RESOURCE LETTER

Resource Letter HCMP-1: History of Condensed Matter Physics

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This Resource Letter provides a guide to the literature on the history of condensed matter physics, including discussions of the development of the field and strategies for approaching its complicated historical trajectory. Following the presentation of general resources, journal articles and books are cited for the following topics: conceptual development; institutional and community structure; social, cultural, and political history; and connections between condensed matter physics and technology.
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I. INTRODUCTION

Scientists have long been interested in the properties of solids, liquids, molecules, and other forms of condensed matter. Not only do the ordinary material substances that surround us—and the exotic ones that can be created only in controlled laboratory conditions—exhibit fascinating properties that pique our curiosity and invite explanation, but those properties often prove useful for accomplishing practical ends. However, despite the long tradition of scientific investigations into matter's properties, condensed matter physics is of recent vintage as a distinct field of physics. Its emergence as a field required the advent of quantum mechanics, which provided the theoretical grounding and mathematical language that could explain those properties that we have found both fascinating and useful for so long. This Resource Letter focuses on describing the historical resources that collectively tell the story of the application of quantum physics to condensed matter, the experimental techniques that made it possible, the technological outcomes of such research, and how these threads combined to form the field of condensed matter physics.

The history of condensed matter physics is a relative newcomer to the history of science. Navigating that history requires careful attention to terminology. Searching for "history of condensed matter physics" in search engines or databases is unlikely to yield many results, but this should not be mistaken for a lack of material on the subject. The name "condensed matter physics" did not become standard until the 1970s, when it began to take the place of "solid state physics," itself little-used before the 1940s, among some segments of the physics community. Whereas physicists are likely to regard the term solid state physics as outmoded, or to think of it as referring only to the subfield of condensed matter physics dedicated to solids with regular crystal lattices, historians who study times when solid state physics was more widely used to identify what we would now call condensed matter physics prefer to remain true to the eras they study and use older phrase. Furthermore, neither term was used as a name for a scientific field before World War II, when the research programs that would eventually compose it fell within acoustics, optics, mechanics, thermodynamics, metallurgy, quantum physics, quantum chemistry, high pressure physics, low temperature physics, x-ray crystallography, and other specialties.

The challenges of terminology are compounded by the fact that condensed matter physics is a broad and diverse field. In addition to research on regular solids and the behavior of fluids, it encompasses work on liquid crystals and quasicrystals, colloids and gels, glasses and ceramics, granular and soft matter, polymers and other complex molecules, and other subjects. Research we would today classify as condensed matter physics might at one point have been—and in some contexts might still be—identified by terms such as solid state physics, many body physics, low temperature physics, statistical physics, physics of complex systems, semiconductor physics, materials science or materials physics, nanophysics, mesoscopic physics, chemical physics, quantum chemistry, solid state chemistry, or others. Here, I focus most sharply on those fields that were considered element of the core of solid state and condensed matter physics in their own times. Many of these research traditions have roots reaching into the very early twentieth century, or even the nineteenth. To avoid venturing too far afield, I limit discussions of the early theoretical and experimental headwaters of research programs that eventually found themselves included within condensed matter physics, except where such origins are particularly notable.

The historical literature addressing condensed matter physics has only begun to scratch the surface of all the topics, research programs, disciplinary classifications, national contexts, and institutional settings it includes. For the purposes of this Resource Letter, I have, from necessity, emphasized certain elements of this complex amalgam over others, focusing mostly on those areas that have received the greatest attention from professional historians. What follows therefore reflects biases inherent in the literature by beginning from the early days of solid state physics and following forward those research programs that defined it in its early stages and which continued to dominate when condensed matter physics became a preferred disciplinary classification in the 1970s and 1980s. It also reflects a bias toward the American context, which is the most thoroughly explored by English-language works. Although these elements of the history of condensed matter physics are the most thoroughly explored at the present moment, they should not be mistaken for whole story, or even for its better part, and where applicable I have sought to direct readers to resources that can fill out the stories I cover in only a cursory manner here.

The direct relevance of much of condensed matter physics to technological applications adds another wrinkle to its history. Condensed matter physics grew alongside multidisciplinary technical enterprise such as materials science and nanotechnology for much of the second half of the twentieth century, and these technologically oriented fields frequently included solid state and condensed matter physicists as critical collaborators. As a result, the history of technology literature is often relevant for understanding the development of condensed matter physics. A comprehensive perspective on the history of condensed matter physics therefore requires considering how our scientific understanding of complex material systems grew alongside questions of how the physics community organized to pursue that research, how and why societies supported it, and how it connected with industrial development.

This Resource Letter offers a guide to each of these dimensions of the history of condensed matter physics. It presents some general resources, followed by targeted sets of references that describe: the conceptual development of the field; its institutional and community structure; its social, cultural, and political history; and the longstanding connection between condensed matter physics and technology. Finally, it concludes with some reflections on future directions for research in the field.

N.B.: Many of the sources listed below are relevant to multiple categories. To decide where to place sources that address multiple themes, I have considered how well they complement the other sources in the category.

II. GENERAL RESOURCES

A. Journals

Due to the breadth of condensed matter physics and its many applications, historical research addressing it can be found in a wide range of journals. Relevant research articles and reviews appear in the following venues:

American Journal of Physics
Ambix
Annual Review of Condensed Matter Physics
Archive for History of Exact Sciences
British Journal for the History of Science
Centaurus
Endeavour
The European Physical Journal H
Foundations of Chemistry
Historia Scientiarum
Historical Studies in the Natural Sciences (previously known as *Historical Studies in the Physical Sciences* and *Historical Studies in the Physical and Biological Sciences*)
History and Technology
History of Science
IEEE Annals of the History of Computing
Isis
Kagakusi Kenkyu
Metascience
Minerva
Osiris
Perspectives on Science
Physics in Perspective
Physics Today
Reviews of Modern Physics
Science in Context
Science, Technology, and Human Values
Social Studies of Science
Studies in History and Philosophy of Science Part A
Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics
Technology and Culture

B. Books and edited collections

Only a few book-length historical studies are devoted to the history of condensed matter physics. Supplementing these are biographies of some of the field's leading lights, edited collections that bring together important papers and reflections from participants in the history of the field, and autobiographical accounts by several leading condensed matter physicists, whose recollections provide effective first drafts of the history of their professional activities and research areas.

