

Coloration and Chemistry in the Eighteenth Century

What is color? How does it get into or onto an object? Answers to these questions encapsulate two complementary sets of interests, both of which figured strongly in eighteenth-century efforts to understand color. What color is and why it exists—theories of color—were generally approached through the study of physics, optics, the refraction of light, and vision. Theories of coloration—how color gets onto an object and, perhaps more important, how it stays there—depend on chemistry. The differences in these questions are obvious to us; physicists and chemists practice two different branches of the sciences. A distinction was also obvious to eighteenth-century students of color. However, because physics and chemistry—and their relationship to each other—were different in the eighteenth century, our modern assumptions about the similarities or differences between theories of color and theories of coloration cannot be adopted wholesale.¹

The greatest perfection in the art of *colours* would be to find the means of preparing the finest *colours* without the use either of acid or alkaline salts, which usually subject the *colours* to change, or else are apt to prey upon the cloth, canvas, &c. as we see in verdigrise, the blue and green crystals of copper, &c.

Ephraim Chambers, "Colour in Dying" *Cyclopædia* (London, 1786) 1:n.p.

In the eighteenth century, general questions about coloration were often answered through references to certain properties, particularly refraction and reflection, but my interest here is not those interpretations based in physics. Nor will this section contribute to the ongoing debates about the nature of chemistry and chemical understanding, or debates about the significant theoretical reforms in the latter part of the century.² Instead, I wish to look at efforts to understand color as a practical phenomenon that relies on chemistry but is not only a chemical entity. To date, there have been few investigations of changing theories about the creation of color on objects as an aspect of eighteenth century chemistry, and few studies of ways that these changing theories served—within general discussions of chemistry's role in public science—to connect sciences to practices. Attempts to develop a theory of coloration were attempts to address problems important to both. Better understanding of colormaking would improve colors. It would show how to make them more durable or less expensive, and suggest ways to design or imitate colors made fashionable elsewhere. How objects accept and retain color was a question that physics failed to answer. Chemistry, as the study of operations that transform matter, could do better. Whether the focus was a textile, a pot, or a painting, eighteenth-century ideas about coloration of objects incorporated observations and behaviors from several different practices, and often incorporated accepted theories of color in order to attempt the creation of an idealized, unified whole. Whether the desire of those

people who proposed new theories of coloration was to prove Newton wholly correct or completely wrong or something in between, drawing together the different bases of colors was a subtheme of many chemical studies of color.³

Chemistry makes colors. Colors describe chemical change. Eighteenth-century discussions—especially among apothecaries, druggists, and others who sold or worked with coloring materials—highlight the mysteries of this bilateral relationship. Color was a defining characteristic of substances. It could be a clue to origin, or an indicator of purity or the degree of refinement. Color changes that occurred during a chemical operation suggested the progress of a reaction or confirmed the quality of the result; in certain substances, they indicated composition. The use of color in chemistry was especially provocative for colormaking: Could the change be harnessed and controlled, made practical for painting or dyeing? If so, colorists might then possess a range of colors with a theoretical as well as visual relationship. Would that same knowledge lead to more-certain color preparations and, in turn, to better objects?

Several attempts have been made to arrange and class the different species of colouring matters employed for dying and callico printing; but none seems to accord with, or give any just ideas of, their several natures and properties. Mr. Berthollet indeed alleges sufficient reasons for not dividing these matters, as Mr. Macquer did, into extractive and resinous, and also for not making their effects depend, as Mr. Pœrner has done, upon the mucilaginous, earthy, saline, resinous, or oily parts of which they were supposed to be compounded, but without proposing any suitable arrangement of his own.

Edward Bancroft, *Experimental Researches Concerning the Philosophy of Permanent Colours* (London, 1794), 77.

Color-based industries—the dye house, the apothecary's laboratory, the color mill, manufactures that used coloring materials or coloring techniques—were fertile ground for the creation and testing both of theories of coloration and of theories of color. The work of those industries was examined by a number of natural philosophers even before the eighteenth century. Some of those studies were known to artisan communities, to whom they offered explanations of technique, sources of new ideas for improvements, or, more generally, explanations of the connection between color change and chemistry.⁴ Chemists, apothecaries, manufacturers, mineralogists, amateurs, and artisans all used chemistry to explain the processes they advocated. We can read their interpretations as ways to consider the combination of practices and theory, as the ways that ideas were rearranged into new forms to acknowledge experience, and as the ways that changing ideas of the sciences were absorbed into practices. Nevertheless, the absorption and acceptance of these changes was uneven, and always slow. This assessment, entirely predictable, remained true during the introduction of conjectured substances such as phlogiston, of concepts such as affinity, and the new concepts developed by Antoine Lavoisier and his colleagues. How would a practical person, one involved with a color-dependent manufacture, describe or understand the rationales of daily work in the eighteenth century?

Chemistry in the Eighteenth Century

One long-standing trajectory in the historiography of chemistry suggests that the eighteenth century holds little worthy of study until its later years.⁵ Although understanding of the foundations of chemistry had advanced during the seventeenth century through the work of natural philosophers such as Robert Boyle, mineralogists such as Johann Henckel, and iatrochemists such as Johann Glauber, the discipline operated on instinct rather than any concrete methodology. For the most part, the chemistry that predated the changes of the later eighteenth century was fanciful and ultimately futile groping. Its defects were made more obvious by the revised system of chemical nomenclature and a new emphasis on methods of quantification that are characteristic of modern chemistry. Even for those who allowed that chemistry did not appear suddenly and fully fledged, on publication of Lavoisier's *Traité élémentaire de chimie* (1789), who acknowledged that it emerged gradually over the course of the century, this early chemistry could be equal parts discomfoting and fascinating.

It has been at least twenty-five years since most historians of science have rejected this construal of prehistory for chemistry and for us now, chemistry is more than a disorderly and occasionally embarrassing collection of craft skills, alchemy, and medicine. The earlier view is worth mentioning because its imagery persists in popular presentations and in other disciplines, a reminder to be thankful that such unscientific ideas are now reduced to curiosities.

The Causes of *Vegetable Colours*.

1. While the Sulphur and Saline Principles of Plants do only swim together and are not yet united into one Precipitate, no Colour results from them, but the Contents are rather Limpid;...
2. But when they are united, and the Alkalines are predominant, they produce a *Green* Colour.
3. When the Sulphur and Alkaline are more equal they make a *Tawny*.
4. When the Sulphur, Acid, and Alkaline are nearly equal, they produce a *Yellow*.
5. When the Sulphur is predominant and the Acid and Alkaline equal, it makes a *Blue*. But,
6. When the Sulphur and Acid are predominant (sic) to the Alkaline, it produces a *Purple*.
7. When the Sulphur is predominant to the Alkaline Principle, and the Acid to them both, it produces a *Scarlet*: But,
8. When the Acid is predominant to the Alkaline, and the Sulphur to them both, a *Blood Red*; which is the highest and most Sulphureous Colour in Nature.

John Harris, "Colour" *Lexicon Technicum*(London, 1704) n.p.

Although the view of chemistry as a practical but largely inexplicable endeavor in the early modern world is not unwarranted, interest in it as a science, in its operations, and in chemical theories or philosophies as ideas of value predates the eighteenth century. Chemistry-based explanations of how materials combined

were summoned to the efforts to rationalize practices, most notably in mining and medicine, but also in practices of colormaking. It is true that the best-known features of eighteenth-century chemistry—pneumatic chemistry, or the separation of "air" into "airs," and the emphasis on order and quantification as connected to Lavoisier—seem to have been important to only a small part of that group of people concerned with color in the eighteenth-century. These expressions do not enter presentations about color with any regularity until the first years of the nineteenth century. Among the important ideas retained from the earlier tradition were three- and four-element theories, the concepts of salts and of acids and alkalis, theories of phlogiston, and theories of affinity (as a theory of combination).

