Institutions and the Quantum Revolution

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The end of WWI marked not only the end of a political era, but the beginning of an academic revolution. Surprisingly, one of the most divided eras in modern history created a desire for more fundamental research and motivated academic communities around the world to establish the collaborative scientific institutions we enjoy today. This shift enabled the rapid dissemination and advancement of quantum mechanics around the world. Europe witnessed the birth of quantum mechanics and its continued growth through institutions, such as Bohr's Institute for Theoretical Physics, which embodied the "Copenhagen spirit," emphasizing collaborative research. Meanwhile, in the United States, an increase in funding and support for basic science research, as well as the desire to replicate the success of the European model, inspired Americans to revamp their academic institutions, fostering more collaboration, interdisciplinary work, and strong ties with their European counterparts. Japan soon experienced a similar progression, brought forth by a rebellion among a younger generation of European-trained physicists. In this paper, we will focus on how, despite having very different philosophical views of quantum mechanics and national goals, the US, Japan, and the countries of central Europe established similar institutes for high-level quantum mechanics research and social structures for quickly and efficiently disseminating that knowledge at the institute, national, and global level. This would enable an unprecedented advancement in the field of quantum mechanics.

Although the Americans and Japanese modeled their institutions after those of the Europeans, Europe had a unique, passionate, and philosophical view of quantum mechanics

that was not replicated in either of these nations. Quantum mechanics was born and flourished in Europe, with the work of Einstein, Bohr, Heisenberg, Schrödinger, Dirac, DeBroglie, and many other greats. From its conception, however, Europeans defended their theories not only by the experimental results they could calculate, but the philosophical implications, as illustrated by the feuds between Heisenberg and Schrödinger as well as between Heisenberg and Bohr.[1] While they knew that their work would have real-world implications, as became quickly apparent with the advent of WWII, they were deeply intrigued by the physics itself.[2] Sheer passion for philosophical ideals sometimes led them down the wrong path, as with Einstein's insistence on classical causality.[3] However, as Europeans transitioned away from these divided environments and towards collaborative institutes dedicated to advancing the field, publications grew at an unprecedented rate,[4] which continued until the political turmoil of WWII caused many European scientists to flee or halt research to serve their country. The original excitement for quantum mechanics can be attributed to the so called "Copenhagen spirit" cultivated at Bohr's Institute for Theoretical Physics, the premier theoretical physics institute of the time. Founded by Neils Bohr, himself, this institution was at the forefront of most of the initial research in quantum mechanics, dedicated to developing the Copenhagen Interpretation. It became iconic not only for its academic findings, but also the collaborative institutional structure that enabled its productive research output. "Since its inception in 1916, Bohr's institute aimed to accommodate both theory and experiment under one roof, keeping

[1]David C. Cassidy, "Heisenberg, Uncertainty and the Quantum Revolution," *Scientific American* (1992): 106-112, on 109-112.

[2]Helge Kragh, *Quantum Generation: A History of Physics in the Twentieth Century*, 156-173 (Princeton, NJ: Princeton University Press, 1999), on 171-172

[3]John L. Heilbron, "The earliest missionaries of the Copenhagen spirit," *Revue d'histoire des sciences* (1985): 195-230, on 210-213

[4]A. Kozhevnikov and O. Novik, "Analysis of Informational Ties in Early Quantum Mechanics (1925-1927)," *Acta historiae rerum naturalium necnon technicarum* (1989): 115-59, on 117.

a close tie between them. Interdisciplinary collaboration was not rare at Bohr's institute."[5] In fact, many of the leading scientists in the US and Japan in the 1920s spent time as students or researchers at Bohr's Institute. As will be discussed, they were greatly inspired by the structure and work of the Institute and proposed changes to their home universities. However, primarily due to cultural differences, they did not replicate the philosophical appreciation and discussion of work that embodied the European institutes. Hence, much of the early work in quantum mechanics happened in Europe. There, despite its origins as a niche area of dispute between a few great scientists, quantum mechanics quickly became an established field of study, growing rapidly with the development of collaborative European institutions, namely Bohr's Institute. The influence of these institutions spread far beyond European borders, initiating a global transition in academic institutes and propelling the development of quantum mechanics.

