



# CONTENTS

	PAGE
Preface . . . . .	iv
The Theory of the Superconductive State. By H. FRÖHLICH . . . . .	1
High Current Gas Discharges. By A. A. WARE . . . . .	24
Cosmic Radio Waves and their Interpretation. By J. L. PAWSEY and E. R. HILL . . . . .	69
Magnetic Domains. By D. J. CRAIK and R. S. TEBBLE . . . . .	116
Photoelectronic Image Intensifiers. By J. D. MCGEE . . . . .	167
Ferrimagnetism. By W. P. WOLF . . . . .	212
Theory and Applications of the Density Matrix. By D. TER HAAR . . . . .	304
The Dynamics of High Temperature Plasmas. By W. B. THOMPSON . . . . .	363



# THE THEORY OF THE SUPERCONDUCTIVE STATE

By H. FRÖHLICH

Department of Theoretical Physics, University of Liverpool

## CONTENTS

	PAGE
§ 1. Preface .....	1
§ 2. Introduction—Phenomenological descriptions .....	2
2.1. The London equations.....	3
2.2. The gap .....	5
§ 3. The introduction of field theory into solid state physics.....	6
3.1. Bloch's theory of conductivity .....	8
3.2. Field theoretical aspect .....	9
§ 4. Isotope effect and gap.....	10
4.1. Classification of interaction.....	10
4.2. The isotope effect.....	11
4.3. The gap, one-dimensional.....	12
4.4. Pairs and the gap .....	14
§ 5. Criticisms ; Meissner effect.....	15
5.1. Gauge invariance .....	16
5.2. Other criticisms.....	18
5.3. Meissner effect .....	19
§ 6. The psychology of superconductivity.....	20
§ 7. Outlook.....	21
References .....	22

# HIGH CURRENT GAS DISCHARGES†

By A. A. WARE‡

John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division  
of General Dynamics Corporation, San Diego, California

## CONTENTS

	PAGE
§ 1. Introduction.....	25
1.1. The class of discharges to be reviewed.....	25
1.2. Introductory and historical survey.....	26
§ 2. The plasma equations and some physical concepts.....	33
2.1. A set of plasma equations.....	33
2.2. The magnetohydrodynamic approximations.....	36
2.3. The collisionless plasma approximation.....	36
2.4. Simple physical concepts.....	37
2.4.1. Magnetic pressure.....	37
2.4.2. 'Freezing in' of magnetic lines of force.....	38
§ 3. Discharge initiation and contraction.....	38
3.1. Ionization.....	38
3.2. Discharge contraction.....	39
3.2.1. High rate of rise of current, no axial magnetic field	39
3.2.2. High rate of rise of current with an axial magnetic	
field.....	42
3.2.3. Low rate of rise of current, no axial magnetic field	43
3.2.4. Low rate of rise of current with an axial magnetic	
field.....	43
§ 4. Discharge equilibrium.....	44
4.1. Linear discharges.....	44
4.2. Toroidal discharges.....	45
§ 5. Magnetohydrodynamic stability.....	46
5.1. Theory.....	46
5.1.1. Perfectly conducting compressible cylinder with	
infinitely thin current sheath.....	47
5.1.2. Perfectly conducting cylinder with finite current	
sheath.....	48
5.1.3. Perfectly conducting discharge with constant pitch	
magnetic field.....	49
5.1.4. Discharges with $B_z \gg B_\theta$ .....	49
5.1.5. Discharge models with dissipative effects.....	50
5.1.6. Stable configurations.....	50
5.1.7. Toroidal discharges.....	50
5.2. Experimental observations on stability.....	50
5.2.1. Discharges with trapped axial magnetic field.....	50
5.2.2. Discharges with approximately constant pitch mag-	
netic fields.....	52
5.2.3. Discharges with $B_z \gg B_\theta$ .....	52
5.3. Instability waves.....	53

† Research on controlled thermonuclear reactions is a joint programme carried out by the General Atomic Division of General Dynamics Corporation and the Texas Atomic Energy Research Foundation.

