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PIERRE JACQUES ANTOINE BÉCHAMP

Contributions to chemistry

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ABSTRACT

Pierre Jacques Antoine Béchamp (1816-1908) was a French chemist and physician who studied the preparation, properties, and derivatives of collodion, and found that its behavior was similar to that of ethyl nitrate. He developed a very fast and efficient method for reducing nitrobenzene to aniline and naphthylamine with ferrous salts with ferrous salts and acetic acid, or acetic acid and iron filings. The reaction was probably done by nascent hydrogen (a prelude of the modern process of catalytic hydrogenation of nitrobenzene). This discovery led to a better and more economical method for manufacturing aniline violet, fuchsine, and *p*-aminophenylarsonic acid (arsanylic acid). The synthesis of the latter opened the door for the preparation of many medicines based on arsenic. He also discovered the ability of sodium ethylate to reduce nitrobenzene. His study of the action of mineral acids, glacial acetic acid, zinc chloride, and caustic alkalis, on starch led to the synthesis of modified starches, soluble in water and different from dextrin.

Keywords: aniline; collodion; fuchsine; naphthylamine; *p*-aminophenylarsonic acid; pyroxylin; soluble starches

RESUMEN

Pierre Jacques Antoine Béchamp (1816-1908) fue un químico y médico francés que estudió la preparación, propiedades y derivados del colodión y demostró que su comportamiento era similar al del nitrato de etilo. Desarrolló un método rápido y eficiente para reducir el nitrobenzeno a anilina y el nitronaftaleno a naftilamina mediante sales ferrosas y ácido acético, o limaduras de hierro y ácido acético, y que la reacción se debía, probablemente, al hidrógeno naciente (un preludio del proceso moderno de hidrogenación catalítica del nitrobenzeno). Este descubrimiento condujo a un método mejor y más económico para fabricar violeta de anilina, fucsina, y ácido *p*-aminofenilarsónico (ácido arsanílico). La síntesis del último abrió la puerta a la preparación de diversos fármacos basados en el arsénico. También descubrió la habilidad del etilato de sodio de reducir el nitrobenzeno. Su estudio de la acción de los ácidos minerales, el ácido acético, el cloruro de zinc y los álcalis cáusticos sobre el almidón, llevó a la síntesis de almidones modificados, solubles en agua y diferentes de la dextrina.

Palabras clave: ácido *p*-aminofenilarsínico almidones solubles; anilina; colodión; fucsina; naftilamina; piroxilina

INTRODUCTION

Life and career

Pierre Jacques Antoine Béchamp, the son of Jacques Béchamp, a miller, and Marie Catherine Antoine, was born in October 18, 1816, in Bassing, department of Meurthe, France. When he was seven years old, his uncle, a diplomat who worked in the French ambassador's office in Bucharest, convinced his mother to have the child educated in Bucharest, under his tuition. In 1834 Antoine returned to France after the death of the uncle during the cholera epidemics that affected Bucharest for several years. During his stay in Rumania he completed his basic education at the Collège Saint-Sava, begun a pharmacy apprenticeship under the direction of Ignaz Mausel, the most important pharmacist in Bucharest, and obtained a diploma of maître apothicaire. In Strasbourg he registered at the École Supérieure de Pharmacie, while working in a pharmacy located in Benfeld (about 30 km from Strasbourg) and as préparateur de chimie in the Faculty of Sciences of the University of Strasbourg (1840-1842). He also took the examinations for the baccalauréat (bachelier ès-lettres and bachelier ès-sciences mathématiques), which, at that time, were the compulsory requirements for exerting the pharmacy profession in France. After graduation (1843) he opened his own pharmacy and in 1851 postulated by competition and won the position of agrégé at the École de Pharmacie, after presenting a thesis entitled "De l'air atmosphérique considéré sous le point de vue de la physique, de la toxicologie". His many activities did not prevent him from continuing his studies at the University of Strasbourg, earning a degree of docteur ès-sciences after successfully defending a chemistry thesis about pyroxylin (Béchamp, 1853a) and a physics thesis about the chemical action of light (Béchamp, 1853b), followed by a degree of doctor of medicine in 1856, after defending a thesis with an "Essai sur les substances albuminoïdes et sur leur transformation en urée" (Béchamp, 1856b). In 1854 Béchamp was appointed professor of medical chemistry and pharmacy at Université de Montpellier (Béchamp, 1856c), at the recommendation of Jean Baptiste Dumas (1800-1884), a position he kept for 25 years. In the same year he was appointed professor of chemistry at the University of Strasbourg, a post previously held by Louis Pasteur (1822-1895).