Interaction and combination

Chemical interaction, as it was understood during much of the eighteenth century, involved a series of relationships among basic elements. In Greek philosophy, earth, water, fire, and air were the constituents of all bodies. In the sixteenth century, Paracelsian chemistry reduced and rearranged the four elements to three active principles: sulfur, salt, and mercury. The three-element system functioned in essence as the earlier four-element system had. All substances were a combination of these three principles and possessed properties that were determined by the precise quantities of each. Salt gave bodies solidity—it was dry and briny. Mercury was the acidic liquid that determined the movement, force, and color of any body. Sulfur, an oily and viscous material, made bodies flammable and reconciled mercury with salt.

Around the end of the seventeenth century, Johann Joachim Becher further reorganized this system. He proposed that the constituents of all bodies were the passive principles air and water, plus three active and earthy ones: an oily, inflammable earth that corresponded approximately to sulfur; a mercurial earth; and a vitreous or fusible earth that resembled salts. Becher conjectured that the oily or inflammable earth was released during combustion. The nature of this oily substance was further defined by Georg Stahl about 1703, and it came to be known by his name for it: Phlogiston (ϕ).⁶

Tous les Chymistes tombent d'accord que c'est une fluide qui est le principe ou la cause des couleurs; ils conviennent en même-temps que ce fluide est si subtil, [sic] qu'il pénètre tous les corps, & qu'il est l'ame & l'agent de tous les phénomènes de la nature. Les uns le regardant comme le principe de feu, l'ont appelé simplement la matière inflammable; d'autres l'ont nommé le *soufre principe*; enfin Stahl lui a donné le nom de *phlogistique*, qui a été adopté par tous ceux qui l'on suivi. Le phlogistique n'ayant aucune couleur par lui-même, & étant toujours intrinséquement de même nature, ne peut occasionner tant de variétés de couleurs dans les corps, qu'autant qu'il y rencontre une base à laquelle il s'unit en plus ou moins grande quantité.

Didier-François d'Arclais de Montamy, *Traité des couleurs pour la peinture* (Paris, 1765), 34–35.

Phlogiston was several things. It was not fire but a fiery principle. It was an oily, flammable substance contained in greater or lesser quantity (according to

prevailing theories of elements) in everything. An article that burns easily contains more phlogiston: oils, waxes, and charcoal were all phlogiston-rich substances. Phlogiston was essential to the understanding of coloration in the eighteenth century. The quantity of phlogiston in any substance determined its color and the addition or subtraction of phlogiston caused color change. The obvious evidence of this was the way that objects change color when heated. Heating caused the phlogiston to escape; reheating in the proximity of a phlogiston-rich substance would generally restore the color.

The way to find how much Phlogiston is contain'd in any given Body as I learn'd from Mr. More

Take any quantity of nitre & melt it in a Crucible & take a like quantity of any Body containing a Phlogiston, & while the Nitre is hot throw on little & little the Phlogistic matter till all is thrown on, then weigh the ashes & as much as it has lost of its original weight so much it contain'd of the Phlogiston.

George Berg, *Experiments in Chemistry 1759–1774* (n.p.)) Dudley Archives Centre RBC/7/8/1. (No longer available). Quoted by kind permission of Mr. D. Williams-Thomas.

The specifics of the interaction between phlogiston and color however, were open to debate. According to one theory, phlogiston dilated the object surface and so changed the refraction of light rays. Another conjecture was based on the ability of phlogiston to attract and hold acids. The correct quantity of phlogiston would make permanent the often fluctuating color changes found in acid-alkali indicator substances that were believed to be a quality of nearly all other coloring materials. Because phlogiston was volatile in nature, and because it affected both color and color change, it was especially important for colorists to understand. The control of phlogiston possible through improved understanding would prevent unwanted color change in objects.

Acids and alkalis, as they were understood in the eighteenth century, had an equally significant role that coexisted with that of phlogiston. As constituents of all salts, acids and alkalis were integral parts of chemical combination. The physical appearance and behavior of salt explained how materials combined. Acids were sharp and pointy. Alkalis were softer, more porous particles, to which the points of the acids could attach. When acids and alkalis combined in correct proportion, they neutralized each other. The size and shape of each particle, which was specific to the type of acid or alkali, further determined the properties of the substance that contained them, and each combination of had a unique shape. Eighteenth-century variations on these ideas maintained the essentially corpuscular or mechanical imagery of seventeenth-century philosophers. Later, as investigators continued to exploit these concepts, they refined and added to the theories and to the related operations they employed.

Another set of theories about chemical combination that developed concurrently with these ideas in the eighteenth century, and that surfaced occasionally in

theories of coloration, concerned the likelihood of combination and particularly of permanent combination. Combination had become, since the sixteenth century, an increasingly mathematized concept, often expressed as the likelihood of attraction or affinity between substances. Without a means of elemental analysis or, in fact, a notion of the elemental makeup of components of the three kingdoms, affinity theories were a general idea that complemented the acid-alkali combination, and was adjunct to other explanations for adherence and change. The similar concept of aggregation, described by Pierre-Joseph Macquer, appears not at all in eighteenth-century theories of coloration, despite his prominent role at the Paris Academy of Sciences and his association with color production at Sèvres and Gobelins.

Early Ideas about Coloration

Newtonian mechanical theory of colors held that the size and density of the coloring parts established the degree of opacity in colors of bodies. Transductive relationships such as this, which assumed that submicroscopic behavior was predicted by more-visible action, were central to the mechanical philosophy, and they formed a common foundation for eighteenth-century theories of coloration.⁷ Moreover, such explanations assumed a correspondence among theories in chemistry, observations under the microscope, and examples gleaned from practice, so they were often a feature in describing that common ground.

Le jaune & le bleu unis admettent encore entre eux le rouge, c'est-à-dire que de l'étoffe blanche dont une infinité de parties avoient pris le jaune, une infinité d'autres parties le bleu, il en restoit encore une infinité de parties blanches qui pouvoient prendre le rouge. Quel ouvrage de Marqueterie, & à quel point cette Marqueterie est-elle fine!

"Sur le mélange de quelques couleurs dans la teinture," *Histoire de l'Académie royale des Sciences année 1737* (Paris, 1740), 61–2

Perverse as it may seem now, transductive reasoning justified most eighteenth-century frameworks that combined theories and operations.⁸ Within practice-focused investigations, transduction reinforced the idea that technique is the independent variable in describing theory. If practice supports theory, it is because theory cannot stand without it.

An example of the use of transductive theories to understand color production is found in the vision of textile coloration articulated by Charles-François Dufay and Jean Hellot.⁹ Theirs was certainly the best-known and perhaps the most comprehensive explanation for the coloration of objects created in the first part of the eighteenth century. Dufay's work was undertaken as part of an effort to reorganize the French dye industry in the 1730s; Hellot continued Dufay's studies on the latter's death.¹⁰ Dufay proposed several ideas key to all coloration. He observed, for example, that different types of fibers required different techniques to achieve a similar color; and that successful coloration was dependant on the

relationship between coloring materials and the object accepting the color. He also established that, for compound colors, the order in which fiber or cloth was dyed had no relationship to the color of the result. This could be construed as an indication that the skill of the practitioner was not the sole criterion for success, an idea that may have validated experimentation outside of the communities of artisan dyers. Dufay's proof that order of application was unrelated to final color also showed that colors are not made up of transparent coloring molecules lying one on top of another. This idea of color layering may have been suggested to Dufay by Jacob Christoph Le Blon's printing process. It seemed to be confirmed by glazing techniques employed by painters, and the practices of multiple firings used in some vitreous colormaking. In Dufay's model, colored molecules lie next to each other, in the interstices of the material comprising the object. This description supported Newton's assessment of the relationship between the size of the coloring particle and the color of the larger body, while also containing references to prevailing chemical theories. Each of the three principal colors had a size (or limited range of sizes). Each coloring particle could fit only into a specific part of the fiber; a substrate could accommodate compounds made of any combination of red, yellow, and blue coloring particles. When mixed, the compound color formed in the eye in the same way that, in Newton's example, yellow and blue powders created green.

