
Chemical Microbiology, an Interdisciplinary Field on the Road to Molecular Biology, 1920-1948

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Since the second half of the 19th century scientific development has been characterised among others by intense integration and differentiation of scientific disciplines resulting in the evolvement of new interdisciplinary sciences and fields. This is also true about chemistry which has interacted with numerous other disciplines and fields with serious consequences for the structure of scientific disciplines which was this way enriched with new interdisciplinary fields and sciences. Although a number of authors attempted to characterise and analyse the notions of “scientific discipline”, “interdisciplinary science” or “interdisciplinary field”,¹ historians of science still have not agreed on their generally acceptable definitions. This paper is aimed at contributing to this discussion using the example of emergence of chemical microbiology which became constituted between 1930 and 1950, approximately, on the boundary of several chemical and biological disciplines.

From biochemistry to chemical microbiology

In order to understand the genesis of chemical microbiology it is necessary to recall a few particulars related to the formation of biochemistry, one of its “parent” interdisciplinary sciences, which dominated the scientific scene in the first half of the 20th century.²

As many historians have agreed, biochemistry became an independent discipline after 1900 with all necessary attributes: an institutional and communication base, an international scientific community, an independent subject taught in a number of universities, with a specific social mission and social acknowledgement and various strategic concepts outlining its program. The most significant for the future development of biochemistry, and will be seen, also for chemical microbiol-

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ogy, became especially the strategic programme of the new independent discipline published by the leading British biochemist F.G. Hopkins in 1913 in the journal *Nature* under the title “The Dynamic Side of Biochemistry”.³

The essential problems to be resolved by the young discipline, marked out by Hopkins, were amongst others:

- Cellular intermediary metabolism
- The nature and function of enzymes
- Mechanism of maintenance of the cellular dynamic equilibrium
- Cellular regulatory mechanisms
- Response of tissues and cells to chemical stimuli, including immunity reactions and drug action
- The role of cellular particles (structures) in these events
- Devising specific biochemical methods

It is obvious that focus on chemical approach to biological problems was the leit-motif to Hopkins’ program aiming in the first instance at resolving cellular chemical processes and their regulation. At the same time, he understood the cell as a general entity, a place where all crucial chemical processes took place.

Hopkins’ paper turned out to be the unifying agent of the various biochemical programmes presented earlier and also a certain guideline of biochemistry development for the next forty years to come. Hopkins invited chemists and biologists to participate in his agenda with a special appeal on organic and physical chemists, who in the 19th century had kept aloof from biological problems.

In 1914 was opened his Biochemical Department in Cambridge⁴ where his vision was to be realised. It gradually developed into a major institute with international fame, the Dunn Institute of Biochemistry launched in 1924⁵ where Hopkins’ collaborators⁶ were making real the previously outlined programme of dynamic biochemistry. The important distinction of the Hopkins group was its interdisciplinarity and the research freedom given to its members. As pointed out by Kohler, “*Hopkins’ operating method was to hook ambitious young biochemists with the prospect of big biological problems to be solved, then to leave them alone to develop their special areas.*”⁷. Many of those who for a longer or shorter period joined the Department were to become leading figures of world biochemistry, among them Hans Krebs, J.B.S. Haldane, Albert Szent-Györgyi, Joseph and Dorothy Needham and many others. We will pay here special attention to Marjory Stephenson who joined the Cambridge Biochemical Laboratory in 1919.

Stephenson and Hopkins⁸

Marjory Stephenson was a noteworthy personality not only because of her scientific achievements but also as one of the first women in a managerial position in a scientific institution and one of the first two women elected Fellows of the Royal Society.⁹ She was born on January 24, 1885 at Burwell near Cambridge in an educated family of farmers. Both parents and Marjory's governess influenced the scientific and artistic interests of the young girl. After attending the Berkhamsted High School for Girls in 1897-1902, where she also received tuition in physiology, she enrolled in 1903 in Newnham College, Cambridge, where she took a Part I Natural Science Tripos in chemistry, physiology and zoology. Stephenson's scientific career started in 1911 when she became research assistant to the nutritional chemist R. H. A. Plimmer at University College, London. Nutrition and dietetics also became the bridge to her cooperation with F.G. Hopkins who got the Nobel Prize in 1929 for his early studies of vitamins. Paradoxically, when she arrived to Cambridge in 1919, Hopkins was no longer interested in vitamins. Dynamic or general biochemistry was the area he offered Stephenson in which to participate in his vision of biochemistry. Stephenson went on to accomplish one of the central points of his programme, which was research into the biochemistry of micro-organisms.

