

• 科学技术史 •

在原子论、元素论和经验主义之间：若弗鲁瓦的化学研究

Between Atomism, Elementalism, and Empiricism: The Chemical Studies of Étienne-François Geoffroy

佟艺辰 / TONG Yichen

(中国科学院大学人文学院, 北京, 100049)
(School of Humanities, University of Chinese Academy of Sciences, Beijing, 100049)

摘要: 艾蒂安-弗朗索瓦·若弗鲁瓦是18世纪初期的著名法国化学家, 以其1718年发表的《物质间关系表》闻名于世, 开启了法国的亲合力化学研究。本文发现, 在若弗鲁瓦涉足亲合力化学研究之前, 他一方面采纳了原子论化学的形而上学, 另一方面利用元素论构建了其化学物质理论并以之研究金属构成问题。在发表《物质间关系表》之后, 他则将他从经验中归纳出的“物质间关系”称为“理论”, 并将其用于普鲁士蓝研究。综观若弗鲁瓦的化学研究, 他始终将具体问题作为研究的重心, 无意提出一套总括全局的化学形而上学或化学理论。他既不是牛顿主义者, 也没有开启“化学革命”, 而是一位既有学说的综合者。

关键词: 化学史 若弗鲁瓦 原子论 元素论 经验主义

Abstract: Étienne-François Geoffroy was a French chemist in the early 18th century famous for his “Table des différents Rapports” published in 1718, which initiated the study of affinity chemistry in France. This paper finds that before Geoffroy’s involvement in the study of affinity chemistry, he adopted the metaphysics of atomistic chemistry on the one hand, and used elementalistic theory to construct his theory of chemical substances and to study the composition of metals on the other. After the publication of the “Table des différents Rapports,” he used the word “théorie” to refer to his empirical “rapport,” and applied it to his Prussian Blue studies. In his chemical research, Geoffroy always focused on specific problems and did not intend to propose a comprehensive metaphysics or theory of chemistry. He was neither a Newtonian nor an initiator of a “chemical revolution,” but a synthesizer of existing doctrines.

Key Words: History of Chemistry; Étienne-François Geoffroy; Atomism; Elementalism; Empiricism

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Étienne-François Geoffroy(1672-1731) was an active chemist in Paris during the first half of the 18th century. He was elected as a Fellow of the Royal Society of London in 1698, and a member of the Royal Academy of Sciences of Paris in 1699. In 1718, he published the first affinity table in *Histoire de*

l’Academie Royale de Paris, which is regarded as the beginning of affinity chemistry in the 18th century and therefore his most important contribution to chemistry.¹ Besides several chemical and pharmaceutical papers, his only book, *Traité de la Matière Medicale*, which was compiled from his lectures on pharmacology

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作者简介: 佟艺辰(1992-)男, 黑龙江齐齐哈尔人, 中国科学院大学人文学院特别研究助理。研究方向为化学史、科学编史学。Email: tongyichen@ucas.ac.cn

given around 1710, came out posthumously from 1743 to 1750.

Historians of chemistry have not come to an agreement over the historical position of Geoffroy. J. R. Partington argues that Geoffroy was a follower of Descartes' doctrine,² while Arnold Thackray believes that the "affinity table" was derived from Newton's work on the order of activity of metals in acids so that Geoffroy was therefore an advocate of Newtonianism in France.³ W. A. Smeaton pointed out that there was little basis for this claim and Geoffroy's view on fundamental chemical substances is close to a Cartesian chemist.⁴ In the opinion of Ursula Klein, the concept of "composition" shown in Geoffroy's "affinity table" laid the foundation for modern chemistry so he was supposed to be the initiator of a "chemical revolution".⁵ But for Bernard Joly, Geoffroy was rather a successor of the alchemical tradition in the 17th century than a follower of Cartesian chemistry, which did not exist.⁶ In sum, previous studies have focused mostly on two issues: first, the meaning and historical significance of his "affinity table"; and, second, whether or not he was a Newtonian. However, taken as a whole, previous scholarship on Geoffroy does not seem to give a clear picture of him. If we want to understand his chemical research more comprehensively, we need not only to extend the scope of the investigation from the affinity table to his other research fields, but also to go beyond the perspective of "Newtonianism" and find out another way towards a better interpretation.

Therefore, I am going to integrate Geoffroy's studies on various topics, such as thermology, compositions of different substances (especially metals), chemical affinities, and Prussian Blue, under a perspective other than which chemical school he belonged to, but what roles different thoughts played in his chemical studies. By investigating how atomistic and elementalistic traditions — as I state below — interacted and worked in his explanation of phenomena, establishment of theory, and design of experiments, I try to provide a picture of a synthesizer of existing chemical doctrines in preference to a portrait of a believer of some chemical sect.

