

Volume 12
Magnetic and Other Properties of Oxides and Related Compounds

Subvolume B
Part B: Spinels, Fe Oxides, and Fe-Me-O Compounds

Introductory material

3	Fe oxides and Fe-Me-O compounds (R. LEFEVER)	1
3.0	Introduction	1
3.0.1	General remarks	1
3.0.2	List of frequently used symbols and abbreviations	1
3.1	Fe oxides	2
3.1.1	Wüstite Fe_xO and wüstite with substitutions	2
3.1.1.1	Data	2
3.1.1.2	References for 3.1.1	6
3.1.2	Hematite $\alpha\text{-Fe}_2\text{O}_3$, and hematite with substitutions	7
3.1.2.1	Data	7
3.1.2.2	References for 3.1.2	19
3.1.3	Maghemite $\gamma\text{-Fe}_2\text{O}_3$	21
3.1.3.1	Data	21
3.1.3.2	References for 3.1.3	26
3.2	Fe-Me-O compounds	27
3.2.1	Data	27
3.2.2	References for 3.2	51
4	Spinels	54
4.0	Structure table of spinels (H. VON PHILIPSBORN, L. TREITINGER)	54
4.1	Fe^{3+} spinels	55
4.1.1	$\text{Fe}^{2+}\text{-Fe}^{3+}$, spinels (magnetite) and $\text{Fe}_{2+}\text{-Fe}_{3+}$ spinels with substitutions (R. LEFEVER)	55
4.1.1.0	Introduction	55
4.1.1.0.1	Special remarks	55
4.1.1.0.2	List of frequently used symbols and abbreviations	55
4.1.1.1	Summary of physical and magnetic properties	58
4.1.1.2	Magnetic order and magnetization	59
4.1.1.3	Magnetocrystalline anisotropy	61
4.1.1.4	Magnetostriction and elastic constants	62
4.1.1.5	Nuclear magnetic resonance	64
4.1.1.6	Mössbauer data	65
4.1.1.7	Optical and thermal properties	74
4.1.1.8	Electrical properties	77
4.1.1.9	Phase diagrams	84
4.1.1.10	References for 4.1.1.0 - 4.1.1.9	84
4.1.2	Ni-Fe^{3+} spinels (Ni ferrite) and Ni-Fe^{3+} spinels with substitutions (T.R. MCGUIRE)	88
4.1.2.0	List of frequently used symbols and abbreviations	88
4.1.2.1	Ni ferrite NiFe_2O_4	89
4.1.2.2	Ni ferrite with Zn substitutions	99
4.1.2.3	Ni ferrite with Co substitutions	111

