

Contents

	Foreword	V
Part I	Introduction and Overview	1
1	The Simplest Metal: Potassium	3
2	SDW and CDW Instabilities	5
3	The CDW Wavevector Q and Q-domains	7
4	Optical Anomalies	8
5	Phase Excitations of an Incommensurate CDW	10
6	Neutron Diffraction Satellites	12
7	Phason Phenomena	14
8	Fermi-Surface Distortion and the Spin-Resonance Splitting	16
9	Magnetoresistivity and the Induced Torque Technique	18
10	Induced Torque Anisotropy	20
11	Microwave Transmission Through K Slabs in a Perpendicular Field H	22
12	Angle-Resolved Photoemission	24
13	Concluding Remarks	26
Part II	Reprints of SDW or CDW Phenomena in Simple Metals	29
R 1	Giant Spin Density Waves	33
R 2	Mechanism of Antiferromagnetism in Dilute Alloys	38
2.1	Introduction	38
2.2	Dynamics of a Spin-Density Wave	41
2.3	Thermodynamics of the Antiferromagnetic Phase	45
2.4	Concluding Remarks	47
A	Appendix	48
A.1	Objection 1	48
A.2	Reply to Objection 1	48

A.3	Objection 2	49
A.4	Reply to Objection 2	49
A.5	Objection 3	49
A.6	Reply to Objection 3	49
A.7	Objection 4	50
A.8	Reply to Objection 4	50
R 3	Spin Density Waves in an Electron Gas	51
3.1	Introduction	51
3.2	Nature of a Spin Density Wave	53
3.3	General Proof of the SDW Instability	56
3.4	Linear Spin Density Waves	60
3.5	Spin Susceptibility of the Paramagnetic State	62
3.6	Detection of SDW's by Neutron Diffraction	65
3.7	Temperature Dependence of SDW Parameters	67
3.8	Antiferromagnetism of Chromium	69
3.9	Accidental Ferrimagnetism	73
R 4	Spin-Density-Wave Antiferromagnetism in Potassium	76
R 5	Helicon Propagation in Metals Near the Cyclotron Edge	80
5.1	Introduction	80
5.2	The Surface Impedance	82
5.3	Helicon Propagation in a Spin-Density Wave Metal	87
R 6	Exchange and Correlation Instabilities of Simple Metals	91
6.1	Introduction	91
6.2	Matrix-Element Contributions to the Correlation Energy	95
6.3	Parallel-Spin Correlation and Umklapp Correlation	98
6.4	Charge-Density-Wave Instabilities	100
A	Appendix	102
R 7	Splitting of Conduction-Electron Spin Resonance in Potassium	105
7.1	Introduction	105
7.2	Anisotropy of g	107
7.3	Stress-Induced Q Domains	110
R 8	Magnetoresistance of Potassium	113
8.1	Introduction	113
8.2	Single-Crystal Magnetoresistivity of Potassium	115
8.3	Model Calculations of Magnetoresistance in Metals with Magnetic Breakdown	115
8.4	Fermi Surface of Potassium	116
8.5	Conclusions	119
R 9	Exchange Potentials in a Nonuniform Electron Gas	121
R 10	Observability of Charge-Density Waves by Neutron Diffraction	125
10.1	Introduction	125
10.2	CDW Satellites	126

10.3	Structure Factors of Cubic Reflections	127
10.4	Magnetic Field Modulation of $F(\vec{K})$	128
10.5	Phase Modulation of CDW	129
10.6	Debye–Waller Factors for Phasons	132
10.7	Survey of Electronic Anomalies	134
10.7.1	Optical Anomalies	134
10.7.2	Conduction-Electron Spin Resonances	134
10.7.3	Doppler-Shifted Cyclotron Resonance	135
10.7.4	Magnetoresistance	135
10.7.5	Hall Effect	136
10.7.6	De Haas–van Alphen Effect	136
10.7.7	Electron–Phonon Interaction	137
10.7.8	Positron Annihilation	137
10.7.9	Other Properties	137
10.8	Conclusion	138
R 11	Questions About the Mayer–El Naby Optical Anomaly in Potassium	141
11.1	Introduction	141
11.2	Extrinsic Mechanisms	142
11.2.1	Absorption in KOH	142
11.2.2	Interference	142
11.2.3	Surface Roughness	143
11.2.4	Plasmon Absorption	143
11.2.5	Scattering by KOH Aggregates	143
11.2.6	Color Centers in KOH	143
11.2.7	Surface States	144
11.2.8	Absorption by K Particles in KOH	144
11.2.9	Impurity Absorption in Potassium	144
11.2.10	Unknown Mechanism	144
11.3	Intrinsic Mechanisms	145
11.4	Two Critical Experiments	147
R 12	Theory of the Residual Resistivity Anomaly in Potassium	149
R 13	Electromagnetic Generation of Ultrasound in Metals	154
13.1	Introduction	154
13.2	Force on Lattice Ions	157
13.3	Generated Sound-wave Amplitude	158
13.3.1	Local Limit	160
13.3.2	Nonlocal Limit	161
13.4	Ultrasonic Attenuation and the Helicon–Phonon Interaction	163
13.4.1	Ultrasonic attenuation	163
13.4.2	Helicon–Phonon Interaction	165
13.5	Summary and Concluding Remarks	166
A	Appendix	166

