Antoine Béchamp: père de la biologie. Oui ou non?

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There is an alternative medicine lobby that, in conjunction with antivivisectionists, believes Louis Pasteur to have been a fraud [R. Bottomley's *You Don't* Have *to Feel Unwell!* (Newleaf, 1994) is a recent example]. They frame their accusations around a rivalry between Pasteur and a contemporary, Antoine Béchamp, from whom they suggest Pasteur stole his ideas and then distorted them for his own purposes. This article explores some aspects of the controversies between Béchamp and Pasteur.

Claims of priority and of the stealing of ideas in science, as seen in a recent article by R.J.P. Williams[1] concerning the central mechanism of oxidative phosphorylation, are not new. An International Medical Congress was held in London in the summer of 1881. Describing a session concerning the role of bacteria in disease, Professor Antoine Béchamp from Lille subsequently wrote:

> M. Pasteur began to lecture and suddenly, in my presence, before I had said a word, he condemned me in a general anathema towards all aspects of heterogenesis[2]. I was waiting to speak, because I was due to lecture after him. But soon I was obliged to go down from my place to the front to sit opposite M. Pasteur because he had dared to say 'that even if there were any points in my results, I had only incorporated his ideas and made them mine'. In short M. Pasteur had just claimed a priority of views and made an accusation of unprecedented plagiarism. In an indignant voice I demanded of M. Pasteur to prove his assertion, since I would myself show him that the contrary was true. M. Pasteur, refusing a public discussion, left the session.[3]

Béchamp goes on to say that *The Times* of 8 August carried full details of the incident.

In fact, *The Times* report[4] was more restrained[5] and the summary of Pasteur's lecture (delivered in French, as was Béchamp's) was directed towards criticism of the work of the Englishman, Henry Charlton Bastian[6]. However, Béchamp is reported to have 'affirmed that the microzymas in chalk did exist and that if Pasteur has not obtained such results it was because his experiments were badly conducted. Béchamp held that the cause of disease and death lay in the animal itself'. The report of the same session in the *British Medical Journal*[7] describes Béchamp as 'vindicating his claim to priority in the discovery of the organisms (microzymes) which caused the fermentation of milk. He also defended the accuracy of his experimental methods from the aspersions cast upon them by M. Pasteur.'[8]

Who was this Antoine Béchamp and what were the scientific differences of opinion and his ideas against which Pasteur so inveighed?

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Antoine Béchamp

Pierre Jacques Antoine Béchamp[9–11] was born the son of a miller at Bassing near Dienze (Moselle) on 18 October 1816 (Pasteur was born the son of a tanner in 1822). Between the ages of 7 and 18, he lived in Bucharest with an uncle who was an official to the ambassador. There, he began to study pharmacy. After the death of his uncle from cholera, he moved in 1834 to Strasbourg to continue his studies. In 1843, he opened a pharmacy (which existed up to the time of his death). For a period, he taught in various of the Faculties of the University of Strasbourg, in 1854 succeeding Pasteur (who had moved to Lille) as Professor of Chemistry in the Faculty of Science. He became doctor of science in 1853 and doctor of medicine in 1856, with the thesis *On the Albuminoids and Their Transformation Into Urea*, in which he showed that urea can be formed from albuminoids (proteinaceous materials) by oxidation with potassium permanganate[12].

In 1856, he was appointed professor of medical chemistry and pharmacy in the faculty of medicine of the University of Montpellier (Figure 1). In 1876, he became professor of medical chemistry and pharmacy, and Dean of the Free (Catholic) Faculty of Medicine in Lille until his retirement in 1886 amidst deep controversy. The rector of the Catholic University wanted to have Béchamp's book *Les Microzymas*[3], published in 1883, placed on the Index of prohibited reading for Catholics. The book, for which it is said Béchamp had difficulty in finding a publisher, had been written in anger following the London meeting, with a desire to set the record straight, as Béchamp saw it. His theories could not but cause excitement amongst Catholics, evolutionists, vitalists and materialists – quite an achievement! Although, with his son Joseph, Béchamp then resumed the pharmaceutical trade in Le Havre, after Joseph's death, he moved to Paris, where he was offered the use of a small laboratory at the Sorbonne in which he continued to work for some years. He died in 1908 aged 91.