4.1.2.4	Ni ferrite and Ni ferrite aluminate with dilute Mn and Co substitutions (see Vol. 4B)	
4.1.2.5	Ni ferrite with Ge substitutions (see Vol. 4B)	
4.1.2.6	Ni ferrite chromite	113
4.1.2.7	Ni ferrite vanadate (see Vol. 4B)	
4.1.2.8	Ni ferrite aluminate	115
4.1.2.9	Ni ferrite gallate (see Vol. 4B)	
4.1.2.10	Ni ferrite with Cu substitutions	116
4.1.2.11	Ni ferrite with Ti substitutions	116
4.1.2.12	Ni ferrite with Sn substitutions	117
4.1.2.13	Ni indate ferrite	118
4.1.2.14	Ni ferrite with Mn substitutions	118
4.1.2.15	Ni ferrite with Ru substitutions	119
4.1.2.16	Ni ferrite scandate	119
4.1.2.17	References for 4.1.2	119
4.1.3	Mn-Fe ³⁺ , spinels (Mn ferrites) and Mn-Fe ³⁺ spinels with substitutions (M. PAULUS, R. VAUTIER)	122
4.1.3.0	List of frequently used symbols and abbreviations	122
4.1.3.1	Phase equilibria and structure	123
4.1.3.1.1	Phase equilibria	123
4.1.3.1.2	Equilibrium oxygen partial pressure	126
4.1.3.1.3	Lattice constants	129
4.1.3.1.4	Ionic distribution	132
4.1.3.1.5	Mössbauer data or spin arrangements	132
4.1.3.2	Thermal properties	133
4.1.3.2.6	Solid state crystal growth	134
4.1.3.2.7	Reactivity and sintering	135
4.1.3.3	Mechanical properties	135
4.1.3.3.1	Elastic properties	136
4.1.3.3.2	Hardness	136
4.1.3.4	Electrical properties	136
4.1.3.4.1	Electrical resistivity	137
4.1.3.4.4	Seebeck effect	140
4.1.3.5	Spontaneous magnetization	140
4.1.3.5.1	Saturation moment at 0 K	141
4.1.3.5.2	Magnetization as a function of temperature	142
4.1.3.5.4	Curie temperatures	142
4.1.3.5.5	Exchange interaction	144
4.1.3.6	Magnetocrystalline anisotropy	144
4.1.3.6.2	Magnetocrystalline anisotropy in Mn ferrites with substitutions	145
4.1.3.6.4	Magnetic annealing	146
4.1.3.7	Domain and domain walls (see Vol. 4B)	
4.1.3.8	Response of magnetization to a field	147
4.1.3.8.3	Permeability variation with composition, impurities, irradiation and grain size	148
4.1.3.8.4	Permeability vs. temperature	149
4.1.3.8.7	After-effect, disaccommodation, and viscosity	150
4.1.3.8.8	Coercive force	153
4.1.3.8.9	Losses	154
4.1.3.9	Microwave properties	155
4.1.3.9.1	Resonance linewidth	155

4.1.3.10	Optical properties	156
4.1.3.11	References for 4.1.3	158
4.1.4	Mg-Fe ³⁺ spinels (Mg ferrites) and Mg-Fe ³⁺ spinels with substitutions (M. SUGIMOTO)	160
4.1.4.0	List of frequently used symbols and abbreviations	160
4.1.4.1	Mg ferrite MgFe ₂ O ₄	162
4.1.4.2	Mg ferrite and Mg-Fe mixed oxides	166
4.1.4.3	Other ferrite systems containing Mg	167
4.1.4.3.1	Systems containing Mn ²⁺	167
4.1.4.3.2	Systems containing Zn ²⁺ and Cd ²⁺	168
4.1.4.3.3	Systems containing Cu ²⁺	170
4.1.4.3.4	Systems containing Ni ²⁺	170
4.1.4.3.5	Systems containing Co ²⁺	172
4.1.4.3.6	Other systems containing trivalent and higher valency cations (See also Appendix)	173
4.1.4.4	References for 4.1.4.1 - 4.1.4.3	175
4.1.5	Zn-Fe ³⁺ spinels (Zn ferrites) and Zn-Fe ³⁺ spinels with substitutions	176
4.1.5.1	Zn ferrite ZnFe ₂ O ₄ (See also Appendix)	176
4.1.5.2	Zn ferrite and Zn-Fe mixed oxides (See also Appendix)	179
4.1.5.3	Zn-Ni, Zn-Ni-Co, Zn-Co, Zn-Ni-Cu and Zn-Ti ferrites (See also Appendix)	181
4.1.5.4	References for 4.1.5.1 - 4.1.5.3	185
4.1.6	Li-Fe ³⁺ spinels (Li ferrites) and Li-Fe ³⁺ spinels with substitutions	186
4.1.6.1	Tables and figures (See also Appendix)	186
4.1.6.2	References for 4.1.6.1	189
4.1.7	Cu-Fe ³⁺ spinels (Cu ferrites) and Cu-Fe ³⁺ spinels with substitutions	190
4.1.7.0	General remarks	190
4.1.7.1	Cu ferrite CuFe ₂ O ₄ (See also Appendix)	190
4.1.7.2	Cu-Zn and Cu-Cd ferrites	208
4.1.7.3	Cu-Mn ferrites and those containing other oxides	210
4.1.7.4	Cu-Ni ferrites and those containing other oxides	222
4.1.7.5	Cu-Li ferrites and those containing other oxides	225
4.1.7.6	Other ferrites systems containing Cu (See also Appendix)	228
4.1.7.7	References for 4.1.7.1 - 4.1.7.6	230
4.1.8	Co-Fe ³⁺ spinels (Co ferrites) and Co-Fe ³⁺ spinels with substitutions	232
4.1.8.1	Co ferrite CoFe ₂ O ₄ (See also Appendix)	232
4.1.8.2	Co ferrite and Co-Fe mixed oxides	245
4.1.8.3	Co-Zn, Co-Cd ferrites	251
4.1.8.4	Co-Mn, Co-Ni, Co-Ti and other ferrites (See also Appendix)	265
4.1.8.5	References for 4.1.8.1 - 4.1.8.4	282
4.2	Chromium spinels	285
4.2.0	Introduction and comparative data (H. VON PHILIPSBORN, L. TREITINGER)	285
4.2.0.1	List of frequently used symbols and abbreviations	285
4.2.0.2	Comments on data	288
4.2.0.2.1	Data acquisition and processing	288
4.2.0.2.2	Data arraying and retrieval	289
4.2.0.3	Comments on material	289
4.2.0.3.1	Occurrence of chromium spinels	289
4.2.0.3.2	Versatile properties in science and technology	289
4.2.0.3.3	Crystal chemistry	290

