

Survey

Part a

- 1 Fe oxides and Fe-Me-O compound systems (except ferrites, garnets and perovskites)
- 2 Compounds with lanthanide and actinide elements of some special structure types (except garnets and perovskites)
- 3 Perovskites
- 4 Yttrium and rare earth iron garnets

Part b

- 5 Non-iron garnets
- 6 Spinels
- 7 Hexagonal ferrites
- 8 Index of substances

Übersicht

Teil a

- 1 Fe-Oxide und Fe-Me-O-Verbindungen (ausgenommen Ferrite, Granate und Perowskite)
- 2 Lanthaniden- und Aktiniden-Verbindungen einiger spezieller Strukturtypen (ausgenommen Granate und Perowskite)
- 3 Perowskite
- 4 Yttrium- und Selten-Erd-Eisengranate

Teil b

- 5 Nichteisengranate
- 6 Spinelle
- 7 Hexagonale Ferrite
- 8 Substanzenverzeichnis

Table of contents — Inhaltsverzeichnis

5 Non-iron garnets

By W. GRÄPER, Technische Hochschule Darmstadt, Germany

5.0	Introduction — Einleitung	1
5.1	Magnetic susceptibility data	2
	A. Paramagnetic susceptibility above the ordering temperature	2
	B. Susceptibility data at low temperatures in the vicinity of an ordering temperature	4
	C. Summary of susceptibility parameters and transition temperatures	7
5.2	Magnetization	8
5.3	Crystallographic and structural data	12
	A. Location and environment of ions in the unit cell of the garnet lattice	12
	B. Oxygen coordinates, interionic spacings, and angles of compounds with garnet structure	13
	C. Lattice parameters and density of garnet systems	15
	D. Magnetic structure of DyAlG and ErGaG	16
5.4	Results of magnetic resonance experiments	18
	A. Paramagnetic resonance of rare earth impurities in diamagnetic garnets	18
	B. Paramagnetic resonance of impurities with d electrons in diamagnetic garnets	20
	C. Paramagnetic resonance of impurities in paramagnetic garnets	23
	D. Nuclear magnetic resonance experiments	24
5.5	Results from optical spectra	26
	A. Crystal field analysis and parameters	26
	B. Summary of references for some results from optical measurements	27
5.6	Spin-lattice relaxation of paramagnetic ions in garnets	28
	A. Temperature dependence of the spin-lattice relaxation time T_1	28
	B. The dependence of the spin-lattice relaxation time on magnetic field	33
5.7	Thermal properties near the transition temperature	34
	A. Specific heat of rare earth gallium garnets	34
	B. Specific heat of two rare earth aluminium garnets	36
5.8	Faraday rotation in paramagnetic non-iron garnets	38
5.9	Magnetomechanical properties	41
	A. Magnetostriction of rare earth gallates and germanates with a garnet structure	41
	B. Microscopic magnetoelastic tensors for paramagnetic rare earth ions in diamagnetic garnet hosts	42
	C. Magnetoacoustic properties	42
5.10	Neutron diffraction results near and below the magnetic ordering point	43
5.11	References	45
	A. Primary references	45
	B. Supplementary references	47

6 Spinel

	Arrangement — Anordnung	50
6.0	Introduction — Einleitung	51
	By B. A. CALHOUN, IBM, Poughkeepsie, N. Y., USA	
6.0.1	General remarks — Allgemeine Bemerkungen	51
6.0.2	Structure — Struktur	51
6.1	Fe ³⁺ spinels (cubic ferrites)	54
6.1.0	Ferrimagnetism; magnetic behaviour of ferrites — Ferrimagnetismus; magnetisches Verhalten der Ferrite	54
	By B. A. CALHOUN, IBM, Poughkeepsie, N. Y., USA	

