Final Report

THEORETICAL AND EXPERIMENTAL INVESTIGATIONS OF SUPERCONDUCTIVITY

NASA GRANT NsG-352

The University of Chicago

For the Period

March 1, 1963 to February 28, 1970

and

AMORPHOUS SEMICONDUCTORS, SUPERCONDUCTIVITY AND MAGNETISM

NASA GRANT NGL 14-001-009

The University of Chicago

For the Period

March 1, 1970 to February 28, 1973

Prepared by

MORREL H. COHEN

SUMMARY OF ACCOMPLISHMENTS

Grants NsG 352 and NGL 14-001-009 continued for a period of ten years from March 1, 1963 to February 28, 1973. During that time twenty two Ph.D. degrees were granted by the Physics Department of the University to graduate students who carried out all or a part of their Ph.D. research activities under the aegis of the Grants. Thirty six major lectures were given. One hundred thirty papers were published.

Ph.D. Degrees Granted

Marvin L. Cohen - March, 1964

P. Soven - March, 1965

A. Bennett - December, 1965

D. R. Penn - December, 1965

J. W. Garland, Jr. - March, 1966

J. Hermanson - August, 1966

J. A. Appelbaum - December, 1966

R. Glosser - March, 1967

S. L. Norman - March, 1968

R. A. Young - August, 1968

R. M. Martin - June, 1969

K. L. Ngai - June, 1969

J. A. Van Vechten - June, 1969

G. Juras - August, 1969

J. Kimball - August, 1969

F. M. Mueller - August, 1969

E. Zornberg - August, 1969

E. N. Economou - December, 1969

M. W. Cole - August, 1970

T. P. Eggarter - December, 1971

G. Srinivasan - December, 1971

D. L. Johnson - December, 1972

Major Lectures

1. Role of Coulomb Interactions in Superconductivity, J. W. Garland, Invited Paper, American Physical Society, Bull. Am. Phys. Soc. II, 8, 211 (1963).
2. The Influence of Impurities on the Interactions Responsible for Superconductivity, Morrel H. Cohen, Contributed Paper, International Conference on the Science of Superconductivity, Hamilton, New York, August, 1963.
3. The Existence of a Superconducting State in Semiconductors, Marvin L. Cohen, Contributed Paper, International Conference on the Science of Superconductivity, Hamilton, New York, August, 1963.
4. Coherent Pairing of the Second Kind, M. H. Cohen, Midwest Conference on Theoretical Physics, Ames, Iowa, June, 1964.
5. Interpolation and Resonance Theories of Transition and Noble Metals, J. C. Phillips, Invited Paper, 1966 Washington APS meeting, Bull.Am.Phys.Soc. 11, 315.
6. Electronic Structure of the Liquid Alkali Metals and Their Alloys, Morrel H. Cohen, International Conference on Liquid Metals, Brookhaven, 1966.

7. Magnetic, Superconducting and Other Phase Transitions within the Metallic State, Morrel H. Cohen, Sigma Xi and RESA National Lecture Southwest Tour, Spring, 1966, American Scientist.

8. Resonances in the Fundamental Optical Spectra of Solids, J. C. Phillips, Eight Lectures at the Enrico Fermi Summer School, Varenna, Italy, 1966.

9. Optical Spectra of Metals, J. C. Phillips, major introductory lecture at the International Conference on the Optical Properties of Metals, Paris, 1966.

10. Anomalous Resonances in the Optical Spectra of Alkali Metals, M. H. Cohen, Invited Paper of the International Conference on the Optical Properties of Metals, Paris, 1966.

11. Orthogonalized Plane Waves and Pseudopotentials: A Short Review, L. M. Falicov, presented at the Symposium on Band Structure, AIME Meeting, Los Angeles, February, 1967.

12. Present State of the Theory of the Metal-Insulator Transition, M. H. Cohen, presented at the APS Southwestern Meeting at Austin, Texas, February, 1967.

13. Microscopic Theory of Zero-Bias Tunneling Anomalies, J. Appelbaum, presented at the DSSP Symposium on Microscopic Excitations in Tunneling Barriers, APS meeting at Chicago, March, 1967.