‡ On leave of absence from Associated Electrical Industries Research Laboratory, Aldermaston, Berks.

	PAGE
§ 6. Particle heating and energy loss . . . . .	54
6.1. The electron temperature and energy loss . . . . .	54
6.2. The positive ion temperature and heating mechanism . . . . .	56
§ 7. Nuclear reactions . . . . .	57
7.1. The linear pinch without an axial magnetic field . . . . .	57
7.2. The linear pinch with an axial magnetic field . . . . .	58
7.3. The toroidal pinch with magnetic field . . . . .	59
§ 8. High current discharges with other geometrical configurations . . . . .	59
8.1. Azimuthal discharges . . . . .	59
8.2. Annular discharges ( ' triax ' and ' hard-core ' ) . . . . .	61
8.3. Rotating plasmas . . . . .	62
8.4. Plasma ' guns ' . . . . .	63
Acknowledgments . . . . .	63
References . . . . .	64



# COSMIC RADIO WAVES AND THEIR INTERPRETATION

BY J. L. PAWSEY AND E. R. HILL

Radiophysics Laboratory, Commonwealth Scientific and Industrial Research Organization,  
Sydney, Australia

## CONTENTS

	PAGE
§ 1. Introduction .....	70
§ 2. General nature of the observations and their interpretation.....	71
2.1. Basic instrumental limitations .....	75
§ 3. Theory of the known mechanisms of emission.....	76
3.1. Thermal emission from fully ionized hydrogen.....	76
3.2. Synchrotron radiation.....	79
3.3. The 21-cm line of atomic hydrogen.....	81
§ 4. Studies of individual galactic objects.....	82
§ 5. Large-scale structure in our galaxy.....	84
5.1. Differential galactic rotation and the mass of the galaxy.....	85
5.2. Spiral and other structure in the galactic disk.....	87
5.2.1. Spiral structure.....	87
5.2.2. The shape of the galactic disk.....	90
5.2.3. The distribution of interstellar hydrogen in the galaxy	92
5.3. Expansion and other phenomena near the galactic centre.....	93
5.4. The galactic corona .....	96
§ 6. Comparative observations of normal galaxies.....	99
6.1. Continuum observations.....	99
6.2. Hydrogen line observations.....	102
§ 7. Radio galaxies and cosmology.....	104
7.1. The nature of radio galaxies.....	105
7.2. Number counts, background brightness and cosmology.....	110
Acknowledgments .....	113
References.....	113



