρ_i,* microhm-cm 22°C	ρ_p/ρ_i,† at 100.000 kg/cm²	R,‡ cm³/coul × 10⁴
Tin	10.1	11.0	0.548	−0.04
Titanium	39.0[d]	43.1[d]	0.910	
Tungsten	4.82[d]	5.33[d]	0.895	+1.18
Uranium	24.1	25.7	0.724	
Vanadium	18.3[d]	19.9[d]	0.878	
Ytterbium	25.5	26.4		
Yttrium	53.7	58.5		
Zinc	5.45	5.92	0.679	+0.33
Zirconium	38.6[d]	42.4[d]	0.9836	

* Unless otherwise indicated, most of the ρ_i values were taken from G. T. Meaden, "Electrical Resistance of Metals," Plenum Press, Plenum Publishing Corporation, New York, 1965.

† ρ_p/ρ taken from P. W. Bridgeman, *Proc. Am. Acad. Arts Sci.* **81**, 165 (1952).

‡ R taken from J. Bardeen, "Handbook of Physics," pp. 4-74, E. U. Condon and H. Odishaw, eds., McGraw-Hill Book Company, New York, 1958.

[a] L. A. Hall, "Survey of Electrical Resistivity Measurements on 16 Pure Metals in the Temperature Range 0 to 273°K," *NBS Tech. Note* 365, February, 1968.

[b] F. X. Kayser and S. D. Soderquist, *J. Phys. Chem. Solids*, **28**, 2313 (1067).

[c] J. A. Gibson et al.: "The Properties of Rare Earth Metals and Compounds," Battelle Memorial Institute, Columbus, Ohio, 1959.

[d] G. K. White and S. B. Woods, *Phil. Trans. Roy. Soc. London*, ser. A, **251**, 273 (1959).

[e] R. B. Stewart and V. J. Johnson, eds., A Compendium of the Properties of Materials at Low Temperatures (Phase II), *WADD Tech. Rept.* 60–56, part IV, chap. 6. Wright-Patterson Air Force Base, Ohio: Aeronautical Systems Division, Air Force Systems Command, December, 1961.

273 K (0°C) and at 295 K (22°C). Table 9d-2a lists ρ_i, θ, and n for the noble metals (Group IB) and the transition metals (Groups IVA, VA, VIA, VIIA, and VIIIA). Table 9d-2b lists ρ_i and θ for the remaining groups of metals other than the noble and the transition metals.

9d-3. Electronic Structure of Metals. The metals listed in Table 9d-3 are divided into three groups, simple metals, transition metals, and semimetals. The reference list is not complete, but the numbers next to the element names refer to recent papers which contain fairly complete references. A recent review article [1] gives rather complete references to de Haas-van Alphen effect studies up to 1968.

In the first column under the name of the metal are given the lattice constants in angstroms and the crystal structure. Values of the lattice constants are given at low temperatures, approximately 4.2 K, where these are available. In some cases these have been estimated from low-temperature thermal expansion data. Where low-temperature data are not available, room-temperature (R.T.) values are listed. One useful reference is Pearson's compilation [2].

In the next four columns the Fermi surface description is given. For most metals the identifications are based upon band structure calculations, and in some cases the descriptions are extremely tentative. The letters in the description refer to symmetry points in the Brillouin zone following the standard convention as given, for example, by Koster [3]. The names of the parts of Fermi surface are taken from the appropriate references. e and h refer to electrons and holes, respectively. In the majority of cases the type of carrier has been determined from band structure calculations rather than from actual experiments. The magnetic field direction is given in column 6 and refers to the normal to an extremal Fermi surface cross section. The frequencies given in column 7 were obtained from de Haas-van Alphen effect measurements. When

Table 9d-2a. Ideal Electrical Resistivities in Microhm-cm of Pure Metals at Low Temperatures*

T, K	Group IB			Group IVA			Group VA			Group VIA			Group VIIA		Group VIIIA								
	Cu	Ag	Au	Ti	Zr	Hf	V	Nb	Ta	Cr	Mo	W	Mn	Re	Fe	Ru	Os	Co	Rh	Ir	Ni	Pd	Pt
250	1.40	1.34	1.83	34.8	34.6	25.3	16.6_5	12.3	11.0	10.9_5	4.3_9	4.3_2	133	5.2	7.5_2	5.9_6	7.5_0	4.5_0	3.9_0	4.1_9	5.4_0	8.8_2	8.70
220	1.20	1.16	1.60	29.3	29.4	21.7	14.5	10.8	9.6	9.0_5	3.6_4	3.6_6	131	12.9_5	6.2	5.0_2	6.4_5	3.7_2	3.3_1	3.5_0	4.3_6	7.6_1	7.54
200	1.06	1.04	1.44	25.7	26.1	19.3	12.9	9.8	8.6	7.7_5	3.1_8	3.2_2	131	11.4_5	5.3	4.3_8	5.7_0	3.2_3	2.9_2	3.2_0	3.7_2	6.9_0	6.76
180	0.92	0.92	1.28	22.1	22.6	16.9	11.2	8.7	7.6_5	6.4	2.7_4	2.7_3	130	9.9_5	4.4_6	3.7_5	5.0_0	2.7_5	2.5_2	2.8_0	3.1_0	6.0_6	5.97
160	0.77_5	0.79_5	1.12	18.5	19.3	14.5	9.5	7.5_5	6.6_5	5.2	2.2_7	2.3_3	127	8.4	3.5_2	3.1_0	4.2_2	2.2_6	2.1_2	2.3_8	2.5_2	5.1_9	5.18
140	0.63_6	0.67_6	0.95_6	14.8	16.0	12.2	7.7_5	6.4	5.6	3.9	1.8_2	1.8_8	125	6.9	2.7_3	2.4_8	3.50	1.7_8	1.7_1	1.9_6	1.9_7	4.3_1	4.37_5
120	0.49_0	0.54_5	0.79_0	11.2	12.8	9.9	6.0	5.2	4.6	2.6_6	1.36	1.44	123	5.3_5	1.9_5	1.8_5	2.70	1.3_2	1.2_8	1.5_6	1.4_6	3.4_6	3.56_2
100	0.35_0	0.42_0	0.63_0	7.9	9.5_6	7.6	4.3	3.9_5	3.5_6	1.6_2	0.92	1.02	121	3.9_2	1.2_4	1.2_5	1.90	0.91	0.8_9	1.1_0	1.0_0	2.6_0	2.74_2
90	0.28_0	0.35_5	0.54_8	6.3_6	7.9_0	6.5	3.5_0†	3.3_0	3.0_8	1.1_8	0.71_4	0.82_0	120	3.2	0.92	0.91	1.50	0.72	0.69_8	0.90	0.75	2.1_7	2.32_6
80	0.21_6	0.29_0	0.46_0	4.8_5	6.4	5.4	2.6_5	2.6_8	2.5_0	0.8_1	0.51_5	0.66_0	121	2.5_3	0.64	0.64	1.10	0.54	0.51	0.72	0.55	1.7_2	1.90_9
70	0.15_3	0.23_0	0.38	3.5	4.9_0	4.3	1.9_0	2.0_7	1.9_6	0.5_2	0.35_4	0.42_5	122	1.8_6	0.4_2	0.43	0.79	0.38	0.34	0.53	0.38	1.3_0	1.49_7
60	0.095	0.17	0.29	2.3†	3.5_0	3.2	1.2_7	1.5	1.4_3	0.3_0	0.21_6†	0.27_1	122	1.2_7	0.25	0.24	0.50	0.25	0.20_4	0.35	0.24_5	0.92	1.09_4
50	0.050	0.11	0.20	1.4	2.2_4	2.1†	0.7_5	0.9_7	0.9_5	0.16_5	0.11_3	0.15	117	0.7	0.13_5†	0.10_5	0.26	0.14_5	0.10_2	0.20	0.15	0.58	0.719
40	0.022	0.058	0.12	0.6_4	1.2_0	1.2_5	0.3_8	0.56†	0.5_1	0.07_8†	0.047	0.066†	105	0.3_7	0.06_0	0.03_8†	0.11†	0.07_2†	0.043	0.10	0.07_3	0.32	0.396
30	0.0063†	0.020	0.050	0.2_0	0.47†	0.5_1	0.1_4	0.25	0.2_3†	0.02_9	0.01_2	0.02_2	82	0.11	0.05_2	0.01_0	0.02_8	0.02_7	0.011_6†	0.03_2†	0.03_0†	0.13	0.160
25	0.0025	0.010†	0.027	0.07_5	0.23_5	0.2_6	0.07_6	0.1_5	0.1_2	0.015_5	0.004_6	0.011_5	65	0.04_7†	0.012_5	0.00_5	0.01_2	0.01_4	0.004_9	0.014_5	0.017	0.074	0.0837
20	0.0008	0.0038	0.0125†	0.02_0	0.09_0	0.10_5	0.03_7	0.08	0.05_1	0.007_2	.....	0.005_6	46	0.016_5	0.00_6	.....	.....	0.006_6	0.001_8	0.005_0	0.009	0.036†	0.0359
15	0.0001_7	0.0011	0.0037	.....	0.02_5	0.02_7	0.01_1	0.03	0.01_7	0.002_7	.....	0.002_1	28	0.004_5	.....	.....	.....	0.002	.....	0.001	0.004	0.011	0.0116†
10	.....	0.0002	0.0006	.....	.....	0.005	.....	.....	0.003_2	.....	.....	.....	12†	.....	.....	.....	.....	0.001	.....	.....	.....	0.004	0.0029
θ, K	310	220	185	360	250	210	390	250	230	480	380	315	410	280	400	500	400	380	350	290	390	295	225
n	5.1	4.7	5.1	5.3	4.5	4.7	3.4	2.7	3.8	3.2	5.1	4.0	2.0	4.6	3.3	4.7	4.7	3.3	4.6	4.7	3.1	3.2	3.7