The chemical thoughts in 18th century could be

classified into two traditions, atomistic chemistry and elementalistic chemistry. The two chemical traditions can be summarized as follows: atomistic chemistry presupposes that matter consists of tiny, indivisible, discrete atoms, which can be combined into different particles, and that the properties of material things are determined by the size, shape, motion (and later even interactive forces) of atoms and particles; elementalistic chemistry presupposes that matters consist of a number of non-transmutable, continuous elements, which are burdened with different properties, and that the properties of macroscopic matters are determined by their elements. The two chemical traditions emerged from ancient Greece and coexisted for a long time until the 19th century, when Mendeleev (1834-1907) was actually a defender of elementalism.⁷ The collision and integration of them is not only a key clue to understand the history of chemistry in 18th century France,⁸ but also an important entry point to understand the construction of the research program of modern chemistry.⁹

Using Geoffroy's papers and writings as sources, this paper attempts to take a more comprehensive view of his attitude to the metaphysics of chemistry, and to examine how his chemical theories, mainly the "théorie" of "différents rapports entre différentes substances," were applied to his explanations of chemical phenomena and design of chemical experiments.

I. Atomism and Elementalism: Geoffroy's Early Exploration of the Metaphysics of Chemistry and the Theory of Chemical Substances

1. Atomism: The Metaphysics of Chemistry

As Smeaton demonstrates, *Traité de Matière Medicale* showed that Geoffroy might have tended to explain the chemical properties of substances in a mechanical way. Firstly, the fundamental substances were corpuscles with various shapes:

There were three very simple substances to which he gave the name "element." These were: fire, which could exist only in combination with the other two; water, composed of hard, smooth,

oval or wedge-shaped particles that entered into the pores of earthy substances and so dissolved them; and earth, composed of particles that were irregular in shape and therefore formed a porous mass.⁴

The other two “principles” were salt (acid and alkali) and sulphur (or oil). Secondly, chemical properties came from the shapes of the corpuscles. For example,

Alkali contained higher proportions of earth and fire, and its particles were spherical, with projecting spikes; they slid over the tongue and scraped it, whereas acid particles pricked it. When alkali particles joined together, they did so by the spikes and a porous globule was produced, into which other particles could easily enter.⁴

Based on these, Smeaton defines Geoffroy as a follower of Cartesian chemistry, especially close to Nicolas Hartsoeker (1656-1725), a Cartesian mathematician and physicist who speculated about the penetration of hollow alkaline particles by pointed acid particles.¹⁰ All these beliefs about the fundamental substances in chemistry are unable to be verified by observation or measurement, so we can classify them as the metaphysics of chemistry.

In fact, Geoffroy had started to think about chemical metaphysics as early as around 1700. In a paper published in 1700, he described the phenomenon of temperature change due to the dissolution and fermentation of some substances and explained it in terms of the degree of relative motion between the particles of matter: the more violent the motion of the particles of matter, the higher the temperature of the solution; vice versa. In aqueous solutions, water undoubtedly makes the largest proportion, so whether the solution temperature is high or low mainly depends on the degree of violent movement of the particles of water. If the solute dissolves so that the movement of a large number of water particles becomes more violent, then the solution temperature increases; vice versa. For example, he believed that the reason why some calcined salt heats up the liquid when it dissolves is that the fire particles fixed in the salt during calcination are released when it dissolves, raising the churning of the water and thus making it

hot.¹¹

Geoffroy’s metaphysical ideas can also be found in his article “Observations sur le vitriol et sur le fer” published in 1713. In this paper he argued that the acidity of sulfuric acid comes from the spiky shape of its particles, and that its “coarseness, and perhaps even the shape of the vitriolic salts, prevents them from entering the pores of the iron: they therefore attach themselves only very superficially, so that they separate very easily.” Thereby, when dissolving vitriol in water for digestion, “a part of the acid points, gives up the ferruginous molecules which one sees precipitating at the bottom in yellow powder.”¹² It is evident that Geoffroy not only explained the sensible properties of substances (such as taste) in an atomistic way, but also their chemical properties.

Therefore, in the very beginning of the 18th century, Geoffroy used an atomistic approach to explain the mechanism of temperature change in chemical reactions, where fire particles could stir the solution and make it heated. Then in the 1710s, chemical properties and the mechanism of chemical reactions could be reduced to the shape and movement of the small particles. Given that Geoffroy’s chemical teacher was Wilhelm Homberg (1652-1715), a student of Robert Boyle (1627-1691), and he travelled to Britain for a couple of years, it’s reasonable to assume that his atomistic views could be traced to Boyle rather than Newton or Descartes. In essence, Geoffroy had referred to Boyle’s papers several times. Furthermore, fire played an important role in Geoffroy’s chemistry, which is evidence that Geoffroy was deeply influenced by Homberg. We will deal with this point in the following section.

2. Elementalism: The Theory of Chemical Substances

Geoffroy’s chemical metaphysics was atomistic. However, his theory of chemical substances was elementalistic. In “Des principes des Corps,” the second chapter of *Traité de Matière Medicale*, Geoffroy first distinguished between ancient and modern chemists. He stated that ancient chemists believed that matter could be reduced to five elements: spirit or mercury, sulfur, salt, water, and earth.¹³ This view, said to be that of the ancient chemists, actually

came from his teacher, Homberg.¹⁴ According to Geoffroy, the new chemists denied that spirit was one of the basic substances and considered it to be nothing more than an aqueous solution of salt or sulfur.¹³ He also denied that salt was a basic substance, and salt could be considered as consisting of earth and water. Sulfur can also be analyzed chemically as salt, water and earth. Thus, after the chemical analysis of spirit, salt, sulfur, water, and earth, which in the eyes of ancient chemists could be called basic substances, only water and earth were qualified to be considered an “element.”