R 14	Dynamics of an Incommensurate Charge-Density Wave	169
14.1	Introduction	169
14.2	Equations of Motion	170
14.3	Jellium Model for a CDW	171
14.4	Current	172
14.5	Effects of an Applied Electric Field	173
14.6	CDW Acceleration and Effective Mass	175
14.7	Conclusion	177
A	Appendix	177
R 15	Magnetodynamics of Incommensurate Charge-Density Waves	179
15.1	Introduction	179
15.2	Equations of Motion	179
15.3	Effects of an Applied Magnetic Field	180
15.4	Magnetoresistance and Hall Coefficient	185
15.5	Theory of the Induced Torque	186
15.6	Conclusions	187
A	Appendix	188
R 16	Phase Excitations of Charge Density Waves	190
16.1	Fermi-Surface Instabilities	190
16.2	Hyperfine Effects of CDW's	191
16.3	Phasons	192
16.4	Phason Temperature Factor	193
16.5	Phason Narrowing of Hyperfine Broadening	194
16.6	Conclusions	196
A	Discussion	196
R 17	Frictional Force on a Drifting Charge-Density Wave	199
17.1	Introduction	199
17.2	Equilibrium Electron Distribution	200
17.3	Electron Relaxation Time	205
17.4	Frictional Effects of Scattering on the CDW Drift Velocity	207
17.5	Conclusions	210
R 18	Attenuation of Phase Excitations in Charge-Density Wave Systems	212
18.1	Introduction	212
18.2	Phasons and Electron–Phason interaction	213
18.3	Scattering of “Belly” Electrons	215
18.4	Scattering of “Conical Point” Electrons	217
18.5	Conclusions	219
A	Appendix	220
R 19	Charge-Density Waves and Isotropic Metals	221
19.1	Introduction	221
19.2	Theoretical Summary	222
19.2.1	Wave-Mechanical Description	222

19.2.2	Detection of CDWs by Diffraction	224
19.2.3	Fermi-Surface Instability Theorem	225
19.2.4	Role of Electron Correlations	225
19.2.5	Fermi-Surface Shape and Dimensionality	226
19.2.6	CDW Instability in Isotropic Metals	228
19.3	Experimental Manifestations	229
19.3.1	The Alkali Metals	229
19.3.2	Torque Anomalies	230
19.3.3	Optical Anomalies	231
19.3.4	Spin-Resonance Anisotropy	232
19.3.5	Residual-Resistivity Anisotropy	232
19.3.6	Hall Coefficient Discrepancy	232
19.3.7	The Significance of Irreproducibility	233
19.3.8	The Challenge: Q Domain Control	233
19.3.9	Phase Excitations and Satellite Intensity	234
19.3.10	The de Haas–van Alphen Difficulty	235
19.4	Prospects for the future	235
R 20	Residual-Resistivity Anisotropy in Potassium	238
20.1	Introduction	238
20.2	Induced-Torque Experiments	239
20.3	Charge-Density Waves	243
20.4	Model Scattering Potentials	247
20.5	Residual-Resistivity Calculation	250
20.6	Numerical Results	256
20.7	Conclusions	260
R 21	Detection of a Charge-Density Wave by Angle-Resolved Photoemission	262
R 22	Ultra-low-temperature Anomalies in Heat Capacities of Metals Caused by Charge-density Waves	266
22.1	Introduction	266
22.2	Phason Heat Capacity	267
22.3	Total Heat Capacity	269
22.4	Conclusion	273
R 23	Analysis of the Anomalous Temperature-dependent Resistivity on Potassium Below 1.6 K	274
R 24	Wave-Vector Orientation of a Charge-Density Wave in Potassium	278
24.1	Introduction	278
24.2	Sources of Anisotropy	278
24.3	Geometrical Factors	279
24.4	Energy Analysis	280
24.5	Results	281
R 25	Theory of Transverse Phasons in Potassium	284
25.1	Introduction	284