1. **Out of the Crystal Maze: Chapters from the History of Solid State Physics**, edited by L. Hoddeson, E. Braun, J. Teichmann, and S. Weart (Oxford U.P., Oxford, UK, 1992). The histories of solid state physics research programs in band theory, crystal defects, mechanical and magnetic properties, semiconductors, and collective phenomena are reconstructed in this classic volume in a technically sophisticated way. (A)
2. **Making the History of Physics Dirtier: Solid State Physics in the Twentieth Century**, edited by J. D. Martin and M. Janssen, *Historical Studies in the Natural Sciences* **45**(5) (2015). This journal special issue includes a critical introduction and three research essays documenting aspects of the conceptual, institutional, and social history of solid state and condensed matter physics. (I)
3. **Crystals, Electrons, Transistors: From Scholar's Study to Industrial Research**, M. Eckert and H. Schubert, translated by T. Hughes (American Institute of Physics, New York, 1990). Begins in the nineteenth century and charts both the growing theoretical understanding of the structure of solids and the emergence of the

industrial infrastructures that enabled that understanding to be applied at scale. (I)

4. **Crystal Fire: The Invention of the Transistor and the Birth of the Information Age**, L. Hoddeson and M. Riordan (W. W. Norton & Company, New York, 1997). The considerable contributions of solid state physics to the computing industry are discussed here. (I)
5. **The Beginnings of Solid State Physics: A Symposium Organized by Sir Nevill Mott, held 30 April–2 May 1979**, edited by N. F. Mott (Royal Society, London, 1980). The first systematic effort to tell the history of solid state physics, a conference organized by Nevill Mott, produced this proceedings volume focusing on the conceptual evolution of a few key research programs. (I)
6. **Solid State Science: Past, Present and Predicted**, edited by D. L. Weaire and C. G. Windsor (Adam Hilger, Bristol, 1987). A moderately technical, but still accessible overview of the major research programs and conceptual developments in solid state physics, from the early twentieth century through the 1980s. (I)
7. **Guide to Sources for History of Solid State Physics**, J. Warnow-Blewett and J. Teichmann. (Center for History of Physics, American Institute of Physics, New York, 1992). An annotated bibliography constructed during research for **Out of the Crystal Maze** (Ref. 1), including both primary and secondary sources relevant to the history of solid state physics. (E)
8. **BCS: 50 Years**, edited by L. N. Cooper and D. Feldman (World Scientific, Singapore, 2011). Many of the pioneers of superconductivity research contribute essays, some accessible but others quite technical, to this collection celebrating the influence of the Bardeen-Cooper-Schrieffer theory of superconductivity. (A)
9. **True Genius: The Life and Science of John Bardeen: The Only Winner of Two Nobel Prizes in Physics**, L. Hoddeson and V. Daitch (Joseph Henry Press, Washington, D.C., 2002). This readable biography of John Bardeen discusses his role in some of the most notable developments of the Cold War era and the environment at University of Illinois, a major center of condensed matter physics research. (E)
10. **Manuel Cardona: Memories and Reminiscences**, edited by K. Ensslin and L. Viña (Springer, Cham, 2016). This collection of personal accounts paint both a personal and scientific picture of one of the most prolific solid state physicists of the twentieth century. Many contributions are narrative and highly accessible, whereas others contain more technical content. (I)
11. **Piere-Gilles De Gennes: A Life in Science**, L. Plévert (World Scientific, Singapore, 2011). An authorized biography of one of the principal contributors to research into superconductors, liquid crystals, and polymers, celebrating his life and work. (E)
12. **Herbert Fröhlich: A Physicist Ahead of His Time**, G. H. Hyland (Springer, Cham, 2015). A celebration of the wide-ranging career of Herbert Frölich, who made foundational contributions to superconductivity and pioneered the application of quantum field theory to condensed matter. (I)
13. **Douglas Rayner Hartree: His Life in Science and Computing**, Froese Fischer (World Scientific, Singapore, 2003). An accessibly written, though at times technical account, of Hartree's life and work, which included developing some of the early quantum approximation methods necessary for theoretical solid state physics. (I)
14. **Kapitza in Cambridge and Moscow: Life and Letters of a Russian Physicist**, edited by J. W. Boag, P. E. Rubinin, and D. Shoenberg (North-Holland, Amsterdam, 1990). Pyotr Kapitsa was a leader in low temperature physics. This volume offers an overview of his life and an edited collection of his correspondence. (E)
15. **Fritz London: A Scientific Biography**, K. Gavroglu (Cambridge U.P., Cambridge, UK, 1995). An intellectual biography that includes detailed discussion of London's contributions to superconductivity and superfluidity. (I)
16. **Broken Genius: The Rise and Fall of William Shockley, Creator of the Electronic Age**, J. Shurkin (Macmillan, New York, 2006). This accessible biography of William Shockley traces his early contributions to solid state physics, including the invention of the transistor, and his role in founding the semiconductor industry in the San Francisco Bay Area. It also confronts his subsequent forays into latter-day eugenics, which alienated him from the scientific community. (E)
17. **Great Solid State Physicists of the 20th Century**, edited by J. A. Gonzalo and A. López (World Scientific, Singapore, 2003). Biographical vignettes of William Henry Bragg, William Lawrence Bragg, Peter Debye, John Bardeen, and Lev Landau, with an overview of Nobel Prizes awarded for work in solid state physics. (E)
18. **The Laser in America, 1950–1970**, J. Bromberg (MIT Press, Cambridge, MA, 1991). This book addresses both the technical and conceptual development of the laser and the Cold War political conditions that shaped it. (I)
19. **Beam: The Race to Make the Laser**, J. Hecht (Oxford U.P., Oxford, UK, 2005). A narrative account of the social and institutional environment in which various research groups competed to develop a working laser, featuring discussion of the roles of Charles Townes, Arthur Schawlow, Theodore Maiman, Gordon Gould, and others. (I)
20. **More and Different: Notes from a Thoughtful Curmudgeon**, P. W. Anderson (World Scientific, Singapore, 2011). Philip W. Anderson collects essays reflecting on all aspects of his career as a condensed matter physicist and commentator on the public place of science, with an emphasis on his opposition to reductionism. (I)
21. **Landau: The Physicist and the Man: Recollections of L. D. Landau**, edited by J. B. Sykes (Pergamon Press, Oxford, UK, 1989). Landau's recollections of his career, edited and transcribed, including insights into his early contributions to the quantum theory of condensed matter. (I)
22. **On the Frontier, My Life in Science**, F. Seitz (American Institute of Physics, New York, 1994). Frederick Seitz's autobiography chronicles his life and career, during which he wrote the first textbook on solid state theory and became an influential government advisor and corporate consultant. (E)
23. **Solid State and Molecular Theory: A Scientific Biography**, J. C. Slater (John Wiley & Sons, New York, 1975). John Clarke Slater's autobiography focuses on his scientific contributions, particularly the use of *ab initio* quantum methods to understand the structure of solids and molecules. (I)

24. **On Superconductivity and Superfluidity: A Scientific Autobiography**, V. L. Ginzburg (Springer, Berlin, 2009). A technical, first-hand account of Vitaly L. Ginzberg's contributions to the theoretical development of landmark theories of superconductivity and superfluidity. (A)

C. Oral histories

The research for **Out of the Crystal Maze: Chapters from the History of Solid State Physics** (Ref. 1) and **The Laser in America** (Ref. 18) involved conducting oral history interviews with influential members of the field. Combined with other oral histories, these constitute one of the richest sources of material on the history of condensed matter physics. Most of these oral histories can be found at the Niels Bohr Library and Archives of the American Institute of Physics in College Park, Maryland. Collectively, they document the childhood experiences, educational backgrounds, and careers of influential figures in the field, as well as their perspectives on larger-scale institutional and political developments. All contain highly accessible material, and some venture into more intermediate and advanced territory. A significant proportion of the oral histories held at the Niels Bohr Library and Archives are transcribed and are available online, where they are keyword searchable and sometimes include audio excerpts: https://www.aip.org/history-programs/niels-bohr-library/oral-histories/.