How did Stephenson come to such task? As already hinted, Hopkins had focused since the second decade of the 20th century on cellular biochemical processes and chemical approaches to clarifying them. He claimed that these processes were analogous in the cells of various organisms and if biochemists want to learn more about them they should study metabolism and its regulation in simple suitable models like unicellular organisms, preferably bacteria. This was an unexplored area and Stephenson was to develop it through research into bacterial metabolism. Encouraged by Hopkins, Stephenson devised her programme accordingly and pursued it during her whole life.

In 1922 Stephenson joined the Medical Research Council (MRC) and as such was not dependent anymore on the Biochemistry Department's budget. From 1929 she was for the rest of her life a full-time member of the MRC's staff at the newly established MRC research unit in Cambridge linked to the Dunn Biochemical Institute. She soon started to manage her own small research group. Under her guidance worked not only collaborators paid by the MRC but also graduate students, local and foreign visitors and several members of the Hopkins Department paid from various other sources (Table 1).

It is necessary to emphasise that a woman heading a research team was at that time an unusual phenomenon but the sources¹⁰ bear witness to the fact that Stephenson coped with her managerial position in the laboratory and developing her scientific field, like most men scientists of the time holding a similar rank. However, the experience of a woman playing prominent role in the scientific community differed from that of a man. Although in reality she acted as director of the Cambridge MRC Laboratory with all attributes and responsibilities, the MRC management never recognised her position officially.

Table 1**Collaborators of Marjory Stephenson 1922-1948¹¹**

Collaborators at the MRC Research Unit	18
Members of the Biochemistry Department	21
Loosely attached collaborators	11
Others	6
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Total number of collaborators	56
Number of women collaborators	14
Percentage of women collaborators	25

Research pursued by Stephenson and her group¹²

In the 1920s, studies of enzymes and metabolic phenomena in microbial cells were still at their beginnings and thus exploration of biological organisation of chemical reactions in cells and tissues (Table 2) represented a new original research direction.

Table 2

<i>Time interval</i>	<i>Topics</i>	<i>Main collaborators</i>
1920s	Washed cell or resting cell technique	Quastel, Whetham
	Notion of "active centres" in cell surfaces	Quastel, Whetham, and Wooldridge
1930s	Enzyme action in microbial cell	Cook, Whetham
1930s-1940s	Discovery, isolation and investigation of new bacterial enzymes	Stickland, Gale
1932-1936	Adaptation and control phenomena in bacterial cells	Yudkin, Gale
1930-1949	Bacterial Metabolism monograph	
WW2	New biotechnologies	
1946-1948	Nucleic acids in bacteria	

Main research topics in chemical microbiology pursued by Stephenson and her collaborators

Since the early 1920s Stephenson with her direct collaborators and in cooperation with other members of the Biochemical Department, investigated various manifestations of metabolic activities in microorganisms, like the actions of bacterial enzymes. To accomplish such studies they also had to devise new methods. Among the most important ones was the washed cell or resting cell technique developed by Juda H. Quastel and Margaret D. Whetham;¹³ this facilitated utilising bacteria as models of the cell for biochemical investigations. Bacterial cells were centrifuged out of culture, washed in water, suspended in a medium without nutrients and then used for experiments. Such a method made it possible to study chemical activities in whole intact living non-growing cells in contrast to the previous routines studying the contents of disrupted cells. Using the method various aspects of the metabolic activities in microbial cells, for instance actions of hydrogen-activating enzymes, were investigated. Several new enzymes were isolated and identified, the first being lactate dehydrogenase, in 1928.