Figure 1 Pierre Jacques Antoine Béchamp when Professor of Medical Chemistry and Pharmacy at the University of Montpellier (1857–1875).

In 1852, Béchamp had developed a cheap industrial process to produce aniline by the reduction of nitrobenzene with iron filings and acetic acid[13]. This method greatly contributed to the emergence of the synthetic dye industry. For this work, together with others, he was awarded (in 1864) the Daniel Dollfus Prize of the Société Industrielle de Mulhouse. He also first synthesized the organic derivative of arsenic, *p*-aminophenylarsonate (Figure 2), which was subsequently used in the treatment of trypanosomiasis[14].

Béchamp or Pasteur?

Béchamp believed that a question of pure chemistry often turns into one of 'subtle physiology'. Presumably, the same could be said of Pasteur, whose academic study of stereoisomerism led to his study of fermentation. Partly because of Pasteur's prestige and the pasteurian legend that developed after his death, when Béchamp died (in 1908, 13 years after Pasteur), the Johns Hopkins professor of medicine, Montague Leverson, was scandalized to find no mention of Béchamp's passing in the French press, although it was recorded in the *New York Herald*. In 1911, he prepared a manuscript entitled *The Debt of France to Béchamp*, which was taken over on his death by Ethel Douglas Hume and first published in 1923 under the title *Béchamp or Pasteur? A Lost Chapter in the History of Biology*[15]. Republished many times, most recently in 1996, it is largely a tirade against Pasteur for his supposed abuse of Béchamp. In effect, it uses Béchamp's concept of microzymes as a stalking horse to denounce Pasteur's germ theory.

Inversion of sucrose

Béchamp's concern was that it was he rather than Pasteur who had first shown the existence of airborne germs[16] that could secrete ferments (what we now call enzymes). The controversy dates from the 1850s. Béchamp was anxious to establish whether the partial inversion[17] (hydrolysis) to glucose and fructose of cane sugar dissolved in water and left to stand in stoppered bottles at room temperature for up to 9 months was the result of an action of water alone or had some other cause.

Béchamp's first published work on this topic[18] in 1855 was to show that, if he added 25% calcium or zinc chloride to the sucrose solution, no inversion was observed. In the solution without salts, a footnote in the table indicates that some mould appeared within a month but, in subsequent months, it did not increase in extent, although inversion was then taking place. At this date, it was known that acids could bring about inversion of sucrose. Béchamp concluded from this experiment that the acidity of salts was not comparable to the acidity of an acid, yet water acted on the sucrose by virtue of its acid nature, although not showing an acid reaction with coloured indicators. Béchamp was surprised to see no effect of zinc chloride because it did show an acid reaction. In this work, Béchamp makes no suggestion that the appearance of the mould was a significant factor in the occurrence of inversion. Whether the thought had passed through his mind we do not know, which is unfortunate, because it is this uncertainty that constitutes the basis of the controversy over priority between Béchamp and Pasteur.

In a subsequent paper[19], however, published at the beginning of 1858, he pointed out that experiments he had conducted since 1855 forced him to modify his earlier conclusions. He now believed that cold water alone does not invert sucrose but that the reaction when it occurs is the result of a 'true fermentation'. He concluded that moulds do not develop in the absence of air and that, in its absence, inversion does not occur, but that if simple solutions of sucrose are in contact with air then moulds develop and inversion occurs in proportion to the development of the mould. With these findings, also, Béchamp regarded himself as being the first to show the development of ferments in sugar solutions in the absence of proteinaceous material (i.e. that the ferment had to arise from the living cell).