25. P. W. Anderson, interview by A. B. Kojevnikov, 30 March, 30 May, 23 November 1999, and 29 June 2000 (Niels Bohr Library & Archives, American Institute of Physics, College Park, MD, [hereafter NBL]). (E)
26. P. W. Anderson, interview by P. Chandra, P. Coleman, and S. Sondhi, 15 October, 29 October, and 5 November 1999 (NBL). (E)
27. P. W. Anderson, interview by L. Hoddeson, 10 May 1988 (NBL). (E)
28. J. Bardeen, interview by W. Aspray, 29 May 1984 (NBL). (E)
29. J. Bardeen, interview by L. Hoddeson, 13 February 1980 (NBL). (E)
30. H. Bethe, interview by L. Hoddeson, 29 April 1981 (NBL). (E)
31. F. Bloch, interview by C. Weiner, 15 August 1968 (NBL). (E)
32. F. Bloch, interview by L. Hoddeson, 15 December 1981 (NBL). (E)
33. N. Bloembergen, interview by J. Bromberg and P. L. Kelley, 27 June 1983 (NBL). (E)
34. W. H. Brattain, interview by A. N. Holden, W. J. King, and C. Weiner, 1 January 1964 and 28 May 1974 (NBL). (E)
35. W. Brinkman, interview by S. Hochheiser, 7 March 2006 (NBL). (E)
36. E. U. Condon, interview by C. Weiner, 17 October 1967 to 12 September 1973 (NBL). (E)
37. K. Darrow, interview by H. Barton and W. J. King, 2 April 1964 (NBL). (E)
38. P. J. W. Debye, interview by D. M. Kerr, Jr. and L. P. Williams, 22 December 1965 and 16 June 1966 (NBL). (E)
39. M. Dresselhaus, interview by B. Bensaude-Vincent and A. Hessenbruch, 25 October 2001; available online at: http://authors.library.caltech.edu/5456/1/hrst.mit.edu/hrs/materials/public/Dresselhaus/Dresselhaus(HelenaFu_plus).html. (E)
40. M. Dresselhaus, interview by J. D. Martin, 24 June 2014 (NBL). (E).
41. J. B. Fisk, interview by L. Hoddeson and A. Holden, 24 June 1976 (NBL). (E)
42. F. Fumi, interview by L. Belloni, 27 November 1982 (NBL). (E)
43. W. C. Herring, interview by A. B. Kojevnikov, 5 August 2000 (NBL). (E)
44. K. M. Kelly, interview by L. Hoddeson, 2 July 1976 (NBL). (E)
45. A. Landé, interview by C. Weiner, 3 October 1973 (NBL). (E)
46. B. Lax, interview by J. L. Bromberg, 15 May 1986 (NBL). (E)
47. P. O. Löwdin, interview by L. Hoddeson, 27 January 1975 (NBL). (E)
48. H. Margenau, interview by R. B. Lindsay and W. J. King, 6 May 1964 (NBL). (E)
49. Sir N. F. Mott, interview by P. Hoch and E. Braun, 15 January 1981 (NBL). (E)
50. L. Néel, interview by A. Guinier and L. Hoddeson, 29 May 1981 (NBL). (E)
51. A. W. Overhauser, interview by K. Szymborksi, 22 February 1982 (NBL). (E)
52. E. M. Purcell, interview by P. Hendrikson, 29 June 1982 (NBL). (E)
53. F. Seitz, interview by L. Hoddeson and P. Hendrikson, 26 and 27 January, 24 March 1981, and 16 March 1982 (NBL). (E)
54. F. Seitz, interview by S. Weart, 6 October 1982 (NBL). (E).
55. F. Seitz, interview by A. Needell and R. Doel, 19 July 1994 (NBL). (E)
56. W. Shockley, interview by L. Hoddeson, 10 September 1974 (NBL). (E)
57. J. C. Slater, interview by C. Weiner, 23 February and 7 August 1970 (NBL). (E)
58. J. C. Slater, interview by T. S. Kuhn, 3 and October 1963 (NBL). (E)
59. C. Slichter, interview by L. Hoddeson, 29 April 1977 (NBL). (E)
60. C. Slichter, interview by B. Ashrafi, 26 March 2005 (NBL). (E)
61. R. Smoluchowski, interview by K. Szymborski, 16 August 1982 (NBL). (E)
62. L. Tisza, interview by K. Gavroglou, 12 January 1988 (NBL). (E)
63. J. Valasek, interview by R. H. Stuewer, 8 May 1969 (NBL). (E)
64. J. H. Van Vleck, interview by C. Weiner and G. Lubkin, 28 February 1966 and 19 January 1973 (NBL). (E)
65. E. P. Wigner, interview by L. Hoddeson, 24 January 1981 (NBL). (E)

D. Additional online resources

The following freely available online resources can be used to locate additional materials on topics not covered, or covered only in a cursory way, in this Resource Letter.

66. "Array of Contemporary American Physicists," American Institute of Physics, Center for History of Physics. Available online at: http://www.aip.org/history/acap/. This database of American physicists charts their

education and employment histories, notable awards, distinctions, and leadership positions, and cross references them with institutions and topic areas. (E)

67. "International Catalog of Sources," American Institute of Physics. Available online at: http://libserv.aip.org:81/ipac20/ipac.jsp?profile=icos. A searchable database of primary and secondary historical sources, both published and unpublished, related to the history of physics held at libraries worldwide. (E)

68. "Biographical Memoirs of the National Academy of Sciences," National Academy of Sciences. Available online at: http://www.nasonline.org/publications/biographical-memoirs/. The eulogia the National Academy of Sciences publishes for its deceased members, including many condensed matter physicists, document their life histories and professional accomplishments. (E)

69. "IsisCB Explore," History of Science Society. Available online at: http://data.isiscb.org/. A keyword-searchable database based on the "*Isis* Current Bibliography," a continually updated bibliography of published research in the history of science. (E)

70. "All Nobel Prizes in Physics," NobelPrize.org. Available online at: http://www.nobelprize.org/nobel_prizes/physics/laureates/. The Nobel Foundation's website contains biographical overviews of past winners, as well as copies of their Nobel lectures and banquet speeches. (E)

III. CONCEPTUAL DEVELOPMENT OF RESEARCH PROGRAMS

Condensed matter physics is a broad, diverse field, and the range of topics it contains makes telling its history challenging. Historians often meet this challenge by focusing their attention on the progress of a particular theory, experimental technique, or research program. Many such studies focus on the era between the advent of quantum mechanics in the 1920s and the Bardeen-Cooper-Schrieffer theory of superconductivity in the late 1950s, making the conceptual history of condensed matter physics during this era the best studied of its many historical dimensions. The list below presents studies of this variety in rough chronological order, beginning with early twentieth century applications of quantum physics to condensed matter.