In 1872 Béchamp married Clémentine Mertian; two daughters and two sons were born of this union.

In 1876 Béchamp was elected the first dean of the Faculté Libre de Lille; a position he left in 1887 after a bitter discussion with the rector and the administration about his research, which they thought was too materialistic. He then moved to Le Havre where in association with his son Joseph they purchased a pharmacy and a laboratory. After the death of his son, Béchamp sold the pharmacy and moved to Paris to work in the laboratory of Charles Friedel (1832-1899) at the Sorbonne. He passed away in Paris on April 15, 1898, and was buried in the Montparnasse cemetery (Grasset, 1913; Nonclerq, 1982; Manchester, 2001).

Béchamp received many honors and awards for his scientific achievements, among them: election as corresponding member of the Société de Pharmacie (1856), member of the Académie des Sciences et Lettres de Montpellier (1860) and of the Société de Médecine of Strasbourg (1892), honorary member of the Société des Sciences of Bucharest (1894), officier de Instruction Publique (1867), chevalier of the Légion d'Honneur (1870), chevalier de l'Ordre de la Rose (Brazil, 1872), chevalier de l'Ordre de Saint-Grégoire-le-Grand (decoration awarded by the Saint-Siège of the Vatican) (1877), commandeur de l'Ordre de la Couronne de Roumanie (1894), Daniel Dollfus Prize of the Société Industrielle de Mulhouse for his work on the synthesis of aniline (1864), etc. (Grasset, 1913; Nonclerq, 1982; Manchester, 2001).

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Scientific contribution

Béchamp wrote over 100 papers and books (e.g. Béchamp, 1863a, 1883, 1886, 1904) on the subjects of inorganic, organic, and industrial chemistry, biochemistry, microbiology, mineralogy, agriculture, and winery. In addition to the subjects described below, he also studied the constitution of esters (Béchamp, 1855c); the preparation of chlorides and bromides of organic radicals (alkyl halides) (Béchamp, 1856d); the variation of the rotatory power of the sugar of starch and its probable cause (Béchamp, 1856ef); the effect of acetic acid and other low carbon chain acids on the alcoholic fermentation (Béchamp, 1863c); presence of caproic and caprylic acids in the fermentation of ethanol (Béchamp, 1868b); wine fermentation (Béchamp, 1863a); spontaneous generation (Béchamp, 1863d); alcoholic fermentation (Béchamp, 1864b); mineral waters (Béchamp, 1866ac); the silkworm and its parasites (Béchamp, 1867, 1866b, 1868a); the conversion of cane-sugar into glucose (Béchamp, 1864c); the fruit of *Gingko biloba* (Béchamp, 1864a); etc. Béchamp's work on fermentation, the origin of ferments, etc. and his acrid polemic with Louis Pasteur (1822-1895) will not be presented here, as they have been discussed extensively elsewhere (Béchamp, 1904; Grasset, 1913; Hume, 1923; Ximenes, 1960; Manchester, 2001; etc.).

Pyroxylin (nitrocellulose)

Béchamp started investigating the behavior of pyroxylin and its solution in ether and alcohol (collodion) while he was adjunct to the *École de Pharmacie* of Strasbourg (Béchamp, 1852). As mentioned before, this research was the subject of one of the two theses he defended to obtain his doctorate in sciences (Béchamp, 1853a).

In the first memoir, Béchamp wrote that he had prepared soluble pyroxylin using the procedures of Marc Antoine Augustin Gaudin (1804-1880) (Gaudin, 1847) and Louis Mialhe (1806-1888) (Malgaigne, 1848). Gaudin and Mialhe prepared pyroxylin soluble in ether by treating one part of cotton with a mixture of two parts of potassium nitrate and three of concentrated sulfuric acid; a procedure which Eugène Soubeiran (1797-1859) had tested and found to be successful almost every time (Soubeiran, 1848). According to Béchamp, pyroxylin prepared by adding cotton to a cold mixture of sulfuric and nitric acid was fulminant and insoluble in ether but adding the cotton to the acid mixture at room temperature and letting it run at the developing temperature resulted in a product that was both fulminant and soluble in ether. Béchamp believed this was the best procedure for preparing collodion. In addition, the insoluble pyroxylin became soluble when added to a hot mixture of sulfuric acid and potassium nitrate (Béchamp, 1852, 1853ac).