Perhaps influenced by Homberg, Geoffroy added fire, which he often called “substance subtile,” as an element to these two substances. As a disciple of Boyle, Homberg saw fire as a partial substitute for light, the key to chemical analysis.¹⁵ Geoffroy, on the other hand, believed that the presence of fire was necessary to provide movement for substances to combine into mixtures. Without the presence of fire, earth could not move on its own, water would freeze for lack of movement, and some substances derive their volatility, fineness and fluidity from fire.¹³

Thus, in Geoffroy’s theory of matter, there were three fundamental substances, “to which we give the name of Elements. One is active, we call it the Fire; the other two are passive, it’s the Earth and the Water.”¹³ The substances made up by the combination of elements are called principles. The combination of water and earth formed a salt principle, while the combination of water, earth and fire formed a sulfur principle, or oil.¹³ Since elements and principles can also be combined with each other to form more complex objects, all five substances can also be collectively referred to as principles. It is these elements or principles that determined the nature of matter. For example, he mentioned that “volatile salts are nothing more than fixed salts freed from the largest part of the earth and combined with some parts of oil.”¹⁶ This is equivalent to saying that the earth is responsible for the fixity of the salt, while the oil is responsible for the volatility of it. In another paper, Geoffroy gave a more detailed elaboration:

These alkali salts are nothing other than acid salts concentrated in a few molecules of

earth and united with a few parts of oil by the intermediary of fire, either in fermentation or in deflagration: this is what experience shows.

The difference between volatile alkali salts and fixed alkali salts depends mainly on the quantity of earth, greater or lesser, which is united with the acids and sulfurs. In the fixed salts there is a great deal of earth which serves as a base, and in which the acids are engaged with a little oil. In the volatile salts, on the contrary, there is very little earth and a lot of oil which shapes the acids.¹⁷

It is not only the properties of salts like acids or bases that were provided by their elements, but also metals. Geoffroy spoke of “this sulfur principle that is not only present in metallic substances, but also gives these materials their fusibility, ductility and metallic form. This is what I will show in most metallic materials.”¹⁶ Through experimental studies on a variety of metals, Geoffroy established his theory of metal composition:

The metals which are called imperfect, namely, Iron, Copper, Tin, & Lead are composed of a sulfur or an oily substance & of a matter capable of vitrifying.

From this sulfur or oil that the opacity, luster, and malleability of the metal comes.

This metallic sulfur does not appear to be any different from the oil of plants or animals.

It is the same in the four imperfect metals and even in Mercury.

These four metals have for a base a matter susceptible of vitrification.

This matter is different in each of these four metals, since it vitrifies differently:

And it is from this difference that the difference of the metals depends.¹⁸

This view that metals are composed of vitrifiable clays and sulfur elements is actually identical to the idea about the composition of metals of Pierre-Joseph Macquer (1718-1784), the author of the famous *Dictionnaire de Chymie* (first edition in 1766, second edition in 1778). It was on these principles that Macquer relied to design his alchemical experiments, which attempted to create different metals by

combining various different glassy clays with sulfur elements.¹⁹

3. The Relationship Between Geoffroy's Atomistic and Elementalistic Ideas

The “element-property” correspondence principle, then, played a key role Geoffroy's theoretical construction and experimental design. This brings us to a problem: on the one hand, the atomists adhere to the “structure-property” correspondence rule, explaining the properties of matter in terms of the size, shape, and motion of particles; on the other hand, the elementalists adhere to the “element-property” correspondence rule, in which an element or a principle is always responsible for a certain property of matter.⁹ Does it constitute a contradiction that, before the publication of the “Table des différents Rapports observés en Chimie entre différentes substances” in 1718, Geoffroy applied two very different metaphysical doctrines at the same time?

We should note that the word “théorie” does not appear in any of the papers published before 1718. Thus, in Geoffroy's eyes, the real theory created by himself was his empiricist table of relationships between substances, which will be discussed below. Before that, the atomistic metaphysics of chemistry, and the elementalistic ideas, including the theories about the classification, the hierarchy, and the property of chemical matters, were both applied in his chemical studies to explain specific chemical phenomena and to guide specific experimental designs. Even for the seemingly complete theory of metal composition, he clearly pointed out that he was talking about the composition of four imperfect metals, iron, copper, tin, and lead, and not the composition of all metals^①. In other words, for him, both the elementalistic and atomistic traditions were at his disposal as resources of thought to help him in his specific chemical studies.

Geoffroy was not only influenced by British chemistry, but was also very familiar with the chemical research of the German chemist, physician, and philosopher Georg Ernst Stahl (1660-1734).²⁰

Stahl insisted on the impenetrability of the smallest particles while also insisting on a certain “element-property” correspondence rule, for example his “phlogiston” theory.²¹ Geoffroy himself also acknowledged that his fire element corresponded to phlogiston. As I attempt to demonstrate in this paper, Geoffroy's metaphysics or theory of chemistry is in a position of “both elementalism and atomism.” This might remind us that at the turn of the 17th and 18th centuries, although European chemists were at a methodological turning from analysis to “synthesis + analysis,”²² some of them were more inclined to adopt an eclectic approach to existing sources of thought than to re-establish a new system of basic concepts.