14. Resonance Theory of d Bands, V. Heine, presented at the DSSP Symposium on Electron Theory of Metals, APS meeting at Chicago, March, 1967.

15. Periodicity of Spin-Density Waves in Chromium Alloys, L. M. Falicov, presented at the DSSP Symposium on Electron Theory of Metals, APS meeting at Chicago, March, 1967.

16. Optical Spectra of Transition and Noble Metals, J. C. Phillips, presented at the 1967 International Conference on Magnetism, Sheraton-Boston Hotel, Boston, Mass., September 1967.

17. Summary and Review, M. H. Cohen, presented at the Metal-Nonmetal Transition Conference, American Physical Society March 1968 Meeting in San Francisco.

18. Pseudopotential Band-Structure Calculations of Insulators, T. Bergstresser, Invited Paper, American Physical Society March Meeting, Berkeley, Calif., 1968.

19. Electronic Spectra of Solids, J. C. Phillips, presented at the Second International Conference on Vacuum Ultraviolet Radiation Physics; Interaction with Solids, April, 1968, Gatlinburg, Tennessee.

20. Transport Theory in Amorphous Systems, M. H. Cohen, Chairman, Gordon Conference on the Chemistry and Physics of Solids, August, 1968, Meriden, New Hampshire.

21. Double Dispersion Relations in Quantum Statistical Mechanics, M. H. Cohen, presented at the International Conference on Statistical Mechanics, September, 1968, Kyoto, Japan.

22. Magnetic Breakdown in Ferromagnetic Nickel, E. I. Zornberg, presented at the 14th Annual Conference on Magnetism and Magnetic Materials, November, 1968, New York, New York.

23. International Summer Course on Solid State Physics, NATO-Gent, Belgium, August 25-September 5, 1969, M. H. Cohen. Four Lectures on the Electronic Structures of Amorphous Semiconductors.

24. International Conference on Amorphous and Liquid Semiconductors, Cambridge, England, September 24-27, 1969, M. H. Cohen. Review of the Theory of Amorphous Semiconductors, Principal Theoretical Paper.

25. SEAS Symposium, New York, M. H. Cohen, May 14-17, 1969. Invited Paper.

26. Greater Washington Solid State Physics Colloquium, M. H. Cohen, March, 1969.

27. Annual Solid State Seminar, Dalhousie University, Halifax, N. S., Canada, M. H. Cohen, June 30-July 2, 1969. Three lectures on Electrons in Disordered Structures.

28. Principal Address, Midwest Solid State Physics Conference, University of Iowa, M. H. Cohen, October 18, 1969.

29. Materials Sciences Colloquium (Distinguished Contribution to Materials Sciences), Stanford University, Stanford, California, M. H. Cohen, October, 1969.

30. Invited Paper on "Electronic Structure of Disordered Materials", M. H. Cohen, 1970 Midwest Theory Conference, Notre Dame, Indiana, April 3-4, 1970.

31. Lecture on "Electronic Structure of Disordered Materials", M. H. Cohen, Gordon Conference, Seattle, Washington, July 27-31, 1970.

32. "Basic Concepts in the Theory of Amorphous Semiconductors", M. H. Cohen, Invited Paper at 10th Intl. Conf. on the Physics of Semiconductors, Cambridge, Mass., Aug. 17-21, 1970.

33. Invited Paper on "Basic Concepts in the Theory of Amorphous Semiconductors", M. H. Cohen, Intl. Conf. on Radiation Effects in Semiconductors, State University of New York, Albany, New York, Aug. 24-26, 1970.

34. Invited Paper on the "Theory of Amorphous Semiconductors, presented by E. N. Economou at the Annual Meeting of the Electrochemical Society, Atlantic City, New Jersey, October 4-9, 1970.

35. Invited Paper on the "Theory of Amorphous Semiconductors", M. H. Cohen, Annual Meeting of the APS, New York, N. Y., Feb., 1971.

36. M. H. Cohen, Chairman, 4th International Conference on Amorphous and Liquid Semiconductors, University of Michigan, Ann Arbor, Aug. 8-13, 1971.

