CHAPTER IV

BÉCHAMP'S BEACON EXPERIMENT

WE may recall the fact that it was in the Alsatian capital, Strasbourg, that Professor Béchamp achieved his first scientific triumphs, to which we have already alluded. It was there, during the course of his chemical studies, that the idea occurred to him to put the popular belief in the spontaneous alteration of cane-sugar into grape-sugar[1] to the test of a rigid experiment. In those days organic matter derived from living bodies, whether vegetable or animal, was looked upon as being dead and, according to the views held at that time, because dead liable to spontaneous alteration. This was the belief that Pasteur combated in the way that we have already criticised. Béchamp was before him in attacking the problem by methods obviously more rigid and with results that we think will now appear to be considerably more illuminating.

An experiment upon starch made Béchamp doubt the truth of the popular theory that cane-sugar dissolved in water was spontaneously transformed at an ordinary temperature into invert-sugar, which is a mixture of equal parts of glucose and fructose, the change being technically known as the inversion of sugar. Here was a puzzle that needed investigation, and in attacking this chemical mystery the Professor had no suspicion of the biological results that were to ensue from Nature's answers.

In May 1854 he started a series of observations to which he later on gave the name of *"Expérience Maitresse,"* and finally agreed to call his "Beacon Experiment."

It was on 16th May, 1854, that the first of the series was commenced in the laboratory of the School of Pharmacy in Strasbourg. The experiment was concluded on 3rd February, 1855.

In this experiment perfectly pure cane-sugar was dissolved in distilled water in a glass bottle with an air-tight stopper but containing a little air. This was left on the laboratory table at ordinary temperature and in diffused light.

At the same time, control experiments were prepared. These consisted of solutions of similar distilled water and cane-sugar, to

[1] See note to p. 35.

one of which was added a little zinc chloride and to the others a little calcium chloride; in each one a small amount of air was left, just as in the bottle containing the first, or test, solution. These bottles were stoppered in the same way as the first, and all were left alongside each other in the laboratory.

In the course of some months the cane-sugar in the distilled water was partially transformed into grape-sugar, and the polarimeter showed that alteration had taken place in the medium, since there was a change in the angle of rotation. In short, an alteration had taken place, but possibly not spontaneously, for on 15th June moulds had put in an appearance, and from that date alteration progressed much more rapidly.

The following Table I is a brief summary of the results of Béchamp's experiments.

[1]TABLE I

Béchamp's Beacon Experiment.

Béchamp prepared solutions of Cane Sugar 16.365 grams in 100 cubic centimetres of various solvents and polarised each of these solutions several times at varying intervals obtaining certan variations in the angle of rotation.

16.365 grm. of Cane Sugar dissolved in 100 c.c. of each of the following:	Rotation May 16th 1854	Rotation May 17th 1854	Rotation May 20th 1854	Rotation June 15th 1854	Rotation August 20th 1854	Rotation Feb. 3rd 1855	Remarks
1. Distilled Water .	23.88°	23.17°	22.85°	22.39° *	17.28°	7.80°	*Moulds appeared but did not greatly increase.
2. 25% solution of Chloride of Zinc .	22.32°	22.20°	22.10° **	22.14°	22.27°	22.28°	**The Solution began to get cloudy. Later there was found a slight deposit of Oxy-Chloride of Zinc.
3. A solution of Calcium Chloride containing an amount of Calcium Chloride equivalent to the Chloride of Zinc.[2]	22.34°	22.13°	22.17°	22.25°	22.22°	22.29°	No moulds appeared.
4. 25% solution of Calcium Chloride.	22.34°	22.15°	22.10°	22.08°	22.14°	22.28°	No moulds appeared.