According to this theory of coloration, fibers take on color when they open their pores and capture the coloring particles, an action confirmed by microscopic observation. Wool fibers have a scalelike surface structure; the scales will expand slightly on exposure to hot water (that of the dye bath, for example) and contract again on cooling. One might observe this, determine that other fibers have scales or pores that are not as large as those of wool, and so extend the analogy of expansion, retraction and color retention to silk, cotton, and even linen. In this description, the principal mechanism of the coloring process is the dilation of fiber pores.

A similar observation had been made by William Petty in his late seventeenth-century investigation of dye practices in England.¹¹ Petty's writing suggests that his notion of a soluble casing on fibers was based in a common explanation among practitioners. In that explanation, the dye assistants added to the dyebath removed an outer layer of the fiber during the dye process. This brightened the final color, much as removing the gummy, varnish-like outer coating on silk made that fiber brighter and easier to dye.

Hellot's reports of his chemical investigations into wool dyeing were read at and published by the Paris Academy of Sciences during the 1740s and issued as a separate treatise in 1750.¹² According to Hellot, to understand the coloration of textiles one must pay attention to the saline coating found on all fibers. When a coloring material enters the pores of a fiber, this coating congeals around it,

holding the colored atom in place. When removed from the dyebath and cooled, the coating becomes hard and crystalline, even varnish-like: This makes the color permanent. Connections or analogies between ceramic or glass coloring and textile coloring are obvious in this description. The connection continues, as it is the cooling or drying stages that "set" the color, when the risk of fugitive dyes ends (at least in good color) and the color becomes inseparable from the object, just as a glaze will remain runny until it has set and cooled.

The cause of the defect immediately occurred I consider the Pores of threads & cotton to be extremely small with respect to silk & all animal substances which readily absorb the tinging particles of vegetables, while the former exclude or resist their entry very powerfully when assisted with the most subtle penetrating saline additions; . . .

I conceive the whole art to depend on . . . Extraction of the tingeing fecula of vegetables rendered more minutely divided by admixture with salino-aqueous fluids with which the pores of the subjects to be dyed are to be impregnated and therein fixed as much as possible by such bodies as are known to be greatly astringent particularly those which precipitate the fecula from their dissolved state in fluids not unlike the manner by which Lakes are prepared for the painter.

Philo-Tinctorius to the Chemistry Committee, 3 December 1765, [R]SA Guard Book PR.GE/110/19/52.

Hellot's presentation further suggested to readers that finding good color meant choosing colors that could be, and would remain, enclosed within the fiber. It thereby included behaviors observed within different classes of dyes. *Petit teint* colors lack solidity because the coloring atoms are large or coarse, and the fiber pores are too small to hold them. The color is only on the surface and the coloring particles are dislodged by even the slightest impact, such as rubbing. Implicit was the idea that, if one could find the correct mordant or some method to open the pores of the fibers further, *petit teint* colors might become as good as *grand teint*. Again, the theory can be derived from transduction of the behavior of dyed fibers, particularly that observed in wool. The path to improved color is clearly shown by this chemical explanation: Find a way to make the particles of a fugitive color smaller and they will become more permanent.

The rapid transmission throughout Europe of Hellot's theory of coloration is not surprising: He was at the time of his investigation the most prominent chemist in France, the country with the most-envied dye industry. The publication of the *mémoires* and the treatise had an immediate impact on the textile and other color-dependent manufactures throughout Europe. A German-language version of the treatise appeared within a year of the original.¹³ Familiarity with the content is evident in discussions at the Society of Arts in the 1760s, several years before its translation into English. Based on his understanding of Hellot's presentation, for example, Philo-tinctorius described a remedy for poor-quality red and yellow colors on cotton and linen. His experiments showed that, as Hellot indicated, coloring particles that were more finely ground had an advantage in the dye process.¹⁴

L'huile dans l'action du meulage ne pénètre pas les matériaux complètement au début, mais quand ils sont prolongés par le toile, le filtre un apparent dans les pores des pièces qu'ils couvrent laisser par conséquent un vuide entre chacun et proportionnellement au chemin d'air il entre dans la fermentation, il est augmentée à l'extérieur par l'action des pièces subtiles qui s'échappent, du restant le plus brut sur la surface et de former un petit pellicule qui s'épaissit, lentement en raison de l'activité d'air qui la sèche jusque finalement à toute l'épaisseur des formes enduisantes pas plus qu'une croûte qui durcit de sorte que l'huile qui reste devienne plus ou moins concret.

Armand Vincent de Montpetit, *Essais sur les moyens de conserver les portraits peints à l'huile*, 29 April, 1775, AdS *pochette*, p. 4.

The idea that one color is captured and held in place by several forces simultaneously appears in writing by others, and writing about other coloring techniques, particularly painting. Miniature painting, for example, like any technique for creating a readable colored image in a very small space, used application methods based on small points of color. Careful placement of the colors created a perception of the juxtaposed colors as a single cohesive image. At a more macroscopic level, the same entrapment of color was one of several goals of the varnishing stage in painting and ceramics. In the best analogy of all, from the point of view of many eighteenth-century investigators, the action of heat on vitreous coloring materials trapped and melted those metal calxes, exposing the color as it made them permanent.

Wherefore, ... I conclude (as the most probable opinion) that the use of Allum is to be a *Vinculum* between the Cloth and the Colour, as clammy-Oyls and Gum-waters are in Painting and Limming (sic); Allum being such a thing, whose particles and *Aculei* dissolved with hot Liquors will stick to the Stuffs, and pitch themselves into their Pores; and such also, as on which the particles of the Dying Drugs will also catch hold, as we see the particles of Copperas and other Crystallizing materials, do of the Boughs and Twigs in the Vessel, where such Crystallization is made.

Sir William Petty, "An Apparatus to the History of . . . Dying," in Thomas Sprat, *History of the Royal Society*. Jackson I. Cope and Harold Whitmore Jones (1667; reprint St. Louis, 1958), 289–290.

Another key aspect of textile coloration often attributed to Dufay was the description of mordant action, a term and concept that was already common in vitreous color production. In ceramic painting, a mordant was some sticky substance (garlic-based glues were not uncommon) that held a dry powdered color, such as pure gold or silver, on the surface of the object. Firing melted the powder and fused it to the glazed surface of the object; at that point, the mordant had already burned off or evaporated. In a similar manner, Dufay characterized dyers' mordants as something that "bit" (*mordre*) both the cloth and the coloring particles, holding them in place until they became permanent. Earlier, however, William Petty credited dyers with a slightly different explanation of the need for these assistants.¹⁵ Petty noted that the addition of alum or other mineral salts to the dyebath allowed fibers to better accept color. Fiber, alum and coloring particle were like links in a chain, he suggested, just as the chain formed by the oils or gummed water in painting held pigment onto a prepared ground.

Some years later, the textile printer Charles O'Brien also called on mechanistic concepts of coloration to explain why the most permanent colors are often the least brilliant.¹⁶ O'Brien attributed this to the crowding of the coloring particles on the cloth. The vivacity of a color is related to the number of refractive surfaces in or on the object. In fugitive colors, particles are packed closely (perhaps because, although he does not say so, they tend to remain on the surface of the fibers) and so exhibit their rays more "glowingly" than they would if the color were dispersed or separated. The dispersion that is characteristic of duller, more solid colors is a result, entirely expected, of the coloring particles that enter into cells able to receive and retain them. Because there is a discrete place for each coloring particle, only a limited number can be accepted. There is therefore a limit to the refractive surfaces on any solid color. Saturation and brilliance, which result from the play of light on the surface of the object are correspondingly limited as well.