25.2	Phason Energy Spectrum	284
25.3	Energy of the Conduction Electron–Ion System	287
25.4	Transverse-Phason Velocity in Potassium	290
25.5	Discussion	291
A	Positive-Ion Form Factors	292
A.1	Pseudo-Ion Form Factor $\bar{\rho}_{\bar{p}}$	292
A.2	Real-Ion Form Factor $\rho_{\bar{Q}}$	293
B	CDW Energy Minimization	293
R 26	Charge-Density-Wave Satellite Intensity in Potassium	295
26.1	Introduction	295
26.2	Neutron-Scattering Elastic Intensity	296
26.3	Lattice Distortion	298
26.4	CDW Fractional Amplitude in Potassium	298
26.5	Results	300
R 27	Theory of Electron–Phason Scattering and the Low-temperature Resistivity of Potassium	302
27.1	Introduction	302
27.2	Analysis of Experiments	303
27.3	Phasons and the Electron–Phason Interaction	307
27.4	Derivation of the Electron–Phason Resistivity	313
27.5	Numerical Results	321
27.6	Conclusions	324
R 28	Structure Factor of a Charge-Density Wave	327
28.1	Introduction	327
28.2	Dynamical Structure Factor for a CDW	328
28.3	Excitation Spectrum	332
28.4	Phason and Ampliton Temperature Factors	333
28.5	Discussion	335
R 29	Effective-Medium Theory of Open-Orbit Inclusions	338
29.1	Introduction	338
29.2	Approximations for the Effective Conductivity	338
29.3	Electric Field in a Spherical Inhomogeneity	340
29.4	Magnetoresistance of Open-Orbit Inclusions	342
29.5	Discussion	346
R 30	Theory of the Open-Orbit Magnetoresistance of Potassium	348
R 31	Open-Orbit Magnetoresistance Spectra of Potassium	353
31.1	Introduction	353
31.2	Open-Orbit Magnetoresistance	355
31.3	Open-Orbit Directions	357
31.4	Open-Orbit Magnetoresistance of Potassium	359
31.5	Directions for Future Research	363
31.6	Conclusion	364

- R 32 The Open Orbits of Potassium 369**
- 32.1 Introduction 369
 - 32.2 Direct Observation of Open Orbits 370
 - 32.3 Open Orbits of a Single Q Domain 371
 - 32.4 Effective-Medium Theory for Q Domains 373
 - 32.5 Discussion 375
- R 33 Open-Orbit Effects in Thermal Magnetoresistance 377**
- 33.1 Introduction 377
 - 33.2 Theory 377
 - 33.3 Results 379
 - 33.4 Discussion 381
- R 34 Insights in Many-Electron Theory From the Charge Density Wave Structure of Potassium 383**
- 34.1 Introduction 383
 - 34.2 Optical Absorption of a CDW 384
 - 34.3 Other CDW Phenomena in K 386
 - 34.3.1 Conduction-Electron Spin-Resonance Splitting 386
 - 34.3.2 Doppler-Shifted Cyclotron-Resonance Shift 386
 - 34.3.3 Residual Resistivity Anisotropy 386
 - 34.3.4 Linear Magnetoresistance 387
 - 34.3.5 Induced Torque Anisotropy 387
 - 34.3.6 The Oil Drop Effect 387
 - 34.3.7 Variability of the Residual Resistivity 387
 - 34.3.8 High-Field Hall Constant 387
 - 34.3.9 Phason Heat Capacity Anomaly 388
 - 34.3.10 Direct Observation of Electron-Phason Scattering 388
 - 34.3.11 Difficulties 388
 - 34.4 The Open Orbits of Potassium 388
 - 34.4.1 Origin of Open Orbits 388
 - 34.4.2 Theoretical Open-Orbit Spectrum 389
 - 34.4.3 Observed Open-Orbit Spectrum 390
 - 34.5 Implications for Many-Electron Theory 390
 - 34.5.1 Local-Density Approximations to Exchange and Correlation are not Predictive 390
 - 34.5.2 Screened Interactions are Dangerous 392
 - 34.5.3 The Coulomb Hole is Important 392
- R 35 Charge Density Wave Phenomena in Potassium 394**
- 35.1 The Mysteries of the Simple Metals 394
 - 35.1.1 Introduction 394
 - 35.1.2 Charge-Density-Wave Structure 394
 - 35.1.3 Mayer–El Naby Optical Anomaly 395
 - 35.1.4 Low-Temperature Magnetoresistance 396
 - 35.1.5 Induced-Torque Measurements 397
 - 35.1.6 The Oil Drop Effect 398
 - 35.1.7 Other Anomalous Phenomena 398