Pasteur's work on fermentation

Controversy with Pasteur over priority of findings and explanations erupted several times and it is therefore necessary to look at Pasteur's activities in this period. Pasteur's entry into studies of fermentation had begun in 1855 in Lille. The pasteurian myth is that his interests in lactic fermentation sprang from a cry for help from local manufacturers facing difficulties. However, his first paper on the subject[20] late in 1857[21] begins by saying that he was led to look at fermentation following his previous

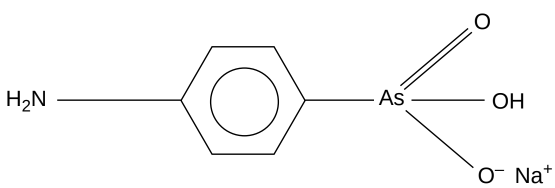

Figure 2 Structure of *p*-aminophenylarsonate.

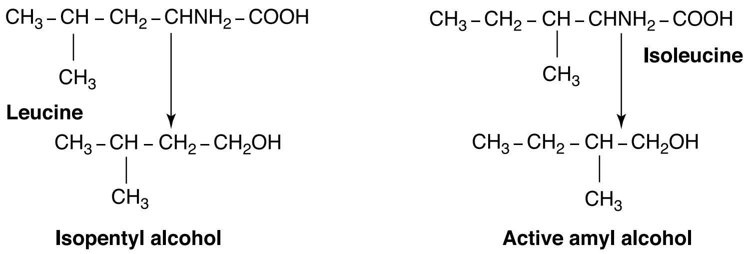

Figure 3 Structures of leucine and isoleucine, and the related amyl alcohols derived from them during fermentations. Another name for the amyl alcohols is fusel oil, an acrid oily liquid occurring in insufficiently distilled alcoholic liquors.

researches into the properties of the amyl alcohols (Figure 3) found in fermentation liquors and the crystallographic peculiarities of their derivatives. Either way, his point of entry was very different from that of Béchamp.

For the first time, in these studies of Pasteur, organisms different from beer yeast, namely the lactobacilli, were observed and identified as the origin of the lactic acid formed[20]. In these experiments, Pasteur had used a medium containing sugar, plus casein, fibrin or gluten, mixed with a yeast broth. It was in such media that Pasteur observed the growth of yeast cells and of the much smaller lactobacilli. It was not, however, immediately obvious to everyone from these experiments, even if it was to Pasteur, that it was the yeast or lactobacilli that were responsible for the fermentation as opposed to the albuminoid materials, as was maintained by the influential Justus von Liebig and others, except that whether alcohol or lactate was produced depended which form of 'globules' developed. Pasteur did in fact show soon after that yeast would grow, develop and ferment sucrose in a synthetic medium devoid of albuminoids but containing salts and a source of nitrogen[22]. Alcoholic fermentation obviously involves a more complex set of reactions than what Béchamp had studied, namely the inversion of sucrose, which Pasteur did not recognize as a fermentation.

Marcelin Berthelot, in a concise and hard hitting memoir[23], proceeded to demolish Pasteur's claim that the inversion of sucrose was brought about by the acidity of succinic acid formed during alcoholic fermentation and was not due to the action of a ferment. Berthelot suggested that there was no fundamental difference between the soluble ferments, such as *ferment glucosique*, as he called invertase, and the insoluble ferments responsible for ethanol or lactate production; it was not the ferment that was living but the cell that produced it.

It is not obvious why Pasteur, no doubt stung by the attack but at the same time with a background in chemistry rather than biology, was not willing to accept this seemingly very sensible suggestion. He sought instead to rebut Bethelot's proposal with two rather lame remarks[24]: first, that he was not very interested in soluble ferments because similar actions were carried out by many substances; and second, by describing only those fermentations carried out by cells as being 'proper' fermentations, thereby introducing a degree of semantic mysticism. Thus, fermentation so defined had to correlate with a vital phenomenon.