Béchamp found that bubbling ammonia gas through a solution of 2 parts of pyroxylin, 80 of alcohol, and 30 of alcohol of relative density 0.8631 decreased its viscosity significantly and that treating the latter solution with hydrogen sulfide precipitated a complex yellow substance insoluble in alcohol of relative density 0.8351. Mixing the ammonia solution with 15 to 20 times its volume of water precipitated a white powder, tasteless and odorless, insoluble in water, soluble in sulfuric acid, and soluble in fuming HCl, accompanied by the release of abundant chlorine. The powder fulminated upon heating, releasing nitrous vapors and leaving a carbonaceous residue. Elemental analysis indicated that it contained, by weight, 28.216% carbon, 3.575% hydrogen, 10.777% nitrogen, and 57.432% oxygen, corresponding to the formula $C_{12}H_9(NO_4)_2O_{11}$ (Béchamp is assuming $H = 1$) (Béchamp, 1852, 1853ac).

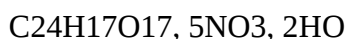
In a following short note Béchamp reported to the *Académie des Sciences* that the reaction of pyroxylin with a concentrated solution of ferrous chloride at 100 °C resulted in a darkening of the

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solution, the release of NO₂ pure, and the decomposition of the pyroxylin into cotton fibers quite identical to the raw material used to prepare the pyroxylin, as shown by their microscopic examination (Béchamp, 1853d). Treatment of these fibers with concentrated sulfuric acid according to Henri Braconnot's (1780-1855) method (Braconnot, 1819) yielded a substance having the appearance and properties of dextrin, while treatment with a mixture of three parts of fuming nitric acid and five of concentrated sulfuric acid regenerated a pyroxylin more fulminant than the primitive one, and highly soluble in ether. Béchamp mentioned that the same procedure applied to nitrocellulose (nitramidine, xyloidine) and nitrogum, regenerated the original starch and gum, respectively (Béchamp, 1853d). These findings were discussed in detail in a following longer paper, which extended the experiments to nitronaphthalene and nitrobenzene (Béchamp, 1854a).

Béchamp now found that the reaction of ferrous chloride with pyroxylin resulted in the release of all the nitrogen present in the latter, in the form of nitrogen dioxide, while the ferrous chloride oxidized to ferric chloride under the influence of the remaining oxygen of the nitrate group. He also reported that using other reducing agents, such as hydrogen sulfide, resulted in a completely different reaction. The reaction of nitronaphthalene and nitrobenzene with ferrous salts was very similar to that with hydrogen sulfide: the corresponding organic base was regenerated while all the nitrogen of the nitro group combined with the residual elements of the hydrocarbon. Although the reduction of nitrobenzene to aniline by means of hydrogen sulfide was very difficult, it took place very easily with ferrous salts. Béchamp believed that the new procedure he had discovered was better than all the known procedures for reducing nitrobenzene to aniline.*Similarly, nitronaphthalene was easily reduced to naphthylamine by means of ferrous salts. Ferrous chloride, sulfate, and oxalate were unable to reduce nitronaphthalene and nitrobenzene, but ferrous acetate did it very easily: in this case the formation of aniline and naphthylamine was accompanied by the precipitation of ferric oxide. Béchamp described in detail the procedure to carry on these reactions where instead of using ferrous acetate as such, he reacted the nitro compound with commercial acetic acid and iron filings (the reduction was probably done by the nascent hydrogen, a prelude to the modern process of catalytic hydrogenation of nitrobenzene). This reaction became known as Béchamp's reduction (Béchamp, 1854a).

In his next publication Béchamp reported additional data about the action of alkalis and reducing agents upon pyroxylin (Béchamp, 1855b). He found that although the reaction of nitric acid with an organic substance generated water, the action of the above mentioned reagents on the resulting products led to new nitrogenized products that contained all the nitrogen present in the nitro compound, or (i.e. ethyl nitrate), to the regeneration of the primitive material accompanied by elimination of nitric acid or different nitrogenized compounds. Béchamp's results indicated the behavior of pyroxylin was like that of ethyl nitrate, or, in general as that of the nitrates (Béchamp, 1855b). For example, he mentioned that during the reaction of pyroxylin with KOH nitric acid was eliminated and appeared as part of substances less nitrogenized, accompanied by sugar. In the reaction between pyroxylin and ferrous chloride all the nitrogen was eliminated as ammonia, while in the reaction with acetic acid and iron filings all the ammonia remained in the new compound formed (aniline). In other words, the results of the action of alkalis or of reducing agents showed that there were two series of nitro derivatives, one formed by nitrobenzene and similar compounds, the other of which pyroxylin was the type (i.e. starch, mannitol, etc.). In the first series the hydrogen was replaced by NO₄, and in the second by NO₅. These results empowered Béchamp to assign the following formulas and names to the nitro derivatives of cellulose (H = 1 and water = HO):