* Data taken from G. K. White and S. B. Woods: *Phil. Trans. Roy. Soc. London*, ser. *A*, **251**, 273 (1959).
† Values for ρ_i at which $\rho_i \cong \rho_0$ (or $\rho \cong 2\rho_0$).

TABLE 9d-2b. IDEAL ELECTRICAL RESISTIVITIES IN MICROHM-CM OF PURE METALS AT LOW TEMPERATURES*

Metal	20 K	50 K	80 K	100 K	150 K	200 K	250 K	θ, K†
Group IA:								
Li	0.015	0.27	0.995	1.714	3.708	5.704	7.613	370
Na	0.0165	0.317	0.805	1.145	1.994	2.874	3.821	158
K	0.1074	0.710	1.389	1.836	3.005	4.281	5.720	90
Rb	0.433	1.57$_2$	2.70$_0$	3.46$_1$	5.46$_6$	7.64$_3$	10.01	52
Cs	0.882	2.65$_6$	4.42$_4$	5.63$_7$	8.78$_0$	12.22	16.06	54‡
Group IIA:								
Be	0.0004	0.0077	0.038$_9$	0.090$_7$	0.436	1.15$_1$	2.15$_6$	1160
Mg	0.008$_4$	0.1$_2$	0.55	0.89	.....	2.6	.....	400
Ca	0.03	0.25	0.57	0.87	1.52	2.14	2.74	230
Sr	0.48	2.5	4.6	6.3	.....	14.1	.....	147
Ba	0.73	3.5	7.8	10.7	.....	25	.....	110
Group IIIA:								
Sc	0.16	2.9	8	11.$_2$	20.$_7$	29.$_8$	38.$_3$	
Y	0.3$_6$	4.8	11.$_2$	15.$_4$	26.$_6$	37.$_6$	48.$_6$	214‡
Group IIB:								
Zn	0.052	0.49	1.16	1.6$_2$	2.7$_2$	3.8$_4$	4.9$_2$	310
Cd	0.13	0.87	1.7	2.3	3.6	4.9	6.2	188
Hg	1.24	3.9$_6$	6.6$_2$	8.6	13.3	18.4	92.2	80
Group IIIB:								
Al	0.0006	0.05	0.25	0.47	1.0$_8$	1.6$_8$	2.24	428
Ga	0.09	.....	2.7$_4$	3.9$_5$	6.8	9.5$_6$	12.3	320
In	0.16	0.9$_4$	1.8$_0$	2.3$_3$	3.8$_4$	5.4$_3$	7.1$_5$	108
Tl	0.42	2.0	3.6	4.7	7.5	10.3$_5$	13.5	87
Group IVB:								
Sn	0.10	0.9$_5$	2.1$_5$	2.9$_5$	4.9$_5$	7.0	9.1	178
Pb	0.56	2.76	4.97	6.5	10.2	13.$_9$	17.$_6$	110
Group VB:								
As	0.2$_9$	1.$_9$	4.$_5$	6.$_4$	.....	.....	.....	285‡
Sb	0.4$_2$	3.2	7.2	10.0	17.9	25.9	34.0	207
Bi	5.8	19	30	37	55	74	96	119
Rare-earth metals:								
La	3.3	17	29	36	49.$_6$	61	71	142
Pr	.....	8.$_6$	23	36	46	54	61	74‡
Nd	8.$_3$	17	25	29.$_6$	38.$_6$	46	53	
Sm	14	33	52	64	73	82	91	
Eu	8.$_6$	33	61	78	75	78	83	
Gd	1.0	12.$_6$	29.$_7$	41.$_2$	69.$_0$	95.$_6$	119.$_3$	152‡
Tb	0.9$_5$	12.$_6$	27	38	64	93	108	158‡
Dy	1.1	11.$_3$	28.$_0$	40.$_3$	72.$_6$	81	85	140
Ho	3.4	15	31	43	56	64	71	
Er	4.$_6$	24	39	42	52	63	73	
Tm	2.$_1$	21	25.$_6$	29	38	46	55	
Yb	1.$_2$	6.$_2$	10.$_8$	13.$_4$	17.$_3$	21.$_5$	24.$_4$	
Lu	0.7$_3$	6.$_0$	11.$_9$	16	26	36	45	166‡
Actinide metals:								
Th	0.19	1.67	3.34	4.4	7.2	9.9$_4$	12.7	170
U	0.52	4.54	7.4	9.4	14.0	18.3	22.3	200
Np	1.91	24.2	40.8	63.1	87.3	102.5	112.7	
Pu	20	116	153	156	153	148	145	

* Except for calcium, the ρ_i values were taken from G. T. Meaden, "Electrical Resistance of Metals," Plenum Press, Plenum Publishing Corporation, New York, 1965. The ρ_i values for calcium were taken from F. X. Kayser and S. D. Soderquist, *J. Phys. Chem. Solids*, **28**, 2343 (1967).

