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In the Circulation Sphere of the Biomolecular Age: Economics and Gender Matter**

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Summary: This contribution draws attention to the circulation of materialities and persons as a central feature in the constitution of experimental cultures. The protein and ribosome research at the Max Planck Society (*MPG*)—with a main focus on the research conducted by Brigitte Wittmann-Liebold at the Max Planck Institute for Molecular Genetics—serves as an example to highlight some of the central conditions that determined the material circulation in molecular biology: the very organizational framework of gender and economics. In doing so, this contribution argues for a historical narrative that stresses the conditions facilitating the circulation of technologies, materials, and personnel. Histories of this kind contribute to an integrated view of the scientific, technological, social, political, economic, and cultural specificities of experimental cultures.

Keywords: molecular biology, experimental cultures, research technologies, research organization, commercialization, gender, Max Planck Society, Applied Biosystems

The biochemist Brigitte Wittmann-Liebold (*1931) and her team formed one of the most renowned research groups on protein sequencing and on the development of sequencing technologies in the 1970s and 1980s. Wittmann-Liebold spent much of her career at the Max Planck Institute for Molecular Genetics (*Max-Planck-Institut für molekulare Genetik*), one of many institutes under the umbrella of the Max Planck Society (*Max-Planck-Gesellschaft*,

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** This article is part of a special issue, *On Epistemic Times: Writing History 25 Years after Synthesizing Proteins in the Test Tube*, and refers partly to the results of the *MPG* history research group, which will be published in Kocka et al., forthcoming. It has profoundly benefited from thoughtful comments by the editors and an anonymous reviewer as well as from useful input by Miguel Garcia-Sancho and English editing by Elizabeth Hughes and Klara Schwalbe.

MPG).[1] Her struggles with ever-changing technologies in the research of the structure of proteins are reminiscent of the enormous impact that analytical chemistry and new research technologies have had on the progress of molecular biology. Further, it emphasizes that the circulation of things and persons is one of the basic conditions for experimental laboratory research.

Scientific work does not end at a laboratory's doorstep, but, in a constant "material interaction," extends to further experimental systems.[2] Hans-Jörg Rheinberger emphasizes that the circulation of materialities among laboratories plays a crucial role for scientific research, as it gives shape to experimental practices, experimental systems and, eventually, the emergence of new knowledge.[3] He identifies three types of circulation: shared use of research technologies, flow of materials, and exchange of personnel.[4] Together, the circulations of things and persons form structures (*Strukturen*) and networks (*Netzwerke*), so-called experimental cultures.[5]

This contribution raises the question what it is that determines the circulation of research technologies, materials, and personnel and hence the emergence of experimental cultures? Rheinberger emphasizes that "epistemic, technical and social moments are inextricably intertwined" in the constitution of experimental cultures and that the interaction among the labs is a "social, collectively constituted process."[6] He arrived at this conclusion from studying the in vitro culture in biology: This laboratory-centered way of doing research was fundamental to the life sciences in the twentieth century and paved the way for the conjuncture of biology, chemistry, and physics, and hence the molecularization of the biological sciences.[7] Following Rheinberger, the in vitro culture began with the invention of test tube experiments in the late nineteenth century, continued with the extracorporeal cultivation of tissues and cells, and ultimately led to the invention of various technologies, such as centrifugation and radioactive labeling, that helped to unravel the contents of cells in increasingly more detail.[8] However, these spotlights on the history of the biological laboratory are also a reminder that the history of the in vitro culture

[1] Today, the *Max-Planck-Gesellschaft* (*MPG*) comprises about 80 institutes, mainly in the fields of physics, chemistry, life sciences, and technology. For an overview, see: https://www.mpg.de/institutes.

[2] Rheinberger 2021, on 164–165. Translation is mine here and in the following.

[3] Rheinberger 1997, on 140; Rheinberger 2021, on 185–186.

[4] This extended definition of experimental cultures reflects Volker Roelcke's suggestion that the movements of scientists through space and time should be specifically considered. Roelcke 2010, on 184–189. For the evolution of this definition, see: Rheinberger 1997; Rheinberger 2017, on 290; Rheinberger 2019, on 32.

[5] Rheinberger 1997, on 140; Rheinberger 2021, on 185. This concept differs from other usages of *culture* in the context of the history of science and science studies, such as epistemic culture, scientific culture, or cultures of knowing. See for an overview Knorr Cetina 2016; see also Chemla and Fox Keller 2017. For an interesting focus on the enculturing of scientific junior staff, see Arnold and Fischer 2004.

[6] Rheinberger 2021, on 189.

[7] Ibid., on 166–167.