4.2.0.3.4	Materials preparation and characterization	291
4.2.0.4	ACr ₂ X ₄ data, compared	294
4.2.0.5	References for 4.2.0.4	316
4.2.1	Chromium oxide spinels of Li, Mg, Mn, Fe, Co, Ni, Cu, Zn, Cd. (H. VON PHILIPSBORN, L. TREITINGER)	318
4.2.1.0	Locating of the data	318
4.2.1.0.1	Survey of contents	318
4.2.1.0.2	Quotation tables	321
4.2.1.1	ACr ₂ O ₄ data, compared	322
4.2.1.2	(Li, A) (Cr, B) ₂ O ₄	324
4.2.1.3	Mg-Cr spinels	330
4.2.1.3.1	MgCr ₂ O ₄	330
4.2.1.3.2	Mg-Cr spinels with substitutions	337
4.2.1.4	Mn-Cr spinels	344
4.2.1.4.1	MnCr ₂ O ₄	344
4.2.1.4.2	Mn-Cr spinels with substitutions	347
4.2.1.5	Fe-Cr spinels	354
4.2.1.5.1	Crystallographic and thermodynamic properties (including neutron diffraction)	354
4.2.1.5.1.1	FeCr ₂ O ₄	354
4.2.1.5.1.2	Fe-Cr spinels with Ni substitutions	356
4.2.1.5.1.3	Chromite-magnetite solid solutions	357
4.2.1.5.1.4	Fe(Cr, B) ₂ O ₄ with B = Al or Ti	362
4.2.1.5.2	Magnetic and related properties	364
4.2.1.5.3	Electrical properties	370
4.2.1.6	Co-Cr spinels	373
4.2.1.6.1	Crystallographic and thermodynamic properties	373
4.2.1.6.2	Magnetic properties	375
4.2.1.6.3	Electrical properties	379
4.2.1.7	Ni-Cr spinels	379
4.2.1.7.1	Crystallographic, elastic and thermodynamic properties	379
4.2.1.7.2	Magnetic and related properties	387
4.2.1.8	Cu-Cr spinels	391
4.2.1.8.1	Crystallographic properties	391
4.2.1.8.2	Other properties	394
4.2.1.9	Zn-Cr spinels	396
4.2.1.9.1	Crystallographic and elastic properties (including neutron diffraction)	396
4.2.1.9.2	Magnetic and optical properties	398
4.2.1.10	References for 4.2.1.0. - 4.2.1.9	401
4.2.2	Chromium sulfide, selenide and telluride spinels of Mn, Fe, Co, Cu, Zn (H. VON PHILIPSBORN, L. TREITINGER)	405
4.2.2.0	Locating of the data	405
4.2.2.0.1	Survey of contents	405
4.2.2.0.2	Quotation tables	408
4.2.2.1	(A,B)Cr ₂ X ₄ spinels, compared	409
4.2.2.1.1	Crystal synthesis and thermodynamics	409
4.2.2.1.2	Lattice parameters, magnetic and electrical properties	413
4.2.2.1.3	Comparison of some properties of A-site ordered spinels	417
4.2.2.2	Cu-Cr spinels	419
4.2.2.2.1	Crystallographic and thermodynamic properties (magnetic structures included)	419