cellulose pentanitrate

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C ₂₄ H ₁₇ O ₁₇ , 4NO ₃ , 2HO	cellulose tetranitrate
C ₂₄ H ₁₇ O ₁₇ , 3NO ₃ , 2HO	cellulose trinitrate
C ₂₄ H ₁₇ O ₁₇	cellulose

This result proved that alkalis were able to eliminate successively the nitric acid combined in pyroxylin, while extreme reducing agents regenerated the cotton (Béchamp, 1855b).

Béchamp also studied the action of several reagents upon pyroxylin (aqueous alkalis, an alcoholic solution of ether, ammonia and KOH in the presence of water, and ammonia and KOH in solution with ether and alcohol), the preparation and properties of the different nitrates of cellulose, the action of several reducing agents upon pyroxylin (sulfur dioxide, hydrogen sulfide, ferrous chloride), and the action of nitric acid on starch, gum, mannitol, and quercitol (Béchamp, 1856a).

His main results were the following: (1) the reaction between ammonia, KOH and wet pyroxylin eliminated the nitric acid as ammonium or potassium nitrate, although the particular details were ill defined. An aqueous solution of KOH, heated between 600 and 80 °C generated sugar; (2) an ether alcohol solution of KOH decomposed pyroxylin generating potassium nitrate and a less nitrified compound, which seemed to be cellulose trinitrate; (3) treatment of cotton with a solution of fuming nitric acid and sulfuric acid produced cellulose pentanitate (pyroxylin); (4) sulfur dioxide did not act upon wet pyroxylin; (5) hydrogen sulfide did not react with pyroxylin dissolved in a mixture of ether and alcohol but it exerted a slow action on cellulose tetra and trinitrate dissolved in the same solvent; and (6) ferrous chloride released all the nitrogen present in pyroxylin in the form of NO₂, with simultaneous formation of cotton; the same result was obtained with the nitro derivative of starch, gum, mannitol, and quercitol (Béchamp, 1856a).

In 1889 Béchamp published a short historical review of the events that led him to discover his process for the economical synthesis of aniline by the reduction of nitrobenzene with iron filings and acetic acid (Béchamp, 1889).

Aniline and derivatives

Fuchsin

François Émanuel Verguin (1814-1864), a former school teacher managing the chemical factory of Louis Rafard in Lyon, carried on a large number of experiments on the reaction of aniline with a wide variety of reagents. In 1858 he discovered that the reaction of aniline with mercury chloride or stannic chloride at high temperature produced a beautiful red color similar to that of the flower fuchsia. Verguin sold his discovery and patent (Verguin, 1859) to the Lyon silk dyers and chemical manufacturers Renard Frères et Franc, who took a patent on the process (Renard, Frères, 1859) and began marketing the new dyestuff under the name *fuchsine*. The name of the product was changed in the same year to *magenta* to celebrate the victory of Napoleon III and the Sardinians over the Austrians in the battle of Magenta (June 4, 1859), during the Second Italian War of Independence. The English patent specified that the "new dyes...Fuchsicine...are prepared by heating together, to the point of ebullition, a mixture of aniline and of anhydrous bichloride of tin; the boiling should be maintained for from about 15 to 20 minutes. At first the mixture is of a yellowish tint, then of a reddish tint, and finally becomes a beautiful red, when thin layers are held to the light, but in bulk it appears black...The invention also consists in producing a red dye by mixing with aniline bichloride of mercury, perchloride of iron, or the protochloride of copper (Renard, Frères, 1859).