Controversy between Béchamp and Pasteur in the Academies

Things began quietly. At a meeting of the Sociétés Savantes in 1862, Pasteur, in the presence of Béchamp, claimed precedence for showing the appearance of living organisms in a medium devoid of albuminoid matter. The meeting report[25] reads 'M. Béchamp quoted some experiments, in which the transformation of cane sugar into grape sugar, brought about under the influence of air, is always accompanied by moulds. These experiments agree with the results obtained by M. Pasteur, who hastened to acknowledge that the fact put forward by M. Béchamp is one of the most rigid exactness.'

The (French) Academy of Sciences was a very important venue for airing and developing views and a place to put forward novel ideas. In 1864, Béchamp felt moved to present a memoir[26] in which he suggested that only soluble ferments (like invertase, to which he gave the name zymase) were constant in their actions. The organized ferments (Pasteur's 'properly called' fermentations) produced variable amounts of products, according to circumstances, because, as Jean Baptiste Dumas had pointed out 20 years before, in 1843, they reflected the nutritional activities of cells, which consume organic materials, breaking them down and converting them into simpler forms[27]. It often requires several successive fermentations (in modern terms, several enzymes) to produce the total effect. For Béchamp, alcoholic fermentation and the fermentations by organized ferments are not 'properly called' fermentations, they are simply manifestations of nutrition. Béchamp observed that yeast incubated without sugar still makes a certain amount of alcohol, from which he concluded that sugar is not directly necessary for its formation. At this time, it was not known that yeast contains glycogen, a point only realized around 1900[28].

In 1872, we find Béchamp telling the Academy[29] that he believed that he was the first to point out that organized ferments can develop in media in the absence of proteinaceous material and that fermentation is essentially an act of nutrition, which includes excretion. Pasteur's collaborator Émile Duclaux[30] asked how a small amount of yeast can itself be the origin of a large amount of alcohol produced from a large amount of sugar? To which Béchamp replies[29] 'Suppose an adult man to have lived a century, to weigh an average of 60 kilograms; he will have consumed in that time, besides other foods, the equivalent of 20 000 kilograms of flesh and produced about 800 kilograms of urea[31]. Shall it be said that it is impossible to admit that this mass of flesh and of urea could at any moment of his life form part of his being? Just as a man consumes all that food only by repeating the same act a great many times, the yeast cell consumes the great mass of sugar only by constantly assimilating and disassimilating it bit by bit.' This line of thinking seems so straightforward that it is difficult for us to understand why there should be need for its enunciation.

Études sur la Bière versus *Les Microzymas*

In *Les Microzymas*[3], Béchamp describes how Pasteur in 1876 in his *Études sur La Bière*[32] 'in cold blood' (not unlike Ref. 1) tried to demolish him once and for all.

> The first note of M. Béchamp on the inversion of sucrose is in 1855[18]. There is no mention there of the influence of moulds, the second where he states this influence is of 4 January 1858[19], after my work on lactic fermentation, published 30 November 1857[20] where I establish for the first time that the lactic ferment is an organized living being, that albuminoid materials do nothing in the cause of fermentation, after also my first work on alcoholic fermentation published on 21 December 1857[22]. What is certain, one is at pains to point out, is that M. Béchamp, who since 1855 has not suggested the action of moulds on sugar, although he had noted their presence, has now modified his former conclusions[32].

The implications of this is that the change of Béchamp's ideas which took place between his first paper in 1855[18] and the note that appeared in January 1858[19] occurred after he had heard of Pasteur's work as presented to the Academy[21] in November[20] and December[22] 1857. To us, familiar with long intervals between submission of a manuscript and eventual publication, this charge would seem improbable but, on occasion, publication could be very rapid[33]. Pasteur's accusation could be justified because, although inversion is described in the first paragraph of Béchamp's 1858 paper as being a true fermentation, this idea is not developed any further except to conclude first that moulds do not develop in the absence of air (and, in this instance, inversion does not occur), and second that the flasks in which the fluid is in contact with air produce variable development of mould.