# MAGNETIC DOMAINS

BY D. J. CRAIK† AND R. S. TEBBLE‡

† Boots Pure Drug Company, Nottingham

‡ Department of Physics, Sheffield University

## CONTENTS

	PAGE
§ 1. Introduction . . . . .	117
§ 2. General principles . . . . .	117
2.1. Free pole effects (magnetostatic energy; shape anisotropy) . . . . .	118
2.2. Magneto-crystalline anisotropy . . . . .	119
2.3. Magnetostriction . . . . .	119
2.4. Exchange energy . . . . .	120
2.5. Boundary energy and thickness . . . . .	120
2.6. Closure domains and subsidiary domain structure . . . . .	122
2.7. The width of domains . . . . .	123
2.8. The $\mu^*$ effect . . . . .	123
2.9. Single domain particles . . . . .	123
§ 3. Methods of observation . . . . .	124
3.1. Bitter figure technique . . . . .	125
3.2. Modification for electron microscopy . . . . .	127
3.3. Transmission electron microscopy . . . . .	127
3.4. Electron beam methods . . . . .	128
3.5. Electron mirror microscopy . . . . .	129
3.6. The photoelectron method . . . . .	129
3.7. Probe method . . . . .	129
3.8. Kerr and Faraday effects . . . . .	129
3.9. Comparison of the methods . . . . .	131
§ 4. Domain structures of materials with uniaxial anisotropy . . . . .	132
4.1. Domain structures of uniaxial crystals . . . . .	132
4.2. Materials with low saturation magnetization—single crystals . . . . .	132
4.3. Materials with low magnetization—polycrystalline specimens . . . . .	135
4.4. Crystals with high saturation magnetization . . . . .	136
4.5. The magnetization of uniaxial crystals . . . . .	137
§ 5. Domain structure in iron . . . . .	139
5.1. Iron crystals . . . . .	139
5.2. Whiskers . . . . .	142
5.3. Polycrystalline specimens . . . . .	143
§ 6. Domain structure of nickel-like materials . . . . .	145
6.1. Nickel and face-centred cubic alloys (single crystals) . . . . .	145
6.2. Domain structure of cubic ferrites—single crystals . . . . .	147
6.3. Polycrystalline cubic ferrites . . . . .	149
6.4. Rare earth garnets and ortho-ferrites . . . . .	151
§ 7. Alloys which respond to magnetic annealing, and powders . . . . .	153
7.1. Annealed nickel-cobalt . . . . .	153
7.2. Perminvar . . . . .	154
7.3. Cobalt-nickel alloys . . . . .	155
7.4. Precipitation hardened alloys . . . . .	156
7.5. Powder or elongated single domain magnets . . . . .	157
§ 8. Thin films . . . . .	158
§ 9. Domain walls . . . . .	161
§ 10. Summary . . . . .	162
Acknowledgments . . . . .	164
References . . . . .	164





# PHOTOELECTRONIC IMAGE INTENSIFIERS

By J. D. McGEE

Imperial College, London

## CONTENTS

	PAGE
§ 1. Introduction : Statement of problem and its relation to photography . . . .	168
§ 2. Single-stage image intensifiers . . . . .	172
2.1. Image intensifier with phosphor screen and transfer optics . . . . .	172
2.2. Image intensifier with thin window, phosphor screen and contact recording . . . . .	174
2.3. Lime-soda glass, thin-window image intensifier . . . . .	177
2.4. Electron-transmitting mica-window image tubes . . . . .	181
2.5. Lallemand's electronic camera . . . . .	182
2.6. The two-chamber, single-stage image-recording tube . . . . .	186
2.7. Electrostatic focusing, single-stage tube . . . . .	187
2.8. X-ray image intensifier . . . . .	188
2.9. High-speed shutter image tube . . . . .	189
§ 3. Multi-stage image intensifiers . . . . .	190
3.1. General considerations . . . . .	190
3.2. Cascaded phosphor-photocathode intensifying screen tubes . . . . .	191
3.3. Transmission secondary-emission image intensifier . . . . .	196
3.4. The channelled secondary-emission image multiplier . . . . .	200
§ 4. Positive feedback image intensifying systems . . . . .	203
4.1. General considerations . . . . .	203
4.2. Single-tube system with accurate registration . . . . .	204
4.3. Systems without registration . . . . .	205
§ 5. Image intensifier tube applications . . . . .	205
5.1. Astronomy . . . . .	205
5.2. Nuclear physics . . . . .	207
5.3. Spectroscopy . . . . .	208
5.4. Radiology . . . . .	209
Acknowledgments . . . . .	210
References . . . . .	210

