

| | | |
|--------|---|----|
| 3.3. | Iron/Aluminum | 44 |
| 3.3.1. | Single Iron/Aluminum Interface | 45 |
| 3.3.2. | Multiple Iron/Aluminum Interface | 46 |
| 3.4. | Iron/Copper. | 49 |
| 3.5. | Iron/Molybdenum | 52 |
| 3.6. | Iron/Titanium | 53 |
| 3.7. | Iron/Zirconium | 54 |
| 3.8. | Iron/Cobalt | 54 |
| 3.9. | Iron/Palladium | 55 |
| 3.10. | Tin/Nickel and Tin/Aluminum | 55 |
| 4. | Metal Insulator Systems | 56 |
| 4.1. | Fe/SiO ₂ Interface | 57 |
| 4.1.1. | Effects of 100-keV Ar ⁺ Irradiation | 57 |
| 4.1.2. | Effects of 200-keV Kr ²⁺ Irradiation | 60 |
| 4.2. | Fe/Al ₂ O ₃ Interface | 63 |
| 4.3. | Fe/Glass Interface | 65 |
| 5. | Metal/Semiconductor Systems | 66 |
| 6. | Metal/Polymer Systems | 71 |
| 7. | Conclusions | 73 |
| | References | 73 |

3. Applied Field Mossbauer Spectroscopy of Magnetic Powders

Q | **A. Pankhurst and R. J. Pollard**

| | | |
|--------|--|----|
| 1. | Introduction | 7: |
| 2. | Context | 78 |
| 2.1. | Applications. | 79 |
| 2.1.1. | Magnetic Fluids | 79 |
| 2.1.2. | Magnetic Separation | 80 |
| 2.1.3. | Magnetic Recording | 8: |
| 2.1.4. | Biomagnetism and Medicine | 8: |
| 2.2. | Fundamental Research | 8: |
| 2.2.1. | Interparticle Interactions | 8: |
| 2.2.2. | Surface Effects | 84 |
| 2.2.3. | Magnetization Reversal Mechanisms | 84 |
| 2.2.4. | Structural and Magnetic Disorder | 81 |
| 2.3. | Applied Field Mossbauer Spectroscopy | 84 |
| 3. | Physical Behavior and Modeling | 8 |
| 3.1. | Atomic Spin Hamiltonian | 81 |
| 3.2. | Probability Distributions | 90 |
| 3.3. | Superoperator Method. | 9: |
| 4. | Ferrimagnets | 9: |
| 4.1. | Maghemite | 9: |

| | |
|--|-----|
| 4.2. Barium Ferrite. | 95 |
| 4.3. Feroxyhite | 96 |
| 4.4. Magnetite | 97 |
| 5. Antiferromagnets | 99 |
| 5.1. Hematite | 99 |
| 5.2. Goethite | 100 |
| 5.3. Aluminous Goethite | 102 |
| 5.4. Ferrihydrite | 104 |
| 6. Conclusions | 105 |
| 6.1. Industrial Applications | 105 |
| 6.2. Research Directions | 108 |
| References | 109 |

4. Mössbauer Effect Studies of Magnetic Soils and Sediments

Lawrence H. Bowen, Eddy De Grave, and Robert E. Vandenberghe

| | |
|---|-----|
| 1. Introduction | 115 |
| 2. Hydrated Iron Oxides | 118 |
| 2.1. Goethite | 118 |
| 2.2. Lepidocrocite | 125 |
| 2.3. Akaganeite | 126 |
| 2.4. Feroxyhite | 128 |
| 2.5. Ferrihydrite | 129 |
| 3. Nonhydrated Iron Oxides | 132 |
| 3.1. Hematite | 132 |
| 3.2. Magnetite | 136 |
| 3.3. Maghemite | 138 |
| 4. Environmental Samples | 141 |
| 4.1. Soils | 142 |
| 4.2. Lake and Ocean Sediments | 148 |
| 4.3. Volcanic Samples | 151 |
| 5. Special Environments | 153 |
| 5.1. Meteorites | 153 |
| 5.2. Martian Soil Analogues | 154 |
| 6. Conclusions | 154 |
| References | 156 |

