Transcending the Margins

The discovery of osmosis and the ensuing controversy
(1820s - 1840s)

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Onder de gewichtigste vraagstukken der plantenphysiologie behoort, zonder twijfel, de sapbeweging in de gewassen. In het laatst van het vorige jaar, ontstonden bij de *Fransche Akademie* nog discussiën over dit onderwerp.[1]

Walter Sobchak: "Am I wrong?"
The Dude: "No."
Walter Sobchak: "Am I wrong?"
The Dude: "Yeah. But..."
Walter Sobchack: "OK, then."[2]

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[1] M-R [Probably M.J. Reynhout], "Wetenschappelijke berigten", *Bijdragen tot de natuurkundige wetenschappen*, Part II (1827):113.

[2] Ethan Coen (Producer/Writer), Joel Coen (Writer/Director), *The Big Lebowksi* [Motion Picture] (Universal Studios, 1998):9.02 min.

Contents

Introduction

Take a membrane and use it to separate two solutions with different concentrations. What you will see is osmosis in action. Most of us have learned about this phenomenon in secondary school, during biology class. The teacher probably pointed out that osmosis plays a vital role in animal and plant physiology. It explains why flowers whither when they are deprived of fresh water, and it proves that it is foolish to drink seawater when you are thirsty and floating around in the South Atlantic.[3] But as bored as some of us were when we still had to learn about the umpteenth biological fact, as intrigued were many great scientists during the nineteenth century when they learned about the phenomenon. It is not difficult to point at celebrities like the heralded German chemist Justus von Liebig (1803-1873), or his eminent British colleague Thomas Graham (1805-1869). They were joined by physiological heavyweights like Carl Ludwig (1816-1895), or Julius Sachs (1832-1897), and even Karl Marx (1818-1883) and Friedrich Engels (1820-1895) took an interest in osmosis due to the philosophical implications it had.[4] Ultimately, osmosis made it to Stockholm in 1901, when the Dutch chemist J.H. van 't Hoff (1852-1911) was awarded the first Nobel Prize in Chemistry for his discovery of the osmotic pressure law.

This thesis is concerned with the history of osmosis, of which the better part played in the nineteenth century. But unlike the paraphrase above, the story I am about to unfold does not classify as a heroic tale. Rather it is concerned with, and limited to, the troublesome origins of osmosis, and the struggles of its patron and discoverer to get the right attention. When the French physiologist Henri Dutrochet (1776-1847) discovered osmosis in 1826, he did not foresee that his phenomenon would get caught in a controversy. Eventually it took about two decades before osmosis reached the center of scientific interest. But by then it had already been shaped, transformed and molded into a phenomenon whose explanatory potential could eventually be recognized. This thesis takes this transformation as its central theme, and simultaneously tries to answer the question that arises from it. Because how did osmosis gradually evolve into an object that was of appreciable interest to the scientific community? It will be shown in this

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[3] *"Water, water, everywhere,*
And all the boards did shrink;
Water, water, everywhere,
Nor any drop to drink."
(Samuel Taylor Coleridge, *The Rime of the Ancient Mariner*.)

[4] Friedrich Engels, *Hernn Eugen Dühring's Umwälzung der Wissenschaft*, 3rd ed. (Stuttgart, 1894):75.

thesis that Dutrochet was a marginal figure who did not have the proper resources to put osmosis on the scientific map. Instead, the general acceptance of osmosis only followed after the phenomenon overcame its exclusive association with its discoverer.

Even though the study of such a controversy-steered transformation would have been interesting enough in itself, my motivation to focus exclusively on the troublesome beginnings of osmosis stemmed from another concern, which, in fact, was much more pragmatic: there is almost no mention of osmosis in the current historiography of nineteenth-century science. In brief, this means that the integral story of osmosis has yet to be told. And if we tell stories, we always start at the beginning.

Although it is plain and simple that this historiographical gap is undeserved – we only need to consider the eventual and major contemporary interest – it is also very understandable why this gap exists. The reason has to be sought in the very features of osmosis itself. Already during the nineteenth century, osmosis cut through many disciplinary boundaries. Its natural habitat was physiology; its origin was physics, and its behavior could be manipulated by chemistry. As such, osmosis is a natural example in which the histories of chemistry, physics and physiology are inextricably intertwined. To reveal osmosis in the course of science, we therefore need to look precisely beyond the boundaries that are inflicted by these disciplines. Osmosis continually crossed those boundaries and hence refuses to get caught in an orderly structured and disciplined historiographical web. On a higher level, there is thus a historiographical point to be made, since osmosis will urge us sometimes to leave the comforting boundaries of the disciplines as well. Actually, one important reason for the eventual contemporary interest in osmosis will be found in the fact that it merged physiology with the physical sciences.

While it is true that very little has been written about the history of osmosis, there are a few exceptions. Fortunately, there have been two historians who already picked up the glove. During the 1970s, the historian John Pickstone published three articles on Dutrochet and osmosis.[5] In these articles Pickstone explored the case of osmosis principally to gain further insight into the development and functioning of French physiology. The other historian, Joseph Schiller, published around the same time a selection of Dutrochet's correspondence and two never published memoires, accompanied by a few chapters on Dutrochet's biography and scientific

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[5] J.V. Pickstone, "Vital actions and organic physics : Henri Dutrochet and French Physiology during the 1820s", *Bulletin of the History of Medicine* 50 (1976):193.
– "Absorption and Osmosis : French Physiology and Physics in the Early Nineteenth Century", *The Physiologist* 20 (1977):36.
– "Locatin Dutrochet", review of Joseph Schiller, Tetty Schiller, *Henri Dutrochet (Henri du Trochet) 1776-1847) : Le matérialisme mécaniste et la physiologie générale* (Paris : Albert Blanchard, 1975), *The British Journal for the History of Science* 11 (1978):61.

conceptions.[6] Both historians have provided in a firm foundation from which the history of osmosis could be pursued. However, despite the great value of these preceding studies, this thesis diverges from them in some significant ways. Whereas the controversy over osmosis will be the central theme of this thesis, Pickstone and Schiller only slightly touched upon this event. Moreover, this thesis will also be less restricted to France and French physiology.

The method I employed was rather straightforward. I just followed osmosis where it went in order to understand how its cumbersome start eventually connected to the revival of interest in the early 1840s. This also determined much of the choices I made with regard to what parts of the story I wanted to include. I chose for instance to commence the story with Dutrochet's discovery of osmosis, despite the fact that preceding observations of osmosis exist. Dutrochet was nevertheless the first to regard osmosis as a genuine phenomenon, which, as a result, put the osmotic enterprise really into motion. Furthermore, I ignored some of the later studies of Dutrochet and instead decided to cross the borders of French physiology, because the dissemination of osmosis into Germany appeared to have had much more impact on the long run. A decision of another category proved to be the incorporation of the sociological concept of marginality.[7] Dutrochet was a figure who in several ways moved through the margins of the scientific community. A better understanding of his social position would therefore certainly help to come to grips with the controversy over osmosis. Although the concept of marginality will be omnipresent at the background, I will only return explicitly to the problem of marginality in the final conclusion.

This thesis is organized as follows. In the first chapter, I discuss Dutrochet's discovery of osmosis in 1826. The discovery took place in the larger context of experimental physiology that was on the rise in France since the 1800s. The second chapter is concerned with the controversy that followed upon this discovery. The main source of disagreement proved to be the question whether osmosis was a genuine phenomenon. Finally, in chapter three, I shift the attention towards Berlin. It is ultimately in Germany, and not in France that the missing link is found that connects the poor beginnings of osmosis with the brighter future it would have during the remainder of the nineteenth century.

It is clear that I would not have been able to write this thesis without the help and guidance of the following people. I would like to thank Ernst Homburg, who initially helped me exploring the history of osmosis. I am very

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[6] Joseph Schiller, Tetty Schiller, *Henri Dutrochet (Henri du Trochet) 1776-1847) : Le matérialisme mécaniste et la physiologie générale* (Paris : Albert Blanchard, 1975).

[7] Neil McLaughlin, "Optimal Marginality : Innovation and Orthodoxy in Fromm's Revision of Psychoanalysis", *The Sociological Quarterly* 42 (2001):271; Jaap Bos, David W. Park, Petteri Pietikainen, "Strategic Self-Marginalization : The Case of Psychoanalysis", *Journal of the History of the Behavioral Sciences* 41 (2005):207.

grateful to José Ramón Bertomeu-Sánchez, who kindly welcomed me at the Institute for the History of Medicine and Science '*López Piñero*', in Valencia, Spain. The many conversations we had, helped me significantly to define the scope and question of this thesis. Finally I would like to thank Bert Theunissen, who not only guided me through the actual writing process, but also enthusiastically kept helping to come to grips with this peculiar controversy.

1. The Dawn of a New Phenomenon

In October 1826, the French physiologist Henri Dutrochet (1776-1847) introduced the audience at the Academy of Sciences to a recent discovery. For the past few months he had been working on what proved to be a new phenomenon. Having thoroughly performed several experiments and multiple observations, Dutrochet was convinced to have found a phenomenon that was of the utmost importance to the understanding of both vegetal and animal physiology. Nowadays better known as *osmosis*, the phenomenon resonated at the French Academy from the start, and many of Dutrochet's contemporaries were interested to hear what all the fuzz was about.

Whereas the subsequent chapters will deal with the controversy that soon followed the introduction of osmosis, this chapter is a prelude that will enhance a better understanding and ability to follow this controversy. This chapter deals in particular with the scientific, ideological and social environment in which osmosis arrived in 1826. Finally, I will briefly discuss Dutrochet's *l'Agent immédiat du mouvement vital* (1826) and its initial reception, which brings us a step closer towards the actual disclosure of the controversy.

1.1 Chasing the vital force

After Dutrochet's official announcement at the Academy, the scientific community immediately responded to his study of osmosis. Already within a few weeks after the event, reviews and reports appeared of Dutrochet's discovery, while the Academy was the center of discussion. Regardless the nature of the reviews, it seems therefore that Dutrochet had been able to grasp the attention of his public rather easily. Of course he must have been thrilled to see that the scientific community took his discovery so serious. This lucky turn of events was however not necessarily self-evident. The fact that people responded so promptly to the introduction of osmosis had everything to do with the environment in which osmosis arrived in 1826.

Osmosis did not arrive in a sterile or hostile territory. However difficult the acceptation of osmosis proved to be on the long term, at first sight the circumstances were such that osmosis could almost readily be integrated into the existing scientific and ideological structures. The first circumstance that eased the introduction of osmosis is found in the growing attention for experimentalism in the field of physiology during the first two decades of the nineteenth century. Not only did Dutrochet's study of osmosis fit right into this program, it also related to many of its central concepts and questions. In the second place, and despite the upcoming experimentalism, ideas of vitalism were still dominant in physiology. Albeit in different flavors, the basic notion of a fundamental difference between organic and inorganic nature was still much alive. Dutrochet's study of osmosis alluded to these ideas and promised new outlooks on the debate.

The beginning of experimental physiology in France is usually dated back to the turn of the 19th century. While some trace the beginnings of experimentalism to the physiologist Marie François Xavier Bichat (1771-1802), others point to a manifesto published in 1809 by his pupil François Magendie (1783-1855) that should indicate the maturation of the new physiology.[8] In any case, at the beginning of the nineteenth century a physiology arose that explicitly broke with the precedent physiological tradition – a tradition that was characterized by its highly discursive and hypothetical approach, with only marginal attention for experiments. Especially in comparison to the progress that was made in other disciplines like physics and chemistry, many felt that at the end of the eighteenth century physiology was in crisis.

The unstable political landscape caused by the French Revolution in the 1790s eventually proved to be a major incentive for the professional and educational reform of the medical sciences in France, including that of physiology. Formal, pre-revolutionary bodies like the Academy of Sciences and universities were abolished, but as soon as 1794 they were replaced by the First Class of the National Institute, which brought together the pure sciences, as well as the medical sciences under one roof.[9] This provided in a new and fertile milieu for those of the medical community with scientific aspirations. All of a sudden they could immerse themselves among the most respected scientists who, on their turn, motivated the members of the medical community to adopt and employ the scientific standards to reinforce the field of medicine. One could therefore say that to some extent, the French Revolution presented the medical sciences with a *tabula rasa*, an opportunity to reflect on their achievements and methodologies hitherto, and a chance to redirect its future-course.[10]

It was in these circumstances that experimental physiology got its initial shape. This was done in the first place through the teaching and works of Xavier Bichat, himself being part of the first generation of students after the Revolution. He stressed the importance of experimental analysis as a valuable source of information, and sought to redefine physiology into a proper science. This was to be achieved not so much by the assimilation of

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[8] John E. Lesch, *Science and Medicine in France : The Emergence of Experimental Physiology, 1790-1855* (Harvard UP, 1984); Maurice Crosland, "The French Academy of Sciences As a Patron of the Medical Sciences in the Early Nineteenth Century", *Annals of Science* 66 (2009):247-265.

[9] Maurice Crosland, "The French Academy of Sciences":250.

[10] Lesch, *Science and Medicine in France*:42.

physics and chemistry, but rather by setting up a program that would be analogous to these sciences.[11] As the Newtonian laws formed the very heart of physics, physiology should also define its ‘core-business’. Because of its main concern with organic life, the heart of physiology had to be constituted principally by the study of so-called vital properties. These vital properties – sensibility and contractility – should be as central to physiology as Newton's laws were to physics. By means of experimental methods (surgery, animal experiments, clinical observations, and the older eighteenth-century repertoire of experimental procedures) its mechanisms and taxonomy had to be elucidated. Although Bichat's doctrine of vital properties did not have a lasting impact, his emphasize on experimentalism proved all the more to be a constructive foundation on which the science of physiology could be expanded.[12]

It was François Magendie who in 1809 made a further attempt to reform the program of experimental physiology. Already early in his career he published a manifesto, which, according to many, marks the actual birth of the ‘new physiology’.[13] Although he did away with Bichat's doctrine of vital properties, much in line with his predecessor he emphasized the importance of a central and general theme around which physiology had to be organized. For Magendie this was the study of nutrition on the one hand and the study of vital action on the other. Both nutrition and vital action were on their turn caused by the *vital force*, which according to Magendie was physiology's unique and unitary explanatory principle.[14] Just like gravity and molecular affinity, this vital force – the very principle of life – was unknown in its nature, but its existence clearly manifested itself through its effects. These effects of the vital force were found in the changing chemical composition of the molecules (nutrition), and the movements of these molecules (vital action). Since these molecular events were inaccessible – too small to be investigated – Magendie argued to commence with physiology at the level of the perceptible.

The criticism uttered in his manifesto was in the first place directed towards Bichat's doctrine of the vital properties that the latter used as a principle from which the further science of physiology could be deduced.

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[11] Xavier Bichat, *Anatomie générale, appliquée à la physiologie et à la médecine*, Tome 1, 1re Partie (Brosson/Gabon : Paris, 1801):xxxvi-lii.

[12] Lesch, *Science and Medicine in France*:50-79 (chapter 3).

[13] J.M.D. Olmsted, *François Magendie : Pioneer in Experimental Physiology and Scientific Medicine in XIX Century France,* 1e ed. 1944 (New York : Arno Press, 1981), chapter 2; Joseph Schiller, "Physiology's struggle for independence in the first half of the nineteenth century", *History of Science* 7 (1968):64-89; William R. Albury, "Physiological explanation in Magendie's manifesto of 1809", *Bulletin of the History of Medicine* 48 (1974):90-99.

[14] A contemporary review summarizes very clearly Magendie's view: "the author shows that all of the phenomena peculiar to organized beings may be related to nutrition and to the action which would be named its premier cause, the vital force". See: Review of Magendie, "Quelques idées générales sur les phénomènes particuliers aux corps vivans", *Annales des Sciences et des Arts,* Année 1809, 2e partie (1810):139.

According to Magendie this was begging for dogmatism. Instead of deducing a science from vital properties, Magendie proposed therefore a physiology that was directed towards its ultimate end, the vital force.[15] If we perform experiments on the phenomena that we are able to perceive, we will gradually get closer to the molecular level and we will be able to determine the laws through which the vital force operates.[16]

According to the historians Lesch and Albury, these ideas of Magendie were not groundbreaking per se.[17] There is a clear continuity visible with Bichat's experimentalism and also the idea of the vital force had roots extending into the eighteenth century. Nevertheless, it was mostly through the driven motivation of Magendie that experimental physiology won attention. His publications in the 1810s did not stay unnoticed and he could also count on the support of several major figures at the Institute.[18] In 1816, Magendie published a textbook on physiology, his *Précis élémentaire de physiology,* which would go through several editions during his further career.[19] The establishment of an official prize and a proper journal further nourished the upcoming trend of the new physiology. In 1818, the Montyon prize in experimental physiology was founded with the help of Laplace, with the aim to encourage experimental physiologists with an award of 7000 francs. Three years later in 1821, Magendie founded the first journal in the field, the *Journal de physiologie expérimentale et pathologique* and he finally saw himself an elected member to the Institute in the same year.[20] Experimental physiology was without doubt a flourishing field.

In the light of our upcoming discussion of osmosis we need to take a closer look at one particular subject that proved central to Magendie's interest, namely that of absorption. Not only was it a major theme in the program of experimental physiology, it would also determine significantly the response at Dutrochet's discovery of osmosis. Already in 1809, the same year he published his manifesto, Magendie had written an article on the physiological mode of action of strychnine poisons, a class of poisons that recently had been discovered.[21] By means of surgical experiments, Magendie determined

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[15] J.V. Pickstone, "Vital actions and organic physics : Henri Dutrochet and French Physiology during the 1820s", *Bulletin of the History of Medicine* 50 (1976):193.

[16] François Magendie, "Quelques idées générales sur les phénomènes particuliers aux corps vivans", *Bulletin des Sciences Médicales* 4 (1809):145-170.

[17] Lesch, *Science and Medicine in France*: 95; Albury, "Physiological explanation":94.

[18] According to Crosland, Magendie had two powerful patrons who recognized the importance of experimental physiology: both Pierre-Simon Laplace (1749-1827) and Jean Léopold Nicolas Frédéric Cuvier (1769-1832). Maurice Crosland, "The French Academy of Sciences":255-256.

[19] François Magendie, *Précis élémentaire de physiology* (Méquignon-Marivs : Paris, 1816-1817).

[20] J.M.D. Olmsted, *François Magendie*:83-88.

[21] J.V. Pickstone, "Absorption and Osmosis: French Physiology and Physics in the Early Nineteenth Century", *The Physiologist* 20 (1977):31; Lesch, *Science and Medicine in France*:104; J.M.D. Olmsted, *François Magendie*:35-36.

that the quick action of this poison could only be explained when it was taken up in the blood by means of venous absorption. This was an innovative study, because the dominant view in eighteenth-century physiology had been that the lymphatic vessels, rather than the veins were responsible for absorption.[22] Magendie therefore cautiously concluded that "the lymphatic vessels are not always the route by which foreign materials arrive in the blood".[23] Nevertheless, Magendie was now faced with another problem. Since the absorption of compounds in the lymhatic vessels was formerly explained by pointing at the rootlets and mouths of these vessels, Magendie still had to explain how absorption took place in the continuous veins that were lacking these sorts of facilities. In an article published in 1821, he finally provided an answer. According to Magendie, the veins absorbed the foreign materials through their membranes by means of capillarity. The "capillary attraction of the walls of small vessels appears to be the cause, or, more exact, one of the causes of venous absorption."[24]

In the meantime, another experimental physiologist had thrown himself on the topic of absorption. In 1822, the young Sicilian physiologist Michel Foderà (1793-1848) published a study on the absorptive properties of tissues.[25] The study was received enthusiastically at the Academy, and he was awarded the 1823 Montyon prize in experimental physiology.[26] New in this study was that Foderà connected the property of absorption not only to the veins, like Magendie did earlier, but that he connected absorption to the properties of tissues in general. By using both in vitro and in vivo experiments, Foderà demonstrated that chemicals were able to move across the membranes of tissue sacs. According to the historian Pickstone, this discovery had two important consequences.[27] In the first place, it supported Magendie's argument against the eighteenth-century believe that absorption was the result of the active mouths of the lymphatic vessels. The second major implication was however that Foderà removed absorption as a mere feature of the veins, and reinstated it as one of the most general functions of porous animal matter. Absorption took place in either direction across the

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[22] J.V. Pickstone, "Absorption and Osmosis":31.

[23] Magendie, "Mémoire sur les organes de l'absorption chez les mammifères", *Journal de physiologie expérimentale* 1 (1821): 31. The original text (unaltered taken over in the former journal), appeared in the *Bulletin de la Société philomatique* 1 (1808-1809):368-371.

[24] Magendie, "Mémoire sure le mécanisme de l'absorption chez les animaux a sang rounge et chaude", *Journal de physiologie expérimentale* 1 (1821):15.

[25] Michel Foderà, *Recherches expérimentales sur l'absorption et l'exhalation* (Baillière : Paris, 1824). Other places of publication include: Michel Foderà, "Recherches expérimentales sur l'absorption et l'exhalation", *Journal de physiologie expérimentale* 3 (1823):35-45; *Archives générales de médicine* 2 (1823):57-77; *Bulletin de la Société médicale d'émulation de Paris* (1822):364-389.