Publications

Research activity fell into the following main categories:

I. SUPERCONDUCTIVITY

A. Theoretical

1. Mechanisms for Superconductivity in the Transition Metals, J. W. Garland, Phys. Rev. Letters 11, 111 (1963).

2. Isotope Effect in Superconductivity, J. W. Garland, Phys. Rev. Letters 11, 114 (1963).

3. Properties of a Thin Hollow Superconducting Cylinder, D. H. Douglass, Jr., Phys. Rev. 132, 513 (1963).

4. The Superconducting Energy Gap, D. H. Douglass, Jr. and L. M. Falicov, Chapter III in "Progress in Low Temperature Physics", Vol. IV, ed. by C. J. Gorter, North-Holland Publishing Company, Amsterdam (1964), p. 97.

5. Influence of Impurities on the Interactions Responsible for Superconductivity, Morrel H. Cohen, Rev. Mod. Phys. 35, 243 (1964).

6. The Existence of a Superconducting State in Semiconductors, Marvin L. Cohen, Rev. Mod. Phys. 35, 240 (1964).

7. Superconductivity in Many-Valley Semiconductors and in Semimetals, Marvin L. Cohen, Phys. Rev. 134, A511 (1964).

8. Resonance Scattering in Impure Superconductors, M. J. Zuckermann, Phys. Rev. 140, A899 (1965).

9. Theory of the Anisotropic Energy Gap in Superconducting Lead, Alan J. Bennett, Phys. Rev. 140, A1902 (1965).

10. Anomalous Dependence of the Superconducting Transition Temperature on Paramagnetic Impurities, K. H. Bennemann, Phys. Rev. Letters 17, 438 (1966).

11. Magnetic, Superconducting and Other Phase Transitions within the Metallic State, Morrel H. Cohen, American Scientist 54, 432 (1966).

12. Phenomenological Landau-Ginzburg Theory for Anisotropic Superconductors. Alan J. Bennett and L. M. Falicov, Phys. Rev. 152 , 302 (1967).

13. Band Structure Effects in Superconductivity. I: Formalism, J. Garland, Phys. Rev. 153, 460 (1967).

14. The Anomalous Specific Heat of Superconducting Magnetic Alloys, K. H. Bennemann and J. W. Garland, Phys. Rev. 159, 369 (1967).

15. Anomalous Electromagnetic Microwave Absorption of the Superconducting Alloys in a Static Magnetic Field, K. H. Bennemann, Phys. Letters 24A , 357 (1967).

16. Superconductive Pairing Across Electron Barriers, Morrel H. Cohen and D. H. Douglass, Jr., Phys. Rev. Letters 19, 118 (1967).

17. The Free Energy of Josephson Junctions, K. L. Ngai, Joel A. Appelbaum, Morrel H. Cohen and J. C. Phillips, Phys. Rev. 163, 352 (1967).

18. Interaction of the ac Josephson Current with Surface Plasmons, E. N. Economou and K. L. Ngai, Phys. Rev. Letters 20, 547 (1968).

19. Interaction of ac Josephson Currents with Surface Plasmons in Thin Superconducting Films, K. L. Ngai, Phys. Rev. 182, 555 (1969).

B. Experimental

20. Magnetic Field Dependence of the Microwave Surface Impedance of Superconducting Aluminum, R. Glosser and D. H. Douglass, Jr., Proceedings of the IXth International Conference on Low Temperature Physics, Moscow, 1966.

21. Precursor Absorption in Superconducting Lead, S. L. Norman and D. H. Douglass, Jr., Bull. Am. Phys. Soc. 11, 87 (1966).

22. Effect of Dielectric and High-Resistivity Barriers on the Superconducting Transition Temperature of Thin Films, M. Strongin, O. F. Kammerer, D. H. Douglass, Jr. and Morrel H. Cohen, Phys. Rev. Letters 19, 121 (1967).

II. MANY-BODY THEORY

23. Evidence for a New Collective Resonance in a "Free Electron" Metal, M. H. Cohen and J. C. Phillips, Phys. Rev. Letters 12, 662 (1964).

24. Coherent Pairing of the Second Kind for Strongly Interacting Fermions, M. H. Cohen, Phys. Rev. Letters 12, 664 (1964).