Few investigations have no previous history and few topics in science reach a state of finality

Béchamp's answer in *Les Microzymas*[3] to Pasteur's accusations are, first, outrage that Pasteur could make such suggestions and, second, that all his (Béchamp's) new ideas were contained in his memoir of 1857. Unfortunately, there is no memoir published in 1857, but an apologist[15] says that this memoir is his paper in *Annales de Chimie*[34] that, for unknown reasons, appeared only in September 1858. Dates of submission of manuscripts are not indicated in the final publication.

The microzymes

The microzymes are a form of life that Béchamp, over a period of 30 years, believed that he had discovered, beginning, as he points out[3], with his experiments carried out in the 1850s on the influence of moulds on the hydrolysis of sucrose. In the book, he tries to bring together all the relevant data that have brought him to the belief that the microzymes are at the basis of all life and death.

As an aside, it is interesting that both Béchamp and Pasteur started their careers more as physical scientists than biologists, but were gradually led into biology through studying aspects of fermentation, then turned their attention to the diseases of man and higher animals. There are similar and notable examples recorded in the 20th century. Béchamp, like Pasteur, also worked on the diseases of wine and of silkworms, making significant findings that did not attract the publicity of Pasteur's studies, but this work is not covered here even though it too involved accusations by Béchamp that Pasteur had plagiarized his work[35].

Few investigations have no previous history and few topics in science reach a state of finality. In setting forth his views in *Les Microzymas*[3], Béchamp starts with an impressive quotation from Lavoisier[36], whom Béchamp clearly regards as the founder of modern science, the implication being that Béchamp felt compelled to set forth his views even though he realized that his findings were incomplete. Béchamp considered[3] that the theory of the microzymes provided biology with an experimental basis as secure as that provided by Lavoisier for chemistry.

When examining solutions in which the hydrolysis of sucrose was taking place, Béchamp observed extremely small microscopic forms, different from those seen in fermentations. In his memoir of 1857 (which only appeared in 1858), he designates them 'little bodies' and regards them as organized bodies similar to ferments. He also compares them to the molecular granulations that Berthelot had noticed in his researches on alcoholic fermentation, without giving them a role, considering them to be amorphous material, like particles exhibiting Brownian movement[37] – material in a state of extreme division. Thus, he came to regard the molecular granulations of the histologists as being organized, living ferments. In a letter to Dumas in September 1865 (Ref. 38), he also included the molecular granulations seen in chalk and milk. 'It is certainly not Pasteur who helped me to make these discoveries,' he points out, 'nor to unravel the meaning; his sarcasms would have soon produced discouragement.'[3] Béchamp expresses his thanks to the Academy for receiving his communications and allowing him to persevere with his work.

In 1865, Béchamp had produced a startling finding[39]. It was a well-established procedure to add chalk, mainly powdered limestone, to lactic and other acid fermentations to maintain neutrality. Béchamp asked whether this is the only role of the chalk, because he found that, as well as consisting of the fossil remains of crustaceans, it still contained extremely small organisms, smaller than the yeasts. Not only did they exist but also they were alive, despite their extreme geological age. They grew with a rare energy, like ferments (yeasts). They were the most active ferments that Béchamp had encountered and they nourished themselves on very diverse organic substances. To the organisms from lime (killed when heated to 300°C), Béchamp gives the name *Microzyma cretae*, but he found microzymes (minute ferments) everywhere, including in soil. Béchamp's paper[39] is logically presented, with sequential arguments, and the remarkable nature of his results is clear to him. Could it be that Béchamp was actually the first to observe, both physically and biochemically, the bacteria?

With a medical colleague, Alfred Estor, Béchamp observed granulations in cells (they mainly studied liver of different species)[40]. In the physiological state, these granules, which they considered to be microzymes, are spherical but, outside the cell, they develop into bead-like elongated structures, eventually recognizable as bacteria. From observations of bacteria in blood, they concluded that bacteria, far from being the cause of illness, are actually the result of it. In a subsequent paper, Béchamp suggests that the microzymes of chalk are 'the organized and yet living remains of beings that lived in long past ages.'[41] Thus, in death, the microzymes become bacteria, eventually reducing the cells of higher organisms to dust and then reverting to microzymes. Airborne germs arise from microzymes in dead plant and animal life. 'The microzyme is at the beginning and at the end of every cell organization. It is the fundamental anatomical element by which the cells, the tissues, the organism, the whole of an organism are constituted living'[3].