II. Geoffroy's Affinity Studies and His Change of Attitude Toward Metaphysics

In 1713, Geoffroy had no reservations using metaphysical concepts. But as his own research and existing historical studies have shown,²³ his affinity studies were clearly inclined to empiricism. This may suggest that the affinity studies led to a turn in Geoffroy's attitude towards the metaphysics of chemistry.

When did Geoffroy become interested in the problem of chemical affinity? According to the available information, a letter between him and Hans Sloane (1660-1753), then secretary of the Royal Society, may give us some clues. On May 31, 1715, Geoffroy wrote to Sloane to express his gratitude for the hospitality Sloane had shown to his brother and for the books he had sent to him. In the letter, he writes.

I have seen what there is in the *Philosophical Transactions* concerning Attraction, Magnetism or Electricity of bodies and centripetal and centrifugal forces. You speak to me of an account of several experiments relating to it before the Royal Society. Is this a simple Index of these experiments, or a collection? Whatever it is, you will be pleased to send it to me. These experiments seemed to us

① Bernard Joly believes that Geoffroy's theory about metal composition was established in order to be suitable to all metals, but this theory was never applied to the metals apart from the imperfect ones. (see reference 6)

very curious, but it is difficult to get used to the term “attraction” which seems to bring us back to occult qualities. The term magnetism gives a more sensitive idea of the way in which this approximation or...the gap of matters. In truth, it may carry with it a prejudice that we avoid by using the word attraction, which simply marks an effect whose cause, according to Mr. Newton, is still unknown to us.²⁴

This letter suggests that it was probably in 1715 that Geoffroy became interested in the study of attraction (or rather, affinity or inter-material relationships) after learning about the experiments and doctrines of attraction in the *Philosophical Transactions* that Sloan sent him.

Interestingly, Geoffroy’s curiosity about affinity began with exposure to the works of British scholars, and it is difficult not to relate these results to Newton (especially since Geoffroy specifically mentioned the

word “attraction”), but, as I argued, he deliberately avoided all concepts and theories with Newtonian tendencies or any ontological presumptions.²³ Thus, the article “Table des différents Rappports observés en Chimie entre différentes substances” [FIGURE 1] is also a representative work that reflects his empiricist tendencies.²⁵

At the beginning of the article, Geoffroy claimed that

In chemistry one observes different relationships between different bodies, which act such that they unite easily with one another. These relationships have their degrees and their laws.²⁵

Furthermore, he said,

I display today in this table the different relationships that I gathered, as much from the experiments and observations of other chemists as from my own.²⁵