The endeavour to investigate how chemical reactions in the cell are organised got its most pronounced expression in studies of enzyme adaptation phenomena.¹⁴ In 1930, Stephenson and Leonard Stickland discovered a new enzyme, formic hydrogenlyase, produced by *Escherichia coli*. In the years 1932 to 1936 Stephenson with John Yudkin and Ernest F. Gale proved that this and several other enzymes, called adaptive enzymes, were formed in *E. coli* when a substrate of the enzyme is added to the growth medium. Such observations were not by then a novelty. Earlier, in the first two decades of the 20th century, various instances of such adaptive enzyme formation in multiplying cultures were investigated, but Stephenson and her collaborators were first to prove that also non-growing bacterial cultures and individual cells were capable of fast adaptive formation of substrate-specific enzymes. These findings prompted Stephenson and Yudkin to define in 1936 the *enzymic type of adaptation* as a “*direct a response of the enzymic composition of the cell to the constituents of the growth medium*”, independent of mutant formation or cell division, that “*is definitely temporary and does not affect the heredity mechanism of the cell, which reverts to normal ...when the organism is grown without the specific stimulus*”.¹⁵ The first relevant so-called “mass action” theory of adaptive enzyme formation was then advanced in the years 1936 to 1938 by John Yudkin.

During World War II, Stephenson was involved among other things, in projects related to strategically important biotechnological production of organic compounds and this way contributed to the fast advance of biotechnology after WW2. In the last two years of her life, Stephenson investigated nucleic acids in bacteria and their enzymatic breakdown within the cell.¹⁶

These studies were interrupted by her illness and death by cancer on December 12, 1948.

Formation of a new field – criteria and circumstances

Herein it is attempted to reason that in the years 1930-1948, approximately, a new interdisciplinary field chemical microbiology or general microbiology was emerging. Support to this statement relies on some criteria defining the process of the formation of a new interdisciplinary field or discipline specified earlier and explained in more detail in a paper on the formation of biochemistry as an interdisciplinary science.¹⁷ The preferred criteria are the following:¹⁸

1. The process leading to the formation of an interdisciplinary science or field is complex and cannot be identified with an isolated event, like a discovery, creation of an institution or journal, a method and the like.
2. Interdisciplinarity is a historical notion connected with complex multistage interaction of various “parent” disciplines resulting in the formation of a qualitatively new field or discipline.
3. If speaking of an interdisciplinary science or fields one should always have in mind a customary term originating historically from interrelations of various scientific disciplines, fields and specialties.
4. To decide whether a new discipline integrating several parent disciplines has emerged one should settle on features which characterise a new interdisciplinary science or a field. The following are regarded as decisive:
 - New quality of cognition with methods specific to the new field.
 - Establishment of specialised institutional and communication network
 - Introduction of the field as a separate teaching subject at the university
 - Declaration of a concept and/or programme of the field or discipline and definition of its contents and objective of research.

Investigation of the question, how the process of the formation of chemical or general microbiology answered these criteria now follows.

New quality of cognition and specific methods in chemical microbiology

It results from what has been said about Stephenson’s research that microorganisms represented for her both objects of research and a model enabling deeper

understanding of cellular events and their organisation in general, that is, not only in bacteria. She understood very soon that “*Data on the chemical activities of bacteria...may help us to gain an insight into the chemical processes accompanying the life of the organisms concerned...Perhaps bacteria may tentatively be regarded as biochemical experimenters...*”.¹⁹ Her experiments demonstrating that bacterial enzymes behave similarly as enzymes in higher organisms and that metabolism and its control in bacteria was governed by regularities analogous to those in higher organisms, contributed to the acceptance of the principle of unity in biochemistry, coined by F.G. Hopkins and articulated by Kluver and Donker.²⁰ The experimental and theoretical approach to enzymatic adaptation (later known as enzymatic induction) elaborated in her laboratory in the 1930s was taken up by J. Monod in the 1940s and as such became the point of departure for theories of cellular regulatory mechanisms and protein synthesis developed in the 1950s and 1960s as a theoretical base for molecular biology. The methods developed in Stephenson’s laboratory, for instance the resting cell method, became standard methods when using micro-organisms as models in molecular biology.