† Unless otherwise indicated, most of the θ values were taken from G. T. Furukawa and T. B. Douglass, "American Institute of Physics Handbook," 2d ed., pp. 4–61, D. E. Gray, ed., McGraw-Hill Book Company, New York, 1963.

‡ These θ values were taken from F. J. Blatt: "Physics of Electronic Conduction in Solids," pp. 48–49, McGraw-Hill Book Company, New York, 1968.

extremal areas A were given in angstroms or atomic units, the conversion to frequency F was made, using the following relations:

$$F \text{ (gauss)} = A \text{ (a.u.}^{-2}) \times 3.741 \times 10^8$$
$$F \text{ (gauss)} = A \text{ (angstroms}^{-2}) \times 1.04728 \times 10^8$$

An $\sim$ sign is used for values estimated from graphs. Error estimates are not given here, but can be obtained from the references. If no reference is indicated for a specific measurement, the first reference given for that element is implied.

In columns 8 and 9 are given cyclotron mass values obtained from de Haas–van Alphen effect and cyclotron resonance measurements. No attempt has been made to give a complete listing of the values obtained from cyclotron resonance even though more accurate measurements are usually obtained by this technique.

In the final column are listed other experiments that have been performed on these metals, using the following abbreviations:

ASE	Anomalous skin effect	MA	Magnetoacoustic
CR	Cyclotron resonance	MT	Magnetothermal
GM	Galvanomagnetic	PA	Positive annihilation
H	Helicons	SE	Size effect
KE	Kohn effect		

Descriptions of these experiments can be found by referring to the references given in this table.

TABLE 9d-3. ELECTRONIC STRUCTURE OF METALS

Metal	Fermi surface nomenclature		Carrier	Orbit description	Magnetic field direction	F (in 10^6 Gauss)	Mass values, m^*/m		Other experiments
	Band	Description					de Haas–van Alphen	Cyclotron resonance	
I. SIMPLE METALS									
1. Aluminum [4]	1	Full							
f.c.c.	2	Large closed surface	h	.....	[110]	436.6 [6, 7]	.....	.....	GM, MA, SE,
a = 4.0236 [5]		centered at Γ			[111]	411 [7]	1.3 [6, 7]	1.3 [8]	ASE, KE, H
					[100]	680 [7]			
	3	Multiply connected	e	Central sections	[110]	2.86	0.130		
		surface of [110] arms		through K	[111]	3.44	0.150	0.161 [8]	
					[100]	3.89	0.180	0.183 [8]	
				Minimum arm	[110]	~0.26	~0.09		
				cross sections	[100]	0.28	0.091		
					[111]	0.36			
				Arm joints	[100]	0.466	0.102		
					[110]	~0.51	0.118		
2. Beryllium [9]	1 and 2	6-cornered coronet	h	Neck	[11$\bar{2}$0]	0.109	0.0196	.....	GM, PA, MT
h.c.p.				B_1 belly	[11$\bar{2}$0]	12.4	0.25		
a = 3.5814				B_2 belly	[10$\bar{1}$0]	14.82	0.34		
c = 2.2828				Inner circle	[0001]	381 [10]			
	3 and 4	Cigars	e	Waist central	[0001]	9.42	0.164		
				Waist noncentral	[0001]	9.72	0.174		
				Long section	[10$\bar{1}$0]	53.5			
					[11$\bar{2}$0]	53.1			
3. Cadmium [11]	1 and 2	Pinched-off monster	h	.....	[0001]	5.98 [14]	.....	.....	GM, MA, CR,
h.c.p.					[11$\bar{2}$0]	12.7 [15]			SE
a = 2.9684 [12]		Band 1 caps at H			[10$\bar{1}$0]	11.4 [15]			
c = 5.5261 [12]									
		Band 2 undulating		AHL plane	[0001]	~6.4 [14]			
		cylinder along K–H		Belly	[0001]	~61 [14]			
	3 and 4	Lens-shaped centered	e	.....	[0001]	196 [15]	.....	1.23 [16]	
		at Γ			[11$\bar{2}$0]	64 [15]	.....	~0.59 [16]	
					[10$\bar{1}$0]	63 [15]	.....	~0.59 [16]	
4. Calcium [17]	.....	Data from polycrys-		"Hyperboloidal	.....	3.3	0.35		
f.c.c.		talline samples only		surface"		13	0.62		
a = 5.57 (R.T.)						17.6	0.65		

5. Cesium [18], [106]	1	Free-electron-like	*e*	.....	[110]	136.4	1.25-1.40		
b.c.c.		spherical surface			[100]	~139			
a = 6.045					[111]	~140			
6. Gallium [19]	.....	De Haas–Van Alphen	...	.....	[100]	0.135	.....	0.0973-	GM, MA, SE
		frequencies and				0.495	.....	0.896 [20]	
		masses have not				0.855			
		been completely				23.5			
		correlated with				56.7			
		band structure							
					[010]	0.345	.....	0.0513-	
						0.725	.....	0.728 [20]	
						19.2			
						22.5			
						30.0			
						63.5			
					[001]	0.20	.....	0.063-	
						0.22	.....	0.772 [20]	
						0.765			
						8.3			
						13			
						20.5			
7. Indium [21]	1	Full							
f.c.t.									
a = 4.5557	2	Large closed surface	*h*	Central	[110]	295 [23]	~1.2 [22]	1.17 [23]	GM, MA, SE
c = 4.9342		centered at Γ		Noncentral	[110]	339 [23]			
				Central	[011]	332 [23]	~1.3 [22]	1.34 [23]	
				Central	[001]	476 [23]	.....	2.07 [23]	
				Central	[111]	317 [23]	~1.5 [22]	1.54 [23]	
	3	Rings of [110] arms	*e*	Arm cross section	[110]	4.59	0.204	0.202 [23]	
				Centered at K	[011]	8.25	0.36	0.36 [23]	
					[100]	6.05	.....	0.27 [23]	
				Arm junction	[100]	0.092			
					[011]	0.148	0.20		
					[110]	0.140	0.18	0.18 [23]	
8. Lead [24]	1	Full							
f.c.c.	2	Large closed surface	*h*	.....	[110]	159 [26]	1.09 [25]	1.12 [27]	GM, MA, SE,
a = 4.90		centered at Γ			[111]	156 [26]	1.11 [25]	1.15 [27]	ASE, KE
					[100]	204 [28]	1.47 [25]	1.58 [27]	
	3	Multiply connected	*e*	Arm cross sections	[110]	18.1 [26]	0.51 [25]	0.56 [27]	
		surface of [110] arms		centered at K	[100]	24 [26]	0.70 [25]	0.75 [27]	
					[111]	22.4 [26]	0.65 [25]	0.70 [27]	
				Junction of arms centered at W	[100]	51.3 [26]	1.20 [25]	1.23 [27]	
				Inside four arms	[100]	36.0 [26]	0.87 [25]		