6.1.0.1	<i>A-B</i> exchange interaction; magnetization — (<i>A-B</i>)-Austauschwechselwirkung; Magnetisierung	54
6.1.0.2	<i>A-A</i> , <i>B-B</i> exchange interaction; magnetic order — (<i>A-A</i>)-, (<i>B-B</i>)-Austauschwechselwirkung; magnetische Ordnung	56
6.1.0.3	Hyperfine interactions (Mössbauer and NMR methods) — Hyperfeinwechselwirkungen (Mössbauer- und NMR-Verfahren)	57
6.1.0.4	Anisotropy — Anisotropie	59
6.1.0.5	Ferrimagnetic resonance — Ferrimagnetische Resonanz	60
6.1.0.6	Accuracy — Genauigkeit	63
6.1.0.7	References for 6.0 and 6.1.0	64
6.1.1	$\text{Fe}^{2+}\text{-Fe}^{3+}$ spinels (magnetite) and $\text{Fe}^{2+}\text{-Fe}^{3+}$ spinels with substitutions	65
	By R. A. LEFEVER, Sandia Corporation, Albuquerque, N. M., USA	
6.1.1.1	Tables and figures.	65
6.1.1.2	References for 6.1.1.1	73
6.1.2	NiFe^{3+} spinels (Ni ferrites) and NiFe^{3+} spinels with substitutions	75
	By T. R. Mc GUIRE, IBM, Thomas J. Watson Research Center, Yorktown Heights, USA, and E. L. BOYD, IBM, Component Division, Hopewell Junction, N. Y., USA	
6.1.2.0	Introduction	75
6.1.2.1	Ni ferrite NiFe_2O_4	75
6.1.2.2	Zn substituted Ni ferrite	82
6.1.2.3	Ni ferrite with Co substitutions	89
6.1.2.4	Dilute Mn and Co substitutions in Ni ferrite and Ni ferrite aluminate	91
6.1.2.5	Ge substituted Ni ferrite	96
6.1.2.6	Ni ferrite chromite	97
6.1.2.7	Ni ferrite vanadate	99
6.1.2.8	Ni ferrite aluminate	100
6.1.2.9	Ni gallate ferrite	103
6.1.2.10	References for 6.1.2.0...6.1.2.9	103
6.1.3	Mn-Fe^{3+} spinels (Mn ferrites) and Mn-Fe^{3+} spinels with substitutions	106
	By R. VAUTIER and M. PAULUS, Centre National de la Recherche Scientifique, Bellevue, France	
6.1.3.0	Introduction	106
6.1.3.1	Phase equilibria and structure	106
6.1.3.1.1	Phase equilibria	106
6.1.3.1.2	Equilibrium oxygen partial pressure (Errata see p. XVI).	109
6.1.3.1.3	Lattice constants (Errata see p. XVI)	117
6.1.3.1.4	Ionic distribution	124
6.1.3.1.5	Spin arrangement	127
6.1.3.2	Thermal properties	128
6.1.3.2.1	Specific heat	128
6.1.3.2.2	Thermal conductivity	129
6.1.3.2.3	Thermal expansion	130
6.1.3.2.4	Diffusion and oxidation coefficients	130
6.1.3.2.5	Ferrite thermodynamics	131
6.1.3.2.6	Solid crystal growth	133
6.1.3.2.7	Reactivity and sintering	135
6.1.3.3	Mechanical properties	136
6.1.3.4	Electrical properties	139
6.1.3.4.1	Electrical resistivity	139
6.1.3.4.2	Magnetoresistance and thermomagnetic effect	147
6.1.3.4.3	Hall effect	149
6.1.3.4.4	Seebeck effect	151
6.1.3.5	Spontaneous magnetization	152
6.1.3.5.1	Saturation moment at 0 °K	152
6.1.3.5.2	Magnetization as a function of temperature	155
6.1.3.5.3	Magnetization in the region of the Curie point	156
6.1.3.5.4	Curie temperatures	158
6.1.3.6	Magnetocrystalline anisotropy	160
6.1.3.6.1	Magnetocrystalline anisotropy in Mn ferrite	160
6.1.3.6.2	Magnetocrystalline anisotropy in Mn ferrite with substitutions	164
6.1.3.6.3	Linear magnetostriction	170
6.1.3.6.4	Magnetic annealing	173