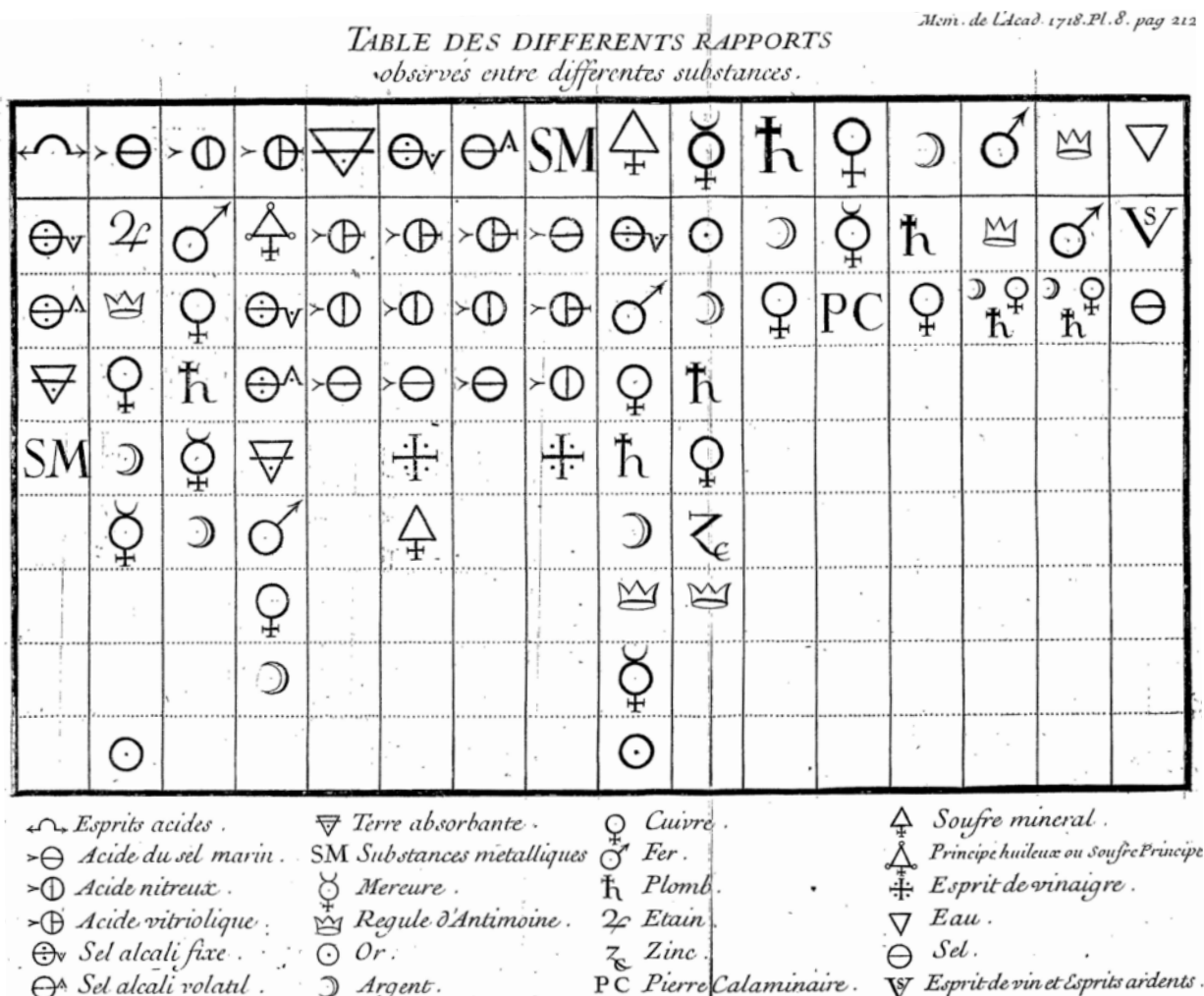


Figure 1 Geoffroy’s “Table des différents Rappports”

It's apparent that the "relationships" between different chemical substances were facts observed and gathered from the experiments, rather than some general principles, such as "affinity" the meaning of which is vague and often elaborated as "similar substances tend to unite." In fact, according to the *Proces Verbaux* of the Royal Academy of Sciences of Paris, the original version of the article was about "the different degrees of affinity of chemical materials."²⁶ As we know, however, Geoffroy actually used the word "relationship" in the formally published article.

In addition to the difference between the concepts of "affinity" and "relationship," Geoffroy's essay expresses his empiricist tendencies in two distinct aspects.

First, he used the term "théorie" in this essay, but did not appeal to any ontological presuppositions. Geoffroy used the term "théorie" when he used his table of relationships to explain the principles of the preparation of Sublimé corrosif (mercuric chloride, HgCl_2). He said that

To make evident presently of what utility this table can be for discovering what happens in the different mixtures of mixed bodies, and to preview what should result from it, let us take for example the preparation of corrosive sublimate, which is an entirely ordinary operation and yet of which the theory is very little known.²⁵

He mentioned that chemists of the time usually

prepared Sublimé corrosif by mixing vitriol (ferrous sulfate, FeSO_4), Sel Marin (sodium chloride, NaCl) and Sel nitreux-mercuriel (mercuric nitrate, $\text{Hg}(\text{NO}_3)_2$) and heating them. According to him, Sel Marin was composed of sea salt acid and an absorbent earth, vitriol of sulfuric acid and iron, and Sel nitreux-mercuriel of nitric acid and mercury. According to the "table des rapports," the rapport between sulfuric acid and absorbent earth is greater than that between acid and metal, and that between nitric or sea salt acid and absorbent earth, so that sulfuric acid combines preferentially with absorbent earth, while sea salt acid and iron are released, and sea salt acid then "attacks at the same time the iron of vitriol & the mercury of nitre." Again, according to the "table des rapports," the rapport between sea salt acid and mercury is greater than that between nitric acid, which, because there is no substance to hold it in place, escapes in the form of red or yellow fumes under the action of fire; the composition of sea salt acid and iron is not volatile and thus remains at the bottom of the retort; the composition of sea salt acid and mercury is volatile and thus this is the reason why chemists call it "Sublimé corrosif."²⁵ [FIGURE 2]

We see that Geoffroy's explanation of the principle of preparing Sublimé corrosif ultimately resorts to the "table of relationships" which is actually a set of rules of thumb, rather than to any theory with metaphysical presumptions. Thus, the "théorie" he