Post-WWI, Americans realized that if they wanted to be at the technological forefront, they would need to invest more in fundamental research. In particular, they wanted to join the quantum revolution that was rapidly growing in Europe. This led both federal and private institutes to make large investments, that provided funding for equipment, facilities, and increased the number of graduate and research positions.[6] Especially important was the fact that this funding was not restricted to the US. The grants generously allowed students from the US to study in Europe, Europeans to study in the US, and brought some of the best European minds to conduct research and teach in the US. It became

[5]Kenji Ito, "The Geist in the Institute: The Production of Quantum Physicists in 1930s Japan," in *Pedagogy and the Practice of Science: Historical and Contemporary Perspectives*, ed. David Kaiser (Cambridge, MA: The MIT Press, 2005), 151-183, quotation on 163.

[6]Stanley Coben, "The Scientific Establishment and the Transmission of Quantum Mechanics to the United States, 1919-32," *The American Historical Review* (1990): 442-466, on 447-448.

clear that the United States was actively looking to attract European talent, establish a precedent of international collaboration, and train the next generation of American physics researchers and professors.[7] Although the American universities were at first frowned upon by visiting European scientists, for their isolation and lack of collaboration, steps were taken to improve the American academic environment. At Caltech, Robert Millikan created the first European-style center for theoretical physics. He sparked interest in the field by beginning a rotation program, with year-long visits from the likes of Einstein, Ehrenfest, Sommerfeld, Darwin, and Born.[8] By the 1920s, Americans supported by "European journals, foundation fellowships, and the vastly expanded number of visits to the United States made by leading European theoretical physicists" were able to make significant contributions to quantum mechanics.[9] Later on, at MIT, John Slater focused on the application of quantum mechanics and pushed specifically for cross-department collaboration. This enabled the US to dominate the field of quantum chemistry,[10] a subject most European scientists had no interest in.[11] In all, relative to the Europeans, American institutions were far more practically oriented, assessing their work mostly on the basis of quantitative performance. They had no interest in the philosophical implications of their theories and saw the advancement of physics as an important part of advancing fields, such as biology or chemistry, built on physics foundations.[12] However, this practical view of quantum mechanics incentivized increases in funding, which would enable American physicists to remodel their institutions after those in

[7]Coben, "Scientific Establishment and Transmission of QM to the US," on 449-452.

[8]Coben, "Scientific Establishment and Transmission of QM to the US," on 452-453.

[9]Coben, "Scientific Establishment and Transmission of QM to the US," quotation on 457.

[10]S. S. Schweber, "The Young John Clarke Slater and the Development of Quantum Chemistry," *Historical Studies in the Physical and Biological Sciences* (1990): 339-406, on 390-406.

[11]Coben, "Scientific Establishment and Transmission of QM to the US," on 465.

[12]Helge Kragh, *Quantum Generation: A History of Physics in the Twentieth Century*, on 172.

Europe. In this manner, Americans were able to catch-up to their European counterparts, advancing quantum mechanics and related fields.

After WWI, Japan was looking to industrialize and catch-up with its Western counterparts. There was a strong tradition of calculation in Japanese physics departments, very similar to the Cambridge Wranglers.[13] In fact, physics was often seen as a dead-end career, as there were few jobs outside of academics. Even within academics physicists were often used to solve mathematics for the engineering department. The best option, at the time, was the Riken Institute of Physical and Chemical Research, one of the few physics research institutes in Japan. By the late 1920s, a wave of dissatisfaction overcame young physicists and students, who rebelled against the system by studying quantum mechanics (a subject that most professors did not approve of) on their own. They went as far as creating the "Physics Reading Group," an independent study group that would make Japanese digests of the most important publications.[14] As the Japanese physics community embraced quantum mechanics research, an opportunity emerged for Nishina Yoshio, a Riken physicist who spent roughly seven years researching at European institutions, including the Bohr Institute, to bring the European institutional style to Japan.[15] Nishina helped bring Japan up to speed in quantum mechanics by translating and publishing Heisenberg and Dirac's lectures in Japanese, lecturing on the topic at universities, and inviting both Heisenberg and Dirac to visit. He managed to build an active group of theoretical physicists at Riken and bring the "Copenhagen spirit" to Japan. Like Bohr, he promoted collaboration between experimentalists and theorists, different disciplines, and different nationalities.[16] However, unlike Bohr, and