6.1.3.7	Domains and domain walls	176
6.1.3.7.1	Domain wall motion experiments	176
6.1.3.7.2	Domain structure	179
6.1.3.8	Response of magnetization to a field	179
6.1.3.8.1	High temperature susceptibility	180
6.1.3.8.2	High field susceptibility in the ferrimagnetic state	181
6.1.3.8.3	Permeability variation with composition, impurities, irradiation, and grain size	181
6.1.3.8.4	Permeability vs. temperature	184
6.1.3.8.5	Permeability vs. pressure	186
6.1.3.8.6	Permeability vs. frequency	187
6.1.3.8.7	After-effect, disaccommodation, and viscosity	188
6.1.3.9	Microwave properties	200
6.1.3.9.1	Resonance line width	200
6.1.3.9.2	Spectroscopic splitting factor	206
6.1.3.10	Optical properties (absorption)	207
6.1.3.11	References for 6.1.3.0...6.1.3.10	208
6.1.4	Mg-Fe ³⁺ spinels (Mg ferrites) and Mg-Fe ³⁺ spinels with substitutions	216
	By C. J. KRIESSMAN, Ferroxcube Corporation, Saugerties, N. Y., USA, and A. P. GREIFER, Univac, Blue Bell, Pa., USA	
6.1.4.1	Mg ferrite MgFe ₂ O ₄	216
6.1.4.2	MgMn ferrites and MgMn ferrites with substitutions	228
6.1.4.2.0	Introductory remarks	228
6.1.4.2.1	Crystallographic properties, physical properties, phase data, magnetic moments	228
6.1.4.2.2	Anisotropy	239
6.1.4.2.3	Losses	243
6.1.4.2.4	Square-loop properties	247
6.1.4.2.5	Microwave properties	268
6.1.4.3	Other ferrite systems containing Mg	280
6.1.4.3.0	Introductory remarks	280
6.1.4.3.1	Systems containing Zn ²⁺	280
6.1.4.3.2	Systems containing Cu ²⁺	283
6.1.4.3.3	Systems containing Ni ²⁺	286
6.1.4.3.4	Systems containing Al ³⁺	290
6.1.4.3.5	Systems containing Cr ³⁺	296
6.1.4.3.6	Systems containing Al ³⁺ + Cr ³⁺	301
6.1.4.3.7	Other systems containing trivalent and higher valency cations	302
6.1.4.3.8	Systems containing F ⁻ and Li ⁺	310
6.1.4.4	References for 6.1.4.1...6.1.4.3	311
6.1.5	Zn-Fe ³⁺ spinels (Zn ferrites) and Zn-Fe ³⁺ spinels with substitutions	315
	By V. J. FOLEN, U. S. Naval Research Laboratory, Washington, D. C., USA	
6.1.5.1	Zn, Zn-Fe, Zn-Ti, Zn-Li, Zn-Ti-Li, Zn-Cd, Zn-Mg, Zn-Co, and Zn-Cu ferrites	315
6.1.5.2	Zn-Ni, Zn-Ni-Ge, and Zn-Ni-Sb ferrites	320
6.1.5.3	References for 6.1.5.1 and 6.1.5.2	324
6.1.6	Li-Fe ³⁺ spinels (Li ferrites) and Li-Fe ³⁺ spinels with substitutions	325
	By V. J. FOLEN, U. S. Naval Research Laboratory, Washington, D. C., USA	
6.1.6.1	Li ferrite	325
6.1.6.2	Li-Cr ferrites	332
6.1.6.3	Li-Zn, Li-Zn-Co, Li-Ti, Li-Zn-Ti, and Li-Zn-Ti-Al-Mn ferrites	334
6.1.6.4	Li-Al, Li-Ga, Li-Cd ferrites and Li-Fe ferrites	338
6.1.6.5	Li-Mn, Li-V, and Li-Ge ferrites	341
6.1.6.6	References for 6.1.6.1...6.1.6.5	342
6.1.7	Cu-Fe ³⁺ spinels (Cu ferrites) and Cu-Fe ³⁺ spinels with substitutions	343
	By V. J. FOLEN, U. S. Naval Research Laboratory, Washington, D. C., USA	
6.1.7.1	Cu ferrite CuFe ₂ O ₄	343
6.1.7.2	Cu-Zn and Cu-Cd ferrites	351
6.1.7.3	Cu-Cr ferrites	356
6.1.7.4	Cu-Mg ferrites	357
6.1.7.5	Other ferrites, oxide compounds, and oxide mixtures containing Cu	360
6.1.7.6	References for 6.1.7.1...6.1.7.5	365