[26] Foderà had to share the prize with another prize-winner: M. Flourens, who had written a memoire on the nerve system. See the section "Variétés", *Archives Générales de Médicine* 2 (1823):303; Ernest Maindron, *Les fondations de prix a l'académie des sciences* (Paris : Gauthier-Villars, 1881):89.

[27] J.V. Pickstone, "Absorption and Osmosis":32.

membranes of different types of organic matter (tissues, veins, vessels etc.) and was caused by the physical phenomenon of capillarity.

> One can conclude from the above that exhalation and absorption[28] are general functions, because they are present in all parts of the organization of all living beings; they can act simultaneously and depend on capillary tissues. These functions [...] are the main cause, or the most powerful maintenance of life.[29]

The experiments done by Foderà proved that Magendie had been wrong in constraining absorption as a mere function of the veins. Not only proved absorption to be a general function of tissues, this very generality also turned it into an essential function to life itself. A few years later, Magendie revised his former opinion and decided to adopt Foderà's new insight by writing that one "no longer will discuss whether it is the veins or the lymphatics which absorb, since all the tissues are endowed with this property".[30]

Absorption now, stood in the middle of physiological attention.[31] In the meantime however, another development had taken place. The first decades of the nineteenth century witnessed a shift in the way physiologists dealt with the doctrine of vitalism. At the turn of the century, Bichat had claimed for instance that there was a huge gap separating the phenomena of life and the physical phenomena. Out of principle, there was therefore no possibility of adopting chemistry or physics into the science of physiology. Bichat wrote in 1805 that to "say that physiology is the physics of animals is to give an extremely inaccurate idea; I could as well say that astronomy is the physiology of the stars."[32] Albeit that the physical sciences could be of limited use to physiology, in the end physiological phenomena begged for a mere physiological explanation with which chemistry, physics or astronomy had

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[28] The used terminology might be confusing. In this article Foderà uses two pair of terms. First there are exhalation and absorption. Whereas absorption designates the movement of matter from the exterior towards the interior, exhalation designates the inverse movement. Secondly, Foderà uses the terms transudation and imbibition. Imbibition again designates the movement towards interior, transudation the movement towards the exterior. Although the two pairs have obviously different origins, Foderà argues that they posses the same meaning and could be used interchangeably. The use of these pairs however lost their relevance, as Foderà shows that both movements take place simultaneously and indifferently. In the period after Foderà's publication, people therefore tend to only use absorption and imbibition synonymously. See: Foderà, *Recherches expérimentales*:8.

[29] Foderà, *Recherches expérimentales*:67.

[30] François Magendie, *Précis élémentaire de physiologie,* 2nd ed. Tome 2 (Méquignon-Marivs : Paris, 1825):272. I used the translation as appeared in J.V. Pickstone, "Absorption and Osmosis":32.

[31] This claim should not be underestimated. Pickstone points at the very issue of absorption as an explanation why tissues became a major subject of investigation in the life sciences later on. J.V. Pickstone, "Absorption and Osmosis":33.

[32] Xavier Bichat, *Recherches physiologiques sur la vie et la mort,* 3rd ed. (Brosson/ Gobon : Paris, 1805):78.

nothing to do. Yet, in the 1820s something had changed.[33] If we look at the case of absorption, it is clear that both Magendie and Foderà were arguing that capillarity was the underlying cause of this very phenomenon. In other words: whereas Bichat excluded the physical sciences when it came down to physiological explanations, Magendie and Foderà precisely turned to physics for the definitive answer.

Even though Magendie revolted already in 1809 from Bichat's physiology, his turn to the incorporation of the physical sciences must be sought somewhat later in his career. If we take a look at the preface of the textbook he published in 1816, we see that Magendie has opened the door for a contributable role for physics and chemistry. Of course, there is still a strict distinction between physical phenomena and the phenomena of life, but "I [Magendie] did not, however, neglect the possible and useful applications of the principles of physics to the phenomena of life".[34] One year later, he confirmed this position when he declared that there are several scientists who "recognize the inadequacy of the laws of nature, inert to many phenomena of life", but who at the same time "are not afraid to regard several of these phenomena fully covered by these laws".[35] Magendie saw himself as a part of this group, which, at least to some extent, explains his readiness to admit that a physical phenomenon like capillarity was the underlying cause of absorption that he believed to be a phenomenon of life.[36]

Meanwhile, the search for Magendie's vital force remained central to the program of experimental physiology throughout the 1820s.[37] We would

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[33] A beautiful description of the changing attitude towards ideas of vitalism is provided by the contemporary French physician Gaultier de Claubry (1792-1878.) He writes: "M. Chaussier ne cessait de répéter dans ses leçons de physiologie, que l'homme n'est ni un laboratoire de chimie, ni une machine hydraulique, ni un appareil de physique purement et simplement [...] Depuis lors, une secte de physiologistes s'est élevée, qui, craignant de ne pas assez rapprocher la nature organisée et vivante de la matière brute et innanimée, n'a cessé de chercher à prouver que les principaux actes de la vie s'accomplissent par le seul fait et sous l'influence des lois purement physiques. En particulier, on sait quel rôle M. Magendie a fait jouer à la simple capillarité, à la porosité, pour expliquer les phénomènes supposés vitaux de l'absorption, de l'inhilation." See: M. Gaultier de Claubry, "Mouvement Vital", review of *L'Agent immédiat du mouvement vital* by Dutrochet, *Journal Générale de Médicine*, Tome 99 (1827):76-77.

[34] François Magendie, *Précis élémentaire de physiology*, Tome 1 (Méquignon-Marivs : Paris, 1816):v.

[35] François Magendie, ‘‘An essay on chymical history and medical treatment of calculous disorders" by A. Marcet, *Nouveau journal de médecine*, 1 (1818), 260. This source has been found and described in the following and very useful article: José Ramón Bertomeu-Sánchez, "Animal Experiments, Vital Forces and Courtrooms: Mateu Orfila, François Magendie and the Study of Poisons in Nineteenth-century France", *Annals of Science* 69 (2012):1-26.

[36] Pickstone also points at the possibility that Magendie was motivated by political reasons to adopt the phenomenon of capillarity. His important patron at the Academy, Laplace, was the contemporary authority on capillarity. Magendie's sudden incorporation of this phenomenon might therefore also be interpreted as a 'political statement', by which Magendie demonstrated his adherence to the core of the Academy of Sciences. See: J.V. Pickstone, "Absorption and Osmosis":32.

[37] J.V. Pickstone, "Vital actions and organic":192.

be wrong in assuming that the increased attention for chemistry and physics had downplayed the very centrality of this principle. This is nicely illustrated if we take a look at Anthelme Richerand's (1779-1840) famous textbook on physiology.[38] If we compare the sections on the vital force between the edition of 1820 and a subsequent edition of 1833, we see that the texts remain largely unedited and that in both cases the discussion of the vital force is included in the *prolégomènes*,[39] which suggests its importance to the theoretical framework within which physiology operated.[40]

Although the postulation of the vital force remained as necessary to physiology as gravitation was essential to astronomical calculations, Richerand simultaneously acknowledged that the laws of the physical sciences could safely be extended to the domain of the living: "This constant opposition between the vital laws, and those of physics, mechanics and chemistry, does not exclude living bodies from the experience of the latter. In the living machines [*les machines animées*], effects occur of an obvious chemical, physical or mechanical nature, only are they being influenced, modified and altered by the forces of life."[41]

Considering the earlier position held by Bichat, a development emerged in the thinking about vitalism towards a position that has been called 'material vitalism'.[42] Roughly speaking, the distinction between organic and inorganic phenomena was still left intact, but the increased use of the physical sciences in physiology caused this distinction to become much more diffuse than it always had been. Magendie, but also others, started to attribute a significant role to physics and chemistry. According to the historian José Ramón Bertomeu-Sánchez, this shifting approach shows that vitalism became more and more a methodological issue, rather than the strong philosophical 'outlook' it has always been.[43] Instead of being the impregnable fence between organic and inorganic phenomena, ideas of 'material vitalism' now served to regulate the interaction between the two, while the quest for the vital force remained the physiologists' holy grail.

It was in this environment that osmosis was introduced in 1826. Experimental physiology was a flourishing field; the physiological cabinet had just been expanded with innovative studies on absorption; and at the

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[38] Richerand, *Nouveaux Élémens de Physiologie,* 8th ed., Tome 1 (Caille et Ravier : Paris, 1820); Richerand, *Nouveaux Élémens de Physiologie,* 10th ed., Tome 1 (Béchet Jeune : Paris, 1833).

[39] The discursive introduction before Richerand embarks on the actual fruits of physiology itself.

[40] Yet, in the 1833 edition, Richerand notes that a few people began doubting the existence of this principle of life. See: Richerand, *Nouveaux Élémens* (1833):99.

[41] Richerand, *Nouveaux Élémens* (1820):92.

[42] José Ramón Bertomeu-Sánchez, "Animal Experiments": 11. Bertomeu-Sánchez on his turn refers to Temkin for this terminology. See: Owsei Temkin, "Materialism in French and German Physiology in the Early Nineteenth century", *Bulletin of the History of Medicine* 20 (1946):323-327.

[43] José Ramón Bertomeu-Sánchez, "Animal Experiments":11.

background, the search for the vital force and its effects on the living bodies still remained an issue to which many physiologists were particularly sensitive. When Dutrochet announced his discovery, osmosis entered a scientific environment in which interaction with each of these elements was possible.

1.2 Endosmose and exosmose

Born in 1776, Henri Dutrochet was about 50 years old when he published his first study on osmosis. He belonged to the same generation of physiologists as Magendie did, with Magendie only being slightly younger than Dutrochet. As a son of a noble family, he had been raised in the Touraine. In 1802 he moved to Paris to take up his medical studies, which he alternated with courses in the natural sciences at the Museum of Natural History. In 1806, he published his doctoral thesis that contained a new physiological theory of the voice. Soon after finishing his studies in Paris, he signed up as an army doctor during the peninsular war, which forced him to leave for Spain where he was put in charge of a typhus hospital in Burgos. Unfortunately, Dutrochet got himself infected with the disease and had to return to France, which forced him to terminate his military career earlier than planned. After writing several letters to the army staff, he finally got his discharge after which he spend the rest of his career in the service of physiology.[44]

Much like Magendie and most of his other contemporaries, Dutrochet believed that experimentalism was the only path leading towards a successful science of physiology. Already in his early years, Dutrochet acknowledged that however powerful theoretical ideas may be, in the end they do not enlarge the scope of our positive knowledge.[45] Observations and experimentalism were meant to fulfill this job. Dutrochet's reputation as an experimental physiologist was officially established in 1821, when he won the Montyon Prize for an anatomical study on the growth and reproduction of plants.

In another sense, Dutrochet differed however from his colleagues. A general trend that featured in his work was Dutrochet's conviction that the physiology of plants and animal physiology were in fact not two different fields. Instead, Dutrochet believed that both physiologies were not separable and should be taken together as one general physiology of life. This was an odd claim, given that many of his contemporaries still practiced the old distinction between the two.[46] A reviewer could therefore write in 1826 that Dutrochet was the only one in France who, with his studies on anatomy and

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[44] J.V. Pickstone, "Vital actions and organic":195-196; Joseph Schiller, Tetty Schiller, *Henri Dutrochet (Henri du Trochet 1776-1847) : Le matérialisme mécaniste et la physiologie générale* (Paris : Albert Blanchard, 1975):5-24.

[45] Henri Dutrochet, "Notice sur ma vie", in Joseph Schiller, *Henri Dutrochet*:79.

[46] Bichat, for example, practiced this distinction rather clearly in his *Recherches*. See Xavier Bichat, *Recherches physiologiques*:2-4.

comparative physiology, transgressed the boundary between these two "great divisions".[47] Dutrochet worked out several plant-animal analogies. He published for instance a study in 1824 – with the revealing title *Anatomical and physiological investigations into the intimate structure of the animals and the vegetal* – in which he attempted to demonstrate similarities between the nerve substance of animals and plants.[48] Yet, the very publication we are about to discuss is most probably the best example of Dutrochet joining the domains of the animal and the vegetal. After all, osmosis would appear to be a physiological phenomenon underlying both worlds.

A biographical detail of importance concerns Dutrochet's social position. He appears to have been a figure that was never fully part of its scientific community. Although he was a well-known physiologist with an established reputation, he never was able to occupy a role similar to that of Magendie in physiology. This, to some extent, marginal position is expressed in two different ways. In the first place there is the above-mentioned conviction that both plant and animal physiology should be integrated into one physiology of life. Judged to contemporary standards, this was literally an eccentric conviction, which placed Dutrochet outside the center of scientific consensus. In the second place, Dutrochet was also geographically separated from Paris, the capital of French science. By far most of his years he spent outside of Paris, at the Touraine castle *Renault*, which he inherited from his family. This meant that Dutrochet was not able to actively partake in the Parisian scientific community, and that therefore most of his career was spent in isolation. His geographical isolation should however not be interpreted as a mere disadvantage. Probably, it provided him also with the merits of scientific independence. Whereas other physiologists like Magendie were dependent on teaching positions and had (much closer) relations to nourish with the Academy, Dutrochet could fully support himself by means of his inheritance. This might explain why he could afford it to swim against the tide at times, like he did with his ideas about the unification of physiology.

Nevertheless, this all does not mean that Dutrochet never tried to enter the Academy of Sciences as a member. In a letter to his friend and naturalist Étienne Geoffroy Saint-Hilaire (1772-1844), Dutrochet wrote that he had applied for the position of corresponding member at the Academy – a position that he was awarded in 1819.[49] Furthermore, Dutrochet kept trying to enter the Academy as a full member. Whenever a position became vacant he would put himself to the fore as a candidate. In 1828, after his discovery of osmosis, Dutrochet tried to take over the membership of the naturalist Louis

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[47] Anonymous, *Le Globe, Journal Littéraire*, 11 may 1826 (Tome 3, No. 60):317.

[48] Henri Dutrochet, *Recherches anatomiques et physiologiques sur la structure intime des animaux et des végétaux et sur leur motilité* (Paris : Baillière, 1824).

[49] Dutrochet, letter to Geoffroy Saint-Hilaire, 18 May 1819, in Joseph Schiller, *Henri Dutrochet*:182. Dutrochet won the election of corresponding member with a majority of 29 votes against 17 for the German naturalist C.A. Rudolphi (1171-1832). See notes of the Schillers at page 183.

Augustin Guillaume Bosc (1759-1828) who recently passed away.[50] He lost the election. Another attempt was made with the death of Louis-Marie Aubert Dupetit Thouars (1758-1831).[51] Despite that Dutrochet continuously struggled to work himself up the ladder, at the moment he presented his discovery of osmosis to the world, he was nonetheless a correspondent of the *Academie royale des sciences* and an associate member of the *Academie royale de médecine*.

Dutrochet's discovery of osmosis might be seen as a continuous prolongation of his earlier work on plant and animal physiology. Osmosis was a phenomenon that occurred in the world of micro-physiology and in the anatomy of microscopic structures – a topic on which he had already been working in 1824 before coming across the phenomenon. It is interesting to see that in his *Recherches*, Dutrochet already sketches an interpretive framework in which his future-discovery of osmosis would seamlessly fit. He opened the book by saying that all living beings "are susceptible to certain vital modifications through the influence of certain agents that are external to them".[52] Although the book did not yet touch at the phenomenon, in 1826 it would appear that osmosis, triggered by external agents, indeed effected such vital modification in all living beings (both vegetation and animals).[53] Furthermore, the discovery of osmosis was made at the level of microstructures, respectively in those of a little fish, a little bulb of 'mold' and the little sperm sac of a snail.

It was not self-evident that Dutrochet would observe osmosis at a microscopic level. Other scientists before Dutrochet had already repeatedly reported observations of the phenomenon on a macro-level. In the nineteenth-century historical canon, these scientists were in *hindsight* heralded as the true discoverers of osmosis instead of Dutrochet.[54] But being

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[50] Dutrochet, letter to Geoffroy Saint-Hilaire, 12 June 1828, in Joseph Schiller, *Henri Dutrochet*:203.

[51] Dutrochet, letter to the president of the Academy of Sciences, 26 May 1831, in Joseph Schiller, *Henri Dutrochet*:206.

[52] Henri Dutrochet, *Recherches anatomiques*:1.

[53] Note that also Pickstone sees a contineous relation between Dutrochet's discovery of osmosis and his earlier work on plant physiology. See: J.V. Pickstone, "Absorption and Osmosis":35.

[54] Although I refrain from the perpetual discussion over priority-claims, Dutrochet's predecessors never came further than the mere acknowledgement that they had found a curious fact. Dutrochet thus, was the first and foremost to fully dive into a thorough study of the phenomenon. Whether this provides him with the honor of the discovery I do not know, but he remained the first to put the phenomenon on the scientific map, in such fashion that it proved fertile ground for subsequent nineteenth-century studies of osmosis. In the nineteenth-century canon of osmosis, the following studies were regarded as important pre-Dutrochetian milestones. Abbé Nollet, "Recherches sur les causes du bouillonnement des liquids", *Mémoires de Mathématique & de Physique* (1748):57-104; Georg Friedrich Parrot, *Ueber den Eingluß der Physik und Chemie* (Dorpat : Michael Gerhard Grenzius, 1802). Another and later predecessor of Dutrochet was N.W. Fischer, "Ueber die Wiederherstellung eines Metalls durch ein anderes, und über die Eigenschaft der thierischen Blase Flüssigkeiten

the true discoverers or not, these historical cases show at least that it was not obvious ‘where’ exactly in nature osmosis was to be found. The first of Dutrochet's predecessors was the French Abbé Nollet (1770-1770) who observed the phenomenon in 1748 by accident, while he was writing a study on the causes of the boiling of liquids. In order to keep a certain amount of *esprit de vin* (alcohol) airtight, he decided to put the alcohol in a flask which he sealed with a piece of bladder. Nollet then threw the flask in a vase filled with water to be absolutely sure that no air could reach the alcohol. After he returned five or six hours later, he was surprised to find that the bladder was bulging outwards. Pricking the bladder with a needle released a jet of liquid that reached about one foot height. After repeating this observation in a few other experiments, Nollet concluded that this curious fact could only be explained as an apparent feature of the bladder. When both water on the one side, and alcohol on the other were in contact with the bladder, the bladder prefered to lent passage to water and refused it to alcohol, which caused the increased pressure.[55] The German Georg Friedrich Parrot (1767-1852) reported a much similar experiment in 1802, with the additional and questionable remark that his liquid jet spurted to an unlikely height of ten feet.[56]

Most likely, Dutrochet had not been familiar with these studies at the moment of his discovery, and the fact that he approached his phenomenon from the microscopic world confirms this suspicion. Indeed, Dutrochet found out about osmosis while observing the tiniest of things. There is no mentioning of water jets spurting about ten feet high and he did not need bladders; instead Dutrochet was looking through his microscope when he discovered a phenomenon that bewildered him. What did he see?

In order to trace Dutrochet's observations, we need to open up the two hundred-page book in which his discovery and analysis of osmosis was precipitated. It was published about one month after Dutrochet had announced his discovery, probably on Wednesday 29 November 1826.[57] The book had the following curious and pompous title: *The immediate agent of the vital movement revealed in its nature and its mode of action in vegetation and animals.*

If we leave through the book, we find that Dutrochet first encountered osmosis in an experiment he performed with a little fish.[58] After he had cut

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durch sich hindurch zu lassen, und sie in einigen Fällen anzuheben", *Annalen der Physik und der physikalischen Chemie* 72 (1822):289-307.

[55] Abbé Nollet, "Recherches sur les causes du bouillonnement":101-103.

[56] Georg Friedrich Parrot, *Ueber den Eingluß der Physik und Chemie*:18.

[57] On 12 November, Dutrochet wrote to Étienne Geoffroy-Hilaire that his book "est sous presse & paraitra d'ici à quinze jours". See: Dutrochet, letter to Geoffroy Saint-Hilaire, 12 November 1826, in Joseph Schiller, *Henri Dutrochet*:202.

[58] Dutrochet had performed this observation already in 1809, but never attached any significance to it until now. See: Henri Dutrochet, *Mémoires pour servir a l'histoire anatomique et physiologique des vegétaux et des animaux* (Bruxelles : Meline, 1837):15.

off its tail, he placed the fish back into water while it was still alive. The next thing Dutrochet noticed was that the tail-wound of the fish began to produce moldy filaments, at each end of which had formed a little bulge that was perceptible to the naked eye. Curious why this form of 'vegetation' was growing on the fish, Dutrochet placed the filaments under the microscope to observe them more conveniently. What he then saw, took his full attention. The bulges at the end of every filament were expelling little globules with force, while the bulges themselves were not in any state of contraction whatsoever. What was happening, and what caused this expulsion of globules if it did not happen through simple mechanic contraction? After looking more closely, Dutrochet observed that at the other side of the bulge, water was entering and accumulating inside of it, which apparently pressed the globules out of the bulge like a 'syringe's piston'. The water thus substituted the globules.[59]

Dutrochet's mentioning of contraction was no loose comment, but should be interpreted in the larger context of physiological explanations provided for the movements of liquid across bodies. Already earlier, Dutrochet had expressed his discontentedness with the way physiology had solved the question of liquid movement. Thus far, the cause of the progression of the sap in plants was explained by pointing at capillarity on the one hand, and organic contractions on the other. Albeit that Dutrochet judged these causes to be plausible, he found them in no way profound enough to explain in full extent why saps and liquids were able to move through plants and animals. "The combination of these two factors probably gives a fairly plausible explanation for the movement of the sap; but this explanation has not the evidential character, which could dispel any doubts and lead to conviction."[60] With the fish-experiment however, Dutrochet had observed a movement in which contraction did not play any role at all. Instead, the introduction of water appeared to have been the force that drove the globules out of the bulge. But, so wondered Dutrochet, "where does this water come from and what pushes it into the interior of the bulge"?[61]

In order to answer these questions, Dutrochet began repeating his earlier experiment; only now by placing little bulges of mold under the microscope that were produced on death matter. Another grateful object was found in the little sperm sac of a snail. All three objects however, demonstrated the same features when placed into water, which enabled Dutrochet to come up with more general conclusions. The objects he studied (the bulges and sperm sacs) were in fact hollow cavities, the content of which could be replaced through their permeable walls. The only necessary condition was that the content had to possess a higher density than the surrounding water.