[8] See ibid., on 164–189.

has not be written yet.[9] Especially, a comprehensive account of the relevant historical factors, including political, economic, and cultural ones, that triggered and nurtured this and other experimental cultures—that is, the circulation of things and persons—is yet to be given.[10]

In order to highlight the crucial role of circulation as a link between laboratory work, politics, economics, and culture, I will address circulation and its conditions as the circulation sphere of experimental science. The conditions and factors of circulation can be diverse, contingent, local, and regional; however, as the circulation sphere mainly unfolds on a meso level, it brings together micro and macro histories.[11] Hence, the description of the whole spectrum of spatial and temporal conditions may form into synchronic or diachronic patterns that will help to illustrate how and why a certain experimental culture emerged or even came into dominance.[12]

In the following, I focus on a selection of factors that determined circulation in protein research and that have not been sufficiently taken into account in the history of molecular biology—that is institutions, economics, and gender.

1. Wittmann-Liebold and Career Development Opportunities within the Max Planck Society (*MPG*)

Brigitte Liebold's career began in the late 1950s at the Max Planck Institute (MPI) for Biochemistry in Munich (*Max-Planck-Institut für Biochemie*), where she wrote her dissertation and became a postdoc in Gerhard Braunitzer's department.[13] Braunitzer's laboratory was one of the internationally renowned sites for protein research. Previously, Braunitzer had worked together with Gerhard Schramm in Tübingen on the structure of tobacco mosaic viruses (TMV)—in close competition with Wendell Stanley's group at the University of California, Berkeley.[14] At the MPI in Munich, he and his group continued to analyze polypeptides, resulting in the identification of the primary structure of 100 different hemoglobin proteins and in special expertise on the application of column chromatography for the separation of macromolecules. Also, the group became increasingly involved in the development of methods

[9] See ibid., on 167.

[10] The reason to emphasize this broad approach lies in the very concept of circulation. Firstly, the conditions that determine circulation are principally not limited to the realm of science. Secondly and historically, there has never been an ideal sphere of free scientific exchange independent of social realities.

[11] For the significance of meso level structures in the German science system, see Maier 2007, on 64–83. For an appeal for the local in the analysis of cultures, see Borck 2018.

[12] In a similar way, de Chadarevian 2009 suggests to reconstruct the multiple contexts and connections that link apparently small events with broader structures. Suárez-Díaz 2022 (this issue) argues for the integration of the histories of interconnected experimental systems with a more global perspective.

[13] For biographical information here and in the following, see Kinas 2004, on 191.

[14] Creager 2002, on 267–269; Brandt 2004, on 164–168.

for the analysis of large proteins.[15] However, there was still a language barrier between the labs in West Germany and abroad, as Braunitzer's group published most of its results in German-language journals.[16] Because of her crucial contributions and analytical skills, Liebold was recruited by Georg Melchers' department at the Max Planck Institute for Biology (*Max-Planck-Institut für Biologie*) in Tübingen in 1961. Here, she strengthened the ongoing research on TMV proteins aimed at deciphering the genetic code. Heinz-Günter Wittmann (1927–1990), an agricultural science graduate who worked in Melchers' group, was in part responsible for her new position: He had become interested in the problems of molecular biology after research stays in the US and at the MPI in Munich. There, he had met Liebold and was impressed with her analytical skills.[17]

Christina Brandt has used the example of TMV research to show that the exchange among laboratories might profoundly influence the dynamics of experimental systems. However, this exchange was dependent on a number of conditions. Since many German professors were still skeptical about the American way of doing research (as teamwork), it was not common for German postdocs to visit foreign laboratories in the 1950s. In this case, those who benefited from the open-mindedness at the MPIs in Munich and Tübingen could be considered lucky.[18] The *MPG*'s style of enabling career development determined the mobility of scientists in other respects as well, such as family. When Liebold decided to join the group in Tübingen, it was a joint decision with Wittmann, as she and Wittmann were engaged. They married in 1961 and became a lifelong working team.[19] This liaison was not an exception, rather, marriages contributed to the social cohesion of the *MPG.*[20]

Affiliation and social cohesion were important factors for the circulation of scientists in the *MPG.* The MPI for Biochemistry is a good example, though certainly an extreme case. The scientific roots of 24 senior scientists within the *MPG* (such as group leaders and department heads) can be traced back to this MPI when it was led by Adolf Butenandt until 1971.[21] Far from being an exception, this type of *MPG* career represented a system of internal recruitment that dominated appointments within the *MPG* for a long time. Between 1948 and 2000, 63 percent of the molecular biologists within the *MPG* had held a position in the *MPG* prior to their appointments as director.[22]

[15] Wittmann-Liebold 1989, on 90–95; Wenkel 2013, on 161–167.

[16] See lists of publications in the *Jahrbücher* from 1950 to 1960 edited by the *Max-Planck-Gesellschaft.*

[17] Brandt 2004, on 222–232.

[18] Kocka et al., forthcoming.

[19] Brigitte Wittmann-Liebold, interview by the author, 1 July 2015, Digital Archives of the Research Program "History of the Max Planck Society" (*Geschichte der Max-Planck-Gesellschaft*) (=DA GMPG), ID 601042.