The early twentieth century was a time of considerable interest in the physics of condensed matter as a testing ground for the new quantum physics. The theory's successes and failures in the realm of molecules and solids describing phenomena such as bonding, conductivity, and magnetic susceptibility helped pave the way from the old quantum theory to the new quantum mechanics, which was elaborated throughout the 1930s by incorporating concepts from the condensed matter domain, such as tunneling, resonance, and exchange.

In the 1940s and 1950s, the established tradition in the quantum theory of complex matter was bundled with a diverse set of other research programs to create a new field, solid state physics. It was a wildly diverse synthesis of research programs, and a few of these quickly gained prominence, often on the strength of their industrial relevance. The invention of the transistor at Bell Laboratories in 1947 made semiconductor research one of the liveliest areas of physics. A strong community came together around nuclear magnetic resonance, which grew from World War II radar research. The long-awaited theoretical description of superconductivity, which both reinforced the intellectual challenges posed by the physics of complex matter and promised a raft of new applications, made low-temperature work central to solid state physics in the late 1950s.

Later in the twentieth century, segments of the solid state physics community became frustrated with the fact that funding for solid state research was often tied to technological development, and aimed to reinforce the intellectual value and viability of their research. These efforts led to a resurgence of interest in fundamental questions that appear in the condensed matter domain. This involved an intellectual disagreement between condensed matter physicists and high energy physicists over the importance of reductionist thinking for physics, which shaped the conceptual development of both fields.

A. Overview of conceptual histories

71. "The development of ideas on the structure of metals," C. S. Smith, in **Critical Problems in the History of Science**, edited by M. Clagett (University of Wisconsin Press, Madison, WI, 1959), pp. 467–498. A broad overview of the history of metallurgy, from the late middle ages up to the development of X-ray crystallography, with a summary of the then-current scientific understanding of metallic structure. (E)

72. "An essay on condensed matter physics in the twentieth century," W. Kohn, Rev. Mod. Phys. **71**(2), S57–S77 (1999). Major historical landmarks in condensed matter physics, as summarized by a prominent contributor to it. (I)

73. "Elements of solid state physics," H. Kragh, in **Quantum Generations: A History of Physics in the Twentieth Century** (Princeton U.P., Princeton, NJ, 1999), pp. 366–381. Presents solid state physics as one of many areas transformed by the advent of quantum mechanics. (E)

74. "Kuhn losses regained: Van Vleck from spectra to susceptibilities," C. Midwinter and M. Janssen, in **Research and Pedagogy: A History of Early Quantum Physics through its Textbooks**, edited by M. Badino and J. Navarro (Edition Open Access, Berlin, 2013), pp. 137–205. Discusses the role of John Van Vleck's research on magnetic susceptibilities in justifying quantum mechanics; available online at http://edition-open-access.de/studies/2/8/index.html. (A)

75. **The Critical Point: A Historical Introduction to the Modern Theory of Critical Phenomena**, C. Domb (Taylor & Francis, London, 1996). A highly technical reconstruction of research into critical phenomena, one of the most important intellectual traditions in condensed matter physics. (A)

76. "History of the Lenz-Ising model," 3 parts, "1920–1950: From Ferromagnetic to Cooperative Phenomena," "1950–1965: From Irrelevance to Relevance," "1965–1971: The Role of a Simple Model in Understanding Critical Phenomena," M. Niss, Arch. Hist. Exact Sci. **59**(3), 267–318 (2005); **63**(3), 243–287 (2008); **65**(6), 625–658 (2011). Traces the Lenz-Ising model, which was rejected as inadequate to describe ferromagnetism in the early days of quantum mechanics, through its revival as a way to describe cooperative phenomena and critical phenomena. (A)

77. "History of the Lenz-Ising model," S. G. Brush, Rev. Mod. Phys. **39**(4), 883–893 (1967). A brief technical overview of the model, its development, and its applications, with brief biographical overviews of the principle physicists involved in its elaboration. (A)
78. "The development of the quantum mechanical electron theory of metals: 1900–28," L. Hoddeson and G. Baym, Proc. R. Soc. A **371**(1744), 8–23 (1980). The electron theory of metals, critical for explaining phenomena like electrical conductivity, survived its classical origins and, after a semi-classical period, was given a full quantum mechanical treatment. (A)
79. "Analogy, extension, and novelty: Young Schrödinger on electric phenomena in solids," J. Joas and S. Katzir, Stud. Hist. Phil. Mod. Phys. **42**, 43–53 (2011). Within a discussion of the use of analogy in theoretical reasoning, this article presents Erwin Schrödinger's attempts to understand the electrical behavior of solids, particularly dielectrics. (A)
80. "Propaganda in science: Sommerfeld and the spread of the electron theory of metals," M. Eckert, Hist. Stud. Phys. Bio. Sci. **17**(2), 191–233 (1987). Eckert studies the role of influential individuals in disseminating theories, using the case study of Arnold Sommerfeld and his propagation of the electron theory of metals to his many pupils, and accounting for both intellectual and social factors. (I)
81. "A key concept from the electron theory of metals: History of the Fermi surface 1933–60," P. K. Hoch, Contemp. Phys. **24**(1), 3–23 (1983). Discusses the emergence and relevance of the concept of the Fermi surface, which was critical for theoretical understanding of phenomena like electrical conductivity in metals. (I)
82. "Subsequent and subsidiary? Rethinking the role of applications in establishing quantum mechanics," J. James and C. Joas, Hist. Stud. Nat. Sci. **45**(5), 641–702 (2015). Although we often think of a completed quantum mechanics being applied to more complex systems, this paper argues that confronting those systems was essential for the elaboration of the theory. (A)
83. "Hacking the quantum revolution: 1925–1975," S. S. Schweber, Eur. Phys J. H **40**(1), 53–149 (2015). Contends that rich cross-fertilization between disciplines, including condensed matter physics, drove the quantum revolution. (A)
84. "The entry of the quantum theory of solids into the Bell Telephone Laboratories, 1925–40: A case-study of the industrial application of fundamental science," L. Hoddeson, Minerva **18**(3), 422–447 (1980). Examines the close connection between basic research in condensed matter physics and technological development that was distinctive of Cold War industrial laboratories. (I)
85. "The young John Clarke Slater and the development of quantum chemistry," S. S. Schweber, Hist. Stud. Phys. Bio. Sci. **20**(2), 339–406 (1990). Takes John Slater as an exemplar of the rise of American quantum theory in the 1920s, describing his work in quantum chemistry early in his career. (I)
86. "The peculiar notion of exchange forces," pts. 1 and 2, "Origins in quantum mechanics, 1926–1928," and "From nuclear forces to QED, 1929–1950," C. Carson, Stud. Hist. Phil. Mod. Phys. **27**(1), 23–45 (1996); **27**(2), 99–131 (1996). Documents the origin of the exchange concept in atomic physics, quantum chemistry, and ferromagnetism before tracing its rise as a core concept of quantum electrodynamics. (A)
87. "A theory of ferromagnetism by Ettore Majorana," S. Esposito, Ann. Phys. **324**(1), 16–29 (2009). Revisits the all-but-forgotten attempt by Majorana to develop a quantum mechanical account of ferromagnetism and argues that it compares favorably to similar efforts by others in the late 1920s and early 1930s. (A)
88. "The Americanization of molecular physics," A. Assmus, Hist. Stud. Phys. Bio. Sci. **23**(1), 1–34 (1992). Argues that the quantum mechanics of molecules offered a path for American physicists to break into a community dominated by Europeans in the 1920s and 1930s. (I)
89. **Neither Physics nor Chemistry: A History of Quantum Chemistry**, K. Gavroglu and S. Simões (MIT Press, Cambridge, MA, 2011). Traces the disciplinary emergence, conceptual contributions, and technical accomplishments of quantum chemistry, including a discussion of its relationship to contemporary work in solid state physics. (I)
90. "The development of the quantum-mechanical electron theory of metals: 1928–1933," L. Hoddeson, G. Baym, and M. Eckert, Rev. Mod. Phys. **59**(1), 287–326 (1987). A sequel to Ref. 78, this paper examines the function of the solid state as a proving ground for the new quantum mechanics. (A)
91. "Elaborating the crystal concept: Scientific modeling and ordered states of matter," D. Daugherty (Ph.D. dissertation, University of Chicago, 2007). Discusses the role of models and modelling in physical thinking, through the example of studies of crystal structure. (A)
92. **Methodological Aspects of the Development of Low Temperature Physics 1881–1956: Concepts out of Context(s)**, K. Gavroglu and Y. Goudaroulis (Springer, Dordrecht, 1989). Traces early experiments with low temperature apparatus, particularly at H. Kamerlingh Onnes's Leiden laboratory, and subsequent efforts to explain the unexpected phenomena of superconductivity and superfluidity these investigations produced. (I)
93. **Superconductivity: Its Historical Roots and Development from Mercury to the Ceramic Oxides**, P. F. Dahl (American Institute of Physics, New York, 1992). Especially notable for its extensive treatment of the experimental background to superconductivity and discussion of the search for new superconducting materials. (I)
94. **The Cold Wars: A History of Superconductivity**, Jean Matricon and Georges Waysand, trans. Charles Glashausser (New Brunswick, NJ, Rutgers, 2003). A comprehensive account of the development of superconductivity research, which includes detailed discussions of European contexts that are absent from many other accounts. (I)
95. **Superconductivity: Discoveries and Discoverers**, K. Fossheim (Springer, Berlin, 2013). Biographical overviews and autobiographical reflections of ten physicists who won Nobel Prizes for work in superconductivity. (E)
96. "Interpreting superconductivity: The history of quantum theory and the theory of superconductivity and superfluidity, 1933–1957," E. P. Jurkowitz (Ph.D.