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[59] Henri Dutrochet, *L'agent immédiat du mouvement vital dévoilé dans sa nature et dans son mode d'action, chez les végétaux et chez les animaux* (Paris : Dentu, 1826):105-106.
[60] Henri Dutrochet, *L'agent immédiat*:10.
[61] Henri Dutrochet, *L'agent immédiat*:109.

> Hence, the observations of the small hollow organs show that they are endowed with the singular faculty to introduce the water, in which their surfaces bathe, with violence into their cavities and through their walls, in such way as to drive off the substances that were previously contained in these cavities. The cause of this phenomenon eludes us here, but we must note one condition that appears necessary for its production. [...] One necessary condition in determining the exercise of this physical-organic action [...] is that in the organic cavities, a body should be present that is more dense than water.[62]

After establishing these generalities, Dutrochet proceeded by giving a proper name to the phenomenon, to which he added that its very existence should be proven further by means of experience and observation.

> This physical-organic action, the observation of which is new, needs to be given a new expression. I will designate this action – in which small hollow organs are filled with a liquid that appears to be violently pushed and accumulated in their cavity – by the name of endosmosis. Observing the spontaneous operations of organic nature, which we will seek to give confirmatory, empirical evidence, proves the existence of this physical-organic, or vital action.[63]

The novel phenomenon was designated by the term *endosmose*, which derived from the Greek ενδος, 'in', and ωσμος, 'impulse'.[64] Loosely translated, endosmose thus meant something like *inward impulse*. As the name already suggests, endosmose also had an antagonist, whose movement was exactly the opposite. Every time Dutrochet performed his experiments, he saw that there was an opposite movement present that, contrary to endosmose, moved exactly the other way around, namely from the interior towards the exterior. Both movements did always take place simultaneously, urging Dutrochet to believe that endosmose was only a part of the whole phenomenon. Subsequently he introduced an expression for this opposite movement. The term *exosmose* (εξ, 'out') was used to denote the inverse movement of endosmose.[65] Osmosis, as understood by Dutrochet, was therefore a dual-phenomenon. One part of the phenomenon would never occur without the other taking place.[66]

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[62] Henri Dutrochet, *L'agent immédiat*:114.

[63] Henri Dutrochet, *L'agent immédiat*:115.

[64] Henri Dutrochet, *L'agent immédiat*:115n.

[65] Henri Dutrochet, *L'agent immédiat*:126n.

[66] Dutrochet's description of osmosis as a dual-phenomenon proved rather compelling. Nowadays, osmosis is known as a single phenomenon. It took until the 1850s and 60s before Thomas Graham and Moritz Traube would explain that *exosmose* was only due to diffusion and hence had nothing to do with osmosis. It was Thomas Graham who proposed to get rid of the term endosmose and exosmose and introduced the contemporary use of the term of

Up till here, Dutrochet had merely worked with his microscope. His experiments – if they even deserved that name – were almost entirely based on observations of miniature organic entities, which obviously did not allow for much intervention. Hence, Dutrochet decided to scale up his microscopic adventures and began to perform his experiments on osmosis in the macro-world. As we have seen, there was just one important condition for the occurrence of osmosis: the fluid or matter contained in the cavities should be of greater density (or specific gravity) than the fluids or water surrounding the cavities. If this general rule of thumb was right, the phenomenon should also occur on a macro-scale as long as this one requirement was satisfied. In a new experiment, Dutrochet took the cecum (blind gut) of a young chicken. Having the cecum filled with 190 grains of milk, Dutrochet immersed it into clean water. After 24 hours, the cecum had imbibed an additional amount of 73 grains, and after 36 hours a corresponding 117 grains of water had entered. The result must have been quite spectacular, as after 36 hours the total weight of the cecum had increased with a staggering 160 percent.[67]

Dutrochet had shown that endosmose and exosmose spontaneously occurred in organic nature, and that both solely depended upon the *integrité* of the fluids (i.e. their density or specific gravity). Nevertheless, the task that was probably the most difficult had yet to begin. Dutrochet believed that the earlier physiological explanations for the fluidal movement in plants were inadequate. According to Dutrochet, sap did not move because of capillarity, and neither was the sap in plants propelled by the contractions of the organs through which it moved. Instead, he believed that endosmose and exosmose were the underlying causes of the fluidal movement of plants. But how would Dutrochet convince his audience of this fact? What experiment or argument could possibly bear the necessary persuasiveness by which Dutrochet could demonstrate that endosmose was in fact the mere engine behind the vital movements of sap in plants? The solution was surprisingly simple. Dutrochet developed an experiment that was analogous to 'the real thing'. By literally imitating nature *in vitro*, he was able to bridge the gap between his experimental findings and the actual vital movements in the actual plants. Let's find out how it worked.

Dutrochet took a glass tube – 60 cm long and 5 mm in diameter – and fixed a cecum of the chicken to one of its open ends. The cecum was filled with a solution of gum Arabic. The whole thing was, with the cecum beneath, plunged into rainwater and supported in a vertical position. The results were

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osmotic force. Graham and Traube explained Dutrochet's observation of two currents as nothing more than a fallacy of the membranes he employed. With Traube's invention of the chemically engineered membrane these fallacies were overcome and only endosmose (osmose) remained present in the new experiments. See: Thomas Graham, "The Bakerian Lecture - On Osmotic Force", *Philosophical Transactions of the Royal Society of London* 144 (1854):177-228; Moritz Traube, "Experimente zur Theorie der Zellenbildung und Endosmose", (pub. 1867), in *Gesammelte Abhandlungen* (Berlin : Mayer und Müller, 1899):213-277.

[67] Henri Dutrochet, *L'agent immédiat*:115-116.

most clear. After twenty hours, the rainwater had ascended into the tube, even to such extent that it started flowing over the top of the tube. Dutrochet repeated the experiment several times, and began using different membranes. The results remained similar, proving that the cecum of the chicken, the bladder of a carp and also the inflated pod of Bladder Senna (Colutea Arborescens) could be used interchangeably. An interesting coincidence of Dutrochet's employment of different membranes is that it proved that endosmose was not only confined to the vegetal domain, but also extended to the animal domain.[68] In other words, endosmose occurred indiscriminately in both the animal and vegetal kingdom, and was therefore additional evidence for Dutrochet's claim that 'the science of life was one'.[69]

The similarities between the experiment and the plant's physiology were striking. In the experiment, the glass tube imitated the vessels through which the sap ascends, while the rainwater simulated the plant's natural environment. But how could Dutrochet so rigorously substitute the plant's vessel for a plain glass tube? Simply, because he just believed that vessels were indeed nothing else than plain tubes. Dutrochet believed that the movement of sap was not caused by contractility, while earlier he had argued that vessels did not possess any valves to favor the movement of the sap.[70] The plant's vessels were in fact nothing else than plain tubes to Dutrochet. Both the vessels and the glass tube were straight, rigid and did not contain any valves. The analogy was complete, and the experiment served as a rightful model to prove that the plant's fluidal system could indeed be described by osmosis. This very experiment and the model Dutrochet built proved to be the first prototype of a series of *endosmometers*. These instruments would be frequently employed in osmotic experiments, not only by Dutrochet, but also by many others during the remainder of the nineteenth century.[71]

But what was the nature of osmosis itself? Curiously enough, Dutrochet came to believe that endosmose was the result of a certain electrical action.[72] This might seem strange at first sight, but motivated after reading a 'very curious experiment' by the English amateur chemist Robert Porrett (1783-1868), Dutrochet believed that there was more than enough evidence in favor for an electrical explanation of his phenomenon. In an article published in 1816, Porrett demonstrated that it was possible to force water to move through a membrane, simply by applying electricity to it. In this particular experiment, water flowed from the positive pole at one side of the membrane, towards the negative pole at the other side, resulting in a

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[68] Henri Dutrochet, *L'agent immédiat*:130-132. Compare: 188.

[69] "[L]a science de la vie est *une*". Henri Dutrochet, *L'agent immédiat*:V.

[70] Henri Dutrochet, *L'agent immédiat*:14.

[71] One such meter still survives in the Boerhaave Museum in Leiden, the Netherlands. (Catalogue number: V28601.) Probably, this particular item was used by the Dutch chemist Tjaden Modderman. He wrote his doctoral dissertation on osmosis in 1857. See: Tjaden Modderman, *De leer der osmose* (Leeuwarden : Suringar, 1857).

[72] Henri Dutrochet, *L'agent immédiat*:133.

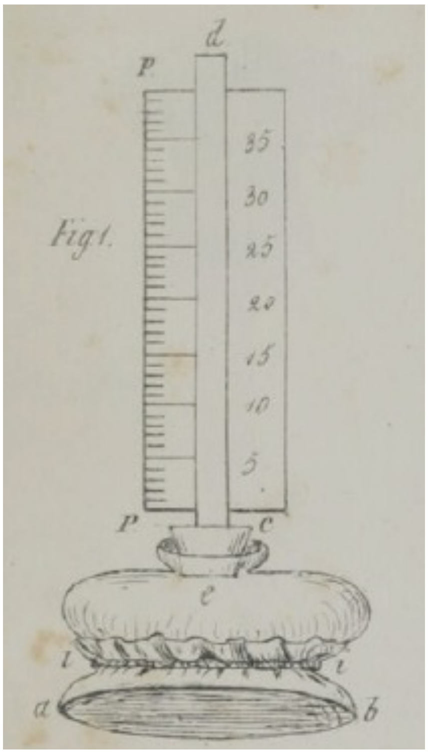

Figure 1: One of Dutrochet's endosmometers. Note the measuring staff to enable accurate results. (Source: Dutrochet, Nouvelles Recherches sur l'Endosmose et l'Exosmose *[etc.] (Paris :Bailliere, 1828).*

difference between the water levels at the two sides of the membrane.[73] It is therefore no surprise that Dutrochet found a stunning analogy between his and Porrett's experiments. After all, both observations of the moving liquids were very similar, with the only exception that Porrett applied an electrical current. Hence, Dutrochet believed that Porrett had revealed the underlying nature of his phenomenon. Porrett's experiment showed that osmosis was electrical in nature. I.e. the vital movements in both animal and vegetal physiology were caused by electrical action.

But where did the electricity come from? In the case of Porrett this was clear: he used a 'little battery' to perform his experiments. But Dutrochet had to look elsewhere for the source of electricity. To find the answer, he took the analogy with Porrett's experiment to a higher level. In the case of the latter, the water moved because both sides of the membranes were charged differently. This, according to Dutrochet, implied that the same was true for the membranes in animal and vegetal life. The globules, or vesicles in physiology appeared therefore to be little *Leyden jars* [bouteille de Leyde], which were charged oppositely at the in- and outside, and eventually gave rise to osmosis. In the case of the inwards movement of endosmose, Dutrochet argued that each "of these vesicles is therefore a little *Leyden jar*, negatively electrified at the inside and positively at the outside."[74] Exosmose was simply its inversion.

Other support for Dutrochet's electrical explanation was found in an experiment of Becquerel.[75] The latter had found that electrical currents intensified when the temperature increases. According to Dutrochet this result was in full harmony with his own findings, in which the intensity of osmosis also increased when the temperature raised. The findings of Porrett,

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[73] R. Porrett, "Curious Galvanic Experiments", *Annals of Philosophy* 8 (1816):74-76.

[74] Henri Dutrochet, *L'agent immédiat*:140.

[75] A proper reference is lacking, but probably Dutrochet referred to an article by Antoine César Becquerel (1788-1878) – the first of the four Becquerel generations – that appeared in 1823. See: Becquerel, "Du Développement de l'électricité par le contact de deux portions d'un même métal, dans un état suffisamment inégal de température [etc.]", *Annales de Chimie et de Physique* 23 (1823):135-154.

as well as those of Becquerel therefore led Dutrochet more and more to believe that osmosis, on its turn, was a manifestation of electricity.[76]

1.3 Getting the hopes up

We began this chapter by wondering why Dutrochet's discovery immediately caught the attention of the Parisian scientific community. Part of the answer must be sought in the way Dutrochet presented his findings to the outer world. Quite revealing in this respect is the title Dutrochet chose to accompany his book: *The immediate agent of the vital movement revealed in its nature and its mode of action in vegetation and animals.* This title could be decomposed into two specific elements, of which each tells us a different story about how Dutrochet saw his discovery in the larger context of scientific ideas and achievements. In first place, the title talks about an 'agent', which, secondly, gets assigned the property of being 'immediate' with regard to the vital movements in vegetation and animals.

The agent of which Dutrochet talks about is the phenomenon of osmosis. An agent is generally understood as something with a mediating function, meaning that osmosis acted 'on behalf' of something else. It is exactly this agency of osmosis that places Dutrochet's discovery straight into the contemporary debate on vitalism. This might seem strange if we consider that Dutrochet applied a rather straightforward physical approach in his analysis of osmosis. Did we not see that ideas of vitalism acted in order to keep the domain of the inorganic world, i.e. physics and chemistry, strictly separated from the domain of organic world? Moreover, Dutrochet repeatedly referred to osmosis as being a *physical-organic* action, which seems to complicate his attitude towards vitalism even more, especially when he also frequently chose to equate this physical-organic action with another term: the *vital action*.[77]

These questions are urgent, but the tension could be released as soon as we take a closer look at the meaning behind the agency of osmosis. The two domains that were formally separated by vitalism were still left intact by Dutrochet, but he placed osmosis straight on the border between those two, in such way that it was through osmosis that both the physical world and the world of the living were able to intersect each other. Osmosis was the agent that established the connection between physics and life. Hence, the term *physical-organic action* was not a mere contradictio in terminis, but exactly the very designation of the agency of osmosis.

Since Magendie proposed the existence of the vital force in 1809, physiologists had always been aware of the centrality of this force to their field. Like its physical brother, gravitation, the nature of the vital force (the principle of life itself) could never be grasped or elucidated; but one could at

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[76] Henri Dutrochet, *L'agent immédiat*:156.

[77] Among others: Henri Dutrochet, *L'agent immédiat*:114, 115, 168, 188 etc.

least try to approach it by studying its material manifestation through the effects it had on life. With the later elucidation of the mechanism of absorption, Magendie believed that he had found one such effect of the vital force. Yet, with his discovery of osmosis, Dutrochet claimed to have penetrated even deeper into the effects of the vital force. Even more than absorption, osmosis was a vital phenomenon too – a phenomenon that was constituted by the ungraspable vital force itself.

It goes without saying that Dutrochet made abundant use of the physical sciences in his physiological analysis of osmosis. His electrical explanation of the osmotic nature serves probably as the best example of his far-reaching dependence on physics. Judged from this perspective, Dutrochet's study is therefore a fine illustration of the ongoing march of physics and chemistry into the field of physiology. Nonetheless, Dutrochet also feared that he might invoke irritation among his fellow physiologists with his rigorous implementation of physics. In the preface to his *l'Agent*, he is therefore at pains to defend himself against possible accusations of being 'anti-vitalist', or of 'arming materialists' with fresh ammunition. The mysterious source of life, and the domain of the soul (i.e. that where the vital force comes from) were inaccessible, and could not be grasped by any scientific investigation whatsoever. Both morality and religion needed therefore not to be afraid that his study of osmosis would support claims of materialism. However, what could be investigated were the agents through which the soul worked. Osmosis in this case, was such an agent. According to Dutrochet, his study was thus all but an attack on vitalism or religion. He even employed the old metaphor of the book of nature to prove his point.[78] To ascend to the knowledge of vital mechanisms, only meant to increase the knowledge of nature's author.[79] Not only did Dutrochet prove here his adherence to contemporary ideas of vitalism, it also illustrates the deep-seated connection of osmosis with the 'mysterious' and 'secret' source of life.

The second element in the title reveals why Dutrochet thought to have touched upon something very fundamental with his discovery of osmosis. We have seen that he connected osmosis, through its agency, with the most fundamental force possible in physiology, but he could not do so without the recognition that osmosis also had to fulfill a fundamental role at the other, *physico*-side of the equation. The title spoke of osmosis as the *immediate* agent of the vital movements in vegetation and animals, and Dutrochet had good reason to call it such. In the first place, he, and others with him, believed that he had brought a series of physiological questions to an end that were all concerned with the elucidation of the mechanisms and routes by which liquids proceed in living entities.[80] An English review of *l'Agent* shed some

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[78] See for an insightful study into this metaphor: Eric Jorink, *Reading the Book of Nature in the Dutch Golden Age, 1575-1715* (Leiden : Brill, 2010).

[79] Henri Dutrochet, *L'agent immédiat*:V-VIII.

[80] Henri Dutrochet, *L'agent immédiat*:9-11.

light on the background against which Dutrochet's analysis should be interpreted.

> The microscopic inquiries of Grew, Malpighi, Leuwenhoek [sic], Hill, Hedwig, Mirbel, Link, Rudolphi, Kieser, and others, have satisfactorily elucidated the structures of plants; but, notwithstanding the correct knowledge of the vegetable organs which these have afforded to us, and the light thrown upon their functions by the labours of Du Hamel, Linnaeus, Sarrabat, Bonnet, Ingenhouz, Darwin, and Mr. Knight, *we were still ignorant of the exact path by which the sap ascends in plants, and of the causes of the progression of this fluid.*[81] [My italics]

The discovery of osmosis thus offered novel explanatory grounds to definitively tackle the debate about vital movements that already had been in place since the days of Carl Linnaeus (1707-1778). We already saw that Dutrochet did away with the unsatisfactory hypothesis of the contractility of the organs by which vital movements had formerly been explained. Contractility was however not the only hypothesis overthrown by Dutrochet. Another explanation for the vital movements had always been sought in capillarity. These two hypotheses were now substituted by osmosis, which in fact provided a much simpler explanation for vital movements and even allowed for a straightforward and measurable in vitro replication. The fact that osmosis could explain these movements turned it simultaneously into an essential phenomenon that immediately constituted a wide range of physiological functions.

One of the physiological functions it could explain was that of the secretion of fluids. Dutrochet had noted that the membranes that invoked osmosis, in fact acted as chemical filters, meaning that these membranes were able to "let only pass molecules of a certain nature". He contrasted this with the mechanical filter, which only filtered particles according to their size.[82] With this concept in hand, Dutrochet could now explain why the kidneys selectively secreted urea from the blood into a person's urine, hereby commenting on an investigation of Pierre Prévost (1751-1839) and Jean-Baptiste Dumas (1800-1884) who a few years earlier had analyzed the pathway of urea.[83] Along the same line of reasoning, Dutrochet also argued that osmosis was responsible for the uptake and circulation of nutrition in the body, not quite accidently one of Magendie's main areas of focus.[84] Because the uptake of nutrition by the vesicles appeared to occur selectively,

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[81] Anonymous, review of *L'Agent du Mouvement Vital dévoilé dans sa Nature et dans son Mode d'Action chez les Végétaux et chez les Animaux* by Dutrochet, *The Foreign Quarterly Review* 1 (1827):214-215.

[82] Henri Dutrochet, *L'agent immédiat*:174.

[83] Prévost, Dumas, "Examen du sang et de son action dans les divers phénomènes de la vie", *Annales de Chimie et de Physique* 23 (1823):50-68; Henri Dutrochet, *L'agent immédiat*:215.

[84] Henri Dutrochet, *L'agent immédiat*:218.

it could not be explained by the mere undiscriminating mechanism of absorption. "The walls of these vesicles are real chemical filters, which, under the influence of an electric current, transmit and modify, certain specific elements from the nutritional fluid."[85]

Dutrochet thus replaced former physiological explanations for the vital movements with osmosis, and simultaneously showed the importance of this phenomenon to some rather basic constituents of life. But, and it is here that we probably find the best illustration of the presumed fundamental and immediate character of osmosis, at the very moment Dutrochet rejected capillarity as a possible explanation of the vital movements, he also had to break open the close bond that Magendie previously forged between capillarity and absorption. If capillarity was no longer a viable candidate to explain vital movements, what consequences did this have for Magendie's absorption-case?

Not surprisingly, Dutrochet argued that osmosis, instead of capillarity, lied at the basis of absorption. Apart from the scientific reasoning behind this decision, it was also a very tactical move. Magendie's authority in the field of experimental physiology, together with the established importance of absorption, made that Dutrochet hopped on a well-riding train. The physiological importance of absorption was generally accepted, and now Dutrochet claimed to have revealed its real, underlying cause while he could reject capillarity as its senseless alternative.