1 *Les Microzymas*, p. 48.
2 The original is "*Solution de chlorure de calcium équivalente au poids du chlorure de zinc*" From this it is inferred that the concentration of $CaCl_2$ was molecularly equivalent, i.e.

$$25\% \times \frac{\text{molecular weight of } CaCl_2}{\text{molecular weight of } ZnCl_2}; \text{ i.e.}$$

$$25\% \times \frac{111.0}{136.3} = 20\%.$$

Professor Béchamp took particular note of the moulds, and found it significant that none had appeared in the solutions to which he had added zinc chloride and calcium chloride; moreover, that the change in rotation in these had been so slight as to be almost negligible, or, as he puts it: "The plane of polarisation underwent no change other than accidental variations." [1]

Béchamp published this experiment in the report of the French Academy of Science on 19th February, 1855.[2] He mentioned the moulds, without attempting to explain their appearance. He reserved their further consideration for future experiments, feeling it important to find the explanation as a probable clue to the cause of what had up to that time been regarded as evidence of spontaneous generation. He was also anxious to discover what was the chemical mechanism of the alteration of sugar, and why a change had not been effected in the solutions to which the chlorides had been added.

Meanwhile another observer, M. Maumené, was also experimenting, and though Béchamp disagreed with his conclusions he was much struck by the observations that were presented to the Academy of Science on 7th April, 1856, and published in the *Annales de Chimie et de Physique* in September 1856.[3]

M. Maumené's experiments were also concerned with polarimetric measurements. The following Table II on page 46 gives a brief résumé of his principal results:

[1] *Les Microzymas, par A. Béchamp*, p. 48.
[2] *Comptes Rendus* 40, p. 436.
[3] *A. de Ch. et de Ph. 3e série*, 48, p. 23.

[1]TABLE II

Experiment by M. Maumené.

Variety of sugar 16.35 gr. in 100 c.c. of solution	Initial rotation in 200 m.m. tube January 4th, 1854	Rotation at the end of 9 months in 200 m.m. tube	Remarks
White candy	+100°	+22°	Slight mould.
Another sample	+100°	+23°	Idem.
Loaf sugar	+98.5°	+31.5°	Mould a little larger.
Another sample	+96.5°	+88°	Slight mould.

Béchamp here saw his own observations borne out. On pages 50 and 51 of *Les Microzymas* he tells us the two questions that had arisen in his mind through his own and M. Maumené's experiments:

"Are moulds endowed with chemical activity?"

"What is the origin of the moulds that appear in the sugared water?"

With a view to finding an answer to these questions he commenced at Strasbourg on 25th June, 1856, a fresh series of experiments that were completed at Montpellier on 5th December, 1857. Thus it was during the course of this work that he left Strasbourg to start his happy successful career at the famous southern university.

The following Table III on page 47 shows his new observations: tions:

[1] *Les Microzymas*, p. 50.

[1]TABLE III

Béchamp's Beacon Experiment.

15.1 grm. of Cane-sugar dissolved in 100 c.c. of water either with or without the addition of certain chemical substances.	Rotations of the Plane of Polarisation.						Observations
	June 25th 1856	July 13th 1856	Nov. 26th 1856	Mar. 19th 1857	July 13th 1857	Dec. 5th 1857	
Pure water	+ 22.03°	+ 21.89°	+ 16.6°	+ 15.84°	+ 10.3°	+ 1.5°	Nov. 26 a slight flocculent deposit which became gradually a bulky mould.
Very pure, arsenious acid, very little	+ 22.04°	+ 21.65°	+ 12.24°	+ 10.8°	+ 7.2°	+ 0.7°	Mould on Nov. 26 which increased and became more abundant than in solution of sugar alone.
Mercuric chloride, very little	+ 22.03°	+ 22.0°	+ 21.9°	+ 22.03°	+ 22.04°	+ 22.1°	Liquid remains transparent.
Pure water, creosoted, one drop .	+ 22.03°	+ 22.0°	+ 22.1°	+ 22.2°	+ 22.2°	+ 22.2°	Idem.
Sulphate of zinc .	+ 22.04°	—	− 3.12°	—	− 7.2°	—	Idem.
Sulphate of aluminium	+ 22.02°	—	− 8.7°	—	—	—	Nov. 26 large green mould.
Nitrate of Potassium	+ 22.05°	+ 21.6°	+ 3.0°	—	—	—	Enormous quantity of moulds developed Nov. 26.
Nitrate of zinc ..	+ 22.01°	+ 22.0°	+ 22.1°	—	+ 22.0°	+ 22.2°	Liquid limpid.
Phosphate of sodium...........	+ 20.23°	+ 19.16°	− 9.7°	—	—	—	Nov. 22 a bulky mould.
Carbonate of potassium........	+ 20.0°	+ 20.0°	+ 20.0°	—	+ 20.3°	—	Liquid remains limpid.
Oxalate of potassium	+ 22.0°	+ 20.34°	+ 10.5°	—	—	− 0.2°	Red moulds.