[20] For more examples for both the *KWG* (*Kaiser-Wilhelm-Gesellschaft*) and the *MPG*, see: ibid.; Oesterhelt and Grote 2022; Satzinger 2009; Kolboske 2022.

[21] See biographies in Kinas 2004.

[22] Kocka et al., forthcoming.

Likewise, the social cohesion of specific scientific groups, such as biochemists, in the *MPG* paid off in epistemic terms.[23] Directors of the MPIs were greatly involved in the selection procedure of new directors and institutes and thus played a major role in determining the scientific course of the *MPG*. In the 1960s came the self-reinforcing effect that more and more directors supported the appointment of new directors and institutes in molecular biology over other disciplines, leading to the disproportionate prominence of the field in the *MPG*.[24] In 1971, a geneticist loudly complained: "Today, there is a dictatorship of molecular biologists in the *MPG*."[25] Wittmann and Liebold benefited from this development, albeit to different degrees. After the *MPG* had decided to abandon one of its remaining genetics institutes—in part because of its Nazi past—Wittmann became the founding director of the Max Planck Institute for Molecular Genetics in Berlin in 1964.[26] Wittmann-Liebold became a group leader in her husband's department. But the additional household and caregiver duties she was primarily responsible for became an obstacle in her scientific career. The practices of governance at the *MPG* further constrained her career; the *MPG* allowed Liebold to continue to work on condition that she renounce her own career development and promise not hinder Wittmann's work.[27]

2. Who's Feeding the Technologization of Biological Research?

While they were still employed at the MPI for Biology at Tübingen in the late 1950s, the Wittmann team had entered the race to unravel the so-called genetic code.[28] Whenever forced competition arises between labs, time and relationship with other labs become crucial factors for any lab in achieving its goals. As we know from a number of studies, new emerging research technologies were key to the acceleration in the developments of molecular biology.[29] The introduction of radioactive isotopes is an example of how the emergence of a new technique opened up new epistemic spaces of in vitro culture.[30] But it is also an example of the extent to which labs became

[23] For the epistemic impact of community building, see also Worliczek 2022 (this issue).

[24] Kocka et al., forthcoming.

[25] Witt to Ernst Telschow, 3 November 1971, Archiv der Max-Planck-Gesellschaft (=AMPG) [Archives of the Max Planck Society], Berlin, III. Abt., Rep. 84/2, Nr. 104/3.

[26] Sachse 2011, on 24–50.

[27] Brigitte Wittmann-Liebold to Thomas A. Trautner, 21 March 1991, Registratur der Generalverwaltung der Max-Planck-Gesellschaft (=GVMPG) [Records of the Administrative Headquarters of the Max Planck Society], Munich, Barcode 236.314, fol. 280; Brigitte Wittmann-Liebold, interview by author, 1 July 2015, DA GMPG, ID 601042. For more examples and thorough insights into the gender order at the *MPG*, see Kolboske 2022; see also Fox Keller 1996, on 342–343.

[28] Brandt 2004, on 220–232.

[29] For a selection, see: Rabinow 1999; Rheinberger 2001; Garcia-Sancho 2012; Creager 2013; Schwerin 2015; Worliczek 2020.

[30] Rheinberger 2021, on 23–29.

dependent on the proliferation of radioactive isotopes, which in turn was dependent on the dawn of the "atomic age" in the context of the Cold War and on the enormous efforts of physics, engineering, and industry, as well as politics and diplomacy.[31] Whether a certain laboratory actually benefited from all this hinged on circumstances that were even more regional and local. Counterfactually, biomolecular progress at the MPIs, as well as their ability for international networking, would have been minimal in the 1950s if the United States and Great Britain had not decided to supply radioisotopes to West Germany, if the *MPG* had not pushed a national organization to distribute them, and if the *Bundesministerium für Atomfragen* had not poured millions of West German Marks (DM) into the nuclear modernization of radiology and radiobiology, with molecular biology as an unintended profiteer.[32] Besides, the West German chemical industry was dedicated to the biochemical and early molecular biology labs of the *MPG* and continually supported them in various forms of contractual exchange: finance, materials, and knowledge circulated from companies, such as Bayer, Hoechst, and Schering, to the MPIs in exchange for junior staff and exclusive knowledge.[33] (However, this kind of circulation and its moving forces were hardly mentioned beyond the lab, which is why Ilana Löwy and Jean-Paul Gaudillière speak of the "invisible industrialist" in the labs.[34])

In the early 1960s, Wittmann's group successfully developed a method for the analysis of the genetic code. A prerequisite was the analysis of protein sequences. With other research groups on the track, the group in Tübingen became part of an international scientific race for the genetic code with protein sequencing as one of the most competitive methodological challenges. The winner of that race would certainly be awarded the Nobel Prize. The race accelerated with the advent of automated amino acid analyzers. The automation of protein sequencing made the determination of protein sequences "one of the most important activities" in the life sciences and led to an "explosion" of sequence data.[35] Eventually, Wittmann's group could not compete with Marshall Nirenberg's group at the National Institutes of Health in Bethesda, which succeeded in developing a different and more efficient in vitro approach.[36] The new method for determining the genetic code relied on pieces of tRNA, not amino acids. Nirenberg received the Nobel Prize in 1968.