6.1.8 Co-Fe ³⁺ spinels (Co ferrites) and Co-Fe ³⁺ spinels with substitutions	366
By V. J. FOLEN, U. S. Naval Research Laboratory, Washington, D. C., USA	
6.1.8.1 Co ferrite	366
6.1.8.2 Co ferrite and Co-Fe mixed oxides	377
6.1.8.3 Co-Zn ferrites	384
6.1.8.4 Co-Cd, Co-Mg, Co-Ni, and Co-Cr ferrites	391
6.1.8.5 References for 6.1.8.1...6.1.8.4	392
6.2 Cr spinels — Cr Spinelle	394
6.2.1 Cr Oxid-Spinelle	394
By D. BONNENBERG, Technische Hochschule Aachen, Germany, and H. P. J. WIJN, Philips Research Laboratories, Eindhoven, Netherlands	
6.2.1.1 Binäre Cr Oxid-Spinelle	394
6.2.1.2 Ternäre und quarternäre Cr Oxid-Spinelle	404
6.2.1.3 Literatur zu 6.2.1.1 und 6.2.1.2	418
6.2.2 Cr sulfide, selenide and telluride spinels	619
By V. J. FOLEN and G. H. STAUSS, U. S. Naval Research Laboratory, Washington, D. C., USA	
6.2.2.1 Comparison of the crystallographic, electrical, and magnetic properties of Cr spinel containing S, Se and Te	619
6.2.2.2 Comparative properties of CdCr ₂ Se ₄ , CdCr ₂ S ₄ , HgCr ₂ Se ₄ , and HgCr ₂ S ₄	621
6.2.2.3 Cd-Cr selenide spinel	622
6.2.2.4 Cd-Cr selenide spinel with substitutions	625
6.2.2.5 Cd-Cr sulfide spinel and substituted compounds	629
6.2.2.6 Hg-Cr selenide, Hg-Cr sulfide spinels and their substituted compounds	632
6.2.2.7 Cu-Cr S, Se and Te spinels	634
6.2.2.8 Cu-Cr S, Se and Te spinels with substitutions.	638
6.2.2.9 Fe-Mn-, Co- and Zn-Cr S and Se spinels and their substituted compounds	642
6.2.2.10 References for 6.2.2.1...6.2.2.9	645
6.3 Andere Spinelle — Further spinels	422
By D. BONNENBERG, Technische Hochschule Aachen, Germany, and H. P. J. WIJN Philips Research Laboratories, Eindhoven, Netherlands	
6.3.1 V Spinelle und substituierte V Spinelle	422
6.3.1.1 V Spinelle mit V ³⁺	422
6.3.1.2 V Spinelle mit V ⁴⁺	426
6.3.1.3 V Spinelle mit V ⁵⁺	430
6.3.1.4 V Spinelle mit sowohl V ³⁺ als auch V ⁴⁺	430
6.3.2 Ge Spinelle und substituierte Ge Spinelle	436
6.3.3 Rh Spinelle und substituierte Rh Spinelle	441
6.3.4 Literatur zu 6.3.1...6.3.3	444
6.3.5 Al Spinelle und substituierte Al Spinelle	446
6.3.6 Ga Spinelle und substituierte Ga Spinelle	467
6.3.7 In Spinelle und substituierte In Spinelle	474
6.3.8 Literatur zu 6.3.5...6.3.7	476
6.3.9 Co Spinelle und substituierte Co Spinelle	481
6.3.10 Ni Spinelle und substituierte Ni Spinelle	488
6.3.11 Te Spinelle und substituierte Te Spinelle	488
6.3.12 Mn Spinelle und substituierte Mn Spinelle	488
6.3.13 Ti Spinelle und substituierte Ti Spinelle	512
6.3.14 Literatur zu 6.3.9...6.3.13	528
6.3.15 Mo Spinelle und substituierte Mo Spinelle	533
6.3.16 W Spinelle und substituierte W Spinelle	533
6.3.17 Nb Spinelle und substituierte Nb Spinelle	533
6.3.18 Zr Spinell	534
6.3.19 Sb Spinelle und substituierte Sb Spinelle	534
6.3.20 Sn Spinelle und substituierte Sn Spinelle	535
6.3.21 Si Spinelle und substituierte Si Spinelle	543
6.3.22 Literatur zu 6.3.15...6.3.21	545