In 1858 the factory of Renard Frères et Franc began manufacturing aniline using Béchamp's process as a starting material for the synthesis of aniline violet (crystal violet) and fuchsine. They had already found that fuchsine could be prepared by boiling aniline with a variety of reducing salts, such as the chlorides, bromides, fluorides, sulfates, and chlorates of mercury, silver, tin, etc., and ferric oxide. Béchamp requested and received authorization to carry a chemical study of fuchsine, particularly in order to find an answer to the following questions: (1) whether the reaction was accomplished with or without loss of weight; (2) whether the base of the intervening metallic compound was reduced or not; and (3) whether the acid of the metallic salt was engaged in the formation of the new product. Appropriate experiments provided the following answers: (1) the reaction occurred in every case without loss of weight, as shown by the weight of the materials at the beginning and end of the process; the only loss was a small amount of aniline distilled (2) the base of the metallic compound was always reduced and the red color was generated only when the base had been reduced to a lower state of oxidation or to a metallic state, otherwise, no red color was produced. For example, boiling a mixture of a highly concentrated solution of ferric chloride with an excess of aniline gave place to a solution colored beautiful red. Addition of water precipitated ferrous chloride, showing that the ferric salt had been reduced. Heating a mixture of mercury(I) nitrate with double its weight of aniline resulted in a precipitate of pure mercury, weighing as the original metal present in the salt; no color was developed when aniline was treated in the same manner with zinc chloride or sulfate, potassium chlorate, and lead nitrate or iodide; (3) the acid of the metallic salt was not involved directly in the formation of the fuchsine but was found unaltered in the coarse product of the reaction. For example, no reaction took place when boiling an excess of aniline with lead nitrite or nitrate, tin sulfate, potassium chlorate, etc. The initial amount of aniline was obtained by distillation of the resulting mixture, showing that the salts of oxidizing acids with a non-reducible base were unable to form the red derivative. One particular finding was that fuchsine could also be prepared by heating aniline with arsenic acid, while arsenious acid did not react Béchamp described in detail the procedure for extracting fuchsine from the product of the reaction of aniline with mercury(I) nitrate and tin dichloride. (Béchamp, 1860a).

Béchamp described fuchsine as follows: Pure fuchsine could be obtained by repeated solution in alcohol and precipitation with ether. The pertinent solid appeared as non-crystallizing scales of a brilliant metallic green; when hydrated, it was of a deep red color. Fuchsine was an organic base, sparingly soluble in water and yielding a red solution; it dissolved with the same color in alcohol, methanol, and acetone. It formed non-crystallizable salts, which generated red solutions when they were neutral and yellow when an excess of acid was present. Sulfur dioxide slowly decolorized these solutions, but by concentration and a gentle heat the red color reappeared.

Fuchsine hydrochloride was a yellow red, non-crystallizable salt producing an intense red solution; a slightly acid solution of this salt reacted with platinum dichloride precipitating a deep violet deposit, which did not decompose upon heating and was soluble in cold water, in ethanol and in methanol. The formula of fuchsine was one of the two following: $C_{24}H_{10}N_2O_2$ or $C_{24}H_{12}N_2O_2$, corresponding to an isomer of azoxybenzene and oxaniline, respectively. Its formation in certain cases was preceded by that of a white compound, which was in direct relation with the reaction, which gave rise to fuchsine (Béchamp, 1860a).

In a following paper Béchamp mentioned again his finding that fuming nitric acid altered aniline intensely and at high temperatures it could not coexist with this base, as shown by the fact that crystalline mercury(I) nitrate, heated to 1800-190 °C, transferred all its acid to aniline to generate the nitrate, while its base oxidized part of aniline forming fuchsine and other coloring substances,

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while reducing to metallic mercury (Béchamp, 1860b). The aniline nitrate dissolved easily in hot aniline and recrystallized upon cooling. At about 200 °C the nitrate and the aniline reacted giving place to many derivatives, among them the red base and the violet combination. The fact that arsenic acid was reduced by aniline was not surprising because it was known that this acid functioned as a base in particular situations. Nevertheless, arsenic acid working as an acid was not reduced by aniline, as shown by the fact that aniline did not react with potassium dihydrogen arsenate or with lead arsenate. Nevertheless, the reaction between arsenic acid and aniline yielded aniline arsenate, a compound, which appeared as brilliant white flakes, soluble in hot aniline and melting at about 140 °C. This arsenate decomposed at 180 °C, releasing aniline and leaving a residue of the acid arsenate, AsO_3 , $\text{C}_{12}\text{H}_7\text{N}$, 3HO (today: *p*-aminophenylarsinic acid); at about 190 °C the residue reacted with itself producing water, arsenious acid, and a certain amount of fuchsine (Béchamp, 1860b, 1861c).

