Phys. Perspect. 23 (2021) 170–175

1422-6944/21/020170-6
https://doi.org/10.1007/s00016-021-00276-2

Physics in Perspective

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Book Review

Andrew Zangwill, *A Mind Over Matter: Philip Anderson and the Physics of the Very Many*, Oxford University Press, 2021, 412 Pages, $25.00 (Hardcover).

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On August 4, 1993, particle physicist Steven Weinberg and condensed matter physicist Philip W. Anderson testified before the US Congress regarding the construction of a ten-billion-dollar particle accelerator. In contrast to Weinberg's grandiloquent speech about the mysteries of the universe that this Superconducting Super Collider (SSC) would unravel, Anderson's opposition to the construction of the colossal machine was simple and poignant: he argued that fundamental principles of nature are not only found at the smallest scales, and thus spending such an exorbitant amount on such a narrow-scope apparatus was not only wholly inefficient, but unethical. Instead, Anderson advocated for a diversification of funds to support disciplines whose focus were equally fundamental, but more relevant and impactful to science and society at large. These disciplines—one of them being his own field of condensed matter physics—seek to understand, not the simplest aspects of the very *few*, but the new and unexpected properties that arise out of the complexity of the *many*. Anderson's testimony, in the end, had little impact on the project's eventual cancellation, however many in particle physics resented his opposition for years.

With this episode begins *A Mind Over Matter: Philip Anderson and the Physics of the Very Many*, the latest publication from condensed matter physicist and historian of physics Andrew Zangwill. The debate over the construction of the SSC is but one example of the many instances in which Anderson fought for the recognition of his field and sought to challenge the established belief that the only ones doing fundamental research are those studying the very small—like nuclear and particle physicists—or those studying the very large and distant—like astrophysicists and cosmologists. Due to this same belief, the history of science and its popularizations have tended to favor stories about these areas of research and the personalities associated with them. Much has been said about the Einsteins, the

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Hawkings, and the Feynmans, and too little about the Andersons. This biography is a valuable and necessary remedy to that asymmetry.

In *A Mind Over Matter,* Zangwill traces the steps of the Nobel-winning physicist, from his Midwestern North American upbringing to his ascent to becoming one of the most influential physicists of the second half of the twentieth century. The author fluently combines the narrative voice with his own physics teacher's voice—he is author of two graduate-level textbooks: *Physics at Surfaces* (1988) and *Modern Electrodynamics* (2013)—creating a harmonious balance between the *mind* and the *matter*. Explanations of physical concepts and phenomena are detailed and rich, but not overly complicated, with barely any formulae or equations needed to convey understanding. This makes the book accessible to anyone with an interest in twentieth-century physics, but it is equally valuable and stimulating for those well-read in the subject—particularly scholars in the history of solid state or condensed matter physics. The same amount of detail that goes into the explanation of the physics goes into the description of the character. Zangwill has done excellent work in bringing together such wealth of material from Anderson's personal archives, as well as interviewing numerous actors, including colleagues, family members, students, and friends. He also had the chance to converse with Anderson himself, through an extensive email correspondence, before he passed away in March 2020.

Born in Urbana, Indiana, in 1923 into a family of academics, Anderson was brought up with a love for nature, a keen interest in literature and politics, and a passion for science. From his undergraduate years in the 1940s, we discover that he was a shy but competitive young student who often swam against the current of popular opinion. As an undergraduate at Harvard University, contrary to the majority of other students who excelled in their physics studies, Anderson chose to major in electronic physics rather than physics, where he met his future thesis supervisor, the theoretical physicist John Van Vleck. From Van Vleck, the young Anderson learnt the ability to "follow the data" brought by experimentalists, to seek the fundamental principles behind phenomena, and to not be blinded by theoretical impositions.

Upon progressing to his doctoral studies, he chose to complete a thesis in molecular spectroscopy with Van Vleck instead of working on the hot topic of nuclear physics with the popular Julian Schwinger, also demonstrating that Anderson avoided both trends and problems already being looked at by too many eyes. He liked to explore new territories where he could be the one to make the first important contribution. The decision to follow the electronic physics curriculum had two major consequences. First, he was sent to the Naval Research Laboratory (NRL) during the war, to work on radar systems, instead of being sent to Los Alamos to work on the Manhattan Project like many of his colleagues who took the physics major. Second, as a result of his training, he preferred to begin his academic career at the AT&T Bell Laboratories. Bell Labs was one of the biggest technological companies in the country in the 1950s, and, unlike universities—

which at that time lacked solid state theory departments due to the field's reputation of being too "applied"—the industrial company offered him the freedom to focus on research without teaching duties. It also afforded Anderson the possibility to learn the basics of solid state physics from some of the best in the field—individuals such as William Shockley, John Bardeen, and Charles Kittel.

The fact that Anderson had no teaching commitments at Bell Labs, combined with a predisposition for intuitive reasoning over technical exactitude, meant that he never developed a clear and organized lecturing style. His first students were physics undergraduates at the University of Cambridge, where he had negotiated a sabbatical year in 1961–62, and secured a part-time position between 1967 and 1975, which he combined with his work at Bell Labs. The abundant personal recollections from students and colleagues that fill the pages of this book describe his classes as akin to sitting in front of an oracle: extremely insightful, but very hard to follow. His papers also tended to suffer from an obscure and often cryptic style, to the point where his wife Joyce Anderson forbade him to publish any non-technical papers that she had not edited first. The challenge involved in understanding and explaining any one aspect of Anderson's scientific achievements, but giving a coherent and detailed picture of the whole of his career as this book does, is an accomplishment for which Zangwill should be commended.