TABLE 9d-3. ELECTRONIC STRUCTURE OF METALS (*Continued*)

Metal	Fermi surface nomenclature		Carrier	Orbit description	Magnetic field direction	F (in 10^6 Gauss)	Mass values, m^*/m		Other experiments
	Band	Description					de Haas–van Alphen	Cyclotron resonance	
I. SIMPLE METALS									
9. Magnesium [29] h.c.p.	1	Cap	h	.....	[0001]	1.18	.....	.....	GM, MA, CR, ASE
a = 3.20 (R.T.)	2	Monster	h	Necks tilted ~28.7° from ΓA zone line in $(10\bar{1}0)$	[0001]	0.804	0.11		
c = 5.20					$[10\bar{1}0]$	1.92			
					$[11\bar{2}0]$	1.53			
				Waists	$[11\bar{2}0]$	2.70	0.138		
					$[10\bar{1}0]$	3.16	0.162		
	3	Cigar	e	.....	[0001]	2.24	0.10		
					$[10\bar{1}0]$	11.7			
		Lens	e	.....	$[11\bar{2}0]$	10.7			
					[0001]	115			
					$[10\bar{1}0]$	27.2	0.42		
	3 and 4	Magnetic breakdown couples 3d-band butterfly and 4th-band pockets	e	.....	$[11\bar{2}0]$	27.16	0.42		
					[0001]	13.9	0.49		
					$[10\bar{1}0]$	8.64			
					$[11\bar{2}0]$	7.78	0.32		
10. Mercury [30, 31]	1	Multiply connected cylinders parallel to [001]	h	....	[011]	0.94	0.20	.....	GM, CR, PA
a, b = 2.9863					[211]	1.07	0.23		
c = 70°44.6′					[100]	0.735	0.16		
Rhomb					[111]	1.06			
					$[10\bar{1}]$	1.34	0.15		
				Larger orbits	$[2\bar{1}\bar{1}]$	19.3			
					[100]	21.5			
					$[10\bar{1}]$	15.8	0.90		
	2	Surfaces centered at L	e	.....	[100]	34.0			
					[101]	32.0			
					[111]	34.5			
					$[2\bar{1}\bar{1}]$	40.0			
					$[1\bar{1}0]$	32.2			
11. Potassium[b] [32], [100]	1	Nearly spherical, centered at Γ	e	.....	[100]	182.7	1.18-1.25 [34]	1.21 [35]	GM, MA, SE, H
a = 5.225[c] [33]					[110]	182.4 [34]			
b.b.c.					[123]	182.4 [34]			

12. Sodium[b] [36] a = 4.225 [33] b.c.c.	1	Nearly spherical, centered at Γ	e		Arbitrary[b]	291.9[a]	1.24 [34]	.....	GM, CR, PA, H
13. Rubidium[b] [34] a = 5.585 [33] b.c.c.	1	Nearly spherical, centered at Γ	e	.....	Average of several directions	160.3	1.28	.....	CR, SE
14. Thallium[b] [37], [111], [112] a = 3.438 [38] c = 5.478 h.c.p.	1 and 2	Full							
	3	Crown	h	Central	$[11\bar{2}0]$	93.5 [39]	.....	.....	GM, MA
				Central	$[10\bar{1}0]$	98.9 [39]			
					[0001]	209 [39]			
	4	Hexagonal network	e	Central arm	$[11\bar{2}0]$				
				Noncentral arm	$[11\bar{2}0]$	27.4 [39]			
				Central	$[10\bar{1}0]$	37.6 [39]			
					[0001]	218 [39]			
					[0001]	1.8 [40]	0.25 [40]		
15. Tin[b] [41], [105] a = 5.80 [42] c = 3.15 b.c.t.	1 and 2	Full	...	.....	.....	.....	.....	.....	GM, MA, CR, SE
	3	Dumbbells centered at X	h	Central	[001]	1.72			
				Noncentral	[001]	3.25	0.16 [43]		
					[100]	15.8			
					[110]	16.7			
	4	Multiply connected intersecting tubes centered at Γ	h	.....	[001]	112			
					[001]	103			
					[100]	32.9	0.56 [43]		
					[1 0]	25.6			
		Crossed convex lens-shaped reentrant region centered at Γ	e	.....	[001]	34.1	0.51 [43]		
	5	Multiply connected tilted tubes with alternate top-up and top-down pear-shaped pieces	e	Large part of pear	[001]	68.1			
				Smallest cross section of pear inside of tilted tube network	[001]	52.8	0.57 [43]		
				Pear section	[110]	80.4			
					[110]	67.7			
				Tilted tubes	[100]	20.6	0.55 [43]		
					[100]	20.9			
	6	Molar-shaped surface centered at Γ	e	.....	[001]	4.45			
					[110]	5.87			
					[100]	4.54	0.31 [43]		

[a] Low-temperature lattice constant may be in error owing to strained samples [32].
[b] The possibility of a martensitic transformation at the low temperatures makes interpretation difficult.

TABLE 9d-3. ELECTRONIC STRUCTURE OF METALS (*Continued*)

Metal	Fermi surface nomenclature: Band	Fermi surface nomenclature: Description	Carrier	Orbit description	Magnetic field direction	F (in 10^8 Gauss)	Mass values, m^*/m: de Haas–van Alphen	Mass values, m^*/m: Cyclotron resonance	Other experiments
I. SIMPLE METALS (*Cont.*):									
16. Zinc [44, 45]	.....	.....	...	.....	.....	.....	.....	.....	
$a = 2.651$	2	Monster	h	Arms minimum	28° from [0001]	4.44 [46]	.....	.....	GM, MA, CR,
$c = 4.838$									SE, MT
h.c.p.				4-arm orbit	[0001]	5.13 [46]			
					[11$\bar{2}$0]	26.6 [46]	0.44 [44]		
					[10$\bar{1}$0]	33.0			
				Waists	[11$\bar{2}$0]	0.446 [46]	~0.11		
					[10$\bar{1}$0]	1.11 [46]	0.13		
	3	Cigar	e	.....	[0001]	0.0157 [46]	0.0075		
					[11$\bar{2}$0]	0.265 [46]	0.09		
		Lens	e	.....	[11$\bar{2}$0]	73.5 [46]	~0.54 [44]	~0.55 [17, 16]	
					[10$\bar{1}$0]	73.5 [46]	~0.59 [44]	~0.57 [17, 16]	
					[0001]	.....	.....	1.20 [17, 16]	
1a. Barium [108]	.....	.....	...	α	[111]	3.29	0.37		
$a = 5.000$ [118]				β	[111]	4.56	0.42		
bcc				γ	[100]	19.5	0.92		
II. TRANSITION METALS									
1. Chromium [48], [103]	.....	De Haas–van Alphen data not tabulated. See [48]	...	.....	.....	~0.2–40	.....	.....	GM
b.c.c.[c]									
1a. Cobalt [104,110]	.....	Preliminary results	...	.....	[11$\bar{2}$3]	~4.9			
$a = 2.5071$					[0001]	~3.8			
$c = 4.0686$ (R.T.)									
h.c.p.									
2. Copper [49]	1	Sphere with necks touching [111]	e	Neck	[111]	21.77 [97]	0.45 [51]	.....	GM, MA, CR,
$a = 3.603$ [50]		Brillouin zone faces	...	Belly	[111]	581.4 [97]	1.5 [50]		ASE, PA, MT
f.c.c.					[100]	599.8 [97]			
				Dog's bone	[110]	251.4 [97]	1.4 [51]		
				4-cornered rosette	[100]	246.2 [97]	~1.3 [51]		
3. Gold [49]	1	Sphere with necks touching [111]	e	Neck	[111]	15.32	~0.29 [47]	.....	GM, MA, CR
$a = 4.065$ [50]		Brillouin zone faces	...	Belly	[111]	449.3	~1.1 [52]		
f.c.c.					[100]	485.0 [97]	~1.1 [52]		
				Dog's bone	[110]	193.8 [97]	~1.0 [52]		
				4-cornered rosette	[100]	200.3 [97]	~1.1 [50]		
3a. Iridium [109,116]	.....	.....	h	.....	[100]	37.8			
$a = 3.8387$ (R.T.)					[100]	55.3			
f.c.c.					[111]	46.3			
					[110]	41.9			
			e		[100]	205			