In the search for useful theories of coloration, all stages of all colormaking operations might be scrutinized for appropriate examples: Theories based in one set of practices surely would hold for all others. Investigators interested in creating a theory of coloration that acknowledged the coloring process did not always confine their examinations to a single colormaking practice. Theorists and theorist-practitioners devised explanations that combined enamels and dyes, textile colors and pigments, painters' colors, and vitreous colors: this remained true throughout the eighteenth century.

Some persons have endeavoured to improve on [colors], by joining a durable one to them; blending them as intimately as possible, from a presumption that the weak substance would have received assistance from the other; but it has always followed that the false colouring substance soon flies off; leaving the permanent one behind. Some have endeavoured to procure a permanent [color], by first putting on a fading one, and covering it afterwards with a permanent one, on a supposition that the permanent one would secure it, and by being externally situated, might defend that beneath it or within it, or at least that it would operate in that manner for some time, so that there might be a little longer durability to the fading one, but this likewise will not answer. . .

Charles O'Brien, "Of Colour-Making," *The Callico Printers' Assistant*(London, 1789) 2:n.p.

Yet whatever significance may be attributed to the explanations of practices developed by or for the scientific academies, alternative theories of coloration did not simply disappear. The "layered" description of color combinations rejected by Dufay in the 1730s, for example, continued to find favor. Near the end of the century, Charles O'Brien complained that many people still used that concept to justify their belief that the durability of colors can be improved by joining materials with different characteristics. O'Brien's derisive attitude may have been part of his own presentation strategy, but contemporary recipe books do continue to suggest the practice and regular statements challenging its efficacy did not end the technique of printing an attractive but fugitive color under a more solid, lighter one.¹⁷ The technique seemed to slow or stop the loss of color, despite the established theories and expert opinions that suggested it was not an effective

coloring technique.

Chemistry in Eighteenth-Century Theories of Coloration

Louis-Guillaume de la Follie's Theory of Coloration

Late in 1767, Louis-Guillaume de la Follie, a Rouen textile manufacturer, submitted a *pli cacheté* to the Paris Academy of Sciences.¹⁸ While this tactic of depositing a sealed envelope at the Academy was often employed to establish the primacy of a discovery, de la Follie's motivation is unclear. In any event, the envelope was opened less than a year later. A committee was appointed to examine what proved to be an essay describing de la Follie's theory of coloration; they reported on it in late 1768.

Telles sont mes sentiments sur la formation et sur le jeu des couleurs; c'est en suivant ces principes que je suis parvenu a simplifier plusieurs opérations de teinture, a produire quelques couleurs plus brillantes, plus solides et plus pénétrante dans la tissure des étoffes.

Louis-Guillaume de la Follie, *Mémoire sur la theorie des couleurs*, 9 January, 1768, AdS *pochette*, p. 24.

In his essay, de la Follie used a combination of sources, drawn from the disciplines that occupied him as a manufacturer and as a man of the sciences, to create his theory of coloration. As such, the theory suggests some typical mid-century concerns about production, processes, and their potential in the development of a theoretical system, as voiced by a knowledgeable and enlightened manufacturer.

The consistent behavior of nature was an obvious foundation for de la Follie's explanation of color and color change: In his theory of coloration he combined aspects of the physics and chemistry of textile and vitreous colors and he substantiated his points with examples from medicine and botany. Color differences within any object are a matter of porosity and pore direction, combined with the degree of vitrification of the coloring particles and tempered by airborne acids and alkalis. In his description of the hard, finely divided (and preferably metallic) earthy particles that create a permanent and beautiful color, de la Follie drew on enamel or ceramic coloring processes: His examples may have been found at the faience factories for which Rouen was famous and that he had investigated on behalf of French government agencies.¹⁹ It is a general law, de la Follie stated, that the more a body contains of these metal-like earthy substances, the more refractionary it is. This is why enamel colors resist fire better than vegetable colors, and why the key to good color is to find a way to make all coloring parts resemble mineral colors.

According to de la Follie's theory, color forms in bodies through several mechanisms simultaneously. First, there are the coloring particles themselves, small molecules of vitrified earth capable of reflecting the light of the bodies to

which they adhere. Coloration occurs when these particles attach to an object. The exact color and its intensity are determined by the porosity of the object and its ability to accept the coloring particles, with the direction of the pores also playing a role in the result. de la Follie seems to build this notion from Hellot's description of color as lodging in the pores of fibers, and he exploits a macroscopic optical effect to explain his microscopic chemical relationship. Some color variations across the surface of a solid-colored textile depend on the position of fibers relative to the light source. Those variations, easily visible on heavily napped or piled fabric, are due to the direction and degree of spin in the yarns. Similar analogies exist elsewhere, perhaps most dramatically in the play of light on a colored wall.

In his chemical explanation, de la Follie identified phlogiston, the igneous principle, as an aid to the vitrification that creates good colors. Because heat made things more solid, phlogiston controlled both the color produced and its tendency toward permanence. Creating a good color required that quantities of phlogiston be fixed within the object. The same need to secure sufficient phlogiston also accounted for the color changes observed over time. Even after cooling, the pores continued to dilate and contract, altering the color on the object. With the introduction of more heat or salts, vitrified atoms break up, dissolve, or recombine, changing the degree of vitrification and so the color. In addition to fire, water and air also had specific and significant parts in de la Follie's theory. Water promoted fermentation or decomposition, and air attracted acids and alkalis. To appreciate the importance of the effect that these two elements could have on color, one need only think of the pattern of color change in plants as they are exposed to air, and in particular the color loss they undergo in the more acidic winter air.

Many of the ideas that de la Follie presented had already been suggested by others—in his *mémoire*, he noted often that his concepts were already well known. The report of the academicians who examined this theory, Pierre Joseph Macquer and Lavoisier, remarked on this when they denied institutional approval to de la Follie's article. Macquer and Lavoisier pointed to the greater simplicity found in Newton's system. They suggested that de la Follie may have misunderstood relevant passages in what was obviously an important source for his ideas: Nollet's *Leçons de physique expérimentale* (1754-65).²⁰ Another misunderstanding the reviewers cite concerns Dufay's statements about the three primitive colors: When Dufay suggested that red, yellow, and blue could be used to imitate all colors of the solar spectrum, he was not implying that there are, as de la Follie seemed to believe, only three kinds of rays. Macquer and Lavoisier noted other problems underlying de la Follie's efforts to join colors of light with colors of objects—his description of angles of refraction, for example, and his belief that coloration was due to light refraction from the many small prisms that

cover the surface of bodies. For the most part however, the reviewers were most critical of de la Follie's understanding of the physics of color; their objections to his ideas about coloration were less sweeping. Concentrating on his acid-alkali explanation, they complained that this simple explanation was too simple. While it is probably true that the different salts, separated in the air and so able to recombine in different ways, had something to do with color, but it was difficult to believe this was the main cause of color. Certain phenomena, such as the formation of Tyrian purple, cannot be fit into the explanation. Other portions of de la Follie's theories, according to Macquer and Lavoisier, are simply gratuitous. His ideas were not worthy of publication.

New Theories of Color

La couleur blanche est celle que prennent ordinairement les corps qui n'ont que peu ou point de phlogistique. . . . On sait, au contraire, que la couleur noire des corps, annonce qu'ils sont chargés d'une grande quantité de matière inflammable.