# FERRIMAGNETISM

By W. P. WOLF

Clarendon Laboratory, Oxford

## CONTENTS

	PAGE
§ 1. Introduction .....	213
§ 2. Ferrimagnetic compounds .....	217
2.1. General considerations .....	217
2.2. Crystal structures .....	220
2.3. Methods of preparation .....	226
2.3.1. Polycrystals .....	227
2.3.2. Single crystals .....	227
§ 3. Magnetostatic properties .....	229
3.1. High temperature susceptibility .....	229
3.2. Spontaneous magnetization .....	232
3.2.1. The magnetic moment at $T = 0^\circ\text{K}$ .....	232
3.2.2. Temperature dependence of magnetization .....	236
3.3. Susceptibilities below the Néel point .....	240
3.4. Crystalline anisotropy .....	243
3.4.1. Experimental methods .....	245
3.4.2. Theory .....	245
3.4.3. Macroscopic effects .....	250
3.5. Magnetic annealing .....	251
3.6. Magnetostriction .....	252
§ 4. Thermal properties .....	253
4.1. Specific heat .....	253
4.2. Thermal conductivity .....	255
4.3. Magnetocaloric effects .....	256
§ 5. Microwave properties .....	257
5.1. Dynamic susceptibility .....	257
5.2. Ferrimagnetic resonance: Introduction .....	260
5.3. Effective $g$ -factor .....	261
5.4. Effect of anisotropy on resonance .....	266
5.5. Resonance near compensation points .....	270
5.6. Non-uniform resonance modes .....	274
5.7. Line widths .....	275
5.8. High power effects .....	281
5.9. Dynamic effects in unsaturated samples .....	285
5.9.1. Multiple microwave resonances .....	285
5.9.2. Domain wall motion .....	285
5.9.3. Initial permeability .....	286
§ 6. Experiments with neutrons .....	287
6.1. Neutron diffraction .....	287
6.2. Inelastic neutron scattering .....	289
§ 7. Optical properties .....	290
7.1. Absorption and Faraday rotation .....	290
7.2. Observation of domains .....	292
§ 8. Recent developments .....	292
8.1. Complex spin configurations .....	292
8.2. Sub-lattice magnetization .....	293
8.3. Spin waves and non-linear effects .....	294
Acknowledgments .....	294
References .....	295



# THEORY AND APPLICATIONS OF THE DENSITY MATRIX

By D. TER HAAR

The Clarendon Laboratory, Oxford

## CONTENTS

	PAGE
§ 1. Introduction .....	304
§ 2. General properties of the density matrix.....	312
§ 3. Green function techniques .....	319
§ 4. The description of statistical equilibrium by the density matrix.....	322
§ 5. Density matrix techniques applied to atoms, molecules and nuclei.....	327
§ 6. The density matrix in solid state physics .....	334
§ 7. Non-equilibrium processes ; transport theory.....	337
§ 8. Polarization, scattering, and angular correlation experiments.....	341
§ 9. Resonance and relaxation phenomena .....	347
§ 10. The theory of measurement .....	353
Concluding remarks and acknowledgments.....	356
References .....	356







# THE DYNAMICS OF HIGH TEMPERATURE PLASMAS

BY W. B. THOMPSON

Theoretical Physics Division, Atomic Energy Research Establishment, Harwell, Berks.

## CONTENTS

	PAGE
Abstract.....	363
Introduction—The plasma and plasma models.....	364
§ 1. The magnetohydrodynamic representation of the plasma.....	365
1.1 The magnetohydrodynamic equations.....	366
1.2. Conditions for idealized magnetohydrodynamics.....	367
1.3. Magnetohydrodynamic equilibrium.....	368
1.4. Small oscillations.....	370
1.5. Stability .....	372
§ 2. The kinetic theory of a dense plasma.....	376
§ 3. The kinetic theory of the diffuse unmagnetized plasma.....	384
3.1. The Vlasov–Landau theory of high frequency phenomena....	384
3.2. Dielectric behaviour and the screened field.....	388
3.3. The Fokker–Planck equation and dielectric screening.....	390
3.4. Electrostatic instabilities .....	395
§ 4. The kinetic theory of the diffuse plasma in a magnetic field.....	397
4.1. The dielectric properties of a cold magnetized plasma.....	397
4.2. Dielectric properties of a hot magnetized plasma.....	400
4.3. Plasma in a non-uniform field ; approximate methods.....	403
4.4. Some exact solutions for the steady state.....	406
4.5. Approximate procedure for solving the Vlasov equation.....	408
4.6. The magnetohydrodynamic equations.....	410
4.7. The equations of state.....	411
4.8. Transverse transport coefficients.....	411
4.9. Solutions to the zero-order constraint ; the guiding centre distribution .....	412
4.10. Perturbation theory .....	414
4.11. Theory of sound.....	418
§ 5. Conclusions .....	420
Acknowledgments .....	422
References .....	422