[1] *Les Microzymas*, p. 52.

The results clearly demonstrated the varying effects of different salts upon the medium, which Béchamp himself has pointed out in the second chapter of his work *Les Microzymas.* As also shown by the earlier experiment, zinc chloride and calcium chloride prevented the alteration of cane-sugar; and a very small quantity of creosote, or of mercuric chloride, had the same preventive influence. This was not the case with arsenious acid when present in very small proportion, or with certain other salts, which did not hamper the appearing of moulds and the alteration of the cane-sugar. Indeed, some of the salts seemed to stimulate the advent of moulds; while, on the contrary, creosote, which has only since the date of these experiments been distinguished from carbolic acid, was particularly effective in the prevention of moulds and of alteration in the sugar.

With his characteristic precision Professor Béchamp determined to investigate thoroughly the rôle of creosote, and with this aim in view started on 27th March, 1857, another series of experiments, which he also continued up to 5th December of the same year.

His own account of his procedure is as follows:[1] He "prepared several sugared solutions according to the technique of the anti-heterogenists, that is to say, the water used was boiled and cooled in such a manner that air could enter only after passing through tubes containing sulphuric acid. This water dissolved the sugar very rapidly, and several jars were completely filled with the carefully filtered solution, so as to leave no air in them. Another part of the solution, having no creosote added to it, was poured into jars in contact with a considerable quantity of common air, without any other care than that of cleanliness. One of the jars contained also some arsenious acid. One jar of the creosoted solution and one without creosote were set apart not to be opened throughout the whole course of the experiment."

The following Table IV gives a summary of the observations:

[1] *Les Microzymas, par A. Béchamp,* p. 53.

[1]TABLE IV

Béchamp's Beacon Experiment.

16.365 grm. of Cane-sugar in 100 c.c.	Rotations of the Plane of Polarisation.						Observations
	1857 Mar. 27	April 30	May 30	June 30	July 30	Dec. 5	
Solution not creosoted (No. 1)	+24°	+24°	+24°	+23°	—	+ 19,68°	Whitish floccula carpeted the bottom of the flasks.
Id. (No. 2)	+24°	+24°	+22.8°	+21.6°	—	+15.6°	In flask No. 2 the floccula became more abundant; June 30, without filtering, one drop of creosote was added; this addition did not prevent the further progress of the inversion.
Id. (No. 3)	+24°	—	+24°	—	—	—	
Id. (No. 4)	+24°	—	—	+24°	+24°	—	
Id. (No. 5)	+24°	—	—	—	—	+24°	
Creosoted solutions (No. 1a)	+24°	+24°	+24°	+24°	+24°	+24°	
Id. (No. 2a)	+24°	—	+24°	+24°	+24°	+24°	
Id. (No. 3a)	+24°	—	—	+24°	+24°	+24°	
Id. (No. 4a)	+24°	—	—	—	+24°	+24°	
(No. 5a)	+24°	—	—	—	—	+24°	
Creosoted arseniated solution	+24°	+24°	—	+24°	+24°	+24°	

Béchamp has himself explained the results.