Christoph Opoix, "Observations Physico-Chymiques sur les Couleurs" *Journal de physique*8 (July 1776): 103.

If light is heterogeneous, as Newton claimed (and de la Follie recognized), why do colors of light separate when they are reflected from bodies? How is it that bodies can reflect one color more than another if the coloring material of light and the nature of phlogiston are one and the same? These questions, raised by Christoph Opoix, suggest the anomalies conspicuous in the development of color theories that incorporated chemical and operational aspects.²¹ Alan E. Shapiro has identified Opoix's physical-chemical theory of colors as the beginning of a shift in theoretical descriptions of color—a shift away from physicists' concerns with properties such as weight and elasticity and toward concern with compositional principles that identify and distinguish all bodies.²² A mémoire by Opoix, presented to the Paris Academy of Sciences in 1774, questioned established beliefs about color and about chemistry as a theoretical pursuit. His explanations challenged a central idea linked to Newton's philosophy, suggesting not simply that the presence of phlogiston controlled the color of a body but that its presence differentiated the colors of objects from the colors of light.

Telle est l'explication que M. Opoix donne de la cause des couleurs. Nous pourrions en suivant l'auteur dans différentes autres parties de son mémoire faire voir également qu'il n'est pas plus heureux dans les explications qu'il donne, qu'il n'est assez instruit des faits; qu'il avance plusieurs choses que l'on n'observe pas, et qu'il en suppose plusieurs autres sans les prouver, mais nous croyons en avoir assez dit pour que la compagnie se forme une idée de ce mémoire sans nous étendre d'avantage. Nous concluons donc en disant que quoiqu'il renferme plusieurs idées ingénieuses et plusieurs observations de chymie curieuses il n'est pas dans le cas d'être approuvé par l'Académie.

"Rapport sur les observations physico-chimiques sur les couleurs de M. Opoix," 2 June 1775, AdS *pochette*.

Opoix's mémoire, like de la Follie's, initially met rejection at the Paris Academy of Sciences.²³ Despite endorsement by Macquer, who presented the mémoire and,

in his *Dictionnaire de chimie* (1778, 2d ed.), acknowledged Opoix's explanations, the academicians who reviewed Opoix's paper (Etienne Mignot de Montigny, Antoine Baumé, and Jean-Baptiste Le Roy) found the explanation difficult to comprehend. Especially problematic was the addition of phlogiston to what was, for them, phenomena already well explained as reflected light. Moreover, as is noted in their report, many of Opoix's conclusions contradicted Newton; this raised questions and suggested further conclusions that challenged the academic scientists in some disturbing ways.

Ne faute-il pas que la lumière passe d'un milieu plus dense dans un milieu plus rare, ou d'un milieu plus rare dans un milieu plus dense pour former des réfractions, & par conséquent des couleurs?

Les terres les plantes, les fleurs, les féculs de tous les végétaux, & les précipités métalliques n'ont-ils pas des pores? La lumière qui les pénètre ne se réfracte-t-elle pas en raison de la diversité ou de la direction des pores de chaque substance? Cette diversité des pores occasionne donc la diversité des couleurs, dont la lumière est toujours le principe.

Si le phlogistique extrait des substances ou ajouté dans ces mêmes substances, produit des changemens considérables sur leurs couleurs, n'est-ce point parce qu'il dilate ou change les pores de ces substances, & occasionne par conséquent un changement dans la réfraction des rayons de lumière?

Mais le phlogistique sans lumière produiroit-il des couleurs? Or, peut on dire que le phlogistique est le principe des couleurs, ou n'en est il que le modificateur?

[Louis-Guillaume] de la Follie "Réflexions sur la Téoerie de la Teinture, Suivies d'Expériences Utiles pour les Manufactures" *Journal de Physique* 10 (January 1778): 66–67.

Although rejected by the Paris Academy of Sciences, the mémoires of both Opoix and de la Follie were published, with revisions, in the *Observations sur la physique sur l'histoire naturelle et sur les arts* (the *Journal de physique*)—Opoix's in 1776, de la Follie's in 1778.²⁴ In the latter, reworked into a theory of dyeing, de la Follie presented new experiments and new explanations. He argued that understanding the operations of dyeing—how to use the materials and how much of them to use—would lead to the simplification that is at the root of improvement for practice. Why would de la Follie have turned to publication at this time, a decade after his first presentation of his mémoire? It is tempting to connect de la Follie's revised work to the publication of Opoix's physical-chemical theory of colors in the same journal. It is equally possible that, having elsewhere received acclaim for his work with dye processes and textile printing, and for his reconfiguration of some textile recipes, de la Follie wished to modify his mémoire accordingly. We do not know.

de la Follie's addition of new ideas based on operational behavior did not manage to save the phenomenon for his whole theory. However, his exchange of a general theory of coloration for a theory of dyeing permitted him to emphasize even more strongly the connection between his practical knowledge and his philosophical understanding. In this article in the *Journal de physique*, de la Follie outlined his beliefs about coloration in six questions, a format that allowed him to

present his ideas succinctly, and without the distraction of arguing every detail. The questions, which restated his presentation to the Paris Academy with a few concessions to the altered focus, show that de la Follie had not divested himself of a mechanical interpretation for the coloration process. Coloring materials precipitate in the pores of cloth, he reminds the reader. Each precipitate is more or less adherent, depending on how it combines with phlogiston and on the quantity of oil, present as an intermediate, available to join coloring particles to cloth.²⁵ His explanation for the use of this material again relies on a macroscopic analogy based on his practical experience. A colored lake, applied in an oil medium to cloth, succeeds in the soap and air (exposure) tests. This explanation, although related to the use of painters materials on cloth, may be based on de la Follie's experience as the owner of a textile-print works and perhaps, even more directly, on his work to develop colors for *indiennes*. He explains that the solidity of the colors is the result of the coloring parts having combined with phlogiston; this combination renders them less attractive to extraneous and harmful salts. De la Follie's development of the theoretical connections between color and phlogiston chemistry lead him to downplay the role of mordants in the creation of color on objects. In this revised version of his theory of coloration, he reassigns to phlogiston many tasks attributed to mordants in the earlier *mémoire*. His model for discussion, indigo, is based on Saxon blue rather than on a traditional vat as it was in the earlier presentation. This is especially important because de la Follie developed several new dyeing processes that employed oil of vitriol—a critical component of the Saxon blue vat. It is likely that he was working on these new techniques in the period between presentation of the *mémoire* to the Paris Academy and publication in *Journal de physique*.

"Observations Physico-Chymiques sur les Couleurs," Opoix's article in the *Journal de physique*, was also a revision of his earlier offering to the Paris Academy. It proved to be considerably more influential than de la Follie's revised *mémoire* was. Opoix's theory was endorsed by other practicing chemists (and by several anti-Newtonian factions). The *Journal de physique* included discussion about it in subsequent numbers and it is probable that the article was issued as a separate publication about 1777. The second part of the *Journal de physique* article "Des Couleurs Considérées dans la Lumière," was republished in the *Journal des sçavans* that year as well.²⁶ German translations included one by Daniel Ribini (1785), as well as inclusion in Johann Beckmann's *Physikalisch-ökonomisches Bibliothek* and in the *Magazin für das Neueste aus der Physik und Naturgeschichte* (Lichtenberg's Magazine).²⁷ "Observations Physico-Chimiques sur les Couleurs" was not translated into English, but Opoix's ideas were available to English readers in the French and German versions, and through their incorporation in Macquer's *Dictionnaire de chimie*.

Macquer's own explanation of the dye process suggested an order that was based

on the characteristics of coloring materials, with reference to whether they were animal, vegetable, or mineral, and with additional references to techniques needed to obtain good colors.²⁸ In keeping with his role as the chief chemist at the Paris Academy at the time of publication, Macquer's terms reflect his view of the process as a series of chemical operations.