4. Iron [53, 54]	.....	Ellipsoids	...	.....	[100]	3.84	.....	.....	GM, PA
a = 2.86					[010]	4.08			
b.c.c.					[111]	4.11	0.35		
					[110]	3.89			
					[101]	4.10			
		Surface (1) centered at Γ	...	.....	[100]	23.8			
					[111]	28.0	0.58		
		Surface (2) centered at Γ	...	.....	[111]	369	2.6		
					[110]	347	2.6		
		Octahedron centered at H	...	.....	[111]	154	1.7		
		Surface centered at Γ (minority)	...	.....	[111]	51.8	2.8		
		?	...	.....	[111]	11.3			
5. Lutetium [96]	.....	Preliminary results	...	.....	[0001]	3.8			
6. Molybdenum [55] [98, 100]	.....	Ellipsoids centered at N	h	.....	[100]	23	.....	.....	GM, MA
a = 3.147 (R.T.)					[001]	31			
b.c.c.					[110]	26	0.34		
					[011]	~29			
					[101]	~39			
					[111]	24			
					[111]	31			
		Octahedron centered at H	h	.....	[100]	154 [56]	~1.0 [56]		
					[110]	~116			
					[111]	110	0.8-0.95 [56]		
		Jack centered at Γ	e	Neck	[100]	~12	~0.43		
					[110]	~32			
					[111]	36.5			
				Waists	[111]	80 [56]			
		Lenses lying along ΓH	e	.....	[100]	~5.3			
					[001]	~8.4	~0.44		
					[110]	~5.0			
					[101]	~5.8			
					[111]	5.5			
7. Nickel [57, 58]	.....	Pockets centered at X	h	.....	[100]	10.12[d]	1.0		
a = 3.5172 [5, 59]					[010]	24.9	1.9		
f.c.c.					[110]	21.9	1.4		
					[101]	14.2	1.35		
					[111]	15.8			
		Necks centered at L	e	.....	[110]	3.84	0.36		
					[111]	2.68	0.25		

[c] Linearly polarized spin-density wave Q‖[001].

[d] The dimensions of the hole pockets depend on the orientation of the magnetic field. Thus the de Haas–van Alphen frequencies cannot be referred to a simple rigid ellipsoidal model. See Hodge et al. [58].

TABLE 9d-3. ELECTRONIC STRUCTURE OF METALS (*Continued*)

Metal	Fermi surface nomenclature: Band	Fermi surface nomenclature: Description	Carrier	Orbit description	Magnetic field direction	F (in 10^8 Gauss)	Mass values, m^*/m: de Haas van Alphen	Mass values, m^*/m: Cyclotron resonance	Other experiments
II. TRANSITION METALS (*Cont.*):									
8. Niobium [60], [62], [99] a = 3.29 (R.T.) b.c.c.	.....	Ellipsoids centered at N	...	.....	..... ~[111]	63–86 [62]	~1.0 [61] 1.28 [62]	.....	GM
		Jungle gym	...	Minimum-arm cross section	[100]	14.5 [62]			
9. Osmium [63] a = 2.7304 (R.T.) c = 4.3097 h.c.p.	.....	Similar to Ruthenium	...	.....	[0001]	~210			
			...	.....	[0001]	~150			
					[0001]	~3			
10. Palladium [64, 65] a = 3.884 f.c.c.	.....	Closed surface centered at Γ	e	.....	[100]	275	2.0	.....	GM
					[110]	309	2.31		
		Ellipsoids centered at X	h	.....	[111]	244	1.95		
					[100]	8.95	1.05		
					[001]	5.71	0.625		
					[110]	8.95	1.05		
					[101]	6.84	0.770		
		Open surface	h	.....	[111]	7.49	0.862		
					[100]	27	2.37		
11. Platinum [66], [107] a = 3.907 [5] f.c.c.	.....	Closed surface centered at Γ	e	.....	[110]	.....	6.2	.....	GM
					[100]	290 [65]	2.44 [65]		
		Ellipsoids centered at X	h	.....	[110]	324 [65]	3.16 [65]		
					[111]	260 [65]	2.06 [65]		
					[100]	1.11 [67]			
					[001]	1.7 [67]			
		Open surface	h	.....	[111]	1.45 [65]	0.363 [65]		
					[100]	27.9 [65]	1.53 [65]		
					[110]	81.6 [65]	3.32 [65]		
12. Rhenium [68] a = 4.447 [69] c = 2.758 [69] h.c.p.	5	Ellipsoids centered at L	h	.....	[101]	68.1 [65]	3.62 [65]		
					[0001]	4.56			
					[10$\bar{1}$0]	0.77			
					[11$\bar{2}$0]	2.63			
	6	Dumbbells centered at L	h	.....	[0001]	7.6			
					[0001]	15.6			
				Rotated 30°	[10$\bar{1}$0]	16.2			
					[10.0]	14.3			
	7	Closed surface centered at L	h	Rotated 30°	[11$\bar{2}$0]	13.6			
				.....	[11$\bar{2}$0]	15.5			
				Rotated 60°	[10$\bar{1}$0]	79.7			
				Rotated 60°	[10$\bar{1}$0]	54.8			
					[11$\bar{2}$0]	38			