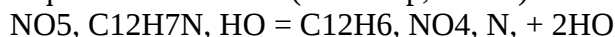
The synthesis of *p*-aminophenylarsinic acid opened the door to the preparation of many medicines based on arsenic, for example, this particular anilide proved to be a potent remedy (atoxyl) for the treatment of trypanosomiasis.

According to Béchamp, the influence of the functional groups present in a substance manifested itself on the color of its combinations. Thus, fuchsine produced with colorless acids salts colored red or yellow, depending on its saturation state. The hydrochloride, the sulfate, nitrate, oxalate, tartrate, arsenate, phosphate, and hydrate were always red, as long as the acid in the dissolution was not in excess. When free and anhydrous, it was green by refraction and red by transmission; in other words, functioning as a base it was always colored. Functioning as acid, it was always colorless. Thus the fresh hydrate of fuchsine produced colorless solutions when dissolved in ammonium, KOH, and baryta water. Fuchsine was a very weak acid, which dissolved in alkaline carbonate producing colorless solutions (Béchamp, 1860b).

Béchamp also reported that aniline homologues such as toluidine, xyloidine, and cumidine, showed the same behavior as aniline (Béchamp, 1860b, 1861a).

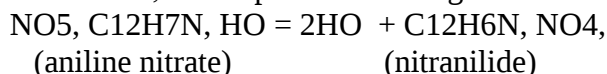
Aniline nitrate

Béchamp wrote that aniline nitrate crystallized as large transparent and hard crystals, unalterable in contact with air. They did not lose water when heated for many hours at temperatures between 100 and 120 °C and when heated in a retort at 150 °C. Hence it could be considered an anhydrous salt represented by the formula $[\text{NO}_3, \text{C}_{12}\text{H}_7\text{N}, \text{HO}]$, and also representing nitraniline plus 2 equivalents of water (Béchamp, 1861b):



This equation led Béchamp to try to synthesize nitraniline. For this purpose he heated aniline nitrate in a retort provided with a receiving flask and noted that it resisted, without decomposition, temperatures up to 210 °C, but if it was maintained at 150 to 180 °C for many hours, it began to sublime, without melting and without releasing water. The parts of the retort that were outside the heating oil bath became covered with brilliant white crystals, which had the properties of nitraniline, for example, they were soluble in water and the solution turned violet in contact with calcium hypochlorite. They also colored red a solution of ferrous sulfate in ordinary sulfuric acid (Béchamp, 1861b). When the distillation temperature reached more than 190 °C, a live reaction took place inside the retort with abundant release of vapors, which condensed as a tarry substance, mixed with a bit of water. Examination of this material showed that it had all the properties of the nitraniline derived from dinitrobenzene. The mode of its preparation indicated that this nitraniline

should be considered *nitranilide*, that is, a compound which was related to aniline nitrate in the same way that nitramide was related to ammonia. In other words, aniline nitrate, under the influence of heat, decomposed according to:



Béchamp reported that a better way for preparing nitranilide was to heat the aniline nitrate mixed with aniline to a temperature between 1800 and 195 °C (Béchamp, 1861b).

Aniline arsenate

As mentioned above, Béchamp found that nitraniline could be prepared by heating aniline nitrate; this method of preparation suggested that nitraniline should actually be called nitranilide. This result led him to synthesize arsenianilide, the corresponding product of arsenic acid, prepared by the action of heat on aniline arsenate (Béchamp, 1860b, 1863b). Treatment of the product of this reaction with aqueous sodium carbonate resulted in the release of CO₂, the formation of a viscous deposit containing aniline colored derivatives, and of an alkaline aqueous phase, colored pale red, containing arsenic acid and the new anilide. The anilide was separated by concentrating the liquid phase, followed by addition of an excess of pure nitric acid. The precipitated anilide appeared as rose-colored crystalline flakes, which were purified by repeated crystallizations from alcohol or water. The purified crystalline material was colorless, not volatile, and soluble in cold water and cold alcohol. By distillation it decomposed into water, aniline, arsenic acid, and metallic arsenic. Elemental analysis indicated that it could be represented by the formulas [C₁₂H₆AsO₄, N, 2HO] or [C₁₂H₈N, AsO₄, 2HO], corresponding to arsenialine and arsenialide, respectively, or also as an arsenylammonium of the hydrate of an ammonium oxide (Béchamp, 1860b, 1863b).