Nonetheless, the Wittmann group had been part of this international race. This was because it could rely on an infrastructure that would not have been

[31] Creager 2013, on 220–259; Schwerin 2015, on 268–299.

[32] Schwerin 2015, on 365–369. Later, the *Bundesministerium für Atomfragen* delegated this task to the state-funded *Stiftung Volkswagenwerk* (Volkswagen Foundation). Schwerin, forthcoming; see also Rheinberger 2002. For the role of state funding in the rise of molecular biology, see Rasmussen 1997, on 245–293.

[33] Gaudillière 2005, on 612–644; Schwerin, in preparation.

[34] Gaudillière and Löwy 1998a.

[35] *Nature*, cited in Strasser 2019, on 143–144.

[36] Brandt 2004, on 230–232; Brigitte Wittmann-Liebold, interview by author, 1 July 2015, DA GMPG, ID 601042; Wittmann and Wittmann-Liebold 1963, on 589–595. For the Nirenberg lab, see Morange 2020, on 133–137.

available to any university department in West Germany at the time. The MPI in Tübingen had two modern protein sequencers at their disposal no later than 1958, which had been developed by William Stein and Stanford Moore at the Rockefeller Institute, New York, and distributed by the Californian company Beckman Instruments.[37] The new sequencers at the MPI made a crucial difference in accelerating and reorganizing the work at the MPI. They enabled the group to speed up the analysis of amino acids by a factor of 1,000 compared to the mid-1950s. In 1962, the MPI owned five devices; each had a purchase price of about DM 70,000.

Definitively, the expenditures for molecular biological research rose with every new emerging technology, especially with the implementation of electronic elements from the 1950s onward and, later on, computing.[38] A high-performance centrifuge cost DM 24,000, a liquid scintillation spectrometer DM 62,500, an electrophoresis diffusion device DM 83,000.[39] Biological laboratories became more and more dependent on third-party funds. The politics and financial resources of the aforementioned Federal Atomic Department became a forceful factor in providing essential technological equipment, which is why the MPI for Molecular Biology in Tübingen belonged to the faithful clients of the atomic complex.[40] Also, the MPIs profited from the *MPG*'s commitment to experimental biology. The *MPG* was anxious to support the technologization of the biosciences, although expenditures skyrocketed in the 1960s. The demands of the MPI for Biology as well as of the MPI for Molecular Genetics were still in the lower range compared to larger institutes, such as the MPI for Biochemistry, which accumulated 155 instruments (starting at DM 50,000) for about DM 20 million until the late 1970s—close to the expenditures for nuclear research (MPI for Nuclear Physics: DM 48 million).[41] However, the state-funded *MPG* itself became more and more dependent on the goodwill and the interests of external sponsors in order to meet the needs of its institutes. Apart from asking the state for more funds, the *MPG* started several campaigns between the 1970s and 1990s in order to collect private money.[42]

3. From Dahlem to Pasadena: The *MPG* License Deal with Applied Biosystems

Sequencing became even more efficient with biochemist Pehr Edman's "Sequenator," which hit the research market in 1967 and "emboldened

[37] Here and in the following, see Brandt 2004, on 222–223, 230. For the early history of sequencing, see Garcia-Sancho 2012, on 34–36.

[38] See Rheinberger 2001.

[39] Schwerin 2015, on 436.

[40] Ibid., on 343–344, 370.

[41] See Titel 820 90 "Erwerb von wissenschaftlichem Inventar," Rechnungsjahr 1978, AMPG, II. Abt., Rep. 69, Nr. 946, fol. 245–254.

[42] See the files in AMPG, II. Abt., Rep. 62, Nr. 843, 935, 936.

researchers to challenge larger and more difficult proteins."[43] This milestone became the basis for a new challenge that the Wittmanns at the MPI for Molecular Genetics in Berlin-Dahlem were now tackling: the analysis of protein biosynthesis, starting with the structure of ribosomes, those complex molecular machines in cells that assemble proteins from amino acids. Over the years, the combined efforts of the researchers at the Wittmann department led to the sequencing of several ribosomal proteins, the analysis of parts of the ribosomal self-assembly mechanism, and functional details of protein assembly.[44] More exactly, the Wittmann department accomplished the isolation and chemical, physical, and immunological characterization of the 54 proteins of the *E. coli* ribosome and later, the determination of the complete amino acid sequences of most of the 54 ribosomal proteins from *E. coli* and more ribosomal proteins from bacteria, eukaryotes, chloroplasts, and mitochondria, the crystallization of ribosomal particles, the reconstruction of the 50S subunit of *E. coli* ribosomes out of 32 proteins and 2 RNA, the identification of RNA binding sites, and more.[45] Because of this life work on ribosomes as well as for the invention of sophisticated techniques, such as two-dimensional electrophoresis, Wittmann was nominated for the Nobel Prize.[46]