	8	Open cylindrical surface	*e*	.....	[0001]	90			
	7 and 8	.....	...	.....	~[11$\bar{2}$0]	300			
13. Rhodium [70, 71]	.....	Ellipsoids along Γ–L	...	.....	[100]	3.34	0.20		
a = 3.8044 (R.T.)					[110]	2.69	0.14		
f.c.c.					[101]	5.07	0.22		
					[111]	2.32	0.12		
					[111]	4.25	0.30		
		Ellipsoids along Γ–X	...	.....	[100]	15.6	0.35		
					[001]	24.6	0.42		
					[110]	17.5	0.43		
					[101]	26.3	~0.5		
					[111]	18.9	0.43		
		Closed surface along Γ–X (tentative)	...	.....	[110]	48.5	1.2		
		Closed surface centered at Γ (tentative)	...	.....	[111]	180	1.65		
14. Ruthenium [72]*	.....	Closed surface probably centered at Γ	*h*	.....	[0001]	~8			
a = 2.69844 (R.T.)					[1 00]	~15			
c = 4.27305					[11$\bar{2}$0]	~15			
h.c.p.		Two closed surfaces centered at Γ	*e*	.....	[0001]	160 210			
					[10$\bar{1}$0]	130–190			
					[11$\bar{2}$0]	130–200			
		Surface centered on line M–L	...	.....	[0001]	~20			
					[10$\bar{1}$0]	~7.5			
					[11$\bar{2}$0]	~8.0			
		Surface centered at L	...	.....	[10$\bar{1}$0]	~3.5			
					[1120]	~4			
15. Silver [73]	.....	Sphere with necks touching [111]	*e*	Neck	[111]	8.921 [49]	~0.4 [74]	.....	GM, MA, CR, ASE, MT
a = 4.069 [50]		Brillouin zone faces	...	Belly	[111]	460.0 [49]	~0.9 [74]		
f.c.c.					[100]	474.6 [97]			
				Dog's bone	[110]	201.6 [97]	~1.0 [74]		
				4-cornered rosette	[100]	196.3 [97]			
16. Tantalum [62], [75]	.....	Distorted ellipsoids centered at N	...	.....	.....	45–63 [62]	~0.8 [76] (1.1–1.25) [77]	.....	GM
a = 3.30 (R.T.)									
b.c.c.		Jungle gym	...	Minimum-arm cross section	[100]	~29 [62]			
17. Thorium [78]	.....	Butterfly-shaped pieces along [110]	*e*	.....	[100]	10.0 [79]	0.66 [79]		
a = 5.084 (R.T.)					[100]	11.9 [79]	0.58 [79]		
f.c.c.					[110]	2.0 [79]			
					[110]	9.6 [79]	0.58 [79]		
					[111]	11.7 [79]			

* Identification of orbits tentative.

TABLE 9d-3. ELECTRONIC STRUCTURE OF METALS (*Continued*)

Metal	Fermi surface nomenclature: Band	Fermi surface nomenclature: Description	Carrier	Orbit description	Magnetic field direction	F (in 10^6 Gauss)	Mass values, m^*/m: de Haas van Alphen	Mass values, m^*/m: Cyclotron resonance	Other experiments
II. TRANSITION METALS (*Cont.*):									
		Quasi-spherical surface centered at Γ	h	.....	[110]	24.8 [79]			
					[111]	24.8 [79]			
					[100]	22.1 [79]	0.75 [79]		
		Dumbbell-shaped pieces centered at L with axes along [111]	h	.....	[110]	19.9 [79]	0.58 [79]		
					[111]	22.5 [79]			
					[111]	10.9 [79]			
18. Tungsten [80, 81] $a = 3.162$ [80] b.c.c.	.....	Ellipsoids centered at N	h	.....	[110]	6.87	0.27	0.27 [82]	GM, MA, CR, SE
					[101]	8.03	0.32	0.32 [82]	
					[011]	9.22	0.36	0.36 [82]	
					[111]	7.03	0.287		
					[111]	7.66	0.287 [55]		
					[100]	5.93	0.28 [55]	0.23 [82]	
					[001]	8.54	0.37	0.33 [82]	
		Octahedron centered at H	h	.....	[100]	143.5	0.93	1.05 [82]	
					[111]	98.8	0.60	0.57 [82]	
					[110]	106.9	0.67	0.67 [82]	
		Jack centered at Γ	e	Necks	[100]	6.12	0.25		
					[111]	23.03			
					[110]	19.5	0.75 [55]		
				Ball of jack	[100]	21.81	0.58	0.54 [82]	
					[110]	22.84	0.60	0.55–0.58 [82]	
				Central orbit around jack body	[112]	69.1			
					[111]	63.8	0.9	0.83 [82]	
				Two-ball orbit	[100]	178.4	.....	2.86 [82]	
				Four-ball orbit	[110]	120.4	.....	1.83 [82]	
19. Vanadium [96] $a = 3.0259$ b.c.c.	.....	Preliminary results	...	Ellipsoids at N	[110]	66.75	1.78–2.3		
					[110]	55.5			
					[110]	52.7			
					[100]	60.3			
20. Ytterbium [17], [83] $a = 5.486$ [84] f.c.c.	.....	.....	...	.....	[100]	~52			
					[110]	~0.17			
					[112]	~0.17			
					[111]	1.4–1.8			
21. Zirconium [85], [114], [115] $a = 3.23$ $c = 5.146$ (R.T.) h.c.p.	3	Surface centered at Γ	h	.....	[0001]	~34.5 [86]			
					[11$\bar{2}$0]	~37 [86]			
					[10$\bar{1}$0]	~36 [86]			
	4		h		[0001]	~50 [86]			

	5	Multiply connected	e	.....	[0001]	~110 [86]			
					[0001]	~77 [86]			
					[0001]	~59 [86]			
III. Semimetals									
1. Antimony [87]	.....	Closed pockets centered at L	e	Minimum cross section	87.7°[g]	0.68	.....	.....	GM, MA, CR, MT
a = 4.3007				Maximum cross section	174.0°[g]	4.35			
c = 11.222 [88] (hexagonal axes)					Binary	3.6	0.084		
trigonal		Six equivalent ellipsoidal pockets centered on the mirror plane	h	Minimum cross section	53.0°[g]	0.613	0.069		
				Maximum cross section	148.8°[g]	1.98			
				Binary	.....	2.16	0.163		
2. Arsenic [89, 90]	.....	Three closed centrosymmetric pockets tilted 86.4° from trigonal	e	Minimum cross section	86.4°[g]	2.13	0.130	.....	MA, CR
trigonal				Maximum cross section	−9.0°[g]	9.58			
				Binary	.....	7.68			
		Six pockets connected by long thin necks	h	Neck minimum cross section	−9.6°[g]	0.0258			
				Neck	Trigonal	0.028			
				Principal pockets minimum cross section	37.25°[g]	1.49			
3. Bismuth [91], [113]	.....	Ellipsoids with one axis parallel to the binary axis and the other two tilted ~6° from the trigonal and bisectrix axes, respectively	e	.....	Binary	0.189	0.14 [92]	.....	GM, CR, MA, MT, H, SE, ASE
a = 4.53					Binary	0.0139	.....	.....	
c = 11.797 (hexagonal axes)					Bisectrix	0.0240	.....	.....	
trigonal					Bisectrix	0.012	0.009 [92]		
					Trigonal	0.084	0.11 [92]		
		Ellipsoid	h	.....	Binary	0.223			
					Bisectrix	0.223			
					Trigonal	0.0635	0.067		
4. Carbon (graphite) [93]	.....	Ellipsoidal surface centered at K along K–H	h[A]	.....	∥c	0.0625 [94]	0.057 [94]	.....	GM, MA, CR
a = 2.46					⊥c	0.77 [94]	0.68 [94]		
c = 6.70									
hex		Ellipsoidal surfaces along K–H	e[A]	.....	∥c	0.046 [94]	0.039 [94]		
					⊥c	0.67 [94]	0.47 [94]		
		Caps at ends of electron surfaces above (minority carriers)	e[A]	.....	∥c	0.0074 [94]	0.0023 [94]		
					⊥c	0.067 [94]	0.017 [94]		

[f] Frequencies associated with dumbbell and quasi-sphere merge at [100]

[g] Tilt from trigonal in trigonal-bisectrix plane.