> Absorption is absolutely independent of capillarity, it is only endosmose that operates [...] We have seen that the absorption in plants is not the result of capillary attraction, but that the introduction of a liquid from the outside to the inside depends entirely on endosmose; it is the same in animals.

A little later, while becoming more personal towards Magendie, Dutrochet continued:

> But it seems to me that the celebrated physiologist went too far in the deductions from his experiences, when he thought he could conclude that absorption is simply the result of capillary action.[86]

Time still had to decide whether Dutrochet was right at this point. Far more interesting was however, that Dutrochet had implicitly started a debate with Magendie on the fundamental character of absorption and osmosis. Dutrochet had restructured the framework in which absorption was embedded, and hence forced Magendie to respond to his claims. The latter could not fail to react on Dutrochet's discovery, which, as we will see, indeed

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[85] Henri Dutrochet, *L'agent immédiat*:216.

[86] Henri Dutrochet, *L'agent immédiat*:177, 211.

happened the very moment osmosis was officially introduced at the Academy.

Osmosis did not enter a sterile scientific environment. Dutrochet's analysis of the phenomenon, which seem to have been carefully composed, generated much opportunities and novel insights that in one way or another led back to many contemporary scientific and physiological ideas shared by him and his colleagues. Take for instance Dutrochet's claim that he had discovered the immediate agent of life: regardless that most people would respond negatively to this claim, at least it resonated with their ideas of vitalism – ideas that in principle allowed for such claims to be made. Indeed, as appears in the reviews that followed upon the publication of *l'Agent*, people did take Dutrochet's claims seriously. Two reviewers even remarked that the 'promising' title of Dutrochet's book – *the immediate agent of the vital movement* – had "excited the curiosity and even the interest of the public".[87]

The reviewers agreed nonetheless unanimously that the idea of osmosis as the immediate agent was one bridge too far. Although it helped Dutrochet getting the attention he wanted, his audience was not willing to follow him here. They even noted somewhat ironically that Dutrochet might have promised a little too much in the title of his new book.

> Many centuries have passed since the wise men began looking for the vital principle, it would indeed be time to reveal it: *mais, hélas!* I must admit that I arrived at the end of Mr. Dutrochet's work without having found it.[88]

Nonetheless, they praised with even greater enthusiasm the precision and strength of Dutrochet's analyses of osmosis and the exceptionally high quality of his experiments, which they did not eschew to describe as 'ingenious' and 'inventive'.[89] In brief, Dutrochet's discovery got lots of attention. Some scientists were open to accept Dutrochet's suggestion that osmosis was a basic constituent of life, among whom the celebrated Georges Cuvier (1769-1832).[90] Others were merely surprised and fascinated by the fact that electricity, the direct cause of osmosis, apparently played such an important role in human physiology.[91] One thing could at least be taken for

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[87] V. [Probably Velpeau], review of *L'Agent immédiat du mouvement vital* by Dutrochet, *Archives Générales de Médicine*, Tome 14 (1827):477; Gaultier de Claubry, "Mouvement Vital":76.

[88] V. [Velpeau?], review of *L'Agent*:477.

[89] Gaultier de Claubry, "Mouvement Vital":80.

[90] Cuvier, "Analyse des travaux de l'Académie pendant l'année 1826", *Memoires de l'Académie des Sciences de l'Institut de France*, Tome 9 (Paris : Firmin Didot Frères, 1830):cxi-cxiii. See also the report that followed one year later: Cuvier, "Analyse des travaux de l'Académie pendant l'année 1827", *Memoires de l'Académie des Sciences de l'Institut de France*, Tome 10 (Paris : Firmin Didot Frères, 1831):cxxxi.

[91] Curiously enough, this element was very prominent in the many reviews and discussions that appeared on Dutrochet's discovery. See: Anonymous, "Sur l'impulsion électrique qui se

granted: osmosis had entered the scientific arena. In the coming years, osmosis would become a frequent topic of discussion at the French Academy, while it also invaded the international scientific community.[92] But was it enough to unleash a revolution in the medical sciences, as one reviewer put it?[93]

Without doubt, Dutrochet managed to grasp the attention of his colleagues at the Academy, and in many cases, his introduction of osmosis was appreciated as a welcome and valuable contribution to the field of experimental physiology. And yet, not everything was so bright and positive. Dutrochet's devotion to clear a space for osmosis in the ontological web of scientific phenomena, proved to be devotion at the expense of absorption. With the arrival of another liquid phenomenon, absorption's monopoly in the field of physiology was no longer self-evident. The seed for a controversy was planted.

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manifeste lors du rapprochement de deux liquides de densités différentes", *Nouveau Bulletin des Sciences par la Societé Philomatique de Paris* (1826):182-183. Anonymous, "Mouvement des liquides dans les végétaux attribué a l'électricité", *Archives Générales de Médicine*, Tome 12 (1826):643-645.

[92] G. Magnus, "Ueber einige Erscheinungen der Capillarität", *Annalen der Physik und Chemie* 86 (1827):153-168; Joseph Togno, "Experiments to prove the Existence of a Peculiar Physico-organic Action, inherent in Animal Tissues, called Endosmose and Exosmose", *The American Journal of the Medical Sciences* 4 (1829):73-91.

[93] Gaultier de Claubry, "Mouvement Vital":80.

2. A Strive for Acknowledgement

On Monday 30 October 1826, the Academy of Sciences gathered for its weekly meeting. As always, it was a rather formal procedure, at which many of the Academy's full and eminent members were present. Among the 52 members who joined in on this particular event were: Geoffroy Saint-Hilaire, Arago, Gay-Lussac, Ampère, Poisson, Laplace, Cuvier, Legendre, Magendie and Lamarck. The desk of the president and the vice-president was littered with papers, documents and other correspondence that had been sent to Paris from all over France. After the session was opened, the minutes of the week before were read, and all incoming correspondence was reported upon. Yet, the most important part of the meeting had still to begin. As usual, the agenda revolved around the reading of mémoires on recent scientific achievements. This part was open to both members and non-members, and considering the existence of a long waiting list for these presentations, we could say that it was truly an honor if someone was allowed to disclose his latest findings at the gathering.[94] On this particular day, it was Dutrochet who presented his mémoire on the discovery of osmosis, which was called: *Investigations into the progression of sap in plants and the causes hereof.*[95] During his presentation, Dutrochet talked about his encounter with the little fish, and the snail's sperm sac. He talked about his subsequent discovery that low-density liquids, if separated by a membrane, tend to flow towards their denser counterparts. He proposed endosmose and exosmose as the new terminology for this novel phenomenon, and finally revealed his arguments to regard electricity as its direct cause.[96]

Dutrochet's presentation was followed by a discussion, in which many of the Academy's prominent scientists took part. Although the discussion had a mild and friendly character, in fact it stood at the cradle of a controversy over osmosis. The aim of this chapter is to follow and analyze this controversy, and to reveal how Dutrochet dealt with this unforeseeable situation.

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[94] Maurice Crosland, *Science under Control : The French Academy of Sciences 1795-1914* (Cambridge : CUP, 1992):76-79.

[95] Académie des Sciences. *Procès-Verbaux des Séances de l'Académie*, Tome 8, Années 1824-1827 (Hendaye : Imprimerie de l'Observatoire d'Abbadia, 1918):449.

[96] Anonymous, *Le Globe, Journal Littéraire*, 2 November 1826 (Tome 4, No. 35):182-183.

2.1 The discussion at the Academy

After Dutrochet finished reading his mémoire, the first person to take the floor was Magendie.[97] He complimented Dutrochet with his very curious findings and noted that he would be delighted to repeat the experiments together with him. Considering the remarks that followed, these compliments probably did not come straight from the heart. Magendie continued his small speech by raising serious doubts about the novelty of Dutrochet's phenomenon. According to Magendie, the latter's phenomenon approached very closely the phenomenon of imbibition (i.e. absorption), whose mechanisms were already unraveled for quite some time. Imbibition was caused by capillarity and depended on the porous texture of the membranes that naturally invoked the fluids to move through it. Given that Dutrochet's phenomenon resembled these phenomena of imbibition and absorption in virtually every aspect, Magendie remained reluctant in believing that osmosis was caused by electricity rather than by capillarity. This criticism seems to have been cautiously delivered, but another contemporary source portrays Magendie in a much more outspoken fashion. "M. Magendie noted that the double law which Dutrochet announced as new, is reducible to what is commonly called *capillarity, imbibition, absorption* and *exhalation*, and the rest of the similar experiments have already been published by Fodéré [sic]".[98]

Magendie, the heralded expert on physiological fluid phenomena, thus subjected osmosis to the reign of absorption, imbibition and capillarity, and refused to regard osmosis as independently operating from these phenomena. At most, Dutrochet's experiments provided additional proof that simply reinforced the correctness of Magendie's and Foderà's earlier studies.[99]

Quite unexpectedly however, another member of the Academy, André-Marie Ampère (1775-1836) mingled into the discussion. Unlike Magendie, he was no physiologist but a physicist, who, during the 1820s, had been busy developing his electrodynamical theories. Probably, his interest in the discussion had been triggered by the electrical explanation Dutrochet gave for the phenomenon. Ampère's support for Dutrochet did however not consist of a direct defense of this explanation. Rather, he chose to lay bare a weak point in Magendie's argumentation. According to Ampère, there was one crucial difference between Dutrochet's phenomenon and capillarity. Whereas osmosis was able to propel a fluid such, that it ascended a tube and

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[97] My account of the discussion is mainly based on an extended report of the meeting that appeared in: *Le Globe* (Tome 4, No. 35):182-183.

[98] Anonymous, "Sur la marche de la sève dans les végétaux", by Dutrochet. Mémoire read at the Académie 30 October 1826, *Bulletin des Sciences Naturelles et de Géologie,* Tome 9 (1826):337.

[99] J.V. Pickstone, "Absorption and Osmosis: French Physiology and Physics in the Early Nineteenth Century", *The Physiologist* 20 (1977):34.

continuously kept flowing over its top, capillarity could only ascend the tube while it evidently stopped at a certain point. "Capillarity may well determine the elevation of a liquid up to the highest part of a tube, but it will never produce the continuous flow of the liquid; if it were otherwise, perpetual motion would be found."[100]

At this point, the mathematician Siméon Denis Poisson (1781-1840) rose from his seat to express his discontentedness with Ampère's defense. Contrary to what the latter claimed, Poisson argued that capillarity could as well suffice in explaining Dutrochet's observations. According to Poisson, the capillary tubes were in some cases able to determine the flow of the liquids in which they are immersed. By means of calculations, the circumstances could be analyzed under which such results might be produced. However, ordinary, everyday experiences provide us already with the truth of these assertions; "there is no one who does not know that you can empty a cup of coffee with a piece of sugar".[101] A few weeks later, Poisson's argument would appear in full detail in Magendie's journal, and by 1831 Poisson published a three hundred-page book that contained a whole new theory of capillary action.[102] Although there is no strict evidence to support this claim, it would not be far-fetched to believe that Dutrochet's discovery had revived the scientist's interest in the very phenomenon.

The story however continues. Ampère stood up and remarked that, despite Poisson's assertions, he still did not agree with him. It might indeed be possible that capillarity played a partial role, but the facts were still far from conclusive. This time, Ampère mobilized an authority to reinforce his argument. The 77 years old mathematician Pierre-Simon Laplace (1749-1827), who was also present at the meeting, was the current leading expert on capillarity since he had published a new theory of capillary action in 1805.[103] Ampère assured his audience that only his argument was in full harmony with Laplace's *true* theory. Laplace on his turn, endorsed Ampère and Dutrochet, and agreed that the intensity with which osmosis occurred, could never be explained by mere capillarity. Finally, Dutrochet wrapped things up and promised that his book (*l'Agent immédiat*), which at that time had not yet been published, would provide new insights and facts that conclusively would show that capillarity had nothing to do with osmosis. Hereafter, the discussion was closed.

During the discussion at the Academy, Dutrochet's discovery gave rise to mainly two problems. Although these problems were still in a premature

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[100] *Le Globe* (Tome 4, No. 35):183.

[101] *Le Globe* (Tome 4, No. 35):183.

[102] Poisson, *Nouvelle Théorie de l'Action Capillaire* (Paris, 1831). Dutrochet also mentions this work of Poisson: Henri Dutrochet, *Mémoires pour servir a l'histoire anatomique et physiologique des vegétaux et des animaux* (Bruxelles : Meline, 1837):48.

[103] Pierre Simon de Laplace, *Traité de Mécanique Céleste,* Tome 4 (Paris : Courcier, 1805), *Supplément au dixième livre*:1-79. See also: Roger Hahn, *Pierre Simon Laplace, 1749-1827 : A Determined Scientist* (Harvard : HUP, 2005):162-167.

stage, they would become much more articulated along the way, and significantly shaped the controversy that soon was to follow. In the first place there was the problem of Dutrochet's explanation. As appeared during the discussion, people simply did not want to adopt electricity as an explanation for Dutrochet's physiological curiosity. Capillarity on the other hand, was thought to be a much more plausible explanation, despite the critical remarks of Ampère. The irony of this whole situation was however that, contrary to the negative reception at the Academy itself, the tone of the many reports that appeared *about* the meeting was more positive with regard to the original explanation. Many cited the electrical explanation of Dutrochet as his most remarkable and curious finding, which gave rise to one-liners such as: *The movement of liquids in vegetation attributed to electricity*.[104] Nevertheless, Dutrochet was still largely disappointed. He wrote in his autobiographical notes that his electrical theory was 'generally repudiated' by his fellow-physiologists.[105]

The second problem that became prominent during the controversy followed directly from Magendie's critical remark that osmosis was no new phenomenon at all. Magendie believed that Dutrochet's observations could also be explained by employing already known and familiar phenomena such as absorption and imbibition. Others picked up this argument and elaborated it during the controversy, after which it soon evolved into the standard answer with which Dutrochet's supposed discovery was waived away.

One might wonder why people were so reluctant in believing that Dutrochet had stumbled across a novel phenomenon. The first answer must be sought in a rather simple political motive, namely that of priority. Magendie as well as Foderà had just discovered and described the crucial physiological phenomenon of absorption for which they claimed priority. Nevertheless, with the discovery of osmosis a significant competitor emerged that not only explained the physiological properties that first belonged to the monopoly of Magendie & Co, but which also was thought to exactly constitute this very phenomenon. The reaction of Magendie during the discussion could therefore be explained as a straightforward defensive move to safeguard his own discovery and priority.

In the second place however, something different was at stake. With osmosis fresh on stage, there was a whole series of liquid phenomena available which were all believed to explain the same sort of physiological problems. Although there is no clear indication that people were actually confused, at least they had a hard time differentiating between these different phenomena. The liquid phenomena of absorption, capillarity and osmosis were still in the process of being investigated, and it is not difficult to

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[104] Anonymous, "Mouvement des liquides dans les végétaux attribué a l'électricité", *Archives Générales de Médicine*, Tome 12 (1826):643.

[105] Henri Dutrochet, "Notice sur ma vie", in Joseph Schiller, Tetty Schiller, *Henri Dutrochet (Henri du Trochet 1776-1847) : Le matérialisme mécaniste et la physiologie générale* (Paris : Albert Blanchard, 1975):87.

see that the conceptual comprehension of these phenomena was constantly shifting. The best example in this case is the fact that Poisson published a whole new mathematical theory on capillarity in 1831. In other words: the scientific ontology in which these phenomena were embedded was in motion, while the conceptual understanding of the liquid phenomena remained fluid itself. This explains, at least to some extent, that people took capillarity to explain osmosis, even when this meant that the very extremes of this phenomenon had to be stretched in order to include osmosis. Hence, at the Academy-discussion, Magendie, Poisson, Ampère and Laplace were thus actually arguing about the properties and limits of capillarity, and about whether or not there were significant constraints available that should prevent the incorporation of Dutrochet's observations under the same denominator.

It also worked the other way around. Osmosis was all but fully understood, which on its turn enhanced the possibility to interpret it flexibly and to apply it to a wider variety of physiological problems. A curious example in this case is provided by some Anglo-Saxon studies on osmosis, in which osmosis was applied to the physiological function of respiration.[106] According to a later study, this showed "how embarrassing our position may be, when we assume the identity of phenomena that may have some vague points of resemblance".[107]

In any case, Dutrochet recognized that the liberal usage of familiar concepts by his peers proved to be the main obstacle that prevented osmosis to be taken seriously as a phenomenon *sui generis*, i.e. a phenomenon in its own right.[108] When Dutrochet, in a later phase in his career, reflected on the initial reception of osmosis, he saw in it a beautiful lesson about the inner workings and pitfalls of science.

> We are naturally inclined to admit that what is observed, is related to what we already know; but philosophical minds warn us against this trend that we have to define nature in the narrow circle of what we know [...] These reflections naturally apply to the discovery of endosmose. When I discovered this phenomenon, people hastened to consider it as the result of some phenomena of mixing and the previously known capillary action. [But, the] full explanation eluded us.[109]

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[106] J.K. Mitchell, *On the Penetrativeness of Fluids* (Philadelphia, 1830). Also published under the same title in *The American Journal of the Medical Sciences* 7 (1830): 36-66. Furthermore: E. Faust, "Experiments and Observations on the Endosmose and Exosmose of Gases, and the Relation of these Phenomena with the Function of Respiration", The *American Journal of the Medical Sciences* 7 (1830):23-35.

[107] Martyn Paine, *Medical and Physiological Commentaries,* Volume 1 (New York : Collins, Keese & Co, 1840):684-685.

[108] Henri Dutrochet, "Notice sur ma vie", in Joseph Schiller, *Henri Dutrochet*:96.

[109] Henri Dutrochet, *Mémoires pour servir a l'histoire*:13.

As scientists, Dutrochet explained, we often turn hastily to familiar concepts to explain the unfamiliar, without leaving open the possibility that something genuinely new has entered the stage. This is what Dutrochet's strive for acknowledgement meant: to convince the scientific community of the genuine novelty of osmosis.

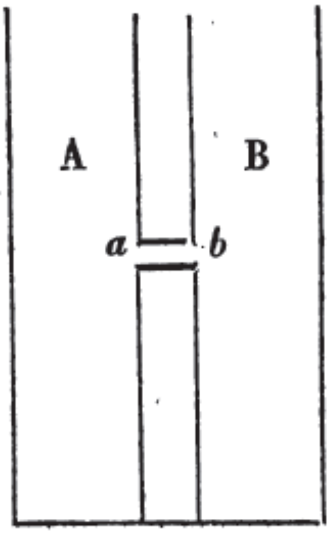

Figure 2: Poisson's thought experiment. (Source: Poisson, "Note sur des effets": 361.)

2.2 The maturation of the controversy

The first challenge for Dutrochet came in the form of an article published by Poisson. This article was the follow-up of the argument he raised during the Academy discussion, in which he claimed that Dutrochet's observations could as well be explained by capillarity. It was Magendie who had arranged for its publication in the *Journal de Physiologie*, of which he was the editor.[110]

The main argument in the article went as follows. Suppose that the membranes in Dutrochet's observations are actually pierced with little, horizontally placed capillary canals, represented by the letters ‘a’ and ‘b’ in Figure 1. Suppose furthermore, that the membrane is placed vertically into a container filled with liquid ‘A’ and ‘B’, such that it separates them. In the case that the liquids have different capillary-properties, it will follow that only the liquid that demonstrates the highest capillary action will be able to occupy the capillary canals in the membrane entirely. Hence, only this liquid will flow through the membrane after which it accumulates at the other side, which increases the pressure. The process will continue until the pressure has built up to such levels, that it sufficiently counters the initial capillary action, after which the whole process will come to an end.

The interesting thing about the article was however, that it contained no experimental data. Poisson thus presented an alternative explanation for osmosis in the form of a though-experiment. He recognized that the lack of experimental evidence was a weak spot in his argument, and he therefore declared that his only goal was to see whether an explanation of Dutrochet's observations was *possible* without an appeal to electricity. "I have not claimed, however, to assign to it [osmosis] a cause exclusive from all others, and neither did I give it a sufficient explanation", Poisson stated at the end of

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[110] Poisson, "Note sur des effets qui peuvent être produits par la capillarité et l'affinité des substances hétérogenènes", *Journal de Physiologie experimentale et pathologie*, Tome 6 (1826):361-365. The note was being republished the next year in the *Annales de Chimie et de Physique*, Tome 35 (1827):98-102.

his article.[111] Nevertheless, despite his apparent modesty, Poisson's argument got wider attention. Most people came to see it as the better alternative to Dutrochet's electrical explanation, and it would not take long before Poisson's argument became intimately connected to Dutrochet's discovery of osmosis. Whenever osmosis would be discussed in the following years, most often Poisson's capillary explanation was named instantly as if it were an official amendment to Dutrochet's theory.[112]

The first response came next year. Early in 1827, Jacques Frederic Saigey (1797-1871), a well-known mathematician, published a review on Poisson's argument.[113] He was one of the few who regarded the latter's capillary explanation with skepticism, although he was convinced that with a few adaptations, it still appeared that it "reduced [the importance of] the observations of Dutrochet".[114] Saigey disagreed with Poisson that it were the capillary properties of the liquids that caused the flow. He argued instead that it was the very texture of the liquids that accounted for Dutrochet's observations. If, for instance, we take a solution of gum arabic, or a solution of albumen (egg-white), "the texture of these substances will oppose their passage through the membrane canals, and the phenomenon is confined, in this case, to the imbibition of substances B by liquid A".[115] Put simply: one liquid flows through the membrane, and the other does not due to its texture. It is remarkable that Saigey chose to discuss the very examples of gum arabic and albumen, since they also served as Dutrochet's favorite substances in his osmotic experiments. Dutrochet featured gum arabic and albumen frequently in his book *L'agent*, and likewise he had been talking about the osmotic properties of these substances at the Academy meeting of 30 October.[116] Saigey therefore implicitly provided a novel explanation for Dutrochet's findings, which contrary to that of Poisson, did not bear the character of an abstract thought-experiment, but attacked Dutrochet's theory by aiming at a very concrete and particular piece of evidence: the substances through which Dutrochet repeatedly demonstrated osmosis at work.