Summary

How to summarize Béchamp's achievements? He made many useful contributions to chemistry, and Fruton[42] suggests that he played a part in the emergence in France of biochemistry as an independent discipline, using chemical methodology in the study of biological phenomena. Purely by definition, therefore, he cannot properly be 'The Father of Biology'[11]. However, Béchamp's theory of life, which he derived from study of the subcellular granulations or the microzymes (particles homologous with bacteria), became his principal interest and led to inevitable clashes, with Pasteur in particular. He did not support spontaneous generation, but neither did he accept the germ theory of disease. The generality of his theory of the microzymes was both its strength and its weakness – it could be used to explain too much but did not lend itself to experimental testing[10]. In a France increasingly idolizing Pasteur and his memory, Béchamp was bound to become increasingly ignored.

It seems likely that, in the 1850s and 1860s, Béchamp and Pasteur were making similar discoveries independently, a not-unknown phenomenon in science. Accusations of plagiarism are therefore probably not justified. Pasteur was, without question, aggressive and intolerant of opposition, and treated Béchamp shabbily. To go back to Williams, 'There are villains in science as much as there are heroes and some scientists are a mixture of both.'[1] The reader is left to make his or her own judgements in this case.

Notes and references

1 Williams, R.J.P. (1999) Heroes in biochemistry? *Biochemist* 21 (December issue), 46–48

2 Heterogenesis could mean either the birth or the organization of a living being other than from a parent of the same kind – a process called archebiosis by Charlton Bastian – or the generation of animal or vegetable life of low organization from inorganic (non-living) matter – called abiogenesis by Thomas Huxley

3 Béchamp, A. (1883) *Les Microzymas: L'hétérogénie, l'histogénie, la physiologie et la pathologie*, Librairie J-B. Baillière et Fils, Paris

4 Report of International Medical Congress (1881) *The Times*, 8 August, p. 6

5 One of the more interesting items in *The Times* was to the effect that the session described was on the Saturday, when they met for only 3 hours. Afterwards, the delegates had the chance to go either to Hampton Court Palace (recently advertised as where Henry VIII spent several honeymoons: 'So *enchanting*, Henry VIII spent his honeymoon here. Again and again.') or to Croydon Sewerage Farm

6 Pasteur said 'If any credence was to be given to the spontaneity of transmissible diseases and to the spontaneous generation of microscopic organisms in disease, a fatal blow would be struck at the progress of medicine and surgery. Besides, they had a sure means of judging the value of the theory. True theories were reproductive, erroneous theories were sterile. That being so he would say, let Dr Bastian state, if he could, a single instance of scientific progress due to the theory he upheld. The opposite doctrine no longer counted its successes.'[4] (Prolonged cheering.) They had good meetings in those days!

7 Report of International Medical Congress (1881) *Br. Med. J.* 2, 547

8 The report on Béchamp's lecture continues with a description of 'related experiments made under his direction.' The details need not concern us

9 Feller, J. (1951) *Béchamp*. In *Dictionaire de Biographie Française* (Vol. 5), pp. 1236–1237, Libraire Letouzey et Ané

10 Guédon, J-C. (1980) Béchamp, Pierre Jacques Antoine. In *Dictionary of Scientific Biography* (Vol. 15) (Gillispie, C.C., ed.), pp. 11–12, Charles Scribner's Sons

11 Nonclercq, M. (1979) Antoine Béchamp, père de la biologie (1816–1908). In *Die Vorträge des Internationalen Pharmaziehistorischen Kongresses Innsbruck 1977* (Ganzinger, K., ed.), pp. 51–60, Wissenschaftliche Verlagsgesellschaft Mbh, Stuttgart, Germany