7 Hexagonal ferrites

By H. P. J. WIJN, Philips Research Laboratories, Eindhoven, Netherlands

7.0	Introduction — Einleitung	547
7.1	Quantities and units — Größen und Maßsysteme	547
7.2	List of symbols — Symbolliste	552
7.3	Chemical compositions and phase diagrams of hexagonal ferrites	555
7.4	Crystal structures	557
7.5	Paramagnetic properties of ferrites with hexagonal crystal structures	561
7.6	M (magnetoplumbite)-type ferrites	562
7.6.1	Survey of the chemical substitutions in the M structure and room temperature lattice constants	562
7.6.2	Electric and dielectric properties of ferrites with M structure	564
7.6.3	Mössbauer spectra, saturation magnetization, and Curie temperature of ferrites with M structure	567
7.6.4	Effective spectroscopic splitting factor g_{eff} of ferrites with M structure	573
7.6.5	Magneto-crystalline anisotropy of ferrites with M structure	573
7.6.6	Hysteresis properties of ferrites with M structure	577
7.6.7	High-frequency magnetic properties of ferrites with M structure	580
7.6.7.1	Magnetic spectrum of ferrites with M structure	580
7.6.7.2	Line width of the ferromagnetic resonance of ferrites with M structure	583
7.7	W-type ferrites	584
7.7.1	Survey of chemical substitutions in the W structure	584
7.7.2	Electric and dielectric properties of ferrites with W structure	585
7.7.3	Saturation magnetization and Curie temperature of ferrites with W structure	586
7.7.4	Effective spectroscopic splitting factor g_{eff} of ferrites with W structure	588
7.7.5	Magneto-crystalline anisotropy of ferrites with W structure	588
7.7.6	Magnetostriction of ferrites with W structure	592
7.7.7	High-frequency magnetic properties of ferrites with W structure	593
7.8	Y-type ferrites	593
7.8.1	Lattice parameters of ferrites with Y structure	593
7.8.2	Electric and dielectric properties of ferrites with Y structure	593
7.8.3	Mössbauer spectra, saturation magnetization, spectroscopic splitting factor, and Curie temperature of ferrites with Y structure	594
7.8.4	Magneto-crystalline anisotropy of ferrites with Y structure	597
7.8.4.1	Magneto-crystalline anisotropy derived from static measurements	597
7.8.4.2	Magneto-crystalline anisotropy field derived from the ferromagnetic resonance frequency	598
7.8.5	Hysteresis properties of ferrites with Y structure	599
7.8.6	High-frequency magnetic properties of ferrites with Y structure	600
7.8.6.1	Magnetic spectrum of the initial permeability of ferrites with Y structure	600
7.8.6.2	Ferromagnetic resonance properties of ferrites with Y structure	600
7.8.6.3	Non-linear effects in the ferromagnetic resonance of ferrites with Y structure	603
7.9	Z-type ferrites	606
7.9.1	Lattice parameters of ferrites with Z structure	606
7.9.2	The resistivity of ferrites with Z structure	606
7.9.3	Saturation magnetization and Curie temperature of ferrites with Z structure	606
7.9.4	Magneto-crystalline anisotropy of ferrites with Z structure	607
7.9.5	High-frequency magnetic properties of ferrites with Z structure	608
7.10	U-type ferrites	608
7.11	Calcium ferrites	609
7.12	References for 7	614

8	Index of substances for III/4a and III/4b	647
----------	--	------------