Establishment of institutional and communication base in chemical or general microbiology

Stephenson deliberately built her laboratory within the MRC as a centre of interdisciplinary studies related to her research programme in spite of a certain disapproval of the MRC authorities. Her attempts to retain her scientific autonomy used to be permanent source of argument with her superiors. From the very beginning Stephenson had to defend the direction of her research concentrating on the problems of chemical microbiology that were not directly related to the MRC’s scheme, in particular to practical medical problems. This is evident for instance from the letter the Secretary of MRC Fletcher wrote in 1931, where he urged Stephenson to reduce the “*purely abstract biochemical point of view*” with a threat that the MRC will only support investigations which are “*likely to assist the progress of medicine*”.²¹ This determined clinging on the research programme, she considered focal, might have been one of the reasons why the Cambridge MRC laboratory was never given the official status of an MRC Unit.²² Its interdisciplinarity was accentuated by the fact that under Stephenson’s guidance there worked in the laboratory specialists of diverse backgrounds; not only collaborators paid by the MRC but also graduate students, local and foreign visitors and several members of the Hopkins Department paid from different sources.

Stephenson was fully aware of the fact that the new field must be anchored in a specialised institution also *de iure*, therefore she herself exerted pressure on the MRC to legitimise the laboratory as an official unit for microbiological chemistry, however without success. Since 1944 in her annual reports she started to call her workplace “*The M.R.C. Research Unit for Microbiological Chemistry, The Biochemical Laboratory Cambridge*” and had the same name painted on the door in spite of the persistent deprecation of the MRC leaders to officially recognise such status. It was a special success that must be attributed to Stephenson’s persistent efforts that the MRC appointed during WW2 a special *Committee on Chemical Microbiology* where Stephenson was invited for membership. Ironically, the unofficial name of the laboratory became legalised by the MRC immediately after her death in 1948 when E.F. Gale was appointed Director of the Unit for Chemical Microbiology.

Another momentous event in institutionalisation of chemical or general microbiology represented the creation of the *Society for General Microbiology*. Although its establishment had been prepared by an organising committee under the leadership of M. Stephenson since 1943, the formal inaugural meeting was only held on February 16, 1945. As the records show, the first candidate for presidency was the biochemist David Keilin, and when he declined Stephenson was asked to take this post.²³ Nevertheless, Stephenson did not accept the position most possibly due to her political tactfulness and/or serious illness²⁴ so eventually Sir Alexander Fleming was elected. We should observe that the society omitted the term “chemical” in its title probably because the Society aimed at transcending the realm of chemical microbiology and drew up its program more generally. The inaugural meeting “*decided that the Society should concern itself with the study of bacteria, viruses, micro-fungi, protozoa and microscopic algae in their various biological activities*” dealing “*predominantly with the more fundamental aspects of the study of these forms, including their physiology, nutrition, chemotherapy, systematics and ecology*”.²⁵ The chemical aspects were still there but hidden in the terms physiology, nutrition, chemotherapy. In 1947, Stephenson eventually agreed to accept the presidency and Fleming became Honorary Member. The same year the *Journal of General Microbiology* was founded. Its contents show that the chemical direction in the journal has been predominant and the majority of papers were related to biochemistry and molecular biology.²⁶ In memory of Marjory Stephenson the Society of General Microbiology awards biennially the Marjory Stephenson Prize Lecture “*for any outstanding contribution of current importance in microbiology*”.²⁷

Another means of specialised communication and institutionalisation in the new field was the *First International Symposium on Chemical Microbiology* which took place in 1951 under the aegis of the World Health Organization,²⁸ to celebrate the opening of the *International Research Center for Chemical Microbiology* in Rome.²⁹

Chemical microbiology in university education

Attempts to establish chemical microbiology as a separate interdisciplinary field also included university education. Stephenson worked hard for several years to start a special Part II Biochemistry (microbiological) in Cambridge. Eventually in 1947 chemical microbiology was recognised by the University as a discipline in its own right and she herself was appointed the first University Reader in Chemical Microbiology.³⁰ As explained the letter of H.H. Dale³¹ to the University's Vice Chancellor H. Thirkill written in 1947, the introduction of the new discipline at the University had been motivated among other things by the great and growing national need "...for scientists who have had a training in the fundamental sciences suitable to equip them for research in the general field of microbiology, with its growing range of technical applications". Stephenson's success as a teacher could "be measured by the steady flow of recruits from the Part II Class to her research team...".³²

The concept and programme of chemical microbiology

The strategic program of chemical or later general microbiology was designed and communicated by Stephenson on several occasions, especially in her monograph and textbook *Bacterial Metabolism* published in three revised editions, 1930, 1939 and 1949.³³ Written in a "lucid and forceful style", as characterised by the prominent British biochemists Elsdon and Pirie,³⁴ it became a reference work for several generations of biochemists and microbiologists all over the world. From the prefaces to the three editions one can follow the development of Stephenson's programmatic vision of chemical microbiology over the years.