4.2.2.2.1.1	Pure compounds CuCr_2X_4	419
4.2.2.2.1.2	Cu-Cr spinels with anion substitutions	421
4.2.2.2.1.3	Cu-Cr spinels with cation substitutions	424
4.2.2.2.2	Magnetic properties (magnetic structures, see 4.2.2.2.1)	427
4.2.2.2.2.1	Pure compounds CuCr_2X_4	427
4.2.2.2.2.2	Cu-Cr spinels with anion substitutions	432
4.2.2.2.2.3	Cu-Cr spinels with A-cation substitutions	435
4.2.2.2.2.4	Cu-Cr spinels with B-cation substitutions	436
4.2.2.2.2.5	NMR and Mössbauer spectroscopy	439
4.2.2.2.3	Optical properties	442
4.2.2.2.4	Electrical properties	443
4.2.2.2.4.1	Pure compounds CuCr_2X_4	443
4.2.2.2.4.2	Cu-Cr spinels with anion substitutions	444
4.2.2.2.4.3	Cu-Cr spinels with cation substitutions	445
4.2.2.3	Mn-, Fe-, Co-Cr spinels	448
4.2.2.3.1	Crystallographic and thermodynamic properties (magnetic structures included)	448
4.2.2.3.2	Magnetic properties (magnetic structures, see 4.2.2.3.1)	453
4.2.2.3.2.1	Pure compounds Mn-, Fe-, Co- Cr_2S_4	453
4.2.2.3.2.2	Mn-, Fe-, Co-Cr spinels with anion substitutions	455
4.2.2.3.2.3	Mn-, Fe-, Co-Cr spinels with cation substitutions	456
4.2.2.3.2.4	NMR and Mössbauer spectroscopy	463
4.2.2.3.3	Optical properties	469
4.2.2.3.3.1	Pure compounds Mn-, Fe-, Co- Cr_2S_4	469
4.2.2.3.3.2	Mn-, Fe-, Co-Cr spinels with cation substitutions	472
4.2.2.3.4	Electrical properties	475
4.2.2.3.4.1	Pure compounds Mn-, Fe-, Co- Cr_2S_4	475
4.2.2.3.4.2	Mn-, Fe-, Co-Cr spinels with cation substitutions	480
4.2.2.4	Zn-Cr spinels	483
4.2.2.4.1	Crystallographic properties (magnetic structures included)	483
4.2.2.4.1.1	Lattice parameters	483
4.2.2.4.1.2	Neutron diffraction	484
4.2.2.4.2	Magnetic properties	487
4.2.2.4.2.1	Pure compounds ZnCr_2X_4	487
4.2.2.4.2.2	Zn-Cr spinels with substitutions	490
4.2.2.4.3	Optical properties	494
4.2.2.4.4	Electrical properties	498
4.2.2.5	References for 4.2.2.0 - 4.2.2.4	501
4.2.3	Chromium sulfide and selenide spinels of Cd and Hg (H. VON PHILIPSBORN, M. RUBINSTEIN, L. TREITINGER)	505
4.2.3.0	Locating of the data	505
4.2.3.0.1	Survey of contents	505
4.2.3.0.2	Quotation tables	506
4.2.3.1	Crystallographic and thermal properties	507
4.2.3.1.1	Preparation	507
4.2.3.1.2	Phase diagrams and thermodynamic properties	510
4.2.3.1.3	Lattice parameter, anion parameter, R-value	514
4.2.3.1.4	Lattice dynamics	518
4.2.3.2	Magnetic properties	520
4.2.3.2.1	Ordering temperatures and exchange interaction	520