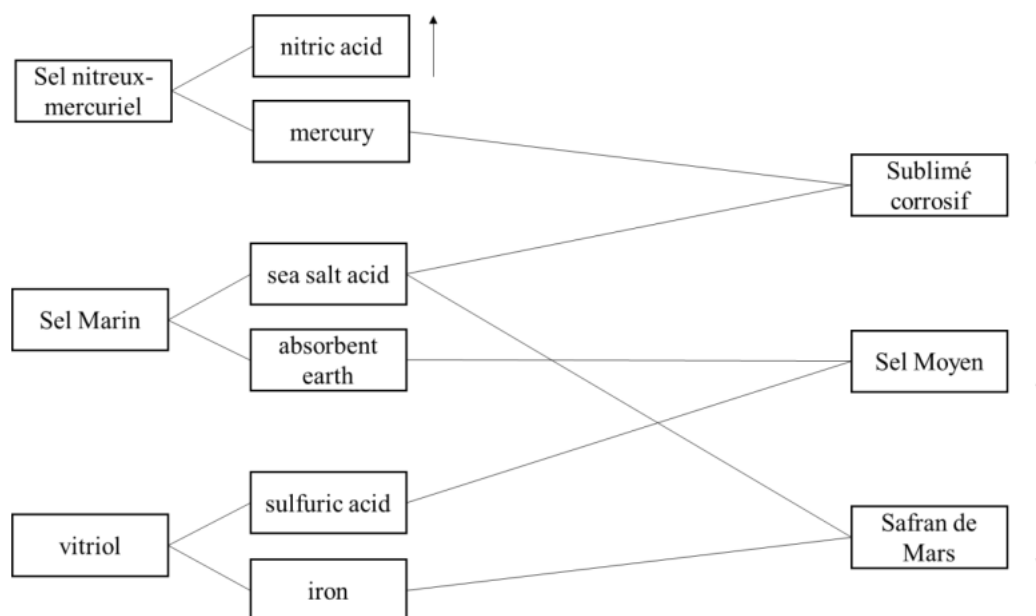


Figure 2 The Preparation of Sublimé Corrosif

referred to in this article is in fact his empiricist “table of relationships.”

Second, in contrast to the article “Observations sur le vitriol et sur le fer,” the article “Table des différents Rapports observés en Chimie entre différentes substances” again addressed the chemical composition of vitriol without referring to any chemical metaphysics, such as particle size, motion, shape, etc., but instead uses its table of relationships exclusively to explain it. For example, he explained why vitriol was not actually needed for the preparation of Sublimé corrosif from mercuric nitrate, while it is necessary from mercury.

Another observation to make is that when one uses mercury reduced to a salt by spirit of niter, one can do without vitriol, whereas if one uses only pure, fluidmercury, it [i.e., vitriol] is absolutely necessary. The reason for this is clear in our principles. The acid of sea salt having a greater relationship with its earth than with metallic substances — as can be seen in the first column (Acid spirits) — will not at all abandon it to attach itself to mercury if it is not led [determine] to this by some cause. There is no such [cause] on the part of the mercury alone. But if one uses mercury reduced to a salt by nitrous acid — this nitrous acid having a greater relationship with the earth of sea salt than does the acid of sea salt, as can be seen in the fifth column (absorbent earths), and this same nitrous acid also having a greater relationship with this same earth than with mercury, as one sees in the first column (Acid spirits) — this same [nitrous] acid, I say, will begin the action: it will abandon the mercury to attach to the earth of sea salt, and it will detach the acid from it. This acid of the salt, finding itself alone and rid of the earth, also encountering the freed mercury, will join to it, and these two substances will together form the compound [compose] of sublimate that rises to the top of the vessel, while the nitrous acid and the earth of the sea salt will form a middle salt that will stay fixed at the bottom of the vessel and that will make good salt peter.²⁵

We can see that in explaining the decomposition

and combination of multiple chemical substances, Geoffroy does not make any metaphysical statements at all, but simply uses the relationships between different substances to give his account. This undoubtedly also reflects his empiricist tendencies.

Why, then, did his approach to metaphysics produce a shift toward empiricism? We may get a glimpse by comparing the chemist Geoffroy with a French physicist of his time, Pierre-Louis Moreau de Maupertuis (1698-1759). Maupertuis summarized three metaphysical views of fundamental matter: “Or 1: All matter is homogeneous, and then different natural bodies differ only in their different shapes and in the different arrangements of the parts of matter. Or 2: All parts of matter are reduced to a certain number of kinds, and these are the elements of all objects, as chemists believe, although they do not agree in the number or nature of the elements, then the objects differ only in different doses and different combinations of these components. Or 3: All the parts of matter are as varied as all the different objects of nature, then each of these objects will consist of the part most similar to itself; gold consists only of the parts of gold, iron of the parts of iron, wood of the parts of wood, etc.”²⁷ For these three views, Maupertuis admitted that they all had some validity and it was impossible to decide which is right and which is wrong. However, he had no doubt about the “attraction” in chemistry.²⁷

For Maupertuis, attraction was already an indisputable fact in astronomy and physics, and there was no way to prove what the fundamental substance is, but only a few possibilities by logical reasoning. The same was true for Geoffroy: the “relationship” between substances with degrees and laws is a proven fact, compared to the size, motion, shape to explain the nature of matter and the combination and decomposition of matter, which was too far from experience. Since “relationship” could be used to explain chemical reactions, which not only let chemists know what was happening in their reactions, but also guided them in predicting what a reaction might produce, the metaphysics of “spikes fit holes” was undoubtedly dwarfed.