Starch

As mentioned before, Béchamp had found that ferrous chloride was able to separate the original starch from nitramidine (Béchamp, 1853d). This finding led him to investigate the action of sulfuric acid, nitric acid, glacial acetic acid, zinc chloride, and caustic alkalis, on starch (Béchamp, 1854b). It was well known that starch, before transforming into dextrin, went through a first modification known as dextrin colorable by iodine. The purpose of this new publication was to demonstrate the existence of a modification of starch, which was soluble in water and intermediate between insoluble starch and dextrin. Starch treated with concentrated nitric acid changed first into a thick paste that eventually it dissolved in the acid. Addition of concentrated alcohol to the final solution separated the starch as a heavy mass, which after washing with alcohol became a neutral white powder, slightly soluble in water. If the viscous mixture of starch and acid was left alone for 48 to 60 hours, or heated until the appearance of sparkling vapors, it became completely liquid. Addition of concentrated alcohol resulted in the complete separation of the starch. This time, the product was completely soluble in water. Béchamp mentioned that in every case the soluble and insoluble fractions were colorable blue by iodine. The same procedures using sulfuric acid instead of nitric acid rendered a starch partially or completely soluble in water. The starch also became completely soluble after being heated to 100 °C for 3 to 5 hours with glacial acetic acid in a closed tube. Heating the starch with concentrated KOH or NaOH resulted in complete elimination of the nitrogen as ammonia. Neutralization of the residue with acetic acid, followed by addition of alcohol, resulted in the complete precipitation of the starch. This starch was sparingly soluble in cold or boiling water (Béchamp, 1854b).

According to Béchamp the soluble starch differed from dextrin in the following aspects: (a) iodine colored it blue; (b) it was precipitated by tannic acid; (c) it clouded lime water and precipitated barite water; (c) its rotating power, $\alpha_D^{20} = 2100$, was substantially larger than that of

dextrin (about 1950); and finally (d) its solution diffused easily through the pores of an animal membrane. Béchamp added that the property of being blue by iodine was independent of the amount of nitrogen content because the starch that had been treated with boiling alkali also turned blue with iodine (Béchamp, 1854b).

In 1814 Jean-Jacques Colin (1784-1865) and Henri-François Gaultier de Claubry (1792-1878) discovered the unique property of iodine of coloring starch blue, present even in minute quantities. This attribute allowed distinguishing easily this compound from a variety of similar analog substances, such as gum, dextrin, and lichenin (Colin and Gaultier de Claubry, 1814). This statement was true as long as it could not be proved that the property belonged to a foreign nitrogenous substance that accompanied always the starch in a very small amount, as claimed by Nicolas Blondlot (1808-1887) (Blondlot, 1853). Blondlot had given the following two situations where iodine was unable to tint starch blue: (1) starch grains left alone in water assumed a yellow color in contact with iodine; and (2) a similar result occurred, almost immediately, with certain organic substances such as saliva, blood serum, and a multitude of other neutral or alkaline fluids. According to Blondlot, the amylaceous material, which constituted the largest fraction of starch, assumed a yellow color, while the nitrogenous impurity become blue, giving a general sensation of a green color. This information led Béchamp to test Blondlot's statement (Béchamp, 1855a).

Béchamp found that addition of a weak solution of iodine to starch granules led initially to a superficial formation of the blue color because a microscopic examination showed that the grains maintained their transparency. Further addition of the reagent increased the intensity of the coloration until the grains looked opaque black, indicating that the coloration had penetrated down to the center of the granules. Addition of ammonia revealed the coloration gradually disappearing from the external surface to the center of the particle. Assuming that Blondlot's nitrogenous substance constituted 2% of the total weight, these changes required that this minute amount absorb most of the reagent, if the final color was to be yellow. Now, diluting one decigram of starch paste in 600 cm³ yielded a solution, which turned deep blue upon addition of one or two drops of iodine tincture. If Blondlot was correct, this meant that the intense blue color was due to 2 mg of the nitrogenous substance dissolved in 300,000 its weight of water (Béchamp, 1855a).

Béchamp repeated the experiences done by Blondlot with saliva and with blood serum. First, he left disorganized grains of starch in water, for several months in contact or out of contact with air, and then added a few drops of iodine tincture: a beautiful blue color appeared immediately. He repeated the experiment with starch that had been heated for a long time, soluble starch that had been prepared by means of acids, zinc chloride, starch deprived of its nitrogen by means of KOH, boiled bread, and samples of saliva, blood serum, white of eggs, gastric fluid of a dog, etc. Iodine did not generate a blue color in all of the experiments done with animal fluids but did with all the samples containing starch. Addition of saliva, serum, etc. to the last samples resulted in a disappearance of the blue color, which was not regenerated by addition of further iodine.