Already in 1929³⁵ in the Preface to the 1930 Edition, Stephenson stressed the importance of data "on chemical activities of bacteria which may help us to gain an insight into the essential chemical processes accompanying the life of the organisms concerned...and to appraise our knowledge of bacteria as living organisms apart from their rôle as disease germs or the bearers of commercially impor-

tant catalysts."³⁶ In the second edition of 1938 Stephenson observed the necessity of bacterial biochemistry in determining the common laws followed by enzymes belonging to the bacterial, animal and vegetable world.³⁷ The preface to the third edition 1949 is almost prophetic in its view of study of bacterial metabolism and its ever more extensive application: "...During the last few years a fresh view of bacterial metabolism has been opened up. Information is now being rapidly gained on the course of the biochemical processes leading to cell synthesis; such studies are peculiar to microbiology though certainly of wider application.; they owe their success to use of biological material which is prone to biochemical variation and tolerant of interference with its normal biochemical habit [that is microorganisms, comment by SŠ]. This new stream of knowledge has its origin in several sources: microbial genetics, nucleic acid metabolism, adaptive enzyme formation...antibiotics...and interference with metabolism resulting from the introduction into the cell of chemical analogues of essential cell metabolites. All these are contributing to produce a picture –at present incomplete and patchy– of the biochemical machinery of growth".³⁸

The programme of chemical microbiology grew into its more definite and extended shape of general microbiology as explained in Stephenson's plenary lecture "*Levels of Microbiological Investigation*"³⁹ read at the inaugural meeting of the Society for General Microbiology in 1945. In the lecture Stephenson defined areas in which research in microbiology should be undertaken, none of which should be considered higher or lower than another in the list:

- (1) Mixed cultures of organisms growing in natural environment,
- (2) Pure growing cultures in complex media,
- (3) Pure growing cultures in highly purified chemically defined media,
- (4) Non-proliferating cells in pure cultures containing chemically defined substrates, and
- (5) Cell-free enzymes and coenzymes and their action on pure substrates.

This programme was exceptional from several standpoints. It was designed in a more universal way than that of chemical microbiology and invited a much wider scientific audience. It stressed not only chemical investigations of cells but also appealed to interdisciplinary collaboration of scientists experimenting at different levels of living matter; from naturally occurring mixed cultures to cell-free environment. It also called attention to the fact that only studying cells at various levels may result in a complex knowledge of the cell's activities. And last but not least it pleaded for better understanding of bacteria as they are found in Nature, a view that has been neglected both by biochemistry of the 1950s and contemporary molecular biology, preferring areas (3-5) and almost completely ignoring area (1).

Stephenson's proposal of problem-solving in area (1) may also be understood to a certain extent as gender-related.⁴⁰ To explain this view it is worth to note, beforehand in 1937 she had called attention to the fact that enzymes studied in the laboratory may behave quite differently than those found in nature. In her essay on cell organisation pleading against simple teleology, Stephenson calls for investigation of live objects, even as small as microorganisms, in their natural environment.⁴¹ It is her respect for the integrity of Nature which can be attributed to her gender and which is at odds to the usual scientists' reductionist stereotype and efforts to study Nature through domination and disintegration.

Conclusions

Robert Kohler in his paper of 1985⁴² evaluates Stephenson's contribution as a "program" of "innovation" in "normal science" namely innovation in bacterial physiology.⁴³ He states: "*Stephenson's program for bacterial physiology was a mixture of Cambridge-style enzymology, comparative physiology and evolutionary biology*". The present paper considers Stephenson's contribution to discipline building to be more substantial than a mere innovation programme within a previously existing field or discipline. Its essence is in a complex formation of a new research field chemical or general microbiology with momentous consequences for the structure of scientific disciplines in the 20th century as it represents an intermediate link between biochemistry and what we call today, molecular biology.