The Wittmann department at the MPI was organized into several research teams.[47] Wittmann's team isolated the ribosomal proteins from bacteria using various techniques of purification–ultracentrifugation, various chromatography techniques, and 2D electrophoresis. The next 24-hour task of Wittmann-Liebold's team was to sequence the ribosomal proteins. Liebold could rely on an active team, including several technicians. Initially, there were not many research groups working in the ribosomal field, because most researchers thought this a too ambitious task. Ribosomal proteins could only become enriched to the extent of some milligrams, so that the quantities of protein that were usually required for sequence analysis were beyond any reasonable scope. Hence, the Wittmanns were interested in new techniques to analyze the hundreds of ribosomal peptides "in a reasonable time" and became more and more dependent on the exchange with the sequencer community. Richard Laursen from the University of Boston was willing to help and gave the Wittmanns the blue prints of his new solid-phase machine. Indeed, the new sequencer was constructed at the workshop of the MPI, and came over to Berlin with Laursen's students Marcus Horn and Alex Bonner to demonstrate the new technique. Together, they scaled down the required amount of protein to the nanomole range. "The good success in our laboratory spread over Germany and Europe, and one after another, scientists came to Berlin to get

[43] Strasser 2019, on 143–144; Garcia-Sancho 2019, on 35–36, 64, 182–183.

[44] Nierhaus 2014, on 54–55.

[45] Erdmann 1990, on 159–160.

[46] Volker A. Erdmann to Bo G. Malmström, 17 January 1986, AMPG, III. Abt., Rep. ZA 55 A, Kasten 22. For the history of electrophoresis, see also Suárez-Díaz 2022 (this issue).

[47] This and the following citations are based on Wittmann-Liebold's memories, see Brigitte Wittmann-Liebold, interview by author, 1 July 2015, DA GMPG, ID 601042. See also Brigitte Wittmann-Liebold to Hans F. Zacher, 27 September 1990, GVMPG, Barcode 236.314, fol. 480–486.

his or her peptides sequenced on this machine."[48] This also marked the beginning of the MPSA-conferences, recurrent meetings on Methods in Protein Sequence Analysis, bringing together scientists working actively in this field, especially protein chemists. The MPSA reflected not only the beginning of modern protein and peptide microsequence analysis, but also the mode of free and rapid exchange of new techniques, tricks and innovations, though only "among the insiders" and dependent on industry sponsoring.

This was going to change. With new groups in the field, Liebold's group felt it was already behind: The group did not receive its first "sequenator" until 1971, while groups in Canada and the US had already received some in 1970. Also, as it turned out, the Beckman sequencers were not perfect for the job, as there were problems with the pressure in the chemical reactor. Liebold inevitably had to evolve into a chemical engineer, but she could also rely on the knowledge and support of two institute technicians: craftsman Heinz Kohls and mechanic Horst Graffunder, who had taught himself electronics while employed at the production sites of Osram and Siemens. Together they took the sequencer apart several times and replaced parts of it, mostly during the day. The machines then ran in the evenings, at night and on weekends while Liebold worked on the publications at home.[49]

Word spread quickly once the Berlin lab was able to improve the Beckman Instruments' amino acid sequencer by adding several improvements, including an automatic conversion device.[50] The *MPG*'s own technology transfer office (Garching Instrumente GmbH) patented Liebold's new device.[51] However, Liebold initially did not make use of the patents, because she wanted to share her knowledge license-free in the context of scientific cooperation and in order to help other laboratories improve their machines. During a research trip, biochemist Leroy Hood of the California Institute of Technology (Caltech) in Pasadena heard from Swiss colleagues that they were enthusiastic about what they called the "Beckman-Wittmann machine." Hood had a strong interest in instrument development, since his lab was also in fierce competition with other labs working on antibody diversity.[52] Therefore, he sent his postdoc Michael

[48] Brigitte Wittmann-Liebold, "Reflections on the MPSA-Conferences: Development and Innovations of Protein and Peptide Structure Analysis in the Past 30 Years," Autumn 2005; on 6, AMPG, III. Abt., Rep. ZA 55 A, Kasten 22.

[49] For instance, Terhorst et al. 1972; Dognin and Wittmann-Liebold 1980, on 131–151; Boege et al. 1981; Wittmann-Liebold 1986.

[50] Wittmann-Liebold et al. 1976. For an overview on changes made, see Wittmann-Liebold 1982, on 41–53.