To understand the mechanical metaphysics of

chemistry, Richard Westfall argues: “As an instrument of explanation, the mechanical philosophy did not in itself offer a chemical theory. The particles of given shapes that Lemery and others discussed were not observed in any sense whatever; they were inferred from the observed properties, and in practice it was possible to imagine particles of any shape and motion that were required for the phenomena in question.”²⁸ Conceivably, this hindsight metaphysics was not of particularly obvious practical value to 18th century French chemistry, which focused on the discovery of facts and their application. It is not only reasonable to abandon metaphysics, or at least to avoid it, after capturing the relationships between different substances, but also to start the trend of using metaphysics cautiously while combining empirical and theoretical studies in 18th century French chemistry of affinity.²³

III. The Use of Chemical Theory in Chemical Practice: Geoffroy’s Prussian Blue Research

Geoffroy’s chemical studies included not only the basic research on the composition of chemical substances such as vitriol and metals mentioned above, but also the research on pharmacology and pigment, in which the research on Prussian blue was rather representative.

Prussian blue was first obtained by chance in 1704 by Diesbach, a pigment manufacturer in Berlin, and was first described in 1710 by an anonymous person as a non-toxic pigment for use in oil painting. But the method of preparation was kept secret. John Woodward described a method of preparation that involved roasting ox blood and potassium carbonate together, dissolving the product in water, adding vitriol and alum for precipitation, and finally treating the resulting green precipitate with hydrochloric acid to obtain the Prussian blue. Later, John Brown showed that alum was not necessary but vitriol was indispensable, and he thus concluded that it was the iron in vitriol that gave the pigment its beautiful color.²

In 1725, Geoffroy published two papers to

discuss the preparation of Prussian blue, where he shared the same view with Brown. In the paper “Observations sur la préparation du Bleu de Prusse, ou de Berlin,” he asserted,

I believe, like Mr. Brown, that it is the iron that provides the basis for this blue. I believe that it is the bituminous part of iron, which (as we know) is found in great quantities in this metal, that gives this color. Several things persuade me of this. 1. The blue color that polished steel takes, being exposed to a moderate fire, where this bitumen rarefied by the heat of the fire is a little raised on the surface of this metal. 2. The blue color of ink which is made with vitriol & walnut, & whose black is an obscure & very dark blue. 3. The blue color that ferruginous waters take with walnut, & especially those of Passy which are highly charged with iron. 4. The blue dye that some chemists obtain from iron by means of ammonia salt.²⁹

“Here is how I see the theory of this operation.” There were three solutions used in the preparation of Prussian Blue: an aqueous solution of the product of roasting ox blood with potassium carbonate, a solution of alum, and a solution of vitriol.²⁹ He used his theory of “relationships” in analyzing the action of each of these substances.

First of all, Geoffroy believed that the oil in ox blood and the alkali would combine to form a soap-like substance, which was suitable for extracting the bituminous substance contained in iron. However, the alkali, if it encountered an acid, would combine with it and discard the oil. Secondly, in his theory, alum is composed of an acid and an absorbent earth, and when it meets an alkali, the acid in it will combine with the alkali to form a sel moyen and discard the earth. Thirdly, he believed that vitriol was composed of an acid and iron, and when it encountered an alkali, the acid would combine with the alkali and the iron would fall to the bottom of the liquid in the form of a yellow powder.²⁹

If the alkaline solution of ox blood, alum, and vitriol are mixed, “the liquid becomes cloudy and a considerable precipitate is formed. This is because the acids of alum and vitriol have a greater relation

to the alkali salts in the solution than to the white earth in alum and the earth in iron metal, which leave each other's earth and combine with the alkali salts. At this point, these earth particles, which are highly decomposed out of these acids, clump together and recombine into particles so large as to be sensible, being too heavy to be suspended in the liquid which supports them [thus forming a precipitate]. But while the acid salts give up their earths in combination with the alkali salts, the alkali salts, in turn, by combining with the acids, also give up the oily parts of the blood with which they remain united during the calcination process. Thus, a double precipitation occurs.”²⁹ [FIGURE 3]

In the words of Geoffroy, this is the “theory” behind the preparation of the reaction of Prussian blue. Here again, he used the word “theory” in the same sense that he used it in his article “Table des différents Rapports.”

In his article “Nouvelles Observations sur la préparation du Bleu de Prusse,” Geoffroy used other substances such as antlers instead of ox blood and these experiments led him to speculate that “combustible elements, that is, asphaltenes permeated by subtle substances or fire elements, are essential to

this reaction.”³⁰

It is interesting to note that in this paper, Geoffroy once again moves to atomistic ideas. Speaking of the roasting of animal oil with potassium carbonate, he argues that “when the substance has not reached this degree of calcination, the pores of the oil are too loose and too large to retain a sufficient amount of fire element or fine matter, and still less [of fire element] when these same pores are filled with watery portions.”³⁰ It can be seen that Geoffroy, who had been “both atomistic and elementalistic” in his chemical metaphysics, still retained some metaphysical residue even after he turned to empiricism in 1718 and systematically applied his doctrine of “différents rapports entre différentes substances” to the design of experiments and the interpretation of phenomena. This metaphysical explanation, however, was no longer sufficient to serve as a theoretical basis for the design of experiments compared to his “théorie” of “différents rapports entre différentes substances.”