This paper endeavours to show that chemical microbiology, or as it was called later general microbiology, was a new interdisciplinary research field which evolved stepwise in the years 1930-1948. Among its "parent" disciplines were microbiology, biochemistry, bacterial physiology, physical and organic chemistry. Chemical microbiology acquired the features of a genuine discipline with its well-defined subject and objective of research including special methods, offering its specific strategic programme and building its institutional, publication and communication base; it became a university education subject, and encompassed its institutionally anchored scientific community and adequate social acknowledgement. However, the terms "general microbiology" or "chemical microbiology" appeared much earlier, at the times before they could be identified with a new field. Already in 1910 the German microbiologist Walther Kruse whom Stephenson used to quote as her predecessor, published a monograph by entitled "*Allgemeine Mikrobiologie*",⁴⁴ and E.B. Chain even considered Pasteur founder of chemical microbiology.⁴⁵

Although there is still much confusion in defining scientific disciplines and their formation, attention is drawn to the recent paper of H. Laitko⁴⁶ who considers one of the “most important perspectives of science research” the one “related to the disciplinary dimension of science that divides science into units dependent upon the difference of subject areas...Corresponding to the multitude of possible initial arrangements a lot of different discipline formation patterns may be described as well as supra-disciplinary types of units like specialties, research areas, etc. which “may be transformed historically into genuine disciplines”. For several reasons, chemical or general microbiology should not be considered according to this terminology discipline but rather as a field of a supra-disciplinary type which played the role of an intermediate stage on the road from biochemistry to the new discipline - molecular biology.

Notes

¹ See for instance *Der Ursprung der modernen wissenschaften*, ed. Martin Guntau and Hubert Laitko (Berlin: Akademie Verlag, 1987); *Die Entstehung biologischer Disziplinen vol. 1*, eds. Ekkehard Höxtermann, Joachim Kaasch and Michael Kaasch, *Verhandlungen zur Geschichte und Theorie der Biologie* (Berlin: VWB, 2002), vol. 8; *Die Entstehung biologischer Disziplinen vol. 2*, eds. Uwe Hossfeld and Thomas Junker, *Verhandlungen zur Geschichte und Theorie der Biologie* (Berlin: VWB, 2002), vol. 9. For the analysis of the formation of biochemistry as an interdisciplinary science, see e.g. Soňa Štrbáňová, “Formation of Interdisciplinary Sciences. The Case of Biochemistry,” in *Science and Technology at the Turn of the 19th and 20th Centuries: Interrelation of Disciplines*, eds. Luboš Nový and Yuri S. Voronkov, *Acta historiae rerum naturalium necnon technicarum* 19 (1985), 193-245, this paper offers detailed reasoning with references on the formation of interdisciplinary sciences and biochemistry; Soňa Štrbáňová, “Forming the Strategy of 20th Century Biochemistry,” in *Highlights of Modern Biochemistry*, eds. Arnošt Kotyk, Jan Škoda and Václav Pačes (Utrecht, Tokyo: VSP International Science Publishers, 1989), 1689-1697.

² For recent treatise on the history of biochemistry see especially Joseph H. Fruton, *Proteins, Enzymes, Genes. The Interplay of chemistry and Biology* (New Haven and London: Yale University Press, 1999); it contains a substantial bibliography on the history of biochemistry and related disciplines and fields.

³ Frederick G. Hopkins, “The Dynamic Side of Biochemistry,” *Nature* 92 (1913): 213-223.

⁴ For details on Hopkins’ biochemistry department see e.g. *Hopkins and Biochemistry*, eds. Joseph Needham and Ernest Baldwin (Cambridge: Heffer, 1949); Joseph Needham, “Frederick Gowland Hopkins,” *Perspectives in Biology and Medicine* 6 (1962): 1-46; Robert E. Kohler, *From Medical Chemistry to Biochemistry* (Cambridge, London, New York, New Rochelle, Melbourne Sidney: Cambridge Univ. Press, 1982), 73-92.

⁵ Robert E Kohler, “Walter Fletcher, F.G. Hopkins, and the Dunn Institute of Biochemistry: A Case Study in the Patronage of Science,” *Isis* 69 (1978): 331-355.