[51] Brigitte Wittmann-Liebold and Horst Graffunder, "Verfahren zur automatisierten Bestimmung der Aminosäuresequenz und Vorrichtung zu ihrer Durchführung," DE2308088 A1, filed 19 February 1973, issued 22 August 1974, online: https://worldwide.espacenet.com/patent/search?q=DE2308088A1 (accessed 7 July 2022). Garching Instrumente GmbH changed its name later to Max Planck Innovation. Founded in 1960 as an agency for the commercialization of research technologies arising from the operation of the Max Planck Institute for Plasma Physics, the agency has gradually expanded its tasks to patenting, licensing, and scientific business start-ups. Balcar 2018. For this kind of agencies, see Mirowski and Van Horn 2005.

[52] Garcia-Sancho 2012, on 119–121.

Hunkapiller to Dahlem, where he stayed for some days and received all the information and blueprints to recreate the "Beckman-Wittmann machine" back at Hood's Caltech lab in Pasadena.[53] Hunkapiller had played an important role in the development of new sequencing techniques and was considered Hood's right-hand man. Hood and Hunkapiller resumed the success of this operation,

> utilizing many design changes originated by Wittmann-Liebold, [we] were able to sequence both proteins and peptides at the subnanomole level with a spinning cup sequenator. These improvements involved extensive changes in almost all mechanical components of the instrument, including the reagent and solvent delivery valves, spinning cup reaction chamber, vacuum system, inert gas supply, and reagent-solvent storage assemblies, as well as the addition of a secondary reaction vessel for automated Pth conversion, extensive purification of the reagents and solvents, and use of a versatile microprocessor controller.[54]

In 1981, Hood and Hunkapiller founded their own company, Applied Biosystems, Inc. (ABI). They launched a protein sequencer and synthesizer between 1982 and 1983, followed by a DNA sequencer in the mid-1980s based on similar technology, which established ABI's commercial foundation and subsequent fame.[55] The new techniques assembled in the new protein sequencer revolutionized protein sequencing by allowing sequencing in the picomole range.[56] However, ABI needed Wittmann-Liebold's approval to proceed with its first product, the protein sequencer.[57] At this point, the *MPG*'s technology transfer office stepped in and negotiated a licensing agreement with ABI. According to the retrospective view of Wittmann-Liebold, the agreement did not produce the best conditions for the *MPG*, as it failed to patent the use of the Dahlem technique for DNA sequencing as well, even though the principles were similar. As Garcia-Sancho has detailed, Hood's research team differed markedly in style and in relation to the commercialization of research findings compared to competing teams in the United

[53] Brigitte Wittmann-Liebold, interview by author, 1 July 2015, DA GMPG, ID 601042; see Dreyer 1999, on 69–70; Hunkapiller and Hood 1978, on 2133. For Hunkapiller, see Garcia-Sancho 2012, on 135.

[54] Hunkapiller and Hood 1983, on 653. For an earlier account, see Hunkapiller and Hood 1978.

[55] Garcia-Sancho 2012, on 144. The principle of the sequenator was published in 1981 and mentioned Wittmann-Liebold's contribution. Hewick et al. 1981, on 7992. The patent claim of Hood and Hunkapiller stated: "The present invention is primarily an improvement on the prior sequenators described above, particularly the sequenator of Penhasi U.S. Pat. No. 3,725,010 as modified in the articles of Wittmann-Liebold." Leroy E. Hood and Michael W. Hunkapiller, "Apparatus for the Performance of Chemical Processes," US4252769A, filed 26 December 1979, issued 24 February 1981, online: https://worldwide.espacenet.com/patent/search/family/022313479/publication/US4252769A?q=US4252769 (accessed 7 July 2022). On patent claims and conflicts related to this paper, see Dreyer 1999, on 73–74, 94–95.

[56] Brigitte Wittmann-Liebold, "Reflections on the MPSA-Conferences: Development and Innovations of Protein and Peptide Structure Analysis in the Past 30 Years," Autumn 2005, on 6–7, AMPG, III. Abt., Rep. ZA 55A, Kasten 22 .

[57] This and the following are based partly on Wittmann-Liebold's memories, see Brigitte Wittmann-Liebold, interview by author, 1 July 2015, DA GMPG, ID 601042.

Kingdom.[58] The research group in Berlin-Dahlem differed in a very similar way. "We would never have thought of founding a company just because of that [invention] […]. Here [in Germany], research and industry were different things […]. And by the way, where would we have gotten the money for such a company?" recalls Wittmann-Liebold. In contrast, Hood's lab at Caltech had a number of potent sponsors at its disposal, whose venture capital ultimately enabled the foundation of ABI, and they used patenting of their inventions strategically to get funding and other advantages.[59]

4. Leaving an Organization and Becoming an Entrepreneur

The difference between Wittmann-Liebold's and Hood's laboratories represented growing tensions in the life sciences, both in terms of commercial and gender issues. The emergence of entrepreneurial scientists like Hood changed the balance of free exchange on the one hand and the commodification of research materials and technologies on the other hand.[60] But even if there had been opportunities for companies to develop from the scientific community in West Germany, Liebold, as a mother of two and dependent on every free hour to do her lab work, would never have had the chance to start her own company and become an entrepreneurial scientist.[61] Wittmann-Liebold, in other words, was not only affected by the moral economy of West German scientists, but also subject to the reproductive economy of West German society, which was loudly combatted by the feminist movement in the streets at that time, but hardly questioned in the biological sciences. Thus, the episode brings together virulent themes of the 1970s and 1980s, just when the history of science turned to practices and cultures.