[A] Experiments on pyrolytic graphite [95] suggest that the surfaces attributed to holes should be attributed to electrons and vice versa.

References for Section 9d and Table 9d-3

1. Gold, A. V.: "Solid State Physics," vol. 1, pp. 120–126, J. F. Cochran and R. Haering, eds, Gordon and Breach, Science Publishers, Inc., New York, 1968.
2. Pearson, W. B.: "Lattice Spacings and Structure of Metals and Alloys," Pergamon Press, New York, 1958.
3. Koster, G. F.: *Solid State Phys.* **5**, 173–256 (1957).
4. Larson, C. O., and W. L. Gordon: *Phys. Rev.* **156**, 703 (1967).
5. Armstrong, R. W.: Private communication.
6. Priestley, M. G.: *Phil. Mag.* **7**, 1205 (1962).
7. Anderson, J. R., and S. Lane: *Phys. Rev.* **B2**, 298 (1970).
8. Spong, F. W., and A. F. Kip: *Phys. Rev.* **137**, A431 (1965).
9. Tripp, J. H., W. L. Gordon, P. M. Everett, and R. W. Stark: *Phys. Letters* **26A**, 98 (1967).
10. Watts, B. R.: *Proc. Roy. Soc* (*London*), ser. **A**, **282**, 521 (1964).
11. Alekseyevsky, N. E., and V. S. Yegorov: *Zh. Eksperim. i Teor. Fiz.* **55**, 1153 (1968).
12. Jones, R. C., R. G. Goodrich, and L. M. Falicov: *Phys. Rev.* **174**, 672 (1968).
13. Naberezhnykh, V. P., A. A. Mar'Yakhin, and V. L. Mel'Nik: *Soviet Phys.—JETP* **25**, 403 (1967).
14. Tsui, D. C., and R. W. Stark: *Phys. Rev. Letters* **16**, 19 (1966).
15. Grassie, A. D. C.: *Phil. Mag.* **9**, 847 (1964).
16. Shaw, M. P., T. G. Eck, and D. A. Zych: *Phys. Rev.* **142**, 406 (1966).
17. Condon, J. H., and J. A. Marcus: *Phys. Rev.* **134**,A 446 (1964).
18. Okumura, K., and I. M. Templeton: *Proc. Roy. Soc.* (*London*), ser. A, **287**, 89 (1965).
19. Goldstein, A., and S. Foner: *Phys. Rev.* **146**, 442 (1966).
20. Moore, T. W.: *Phys. Rev.* **165**, 864 (1968).
21. Hughes, A. J., and J. P. G. Shepherd: *Journal of Physics C* (*Solid State Physics*) **2**, 661 (1969).
22. O'Sullivan, W. J., J. E. Schirber, and J. R. Anderson: *Phys. Letters* **27A**, 144 (1968)
23. Mina, R. T., and M. S. Khaikin: *Soviet Phys—JETP* **24**, 42 (1966).
24. Anderson, J. R., and A. V. Gold: *Phys. Rev.* **139**, A1459 (1965).
25. Phillips, R. A., and A. V. Gold: *Phys. Rev.*, **178**, 932 (1969).
26. Anderson, J. R., W. J. O'Sullivan, and J. E. Schirber: To be published.
27. Mina, R. T., and M. S. Khaikin: *Soviet Phys.—JETP* **18**, 896 (1964).
28. Anderson, J. R., and D. C. Hines: *Phys. Rev.* **B2**, 4752 (1970).
29. Stark, R. W.: *Phys. Rev.* **162**, 589 (1967).
30. Brandt, G. B., and J. A. Rayne: *Phys. Rev.* **148**, 644 (1966).
31. Dishman, J. M., and J. A. Rayne: *Phys. Rev.* **166**, 728 (1968).
32. Thomas, R. L., and G. Turner: *Phys. Rev.* **176**, 768 (1968).
33. Barrett, C. S.: *Acta Cryst.* **9**, 671 (1956).
34. Shoenberg, D., and P. J. Stiles: *Proc. Roy. Soc.* (*London*), ser. A, **281**, 62 (1964).
35. Grimes, C. C., and A. F. Kip: *Phys. Rev.* **132**, 1991 (1963).
36. Lee, M. J. G.: *Proc. Roy. Soc.* (*London*), ser. A., **295**, 440 (1966).
37. Aleksandrov, B. N.: *Soviet Phys. JETP*—**26**, 508 (1968).
38. Barrett, C. S.: *Phys. Rev.* **110**, 1071 (1968).
39. Priestley, M. G.: *Phys. Rev.* **148**, 580 (1966).
40. Anderson, J. R., J. E. Schirber, and D. Stone: *Grenoble High Pressure Conference Proceedings* **188**, 131 (1970).
41. Craven, J. E., and R. W. Stark: *Phys. Rev.* **168**, 849 (1968).
42. Statleu, M. D., and A. R. de Vrooman: *Phys. Stat. Solidi* **23**, 675, 683 (1967).
43. Vaughan, R. W., and D. D. Elleman: *Bull. APS* **13**, 1454 (1968).
44. Ventsel, V. A., A. I. Likhter, and A. V. Rudnex: *Soviet Phys—JETP* **26**, 73 (1968).
45. Ventsel, V. A.: *Zh. Eksperim. i Teor. Fiz.* **55**, 1191 (1968).
46. Higgins, R. J., J. A. Marcus, and D. H. Whitmore: *Phys. Rev.* **137A**, 1172 (1965).
47. Shaw, M. P., P. I. Sumpath, and T. G. Eck: *Phys. Rev.* **142**, 399 (1966).
48. Graebner, J., and J. A. Marcus: *Phys. Rev.* **175**, 659 (1968).
49. Jan, J. P., and I. M. Templeton: *Phys. Rev.* **161**, 556 (1967).
50. Shoenberg, D.: *Phil. Trans. Roy. Soc. London*, ser. A, **255**, 85 (1966).
51. Joseph, A. S., A. C. Thorsen, E. Gertner, and L. E. Valby: *Phys. Rev.* **148**, 569 (1966).
52. Joseph, A. S., A. C. Thorsen, and F. A. Blum: *Phys. Rev.* **140**, A2046 (1965).
53. Panousis, P. T.: *USAEC Rept.* IS-T-175, 1967; and to be published.
54. Gold, A. V.: *J. Appl. Phys.* **39**, 768 (1968).
55. Sparlin, D. M., and J. A. Marcus: *Phys. Rev.* **144**, 484 (1966).
56. Meyers, A., and G. Leaver: "Proceedings 10th Conference on Low Temperature Physics," vol. 3, p. 290, Viniti Publishing House, Moscow, 1967.
57. Tsui, D. C.: *Phys. Rev.* **164**, 669 (1967).