Macquer created four categories of coloring materials for textiles, based on his observations of behavior, techniques and results. The coloring parts of *resinous* (resin-like) dyestuffs are extracted from substances that are insoluble in water, for example annatto, indigo, carthamus, and orchil. Resinous colors require an assistant to make good color, and the process he described was similar to that used to create painters' lakes. *Extractive* colors are soluble in water but the cloth, rather than the color, requires a mordant. Macquer's examples include *bon teint* yellows such as those made from weld, and colors such as Saxon green, madder, and the cochineal reds. It is interesting that, although blue (and Macquer mentions Saxon blue specifically) requires processing as a resinous material, Macquer classed Saxon green as an extractive dye because greens are made by passing citron yellows through the vat or onto a Saxon blue dyed cloth. Was Macquer suggesting that the first stage, the yellow dyeing, should be understood as a mordanting process with respect to the final color?

The *resino-extractive* dyestuffs, in contrast, need no prior preparation at all, as they will attach directly to the fiber. The most famous example of this, according to Macquer, is murex purple (Tyrian purple); he noted that most other colors in this class are light-brown, fawn or root colors. Macquer's fourth group, dye process that relied on *metallic* precipitates, included the processes that yielded Gobelins scarlet, carmine, Prussian blue, and most blacks. The metallic precipitates were not mordants, such as those used with resinous dyestuffs and painters' lakes, but rather coloring materials proper. Like the orders based on the categories of animal, vegetable, and mineral (orders he continued to use to describe colored objects, if not coloring materials), Macquer's four categories could be extended to all kinds of color. Ultimately, organizing the coloring processes and organizing the resulting colors proved to be separate undertakings. In the eighteenth century, they were generally seen as a single endeavor, and that contributed to the problems of identifying an adequate system and the best order of steps.

Reception and Reconfigurations

Compare these different ideas about the creation of color to John Wilson's description of coloration and practical color phenomena.²⁹ In *An Essay on Light and Colours*, Wilson, a Manchester dyer, described his continuing research, first presented some years earlier to the Manchester Literary and Philosophical Society. Except for a summary portion at the end of this pamphlet, details of that

earlier presentation (of 20 March 1782) are lost.

. . . Colours are inherent Properties in Rays of Light, and not in the Particles of Matter, which reflect those Rays. The Form and Densities of the Particles of Matter may be altered so as to reflect other Colours.

John Wilson, *An Essay on Light and Colours* (Manchester, 1786), 8.

Wilson stated that his goal in writing the *Essay* was to reconcile the chemical ideas of color with practice, based on his experiences. He outlined a theory of coloration without resorting to phlogiston at all, depending instead on the dyer's tradition that explained mordant action as the basis for the chemistry of coloration. In the first part of the pamphlet, Wilson argued against Edward Hussey Delaval's second treatise on opaque colors.³⁰ In the second half, he described color production, using his own factory practices as his basis.

Wilson explained that colors are inherent in rays of light only and that color is a question of reflection and refraction. Rather than remaining on the outer surface, as Newton believed, Wilson claimed that the rays enter the colored object. A mutual attraction exists between the rays themselves and particles disposed to receive them. Colors arise—they become visible—when there is an abundant quantity of rays of a single color, even more than the particles can hold. This is demonstrated through the practices of dyeing cotton. Coloring particles, the bodies that form color from the attraction or reflection of rays of light, adhere to this fiber only after the intervention of a salt that has an affinity for both the cotton or linen and the coloring matter. The composition of the salt will also affect the color of the particles.

According to Wilson's explanation, rays of color are reflected from the object; their color, while unique, still may be altered to reflect other colors. His example of this is a familiar series of experiments with a solution of gold in tin chloride. Wilson returned to Newton to bolster this assertion and used prismatic effects as an analogy: Clear faceted glass, or diamonds, divide the rays of light and show all the different colors. Wilson concluded that coloring particles, the bodies that form colors by attraction and reflection from rays of light, are "probably pellucid" and so appear opaque as they collect, an assertion he proved through his experience. Successive dippings of a cloth in one color may give it a darker shade, but no number of repeated dippings or dyeings will ever create black.³¹ Because this experience did not agree with the philosophical statements, he knew that the latter, especially Delaval's claims that colors are inherent properties of objects, must not be true.³²

Unfortunately, although not atypically, Wilson could not deduce known practical results from his conjectures. In a brief section, "Colours in Dyeing Matters," he offered elements of a theory of coloration, returning to the use of salts and the need for an affinity between fiber and coloring materials. In that context, he

described the need for proper grounding and preparation of the fabric. Colors are formed on objects by the variations created by the presence of different salts, held in place on the fiber by mordants, assistants, and grounds. Although he promised explanation of other colormaking procedures for cotton, as practiced in Manchester, not much actually followed: Wilson returned to an anecdotal outline of the processes used in his manufacture, and acknowledged excluding the information that would serve his competition.

Coloration Beyond the Dyehouse

Theories of coloration that explain dyehouse operations are abundant throughout the eighteenth century. The public perception of a need for improvement in all textile processes, and obvious associations between those processes and chemical operations, meant that attempts to devise a theory of coloration based in dyehouse procedure were common. In this specialty in particular, both practitioners and scientists thought about colors and experimented with them in order to derive explanations that echoed their understanding of both philosophical issues and the practicalities of textile coloration.

[Heat] unites the little particles of matter, makes them adhere to the surface of the enamel and vitrify them with itself. When well managed, it gives the colours a polish and brilliancy, that could not be produced without it.

Constant de Massoul, *A Treatise on the Art of Painting* (London, 1797), 45.

Fewer eighteenth-century theories of coloration took as their foundation pigments or vitreous colors. Although many natural philosophers used pigment-making and painting practices as a source or an example in their scientific investigations, another tradition, one that aligned painting with physics, often led painters to express greater concern about light and light reflection than about color composition and permanence. The chemistry of creating a painting was more often the provenance of suppliers. There was no concerted effort to establish a chemical foundation for the creation of painted objects, as there was for the manufacture of colored textiles. Textile painting or printing and related practices such as wallpaper making, all of which called on techniques of fine-art painting and engraving, were generally subsumed under other work about color for textiles. Most written descriptions suggest that, for painting and ceramic techniques, the introduction of color onto objects was a simple, well-understood mechanism. Obtain the appropriate materials. Apply in an appropriate fashion. Allow to set.

Chemical investigations into painting practice were not generally considered essential to its advancement. This did not prevent some practitioners or theorists from conjecturing about the processes whereby colors adhered to painted surfaces. Why did painted-on color adhere to a surface? Descriptions were often based on assumptions similar to those on which coloration theories for dyeing

rested. William Petty drew an analogy between textile mordants and painting media: others drew a similar analogy between painting media and vitreous colors. In both cases, a coloring material was disbursed in a fluid and sticky medium, something tenacious enough to hold the color in place until it set.³³ It was allowed to dry which, with or without the addition of heat, set the color and so increased its permanence.

The combination of phlogiston, acids and alkalis that determined textile colors also controlled color for pigments, enamels, and glass. For painters' colors, however, the problems that chemistry might address were less those of improving application than of stabilizing desirable colors once identified. Colored glass, ceramics, and enamels seemed to offer the best examples of ideal color for painting, but this was rarely acknowledged in theories that developed within the workshops devoted to their production. To explain the coloring processes, writers often turned to mineralogy, and clarification was again based on observation and analogy. Theories about the coloration of ceramics were connected to the chemical and physical operations of glassmaking. There was, nevertheless, the problem of balancing the causes of color for vitreous color and for pigments. Again, phlogiston, acids, alkalis, and substances akin to de la Follie's vitrified coloring particles offered explanations (if ultimately problematic ones), as they did for textiles.³⁴

Enamel painting differs from all other kinds, in the vehicle employed for the colours, (to hold the parts together, and bind them to the ground they are laid upon). This is glass, or some vitreous body, which being mixt with the colours, and fused or melted, by means of heat, becomes fluid, and having incorporated with the colours in that state, forms, together with them, a hard mass when grown cold. It answers, therefore, the same end in this, as oil, gum water, size, or varnish, in the other kinds of painting.