Many of these conditions changed over the next decade, but not so much in terms of the mobility of female scientists. The number of female directors at the *MPG* remained static, and was even behind compared to departments at German universities.[62] The biologist Christiane Nüsslein-Volhard—one of two female directors at that time, compared to about 200 male directors—attempted to improve the gender imbalance by implementing a special childcare program for the postdocs at her department.[63] In the early 1990s, the *MPG* changed its critical stance toward *MPG*-scientists founding spin-off companies; up to then, the *MPG* had been afraid that the self-interests of biotech companies would interfere with the traditionally good relations among

[58] Garcia-Sancho 2012, on 119–143.

[59] Ibid., on 128; Dreyer 1999, on 35, 52, 67–68.

[60] Yi makes this argument with respect to Recombinant DNA technology. Yi 2015, chapter 3. For networks and social structures in the transfer of research technologies, see Reinhardt and Steinhauser 2008. For a selection of papers on the quest of instruments, see: Gaudillière and Löwy 1998b; Joerges and Shinn 2001; Hentschel 2012.

[61] For Germany's late entry into genetic engineering, see Dolata 1996 and Wieland 2009.

[62] For the *MPG*, see Kolboske 2022.

[63] Fox Keller 1996, on 341; Nüsslein-Volhard 1991, on 33–35; Rubner 2008; Kolboske, 2022.

the *MPG*, the MPIs, and big industry.[64] Contrary to that concern, the *MPG* and the MPIs had always profited from license payments. By 1990, they had earned about DM 1 million from Wittmann-Liebold's invention.[65] Generally, the *MPG* became an early scholar of the political move toward the economization of academic research in Germany.[66]

However, the main change for Wittmann-Liebold was that her husband Heinz-Günter died unexpectedly in 1990. Wittmann-Liebold fought for the continuation of the research groups of the department, but the remaining directors of the MPI for Molecular Genetics did not support her in her claim, and the *MPG* refused to give her and her husband's work this final recognition.[67] Although she had published about 280 publications up to this point and the former Wittmann groups were just about to complete the grand task of revealing the structure of the ribosome and crucial mechanisms of protein biosynthesis, Wittmann-Liebold was never promoted to the status of a Scientific Member of the *MPG*, and she was not trusted to take on the interim leadership of the department either — nor was the successful crystallographer Ada Yonath or any another group leader at the Wittmann department, in order to maintain free hand on the departements future.[68] Instead, Ada Yonath became head of a research unit at the German Electron Synchrotron in Hamburg and was awarded the Nobel Prize in 2009 for the analysis of ribosomal structures.[69]

Wittmann-Liebold left the *MPG* and reinvented herself as entrepreneurial scientist. While she was group leader at the Max Delbrück Center for Molecular Medicine (MDC), Berlin, she founded the WITA company (Wittmann Institute of Technology and Analysis of Biomolecules), specializing both in scientific research and technology development.[70] This move was certainly an attempt to regain the position and resources she had formerly had at her disposal at the MPI. At the same time, it was consistent with her scientific career path up to this point, since she had become more and more specialized on the development of new research technologies in the 1980s. For

[64] Balcár 2018, on 57–63; Schwerin, in preparation.

[65] Brigitte Wittmann-Liebold to Thomas A. Trautner, 21 March 1991, GVMPG, Barcode 236.314, fol. 281.

[66] Leendertz 2022.

[67] Brigitte Wittmann-Liebold to Adolf Butenandt, 5 November 1990, AMPG, III. Abt., Rep. 84/2, Nr. 6473, fol. 10–13; Brigitte Wittmann-Liebold to Hans F. Zacher, 27 September 1990, GVMPG, Barcode 236.314, fol. 480–486; Brigitte Wittmann-Liebold, interview by author, 1 July 2015, DA GMPG, ID 601042.

[68] "Vermerk für den Präsidenten," 18 October 1990, GVMPG, Barcode 236.314, fol. 410–411; Brigitte Wittmann-Liebold to Hans F. Zacher, 27 September 1990, ibid., fol. 481–482. The nine working groups of the Wittmann department were reduced little by little. Thomas A. Trautner, "Vermerk," 4 July 1991, ibid., fol. 321–323; Hans-Jörg Rheinberger, interview by the author, 25 July 2022.

[69] Until 2004, the number of publications summed up to 390. Cf. Brigitte Wittmann-Liebold: Publications, AMPG, III. Abt., Rep. ZA 55A, Kasten 22. For Yonath, see Nierhaus 2014, on 55–56.