[13]Kenji Ito, "The Geist in the Institute," on 155.
[14]Kenji Ito, "The Geist in the Institute," on 156-160.
[15]Kenji Ito, "The Geist in the Institute," on 160-161.
[16]Kenji Ito, "The Geist in the Institute," on 164-169.

similar to the Americans, "there was no philosophical bent among the disciples of Nishina." Instead, they were interested in "complementarity and the foundational problems of quantum mechanics."[17] Regardless, this academic cultural change brought by Nishina spread to other Japanese institutions and the Japanese eventually became active contributors to quantum mechanics research, publishing important works, such as Yukawa's meson theory in the 1930s.[18]

By the late 1920s, there were similar social structures, by which collaboration and the dissemination of knowledge was promoted, in Europe, the United States, and Japan, drawing mostly from the precedents set by Bohr's Institute. Surprisingly enough, one of the main ways in which institute leaders such as Bohr, Milikan, Slater, and Nishina promoted interactions between different scientists within their own groups was by organizing daily group lunches or coffee/tea discussions. This social interaction was part of the European lifestyle and was adopted by the academic community at Bohr's Institute. The outings often sparked lively, heated debates about physics topics and gave researchers a chance to learn about and provide suggestions for their own colleagues' work. Unsurprisingly, the practice was disseminated to American and Japanese institutes by visiting scholars, who witnessed the collaborative benefits firsthand.[19] In fact, one of the main complaints of European theorists who traveled to America, before it transitioned to the collaborative university style, was the feeling of isolation and yearning for coffeehouse discussions with their colleagues.[20] Similarly, professors or groups would promote social interactions outside of the lab, such

[17]Kenji Ito, "The Geist in the Institute," quotations on 172.
[18]Kenji Ito, "The Geist in the Institute," on 171.
[19]Kenji Ito, "The Geist in the Institute," on 161-164 and 167-169.
[20]Coben, "Scientific Establishment and Transmission of QM to the US," on 452-453.

as matches of table tennis in the library.[21] These social activities boosted collaboration within groups or even departments, but measures were also taken to promote cross-discipline interactions. These included interdepartmental conferences and colloquia.[22] Finally, an increase in funding and the willingness of major physicists to travel abroad, give lectures, and translate others' work helped advance international collaboration and the widespread dissemination of quantum theory. To summarize, there was a global trend among academic institutions towards fostering increased collaboration within and across departments, as well as with other institutions. Inspired by the successful practices of the Bohr's Institute and aided by an increase in funding, this transformation enabled the rapid spread and advancement of quantum mechanics world-wide.

Although quantum mechanics began as a relatively niche and disputed field, it gained traction in European institutions and then spread to foreign nations, specifically the US and Japan. This transmission of knowledge and progression of the field did not happen by chance, however. It was the product of a change in sentiment after WWI, which led these countries to reassess their technological and scientific capabilities, resulting in increased funding for fundamental research. This allowed the Americans and Japanese to study at the best European institutes and see why exactly they were so dominant. Those who studied abroad brought back not only theoretical knowledge but also an understanding of the "Copenhagen spirit." They instigated changes in their own institutions to promote collaboration and interdisciplinary work, modeled after the Bohr Institute of Theoretical Physics. The Europeans bolstered research in these foreign lands by working abroad, giving lectures, and writing books. Within

[21] Kenji Ito, "The Geist in the Institute," on 163.
[22] S. S. Schweber, "Slater and the Development of Quantum Chemistry," on 367.

a decade, the Americans and Japanese were at the forefront of quantum mechanics research, making significant theoretical and applied contributions. However, one thing remained unique to the Europeans: their philosophical fascination with physics, beyond observable calculations or practical applications. As the birthplace of and intrinsically motivated by the philosophical quandaries of quantum mechanics, Europeans needed no pragmatic motivation to develop the institutions that globally dominated the field and inspired the quantum revolution.

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