It did not take long before Dutrochet hit back with an elaborate response on Poisson's article. On 23 July 1827, some six months after Poisson's first

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[111] Poisson, "Note sur des effets":365.

[112] See for example the renowned textbook on chemistry by Berzelius (French translation): Berzelius, *Traité de Chimie : Chimie Organique* (2nd part), Tome 7, trans. Esslinger (Paris : Didot, 1833):134.

[113] Dora B. Weiner, *Raspail : Scientist and Reformer* (New York : Columbia University Press, 1968):76.

[114] Saigey, "Note sur des effets qui preuvent être produits par la capillarité et l'affinité des substances hétérogènes" by Poisson, *Bulletin des sciences mathématiques, astronomiques, physiques et chimiques,* Tome 7 (1827):369.

[115] Saigey, "Note sur des effets":369.

[116] Henri Dutrochet, *L'agent immédiat du mouvement vital dévoilé dans sa nature et dans son mode d'action, chez les végétaux et chez les animaux* (Paris : Dentu, 1826):122-132; Report on the 30 October Academy meeting, *Journal de Pharmacie et de Sciences Accesoires,* Tome 12 (1826):589.

response (and a few after Saigey's interference), Dutrochet had again an opportunity to speak at the Academy.[117] He read a new memoir called, '*New Observations on endosmose and exosmose, and on the cause of this dual phenomenon*' that included new observations and experiments and the promise that he "shall dispute the claim of the renowned mathematician Monsieur Poisson that it [osmosis] does not depend only on capillarity".[118]

In the memoir, Dutrochet attacked Poisson on one of his vital premises, namely that the capillary behavior of liquids should be reflected in their 'osmotic' behavior. According to Poisson's line of reasoning, it should be possible to predict the direction of the flow of any set of two heterogeneous liquids that are separated by a membrane, because only the liquid with the highest capillary action would accumulate at the other side.[119] By means of experimental analysis Dutrochet proved nonetheless that these predictions were not flawless, and that inverse outcomes were as likely to occur.

Dutrochet had measured the unique capillary action of four fluids. First he took water, and measured its rise in a capillary tube and assigned it a relative height of (100). Compared to this value, he determined the relative capillary heights of respectively olive oil (67), essential lavender oil (58) and alcohol (47). If Poisson was right, it should now be possible to predict the behavior of different sets of heterogeneous fluids that could be assembled with the four fluids that were available.

Poisson's reasoning failed when Dutrochet put it to the test. When Dutrochet took a combination of olive oil (67) and essential lavender oil (58), it turned out that the lavender oil accumulated at the olive-oil side, contrary to what Poisson prescribed. The same results were obtained with the heterogeneous set of lavender oil (58) and alcohol (47), in which alcohol flowed through the membrane, despite having the lowest capillary action. The fact that nature did not consistently obey the logic of Poisson was sufficient reason for Dutrochet to refute the latter's claim that osmosis was the result of capillarity:

> This demonstrates that there is no constant relationship between the accumulation of liquids and their capillary behavior. Consequently, capillary action is not the cause of this phenomenon of accumulation. [...] This result and the fact that two currents of unequal strengths flow simultaneously in opposite directions across the dividing

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[117] *Procès-Verbaux des Séances,* Tome 8:571-572. See also a semi-anonymous review (author abbreviation N.) in the *Journal Générale de Medecine,* Tome 100 (1827):208-210. Dutrochet's article itself appeared in the same issue of the *Annales* as the republication of Poisson's note, see: Dutrochet, "Nouvelles Observations sur l'Endosmose et l'Exosmose, et sur la cause de ce double phénomène", *Annales de Chimie et de Physique*, Tome 35 (1827):393-400..

[118] Henri Dutrochet, "New observations on endosmosis and exosmosis, and on the cause of this dual phenomenon", trans. anonymous, *Journal of Membrane Science* 100 (1995):5.

[119] Henri Dutrochet, "New observations":5-6.

> membrane prove convincingly the ineffectiveness of M. Poisson's mathematical theory.[120]

The experiments of Dutrochet thus seemed to have made possible a compelling case against the capillary explanation. But we get something more. Dutrochet also pointed to the fact that osmosis was initially discovered as a dual phenomenon. Poisson's hypothetical explanation only applied to endosmose, which acted as the more dominant and inverse brother of exosmose. The other minor flow – exosmose – could however never be understood in terms of Poisson's capillary theory. Hence, even if Poisson was right, he still did not provide a proper explanation for the other half of the dual phenomenon, which for Dutrochet was just another token of its implausibility.

But then, a while after Dutrochet's memoir had been published, Saigey again mingled in the debate. Like before, he still disapproved of Poisson's argument, but he also refuted the new argument that Dutrochet had developed against the capillary explanation. Somewhat surprisingly, he was not at all impressed by Dutrochet's new experimental data, and interpreted it merely as another confirmation of the fact that osmosis was indeed nothing more than "just an effect of imbibition [absorption]".[121] The answer that Saigey gave to Dutrochet was as simple as it was short. Capillary action was responsible for the uptake of both liquids into the membrane, while the selective passage of one of the liquids should be explained by means of their *viscosity*. When both liquids were present in the membrane, only the liquid with the lowest viscosity – i.e. the liquid that "experiences the least difficulty" in passing – would effectively flow through the membrane.[122] The appearance of the concept of viscosity was something new in the osmosis debate. Saigey needed it to disarm Dutrochet's potential rebuttal of the capillary argument, and to explain why a combination of alcohol and lavender oil would behave counter-intuitively from a Poissonian point of view.

In a more general sense, we could say that Saigey's contribution was typical of many symptomatic responses that evolved during the entire controversy. Much like his former contribution and that of Poisson, Saigey's arguments turned out to be merely hypothetical, with almost no reference to Dutrochet's detailed experiments. In his autobiographical notes, Dutrochet recalls this particular episode and gives us insight into his grievances about these (supposed) acts of ignorance by his peers:

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[120] Henri Dutrochet, "New observations":6.

[121] Saigey, "Nouvelles Observations sur l'Endosmose et l'Exosmose, et sur la cause de ce double phénomène " by Dutrochet, *Bulletin des sciences mathématiques, astronomiques, physiques et chimiques,* Tome 8 (1827):341.

[122] Saigey, "Nouvelles Observations":341.

> Here it seemed to me that all the explanations of the phenomenon of endosmose, which were based on the difference between the viscosities of the liquids, had to fail. But people believed that these observations and experiments [on osmosis] were worth little of attention, and they did not bother to repeat them.[123]

Typically, the main producer of experimental facts during the controversy was and remained Dutrochet. Much to his disappointment, his claims were easily refuted and people did not seem to care enough about his discovery, or at least not in such fashion that they would pursue significant experimental support that could carry their criticism.

This was also true when it came to the other issue that was central to the controversy. Although that the discussions over the explanation of osmosis and its ontological status were all but separated, it is still possible to distinguish a line in the controversy along which it was consistently argued that osmosis did not exist at all. Apart from the fact that for some Dutrochet's explanation was insufficient, those in favor of the last view repeatedly claimed that Dutrochet's discovery was just another manifestation of imbibition and that it should be treated likewise.

Somewhat surprisingly, it was not Magendie who dealt those cards in the controversy, despite that he had made a strong case against the acceptation of osmosis during the Academy discussion. Probably, this had much to do with the fact that he was also involved in another, much more publicly fought controversy with the Scottish surgeon Charles Bell (1774-1842). Both claimed to have discovered the separate motor and sensory nerve roots, which gave rise to a priority dispute that eventually transformed into a public debate over vivisection. Magendie, who often relied on vivisection, was the common object of British moral complaints that concerned the cruelty of his experiments.[124] This all took place around the same time that osmosis was introduced, and probably divided Magendie's attention.

Nonetheless, another person picked up Magendie’s previous role. One of the most outspoken criticasters of Dutrochet was the French chemist and politician François-Vincent Raspail (1794-1878). After the Academy meeting of 30 October 1826, Raspail was assigned the task to review the new discovery of Dutrochet. Within a week, he had written a rapport, which was read at the subsequent Academy meeting of Monday 6 November.[125] When Dutrochet learned that Raspail was assigned the task to review his discovery, he was most clearly not happy with this decision. He wrote to his friend and

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[123] Henri Dutrochet, "Notice sur ma vie", in Joseph Schiller, *Henri Dutrochet*:96.

[124] Carin Berkowitz, "Disputed discovery: vivisection and experiment in the 19th century", *Endeavour* 30 (2006): 98-102; Harriet Ritvo, *The Animal Estate : The English and Other Creatures in the Victorian Age* (Cambridge : Harverd University Press, 1987):157-166.

[125] *Procès-Verbaux des Séances,* Tome 8:450.

colleague Geoffroy Saint-Hilaire that he judged it impossible that a fair review could be drafted of his discovery, due to the restricted time he previously got at the Academy meeting and the fact that his book on osmosis was still awaiting publication. "Let me count on your kindness by asking you to inform me of everything that will be done in this regard."[126]

In the report, Raspail sought to explain Dutrochet's observations by merely using the facts that were already known concerning the properties of living tissues.[127] This apparently simple approach enabled the harsh conclusion that there was no single innovative feature to be found in Dutrochet's osmotic theory. In the elaborate article that Raspail published in the year thereafter, he concluded his ten-page ongoing criticism with the following remark, that was as cynical as it was short: "Moreover, it seems that by replacing the words endosmosis or exosmosis by those of absorption, exhalation, imbibing and transudation, etc., all applications of the author fit in all that has been written on the statics of one or another reign [i.e. that of the vegetation or that of the animal]."[128] His cynicism becomes even more apparent if we take a look at what Raspail had to say with regard to 'endosmose' and 'exosmose' – the Greek terms that Dutrochet had coined for his phenomenon. He wrote: "Why are we so eager in taking our denominations from a language that we all handle with difficulty, while ours already provides us with an excessive number? *Expulsion* and *impulsion* do not suffice?"[129] A few years later, he phrased it somewhat differently: "We never let the opportunity pass, as people know, to point out how ridiculous it is to resort in every instance to the Greek language, given that we know so little Greek in France."[130] The fact that Raspail mastered the ancient languages makes his comments at least questionable.[131] This was no longer a game played on scientific grounds, but a personal venture to destruct Dutrochet's findings on virtually every front possible.

Why did Raspail respond in this way? Unfortunately, the intrinsic motives that led him to attack Dutrochet evade us for the better part, although he would eventually accuse Dutrochet of plagiarism. Apart from that however, Raspail was known as an outspoken critic of both the political and scientific establishment.[132] Especially the latter is well illustrated by the

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[126] Dutrochet, letter to Geoffroy Saint-Hilaire, 12 November 1826, in Joseph Schiller, *Henri Dutrochet*:202.

[127] Anonymous, "Mouvement des liquides dans les végétaux attribué a l'électricité":646. Report on the 30 October Academy meeting, *Journal de Pharmacie et de Sciences Accesoires*: 590. Anonymous, *Le Globe, Journal Littéraire*, 9 November 1826 (Tome 4, No. 38):199.

[128] Raspail, review of *L'agent immédiat du mouvement vital, dévoilé dans sa nature et dans son mode d'action, chez les végétaux et chez les animaux* by Dutrochet, *Bulletin des Sciences Naturelles et de Géologie,* Tome 10 (1827):250-251.

[129] Raspail, review of *L'agent immédiat*:244n.

[130] Raspail, *Nouveau Système de Chimie Organique*, Tome Premier, 2nd ed. (Paris : J.B. Baillère, 1838):385.

[131] Dora B. Weiner, *Raspail*:55.

[132] Maurice Crosland, *Science under Control*:307.

many controversies, other than that over osmosis, in which he was involved.[133] Moreover, it has also been noted that Raspail was overly quick in accusing others of plagiarizing his work.[134] A British review that appeared on the occasion of a new textbook on chemistry that Raspail published in 1833, speaks of his "rude, rough and uncompromising tone" and describes him as a bitter and "ill-fated celebrity" in France.[135] As a prime example of Raspail's rudeness, they pointed to the latter's treatment of the recent discovery of osmosis.[136]

Raspail's case against osmosis was built around three main arguments that, taken together, suggested that osmosis was a redundant ‘new law’ that was uncalled for. The first explanatory substitute he offered concerned a non-ideal property of the membranes that were used to induce osmosis. Raspail noted that the bladders were subject to decomposition in humid environments. Perhaps unintended, he had touched onto something that in the later course of the nineteenth century was recognized as one of the biggest problems with which one was faced when doing experiments on osmosis. The German physicist Phillip Jolly (1809-1884), who published an extensive article on osmosis in 1849, wrote that it was very difficult to reproduce osmotic experiments accurately, because the animal bladders that were used tended to putrefy after a typical fourteen days.[137] Raspail however, used this very property to replace Dutrochet's explanation. He noted that in the endosmometer, decomposition of the membrane happened faster at the inside than at the outside. The capillary workings at the outside remained therefore intact, whereas the vesicles at the inside of the membrane inflated due to decomposition, which pushed the inside liquid further away. According to Raspail this resulted into a net inwards flow that caused the rising level in the tube of the endosmometer.[138] In the second place, and closely related to the former, Raspail pointed out that in many cases saline solutions were used for osmotic experiments. These saline solutions "tighten the tissue of the membrane by astringency", which shrinks the inner capacity of the membrane and "continuously forces the liquid to ascend".[139] After a while however, the saline solutions drained back through the membrane, and the liquid level in the tube would drop again. Raspail thus

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[133] Among which with Mathieu Orfila (1787-1853) and François Arago (1786-1853). See: Anonymous review of *Nouveau Système de Chimie Organiqe*, by Raspail. *The London Medical Gazette* 12 (1833):645. An elaborate description of Raspail's controversy with Orfila is provided in: José Ramón Bertomeu-Sánchez, "Chemistry, microscopy and smell: bloodstains and nineteenth-century legal medicine", *Annals of Science* [Online publication on the journal's website and awaiting printed publication.] (2015).

[134] Dora B. Weiner, *Raspail*:73.

[135] Raspail, *Nouveau Système de Chimie Organique fondé sur des méthodes nouvelles d'observation* (Paris : J.B. Baillère, 1833).

[136] Anonymous review of *Nouveau Système de Chimie Organiqe*:644-647.

[137] Ph. Jolly, "Experimental - Untersuchungen über Endosmose", *Zeitschrift für rationelle Medicin* 7 (1849):95.

[138] Raspail, review of *L'agent immédiat*:247.

[139] Raspail, review of *L'agent immédiat*:247.

not only provided an alternative explanation for endosmose (i.e. the uptake of liquid in the endosmosmeter), but also for its counterpart, exosmose, which constituted the reverse movement.

The third alternative explanation that Raspail offered revolved around two substances, albumen and arabic gum, which we already encountered earlier in the argument raised by Saigey. Not entirely surprising, Raspail was a friend and colleague of the latter, and also in this case they appear to have been each other's allies.[140] Two years later, in 1829, they would also found a new journal together that only survived four issues.[141] Anyhow, Raspail's third argument stated that the substances of albumen and gum were not able to cross the membranes due to their very texture, much like they would not pass through filter paper. Moreover, these substances actually played a role similar to that of tissues, which, since Foderà, were known to exhibit absorptive properties. In the case these substances were aligned with a membrane and water, water would be sucked up by the albumen or arabic gum, which, again, explained Dutrochet's observations on the mere basis of already known facts.[142] [143]

Based on the above considerations, Raspail concluded that "[t]he new law of M. Dutrochet, apart from some mechanical circumstances that are capable of increasing the intensity, is therefore reduced to a well-known law: *absorption of liquids by tissues*, or *organic capillarity*."[144]

One year after his discovery of osmosis, Dutrochet thus had to defend a phenomenon whose existence was disputed on at least two different grounds. In the first place there were Poisson and Saigey, who severely doubted the electrical explanation, and tried to substitute it for better ones. Yet they did not seem to dispute explicitly the originality of Dutrochet's observation. On the other hand, there was Raspail who rejected the originality of osmosis altogether. Dutrochet wrote about these criticisms that "I would have been wrong in considering the phenomenon in question as new, as well as in giving it a particular name; it would have been nothing but a particular association of already known phenomena."[145]

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[140] Joseph Schiller, *Henri Dutrochet*:204n; Dora B. Weiner, *Raspail*:76.

[141] *Annales des Sciences d'Observation* (1829-1830).

[142] Raspail, review of *L'agent immédiat*:247.

[143] Dutrochet offered a counterargument against Saigey's and Raspail's remarks on the action of albumen. (Henri Dutrochet, "New observations":6.) Dutrochet traced the ideas of Saigey and Raspail back to the idea of a reciprocal affinity between albumen and water. In a simple experiment, he subsequently demonstrated that no such affinity exists between these two liquids. Raspail, on his turn, responded one year later with the remark that affinity does exist between the two, which reinforced the following conclusion: "[l]'objection de M. Dutrochet une fois réfutée, le mouvement vital se réduit donc, ainsi que le Bulletin l'avait déjà annoncé, à un simple phénomène bien connu d'affinité et d'imbibition." (Raspail, "Note du rédacteur", *Bulletin des Sciences Naturelles et de Géologie,* Tome 14 (1828):365.)

[144] Raspail, review of *L'agent immédiat*:248.

[145] Henri Dutrochet, "Notice sur ma vie", in Joseph Schiller, *Henri Dutrochet*:88.

Dutrochet's disappointment over Raspail's attack speaks clearly through this passage, but still, he chose not to openly respond to Raspail's accusations. Instead, he began to adopt other strategies to enhance the acceptance of osmosis by his peers.

2.3 A half-hearted favor

Early in 1828, Dutrochet had prepared another article, which he read at the academy and was able to get published in one of the major scientific organs. The article itself bore the same character as Dutrochet's former responses, and mainly contained new experiments that aimed at countering his opponents' criticisms. This time however, Dutrochet also decided to put his article forward to be considered for the annual Montyon prize in experimental physiology. He had been disillusioned by the minimal impact of his former attempts to falsify the alternative explanations for osmosis, and sought other strategies to reinforce the interest for his experiments and to reinstate osmosis as a phenomenon sui generis.

Apart from many novel and elaborate details on osmosis, the article, *New Investigations of Endosmose and Exosmose*, offered two new and compelling arguments against capillarity. Dutrochet opened his article by stating that he still stood by his former experiments, which, according to him, already provided sufficient ground to ensure that capillary attraction had nothing to do with osmosis. Nonetheless, he immediately continued by spinning out new supportive evidence. First of all, Dutrochet referred to the fact that "we know" that warmer liquids ascend capillary tubes less highly than the same liquids would do under colder circumstances. This means that an increased temperature diminishes the force of the capillary action. Contrary to that however, the case of osmosis demonstrated the exact inverse relation.[146] Like Dutrochet had argued in the years before,[147] the intensity of osmosis increased with a rising temperature, which led him to conclude once more that it "is therefore obvious that it [osmosis] does not at all depend on capillary attraction: it is produced by a particular electrical condition, just like I have announced already, and just like it will be proven more and more by the following experiments."[148]

He began by devising two new categories for the substances and membranes he used in his endosmometer. Dutrochet found out that it was possible to distinguish between substances that, due to their 'chemical qualities', were able to induce osmosis, and substances that were not. Dutrochet chose therefore to categorize them as *active* and *inactive* with regard to their effect. For instance, putrefied animal fluids were inactive

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[146] Henri Dutrochet, "Notice sur mes ouvrages", in Joseph Schiller, *Henri Dutrochet*:132.

[147] Henri Dutrochet, *L'agent immédiat*:154-156.