25. Generalized Selfconsistent Field Theory: Gor'kov Factorization, M. H. Cohen, Phys. Rev. 137, A497 (1965).

26. Further Evidence for Collective Resonances in Monovalent Metals, J. C. Phillips, Phys. Rev. 137, A1835 (1965).

27. Many-Body Resonances in Transition and Noble Metals, J. C. Phillips, Phys. Rev. 140, A1254 (1965).

28. Hall Coefficient of Hubbard's Model, D. C. Langreth, Phys. Rev. 148, 707 (1966).

(12). (Sec. I A). Magnetic, Superconducting and Other Phase Transitions within the Metallic State, Morrel H. Cohen, American Scientist 54, 432 (1966).

29. Double Dispersion Relations in Quantum Statistical Mechanics, A. K. Rajagopal and M. H. Cohen, J. Phys. Soc. Japan 26, 261 (1969).

30. Perturbation Theory for a Bound Polaron, Josef Sak, Phys. Rev. B3,3356 (1971).

III. SUPERFLUIDITY

31. Bose-Einstein Condensation in Narrow Channels, Brij M. Khorana and D. H. Douglass, Jr., Phys. Rev. 136, A35 (1965).

32. Theory of Liquid Helium II in a Rotating Annulus, A. J. Bennett and L. M. Falicov, Phys. Rev. 144, 162 (1966).

IV. ELECTRONIC STRUCTURES AND FERMI SURFACES OF METALS

33. Relativistic Band Structure and Fermi Surface of Thallium. I., Paul Soven, Phys. Rev. A137, 1706 (1965).

34. Relativistic Band Structure and Fermi Surface of Thallium. II. Comparison with Experiment. P. Soven, Phys. Rev. A137, 1717 (1965).

35. Low Temperature Electronic Specific Heats of Simple Metals, N. W. Ashcroft and J. W. Wilkins, Phys. Letters 14, 285 (1965).

36. Fermi Surfaces of Potassium and Rubidium, N. W. Ashcroft, Phys. Rev. 140, A935 (1965).

37. Band Structure and Fermi Surface of Antimony: Pseudopotential Approach, L. M. Falicov and P. J. Lin, Phys. Rev. 141, 562 (1966).

38. Fermi Surface of Arsenic, P. J. Lin and L. M. Falicov, Phys. Rev. 142, 441 (1966).

39. Electronic Spectrum of Crystalline Antimony, P. J. Lin and J. C. Phillips, Phys. Rev. 147, 469 (1966).

40. Fermi Surface of Copper, E. I. Zornberg and F. M. Mueller, Phys. Rev. 151, 557 (1966).

41. Band Structure of Transition Metals, J. C. Phillips, Proceedings of the International School of Physics "Enrico Fermi", Course XXXVII, Theory of Magnetism in Transition Metals, ed. W. Marshall, (Academic Press, 1967), pp. 22-49.

42. Inversion of Cubic de Haas-Van Alphen Data with Application to Palladium, F. M. Mueller and M.G . Priestley, Phys. Rev. 148, 638 (1966).

43. Partial Sum Rules for Transition and Noble Metals, J. C. Phillips, Phys. Rev. 153, 669 (1967).

44. Combined Interpolation Scheme for Transition and Noble Metals, F. M. Mueller, Phys. Rev. 153, 659 (1967).

45. "s-d" Interaction in Transition Metals, V. Heine, Phys. Rev. 153, 673 (1967).

46. The Resistivity of Calcium, Strontium and Barium under Pressure, B. Vasvari and V. Heine, Phil. Mag. 15, 136, 731 (1967).

47. Electronic Structure of Ca, Sr, and Ba under Pressure, B. Vasvari, A. O. E. Animalu and V. Heine, Phys. Rev. 154, 535 (1967).

48. Electronic Structure of Metals, V. Heine, ed. P. B. Hirsch and J. M. Ziman, (Cambridge Univ. Press, London, 1967).

49. Approximate Quantum Numbers for d Band States in Transition Metals, J. C. Phillips and F. M. Mueller, Phys. Rev. 155, 594 (1967).

50. Electronic Spectrum of Crystalline Copper, F. M. Mueller and J. C. Phillips, Phys. Rev. 157, 600 (1967).

51. "The Electronic Structures of Transition and Noble Metals", M. H. Cohen and F. M. Mueller. The Atomic and Electronic Structure of Metals (American Society of Metals, Metals Park, Ohio, 1967), p. 61.