Dossie, Robert. *The Handmaid to the Arts* (London, 1764), 1:261.

In the course of his observations about the colors for enamel painting, Didier-François d'Arclais de Montamy offered a general theory of coloration for those processes.³⁵ In his discussion, which owes much to Johannes Kunckel's *Ars Vitrarya Experimentalis*, de Montamy emphasized the need for a mixture of three kinds of substances in any enamel-coloring material: a fondant, a coloring source (usually a metal), and some phlogiston-rich substance.³⁶ Knowing how to choose the correct balance of these components was important, as it allowed the colormaker to take advantage of the ambient salts and to mitigate damage from harmful ones. Enamel painting techniques called for combining the three substances, finely ground, in a borax-infused water. On applying this mixture to the glass and then firing, de Montamy explained, the borax placed the surface of the glass in fusion so that the phlogiston, which joined to the metal in the production process, attached the color into the glass. It is important, he continued, to pay careful attention to the length of time of firing. If it continued for too long, the phlogiston that places the color on the glass would begin to

dissipate and the enamel picture would be ruined.

De Montamy's theory of coloration for enameling is unusual in eighteenth-century writing—the transformations that created such colored objects were rarely articulated—and we have no way to know whether his ideas were typical or atypical. It was more common, in glassmaking or enameling treatises, to focus attention to chemistry on the creation of coloring materials, particularly the glass-fondant-metal combinations. An underlying belief was that firing would, in addition to melting the as-yet unformed color, exclude potentially harmful airs, as was the case in other painting practice.³⁷ Sometimes a description suggested that the vitreous color or coating held itself in place as a layer constricting the whole. In those instances, the key to good coloration was the creation of a varnish or varnish-like substance that was as cohesive as a coating, and which could embed itself into the surface of the substrate—the metal, glass, or ceramic support.

Chemistry and Restoration

La chymie apprend que toutes ces préparations sont susceptibles de s'altérer par le contact de la lumière. Les chaux de zinc, d'argent, de mercure, prennent des couleurs plus ou moins vives, & se rapprochent d'autant plus du noir, qu'elles ont été exposées plus longtemps, ou d'une manière plus directe, aux rayons du soleil.

L'influence de la lumière sur les végétaux, & la phénomène de l'*heliosement* des plantes, ont frappé depuis longtemps les naturalistes observateurs, & l'on a fait, depuis quelques années, plus d'attention aux altérations que le contact des rayons lumineux fait éprouver à un grand nombre de corps.

"Couleurs," *Encyclopédie Méthodique. Beaux-Arts* (Paris, 1791) 2:454–455.

Science entered the painter's workrooms through demands for color stability and theories of coloration play a part in eighteenth-century discussions about the preservation of paintings. In these cases, and in common with the developing theories about dyeing, the purpose of investigation was often to guarantee its goodness and longevity of new, or novel objects. In part, perhaps, because the techniques of painting seemed immutable, investigators more frequently examined and experimented with improvements to coloring materials to achieve this goal. Suggestions for improvement could focus on the operations of painting and suggest, for example, substances that would bind pastel colors to paper, or improvements to the application methods for varnishes and other coatings.³⁸ Other suggestions explained chemical interactions, and often tied them to examination of the allegedly more permanent works of earlier master painters—e.g., Van Eyck and Rubens—and to conjectures about their painting materials and techniques.

Still, some rationales for the deterioration of painted objects owed as much to physics as they did to chemistry. These explanations included the theory that colors darkened over time because, as they dried, the coloring materials absorbed

the rays of light that earlier they had been able to reflect. This desiccation was not linked to ambient moisture, to explanations that phlogiston escaped as the oil dried, or to other common explanations for darkening colors or increased brittleness of materials at the time; instead it seems simply to have been considered an inherent vice of paintings. Still, it was typical to attribute the failure of artists' colors to chemistry and to describe that failure in terms familiar to the laboratory.

Several painters argued that the key to long-lasting results was nothing more than fully and properly prepared pigments. Coloring materials needed only to be ground to the appropriate degree of fineness, washed clean, and mixed into the proper medium in order to last forever. Although this view dismisses the need for specialized chemical knowledge, it does admit to a chemical subtext. Deterioration and its inverse, the construction of color, were affected by combinations of salts and oils. Often water alone was insufficient to remove the harmful materials. Purity, however, was only a goal in the case of pigments made of potentially dangerous materials: If sulfur could not be removed from orpiment, or copper from verdigris, purification might at least render them less harmful. One means to that end was the development of painting application techniques, for example, eludoric and encaustic painting that protected vulnerable colors.

Johann Heinrich Müntz was one of several people who advocated encaustic techniques to solve several of the perceived visual and chemical problems in painting.³⁹ His own method, based on the publications of the comte de Caylus, involved attempts to expand on and explain encaustic techniques. After conducting experiments to determine why oils painted on a waxed ground were brighter than those painted on an oiled cloth, Müntz confirmed a familiar chemical-mechanical explanation: Deterioration results when priming or grounding is poorly executed. But it was not enough to remove as much of the harmful materials in production as possible, and to allow sufficient curing time. Older colors could become reactivated under certain conditions. Harmful salts trapped in the oil, and even when long dry, would decompose when exposed to sufficient moisture. Newly reactivated, these salts could combine with new oil or with the excesses of salts encountered as they escaped from the ground or priming, creating unwanted color changes.⁴⁰ Deterioration was clearly a function of chemical composition, and it was complicated by the composite nature of all paintings. According to Müntz, surrounding the pigment in wax offered some protection because it diminished the need for the underlayers. Encaustic pigments were encased in a wax that, if pure enough, that did not distort the color and was its own protection from deterioration.

Conclusion

Eighteenth-century efforts to attach chemistry to colormaking processes are often

contextualized entirely within contemporary physics. After the second third of the century, however, those who put forth ideas about color on objects began to incorporate into their ideas explanations of the composition of color. In the process, they began to assess certain assumptions about how or why color was "good." Their explanations fed, and were in turn fed by, attitudes that the general public, academy, and artisan communities had toward science, in general and chemistry more specifically. Responses to new explanations can be linked to regional and social attitudes, especially those that came to prominence later in the century, and to other debates more closely linked to specific techniques. Interest in theories of coloration was directed toward improvement, certainly. But the task of developing a theory, especially one that would work across all coloring practices, was also a means to align these practices with the sciences. If this theory of coloration also enhanced theories of colored light, and so prove the simplicity of nature, so much the better.

Notes:

Note 1: Recent books that discuss color theory and its place in physics or mathematics: Rolf G. Kuehni, *Color Space and Its Divisions: Color Order from Antiquity to the Present* (Hoboken, N.J., 2003); Alan E. Shapiro, *Fits, Passions and Paroxysms: Physics, Method and Chemistry and Newton's Theories of Colored Bodies and Fits of Easy Reflection* (Cambridge, 1993); Paul D. Sherman, *Colour Vision in the Nineteenth Century: The Young-Helmholtz-Maxwell Theory* (Bristol, England, 1981); Casper Hakfurt, *Optics in the Age of Euler: Conceptions of the Nature of Light, 1700–1795* (Cambridge, 1995). See also the several presentations on this subject by the art historians John Gage, esp. in *Color and Culture: Practice and Meaning from Antiquity to Abstraction* (Boston, 1993); and Martin Kemp, esp. in *The Science of Art: Optical Themes in Western Art from Brunelleschi to Seurat* (New Haven, 1990).