⁶ By 1950 passed through Hopkins’ laboratory total about 370 people from all over the world, as shown by Soňa Štrbáňová, “Marjory Stephenson and the Medical Research Council – a New

Managing Role for a Woman Scholar,” in *Women Scholars and Institutions*, eds. Soňa Štrbáňová, Ida H. Stamhuis, Kateřina Mojsejová, *Studies in the History of Sciences and Humanities*, (Prague: Research Centre for the History of Sciences and Humanities, 2004), vol. 13 A, 415-449, on 422.

⁷ Robert E. Kohler, “Innovation in Normal Science. Bacterial Physiology,” *Isis* 76 (1985): 162-181, on 166.

⁸ For Stephenson’s life and work and her relation to Hopkins, see Štrbáňová, “Marjory Stephenson”.

⁹ Stephenson’s managerial position at the MRC is analysed in detail in Štrbáňová, “Marjory Stephenson”. For her Fellowship of the Royal Society see Muriel Robertson, “Marjory Stephenson (1885-1948),” *Obituary Notices of Fellows of the Royal Society* 6 (1948/49): 563-577; Joan Mason, “The Admission of the First Women to the Royal Society of London,” *Notes and Records of the Royal Society* 46 (1992): 272-300.

¹⁰ Ample evidence to this assertion is presented in Štrbáňová, “Marjory Stephenson”.

¹¹ The table was taken from Štrbáňová, “Marjory Stephenson,” 447.

¹² Facts in this paragraph are taken from literature on Stephenson, especially Sidney R. Elsdon and Norman W. Pirie, “Marjory Stephenson 1885-1948,” *Journal of General Microbiology* 3 (1949): 329-339; Muriel Robertson, “Marjory Stephenson”; Donald D. Woods, “Marjory Stephenson 1885-1948,” *Biochemical Journal* 46 (1950): 376-383; Robert E. Kohler, “Stephenson, Marjory,” in *Dictionary of Scientific Biographies* 18, Suppl. II (1981): 851-860; Mark Weatherall, and Harmke Kamminga, *Dynamic Science* (Cambridge: Wellcome Unit for the History of Medicine, 1992), 43, 48-49; Soňa Štrbáňová, “Stephenson, Marjory,” in *Lexikon der Bedeutenden Naturwissenschaftler*, eds. Dieter Hoffmann, Hubert Laitko and Staffan Müller-Wille (München: Elsevier Spektrum Akademischer Verlag, 2004), vol. 3, 326-327.

¹³ See e.g. Juda H. Quastel and Margaret D. Whetham, “The Equilibria Existing Between Succinic, Fumaric and Malic Acids in the Presence of Resting Bacteria,” *Biochemical Journal* 18 (1924): 519.

¹⁴ See Soňa Štrbáňová, “Enzyme adaptation - the road to its understanding: Early theoretical explanation,” in *Biology Integrating Scientific Fundamentals. Contributions to History of Interrelations Between Biology, Chemistry and Physics from the 18th to the 20th Centuries*, ed. Brigitte Hoppe, *Algorismus* (München: Institut für Geschichte der Naturwissenschaften, 1997), vol. 21, 260-285. In this paper are described the experiments and their theoretical outcomes with references.

¹⁵ Both quotes are from Marjory Stephenson, *Bacterial Metabolism, 3rd Edition* (London, New York, Toronto: Longmans Green, 1930), 296.

¹⁶ Robertson, “Marjory Stephenson,” 573.

¹⁷ Štrbáňová, “Formation of Interdisciplinary Sciences”, see especially pages 194-195 and 227-231.

¹⁸ I have chosen these criteria, although other ones may exist that would lead to different conclusions.

¹⁹ Marjory Stephenson, *Bacterial Metabolism* (London-New York-Toronto: Longmans Green, 1930), xi.

²⁰ Albert J. Kluyver and Hendrick J.L. Donker, “Die Einheit in der Biochemie,” *Chemie der Zelle und Gewebe* 13 (1926): 134-190.

²¹ Letter, Fletcher to Stephenson, February 2, 1931, MRC Archives 2036/2/I.

²² The other reason was obviously the mere fact that Stephenson was a woman, compare Štrbáňová, “Marjory Stephenson and the Medical Research Council”.

²³ Copy of letter to Stephenson from Honorary Secretaries, (apparently L.A. Allen and R. St. John-Brooks), 13 July 1944. Archives of the Society for General Microbiology, Reading. The other candidate for presidency was according to this letter D. Keilin.