12 A report of Béchamp's thesis was made to the Academy of Sciences by Dumas [Dumas, J-B. (1856) *Compt. Rend.* 43, 548–550], who commented that he himself had unsuccessfully tried many times to do what Béchamp had succeeded in doing. Dumas also said that Béchamp's finding deserved attention 'not because we learn to produce urea by a new method, those are the familiar games of the organic chemists; but because [his work explains] the origin of urea in the economy of the animal'. Pasteur, who was one of the examiners, is supposed to have remarked 'You are occupying yourself with uncrystallisable materials; you will get nowhere.'[3]

13 Béchamp, A. (1854) De l'action des protosels de fer sur la nitronaphtaline et la nitrobenzine. Nouvelle méthode de formation des bases organiques artificielles de zinin. *Ann. Chim.* (3rd series) 42, 186–196

14 The first organic arsenical originated as a by-product in the commercial production of the triphenylmethane dye parafuschsin. Arsenic acid was used in the process to oxidize a mixture of aniline and *p*-toluidine. In the course of studying the conditions of the reaction, Béchamp isolated a colourless compound that he regarded as an anilide of arsenic acid [Béchamp, A. (1863) De l'action de la chaleur sur l'arséniate d'aniline et de la formation d'un anilide de l'acide arsénique. *Compt. Rend.* 56, 1172–1175]. This compound, under the name Atoxyl, was subsequently recommended at the turn of the century for anaemia and skin diseases. In 1905, Wolferstan Thomas in Liverpool demonstrated the trypanocidal activity of Atoxyl [now recognized to be *p*-aminophenylarsonate; Moore, B. *et al.* (1907) On the treatment of trypanosomiasis by atoxyl (an organic arsenical compound), followed by a mercuric salt (mercuric chloride), being a biochemical study of the reaction of a parasitic protozoon to different chemical reagents at different stages of its life-history. *Biochem. J.* 2, 300–324. It was replaced in the 1920s by tryparsamide (*p*-glycineamidophenylarsonate), which is more easily detoxified, but neither drug is used today

15 Hume, E.D. (1923) *Béchamp or Pasteur? A Lost Chapter in the History of Biology*, Covici–McGee, Chicago, USA

16 In 1813, Charles Astier had claimed that air is the vehicle of every kind of germ [Astier, C. (1813) Expériences faites sur le sirop et le sucre de raisin. *Ann. Chem*. 87, 271–285], and Franz Schulze and Theodor Schwann had shown that the fermentation and putrefaction of boiled infusions did not occur if the air in contact with the infusions had been heated or passed through acid [Fruton, J.S. (1972) *Molecules and Life: Historical Essays on the Interplay of Chemistry and Biology*, p. 45, Wiley–Interscience]. However, these observations do not seem to have been regarded as conclusive and were conveniently ignored by many

17 All naturally occurring sugars rotate the plane of polarized light to the right [dextrorotatary; (+) rotation] or to the left [laevorotatary; (–) rotation]. Polarimetry, a procedure dating from the early years of the 19th century, was once one of the easiest ways of following a reaction such as the hydrolysis of sucrose. Sucrose has a specific rotation of +67°, glucose of +53° and fructose –92°. An equimolar mixture of glucose and fructose is therefore laevorotatary, whereas that of sucrose is dextrorotatary. Invertase thus catalyses a reaction that results in the inversion of the plane of polarization from being to the right to being to the left. An old name for fructose is invert sugar or laevulose, and an old name for glucose is dextrose (or grape sugar), as opposed to cane sugar for sucrose

18 Béchamp, A. (1855) Note sur l'influence que l'eau pure et certaines dissolutions salines exercent sur le sucre de canne. *Compt. Rend*. 40, 436–438

19 Béchamp, A. (1858) De l'influence que l'eau pur ou chargée de divers sels exerce à froid sur le sucre de canne. *Compt. Rend*. 46, 44–47