[148] Henri Dutrochet, "Nouvelles Recherches sur l'Endosmose et l'Exosmose", *Annales de Chimie et de Physique*, Tome 37 (1828):191.

substances, whereas many acids like vinegar, nitric acid and hydrochloric acid were active substances with which osmosis could be produced.[149]

It was possible to make the same distinction for several available membranes. Since Dutrochet had published his first treatise on osmosis, he had found that several inorganic materials, if applied in the right conditions, acted in the same way as the animal bladders that he commonly used to do his experiments with. It is interesting to see that this simple fact had forced Dutrochet in an earlier stage to rethink his position with regard to vitalism, and to openly renounce the Bichatian paradigm.[150] The current interest of this fact however, lies somewhere else. Dutrochet demonstrated that a slice of certain porous minerals could substitute for the bladder without affecting the results of the osmotic experiments. Useful mineral substitutes were slices of clay or slate, but just like there were active and inactive liquids, there were also inactive membranes. It was exactly in these inactive membranes that Dutrochet found new grounds to refute the capillary explanations of his colleagues, because, while these membranes clearly showed capillary properties, they were not capable of inducing osmosis. "This fact cannot leave any doubt about the cause of the phenomenon endosmose; this cause is undoubtedly electricity. The capillary attraction is obviously foreign to this phenomenon, since the porous plates with a siliceous or calcareous basis, cannot produce it, despite their capillarity."[151]

If we consider the experimental approach Dutrochet used to respond to his critics, the article did not differ much from the previous ones. Yet, in another fashion it did, as Dutrochet was willing to seek a middle ground on which both he and Poisson could find each other with regard to capillarity. Although this did not imply that Dutrochet was anywhere near ready to abandon his electrical explanation, he now cautiously allowed for the very association of capillarity with his phenomenon. The reason for this sudden move followed directly from the active/inactive division Dutrochet had imposed on his experiments. Osmosis could only occur if a combination was used of an active liquid with an active membrane. As soon as one of the two was replaced by an inactive variety, the phenomenon would vanish completely. This meant that the membrane was an actual determining factor. The electricity needed for osmosis was therefore not the straight result of electrical differences between the liquids themselves, but stemmed rather from the interaction of the liquids with the membrane. Hence, the origin of osmosis could only lie inside the membrane, where this interaction would actually take place.[152] It was here that Dutrochet was willing to make a concession to Poisson and others, because the only way the fluid could reach

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[149] Henri Dutrochet, "Nouvelles Recherches":194-195.

[150] Henri Dutrochet, "New observations":7. See the next chapter for a more detailed discussion hereof.

[151] Henri Dutrochet, "Nouvelles Recherches":199.

[152] Dutrochet already touched on this idea in his former article: Henri Dutrochet, "New observations":6.

the interior of the membrane was by means of its capillary openings. Only after the liquid had penetrated the membrane through capillarity, osmosis took over and gave it its final and definite impulse. This also explained why Dutrochet could not find any electrical current when he applied a galvanometer to his experiments, because electricity developed within the immeasurable interior of the membranes. The concession itself consisted of a revision of the category in which osmosis was placed. Instead of being referred to as an electrical phenomenon, Dutrochet proposed to refer to osmosis from now on as a *capillo-electrical*, or as an *intra-capillary electricity* phenomenon.[153]

At 17 March 1828, Dutrochet read his new findings at the weekly gathering of the Academy, after which he decided to put it forward for the Montyon prize: [154] "deeply convinced that I had discovered a new physical phenomenon, whose applications to physiology were important and very numerous, I did not hesitate to present my discovery to the contest for the experimental physiology prize to be awarded in 1828".[155] This was an important move, as it could help Dutrochet to establish general recognition within the scientific community – something he had not yet been able to achieve by the sole means of his articles. Unfortunately, things went not so smooth as thought. Dutrochet's participation was even met with malevolence. "I was so badly received", Dutrochet wrote, that he seriously considered withdrawing from the contest.[156] Luckily, he got help from an unexpected quarter. One of the commissioners on the team that was charged with the examination of the participants' submissions was the French chemist Joseph Louis Gay-Lussac (1778-1850).[157] He encouraged Dutrochet to proceed, and he personally took care to ensure that Dutrochet eventually won the Montyon prize, albeit that he had to share it with a team of two other physiologists.[158] Dutrochet's competitors, Jean Victoire Audouin (1797-1841) and Henri Milne-Edwards (1800-1885), won the other gold medal for their work on the circulation and respiration of crustaceans (crabs, lobsters, shrimp etc).[159]

The official reading of the Academy was that they considered Dutrochet's discovery to be so new and important that he deserved the physiology prize, the more so since he had put an end to certain questions

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[153] Henri Dutrochet, "Nouvelles Recherches":200-201.

[154] Académie des Sciences. *Procès-Verbaux des Séances de l'Académie*, Tome 9, Années 1828-1831 (Hendaye : Imprimerie de l'Observatoire d'Abbadia, 1921):43.

[155] Henri Dutrochet, "Notice sur ma vie", in Joseph Schiller, *Henri Dutrochet*:88.

[156] Henri Dutrochet, "Notice sur ma vie", in Joseph Schiller, *Henri Dutrochet*:88.

[157] The other commissaries were Thenard, d'Arcet, Chevreul and Dulong. See: Académie des Sciences. *Procès-Verbaux des Séances de l'Académie*, Tome 9:14.

[158] Henri Dutrochet, "Notice sur ma vie", in Joseph Schiller, *Henri Dutrochet*:88.

[159] *Procès-Verbaux des Séances de l'Académie*, Tome 9:73.

that had hunted physiologists for a long time.[160] The Montyon prize meant that Dutrochet finally got the acknowledgement for which he had been fighting since 1826. It demonstrated the Academy's support for his investigations, and proved that he had more allies among the Parisian scientists than he thought he had.

There was however a second reason why Dutrochet considered the prize as a truly victorious moment. In 1827, the year before, he had submitted his book *l'Agent immédiat* to be considered for the prize, but never made it to the final round due to strong opposition. This opposition probably came from Magendie, who sat in the Montyon commission that year.[161] The official reason given for Dutrochet's exclusion, was that the commission "refrained from passing judgment on its importance", because Dutrochet's discovery was announced 'very recently' and had not yet been 'sufficiently appreciated'.[162]

Nevertheless, by awarding Dutrochet the prize one year later, the Academy thus not only showed their current appreciation of Dutrochet's work, but they also openly rectified their former decision and chose to ignore the criticism that continuously was being raised against osmosis. This is at least how Dutrochet interpreted the event, given the following letter he sent to Geoffroy Saint-Hilaire to thank him for the support he got from him.

> I offer you my sincere thanks for the flattering way you spoke about my latest works to the academy. I am all the more grateful since I was convinced that my work enjoyed just little favor in the minds of some of the academy's members. The way the prize was awarded last year [1827] is proof hereof. Awarding me the prize [in 1828] was an implicit recognition of the physiological importance of my discovery, and due to the fact that the physiological importance was recognized it necessarily followed that they were out of line. [...] I do not know whether this half-hearted favor – which baffled me in these circumstances – stemmed from the physiologists or the physicists. All I know is that I was ill treated by some of them.[163]

Unfortunately for Dutrochet, the bad treatments did not stop after the Montyon ceremony. Even though Dutrochet took it to be an advantageous turning point in the reception of osmosis, some of his opponents were all but impressed by the Academy's decision. Saigey, and his friend Raspail, in whose

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[160] Cuvier, "Analyse des travaux de l'Académie pendant l'année 1828", *Memoires de l'Académie des Sciences de l'Institut de France*, Tome 11 (Paris : Gauthier-Villars, 1832):cxlix-cl.

[161] *Procès-Verbaux des Séances,* Tome 8:496.

[162] *Procès-Verbaux des Séances,* Tome 8:542-543.

[163] Dutrochet, letter to Geoffroy Saint-Hilaire, 11 January 1829, in Joseph Schiller, *Henri Dutrochet*:204-205.

eyes the Academy was already an archaic bastion, began doubting the Academy's capability rather than giving Dutrochet credit for his prize.[164]

Saigey was the first who took up his pen after the event. In a four-page long review, he commented on the Montyon prize and responded to Dutrochet's former article. Despite Dutrochet's newest insights, osmosis could still be broken down to the following three, familiar circumstances. In the first place, Saigey argued, the membrane exercised capillary action on the external fluid. There was nothing new to this point, which already had been uttered repeatedly by several of Dutrochet's opponents. Yet, this time the decor had changed a little, because it had been exactly the point at which Dutrochet had partially come around. Nevertheless, Saigey did not welcome Dutrochet's gesture, and kept arguing that capillarity not only filled the membrane, but also explained the seemingly indefinite character of the observation compared to regular observations of capillarity. In the second place, he pointed at the circumstance that the inner fluid, contrary to the external fluid, was not able to pass the membrane. According to Saigey, most of the fluids that derived from animals possessed this quality, including the much discussed albumen substance. Also this point was not new, and neither was the third that required the reciprocal affinity of the two fluids. If we remember Saigey's and Raspail's former replies to Dutrochet, we see that both the impermeability and affinity of the fluids already previously appeared under different denominations. While Saigey had pointed at texture and viscosity, Raspail had argued that albumen demonstrated tissue-like features that explained its absorption of water.

All three of the above circumstances appear therefore to have been mere reinventions of older arguments. Osmosis boiled down to "well-known principles of capillarity and affinity, or, in other words, imbibition".[165] Even the Montyon prize could not convince Saigey otherwise, and instead he began to question the quality of all papers that were sent in for the competition.

> The experiences of M. Dutrochet are a new way to establish [the phenomenon of] imbibition, and deserve to be published in the form of a Note; but to value its author with an honor as distinguished as that with which he was awarded by the Academy of sciences, does not give a very high opinion of the memoires submitted to the competition for the physiology prize.[166]

Saigey was thus still far from convinced of the genuineness of osmosis. He said of the Montyon jury report that it was a ‘laconic’ statement and thought that it was particularly funny that Dutrochet had won the prize for the down-to-earth discovery of osmosis and not for finding the acclaimed *immediate*

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[164] Raspail, *Nouveau Système de Chimie* (1833):82.

[165] Saigey, "Nouvelles Recherches":62-63.

[166] Saigey, "Nouvelles Recherches":63.

agent of the vital movement.[167] This was a painful remark, given that most of Dutrochet's contemporaries indeed did not believe that Dutrochet's discovery had anything to do with the vital force.

Like his friend Saigey, Raspail was still all but prepared to admit that osmosis was anything more than a fancy word play. For almost two years he did not openly respond to Dutrochet, apart from a cynical remark that appeared in his own journal, saying that: "M. Dutrochet's endosmose and exosmose continue every year to occupy a fairly large number of pages; and, by repeating these words, people will make us believe, no doubt, that this so-called discovery is anything more than a creation of words."[168] Osmosis remained indeed a frequent topic of conversation, which kept annoying Raspail.[169] In an open letter Raspail published in 1830, he accused Dutrochet and two other scientists of plagiarism. Although it concerned another discovery, namely the circulation of the *chara* (a green alga), Raspail nonetheless pointed to the story of Dutrochet's discovery of osmosis to indicate that the latter was capable of doing such things. "When Mr. Dutrochet finds an idea correct, he seizes it, he embroiders it, he changes a few words and replaces, for example, imbibition of the tissues by *endosmose* [...]; in brief, he appropriates the core by changing its form a little."[170] Raspail became tired of all the admiration that had befallen Dutrochet, and feared that the people had grown used to Dutrochet's acclaimed ingeniousness while they were actually getting fooled by the latter.[171]

In general it could be said that the critical attitude towards osmosis, most clearly expressed by Saigey and Raspail, gradually transformed into more personal attacks on Dutrochet. Simultaneously however, most critical remarks became subordinate passages in the comprehensive textbooks that were produced by Dutrochet's criticasters. The first in row, Poisson, probably had the mildest tone of all. In his textbook on capillarity (1831), he merely repeated his original point of view, namely that capillarity explained osmosis sufficiently and that there was no need to rush to other phenomena of another nature.[172] Second in line was Raspail with his textbook on organic chemistry (1833). Apart from a fresh mockery – this time on the endosmometer, which was put aside as trivial physical amusement – Raspail

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[167] Saigey, "Nouvelles Recherches sur l'Endosmose et l'Exosmose" by Dutrochet, *Bulletin des sciences mathématiques, astronomiques, physiques et chimiques,* Tome 10 (1828):60-64.

[168] Anonymous, *Annales des Sciences d'Observation*, Tome II (1829):316.

[169] "Les phénomènes d'endosmose découverts par M. Dutrochet sont tout-à-fait nouveaux, et ne manqueront pas sans doute d'attirer toute l'attention des physiciens et des physiologistes." Pouillet, *Élémens de physique expérimentale et de météorologie*, Tome II, First part (Paris : Béchet Jeune, 1829):31.

[170] Raspail, "1re lettre a un savant de province", *Annales des Sciences d'Observation*, Tome 3 (1830):305.

[171] Raspail, "1re lettre a un savant de province":304.

[172] Poisson, *Nouvelle Théorie de l'Action Capillaire*:300.

gave a fair account of his former objections to osmosis.[173] Remarkably new however, was the return of Magendie. In 1833, six years after his interference at the first Academy discussion, he finally dedicated a few words to the phenomenon. In his textbook on physiology, which already went through its third edition, he indicated that Dutrochet's observation was indeed curious, but that further investigations were needed since its author had exaggerated its importance. Moreover, Magendie regretted the fact that Dutrochet involved himself with certain suppositions that obstructed the advance of experimental physiology [*la marche expérimentale*].[174]

Nonetheless, during the first years of the 1830s, the initial resistance against osmosis began to weaken, older arguments were being recycled, and in the years that followed, the center of the debate transferred from the public arena at the Academy to the more discrete area of the books.

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[173] Raspail, *Nouveau Système de Chimie* (1833):82.

[174] Magendie, *Précis élémentaire de physiologie*, Tome 1, 3rd ed. (Paris : Méquignon-Marvis, 1833):14.

3. The Berliner Takeover

In the preceding chapter we observed osmosis from a micro perspective – a perspective in which osmosis was painted first and foremost as a source of controversy at the French Academy. However true this picture might be, as soon as we abandon this micro perspective for a macroscopic view of the nineteenth century, a different picture emerges in which osmosis reveals itself as a phenomenon that became and remained of appreciable interest to the scientific community during the remainder of the nineteenth century. This urges us to ask the question why osmosis eventually resisted the heat of the controversy on the long run. Even though Dutrochet's initial ideas of osmosis suffered the necessary collateral damage, the rest of the nineteenth century reminds us that the anti-campaign of Raspail and Saigey at least did not prove to be the definitive and lasting answer to Dutrochet's discovery. In this last chapter, I will therefore seek to explain how the controversial episode in Paris connects to the entirety of the history of osmosis in the nineteenth century. We will however need to look beyond the borders of France in order to understand how osmosis reinvented itself during the 1830s and 1840s.

That most of the controversy took place in Paris did not mean that early international contributions to the debate were lacking. On the contrary, already in 1827, while the French controversy was only in a premature stage, a significant view on Dutrochet's discovery was being developed in Germany. The physical distance between the two countries simultaneously brought about that osmosis was taken up in a whole new frame of reference that significantly diverged from that in Paris. Not only enabled this new environment a new perspective on Dutrochet's discovery, it also shaped significantly the way osmosis became and remained an object of scientific interest during the rest of the nineteenth century.

3.1 German interventions

In general, the German intervention in the osmotic debate had two major implications for Dutrochet. In the first place, Dutrochet's priority claim – which already was being disputed in France – became instantly rejected the very moment his investigations became known to the German public. The scientific repertoire in Germany contained several observations and experiments that, although performed independently, bore close resemblance to those of Dutrochet. Moreover, German studies had jumped to similar conclusions as Poisson in France, saying that the main constituent of this series of observations was capillarity. Without doubt, Dutrochet immediately lagged behind as soon as his discovery entered Germany.

Nonetheless, the poor start also came with its advantages. The second major implication of the German involvement was that the dismissal of Dutrochet's priority claim unintentionally secured osmosis as a recognized and independent phenomenon.[175] Contrary to France, where osmosis was believed to be a special manifestation of absorption, in Germany Dutrochet's observations were accommodated in a class allocated specifically for this purpose. Osmosis was thus recognized as a genuine phenomenon, but the prize Dutrochet had to pay was to acknowledge that there were others who had witnessed the same sort of observations before him.

In 1827, the news of Dutrochet's discovery was disseminated into Germany by the young chemist Gustav Magnus (1802-1870).[176] Magnus had just finished his dissertation on Tellurium, when he published an article in the *Poggendorff Annalen* on some curious observations of capillarity.[177] The article was concerned with an experiment of another German chemist, Döbereiner (1780-1849), who had found that the release of hydrogen gas through a small crack in a glass vessel provided enough force to draw water through another opening back into the vessel. Wondering what the cause might be of this miraculous observation, Magnus suggested that hydrogen gas, due to its small size, was able to escape through the capillary openings, while atmospheric air and other sorts of gas were unable to move back in due to their relatively bigger size. The outcome thus depended on the selective permeability of the capillary openings, and as a result, a negative pressure originated that would suck up the water.[178]

According to Magnus, Döbereiner's experiments on hydrogen gas were related to comparable experiments that had been performed on fluids. In 1822, a certain Nicolaus Wolfgang Fischer (1782-1850) had mentioned a few experiments in which he found that the separation of different liquids by a bladder could establish a much similar pressure that forced liquids to accumulate on one side of the bladder.[179] In both cases, Magnus argued, the

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[175] J.C. Poggendorff, "Ueber die Endosmose, ihre Ursache und ihre relative Stärke bei einigen organischen Flüssigkeiten", *Annalen der Physik und Chemie* 104 (1833):359-360.

[176] Poggendorff confirmed that Magnus was the first who introduced Dutrochet to Germany. "Seine [Dutrochet] jetzige Theorie kommt ganz mit der überein, welche durch die Arbeit von Magnus (Annal. Bd. X S. 153) seit Jahren in Deutschland bekannt ist". See: Poggendorf, "Ueber die Endosmose":359.

[177] G. Magnus, "Ueber einige Erscheinungen der Capillarität", *Annalen der Physik und Chemie* 86 (1827):153-168.

[178] Magnus, "Ueber einige Erscheinungen":160.

[179] N. W. Fischer, "Ueber die Wiederherstellung eines Metalls durch ein anderes, und über die Eigenschaft der thierischen Blase Flüssigkeiten durch sich hindurch zu lassen, und sie in einigen Fällen anzuheben" *Annalen der Physik und der physikalischen Chemie* 72 (1822):289-307. An earlier experiment is reported upon in 1814: Anonymous, "Fischer's kritische Untersuchung einiger Erscheinungen, welche als Wirkung der galvanischen Action erklart

originating pressure was related to the selectivity of the capillary openings. To verify Fischer's experiments, Magnus took a glass tube and filled it with a solution of iron or copper that was dissolved in sulphuric acid. The opening was sealed with a piece of bladder, after which the entire device was plunged into distilled water. Unsurprisingly, the liquid inside the tube began to increase after a little while. Having investigated several conditions, Magnus found that the type of bladder, as well as the diameter of the tube had no definitive influence on the phenomenon.[180] But then, at the very moment Magnus was occupied by his experiments, he came across the news of Dutrochet's discovery.

> While I was busy with these experiments, I saw in the Journal de Pharmacie, Novembre 1826, that Mr. Dutrochet had written an extensive work on this subject. Dutrochet however kept the increase [Ansteigen], which he had studied especially by animal fluids, for an electrical appearance.[181]

Because Magnus was the first to report on Dutrochet's investigations in Germany, he elaborately discussed the primary reception of osmosis at the French Academy, and the subsequent responses of Magendie, Poisson and Ampère. Like the others had done in France, Magnus also rejected Dutrochet's electrical explanation, because the earlier German experiments had convinced him already of the fact that the phenomenon's nature had to be sought in capillarity. Magnus was however not completely satisfied with Poisson's alternative, or felt the need to nuance it slightly, since he pursued his own explanation of the phenomenon. Two things in particular needed to be considered according to Magnus. In the first place made the chemist the fundamental assumption that the two fluids in the experiment attracted each other, because nothing else could explain the homogeneous mixture that remained after the experiment. He argued further that the solid parts of the solution attracted the parts of the solvent in such a manner as to surround them. Without this assumption, it would not only be impossible to explain the existence of solutions; but there was no other possibility to explain why the copper parts were able to attract distilled water through a membrane with such force that a significant difference in pressure was reached. In the second place, Magnus appealed to the argument that both fluids demonstrated different properties when it came down to the ease with which they were able to penetrate the capillary openings. The copper solution experienced more difficulty in passing a membrane than water, which resulted in a mere displacement of distilled water towards the cupreous side of the

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worden sind im Allgemeinen, und über Metallreduction auf nassem Wege ins Besondere", *Abhandlungen der Königlichen Akademie der Wissenschaften in Berlin 1814-1815*:241.

[180] Bladders derived from calves, cows and wild boars could be used interchangeably.

[181] Magnus, "Ueber einige Erscheinungen":162.

membrane.[182] It was only a small step for Magnus to arrive at the following conclusion.

> From the presented experiments appear that the rise of liquids through animal bladder is only a phenomenon of capillarity, and by no means of electricity. The phenomenon could be fully accounted for when it is assumed that different liquids pass through the capillary openings with different ease.[183]

Dutrochet's electrical explanation was now officially dismissed in Germany. But Magnus also extended the grounds on which Dutrochet's priority claim was dismissed. He had mentioned the experiments of Fischer and Döbereiner before, but continued by adding two more names to the list. In the first place, Magnus brought up Georg Friedrich Parrot (1767-1852), who in 1802 had observed a similar phenomenon while using alcohol instead of acid metal solutions.[184] Parrot had incorporated this experiment in a later textbook on theoretical physics, through which it came under the attention of Magnus and others.[185] The other German predecessor of Dutrochet was Samuel Thomas von Sömmering (1755-1830), who, in experiments with bladders, had found that they were more permeable for water than for alcohol.[186]

Johann Christian Poggendorff (1796-1877) – the famous German physicist and spokesman for science as well as the editor of the principal scientific journal in Europe – followed Magnus' lead when he declared a few years later that Dutrochet could neither claim priority for the explanation, nor for the discovery of *this entire class of phenomena*, "since it is well known that the observations of Fischer and Döbereiner are much older than his".[187] It was the clearest thing in Germany, that Dutrochet had no right to claim priority over his discovery of osmosis, but Poggendorff also recognized Dutrochet's contribution to the German tradition of bladder experiments. He rightfully gave Dutrochet credit for the terminology he had proposed (*endosmose and exosmose* indeed became common property in Germany) and pointed out that nobody else had performed so profoundly an investigation into the relation between capillarity and endosmose as Dutrochet had done.[188]

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[182] Magnus, "Ueber einige Erscheinungen":163.