One of these "oracular" insights took place already in the beginning of Anderson's career at Bell Labs, when he was asked to work in the topic of antiferromagnetism. The paper he wrote in 1952 about this topic contained the germ of two ideas that would only be generalized a decade later. The first was the description of the process that would later be known as *spontaneous symmetry breaking*: the fact that a system (here, the antiferromagnet) evolves to a ground state that unpredictably ceases to satisfy the symmetry of its equation of motion (here, the full rotation symmetry of the spins in its lattice). This is because the spins in an antiferromagnet find it more energetically efficient to align antiparallel to each other, when the temperature is low enough, instead of rotating freely in the crystal lattice. The second idea was that this sensitivity to the alignment of neighboring spins at low temperatures provokes a synchronization of the spins' small movements into a collective excitation that Anderson called *spin waves.* This would later be formalized by Yoichiro Nambu and, most notably Jeffrey Goldstone in 1961, in the famous theorem that states that every breaking of a continuous symmetry is accompanied by the appearance of a collective massless field. Spin waves are now known as a particular case of a *Goldstone mode.* For this reason, Zangwill is not shy about dubbing Anderson the "discoverer" of spontaneous symmetry breaking (p. 78), a statement that would certainly vex one or two particle physicists.

However, the author's intention is not to sow controversy, but rather to engage with a debate in which Anderson was quite sensitive: that of scientific authorship. Two other major discoveries were inspired by Anderson's involvement in the study of spontaneous symmetry breaking, for which he never felt sufficiently recognized. His discussion about spontaneous symmetry breaking in the context of superconductivity in the early sixties inspired his young student at Cambridge, Brian Josephson, to discover the superconducting tunneling effect that now bears his name and for which he obtained the Nobel prize in 1973. It also led Peter Higgs to corroborate his proposed mechanism for the creation of mass from originally massless fields in the particle physics vacuum, as an analogy to the superconducting symmetry breaking case. This mechanism was finally confirmed by the awaited discovery of the Higgs particle in 2012 at CERN, a discovery which was intended to take place at the Superconducting Super Collider, if the project had not been cancelled almost two decades earlier. Whether Anderson's opposition to the construction of the SSC also contained traces of a deep-rooted resentment against the little recognition he received for his role in the Higgs mechanism story (or whether that recognition was actually insufficient) is something that is left for the reader to judge.

Before his resentment was softened by the announcement of his share of the 1977 Nobel prize for his work on disorder-induced wave localization and magnetic moments in metals (along with his former supervisor John Van Vleck and his colleague at Cambridge, Nevill Mott), Anderson summed up his discontent in the now legendary 1972 paper entitled "More Is Different." This non-technical paper is a defense of the autonomy of solid state physics (which was at the time slowly transitioning to its now more widespread term of condensed matter physics) with regard to the so-called "fundamental" fields of nuclear and particle physics. The message is that equally fundamental principles and new properties emerge from the interaction of the many components of a typical condensed system, which cannot be predicted or extrapolated from the knowledge of the particles that compose it in isolation. This idea would later be associated with the century-old philosophical concept of *emergence*, typically linked to anti-reductionist views of science. The novelty of "More Is Different" is that, for the first time, a mechanism for the appearance of emergent properties was proposed. Anderson used symmetry breaking to account for the novel and unpredictable properties that appear as a result of a fundamental symmetry being broken in a many-particle system (like the appearance of antiferromagnetic properties as a result of the breaking of the full rotation symmetry of the spins in some crystals at low temperatures).

The election of this process as *the* mechanism behind emergence served, in my opinion, another important purpose, which is not highlighted by the author: emphasizing that symmetry breaking is a process that occurs in *many*-particle systems allowed Anderson to claim the ownership of the concept of symmetry breaking back for condensed matter physics. In so doing, he placed his field in a privileged position to analyze complex and emergent behavior at large scales, as opposed to particle physics, which could not deal with things more complicated than a few particles interacting together.

Despite this minor proviso, the importance of symmetry breaking as a backbone in Anderson's trajectory is masterfully reflected in the book. Zangwill even uses this concept metaphorically as a means to indicate the fact that Anderson repeatedly distanced himself from the more obvious or predictable route to tackling a problem, or even choosing a problem. His choice of the not-so-acclaimed field of solid state physics, and his restless (and almost solitary) fight to demonstrate its intellectual significance are, according to the author, examples of Anderson breaking the symmetries in his own life.

After the first six chapters, which follow a linear timeline, mirroring the trajectory of the protagonist's life and career through the mid-fifties, the paths of Anderson's interests and research ramify and diverge in unpredictable ways. Continuing the metaphor, this could be described as the symmetry breaking point of the book, where chapters and subchapters cease to follow a straight temporal line, and the narrative thread starts focusing on a specific problem in Anderson's career—from its conception, to its development and eventual solution, passing through all the actors and places involved in the process, and the consequences it brought about for the physics community and beyond. This problem-centric perspective, and the temporal jumps it requires, can sometimes affect the harmony of the book, but such leaps are essential to grasp the depth of some of Anderson's contributions to physics, such as his journey with the concept of symmetry breaking. An appendix at the end of the book with a timeline of the highlights of Anderson's career is an intelligent and handy addition to help the reader situate herself.

In *A Mind Over Matter* the reader will discover a brilliant, competitive, and sometimes arrogant character who did not shrink from those who referred to him as an "applied" physicist rather than a *theorist.* This was because he was clearly a non-conventional theorist who praised the values of being in constant contact with experimentalists, emphasizing the importance of interdisciplinarity, and remaining in tune with the needs of a broader society. The impact of both his academic achievements and his philosophical views about science make the life and work of Philip Anderson worthy of attention by scholars and interested readers alike. *A Mind Over Matter* is an admirable introduction and fitting tribute to this remarkable personality.

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Funding

Open Access funding enabled and organized by Projekt DEAL.