Béchamp rejected the possibility that the alkalinity of saliva or serum were responsible for the disappearance of the color because eventually the excess iodine added would have recovered the color. He found that addition of a few drops of iodine tincture, followed by addition of small amount of KOH and then of nitric acid, were enough to recover the blue color. Many of these experiences proved him that the starch resisted for a long time the action of saliva, serum, and gastric fluid, and during this time reacted with iodine as usual. For example, in one experiment he dissolved 2 g of soluble starch or starch in granules in 200 g of serum. After one hour, the solution ceased to become blue with iodine. Addition of KOH, followed by neutralization with nitric acid,

produced an abundant precipitate of albumin, but the mass became blue upon addition of the tincture (Béchamp, 1855a).

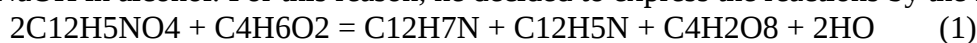
Béchamp ended his paper mentioning a curious experience. He contacted the rootlets of many onions with a solution of soluble starch and after three days found that the iodine tincture did not turn blue the remaining liquid. After treating the liquid with KOH, followed by neutralization with nitric acid, he discovered that the tincture turned it blue. He asked: Which substance secreted by the onion had masked the typical coloration (Béchamp, 1855a)?

Reduction of nitrocompounds

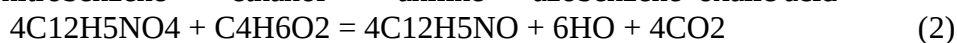
In 1858, Béchamp published the results of his research on the possibility of using ethanol as a reducing agent (Béchamp and Saint-Pierre, 1858). It was known that under many circumstances ethanol operated as powerful reducer and for this reason elaborated about comparing this action with other reagents known to reduce easily compounds such as nitrobenzene, nitrobenzoic acid, etc. to the state of amides. In the first stage he reacted in sealed tubes ethanol and methanol with nitrobenzene and observed that the reaction began at about 1500 or 180 °C; the mixture became brown while a gas was released. Inspection of the remaining liquid showed the absence of known compounds. For this reason, he switched to sodium ethylate and a mixture of nitrobenzene and an alcoholic solution of KOH. This time he observed that the product of the reaction contained azoxybenzene, azobenzide, aniline, oxalic acid, and brown byproducts. He was unable describe the reaction by a given equation because it was known that nitrobenzene did not react with KOH and the reduction products (azoxybenzene, azobenzene, and aniline) had to been formed through the intervention of a reducing agent because all of them contained the carbon of the original material. In addition, KOH was actually an oxidizing agent (Béchamp and Saint-Pierre, 1858).

In the following experiment he reacted 108 g of nitrobenzene with a mixture of alcohol and 44 g of sodium ethylate. The mixture began reacting lively at 65 °C and releasing ethanol vapors; after it had calmed down it was heated further to 90 °C to eliminate the remaining alcohol. The solid residue was extracted with ether and found to contain aniline. Béchamp found that aniline was initially formed when using sodium ethylate alone and afterwards by the action of heat on azoxybenzene, which decomposed into azobenzene, aniline, and a black compound found in the solid residue. The portion of the solid residue insoluble in ether was found to contain oxalic acid.

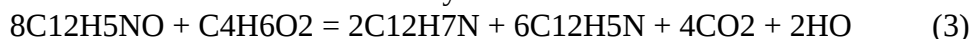
According to Béchamp, all these results indicated that sodium ethylate behaved like a solution of NaOH in alcohol. For this reason, he decided to express the reactions by the following equations:



nitrobenzene ethanol aniline azobenzene oxalic acid



nitrobenzene ethanol azoxybenzene



azoxybenzene ethanol aniline azobenzene

The last equation expressed the consecutive action of the alcohol on azoxybenzene (Béchamp and Saint-Pierre, 1858).

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[1] August Wilhelm Hofmann (1818-1892) discovered the reduction of nitrobenzene dissolved in alcohol, by means of HCl and zinc (Hofmann, 1846). Béchamp proved that alcohol was not necessary and that iron filings could replace zinc with a considerable reduction in costs.

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