[183] Magnus, "Ueber einige Erscheinungen":168.

[184] Georg Friedrich Parrot, *Ueber den Eingluß der Physik und Chemie* (Dorpat : Michael Gerhard Grenzius, 1802):18. Compare chapter 1.

[185] Georg Friedrich Parrot, *Grundriss der Theoretischen Physik* II (Dorpat/Riga : Meinshausen, 1811):331.

[186] Samuel Thomas Soemmering, "Versuche und Betrachtungen über die Verschiedenheit der Verdünstung des Weingeisters durch Häute von Thieren und von Federharz", *Denkschriften der Königlichen Akademie der Wissenschaften zu München für die Jahre 1811 und 1812* (München,1812):273-292. See also: Sömmering, "Über das Verdünsten des Weingeists durch thierische Häute und durch Kautschuck", *Annalen der Physik* 61 (1819):104.

[187] Poggendorf, "Ueber die Endosmose":359-360.

[188] Poggendorf, "Ueber die Endosmose":360.

Rather swiftly, the new line of succession was established. An illustrative example is found in the way osmosis was dealt with in the popular textbooks that were published by the celebrated Swedish chemist Jöns Jacob Berzelius (1779-1848).[189] While it has been argued that textbooks not necessarily act as vehicles for accepted scientific knowledge, they nevertheless help to reveal how the evolving story of osmosis was being perceived by the wider audience.[190] This applies in particular to Berzelius' textbooks, which appeared in several translations and editions, and were gratefully enjoyed by virtually every chemist around Europe.[191]

In case of Berzelius' text, it immediately stands out that Dutrochet's name was minimally mentioned. In the paragraph categorized under the original Dutrochetian terms *endosmose* and *exosmose*, the latter's name only appears after a whole battalion of other scientists is mentioned that preceded or exceeded Dutrochet in his osmotic investigations. It is only at the end of the paragraph, and in the wake of Poisson, Magnus, Porrett and Fischer, that Dutrochet is brought up with the following words: "Finally, the phenomenon was investigated even further by Dutrochet, whose merit in particular had been to draw attention to its influence on the processes of living, organic bodies."[192] The equivocal reference to Dutrochet – that could be found in many other textbooks as well – indicates that most of his contemporaries judged Dutrochet's work to be merely contributory, rather than inventive.

In the meantime, the German discussion of osmosis only got marginal attention in France. Right after Magnus had published his article on capillarity in 1827, a small comment appeared in a French journal that consisted of little more than the following sentence:

> The observations of Mr. Magnus apparently demonstrate that the passage of liquids through animal bladders is only a capillary phenomenon. It does not depend on electricity, and this can be

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[189] Endosmose appeared first in Swedish yearbook edited by Berzelius, see: Berzelius (ed.), *Årsberättelse om framstegen i physik och chemie* (Stockholm, 1828):67. This yearbook was translated into German: Berzelius (ed.), *Jahresbericht über die Fortschritte der physischen Wissenschaften*, trans. Friedrich Wöhler (Tübingen, 1829):69. See for osmosis's first-time appearence in the textbook: Berzelius, *Lehrbuch der Thier-Chemie,* in serie *Lehrbuch der Chemie*, volume 4, part 1, trans. Friedrich Wöhler (Dresden, 1831):126. The German edition was translated in to French: Berzelius, *Traité de Chimie*, 2e partie of *Chimie Organique,* Tome 7, trans. Esslinger (Paris : Didot, 1833):133.

[190] John Hedley Brooke, "Introduction: The Study of Chemical Texbooks", in Anders Lundgren, Bernadette Besaude-Vincent (eds.), *Communicating Chemistry* (Canton : Watson Publishing, 2000):6.

[191] Marika Blondel-Mégrelis, "Berzelius' Textbook: In Translation and Multiple Editions, as Seen Through His Correspondence", in Anders Lundgren, *Communicating Chemistry*:234.

[192] Berzelius, *Lehrbuch der Thier-Chemie*:129.

> perfectly explained as soon as it is accepted that the different liquids traverse the capillary openings with more or less ease.[193]

The remark about electricity was of course an implicit reference to Dutrochet, but it had not been enough to facilitate the inclusion of Magnus' work in the ongoing French controversy. Instead it would take until 1832 before finally a translation of Magnus' original article appeared in the French *Annales de Chimie et de Physique*. The journal's editor briefly clarified the tremendous delay, saying that the publication had only now become interesting, since Dutrochet had recently been occupied by entirely analogous investigations.[194] Even though the editor's comment seems to be trivial, he eventually referred to decisive investigations. After an obstinate period of six years, Dutrochet had finally decided to abandon the electrical explanation he had been endorsing from the beginning. Persuaded by an experiment that Magnus had discussed in his article on capillarity, Dutrochet was encouraged to make the most substantial concession ever to his original theory of osmosis.

One part of Magnus' article we have not discussed yet concerned an elaborate examination of one of Fischer's experiments from 1822. Fischer reported to have taken a tube filled with distilled water, which he had sealed with an animal bladder and immersed into an acid solution. The experiment however differed from other experiments we have seen thus far, in that the tube also contained a small piece of iron wire. Subsequently, Fischer observed two different events that occurred in concert. In the first place, the surrounding solution entered the tube through the bladder and raised its level for about three inches. In the second place however, Fischer observed that the acid was oxidizing the iron wire, which now began to dissolve gradually. Identical results were obtained while using pieces of silver, copper and zinc. The simultaneous events of the increasing level in the tube and the oxidation of the metals, suggested that both events were interrelated. This was an indication for Fischer that the underlying process of the entire phenomenon, "that goes on between the applied liquids and metals", was probably chemical in nature.[195] Yet, Fischer refrained from any further attempt to explain what was precisely going on.

It was Magnus who provided the explanation in retrospective. What actually happened during Fischer's experiment was that the acid moved from the solution, through the bladder, towards the metal that ought to be oxidized. At this point the liquid levels remained at their initial height. Next, the metal dissolved under influence of the acid, which caused a constant

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[193] Anonymous, "Sur uelques phénomènes de capillarité" by M. Magnus, *Bulletin des Sciences Mathématiques, Astronomiques, Physiques et Chimiques*, Tome 9 (1828):175.

[194] Editorial footnote from either Gay-Lussac or Arago to: G. Magnus, "Sur quelques Phénomènes de Capillarité", *Annales de Chimie et de Physique*, Tome 51 (1832):166.

[195] N. W. Fischer, "Ueber die Wiederherstellung eines Metalls":304.

release of solute metal parts. After a little while, the metal concentration reached such a critical height that it prompted the liquid to flow from one side of the bladder towards the other. Once arrived at this point, the phenomenon did not differ any more from other observations of osmosis.[196]

About five years later, the exact line of reasoning convinced Dutrochet of the fact that electricity could no longer be the inevitable cause of osmosis. In an article titled *Investigations of endosmose and of its physical cause*, Dutrochet officially distanced himself from his earlier conviction.[197] The decision was surrounded by a sense of defeat. It was clear to everyone, including to Dutrochet himself, that he was the last man standing to defend the potential electrical nature of osmosis. In order to spare himself the casual 'we-told-you-so', he chose to open his article with a general comment on the methods of science.

> Many physicists have sought to determine the physical cause of endosmose; but it should be noted that everyone who has dealt with this problem, has looked for the solution in a rational way and not in an experimental way. The latter approach is however the only one that can lead to reliable results, since a rational explanation that apparently satisfies all conditions of a phenomenon, might nevertheless be wrong.[198]

Even though Dutrochet's investigations led him to the electrical explanation, at least he had wandered along the right track in order to tackle the phenomenon. He could defend his former choices with dignity, while he was able to accuse his colleagues of neglecting experimentalism as the only right approach. This, in fact, was true. Dutrochet had been the only one who had experimentally scrutinized every detail of osmosis, while by far most of his antagonists (Poisson, Saigey, Raspail, Magendie etc.) had made their claims from behind their desks.

Following a general synthesis of five years of osmotic research, Dutrochet finally returned to the galvanic experiments of Porrett. We saw that in 1816, Porrett had used an electrical current to induce phenomena that were virtually identical to Dutrochet's observations. This resemblance had invoked the latter's idea of an electrical nature in the first place. Now however, Dutrochet laid down a reinterpretation of Porrett's results, which removed electricity from the very heart of osmosis, and turned it into something that could be epiphenomenal at best.

There were two experiments in particular that helped Dutrochet arrive at his new conclusion. In the first, Dutrochet took his endosmometer and filled both the interior and the exterior with water. Both sides of the

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[196] Magnus, "Ueber einige Erscheinungen":168.

[197] Henri Dutrochet, "Recherchers sur l'Endosmose et sur la cause physique de ce phénomène", *Annales de Chimie et de Physique*, Tome 49 (1832):411-437.

[198] Henri Dutrochet, "Recherchers sur l'Endosmose":411-412.

membrane thus stored one and the same fluid. Yet, as soon as he applied an electrical current, Dutrochet saw that the water began to accumulate at the negative pole. It was a remarkable manifestation of osmosis, since osmosis generally required two different fluids, while this experiment succeeded solely on the basis of water. This puzzling situation could only mean two things: either the requirement of two distinguishable fluids proved a false condition for osmosis, or the electricity possessed a particular and unknown property that somehow generated those two fluids.

> Later, while thinking about what possible cause Porrett's phenomenon and endosmosis could have in common, I came to believe that electricity could never be the immediate cause of Porrett's phenomenon. In this circumstance it only produced the heterogeneity between the two liquids of which one was subject to the positive pole and the other the negative pole.[199]

Dutrochet thus reconsidered the very role played by the electrical current. The ultimate evidence in support of his new hypothesis came with the second experiment. Nothing much was changed with respect to the former setup, with the exception that Dutrochet colored the water with an organic dye that was derived from a plant, specifically a species of violets. This adjustment, however small it might seem, was a vital step towards the elucidation of the role of electricity. The violet dye ("*matière colorante des violettes*") was known for its sensitivity to acidity and alkalinity and functioned basically as our contemporary pH indicators, meaning that its initial blue color changed depending on the degree of acidity. The experiment suddenly visualized in the clearest sense possible why Porrett's and Dutrochet's experiments had been so much alike. When Dutrochet finally applied the electrical current, he saw to his surprise that the color of the water began to change. Inside the endosmometer, at the negative pole, the color had changed from blue to red, which indicated an alkaline environment. At the other side of the bladder the color had changed from blue to green, which suggested a sudden increase in the degree of acidity. These changes could only imply one thing, namely that the composition of the water had changed. Being formerly homogeneous, the water had changed into a heterogeneous composition that contained both acid and alkaline substances. Every ground for doubt had suddenly vanished. Not electricity, but the heterogeneity of the fluids gave rise to osmosis. The electrical current had only helped invoking this heterogeneity.

> Hence, electricity could not be the immediate cause of endosmose here; it could only be its remote cause. It just produces the heterogeneity between the two liquids, and it is this heterogeneity that transports the liquids like happened in the endosmotic experiments, of which the discovery belongs to me. [...] It follows

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[199] Henri Dutrochet, "Recherchers sur l'Endosmose":421-422.

> from here that the action of the [voltaic] pile decomposes a dissolved salt into the water that is separated into two parts by a membrane. The pile carries the acid to the positive pole and the alkali to the negative pole – the acid liquid is always carried to the alkaline liquid through endosmose.[200]

Dutrochet came in fact very close to the explanation Magnus provided a few years earlier. Whereas Magnus talked about a 'solution of reduced metal' that eventually initiated osmosis, Dutrochet believed it to be the 'dissolved salt' of the voltaic pile that he used in his experiments. And much in line with his former opponents, Dutrochet now claimed that one of the conditions for osmosis indeed seemed to be that the fluids possessed different capillary properties.[201]

With this publication in 1832, Dutrochet finally revoked his earlier position. It could safely be said that six years after the discovery of osmosis, at least one recurrent theme in the controversy was ultimately agreed upon: electricity could be eliminated as a possible cause. Dutrochet's sudden conversion was received with enthusiasm: a few months after the news became known in Germany, Poggendorff remarked that the period of Dutrochet's stubbornness [*Hartnäckigkeit*] was finally over.

3.2 Revival of interest

It is hard to tell when controversies come to an end, and it is often equally hard to distinguish a winner from a loser.[202] This verdict also applies to the case of osmosis. There was no definite closure of the controversy; rather, the whole debate came slowly to a halt, with less and less people paying attention. And whether Dutrochet came out as a winner depends, quite ordinarily, on the perspective one takes on the whole affair. In France, osmosis never overcame its status as a peculiar manifestation of absorption and capillarity, and in Germany things were not better. Although his German colleagues were prepared to lend osmosis the *sui generis* status Dutrochet had repeatedly called for, this move simultaneously pushed Dutrochet to the margins. Besides, the 1830s had not yielded particular fruitful studies on osmosis, apart from a prize-winning essay from the hand of a young Danish chemist who was endorsed by Hans Christian Ørsted (1777-1851).[203]

Yet, a revival of interest in Dutrochet's work came from an unexpected corner. In the early 1840s, a group of young German physiologists discovered some particular merits that until then had been grossly overlooked. It were

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[200] Henri Dutrochet, "Recherchers sur l'Endosmose":422-423.

[201] Henri Dutrochet, "Recherchers sur l'Endosmose":423.

[202] Bruno Latour, "Pasteur et Pouchet : hétérogenèse de l'histoire des sciences", in Michel Serres (ed.), *Eléments d'histoire des sciences* (Paris : Bordas, 1989):424.

[203] E.B. Jerichau, "Ueber das Zusammenströmen flüssiger Körper, welche durch poröse Lamellen getrennt sind", *Annalen der Physik und Chemie* 110 (1835):613-627.

however not so much Dutrochet's experiments or results that appealed to these young men. Rather, they were after some conceptual insights Dutrochet had offered concerning the place of osmosis in physiology, and the implications that had for the carefully constructed border that still separated the organic world from the inorganic. These young physiologists, Hermann Helmholtz (1821-1894), Emil du Bois-Reymond (1818-1896), Ernst Brücke (1819-1896) and Carl Ludwig (1816-1895) broke with the teleomechanist and romantic paradigm that had dominated German physiology until the second half of the nineteenth century. Instead, they proposed a shift towards a more reductionist and deterministic philosophical framework on which physiology had to be based.[204] The group declared: "We four imagined that we should constitute Physiology on a chemico-physical foundation and give it equal scientific rank with Physics".[205] Organisms should therefore be approached as complex machines, of which parts could be isolated and mechanisms could be unravelled through chemico-physical methods.

Even though these thoughts were articulated towards the end of the 1840s, the seed for this new approach had been planted about a decade earlier. One significant source from which this new generation drew its inspiration was Dutrochet; and especially the latter's work on osmosis served as a fruitful model that demonstrated how to overcome the teleomechanist physiology in which they had received their training.

Right from the beginning, Dutrochet had emphasized the unique position of osmosis in the sciences. According to the explanations offered in his *l'Agent,* osmosis united the worlds of the organic and the inorganic as a physical-organic phenomenon. At first this meant for Dutrochet that osmosis was the actual and immediate agent through which these domains were simply interconnected. But not long after he had outlined his position at the Academy session in October 1826, he encountered new facts that made him rethink his position. Dutrochet had found that inorganic materials were equally qualified as animal bladders to function as suitable membranes. This simple fact had far-reaching consequences, for as long as bladders were used, no one could dispute that osmosis was an organic phenomenon. Dutrochet discovered therefore much to his surprise that he was able to reproduce the phenomenon in its entirety by exclusively employing dead and inorganic materials. On 15 January 1827, he publicly rectified his ideas at the

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[204] Paul F. Cranefield, "The Organic Physics of 1847 and the Biophysics of Today", *Journal of the History of Medicine and Allied Sciences* 12 (1957):407-423; David H. Galaty, "The Philosphical Basis of Mid-Nineteenth Century German Reductionism", *Journal of the History of Medicine and Allied Sciences* 29 (1974):295-316; B. Theunissen, R.P.W. Visser, *De wetten van het leven : Historische grondslagen van de biologie 1750-1950* (Baarn : Ambo, 1996):119-126; Garland E. Allen, *Life Science in The Twentieth Century* (Cambridge : CUP, 1975):xvi.

[205] Carl Ludwig in John Burdon-Sanderson, *A Memoir by the Late Lady Burdon Sanderson* (Oxford : Clarendon Press, 1911):281.

Academy.[206] Osmosis was no longer a physical-organic phenomenon, but had become a phenomenon with a mere physical character and a chief physiological function.

A few months later, Dutrochet was prepared to distance himself from Bichat's vitalism in the clearest terms possible:

> As endosmosis/ exosmosis produced using thin strips of inorganic material permeable to liquids is the same as that produced by, for example, organic membranes, it is not exclusively an organic phenomenon, but has its origins in general physics. [...] The physical processes of living and inorganic matter merge in endosmosis and exosmosis. The further we advance in our understanding of physiology, the more reasons we will have to revise the opinion – whose major proponent is Monsieur Bichat – that life and physical phenomena are essentially different. It is undoubtedly false.[207]

Dutrochet let go of his notion of the immediate agent, and began instead to think of osmosis as something that, more precisely, represented the very fluidity of the border that so rigorously isolated the animate world from that of dead matter. If osmosis eventually was physical in nature while it played such a vital role in physiology, it implied that physical laws operated in the organic world after all. The humble discovery of the osmotic action of thin strips of inorganic material eventually opened, more than ever before, the doors for physics and chemistry to enter physiology. At least, as far as it concerned Dutrochet, because his contemporaries demonstrated much less interest in the matter. Only a small comment appeared in the annual report of the Academie, while Magendie even remarked in 1833 that Dutrochet had obstructed the advance of experimental physiology with his suppositions.[208]

Pickstone, who analysed the rivalry between Magendie and Dutrochet in more detail, believed that their disagreement boiled down to a fundamental difference in their respective approaches of the boundary-issues that arose between physiology and physics. Whereas Magendie continuously sought to translate physics into physiology, Dutrochet rather tried to discover elements of physics in his physiology.[209] Although the difference seems small, in the end it meant that for Dutrochet not every part of physiology was directly viable for a physical incarnation. Osmosis was physical in nature, not because it could be explained by other physical

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[206] Académie des Sciences. *Procès-Verbaux des Séances de l'Académie*, Tome 8, Années 1824-1827 (Hendaye : Imprimerie de l'Observatoire d'Abbadia, 1918):481.

[207] Henri Dutrochet, "New observations on endosmosis and exosmosis, and on the cause of this dual phenomenon", trans. anonymous, *Journal of Membrane Science* 100 (1995):7.

[208] Cuvier, "Analyse des travaux de l'Académie pendant l'année 1827", *Memoires de l'Académie des Sciences de l'Institut de France*, Tome 10 (Paris : Firmin Didot Frères, 1831): cxx; Magendie, *Précis élémentaire de physiologie*, Tome 1, 3rd ed. (Paris : Méquignon-Marvis, 1833):14.

[209] J.V. Pickstone, "Absorption and Osmosis: French Physiology and Physics in the Early Nineteenth Century", *The Physiologist* 20 (1977):36.

phenomena, but because it could be reproduced outside the organic world while its main field of action was and remained physiology.[210]

For a long time it remained silent around this issue. Despite the fact that Dutrochet made an honest attempt at falsifying the vitalistic programme of Bichat, it took a decade before someone took genuine interest in the way Dutrochet positioned the science of physiology. The interest eventually came from Berlin, more specifically from the new generation of reductionist-oriented physiologists. The first who turned to Dutrochet was Emile du Bois-Reymond. In 1841 he wrote to a college friend that, in the light of the current debate over the physiological programme, he tended to agree with Dutrochet's remarks on the matter.

> I want your opinion about the (latent) dispute between Henle, Stilling, Schwann one the one hand and Reichert on the other, concerning the physical conditions [Verhältnisse] of the organisms. I gradually returned to Dutrochet's view: "The further we advance in our understanding of physiology, the more reasons we will have to revise the opinion that life and physical phenomena are essentially different". It is evidently the direction Schwann and Henle endeavour to take.[211]

The debate that Bois-Reymond mentioned in this passage eventually marked a significant watershed in the nineteenth-century development of physiology. All people mentioned in this passage, from Henle to Reichert, had received their training in teleomechanist physiology. Characteristic of this physiological paradigm was the idea that every part of an organism stood in connection to the other parts. This interdependence implied that the entire organism was, in fact, *organised*. Organic nature appeared to be driven towards a goal and it was exactly this sort of organisation that was lacking in dead matter. This meant that German physiology, during the first half of the nineteenth century, was mainly concerned with the functional organisation of organisms. Not the question of *how* organs worked was worthy of answering; this question was rather overshadowed by attempts to elucidate the organs' integral *function*. The practical consequences of this research programme proved to be a main disinterest in experiments, and an even bigger neglect of physics and chemistry. This changed a little when Johannes Müller (1801-1858) established himself as one of the most influential physiologist during the 1830s and 40s. He saw the potential of experiments as a tool to elucidate the functionality of the organ, but never made the step

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[210] J.V. Pickstone, "Locating Dutrochet", review of Joseph Schiller, Tetty Schiller, *Henri Dutrochet (Henri du Trochet 1776-1847) : Le matérialisme mécaniste et la physiologie générale* (Paris : Albert Blanchard, 1975), *The British Journal for the History of Science* 11 (1978):61.