20 Pasteur, L. (1857) Mémoire sur la fermentation appelée lactique. *Compt. Rend*. 45, 913–916

21 The work was first presented in a lecture in Lille on 3 August 1857

22 Pasteur, L. (1857) Mémoire sur la fermentation alcoolique. *Compt. Rend*. 45, 1032–1036

23 Berthelot, M. (1860) Sur la fermentation glucosique du sucre de canne. *Compt. Rend*. 50, 980–984

24 Pasteur, L. (1860) Note sur la fermentation alcoolique. *Compt. Rend.* 50, 1083–1084

25 Meeting Report (1862) *Rev. Soc. Savantes* 1, 81

26 Béchamp, A. (1864) Sur la fermentation alcoolique. *Compt. Rend*. 58, 601–605

27 Schwann, in 1837, had also suggested that alcoholic fermentation was a mechanism by which 'sugar fungus' extracted from sugar the materials necessary for its own nutrition and growth [Fruton, J.S. (1972) *Molecules and Life: Historical Essays on the Interplay of Chemistry and Biology*, p. 45, Wiley–Interscience]

28 Harden, A. (1911) *Alcoholic Fermentation*, Longmans, Green & Co

29 Béchamp, A. (1872) Seconde observation sur quelques communications récentes de M. Pasteur, notamment sur la théorie de la fermentation alcoolique. *Compt. Rend*. 75, 1519–1523

30 Émile Duclaux had contact with Pasteur from 1862 onwards and followed Pasteur as Director of the Institut Pasteur

31 Béchamp's equivalence of 20 000 kg of meat, leading to production of 800 kg of urea is quite acceptable in today's biochemistry. However, his assumption of a daily intake of meat (presumably, mostly red) from birth to death of >500 g a day is not good modern nutritional practice, but Béchamp lived to be 91!

32 Pasteur, L (1876) *Études sur la Bière*, Gautier–Villars, Paris

33 A letter by Béchamp of 26 September 1865 to Dumas was published in October 1865. Similarly, Röntgen wrote up his discovery of X-rays over Christmas 1895, submitted the paper for publication on 28 December and had his reprints to send out on New Year's Day!

34 Béchamp, A. (1858) De l'influence que l'eau pure, ou chargée de divers sels, exerce, à froid, sur le sucre de canne. *Ann. Chim*. (3rd series) 54, 28–42

35 Béchamp, A. (1867) Lettre adressée à *M. le Président*, au sujet de la communication faite par *M. Pasteur* le 29 avril dernier. *Compt. Rend*. 64, 1042–1043

36 'The pace of an experiment is so slow that a scientist, who wishes to wait until he is entirely satisfied before publishing the results of his works, risks coming to the end of his career without having achieved what he set out to do and without having done anything for science and society. It is necessary therefore to have the courage to put forward imperfect findings, to set aside the ideal of having done all that one would like to do, of having said all that one would like to say, indeed to be willing to sacrifice one's self esteem in the desire to be useful and to accelerate the progress of science.' Lavoisier, A.L. (1772) Premier Memoire sur la destruction du diamant. *Memoire de l'Academie royale des Sciences*

37 Brownian movement – the natural continuous motion of minute particles in solution in a microscopic field – was first described in 1828 by the Scottish botanist Robert Brown (1773–1858)

38 Béchamp, A. (1865) Lettre de M. Béchamp à M. Dumas. *Ann. Chim*. (4th series) 6, 248–251

39 Béchamp, A. (1866) Du rôle de la craie dans les fermentations butyrique et lactique, et des organismes actuellement vivants qu'elle contient. *Compt. Rend*. 63, 451–455

40 Béchamp, A. and Estor, A. (1868) De l'origine et du développement des bactéries. *Compt. Rend*. 66, 859–863

41 Béchamp, A. (1870) Sur les microzymas géologiques de diverses origines. *Compt. Rend*. 70, 914–918

42 Fruton, J.S. (1999) *Proteins, Enzymes, Genes: The Interplay of Chemistry and Biology*, Yale University Press