35.2	Phasons: What they are and what they do	399
35.2.1	Introduction	399
35.2.2	Phase Modulation	399
35.2.3	Relation Between Phasons and Phonons	400
35.2.4	The Phason Heat Capacity	401
35.2.5	Low Temperature Resistivity	402
35.2.6	Point Contact Spectroscopy	403
35.2.7	Phason Thermal Diffuse Scattering	403
35.3	Theory of Charge Density Waves	404
35.3.1	Introduction	404
35.3.2	SDW-CDW Instability Theorem	404
35.3.3	The Correlation Energy Correction	405
35.3.4	Analogy with Uniform Deformations	407
35.4	Conclusions	408
R 36	Energy Spectrum of an Incommensurate Charge-Density Wave: Potassium and Sodium	411
36.1	Introduction	411
36.2	Minigaps and Heterodyne Gaps	412
36.3	Results for Na and K	416
36.4	Conclusions	418
R 37	Theory of Charge-Density-Wave-Spin-Density-Wave Mixing	420
R 38	Crystal Structure of Lithium at 4.2 K	424
R 39	Theory of Induced-Torque Anomalies in Potassium	427
39.1	Introduction	427
39.2	Induced-Torque Anomalies	428
39.3	Magnetoresistivity Tensor of Potassium	430
39.4	Calculation of Induced Torque	432
39.5	Discussion	435
R 40	Further Evidence of an Anisotropic Hall Coefficient in Potassium	436
40.1	Introduction	436
40.2	Misalignment Effect	438
40.3	Phase Anomalies	439
40.4	Discussion	444
R 41	Field Dependence of the Residual-Resistivity Anisotropy in Sodium and Potassium	446
41.1	Introduction	446
41.2	Anisotropic Relaxation Time	447
41.3	Zero-Field Resistance	448
41.4	Magnetoresistance	450
41.5	Induced Torque	454
41.6	Discussion	456
A	Appendix	457

- R 42 Effect of an Inhomogeneous Resistivity on the Induced-Torque Pattern of a Metal Sphere** 460
- R 43 Infrared-absorption Spectrum of an Incommensurate Charge-Density Wave: Potassium and Sodium** 465
- 43.1 Introduction 465
- 43.2 Minigap Absorption 468
- 43.3 Results for K and Na 471
- 43.4 Conclusions 474
- R 44 Dynamic *M*-shell Effects in the Ultraviolet Absorption Spectrum of Metallic Potassium** 476
- R 45 Broken Symmetry in Simple Metals** 481
- 45.1 Introduction 481
- 45.2 The Evidence 482
- 45.3 Theory of Charge Density Waves 486
- 45.3.1 SDW-CDW instability theorem 486
- 45.3.2 The correlation energy correction 488
- 45.3.3 Analogy with uniform deformations 490
- 45.3.4 Implications for many-electron theory 490
- 45.4 CDW Phenomena 493
- 45.4.1 Optical Anomalies 493
- 45.4.2 Conduction Electron Spin Resonance Splitting 494
- 45.4.3 Nonreproducibility, a Consequence of *Q* Domains 494
- 45.4.4 Linear Magnetoresistance 495
- 45.4.5 Hall Coefficient Discrepancy 495
- 45.4.6 Induced-torque Anisotropy 495
- 45.4.7 The Oil Drop Effect 497
- 45.4.8 Residual-resistance Anisotropy 497
- 45.4.9 Temperature dependence of resistivity near 1 K 498
- 45.4.10 Temperature Dependence of the Surface Impedance 499
- 45.4.11 Deviations from Matthiessen's Rule 499
- 45.4.12 Doppler-shifted Cyclotron Resonance 499
- 45.4.13 Phason Anomaly in Point Contact Spectroscopy 500
- 45.5 Conclusion 501
- R 46 Photoemission From the Charge-Density Wave in Na and K** 505
- R 47 Phason Narrowing of the Nuclear Magnetic Resonance in Potassium** 509
- 47.1 Introduction 509
- 47.2 NMR Line Shape at $T = 0$ K 510
- 47.3 Review of Phason Properties 512
- 47.4 Motional Narrowing by Phasons 513
- 47.5 Temperature Dependence of ΔH 515