5. Mössbauer Effect Studies of Iron Fluorides

J. M. Grenèche and F. Varret

| | |
|--|-----|
| 1. Introduction | 161 |
| 2. Electric Field Gradients in Fluorides | 162 |

| | |
|--|-----|
| 2.1. The Quadrupole Interaction | 162 |
| 2.2. The Summation Methods | 163 |
| 2.3. Computed EFG and Discussion | 164 |
| 3. Crystalline Fluorides with Noncollinear Magnetic Structures | 166 |
| 3.1. The Polymorphic Crystalline Phases of FeF_3 | 166 |
| 3.2. Frustrated Ferrimagnetic Inverse Weberites | 172 |
| 3.3. Idle Spin Behavior | 176 |
| 4. Amorphous Ferric Fluorides | 182 |
| 4.1. Preparation of the Samples | 183 |
| 4.2. Paramagnetic Behavior | 184 |
| 4.3. Magnetically Frozen Phase | 191 |
| 4.4. Crystallization of Amorphous Fluorides | 196 |
| 4.5. Glassy Fluorides | 198 |
| 5. Conclusions and Perspectives | 199 |
| References | 200 |

6. Mössbauer Spectroscopy Studies of Slow Paramagnetic Relaxation and Magnetic Interactions in Ferrocenium-Based Molecular Magnetic Materials

William M. Reiff

| | |
|---|-----|
| 1. Introduction | 205 |
| 2. Aspects of Electronic Structure of Low-Spin Iron(III) | 206 |
| 2.1. Orbital Contributions | 206 |
| 2.2. Single-Ion Zero-Field Splitting and Slow Paramagnetic Relaxation versus Cooperative Three-Dimensional Order | 208 |
| 3. Zero-Field and Field-Induced Slow Paramagnetic Relaxation for Low-Spin Iron(III) | 209 |
| 3.1. Spatially Nondilute Systems with Diamagnetic Counterions— $\text{K}_3\text{Fe}(\text{CN})_6$ | 209 |
| 3.2. Simple Ferrocenium Salts-Relatively Self-Dilute Cations with Diamagnetic Counteranions | 210 |
| 3.3. $[\text{Fe}(\text{Cp}^*)_2]^+[\text{DDQ}]^-$ Self-Dilute $S = \frac{1}{2}$ Cations with Paramagnetic $S = \frac{1}{2}$ Counteranions | 210 |
| 4. Low-Temperature Cooperative Magnetic Ordering | 216 |
| 4.1. $\text{K}_3\text{Fe}(\text{CN})_6$ (Ultralow Temperature) | 216 |
| 4.2. Donor-Acceptor Charge Transfer-Type Molecular Magnets Based on the Decamethylferrocenium Ion $[\text{Fe}(\text{Cp}^*)_2]^+$ | 217 |
| 4.2.1. Ferromagnets | 217 |
| 4.2.2. Antiferromagnets | 222 |
| 4.2.3. Effects of Systematic Change of Charge Donor. | 229 |

| | | |
|-------|---|-----|
| 4.2.4 | Effects of Systematic Change of Charge Acceptor. | 229 |
| 4.2.5 | Ferromagnetically Coupled Dimers | 230 |
| 5. | Nonlinear Low-Dimensionality Effects—Solitons | 234 |
| 6. | Conclusions and Prospects for Further Research. | 234 |
| 6.1. | Charge Transfer Salt Magnets Based on Completely Open and Half-Open Pentadienyl Iron Systems | 235 |
| 6.2. | Charge Transfer Salt Magnets Based on Fully Detrapped Valence Averaged Binuclear Aggregates of Iron | 235 |
| 6.3. | Charge Transfer Salt Magnets of Ferrocene with Halogenated Buckminsterfullerene (C₆₀) | 236 |
| | References | 237 |

Mossbauer Effect Studies of Nanostructured Materials

S. J. Campbell and H. Gleiter

| | | |
|--------|---|-----|
| 1. | Introduction | 241 |
| 1.1. | Mossbauer Spectroscopy | 241 |
| 1.2. | Nanostructured Materials: Basic Ideas | 243 |
| 2. | Synthesis | 246 |
| 2.1. | Generation of Nanometer-Sized Clusters | 246 |
| 2.1.1. | Vacuum Synthesis | 246 |
| 2.1.2. | Gas-Phase Synthesis | 247 |
| 2.1.3. | Condensed-Phase Synthesis | 250 |
| 2.1.4. | Capped Clusters | 252 |
| 2.1.5. | Cluster Arrays | 252 |
| 2.2. | Cluster Consolidation. | 253 |
| 2.2.1. | Consolidation by High-Speed Deposition | 253 |
| 2.2.2. | Deposition by Ionized Cluster Beams | 253 |
| 2.2.3. | Consolidation | 254 |
| 2.3. | Other Methods | 256 |
| 2.3.1. | High-Energy Milling | 256 |
| 2.3.2. | High-Strain-Rate Deformation | 257 |
| 2.3.3. | Mixalloy Processing | 257 |
| 2.3.4. | Deposition Methods | 257 |
| 2.3.5. | Sol-Gel Method | 258 |
| 3. | Structure | 259 |
| 3.1. | Structure of Pure Nanostructured Materials | 259 |
| 3.2. | Nanostructured Alloys | 266 |
| 3.3. | Imperfect (Distorted) Crystallites: Nanoglasses | 268 |
| 4. | Mossbauer Effect Studies. | 271 |
| 4.1. | Nanostructured Metals: Fe, Ni | 271 |
| 4.2. | Nanostructured Alloys and Nanoglasses | 275 |
| 4.3. | Nanostructured Ionic Materials | 278 |