52. "Orthogonalized Plane Waves and Pseudopotentials: A Short Review", L. M. Falicov, Energy Bands in Metals and Alloys, edited by L. H. Bennett and J. T. Weber (Gordon and Breach, New York, 1968), p. 73.

53. Significance of Model Hamiltonians in Energy-Band Theory, J. C. Phillips, Advances in Physics 17, 79 (1968).

54. Anisotropy in the Fermi Surface of Nickel, E. I. Zornberg, Solid State Comm. 6, 729 (1968).

55. Magnetic Breakdown in Ferromagnetic Nickel, E. I. Zornberg, J. Appl. Phys. 40, 1279 (1968).

56. Symmetry of the Wave Functions in the Band Theory of Ferromagnetic Metals, L. M. Falicov and J. Ruvalds, Phys. Rev. 172, 498 (1968).

57. de Haas-van Alphen Effect, Exchange Splitting and Spin-Orbit Interaction in Ferromagnetic Nickel, J. Ruvalds and L. M. Falicov, Phys.Rev. 172, 508 (1968).

58. Influence of Localized Umklapp Scattering on the Galvanomagnetic Properties of Metals, Richard A. Young, Phys. Rev. 175, 813 (1968).

59. The Band Structure and Fermi Surface of Ferromagnetic Nickel, Eric I. Zornberg, Phys. Rev. B1, 244 (1970).

60. Surface Plasmons in Thin Films, E. N. Economou, Phys. Rev. 182, 539 (1969).

61. Line Shapes in the Radio-Frequency Size Effect of Metals, G. E. Juras, Phys. Rev. 187, 784 (1969).

62. Impurity Lifetime Broadening on Noble Metal Fermi Surfaces, Scott Kirkpatrick, Phys. Rev. B3, 2563 (1971).

V. OPTICAL SPECTRA OF SOLIDS

63. Hybrid Excitons in Diamond, J. C. Phillips, Phys. Rev. 139, A1291 (1965).

64. Spectral Analysis of Photoemissive Yields in Si, Ge, GaAs, GaSb, InAs and InSb, M. L. Cohen and J. C. Phillips, Phys. Rev. 139, A912 (1965).

65. Optical Field Effect on Thresholds, Saddle-Point Edges and Saddle-Point Excitons, J. C. Phillips and B. O. Seraphin, Phys. Rev. Letters 15, 107 (1965).

66. Absorption of Light Due to Interband Transitions in Sodium, J. A. Appelbaum, Phys. Rev. 144, 435 (1966).

67. The Existence of Hyperbolic Excitons, J. Hermanson, Phys. Rev. Letters 18, 170(1967).

68. Optical Spectra of Transition and Noble Metals, J. C. Phillips, J. Appl. Phys. 39, 755 (1968).

69. Phonon Side-Bands in the Exciton Absorption, Josef Sak, Proceedings of the Xth Intl. Conf. on Physics of Semiconductors, Cambridge, Mass., 1970.

70. Phonon Side-Bands in Exciton Absorption: Perturbation Theory, Josef Sak, Phys. Rev. Letters 25, 1654 (1970).

VI. ELECTRONIC STRUCTURES OF INSULATORS AND SEMICONDUCTORS

71. Core Shifts and Pseudopotential Trajectories, P. J. Lin and J. C. Phillips, Advances in Phys. 14, 257 (1965).

72. Phase Shifts and Local Charge Neutrality in Semiconductors, V. Heine, Phys. Rev. 145, 593 (1966).

73. Dangling Bonds and Dislocations in Semiconductors, V. Heine, Phys. Rev. 146, 568 (1966).

74. Pseudopotential Theory of Exciton and Impurity States, J. Hermanson and J. C. Phillips, Phys. Rev. 150, 652 (1966).

75. Exciton and Impurity States in Rare-Gas Solids, J. Hermanson, Phys. Rev. 150, 660 (1966).

76. "T-Matrix Theory of Localized Electronic States Due to a Vacancy with Application to Diamond", K. H. Bennemann, Proceedings of the Semiconductor Conference, Tokyo, 1966 (U.S. Department of Commerce and National Bureau of Standards, 1967).