dissertation, University of Toronto, 1996). Shows how different conceptions of quantum mechanics drove different theoretical approaches to superconductivity up to the Bardeen-Cooper-Schrieffer theory of 1957. (A)

97. "Superconductivity—A challenge to modern physics," C. Joas and G. Waysand, in **History of Artificial Cold, Scientific, Technological and Cultural Issues**, edited by K. Gavroglu (Springer, Dordrecht, 2014), pp. 83–92. Shows how the phenomenon of superconductivity motivated both experimental and theoretical developments. (I)

98. "Superfluid ^{3}He—the early days," D. M. Lee and A. J. Leggett, J. Low Temp. Phys. **164**(3), 140–172 (2011). A detailed reconstruction of the development of superfluidity theory, based on experiments with liquid ^{3}He. (A)

99. "Superfluidity: How quantum mechanics became visible," S. Balibar, in **History of Artificial Cold, Scientific, Technological and Cultural Issues**, edited by K. Gavroglu (Springer, Dordrecht, 2014), 93–117. History of the experimental phenomenon of superfluidity and its theoretical description. (I)

100. "C. V. Raman and the discovery of the Raman effect," R. Singh, Phys. Perspect. **4**(4), 399–420 (2002). Includes a biographical sketch of Raman, the sequence of events leading to the discovery of its eponymous effect, which became a common topic in experimental condensed matter research, and the reception of his work. (I)

101. "Finding the energy bands of silicon," W. A. Harrison, Phys. Persp. **11**(2), 198–208 (2009). Understanding the band structure of solids was critical for exploiting their magnetic and electrical properties; this article describes the process of discovery for silicon. (I)

102. "The education of Walter Kohn and the creation of density functional theory," A. Zangwill, Arch. Hist. Exact Sci. **68**(6), 775–848 (2014). (A)

103. "Hartree and Thomas: The forefathers of density functional theory," A. Zangwill, Arch. Hist. Exact Sci. **67**(3), 331–348 (2013). (A)

104. "A half-century of density functional theory," A. Zangwill, Phys. Today **68**(7), 34–39 (July 2015). This and the previous two articles give a detailed account of the origin and dissemination of one of the most widely used approximation schemes in condensed matter physics. (I)

105. "Chemistry in a physical mode: Molecular spectroscopy and the emergence of NMR," C. Reinhardt, Ann. Sci. **61**(1), 1–32 (2002). Emphasizes the role of Herbert S. Gutowsky in developing nuclear magnetic resonance techniques at Harvard University in the 1940s and 1950s. (I)

106. "Robert Vivian Pound and the discovery of nuclear magnetic resonance in condensed matter," U. Pavlish, Phys. Persp. **12**(2), 180–189 (2010). Based on interviews with Pound, this paper relates a personal account in his involvement in early nuclear magnetic resonance research. (I)

107. "A historical perspective on the rise of the Standard model," S. S. Schweber, in **The Rise of the Standard Model: Particle Physics in the 1960s and 1970s**, edited by L. Hoddeson, L. Brown, M. Riordan, and M. Dresden (Cambridge U.P., Cambridge, UK, 1997), pp. 645–684. Charts the reductionist view that contributed to the standard model, and the contrasting anti-reduction in the condensed matter community. (I)

108. "The physicists' debates on unification in physics at the end of the 20th century," J. Cat, Hist. Stud. Phys. Bio. Sci. **28**(2), 253–299 (1998). Examines the concept of unity and the influence it had over both high energy and condensed matter physicists' understanding of their field. (I)

109. "Fundamental physics and its justifications, 1945–1993," H. Stevens, Hist. Stud. Nat. Sci. **34**(1), 151–197 (2003). Examines the notions of unity and symmetry as they applied to physicists notions of fundamental research, which shaped disagreements between high energy and condensed matter physics. (I)

110. "Fundamental disputations: The philosophical debates that governed American physics, 1939–1993," J. D. Martin, Hist. Stud. Nat. Sci. **45**(5), 703–757 (2015). Ties intellectual debates about reduction and emergence to the institutional evolution of condensed matter physics. (I)

IV. INSTITUTIONAL EVOLUTION AND COMMUNITY STRUCTURE

The research programs that made up solid state and condensed matter physics were thoroughly international throughout the twentieth century, but the first institutions dedicated to the field appeared in the United States after World War II, at which point the community of researchers interested in the physics of condensed matter had become large enough to establish its own institutions and worry about its community structure. The Division of Condensed Matter Physics of the American Physical Society (APS) was founded in 1947, largely on the back of the efforts of the General Electric research physicist Roman Smoluchowski. It was originally proposed as a division for metals physics, and was envisioned as a way to give industrial researchers—a growing constituency in the APS—a home within the society and a greater say over its organization and polices. The division was called the "Division of Solid State Physics" up until it adopted its current name in 1978. Historical examinations of the large-scale community and institutional dynamics of condensed matter physics in the United States focus primarily on this era of the Cold War.