IV. Conclusion

Based on the above analysis, we can draw the following conclusions:

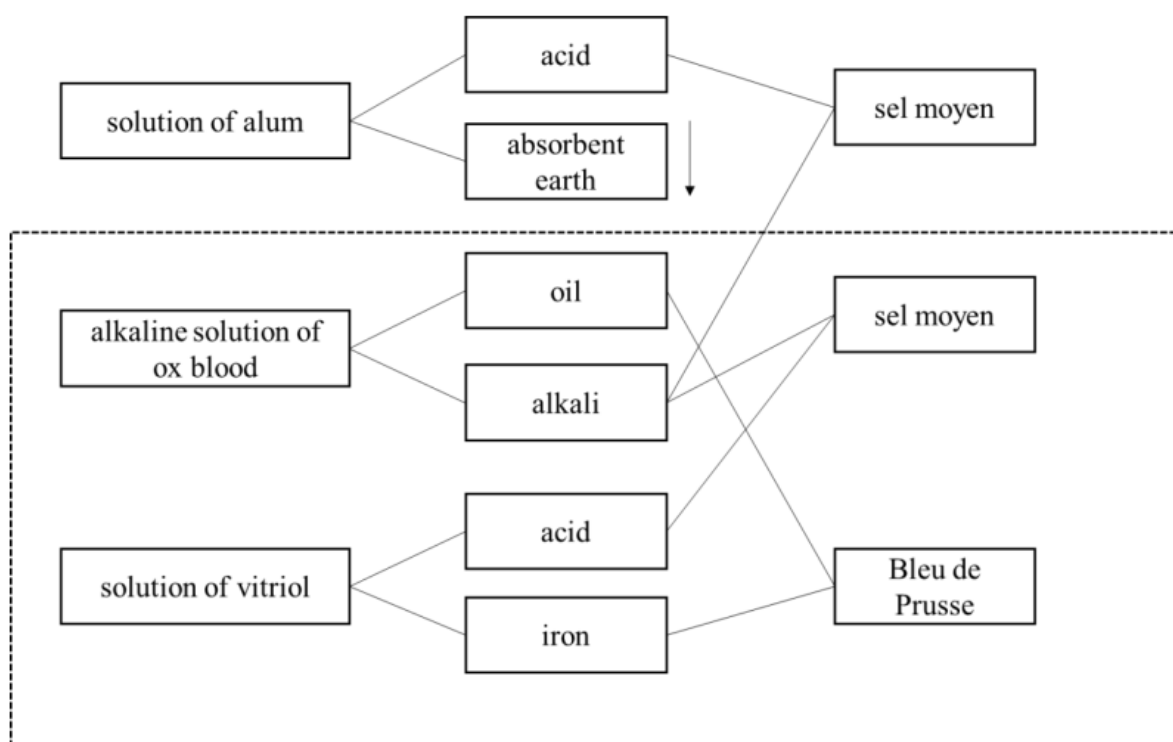


Figure 3 The Preparation of Prussian Blue

First, at the metaphysical level, Geoffroy holds both an atomistic view of chemistry which presupposes the “structure-property” corresponding principle, and an elementalist view which presupposes the “element-property” corresponding principle. In general, however, atomistic chemistry seems to be used mostly as a hindsight explanation, while elementalistic chemistry leads him to his theory of metal composition. On the question of the nature of chemical affinities, he held an empirical attitude and avoided the issue altogether.

Second, at the theoretical level, he argued that elements (fire, water, earth) constitute principles (salt, sulfur), and that elements and principles can be further combined to form more complex objects. On this basis, he proposed a theory of metal composition, arguing that imperfect metals such as iron, copper, tin, and lead are composed of vitrifiable earth and sulfur. In his subsequent studies, he proposed that “alum is composed of acid and a white earth” and “vitriol is composed of acid and iron.” All these ideas have a strong elementalist feature. The “théorie” that Geoffroy himself certified was his doctrine of “différents rapports entre différentes substances,” presented in the form of a “table des différents rapports.” Although Geoffroy described this doctrine in a purely empirical way, it has the status of a chemical theory because of its function of guiding experimental design and explaining experimental phenomena.³¹

Third, he not only made innovations in areas of fundamental research such as the problem of metal composition, but also explored applied research such as the preparation of Prussian Blue. In his studies of these problems, although he occasionally applied atomistic ideas to explain some phenomena (in a hindsight way), the “table des différents rapports” was his main theory and the ideas of elementalist chemistry were the main sources of thought he relied on, as his studies of metal composition showed.

In general, Geoffroy opened up a new field of affinity chemistry in France. However, he was more a synthesizer of old doctrines than a creator of new concepts. The only “théorie” that he himself admitted created by him was, in his eyes, closer to compilations

and generalizations of experience. Therefore, I am afraid we can hardly consider Geoffroy as the pioneer of the “chemical revolution.” He was neither trapped in the metaphysical contradictions of different chemical traditions, nor inventing a new frame of chemical concepts, but brought chemical theory and practice together in affinity chemistry.

Furthermore, this feature became a common quality of British and French affinity chemistry: in England, as Taylor declares, “the advantage of affinity theory was that the chemist was guided and assisted by affinity theory regardless of his ontological commitments;”²⁶ while in France, affinity chemists, represented by Macquer, developed a more refined affinity chemistry theory and applied it to a wider range of practices, and the inconsistency within his metaphysics does not manifest itself as a prominent problem.¹⁹

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