77. Mobility of Electrons in Compensated Semiconductors: II. Theory, L. M. Falicov and M. Cuevas, Phys. Rev. 164, 1025 (1967).

(53) (Sec. IV). Significance of Model Hamiltonians in Energy-Band Theory, J. C. Phillips, Advances in Physics 17, 79 (1968).

78. Microscopic Dielectric Function of a Model Semiconductor, G. Srinivasan, Phys. Rev. 178, 1244 (1969).

79. Energy of the Quasi-Free Electron State in Liquid and Solid Rare Gases, B. Raz and J. Jortner, Chem. Phys. Letters 4, 155 (1969).

80. Experimental Evidence for Trapped Exciton States in Liquid Rare Gases, B. Raz and J. Jortner, Proc. Roy. Soc. of London A317, 113 (1970).

81. Elementary Electronic Excitations in Insulating Liquids, J. Jortner and N. Kestner, Proc. of the II Weyl Conf. on Metal Ammonia Solutions (1970).

82. Optical Phonon Induced 2s-2p Splitting in Shallow Impurities, J. Sak, Phys. Letters 36A, 423 (1971).

VII. THEORY OF MAGNETIC METALS

83. Stability Theory of the Magnetic Phases for a Simple Model of the Transition Metals, David R. Penn, Phys. Rev. 142, 350 (1966).

(12) (Sec. 1A). Magnetic, Superconducting and Other Phase Transitions within the Metallic State, Morrel H. Cohen, American Scientist 54, 432 (1966).

84. Topics in the Theory of Magnetic Metals, Morrel H. Cohen, Proceedings of the International School of Physics "Enrico Fermi", Course XXXVII, Theory of Magnetism in Transition Metals, ed. W. Marshall, (Academic Press, 1967),pp.402-454.

85. Antiferromagnetism in Simple Metals, D. R. Penn and Morrel H. Cohen, Phys. Rev. 155, 468 (1967).

86. Magnetic Breakdown, Fermi Surface and Galvanomagnetic Properties in Antiferromagnetic Metals, L. M. Falicov and M. J. Zuckerman, Phys. Rev. 160, 372 (1967).

87. On the Exchange Character of the Anderson Hamiltonian, Joel A. Appelbaum, K. H. Bennemann and J. W. Garland, Phys. Rev. 161, 583 (1967).

(54) (Sec. IV). Anisotropy in the Fermi Surface of Nickel, E. I. Zornberg, Solid State Comm. 6, 729 (1968).

(55) (Sec. IV). Magnetic Breakdown in Ferromagnetic Nickel, E. I. Zornberg, J. Appl. Phys. 40, 1279 (1968).

(56) (Sec. IV). Symmetry of the Wave Functions in the Band Theory of Ferromagnetic Metals, L. M. Falicov and J. Ruvalds, Phys. Rev. 172, 498 (1968).

(57) (Sec. IV). de Haas-van Alphen Effect, Exchange Splitting and Spin-Orbit Interaction in Ferromagnetic Nickel, J. Ruvalds and L.M.Falicov, Phys. Rev. 172, 508 (1968).

88. Chromium-Like Model for an Itinerant Antiferromagnet, J. Kimball, Phys. Rev. 183, 533 (1969).

(59) (Sec. IV). The Band Structure and Fermi Surface of Ferromagnetic Nickel, Eric I. Zornberg, Phys. Rev. B1, 244 (1970).

VIII. PHYSICS OF SURFACES

89. Role of Screening in Surface Ion Neutralization, V. Heine, Phys. Rev. 151, 561 (1966).

90. Image-Potential Induced Surface Bands in Insulators, Milton W. Cole and Morrel H. Cohen, Phys. Rev. Letters 23, 1238 (1969).

91. Theory of Surface Plasmon Excitation in Low Energy Electron Diffraction and in Photoemission, K. L. Ngai, E. N. Economou and M. H. Cohen, Phys. Rev. Letters 24, 61 (1970).