Much of this literature examines specific institutional contexts. Because of the field's diversity, individual institutions established solid state and condensed matter research programs with widely different emphases. Although the field was originally associated most strongly with the golden age of industrial laboratories at places like Bell, General Electric, Westinghouse, Corning, and RCA, solid state and condensed matter physics grew equally rapidly in industrial laboratories, academic physics departments, and government research facilities, not least the newly established National Laboratory system. Whereas one university or government facility might seek to put condensed matter physicists into conversation with chemists and engineers in order to encourage industrial development, as, for example, happened within the ARPA-funded system of interdisciplinary laboratories hosted on college campuses, others sought to emphasize the field's fundamental intellectual potential.

Institutional structure dedicated to solid state physics (initially) and condensed matter physics (later) quickly grew in other countries as well following World War II. In each of the nations in which it took root, condensed matter physics reflected different economic conditions, political realities, and national priorities. For example, whereas solid state physics in the United States included work on liquids, molecules, and other substances that were not, strictly speaking, solids, "*Festkörperphysik*" in Germany, particularly East Germany, tended to be more narrowly focused on the physics of regular crystal lattices. In France "*physique du solide*," which grew in the late 1950s and early 1960s, did so alongside the better-established "*chimie du solide*," which reflected the long tradition of French chemistry. The English-language literature treats the American context more extensively than it does other national contexts, but condensed matter physics was nevertheless a lively research area worldwide, especially during the Cold War. The sources below, though they do not offer the same depth of coverage of other countries as they do of the United States, are selected to convey a sense of the field's international reach.

The institutional history of condensed matter physics is an exercise in identifying the local conditions that gave the field purpose and meaning. In addition to their intellectual and technical goals, condensed matter physicists actively pursued professional goals, and the pursuit of such goals had consequences for the way their research was organized. A considerable proportion of the existing historical literature focuses on the United States, but available resources nevertheless map out these dynamics in a variety of institutional and national contexts.

A. Overview of institutional histories

111. "The solid community," S. Weart, in **Out of the Crystal Maze: Chapters from the History of Solid State Physics**, edited by L. Hoddeson *et al.* (Oxford U.P., Oxford, UK, 1992), pp. 617–669. An overview of the establishment, growth, and professional identity of the solid state physics community in the early Cold War. (I)

112. "The birth of the solid-state physics community," S. R. Weart, Phys. Today **41**(7), 38–45 (1988). A condensed and more widely accessible articulation of the argument in the work cited directly above. (E)

113. "What's in a name change? Solid state physics, condensed matter physics, and materials science," J. D. Martin, Phys. Persp. **17**(1), 3–32 (2015). Demonstrates how different names for physical research on complex matter reflected the evolving institutional objectives and community priorities that shaped the field. (I)

114. "The construction of a discipline: Materials science in the United States," B. Bensaude-Vincent, Hist. Stud. Phil. Bio. Sci. **31**(2), 223–48 (2001). Characterizes the relationship between materials science and solid state physics. (I)

115. "Properties and phenomena: Basic plasma physics and fusion research in postwar America," G. J. Weisel, Phys. Perspect. **10**(4), 396–437 (2008). Examines the community of plasma physicists in post–World War II America, and explores how they navigated the overwhelming pressure to pursue fusion research at the expense of basic research. (I)

116. "Reflections on my career in condensed matter physics," M. S. Dresselhaus, Annu. Rev. Condens. Matter Phys. **2**(1), 1–9 (2011). Mildred Dresselhaus recounts her career trajectory, including her path into the physics of carbon, to which she made landmark contributions, and reflects more generally on the social and institutional changes in the field throughout her career. (I)

117. "Whatever happened to solid state physics?," J. J. Hopfield, Annu. Rev. Condens. Matter Phys. **5**, 1–13 (2014). A personal recollection of the changes in the field's identity through the late twentieth century. (E)

118. "Nuclear, high energy, and solid state physics," J. D. Martin, in **The Blackwell Companion to the History of American Science**, edited by G, M. Montgomery and M. A. Largent (Blackwell, Oxford, UK, 2016). Presents the development of American solid state physics as parallel to and interdependent with that of nuclear and high energy physics. (E)

119. "The new big science," R. P. Crease and C. Westfall, Phys. Today **69**(5), 30–36 (2016). Shows how large laboratories have evolved to accommodate multiple research strands in diverse fields, including condensed matter physics and materials science. (E)

120. "A different laboratory tale: Fifty years of Mössbauer spectroscopy," C. Westfall, Phys. Persp. **8**(2), 189–213 (2006). Focuses on the solid state physics group at Argonne National Laboratory. (I)

121. "Reactor research in the 1950s," R. P. Crease, in **Making Physics: A Biography of Brookhaven National Laboratory** (University of Chicago Press, Chicago, 1999), pp. 152–199. Discusses the establishment of the reactor-based solid state research program at Brookhaven. (I)

122. "Exemplary additions," P. J. Westwick, in **The National Labs: Science in an American System, 1947–1974** (Harvard U.P., Cambridge, MA, 2003), pp. 241–266. Describes the addition of solid state research programs to the national laboratories in the 1950s. (I)

123. "The roots of solid-state research at Bell Labs," L. Hoddeson, Phys. Today **30**(3), 23–30 (1977). Presents the history of Bell Laboratories' storied solid state group within the larger history of Bell Telephone. (E)

124. "From materials science to nanotechnology: Interdisciplinary center programs at Cornell University, 1960–2000," C. C. M. Mody and H. Choi, Hist. Stud. Nat. Sci. **43**(2), 121–161 (2013). Discusses the "center model" of interdisciplinary research, which co-located representatives from many different disciplines in a single building. This was pioneered at institutions like Cornell and MIT and was quickly adopted across the United States. (I)

125. "A place for materials science: Laboratory buildings and interdisciplinary research at the University of Pennsylvania," H. Choi and B. Shields, Minerva **53**(1), 21–42 (2015). A history of the University of Pennsylvania's ARPA-funded Laboratory for Research on the Structure of Matter. (I)