Flasks 1 and 2 lost a little liquid during manipulation, and thus were not completely filled. Air in consequence came into contact with the solutions they held, and, in these, moulds appeared and alteration in the medium ensued, the dates differing in the two cases and the variation proving more rapid in the flask where the moulds were the more abundant.

On the contrary, the sugared water quite secured from air during the eight months of observation underwent no change, although kept in the warm climate of Montpellier during the months of June, July, August and September. This was noteworthy, for there was nothing to prevent the action of the water, had spontaneous alteration been Nature's method, according to the then prevalent opinion. Furthermore, although the creosoted solutions were in contact with air from the start, and these par-

[1] *Les Microzymas,* p. 54.

ticular flasks were left open, they underwent no variation and showed no trace of moulds, not even the solution to which arsenious acid had been added.

Finally, to return to solution No. 2, moulds appeared before 30th May, with evidence on that date of a diminution of the rotation, which continued to decline, in spite of the fact that on 30th June one drop of creosote was added.

The great worker tells us in his Preface to his work *Le Sang* that these different observations impressed him in the same way as the swing of the cathedral lamp had impressed Galileo in the sixteenth century.

At the period in which he worked it was believed that fermentation could not take place except in the presence of albuminoid matter. We have already seen that Pasteur operated with yeast broth, a complex albuminoid solution. In the media prepared by Béchamp there were, on the contrary, no albuminoid substances. He had operated with carefully distilled water and pure cane-sugar, which, so he tells us, when heated with fresh-slaked lime, did not disengage ammonia. Yet moulds, obviously living organisms and thus necessarily containing albuminoid matter, had appeared in his chemical solutions.

He was awestruck by his discovery, his genius already affording him hints of all it portended. Had he been Pasteur, the country would have rung with the news of it; he would have described the facts by letter to all his acquaintances. Instead, being Béchamp, without a thought of self, immersed in the secrets Nature disclosed, his only anxiety was to start new experiments, consider fresh revelations.

The results of the observations he recorded in a Memoir which he sent up immediately, in December 1857, to the Academy of Science, which published an extract of it among its reports of 4th January, 1858.[1] The full publication of this all-important document was actually, for some unknown reason, deferred for eight months, when it appeared in September 1858 in the *Annale de Chimie et de Physique*.[2]

The title of the Memoir was "On the Influence that Water, Either Pure or Charged with Various Salts, Exercises in the Cold upon Cane-Sugar."

Béchamp thus comments upon this:[3] "By its title the Memoir

[1] *Comptes Rendus* 46, p. 44.
[2] *A. de Ch. et de Ph. 3e série,* 54, p. 28.
[3] *Les Microzymas, par A. Béchamp,* p. 55.

was a work of pure chemistry, which had at first no other object than to determine whether or no pure cold water could invert cane-sugar, and if, further, the salts had any influence on the inversion; but soon the question, as I had foreseen, became complicated; it became at once physiological and dependent upon the phenomena of fermentation and the question of spontaneous generation—thus, from the study of a simple chemical fact, I was led to investigate in my turn the causes of fermentation, the nature and origin of ferments."

The main sweeping result of all the experiments went to prove that "Cold Water modifies Cane-Sugar only in Proportion to the development of Moulds, these Elementary Vegetations then acting as Ferments."[1]

Here at one stroke was felled the theory of alteration through the action of water, the change known as fermentation being declared to be due to the growth of living organisms.

Furthermore, it was proved that "Moulds do not Develop when there is no Contact with Air and that no Change then takes Place in the Rotary Power"; also that "The Solutions that had Come in Contact with Air Varied in Proportion to the Development of Moulds." The necessity of the presence of these living organisms for the processes of fermentation was thus shown clearly.

Béchamp further explained the action of moulds: "They act after the manner of ferments."

"Whence comes the ferment?"