- R 48 Theory of the Perpendicular-Field Cyclotron-Resonance Anomaly in Potassium 517**
- 48.1 Introduction 517
- 48.2 Charge-density-wave Structure and the Fermi Surface 518
- 48.3 Theory of the Surface Impedance 520
- 48.4 Results and Discussion 522
- 48.5 Conclusions 524
- R 49 Direct Observation of the Charge-Density Wave in Potassium by Neutron Diffraction 526**
- R 50 Phason Anisotropy and the Nuclear Magnetic Resonance in Potassium 532**
- R 51 Satellite-Intensity Patterns From the Charge-Density Wave in Potassium 537**
- R 52 Magnetoserpentine Effect in Single-Crystal Potassium 541**
- R 53 Charge Density Wave Satellites in Potassium? 545**
- R 54 Fermi-Surface Structure of Potassium in the Charge-Density-Wave State 557**
- 54.1 Introduction 557
- 54.2 Plane-wave Expansion 558
- 54.3 Approximate Solutions 559
- 54.3.1 Near $\mathbf{k} \cdot \hat{\mathbf{Q}} \cong Q/2$ (minigap region) 559
- 54.3.2 Near $\mathbf{k} \cdot \hat{\mathbf{Q}}' \cong Q'$ (heterodyne-gap region) 561
- 54.4 Conclusions 563
- R 55 Neutron-Diffraction Structure in Potassium Near the [011] and [022] Bragg Points 565**
- R 56 Quantum Oscillations From the Cylindrical Fermi-Surface Sheet of Potassium Created by the Charge-Density Wave 571**
- R 57 Magnetotransmission of Microwaves Through Potassium Slabs 578**
- 57.1 Introduction 578
- 57.2 Nonlocal Theory for an Isotropic Fermi Surface 581
- 57.3 Suppression of GK Oscillations by a Charge-Density Wave 584
- 57.4 Conclusion 586
- R 58 Microwave Surface Resistance of Potassium in a Perpendicular Magnetic Field: Effects of the Charge-Density Wave 589**
- 58.1 Introduction 589
- 58.2 Effect of the Heterodyne Gaps 591
- 58.3 Resonance from the Fermi-Surface Cylinder 595
- 58.4 Conclusion 601
- A Calculation of the Conductivity 603
- B Polarization of the Field Inside an Anisotropic Metal 605

R 59	Cyclotron-Resonance Transmission Through Potassium in a Perpendicular Magnetic Field: Effects of the Charge-Density Wave	610
59.1	Introduction	610
59.2	Microwave Transmission in an Anisotropic, Nonlocal Medium	614
59.3	Effect of Minigaps on Microwave Transmission	617
59.4	Conductivity Tensor from a Tilted Fermi-Surface Cylinder	621
59.5	Conclusions	625
R 60	Influence of Electron-Electron Scattering on the Electrical Resistivity Caused by Oriented Line Imperfections	627
60.1	Introduction	627
60.2	Theory	627
60.3	Discussion	631
R 61	Theory of the Fourfold Induced-Torque Anisotropy in Potassium	633
R 62	Observation of Phasons in Metallic Rubidium	642
R 63	Theory of Induced-Torque Anomalies in Potassium	646
R 64	Magnetoflicker Noise in Na and K	651
64.1	Background	651
64.2	CDW Structure	652
64.3	Fluctuations of \vec{Q} and \vec{Q}'	653
64.4	Magnetoresistance of a Thin Wire	656
64.5	Magnetophonon Noise	657
64.6	Conclusion	659
R 65	Influence of Charge-Density-Wave Structure on Paramagnetic Spin Waves in Alkali Metals	662
65.1	Introduction	662
65.2	Brief Review of Charge-Density-Wave Theory	663
65.3	Brief Review of Landau Fermi-Liquid Theory	666
65.4	Simplified Model for Charge-Density-Wave Effects	670
65.4.1	Closed Orbits	671
65.4.2	Open Orbits	675
65.4.3	Mixed Orbits	676
65.4.4	Transmitted Signals	677
65.5	Comparison with the Platzman–Wolff Theory and Experimental Data	678
65.6	Conclusion	682
Part III	Thirty Unexpected Phenomena Exhibited by Metallic Potassium	685

