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BOOK REVIEW

Climério Paulo da Silva Neto, *Materializing the Foundations of Quantum Mechanics: Instruments and the First Bell Tests*

Cham: Springer Nature, 2023. Pp. 73. ISBN 978-3-031-29796-0. £39.99 (softcover).

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With the promise of quantum computers on the horizon, interest in quantum foundations and the rise of the second quantum revolution – concerned with the control and detection of individual quantum systems – has grown considerably in recent years. Despite this, research into the process that led the prewar *Gedankenexperiments* (thought experiments), conceived in debates between the founding fathers of quantum mechanics, to be transformed into real post-war experiments, has paid little attention to the instruments themselves, even though they are essential to the practice. Silva Neto addresses this gap by examining, in a broad framework extending to the mid-1980s, the material culture of the first significant experiments in the field of quantum foundations, the tests of Bell's inequalities.

Silva Neto begins with a concise yet elegant presentation of the origins of these tests, rooted in the 1935 EPR debate and John Bell's 1964 theorem, which allowed quantum mechanics to be experimentally tested against local hidden-variable theories. The first of a series of progressively more stringent Bell's experiments followed in 1972. In the three main chapters of his book, Silva Neto then systematically explores the origins and developments of their key components: the sources of entangled photons, the analysers and the detection sets.

After the Second World War, three sources of entangled photons emerged: positron annihilation, photon cascades in atomic beams and spontaneous parametric down-conversion. Silva Neto shows that these advances stemmed from a deeper understanding of light–matter interactions. The first two sources, based on pre-war research, became linked to military R & D during the Cold War, particularly in cyclotron research, microwave spectroscopy and quantum electronics, which was crucial for developing masers and lasers. These last technologies paved the way for the third source, developed in the 1960s and incorporated into Bell's inequalities experiments in the 1980s, which has become central to quantum communication and computing.

The availability of analysers significantly influenced the design and results of various experiments. Along with the question of the unreliability of analysers for high-energy photons (gamma rays), Silva Neto focuses on the pile-of-plates polarizers used in Bell's first test, as well as the cube beam splitter introduced in the 1980s for more accurate measurements. These technologies benefited from the post-First World War creation of optics institutes in the United States, the Soviet Union and Western Europe, which, by

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establishing crucial links between scientific research, the military and industry, had a long-standing and significant impact on science and technology.

Finally, Silva Neto examines the development of photomultipliers, central devices in detection sets. He traces their origins to the interwar period, linked to television development, and shows that single-photon-sensitive devices were already being developed in the 1930s. However, single-photon-counting techniques were mastered only in the 1950s and 1960s. Firmly anchored in Second World War and Cold War research in nuclear and solid-state physics, they required improvements in instruments such as scintillation counters, lasers and photocathodes.

Two important recurring patterns emerge in the book. The first, evident from the above, concerns the close links between Cold War research and the military–industrial complex. Silva Neto argues in the last chapter that the same post-war trends that drove physicists away from foundational questions paved the way for the experimental tests of Bell's inequalities. It was precisely the utilitarian and pragmatic goals of the post-war environment that created the material conditions for such tests. The second pattern is the late application to fundamental problems of the various technologies discussed so far. Unlike earlier works, Silva Neto provides a convincing argument about when it became possible to turn pre-war thought experiments into real experiments. By the time Bell published his paper in 1964, it was technically feasible to conduct reliable tests of quantum theory. However, their implementation required a new generation of physicists to adapt these thought experiments to current experimental capabilities. As Silva Neto summarizes, 'Ironically the focus on instruments highlights the role of individuals and sociocultural factors in bringing the EPR though experiment to the laboratory' (p. 71).

In line with this observation, however, one might regret that Silva Neto does not fully explore the stories surrounding the instruments themselves. Put another way, it sometimes seems that what was originally conceived as a research paper, but ended up being published in the Springer Briefs of Science and Technology series because of its length, has not fully made the transition to book format and may be struggling to reach a wider audience. Historians of technology, and possibly Second World War and Cold War historians, could have benefited from more insights into the role of these instruments in industrial and military contexts, as this aspect is treated somewhat unevenly. Additionally, more details on the actors and contexts that facilitated technology transfers would have been valuable. Nonetheless, it is worth noting that Silva Neto avoids the sin of West-centrism and rightly highlights Soviet contributions. Also, he compensates for the aforementioned limitations by a systematic and extensive embedding of his work in the existing literature. This richness in itself justifies an interest in circles beyond that of historians of quantum theory.

In his effort to 'factorize what instruments, technologies, and techniques were important, how they came about, and what they reveal about the historical development of [quantum foundations]' (p. 2), Silva Neto provides a unique historical investigation into the material culture of physics experiments. His short book is a significant contribution to the history of quantum foundations, in line with a central tradition of the Salvador school in the history of physics. Led by Olival Freire Jr – author of *The Quantum Dissidents* (2015), which precisely examines the role of individuals and sociocultural factors in the introduction of the EPR experiment in the laboratory – it has produced a body of work that, taken together, offers an impressive entry into the history of the second quantum revolution.

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