58. Hodges, L., D. R. Stone, and A. V. Gold: *Phys. Rev. Letters* **19**, 655 (1967).
59. Heumann, T.: *Naturwissenschaften* **32**, 296 (1944).
60. Fawcett, E., W. A. Reed, and R. R. Soden: *Phys. Rev.* **159**, 513 (1967).
61. Thorsen, A. C., and T. G. Berlincourt: *Phys. Rev. Letters* **7**, 244 (1961).
62. Halloran, M., J. H. Condon, J. E. Graebner, J. E. Kunzler, and F. S. L. Hsu, *Phys. Rev.* **1B**, 366 (1970).
63. Kamm, G. N., and J. R. Anderson, *Phys. Rev.* **B2**, 2944 (1970).
64. Vuillemin, J.: *Phys. Rev.* **144**, 396 (1966).
65. Windmiller, L. R., J. B. Ketterson, and S. Hornfeldt, *J. Appl. Phys.* **40**, 1291 (1969).
66. Windmiller, L. R., and J. B. Ketterson: *Phys. Rev. Letters* **21**, 1076 (1968).
67. Stafleu, M. D., and A. R. DeVroomen: *Phys. Letters* **19**, 81 (1965).
68. Thorsen, A. C., A. S. Joseph, and L. E. Valby: *Phys. Rev.* **150**, 523, (1966).
69. Matteiss, L. F.: *Phys. Rev.* **151**, 450 (1966).
70. Coleridge, P. T.: *Proc. Roy. Soc.* (*London*), ser. A, **295**, 458 (1966).
71. Ketterson, J. B., L. R. Windmiller, and S. Hornfeldt: *Phys. Letters* **26A**, 115 (1968).
72. Coleridge, P. T., *Phys. Letters* **22**, 367 (1966) and *Journal of Low Temperature Physics* **1**, 577 (1969).
73. Lewis, P. E., and P. M. Lee: *Phys. Rev.* **175**, 795 (1968).
74. Joseph, A. S., and A. C. Thorsen: *Phys. Rev.* **A138**, 1159 (1965).
75. Fawcett, E., W. A. Reed, and R. R. Soden: *Phys. Rev.* **159**, 533 (1967).
76. Thorsen, A. C., and T. G. Berlincourt: *Phys. Rev. Letters* **7**, 244 (1961).
77. Condon, J. H.: *Bull. Am. Phys. Soc.* **11**, 170 (1966).
78. Thorsen, A. C., A. S. Joseph, and L. E. Valby: *Phys. Rev.* **162**, 574 (1967).
79. Boyle, D. J.: *USAEC Rept.* IS-T-261, 1968; D. J. Boyle and A. V. Gold: *Phys. Rev. Letters* **22**, 461 (1969).
80. Girvan, R. F., A. V. Gold, and R. A. Phillips: *J. Phys. Chem. Solids* **29**, 1485 (1968).
81. Girvan, R. F.: *USAEC Rept.* IS-T-103, 1966.
82. Walsh, W. M., Jr.: In "Solid State Physics, vol. 1, p. 160, J. F. Cochran and R. Haering, eds., Gordon and Breach, Science Publishers, Inc., New York, 1968.
83. Tanuma, S., Y. Ishizawa, H. Nagasawa, and T. Sugawava: *Phys. Letters* **25A**, 669 (1967).
84. Gschneidner, K. A., Jr.: "Rare Earth Alloys," D. Van Nostrand Company, Inc., Princeton, N.J., 1961.
85. Loucks, T. L.: *Phys. Rev.* **159**, 544 (1967).
86. Thorsen, A. C., and A. S. Joseph: *Phys. Rev.* **131**, 2078 (1963).
87. Windmiller, L. R.: *Phys. Rev.* **149**, 472 (1966).
88. Barrett, C. S., P. Cucka, and K. Haefner: *Acta Cryst.* **16**, 151 (1963).
89. Vanderkooy, J., and W. R. Datars: *Phys. Rev.* **156**, 671 (1967).
90. Priestley, M. G., L. R. Windmiller, J. B. Ketterson, and Y. Eckstein: *Phys. Rev.* **154**, 671 (1967).
91. Bhargava, R. N.: *Phys. Rev.* **156**, 785 (1967).
92. Kao, Y. H.: *Phys. Rev.* **129**, 1122 (1963)
93. McClure, J. W., and W. J. Spry: *Phys. Rev.* **165**, 809 (1968).
94. Soule, D. E.: *IBM J. Res. Develop.* **8**, 268 (1964).
95. Schroeder, P. P., M. S. Dresselhaus, and A. Javan: *Phys. Rev. Letters* **20**, 1292 (1968).
96. Phillips, R. A.: Private communication.
97. O'Sullivan, W. J., A. C. Switendick, and J. E. Schirber: *Phys. Rev.* **1B**, 1443 (1970).
98. Boiko, V. V., V. A. Gasparov, I. G. Gverdtsiteli, *Soviet Phys. JETP* **29**, 267 (1969).
99. Scott, G. B., and M. Springford, *Proc. Roy. Soc.* (*London*) **A320**, 115 (1970).
100. Leaver, G., and A. Myers, *Phil. Mag.* **19**, 465 (1969).
101. Henmann, R., *Phys. Stat. Sol.* **25**, 661 (1968).
102. Cucka, P., and C. S. Barrett, *Acta Cryst.* **15**, 865 (1962).
103. Arko, A. J., J. A. Marcus, and W. A. Reed, *Phys. Rev.* **185**, 901 (1969).
104. Reed, W. A., and E. Fawcett, *Proc. of the Int'l Conf. on Magnetism* (*Inst. of Phys. and Phys. Soc., London*) 120 (1964).
105. Vaughan, R. W., D. D. Elleman, and D. G. McDonald, *J. Phys. Chem. Solids* **31**, 117 (1970).
106. Glinski, R., and I. M. Templeton, *Jour. of Low Temp. Phys.* **1**, 223 (1969).
107. Ketterson, J. B., and L. R. Windmiller, *Phys. Rev.* **2B**, 4813 (1970).
108. McEwen, K. A., *Phys. Letters* **30A**, 77 (1969).
109. Volkenshtein, N. V., V. A. Vovosydov, V. E. Startsev, *Soviet Phys. JETP* **31**, 862 (1970).
110. Anderson, J. R., and D. R. Stone—private communication.
111. Ishizawa, Y., and A. E. Dixon, *Bull. Am. Phys. Soc.* **16**, 82 (1971).
112. Capocci, F. A., P. M. Holtham, D. Parsons, and M. G. Priestley, *Jour. of Physics C* (*Solid State Physics*) **3**, 2081 (1970).

113. Brown, Rodney D., III, *Phys. Rev.* **B2**, 928 (1970).
114. Everett, P. M., *Bull. Am. Phys. Soc.* **16**, 336 (1971).
115. Schirber, J. E., *Phys. Letters* **33A**, 172 (1970).
116. Grodski, J. J., and A. E. Dixon, *Bull. Am. Phys. Soc.* **16**, 82 (1971).
117. Tanuma, S., W. R. Datars, H. Doi, and A. Dunsworth, *Solid State Comm.* **8**, 1107 (1970).
118. Barrett, C. S., *J. Chem. Phys.* **25**, 1123 (1956).