126. "Solid State Physics Research at Purdue," P. W. Henriksen, Osiris **3**, 237–260 (1987). Shows how World War II semiconductor research at Purdue laid the groundwork for a lively postwar solid state research program. (I)

127. "What do universities really owe industry? The case of solid state electronics at Stanford," C. Lécuyer, Minerva **43**(1), 51–71 (2005). An example of the academia-industry collaboration that became a common feature of condensed matter physics research

during the Cold War, and continues to be a common way research collaborations are structured. (I)

128. **Lenin's Laureate: Zhores Alferov's Life in Communist Science**, P. R. Josephson (MIT Press, Cambridge, MA, 2010). Traces the life of one of the Soviet Union's leading physicists, who made critical contributions to semiconductor physics, and examines how the political and ideological context of the Soviet Union shaped his career. (I)
129. **Stalin's Great Science: The Times and Adventures of Soviet Physicists**, A. B. Kojevnikov (Imperial College Press, London, 2004). Examines how physics unfolded in the Soviet national and political context, with discussions of collective phenomena and the electron theory of metals, and details the careers of Soviet physicists Lev Landau, Piotr Kapitza, and Sergey Vavilov, who contributed to condensed matter research. (I)
130. "Formation of a research school: Theoretical solid state physics at Bristol 1930–54," S. T. Keith and P. K. Hoch, Brit. J. Hist. Sci. **19**(1), 19–44 (1986). Bristol, home of J. E. Lennard-Jones and Nevill Mott, became one of the most influential centers for solid state research in the United Kingdom. (I)
131. "Solid-state chemistry in France: Structures and dynamics of a scientific community since World War II," P. Teissier, Hist. Stud. Nat. Sci. **40**(2), 225–258 (2010). Explores the way in which the existing tradition of chemical research and the particular institutional structure of France after World War II shaped the growth of solid state research there. (I)
132. "Fifty years of *Physica Status Solidi* in historical perspective," D. Hoffmann, Phys. Status Solidi B **250**(4), 871–887 (2013). A history of the pioneering East German solid state physics journal. (E)
133. "From periphery to center: Synchrotron radiation at DESY," T. Heinze, O. Hallonsten, and S. Heinecke, 2 pts., "Part I: 1962–1977," "Part II: 1977–1993." Hist. Stud. Nat. Sci. **45**(3), 447–492 (2015); **45**(4), 513–548 (2015). Documents the establishment and growth of Germany's Deutsches Elektronen-Synchrotron, a synchrotron radiation source used to study the structure of matter. (I)
134. "Fausto Fumi and the emergence of solid-state physics in Italy," D. Lazarus, Il Nuovo Cimento D **15**(2), 139–142 (1993). Argues that solid state physics arrived in Italy through the work of Fausto Fumi, who imported it from the United States after spending a year at the University of Illinois. (I)
135. "The beginnings of theoretical condensed matter physics in Rome: A personal remembrance," C. Di Castro and L. Bonolis, Eur. Phys. J. H **39**(1), 3–36 (2014). An oral history interview with Carlo Di Castro, one of the early contributors to Italian condensed matter physics through his work on statistical methods. (E)
136. "Making science in the periphery: Determination of crystalline structures in Spain, 1940–1955," X. Mañes, in **Beyond Borders: Fresh Perspectives in History of Science**, edited by J. Simon and N. Herran (Cambridge Scholars Publishing, Newcastle, UK, 2008). Discusses the growth of scientific institutions that supported the emergence of a solid state physics community in Spain in the mid-twentieth century. (I)
137. "A rough sketch of history of solid state physics in Japan," A. Katsuki, Historia Scientiarum **7**, 108–123 (1997). A broad overview of individuals and institutions. (I)

V. SOCIAL, CULTURAL, AND POLITICAL SIGNIFICANCE

The political history of condensed matter physics overlaps considerably with its institutional history, and so many of the sources listed in Sec. IV are also relevant here. But the social and cultural histories of condensed matter physics are less thoroughly explored than its conceptual and institutional histories. The social and cultural histories of condensed matter physics also overlap with its technological relevance, particularly in its role as a driver of consumer technologies. Social and cultural histories of technology, however, rarely discuss the scientific background of those technologies, and so the connection between condensed matter research and the devices and materials that populate modern life is not as strong as it could be, either in the historical literature or in the popular imagination. Historians have, however, addressed in some detail the influence of the distinctive political, cultural, and economic features of the Cold War on the way that condensed matter physics, or certain parts of it, developed.

The most prominent question in the current literature on the social and cultural significance of condensed matter physics is that of to what extent military patronage influenced the direction of the field. Solid state physics emerged as a distinct field in the United States at a time when the service agencies were investing considerable amounts of money in scientific research and development. Some historians emphasize the extent to which the interests of the defense establishment exerted pressure on physics, particularly condensed matter physics with its high degree of industrial relevance. Others have focused on the strategies that physicists deployed to pursue their own curiosity-driven research within this context. The picture that emerges is a complex one, in which the strong social forces and funding incentives favoring defense-oriented goals meet and compete with strong-willed individuals who want to pursue their fundamental physical curiosity.

A. Overview of social, cultural, and political histories

138. "The physics of imperfect crystals—A social history," K. Szymborski, Hist. Stud. Phys. Sci. **14**(2), 317–355 (1984). Traces the topic from the late 1800s to the 1930s. (I)
139. "Behind quantum electronics: National security as a basis for physical research in the United States, 1940–1960," P. Forman, Hist. Stud. Phys. Bio. Sci. **18**(1), 149–229 (1987). A provocative argument that military incentives during the Cold War caused American physicists, particularly solid state physicists, to recast their view of basic research in line with military aims. (A)
140. "Device physics vis-à-vis fundamental physics in Cold War America: The case of quantum optics," J. L. Bromberg, Isis **97**(2), 237–259 (2006). A response to Forman (above) arguing that military research and fundamental physical insight could coexist comfortably. (I)

141. "A matter of state," S. W. Leslie, in **The Cold War and American Science: The Military-Industrial-Academic Complex at MIT and Stanford** (Columbia U.P., New York, 1993), pp. 188–211. Solid state is an example of a larger argument that military money changed the university contexts in which Cold War physics research proceeded. (I)

142. "The consultants: Nonlinear optics and the social world of Cold War science," B. Wilson, Hist. Stud. Nat. Sci. **45**(5), 758–804 (2015). An examination of the social dynamics and motivations of the community of condensed matter physicists who were engaged in both defense consulting and fundamental academic research. (I)

143. "Freedom, collectivism, and quasiparticles: Social metaphors in quantum physics," A. Kojevnikov, Hist. Stud. Phys. Bio. Sci. **29**(2), 295–331 (1999). Examines the role of socialism-inspired collectivist metaphors in framing condensed matter physicists, understanding of collective phenomena, such as quasiparticles. Focuses on Yakov Frenkel and Lev Landau in the Soviet Union, and David Bohm in the United States. (I)

144. "'The ennobling unity of science and technology': Materials sciences and engineering, the Department of Energy, and the nanotechnology enigma," M. N. Eisler, Minerva **51**(2), 225–251 (2013). Examines the political realities that made "nanotechnology" an attractive funding category for many condensed matter physicists. (I)

VI. TECHNOLOGICAL APPLICATIONS

Condensed matter physics has had a long, but at times ambivalent relationship with technology. On one hand, research into the physical properties of materials often has evident commercial potential, ensuring consistent government funding and industrial interest. On the other hand, condensed matter physicists have often worried that both funders and the general public only see their work in terms of technological deliverables, and remain either ignorant of, or uninterested in, the contributions condensed matter physics can make, and has made, to basic scientific understanding. This has meant that at certain points, condensed matter physicist have been motivated to advertise their role as the source of new technologies, whereas at other times, they have sought to put some distance between their basic research activities and commercial interests.