[70] Curriculum Vitae Brigitte Wittmann-Liebold, AMPG, III. Abt., Rep. ZA 55A, Kasten 22; Interview Wittmann-Liebold.

instance, she developed the "Berlin Sequencer" in cooperation with Herbert Knauer GmbH, a Berlin based company. This was a system for the analyses of nanograms of proteins and for the integration and miniaturization of all processes of protein analyses in a single 5 × 5 cm, microchip based device.[71] For her developments, she was awarded several developer prizes, such as the technology transfer award of the Federal Department of Research and Technology.[72] Last but not least, her move reflects changing attitudes toward biotech start-ups in Germany in the 1990s and, more generally, the economization of academic science since the 1980s.[73]

6. Conclusions

In this paper, the protein research conducted at the Wittmanns' laboratory served as an example of the multiple conditions and factors—the invisible hands of the scientific challenge—that are needed to make things and persons move among laboratories and to eventually promote changes in research practices.

Economically, it was modern industry that ensured that modern instruments made their way into the war-ravaged laboratories of biochemist Butenandt; the open-mindedness of some senior scientists and official programs moved postdocs to laboratories abroad; the atomic age and the Cold War kept radioisotopes circulating; the *MPG*'s Nazi past moved genetics out of the *MPG* and the Wittmanns into the vacated niches; governmental programs in the wake of the technological gap funded the move of a zoo full of instruments into the biological Max Planck Institutes and enabled their labs to compete internationally, and so on. Only Wittmann-Liebold sending her self-developed Beckman-Wittmann sequencing device to Switzerland was not supported by institutional practices. But patenting turned this altruistic transfer into a new business. In exchange for money, the *MPG* allowed Leroy Hood to start a career as a scientific entrepreneur in the US, while scientific idealism, lack of venture capital, and the close relations of the *MPG* to big industry became a hindrance for the biotech economy to settle down in the MPIs. Wittmann-Liebold only became an entrepreneur when a set of new conditions changed her scientific trajectory.

With regard to gender, this case study also exemplifies the research practices that failed to develop. Postdoc and top chemist Liebold neither moved to the US, nor did she gain a top leadership position during the course of her career at the *MPG*; her scientific supervisors did not support her, and *MPG*

[71] Brigitte Wittmann-Liebold, "Reflections on the MPSA-Conferences: Development and Innovations of Protein and Peptide Structure Analysis in the Past 30 Years," Autumn 2005, on 6–7, AMPG, III. Abt., Rep. ZA 55A, Kasten 22; Wittmann-Liebold 1982, on 50–53.

[72] Max Delbrück Center (MDC), "Pressemitteilung Nr. 19," 19 November 1997, GVMPG, Barcode 233.415, fol. 131–132.

[73] There is little literature on biotech startups in Germany, e. g., Rebentrost 2006 and Stadler, forthcoming. For German academic science, see Mayer 2019.

regulations prevented this kind of circulation. In theory, the discrimination of women scientists was contradictory to one of the guiding principles of the scientific system: guaranteeing that the best researchers get the best opportunities. In terms of experimental cultures, social, and cultural conditions negatively affected the circulation of talented scientists between laboratories. This was even more so in West Germany than in other European countries or in the US. In the end, the *MPG* drove Wittmann-Liebold out into a new environment, where, being already in her sixties, she could hardly come to new fame.

Regarding institutional frameworks, this case study has shown that institutional boundaries were present in all of these examples. Affiliation and social cohesion shaped scientific life of the *MPG* and were factors that determined the circulation of scientists. Institutional boundaries are a reminder of the constraints and conditions of free circulation; the passage of people and things across boundaries is by no means something that just happens nor can it be managed by people and things alone. Rather, they show how heterogeneous conditions, power relations, and social processes may stimulate or interfere with the scientific circulation spheres in the nutshell of an organization. Hence, the institutional framework exemplifies the crucial meaning of the meso level as the melting point of laboratory practices and grander contexts in setting the conditions for the circulation of things and people. The power of it is profound, not only with regard to the career of Wittmann-Liebold, but also in the way the in vitro culture became dominant in the *MPG* life sciences.[74]

Close attention should be paid to the conditions that facilitate or hamper circulation and trajectories of things and persons when dealing with experimental cultures. Only the totality of conditions brings things and people into circulation and eventually enables successful arrangements in the laboratory. Such comprehensive histories of circulation spheres may coalesce into a larger and more nuanced picture of experimental cultures, overcoming the limited focus on the laboratory on the one hand or political programs on the other, but rather integrating them. Or more specifically put: In bringing together histories of this kind, a clearer picture will emerge of what is entailed when the "research process of the life sciences […] become inseparable from industrial, techno-commercial inputs of multiple sorts with respect to the whole triangle of objects, including 'industrialized' organisms themselves, tools, and forms of work."[75]

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[74] For an appeal to focus more on the history of institutions, see Malich 2018.

[75] Rheinberger 2004, on 225.

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