- ²⁴ In September 1944 Stephenson discovered a tumour in her right breast and underwent an operation. Letter Stephenson to Mellanby 21 September 1947, MRC Archives, P.F.216.
- ²⁵ "Society for General Microbiology", *Nature* 155 (1945): 340.
- ²⁶ Both the Society and the Journal exist until today.
- ²⁷ See http://www.socgenmicrobiol.org.uk/about/prize_lectures_rules.cfm
- ²⁸ *Microbial Growth and its Inhibition. First International Symposium on Chemical Microbiology, World Health Organization Monograph Series* (Geneva: W.H.O., Palais des Nations, 1952), No. 10.
- ²⁹ I have this information from the internet, see <http://www.ajtmh.org/cgi/content/abstract/2/5/944-a>, <http://veterinaryrecord.bvapublications.com/cgi/content/citation/63/25/435> and have no other knowledge about this centre as well as about the international symposia on chemical microbiology and their further fate. Nevertheless even these data suggest that for some time chemical microbiology was considered a very important field.
- ³⁰ Complicated negotiations concerning the establishment of the new subject apparently started at the beginning of 1946 as reflected by the correspondence reprinted in Memorandum for the meeting of the MRC General Board. General Board Paper No. 2064, MRC Archives 2036/2/III.
- ³¹ H.H. Dale was at that time President of the Royal Society and member of the Scientific Advisory Committee to the Cabinet.
- ³² Woods, "Marjory Stephenson," 378.
- ³³ Marjory Stephenson, *Bacterial Metabolism* (London-New York-Toronto: Longmans Green, 1930); 2nd Edition, 1939; 3rd Edition, 1949.
- ³⁴ Elsdon and Pirie, "Marjory Stephenson," 335.
- ³⁵ Date of Stephenson's Preface to the First Edition is March 8th, 1929, so she wrote it the year before the book was published.
- ³⁶ Stephenson, *Bacterial Metabolism* (1930), xi.
- ³⁷ Stephenson, *Bacterial Metabolism* (1939), viii-ix.
- ³⁸ Stephenson, *Bacterial Metabolism* (1949), v-vi.
- ³⁹ The text of the lecture has not been published. Information on its contents comes from Woods, "Marjory Stephenson," 378-379; Elsdon and Pirie, "Marjory Stephenson," 331; and the article reporting on the inaugural meeting, see "Society for General Microbiology".
- ⁴⁰ For various aspects of gender-related science see Evelyn Fox Keller, *Reflections on Gender and Science* (New Haven, London: Yale University Press, 1985); Section "Gendered Knowledge and the Reshaping of the 'Normal Science'," in *Women Scholars and Institutions*, ed. Soňa Štrbáňová, Ida H. Stamhuis, Kateřina Mojšejová, *Studies in the history of sciences and humanities*, (Prague: Research Centre for the History of Sciences and Humanities, 2004), vol. 13 B, 727-809.
- ⁴¹ Marjory Stephenson, "The Economy of the Bacterial Cell", in *Perspectives in Biochemistry*, eds. J. Needham and D.E. Green (Cambridge: At the University Press, 1937), 91-98.
- ⁴² Kohler, "Innovation", 170-171.
- ⁴³ Kohler, "Innovation", 171.
- ⁴⁴ Walther Kruse, *Allgemeine Mikrobiologie: die Lehre vom Stoff-und Kraftwechsel der Klebewesen* (Leipzig: Verlag von F. C. W. Vogel, 1910).
- ⁴⁵ E.B. Chain, "Contributions from Chemical Microbiology to Therapeutic Medicine," *Proceedings of the Royal Society of Medicine* 58 (1965): 85-96.
- ⁴⁶ Hubert Laitko, "Die Disziplin als Strukturprinzip und Entwicklungsform der Wissenschaft – Motive, Verläufe und Wirkungen von Disziplinierungen," in *Die Entstehung biologischer Disziplinen 1*, eds. Ekkehard Höxtermann, Joachim Kaasch and Michael Kaasch, *Verhandlungen zur Geschichte und Theorie der Biologie* (Berlin: VWB, 2002), vol.8, 19-55.