| | |
|--|-----|
| 4.4. Nanostructured Oxides | 281 |
| 4.5. Nanostructured Materials: Mechanical Alloying | 283 |
| 4.6. Ultrafine Amorphous Particles | 294 |
| 5. Concluding Remarks | 294 |
| References | 297 |

8. Zinc-67 Mossbauer Spectroscopy

W. Potzel

| | |
|---|-----|
| 1. Introduction | 305 |
| 2. Experimental Developments | 306 |
| 2.1. Sources of High Specific Activity | 307 |
| 2.2. Spectrometer for Ambient Pressure | 307 |
| 2.3. Spectrometer for External Pressures up to 10 GPa | 310 |
| 2.4. Velocity Calibration and Nuclear Pulse Counting | 312 |
| 3. Metallic Systems | 314 |
| 3.1. Zn Metal | 314 |
| 3.1.1. Hyperfine Interactions | 314 |
| 3.1.2. Lattice-Dynamic Effects | 321 |
| 3.2. Cu-Zn Alloys | 325 |
| 3.2.1. Hyperfine Interactions | 325 |
| 3.2.2. Lattice-Dynamic Effects | 331 |
| 4. Semiconductors and Insulators | 335 |
| 4.1. Chalcogenides | 335 |
| 4.1.1. ZnO at Ambient Pressure | 335 |
| 4.1.2. ZnO at High Pressure | 338 |
| 4.1.3. ZnS, ZnSe, and ZnTe | 343 |
| 4.1.4. Theoretical Calculations of s-Electron Densities | 344 |
| 4.1.5. Model Calculations of Lattice-Dynamic Effects | 347 |
| 4.2. ZnF ₂ | 351 |
| 4.2.1. Hyperfine Interactions | 353 |
| 4.2.2. Lattice-Dynamic Effects | 352 |
| 4.2.3. Theoretical Calculations | 353 |
| 4.3. Oxide Spinel | 355 |
| 4.3.1. Normal Spinel | 356 |
| 4.3.2. Inverse Spinel | 358 |
| 4.3.3. Theoretical Calculations | 361 |
| 5. High- T _c Superconductors. | 362 |
| 6. Synthesis on Lattice-Dynamic Effects | 364 |
| 6.1. Second-Order Doppler Shift and Debye Model | 364 |
| 6.2. Phase Transitions | 366 |
| 7. Summary. | 366 |
| References | 367 |

9. Mossbauer Spectroscopy of New Materials Containing Gadolinium

Gordon Czjzek

| | |
|--|-----|
| 1. Introduction | 373 |
| 2. Mössbauer Spectroscopy, with ^{160}Gd | 375 |
| 3. Nuclear Parameters and Hyperfine Interactions for ^{159}Gd | 378 |
| 3.1. Nuclear Spins and Moments | 378 |
| 3.2. Isomer Shift | 380 |
| 3.3. Quadrupole Interaction | 382 |
| 3.4. Magnetic Hyperfine Interaction | 385 |
| 4. Experimental Techniques and Data Analysis | 388 |
| 4.1. Sources and Absorbers | 389 |
| 4.2. Analysis of the Spectra and Results | 390 |
| 5. Metallic Compounds and Alloys | 394 |
| 5.1. Crystalline and Amorphous Alloys | 394 |
| 5.2. Intermetallic Compounds | 395 |
| 5.3. Hydrides | 399 |
| 5.4. Ternary Silicides and Germanides | 400 |
| 5.5. Ternary Borides | 402 |
| 5.6. Materials for Permanent Magnets | 404 |
| 6. Solids with Ionic or Covalent Bonds | 407 |
| 7. Superconductors | 409 |
| 7.1. Magnetism and Superconductivity in Classical Superconductors | 409 |
| 7.2. High- T_c Cuprates and Related Compounds | 412 |
| 8. Outlook | 420 |
| References | 421 |

| | |
|-------------------------------|------------|
| Author Index | 431 |
|-------------------------------|------------|

| | |
|--------------------------------|------------|
| Subject Index | 455 |
|--------------------------------|------------|