92. Width of the Surface Layer of Liquid He^4, Milton W. Cole, Phys. Rev. 1, no. 6, 1838 (1970).

93. Properties of Image-Potential-Induced Surface States of Insulators, Milton W. Cole, Phys. Rev. B2, 4239 (1970).

IX. STRUCTURES OF METALS

94. Structure of Di- and Trivalent Metals, V. Heine and D. Weaire, Phys. Rev. 152, 603 (1966).

95. Pseudopotentials Applied to Stability of Structures, V. Heine, Proc. of Battelle Colloquium "Phase Stability in Metals and Alloys", Mc-Graw Hill, New York (1966).

X. TUNNELING THEORY

96. "s-d" Exchange Model of Zero-Bias Tunneling Anomalies, J. Appelbaum, Phys. Rev. Letters 17, 91 (1966).

97. Exchange Model of Zero-Bias Tunneling Anomalies, Joel A. Appelbaum, Phys. Rev. 154, 633 (1967).

98. Microscopic Theory of Tunneling Anomalies, Joel A. Appelbaum, J. C. Phillips and G. Tzouras, Phys. Rev. 160, 554 (1967).

XI. COVALENT BONDING AND IONICITY

99. A Posteriori Theory of Covalent Bonding, J. C. Phillips, Phys. Rev. Letters 19, 415 (1967).

100. The Covalent Bond in Crystals: I. Elements of a Structural Theory, J. C. Phillips, Phys. Rev. 166, 832 (1968).

101. The Covalent Bond in Crystals: II. Partially Ionic Binding, J. C. Phillips, Phys. Rev. 168, 905 (1968).

102. The Covalent Bond in Crystals: III. Anisotropy and Quadrupole Moments, J. C. Phillips, Phys. Rev. 168, 912 (1968).

103. The Covalent Bond in Crystals: IV. Lattice Deformation Energies, J. C. Phillips, Phys. Rev. 168, 917 (1968).

104. Total Single-Particle Energy of Isotropic Semiconductors, J. A. Van Vechten, Phys. Rev. 170, 773 (1968).

105. The Quantum Dielectric Theory of Electronegativity in Covalent Systems. I: Electronic Dielectric Constant, J. A. VanVechten, Phys. Rev. 182, 891 (1969).

XII. LATTICE VIBRATION THEORY

106. Lattice Vibrations in Silicon: Microscopic Dielectric Model, Richard M. Martin, Phys. Rev. Letters 21, 536 (1968).

107. A Simple Bond Charge Model for Vibrations in Covalent Crystals, Richard M. Martin, Chem. Phys. Letters 2, 268 (1968).

108. Dielectric Screening Model for Lattice Vibrations of Diamond Structure Crystals, R. M. Martin, Phys. Rev. 186, 871 (1969).

109. Two-Phonon Bound States, Morrel H. Cohen and J. Ruvalds, Phys. Rev. Letters 23, 1378 (1969).

XIII. METAL-NONMETAL TRANSITIONS

110. Summary and Review, M. H. Cohen, Rev. Mod. Phys. 40, 839 (1968).

XIV. ELECTRONIC STRUCTURES OF DISORDERED MATERIALS

111. A Simple Band Model for Amorphous Semiconducting Alloys, M. H. Cohen, H. Fritzsche and S. R. Ovshinsky, Phys. Rev. Letters 22, 1065 (1969).

112. Electronic Structure and Transport in Covalent Amorphous Semiconducting Alloys, M. H. Cohen, J. Non-Cryst. Solids 2, 432 (1970).

113. Electronic Structure of Disordered Materials, Lectures presented at the NATO Summer Course on Amorphous Semiconductors, University of Ghent, Belgium (1969).

114. Review of the Theory of Amorphous Semiconductors, Proceedings of the International Conference on Amorphous Semiconductors, Cambridge, England, J. Non-Cryst. Solids 4, 391 (1970).

115. Carrier Kinetics in Amorphous Semiconducting Alloys, Morrel H. Cohen and David Linton Johnson, J. Non-Cryst. Solids 3, 271 (1970).

116. On the Question of Parentage of Localized States, G. Srinivasan and Morrel H. Cohen, J. Non-Cryst. Solids 3, 393 (1970).

117. A Cluster Theory of the Electronic Structure of Disordered Systems, Karl F. Freed and Morrel H. Cohen, Phys. Rev. B3, 3400 (1971).