"In these solutions there existed no albuminoid substance; they were made with pure cane-sugar, which, heated with fresh-slaked lime, does not give off ammonia. It thus appears evident that *air-borne germs* found the sugared solution a favourable medium for their development, and it must be admitted that *the ferment is here produced by the generation of fungi.*"

Here, in direct contradiction to Pasteur's account of the spontaneous origin of beer-yeast and other organisms, Béchamp gave proof positive of Schwann's teaching of air-borne germs, and further specified yeast to be of the order of fungi. Remarkable though such a clear pronouncement was at a date when scientific ideas were in chaotic confusion, the great teacher went much farther afield in his observations.

Moreover he stated: "The matter that develops in the sugared water sometimes presents itself under the form of little isolated

[1] *Comptes Rendus,* 46, p. 44.

bodies, sometimes under the form of voluminous colourless membranes which come out in one mass from the flasks. These membranes, heated with caustic potash, give off ammonia in abundance."

Here he noted the diversity of the organisms of these moulds, an observation that was to result in a deep insight into cellular life and his foundation of a first proper understanding of cytology.

He had a further definite explanation to make on the action of moulds, namely: "The Transformation that Cane-Sugar Undergoes in the Presence of Moulds may be Compared with that Produced upon Starch by Diastase."

This particular conclusion, he tells us,[1] had an enormous bearing on the subject, and was such a novel idea at that epoch that Pasteur, even later, ignored and denied it.

He further explained that "cold water does not act upon cane-sugar except when moulds are able to develop in it; in other words, the transformation is due to a true fermentation and to the development of an acid that is consecutive to the appearance of the ferment."

It was by the acids engendered by the moulds that he explained the process of fermentation.

He drew many more conclusions from the effects of different of various salts upon the solutions. Had Lord Lister only followed Béchamp's teaching instead of Pasteur's, the former might have been spared his subsequent honest recantation of his invention, the carbolic spray, which proved fatal to many patients.

Béchamp taught that "Creosote in Preventing the Development of Moulds also Checks the Transformation of Cane-Sugar."

He also taught that "creosote, with or without prolonged contact with air, prevents at one and the same time the formation of moulds and the transformation of cane-sugar. But from observation it appears that when the moulds are once formed creosote does not prevent their action."

He drew many more conclusions from the effects of different salts and thus generalised: "The influence of saline solutions is variable, not only according to the sort or kind of salt, but moreover according to the degree of saturation and of neutrality of these salts. The salts that prevent the transformation of cane-sugar into glucose (grape-sugar) are generally the salts reputed

[1] *Les Microzymas, par A. Béchamp*, p. 57.

to be antiseptic. In all cases a certain minimum temperature is necessary for the transformation to take place."

Thus we see that at that early date, 1857, when fermentation was such a complete mystery that Pasteur, operating with albuminoid matters, including dead yeast, looked upon this yeast and other organisms as products of spontaneous generation, Béchamp sent out an all-comprehending searchlight which illumined the darkness of the subject for all time.

To recapitulate, in a short summary, he taught that cane-sugar was a proximate principle unalterable by solution in water. He taught that the air had in itself no effect upon it, but that owing to its importation of living organisms the apparent effect of air was all-important. He showed that these organisms, insoluble themselves, brought about the process of fermentation by means of the acids they generated, which acids were regarded as the soluble ferments. He taught that the way to prevent the invasion of organisms in the sugared solution was by first slightly creosoting the medium; but if the organisms had appeared before creosote was added he showed that its subsequent addition would have no power to arrest their development and the consequent inversion of the sugar.

For further revelations we cannot do better than quote two or three paragraphs from Béchamp's own summary of his discovery in the Preface to his last work *Le Sang—The Blood*.[1]

There he writes: "It resulted that the soluble ferment was allied to the insoluble by the reaction of product to producer; the soluble ferment being unable to exist without the organised ferment, which is necessarily insoluble.

"Further, as the soluble ferment and the albuminoid matter, being nitrogenous, could only be formed by obtaining the nitrogen from the limited volume of air left in the flasks, it was at the same time demonstrated that the free nitrogen of the air could help directly in the synthesis of the nitrogenous substance of plants; which up to that time had been a disputed question.[2]

"Thus it became evident that since the material forming the structure of moulds and yeasts was elaborated within the organism, it must also be true that the soluble ferments and products of fermentation are also secreted there, as was the case with the soluble ferment that inverted the cane-sugar. Hence

[1] p. 16.