This ambivalence aside, however, condensed matter physics has been a consistent contributor to the development and dissemination of the countless consumer technologies and industrial processes that have emerged since the end of World War II. The consumer electronics industry owes a particularly sizable debt to condensed matter research, but no less relevant are the improvement of materials for aviation, better understanding of fluid dynamics for infrastructure management, or research into soft-matter biomaterials for medical applications. The actual range of condensed matter physics' technological contributions is significantly broader than the current literature can capture, but historians have documented the stories of many of these technologies, with a particular focus on semiconductor-based electronic devices, offering an account of how condensed matter physics connects to modern society through its applications.

A. Overview of technological histories

145. **A Radar History of World War II: Technical and Military Imperatives**, L. Brown (Taylor & Francis, London, 1999). Describes both the scientific development and military application of semiconductor-based radar technology. (I)

146. "'Swords into ploughshares': Breaking new ground with radar hardware and technique in physical research after World War II," P. Forman, Rev. Mod. Phys. **67**(2), 397–455 (1995). Traces the transfer of the knowledge and knowhow gained from radar research into new contexts after World War II. (I)

147. "The boundaries of industrial research: Making transistors at RCA, 1948–1960," H. Choi, Technol. Cult. **48**(4), 758–782 (2007). Describes the relationship between the laboratory and the factory that was required for large-scale production procedures for new solid-state technologies. (I)

148. "Blue collar science: Bringing the transistor to life in the Lehigh Valley" S. W. Leslie, Hist. Stud. Phys. Bio. Sci. **32**(1), 71–113 (2001). Argues that the knowhow of assembly line workers trained to manufacture vacuum tubes was necessary to mass-produce transistors. (I)

149. "The discovery of the point-contact transistor," L. Hoddeson, Hist. Stud. Phys. Sci. **12**(1), 41–76 (1981). Examines the interplay between the conceptual progress of solid state physics and the institutional structure of Bell Laboratories that led to the transistor. (I)

150. "The invention of the transistor," M. Riordan, L. Hoddeson, and C. Herring, Rev. Mod. Phys. **71**(2), S336–S345 (1999). Presents the scientific background to the first point-contact and junction transistors. (I)

151. **After the Breakthrough: The Emergence of High-Temperature Superconductivity as a Research Field**, H. Nowotny and U. Felt (Cambridge U.P., Cambridge, UK, 1997). The practical application of superconductivity was limited by the very low temperatures needed to make it work. The discovery of high-temperature superconductivity promised to overcome that barrier. This book examines how scientists, policymakers, and the media responded to high-temperature superconductivity and its technological promise. (I)

152. "The logics of materials innovation: The case of gallium nitride and blue light emitting diodes," C. Lécuyer and T. Ueyama, Hist. Stud. Nat. Sci. **43**(3), 243–280 (2013). Describes how a particular material acquired industrial relevance and generated competition among firms to commercialize it. (I)

153. "From lab to iPod: A story of discovery and commercialization in the post–Cold War Era," W. P. McCray, Technol. Cult. **50**(1), 59–81 (2009). Traces the winding path developments in condensed matter physics sometimes take before appearing in consumer technologies. (I)

154. **The Coming of Materials Science**, R. W. Cahn (Elsevier, Kidlington, UK, 2001). Documents the rise of materials science as a discernable field, focused on technical development, with attention to the contributions of solid state and condensed matter physics. (I)

155. **Toward a New Dimension: Exploring the Nanoscale**, A. Marcovich and T. Shinn (Oxford U.P., Oxford, UK, 2014). A detailed investigation of the development of the instruments and techniques used to investigate nanoscale materials and the wide-ranging technological applications to arise from such investigations. (I)

VII. DIRECTIONS FOR FUTURE RESEARCH

Having reviewed the current state of the history of condensed matter physics, what remains to be done? The field is yet young, and myriad opportunities exist for both physicists and historians to help shape its growth. In closing, I consider a few potential growth areas in the conceptual, institutional, social, and technological histories of condensed matter physics.

Despite the thorough mapping of early quantum studies of solids, many topics remain largely unexplored. Even this earlier era lacks systematic studies of the domain concept in magnetism and the role of digital computers in the rise of *ab initio* methods, to give just two examples. Later conceptual developments are even less well explored, in particular, those dating from the late twentieth and early twenty-first centuries, with the intellectual history of the physics of amorphous solids and soft matter, for example, awaiting detailed attention.

Strong historical treatments are available for condensed matter work at Bell Laboratories, many of the National Labs, and several key universities, and a range of national contexts, but the institutional picture requires fleshing out. The University of Illinois was an early center for solid state research, and the University of Chicago's James Franck Institute became a condensed matter hub later in the twentieth century, for example. The need for a more thorough examination of condensed matter physics in industrial laboratories other the few that had the luxury of supporting basic research during the early Cold War is also evident. Solid state and condensed matter physics possessed a large industrial footprint, and most of the physicists working in industry were not at Bell, GE, or Westinghouse.

The vast majority of social, cultural, and political histories of physics in the twentieth century have focused on high energy physics, nuclear physics, and cosmology, and an array of opportunities exists to explore where condensed matter physics fits into those stories. Even though condensed matter physics has been and remains less visible to the public than its better-known sibling fields, it has been the largest field of physics for many decades. The ways in which condensed matter physics interacted with society, through technology, government advising, political advocacy, or other avenues holds the potential to significantly advance our historical understanding of the relationship between physics and the societies that support it.

The connections between condensed matter physics and consumer electronics have been thoroughly documented, and with good reason. But condensed matter physics has contributed to a much more varied array of technological developments. Much of the condensed matter work relevant to military applications, of course, remains classified. But histories can yet be written about the pathway between condensed matter physics and medical devices, the improved ceramic materials and glassware which were pressed into service in kitchens around the world and on spacecraft orbiting it, and the many scientific instruments that have hastened the development of condensed matter physics.

156. "Beyond the crystal maze: Twentieth-century physics from the vantage point of solid state physics," J. D. Martin and M. Janssen, Hist. Stud. Nat. Sci. **45**(5), 631–640 (2015). Further commentary on future directions of the history of condensed matter physics. (E)

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