4.2.3.2.2	Magnetization	523
4.2.3.2.3	Susceptibilities (photoferromagnetism included)	527
4.2.3.2.4	Magnetostriction	530
4.2.3.2.5	Magnetic resonance and torque measurements	531
4.2.3.2.6	Mössbauer spectroscopy	539
4.2.3.3	Optical properties	540
4.2.3.3.1	Refractive index	540
4.2.3.3.2	Transmission and absorption spectra in the band gap region	540
4.2.3.3.3	Band gap and level schemes	549
4.2.3.3.4	Luminescence and other photoinduced effects	554
4.2.3.3.5	Magneto-optical effects (Faraday, Kerr, magnetocircular dichroism, reflectance circular dichroism)	556
4.2.3.3.6	Reflectance and thermoreflectance spectra	561
4.2.3.3.7	Raman and IR phonon spectra	565
4.2.3.4	Electrical properties	578
4.2.3.4.1	Conductivity	578
4.2.3.4.2	Hall effect	585
4.2.3.4.3	Seebeck effect	587
4.2.3.4.4	Photoconductivity	588
4.2.3.4.5	Band structure	593
4.2.3.4.6	ac conductivity	593
4.2.3.4.7	Magnetoresistance	594
4.1.3.4.8	Junctions	602
4.2.3.4.9	Switching	609
4.2.3.5	References for 4.2.3.0 - 4.2.3.4	610
4.3	Further spinels (D. BONNENBERG, K.A. HEMPEL)	614
4.3.0	List of symbols and abbreviations	614
4.3.1	V spinels and V spinels with substitutions	615
4.3.1.1	V spinels containing V^{3+}	615
4.3.1.2	V spinels containing V^{4+}	625
4.3.1.3	V spinels containing V^{5+}	626
4.3.1.4	V spinels containing both V^{3+} and V^{4+} ions	627
4.3.2	Ge spinels and Ge spinels with substitutions	634
4.3.3	Rh spinels and Rh spinels with substitutions	641
4.3.4	References for 4.3.1 - 4.3.3	650
4.3.5	Al spinels and Al spinels with substitutions	654
4.3.6	Ga spinels and Ga spinels with substitutions	673
4.3.7	In spinels and In spinels with substitutions	680
4.3.8	References for 4.3.5 - 4.3.7	683
4.3.9	Co spinels and Co spinels with substitutions	691
4.3.10	Ni spinels and Ni spinels with substitutions (see also Vol. III/4b, p. 488)	695
4.3.11	Te spinels and Te spinels with substitutions (see also Vol. III/4b, p. 488)	695
4.3.12	Mn spinels and Mn spinels with substitutions	695
4.3.13	Ti spinels and Ti spinels with substitutions	712
4.3.14	References for 4.3.9 - 4.3.13	720
4.3.15	Mo spinels and Mo spinels with substitutions	725
4.3.16	W spinels	727
4.3.17	Nb spinels and Nb spinels with substitutions; Ta spinels and Ta spinels with substitutions	728

4.3.18	Zr spinels and Zr spinels with substitutions, Hf spinels and Hf spinels with substitutions	728
4.3.19	Sb spinels and Sb spinels with substitutions; Te spinels and Te spinels with substitutions	729
4.3.20	Sn spinels and Sn spinels with substitutions	730
4.3.21	Si spinels and Si spinels with substitutions	735
4.3.22	Rare earth spinels and rare earth spinels with substitutions	738
4.3.23	References for 4.3.15 - 4.3.22	741
	Appendix (M. SUGIMOTO)	744

Spinels, Fe Oxides, and Fe-Me-O Compounds / Spinelle,
Fe-Oxide und Fe-Me-O-Verbindungen

Bonnenberg, D.; Hempel, K.A.; Lefever, R.A.; McGuire,
T.R.; Paulus, M.; Philipsborn, H. von; Rubinstein, M.;
Sugimoto, M.; Treitinger, L.; Vautier, R.

1980, 758 p., Hardcover

ISBN: 978-3-540-09421-0