[2] It is now considered that atmospheric nitrogen can only be utilised by a few special plants (Natural order—Luguminosæ) and then under special conditions.

I became assured that that which is called fermentation is, in reality, the phenomenon of nutrition, assimilation, disassimilation and excretion of the products disassimilated." [1]

Thus we see how clear and complete was Béchamp's explanation of fermentation so long ago as the year 1857. He showed it to be due to the life processes of living organisms so minute as to require a microscope to render them visible, and in the case of his sugared solutions he proved them to be air-borne. Not only was he incontestably the first to solve the problem, but his initial discovery was to lead him a great deal farther, unfortunately far beyond the understanding of those who, devoid of his insight of genius, became merely obsessed by the idea of atmospheric organisms. But before we proceed to delve deeper in Béchamp's teaching, let us pause and return to Pasteur and see how his work was affected by the great beacon wherewith his rival had illumined science.

[1] In modern phraseology these processes are known as nutrition, constructive metabolism, destructive metabolism and the excretion of the waste products of the last named process.

Who Proved Fermentation in a Chemical Medium to be due to Air-borne Living Organisms—

BÉCHAMP or PASTEUR?

BÉCHAMP

1855[2] and 1857[3]

Experiments upon perfectly pure cane-sugar in distilled water, with or without the addition of different salts, air in some cases excluded, in others admitted.

CONCLUSIONS:

That the inversion of cane-sugar is due to moulds, which are living organisms, imported by the air, and whose influence

[2] *Comptes Rendus de l'Académie des Sciences* 40, p. 436.

[3] *C. R.* 46, p. 44. See also *Annales de Chimie et de Physique, 3e série,* 54, p. 28.

PASTEUR

1857[4]

LACTIC FERMENTATION

Experiment with ferment obtained from a medium of sugar, chalk, caseine or fibrin and gluten and sown in yeast broth (a complex solution of albuminoid and mineral matters) in which sugar had been dissolved with the addition of chalk.

CONCLUSIONS:

A lactic ferment *takes birth spontaneously,* as easily as beer-yeast, in the body of the albuminoid liquid furnished by the

[4] *Comptes Rendus de l'Académie des Sciences* 45, p. 913.

BÉCHAMP

upon cane-sugar may be compared with that exercised upon starch by diastase. That creosote prevents the invasion of moulds, though it does not check their development when once established.

. . . .

COROLLARY

That here was the first clear explanation and proof of the mystery of fermentation and the basic foundation of the knowledge of antiseptics.

PASTEUR

soluble part of the yeast. The lactic ferment is a living being, though this conclusion is among an order of things that *cannot be irrefutably demonstrated.*

ALCOHOLIC FERMENTATION[1]

Experiment with two equal quantities of fresh yeast washed in water. One was left to ferment with pure sugared water, and after extracting from the other all its soluble part by boiling it with plenty of water and filtering it to get rid of the globules, as much sugar was added in the first fermentation, and then a trace of fresh yeast.

CONCLUSIONS:

That in beer-yeast it is not the globules that play the principal part, but the conversion into globules of their soluble part, since the globules may be killed by a temperature of 100° when fermentation takes place spontaneously. The splitting of sugar into alcohol and into carbonic acid is an act correlative of a vital phenomenon.

. . . .

COROLLARY

The albuminoid substances, used in these experiments, in themselves nullified the attempt to probe the mystery of changes in a purely chemical medium. The origin of the ferments was said to be spontaneous, and while fermentation was declared to be a *vital* act, *dead* yeast was made principal use of, and the conclusions in general were pronounced to be beyond the power of proof.

[1] *Comptes Rendus,* 45, p. 1032. See also *Annales de Chimie et de Physique, 3e série,* 52, p. 404.