118. Anderson's Theory of Localization and the Mott-CFO Model, E. N. Economou and Morrel H. Cohen, Mat. Res. Bull. 5, No. 8, 577, Aug. 1970, (Mott Festschrift).

119. Localization in Disordered Materials: Binary Alloys, E. N. Economou, S. Kirkpatrick, Morrel H. Cohen and T. P. Eggarter, Phys. Rev. Letters 25, 520 (1970).

120. Anderson's Theory of Localization: Existence of Mobility Edges, E. N. Economou and Morrel H. Cohen, Phys. Rev. Letters 25, 1445 (1970).

121. Electronic Structure of Disordered Materials, Morrel H. Cohen, Proc. of the 1970 Midwest Theory Conference, Notre Dame, Indiana, Apr.3-4, 1970, p.15.

122. Localization in 1-D Disordered Systems, E. N. Economou and M. H. Cohen, Phys. Rev. B4, 396 (1971).

123. Statistical Mechanics of Charged Traps in an Amorphous Semiconductor, Phys. Rev. B4, 2581 (1971).

124. An Introduction to Percolation Theory, Vinod K. S. Shante and Scott Kirkpatrick, Advances in Physics 20, 325 (1971).

125. A Cluster Theory of the Electronic Structure of Disordered Systems, Karl F. Freed and Morrel H. Cohen, Proc. 3rd IMR Symposium, Electronic Density of States, Nat. Bur. Stand. (U.S.), Spec. Publ. 323, 505 (1972).

126. Existence of Mobility Edges in Anderson's Model for Random Lattices, E. N. Economou and Morrel H. Cohen, Phys. Rev. B5, 2931 (1972).

127. Electronic Structure of Liquid Alloys with Clusters, Morrel H. Cohen and J. Sak, Proc. of the IVth Intl. Conf. on Amorphous and Liquid Semiconductors, (Ann Arbor, Michigan 1971), J. Non-Cryst. Solids 8-10, 696 (1972).

128. Electronic Structure of Disordered Materials: A Review of Current Theoretical Understanding, Morrel H. Cohen, E. N. Economou, Karl F. Freed, S. Kirkpatrick, Chapter in book, "Amorphous and Liquid Semiconductors", edited by J. Tauc, Plenum Press (1973).

XV. PROBLEMS IN MOLECULAR PHYSICS

129. The Energy Gap Law for Radiationless Transitions in Large Molecules, R. Englman and J. Jortner, J. of Luminescence 1, 134 (1969).

130. Electronic Relaxation Processes in Large Molecules, J. Jortner, Plenary Lecture at the XII IUPAC Conf., Aug. 1969.

What is noteworthy about the research is its breadth and the productivity of the group. In addition several contributions of the first importance for the theory of condensed matter should be singled out.

These include papers 1 and 2 which contain the first attempt at a realistic calculation of the superconducting properties of actual materials; papers 8 and 9 which contain a successful theoretical prediction of superconductivity in doped many-valley semiconductors; papers 14 and 15 which contain the first successful relativistic study of the Fermi surfaces of a binary metal; papers 25, 27 and 33 which successfully sort out the electronic structures of the semimetals As and Sb for the first time;

papers 39 and 44 which foreshadow the later systematic work of Heine and his school on the theory of the crystal structures of simple metals; papers 47, 49 and 57 in which a scheme for the electronic structure of transition metals is developed which is almost as simple as the pseudopotential scheme for simpler materials; papers 67, 79, 80, 81, 82 and 83 in which Phillips' theory of covalent bonding and ionicity in crystals is proposed and developed; papers 75, 86 and 96 in which the first realistic microscopic theory of the lattice vibrations of a covalent semiconductor is developed; papers 89, 102, 104, 109, 115, 116, 118, 125, 128, 129 and 130 which make a major contribution to conceptual understanding of the electronic structures of disordered materials; papers 100 and 113 introduce novel electronic surface states for certain insulators; and paper 101 points out the existence of two phonon bound states.

In addition to these works of particular individual significance, there are many others which either alone or in a group contain substantial advances. For example, some of the papers in IA, IV, V, VI, VII, IX, XI and XII taken as a group advance our understanding of electronic structures substantially through the introduction and/or development of simple tools of theoretical calculation and interpretation of experimental results, such as the pseudopotential theory.