[211] Emile du Bois-Reymond in: Estelle du Bois-Reymond, *Jugendbriefe von Emil du Bois-Reymond an Eduard Hallman* (Berlin : Dietrich Reimer, 1918):98.

to experimentally investigate the underlying mechanisms. This last step was made by his pupils, who formed the core of a new generation of physiologists that sought salvation in a reductionist approach to physiology during the 1840s. The dissatisfaction with their predecessors' teleomechanist paradigm grew more and more, as did their belief in the extensive explanatory possibilities that were offered by chemistry and physics.[212]

Such was the situation when du Bois-Reymond mentioned the debate over the physical conditions of organisms. On the one hand there were Henle, Stilling and Schwann, together with Helmholtz, Luwdwig and Brücke, who advocated the adoption of a reductionist programme, and on the other hand there were Reichert and Müller who were very sceptical about the things that could be accomplished by mere experimentation.[213] And at last there was Dutrochet, whose remarks about the advance of physiology resonated in the mind of the young Emile du Bois-Reymond.

But du Bois-Reymond was not the only one who had been fascinated by Dutrochet. Two of his friends took the re-appreciation of the French physiologist to the next level. One of them was Ernst Brücke, who in 1842 delivered a dissertation on the diffusion of fluids through dead and living septa.[214] An important part of this dissertation consisted, like its title suggested, of a discussion of Dutrochet's work on osmosis. And although Brücke remained critical, the following words of praise befell Dutrochet:

> [I]t cannot be denied that Dutrochet by his writings opened a new treasure-house of physiology which the labour of generations will scarcely exhaust, for he grasped that the parts of the living body are not properly divided into solids and liquids but more correctly into contained and containing parts; that the living body was composed of cells, not cavities continuous one with another but vesicles placed side by side; and that the diffusion of fluids through their walls, in the living body, belongs to statics and mechanics no less than do simple capillary attraction and that mechanical force by which the circulation of the blood is ruled and the individual parts of the body can be rendered flaccid and turgid.[215]

With this dissertation, Brücke not only prepared the grounds for a revival of Dutrochet's work among the German physiologists, he also established osmosis as an exemplary model for the reductionist approach he and his

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[212] Timothy Lenoir, *The Strategy of Life : Teleology and Mechanics in Nineteenth Century German Biology* (Dordrecht : Reidel, 1982): Chapters 2-4; B. Theunissen, *De wetten van het leven*: Chapters 3,6.

[213] Timothy Lenoir, *The Strategy of Life*:219-228; David Galaty, "The Philosphical Basis":295-298.

[214] Ernst Brücke, *De diffusione humorum per septa mortua et viva* (Berlin : Schroeder, 1842).

[215] Translation of Ernst Brücke in: J.V. Pickstone, "Locating Dutrochet":61. Original passage: Ernst Brücke, *De diffusione humorum*:43.

fellows tried to put into practice. The diffusion of liquids in the living body was a simple act of statics and mechanics, just like capillary attraction was. No teleomechanist explanation was needed to understand the motion of blood or the turgidity of the cells; instead an answer in mere physical terms was enough. It was no coincidence that in the same year, du Bois-Reymond wrote that "Brücke and I have sworn to make prevail the truth that in the organism no other forces are effective than the purely physical-chemical".[216]

Brücke's gesture was soon taken over by Carl Ludwig, the other proponent of the reductionist movement. He used Brücke's results in his own dissertation on kidney function that he delivered in 1842.[217] The choice for this topic did not come out of nowhere, but was a straightforward attack on one of the prime examples the teleomechanist physiologists employed in their defence. The fact that the kidney was able to selectively secrete harmful substances from the blood proved to them that its complex workings could not be reduced to mere physics or chemistry, but instead, that other, i.e. organic, forces directed its function. When Carl Ludwig completed his dissertation, he demonstrated that this teleomechanist assumption was simply not true. Instead, the kidney function was perfectly explainable by physics and chemistry, and there was no need for teleomechanist assumptions. Rather, the kidney must be understood as a 'hydraulic device for mechanically filtering the blood'.[218] But what exactly was the force that initiated this filtering function?

> When we penetrate into the question that lies before us – what is the source of the force of the urinary secretion? – it is necessary to, once again, think about the functioning of the forces, which until now had been declared as causes for secretion. People assume that there are a vital, a chemical and a mechanical force, by which the secretion of fluid through the membranes of the blood and gland vessels takes place.[219]

Without paying too much attention to it, Ludwig abolished the vital force as something that appeared to be "absurd in the current state of physiology".[220] Although nothing was *a priori* improbable in nature, the vital-force explanation was insufficient. Indeed, the adequate explanation revealed

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[216] Translation of Emile du Bois-Reymond in: Paul F. Cranefield, "The Organic Physics of 1847":408. Original passage: Estelle du Bois-Reymond, *Jugendbriefe von Emil du Bois-Reymond*:108.

[217] Carl Ludwig, *De viribus physicis secretionem urinae adjuvantibus* (Marburg, 1842).

[218] Timothy Lenoir, "Science for the Clinic : Science Policy and the Formation of Carl Ludwig's Institute in Leipzig", in William Coleman, Frederic L. Holmes (eds.), *The Investigative Enterprise : Experimental Physiology in Nineteenth-Century Medicine* (Berkeley : University of California Press, 1988):151-152.

[219] C. Ludwig, *Beiträge zur Lehre vom Mechanismus der Harnsecretion* (Marburg, 1843):19

[220] C. Ludwig, *Beiträge*:21-22.

another force that was more in harmony with the new, reductionist programme. Ultimately, this proved to be osmosis. Ludwig demonstrated through the "strict physical method of proof" that it was exactly this chemical force, that stood at the basis of the filtering function of the kidney.[221]

Although the above cases were only discussed briefly, from a general point of view it appears that Brücke's and Ludwig's recovery of osmosis had a lasting impact. They saw in osmosis an ideal candidate for the physiology they envisioned, which rendered the assumptions of the teleomechanist paradigm superfluous. Over a decade later, the Dutch chemist Tjaden Modderman (1831-1925) wrote that it was thanks to the efforts of these German physiologists that osmosis was permanently on the map, even though still little was known about the phenomenon.[222] Indeed, the new generation of physiologists succeeded where Dutrochet had failed. The anti-campaign of Raspail and Saigey did not provide the definitive answer to osmosis, but neither did Dutrochet. It was in the reductionist climate of the 1840s that osmosis was finally able to flourish.

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[221] C. Ludwig, *Beiträge*:32-37.

[222] Tjaden Modderman, *De leer der osmose* (Leeuwarden : Suringar, 1857):ii.

Transcending the Margins: A Conclusion

The adoption of osmosis by the German reductionists ensured a remaining interest in the phenomenon that would not disappear for the rest of the nineteenth century. After Brücke and Ludwig published their dissertations in the early forties, an exponential growth of osmotic studies developed on German soil that soon spread internationally.[223] In 1848, the German chemist Justus von Liebig (1803-1873), published a small book in which he dealt with the causes of the liquid motions in animals. A surprisingly large part of his argument relied on osmosis.[224] In 1849, the German physicist and future teacher of Max Planck, Philipp von Jolly (1809-1884) acknowledged that osmosis occupied an important place in plant and animal life.[225] In 1854, the British chemist Thomas Graham (1805-1869) spent a *Bakerian Lecture* talking about osmosis in which he confirmed Jolly's statement, and added that osmosis possessed the useful property of transforming chemical affinity into mechanical power: "Now, what is more wanted in the theory of animal functions than a mechanism for obtaining motive power from chemical decomposition as it occurs in tissues?"[226] In 1867, the German chemist Mortiz Traube (1826-1894) was able to engineer an artificial membrane that substituted the animal bladders that were so often used in the osmotic experiments. With these membranes, Traube manufactured models of living cells that were considered so important, that they even appealed to Karl Marx (1818-1883) and Friedrich Engels (1820-1895) for philosophical reasons. According to them, Traube's artificial cells demonstrated clearly that the process of 'organic metabolism' was a lifeless function, while it was formerly regarded as the "most characteristic phenomenon of life".[227]

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[223] For detailed bibliographies on the history of osmosis, see: Tjaden Modderman, *De leer der osmose* (Leeuwarden : Suringar, 1857); Emmanuel Doumerc, *Étude sur l'osmose des liquides au point de vue historique, physique et de ses principales applications* (Bordeaux, 1881); Joseph Schiller, Tetty Schiller, *Henri Dutrochet (Henri du Trochet 1776-1847) : Le matérialisme mécaniste et la physiologie générale* (Paris : Albert Blanchard, 1975).

[224] Justus von Liebig, *Untersuchungen über einige Ursachen der Säftebewegung im thierischen Organismus* (Braunschweig : Friedrich Vieweg und Sohn, 1848).

[225] Ph. Jolly, "Experimental – Untersuchungen über Endosmose", *Zeitschrift für rationelle Medicin* 7 (1849): 83. For the teacher of Max Planck, see: J.L. Heilbron, *The Dilemmas of an Upright Man : Max Plank as Spokesman for German Science* (Berkeley : University of California Press, 1986):10.

[226] The *Bakerian Lectures* were organized at the London Royal Society, and were considered honorable occasions. For the lecture, see: Thomas Graham, "The Bakerian Lecture – On osmotic Force", *Philosophical Transactions of the Royal Society of London* 144 (1854):227.

[227] Moritz Traube, "Experimente zur Theorie der Zellenbildung und Endosmose", (pub. 1867), in *Gesammelte Abhandlungen* (Berlin : Mayer und Müller, 1899):213-277. Concerning the organic/inorganic debate, Engels took Traube's artificial cells as an example that argued

Meanwhile, one of the most prominent figures in late nineteenth-century plant physiology, Julius Sachs (1832-1897), discovered that the turgidity of plant cells was also closely related to osmosis.[228] Sachs, in his turn was the teacher of both Hugo de Vries (1848-1935) and Wilhelm Pfeffer (1845-1920), who picked up the study of osmosis and brought it to the attention of the Dutch chemist Jacobus Henricus van 't Hoff (1852-1911).[229] The latter derived a law for the osmotic pressure, for which he was awarded the first Nobel Prize in the history of chemistry.[230]

Even though this sketchy portrait of osmosis needs much more study, it nevertheless discloses the urgency with which the initial question of this thesis was posed. Because how could a phenomenon, that initially proved to be a mere source of controversy, develop into a phenomenon whose importance was generally recognized? It was clear that at the turn of the twentieth century, osmosis had built an impressive track record. It helped solving an important chemical puzzle by revealing that the behavior of gases was analogous to that of solutions, and it became one of the bridges that connected the life sciences to the physical sciences. In his Nobel Prize lecture, van 't Hoff remarked that "[w]hereas application of the laws of osmosis has proved very fruitful in the field of chemistry, what De Vries and Donders emphasized 15 years ago, namely that osmotic pressure plays a fundamental role in plant and animal life, has since been fully confirmed as well."[231] Although this quote could as well be extended to include Dutrochet – who had emphasized the fundamental role of osmosis from the very beginning – it nevertheless reveals much of the importance that people assigned to the phenomenon at the end of the nineteenth century.

It is worthwhile to take a closer look at the origins and dynamics of the controversy before we return to the initial question. It has been suggested in the introduction that much of the controversy might be better understood

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against such distinction: "Exchange of matter also takes place in the passage of fluids through dead organic and even through inorganic membranes, as in Traube's artificial cells. Here too it is clear that we cannot get any further by means of exchange of matter; for the special exchange of matter which is to explain life itself needs in turn to be explained through life." See: Frederick Engels, *Herr Eugen Dühring's Revolution in Science [Anti-Dühring]*, (pub. 1878) trans. Emile Burns (New York : International Publishers, 1907):93-94.

[228] Julius Sachs, "Ueber das Bewegungsorgan und die periodischen Bewegungen der Blätter von *Phanseolus* und *Oxalis*", *Botanische Zeitung* 15 (20 November 1857):809.

[229] Hugo de Vries, *Untersuchungen über die mechanischen Ursachen der Zellstreckung* (Leipzig : Wilhelm Engelmann, 1977); Wilhelm Pfeffer, *Osmotische Untersuchungen : Studien zur Zellmechanik* (Leipzig : Wilhelm Engelmann, 1977).

[230] J.H. van ‘t Hoff, “L’équilibre chimique dans les systèmes gazeux ou dissous à l’état dilué”, *Archives Néerlandaises des Sciences exactes et naturelles* 20 (1885):239; J.H. van 't Hoff, “Die Rolle des osmotischen Druckes in der Analogie zwischen Lösungen und Gasen”, *Zeitschrift für physikalische Chemie* 1 (1887):481.

[231] J.H. van 't Hoff, *Osmotic pressure and chemical equilibrium*, Nobel Lecture (December 13, 1901):10. URL: http://www.nobelprize.org/nobel_prizes/chemistry/laureates/1901/hoff-lecture.pdf. Consulted 17-03-2015.

with the help of a sociological concept, namely that of marginality. Primarily, because Dutrochet was a marginal figure who resided, both figuratively and literally, outside the center of the scientific community. Not only did he live outside of Paris, he also frequently ventilated controversial ideas. In the second place the concept of marginality is valuable to us, because of the mechanisms that are understood to come with it.

These mechanisms become visible as soon as we stop to perceive the margin as a static position that is completely cut off from the center. On the contrary, there is a continuous dialogue going on between the marginal figure and the authorities at the center, while both relate to each other in a precarious equilibrium that only can be sustained under mutual agreement. As several sociologists pointed out, the marginal should not be regarded as an excluded victim, but rather as someone who voluntarily positions himself outside the center for the advantages that come with that position, such as prospects of originality, independence, creativity and unorthodoxy etc.[232] The center, in its turn, allows for these deviating positions because their very existence reaffirms the norm, i.e. the margin provides the confirmation of the dominant position.[233]

In order to keep the dialogue going with the center, the marginal has to switch continually between two conflicting interests. According to the sociologists Jaap Bos and Leendert Groenendijk this amounts to the following problem: "[i]n a relationship of marginality, the marginal always struggles with the problem of how to contribute something to the doxa, without, at the same time, undermining his own position."[234] On the one hand, the marginal thus has to preserve his own originality and independence by keeping his distance from the center, while on the other hand he needs to preserve a sense of commitment towards the center to keep the dialogue open.[235]

As soon as we take a closer look at the way Dutrochet maneuvered through the controversy, the same struggle appears that is so typical of the marginal. On the one hand, Dutrochet continuously tried to establish his own independence. He did this, among other things, by articulating the idiosyncratic ideas about the unification of plant and animal physiology, and the gospel concerning the immediate agent of life. But there is more to be found in the controversy. For instance, Dutrochet continued fiercely to defend the electrical explanation he initially proposed, despite the fact that virtually every other scientist disagreed and pointed at capillarity and viscosity as more plausible alternatives. Even more illustrative is Dutrochet's decision to place osmosis at the basis of absorption. The fundamental

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[232] Neil McLaughlin, "Optimal Marginality : Innovation and Orthodoxy in Fromm's Revision of Psychoanalysis", *The Sociological Quarterly* 42 (2001):272-274.

[233] Jaap Bos, David W. Park, Petteri Pietikainen, "Strategic Self-Marginalization : The Case of Psychoanalysis", *Journal of the History of the Behavioral Sciences* 41 (2005):222.

[234] Jaap Bos, Leendert Groenendijk,"Marginalization Through Psychoanalysis: An Introduction", in Jaap Bos, Leendert Groenendijk (eds.), *The Self-Marginalization of Wilhelm Stekel : Freudian Circles Inside and Out* (New York : Springer, 2007):6.

[235] Jaap Bos, David W. Park, Petteri Pietikainen, "Strategic Self-Marginalization":208-211.

character of absorption was widely accepted and guarded by Magendie and others, which made that Dutrochet's attempt to restructure this ontology could very well be explained as a straightforward attack on the status quo. On the other hand however, there are also plenty of examples available that demonstrate Dutrochet's attraction to the center of the scientific community. He continually made attempts to enter the Academy as a member, and sought the support of this very institute with his application for the Montyon prize. Moreover, Dutrochet made several concessions to his opponents in order to create a middle ground. He gradually allowed for capillarity to join the osmotic equation, albeit under strict conditions that safeguarded his electrical explanation. But the best token of Dutrochet's commitment is maybe revealed in the way he responded to his critics. Dutrochet always took his opponents seriously. The condescending tone of Raspail and Saigey was answered with politeness, while the often incautiously formulated criticism was rebutted by extensive and detailed reports shored up with new experimental data.

Dutrochet performed a balancing act between his own independence and his loyalty to the Academy while osmosis was caught in the middle of it. On the one hand, he persistently tried in every possible way to propel osmosis to the heart of physiology. Dutrochet strove for acknowledgement of osmosis, while knowing that at the same time he fully depended on the cooperation of his opponents at the center of the scientific community. On the other hand, Dutrochet wanted to remain in full control. Osmosis was his discovery, and he knew that he would sign his own capitulation at the moment he would transfer his authority over to others. This mission was however doomed to fail, because Dutrochet had to exert his power from a marginal position. He thus lacked the necessary momentum to accomplish his goal.

Meanwhile, part of the answer to our question becomes visible. If we want to understand how osmosis developed into an accepted phenomenon, we should start with the recognition that the controversy over osmosis was one that played between the margins and the center. As a result, osmosis had to be picked up from the margins in which it was found. This is what finally happened in Germany. Through the reevaluation of Magnus in 1827, osmosis proved ultimately able to transcend the margins. But in order to do so, it had to overcome its exclusive association with Dutrochet. The great advantage of Magnus' interference was therefore, that he reattached osmosis to a series of less controversial, and already accepted observations. These observations, made by Parrot, Döbereiner, Fischer and Sömmering, were the ultimate vehicle that transferred osmosis to the center. The irony of the whole situation was however that, while Dutrochet got what he wanted, he had to pay with giving up his own independence. This was an intriguing trade-off. Osmosis became accepted as *sui generis*, but this could only happen by pushing Dutrochet even further into the margins. His priority claim was dismissed; his explanation rejected, and he suddenly had to join a queue of apparent predecessors.

Even though Magnus' article was the first step that put osmosis on the scientific map, a true revival of interest developed only in the early 1840s, after a decade in which the attention for osmosis seemed to have slightly ebbed away. What appealed to the young German physiologists who initiated this revival, was that osmosis crossed the same boundaries they were looking for to cross. Osmosis was a chemico-physical phenomenon in physiological clothes. It united several chemists, physicists and physiologists in their common role to elucidate its functions and mechanisms, but at the same time, and exactly through this merger, osmosis revealed something else that was very crucial to the understanding of physiology as a science. While it crossed the disciplinary boundaries, it also crossed a boundary on a paradigmatic level. The discovery of osmosis reinforced the belief that a rigid separation between organic and inorganic matter was uncalled for.

In fact, Dutrochet had recognized much of these boundary-features at an earlier stage. After he presented his first interpretation of osmosis as the immediate agent of the vital movement, Dutrochet completely reversed his opinion when he found that mere inorganic materials were able to produce osmosis as well. In 1827, he distanced himself from Bichat's vitalism in the clearest terms possible, and in several articles he kept insisting on the fact that osmosis was a promising exclave of physics in physiology. In France however, nobody paid much attention to these ideas. The same happened when osmosis arrived in Germany for the first time. The reason for this lack of attention might have something to do with Dutrochet's marginality and failing authority. In France, the generally respected Magendie articulated his discontent with Dutrochet's peculiar opinions, while the German chemists trivialized so much of his discovery that they probably could not care less about Dutrochet's philosophical ideas. However, what remains clear is that it was in the reductionist environment of the 1840s – almost fifteen years after Dutrochet made the necessary amendments – that the boundary-crossing features of osmosis became fully recognized. Osmosis provided Brücke, du Bois-Reymond and Ludwig with a unique possibility to put their reductionist ideals to work. They looked for ways to traverse the gap with the physical sciences, and osmosis presented them with a ready-made bridge.

It is time to formulate the final answer to the initial question. In brief, we could distinguish three crucial moments that turned osmosis into the important phenomenon it proved to be during the remainder of the nineteenth century. In the first place, osmosis had to overcome its exclusive association with Dutrochet in order to transcend the margins. This happened through Magnus' reevaluation of osmosis, which at the same time secured its sui generis acceptation. In the second place, Dutrochet drastically revised his interpretation of osmosis as a vital agent. He observed that osmosis did not at all point in the direction of the vital force, but instead implied its redundancy.

This drastic reinterpretation of osmosis triggered the attention of Brücke, Ludwig and du Bois-Reymond, who placed osmosis at the center of scientific attention, and revealed the true potential of osmosis as a phenomenon that not only merged physiology with chemistry and physics, but also erased the strict separation between dead matter and organisms.

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