Note 2: See, e.g., Marco Beretta, *The Enlightenment of Matter: The Definition of Chemistry from Agricola to Lavoisier* (Nantucket, Mass., 1993); Frederic L. Holmes, *Eighteenth-Century Chemistry as an Investigative Enterprise* (Berkeley, Calif., 1989); Bernadette Benasude-Vincent, "Une Mythologie Révolutionnaire dans la Chimie Française," *Annals of Science* 40 (1983): 189–96; *The Chemical Revolution: Essays in Reinterpretation*, ed. Arthur Donovan, Osiris, 2d ser., 4 (1988).

Note 3: On non-Newtonian or anti-Newtonian sciences in general, see, e.g., Betty Jo Teeter Dobbs and Margaret C. Jacob, *Newton and the Culture of Newtonianism* (Atlantic Highlands, N.J., 1995); on color and optics, Michel Blay, "Castel Critique de la Théorie Newtonienne des Couleurs," in "Autour du père Castel et du clavecin oculaire," ed. Roland Mortier and Hervé Hasquin, *Etudes sur le XVIIIe siècle* 23 (1995): 43–57, (see also the rest of that very interesting number); Clifford Conner, *Jean Paul Marat, Scientist and Revolutionary* (Atlantic Highlands, N.J., 1997); Michel Blay, "Lumière et Couleurs dans le Traité de Haüy, ou 'la Véritable Méthode Pour Parvenir à l'Explication' dans les Sciences," *Revue de la histoire des sciences* 50, no. 3 (1997): 283–92.

Note 4: Robert Boyle, *Experiments and Considerations Touching Colours. First Occasionally Written, Among Some Other Essays, To a Friend; And Now Suffer'd to Come Abroad as the Beginning of an Experimental History of Colours* (1664. Reprint, New York, 1964). See also William Eamon, "New Light on Robert Boyle and the Discovery of Colour Indicators." *Ambix* 27 (1980): 198–202.

Note 5: For more about the entry of Stahl's chemistry into France, see Rhoda Rappaport, "Rouelle and Stahl—The Phlogistic Revolution in France," *Chymia* 7 (1961), 73–102.

Note 6: See, for example, John Harris, *Lexicon Technicum: or, an Universal English Dictionary of Arts and Sciences: Explaining Not Only the Terms of Art but the Arts Themselves* (London, 1710), s.v., "Colour"; Jean-Étienne Montucla, *Histoire des mathématiques: dans laquelle on rend compte de leurs progrès depuis leur origine jusqu'à nos jours; où l'on expose le tableau & le développement des principales découvertes, les contestations qu'elles ont fait naître, et les principaux traits de la vie des mathématiciens les plus célèbres* (Paris, 1758), 2:62; *Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers*. . . . (1751-1780. Reprint, Stuttgart-Bad Cannstatt, 1966), s.v. "Couleur"; Peter Shaw, *Chemical Lectures Publickly Read at London, in the Years 1731, and 1732, and Since at Scarborough, in 1733: For the Improvement of Arts, Trades, and Natural Philosophy* (London, [1734]); Edward Hussey Delaval, *A Letter the Right Honourable The Earl of Morton, President of the Royal Society Containing Experiments and Observations on the Agreement between the Specific Gravities of the Several Metals, and Their Colours*. . . . (London, 1765).

Note 7: Alan E. Shapiro, *Fits, Passions and Paroxysms*, 98–99. See also John J. Beer, "Eighteenth Century Theories on Dyeing," *Isis* 51 (1960): 21–30; and Agustí Nieto-Galan, *Colouring Textiles: A History of Natural Dyestuffs in Industrial Europe* (Dordrecht, Netherlands, 2001), esp. 85–95.

Note 8: Charles-François Dufay, "Observations Physiques sur le Meslange de Quelques Couleurs dans la Teinture" *Histoire de l'Académie royale des Sciences. Année 1737*. . . . (Paris, 1740): 253–68; Jean Hellot, *L'Art de teinture des laines et des étoffes de laine en grand et petit teint. Avec une instruction sur les déboüillis*. (Paris, 1750).

Note 9: Meeting minutes for 16 April and 15 October 1733, Procès-verbaux de le Conseil de Commerce (1733) AN F/12/80.

Note 10: Jean Hellot, *L'Art de teinture des laines*.

Note 11: William Petty, "An Apparatus to the History of the Common Practices of Dying," in Thomas Sprat, *History of the Royal Society*. ed. Jackson I. Cope and Harold Whitmore Jones (1667; reprint St. Louis, 1958), 284–319.

Note 12: Jean Hellot, *L'Art de teinture des laines*.

Note 13: Jean Hellot, *Des Herrn Hellots Färbekunst oder Unterricht Wolle und wollene Zeuge zu färben*. . . ., trans. Abraham Gotthelf Kaestner (Altenburg, 1751), *The Art of Dying Wool and Woollen Stuffs, Translated from the French for the Royal Society of Dublin* (Dublin, 1767).

Note 14: Philo-Tinctorius to the Chemistry Committee, 3 December 1765, [R]SA Guardbook PR.GE/110/19/52; on the same subject see also Eusibius to the Chemistry Committee, 2 December 1766, [R]SA PR.GE/110/23/34.

Note 15: William Petty, "An Apparatus to the History of the Common Practices of Dying."

Note 16: Charles O'Brien, *The Callico Printers' Assistant; from the First Operation of Designing Patterns, to the Delivery of Work for Sale: Including, . . . Thoughts on Genius and Invention. . . . And a Concise History of Callico Printing to the Present Time*. . . . (London, 1789).

Note 17: See, e.g., the Order Book of Joseph and Mary Ware of Crayford, Kent, 1773, The Colour Museum (Bradford, England) BRFCM 1991.42.28; Peel Pattern Book 1807–21, Bolton Museum D.1.1971; Dye Recipe Book, Broad Oak, 1821, Manchester Museum of Science and Industry LIG/TX/TY; Alexander Hargreaves, Addlington Experiment Book, 1830–45, Lancashire Record Office DDX 389. See also J. Kirby, D. Saunders, and J. Cupitt, "Colorants and Colour Change," in *Early Italian Paintings: Techniques and Analysis*, ed. T. Bakkenist, R. Hoppenbrouwers, and H. Dubois (Maastricht, 1997), 65–71, 88–90.

Note 18: Louis-Guillaume de la Follie, "Mémoire sur la théorie des couleurs," 9 January 1768, *pli cacheté*no. 129 AdS *pochette*.

Note 19: Louis-Guillaume de la Follie, "Sur le couleur nommée bleu de argent," July 22 1772, AAR Carton C8.

Note 20: Meeting minutes for 3 December 1768. Procès-verbaux de l'Académie royale des Sciences 87 (1768).

Note 21: Meeting minutes for 2 June 1775 [Étienne Mignot de Montigny, Antoine Baumé, and Jean-Baptiste le Roy], "Rapport de sur les observations physico-chimiques des couleurs par Opoix, Maître Pharmacien à Provins," Procès-verbaux de l'Académie royale des Sciences 94 (1775).

Note 22: Alan E. Shapiro, *Fits, Passions and Paroxysms*, 242.

Note 23: Meeting minutes for 2 June 1775, AdS.

Note 24: Christoph Opoix, "Observations Physico-Chymiques sur les Couleurs," *Observations sur la physique sur l'histoire naturelle et sur les arts [Journal de physique]* 8, pt. 2 (July 1776): 100–116; Christoph Opoix, "Suite des Observations Physico-Chymiques sur les Couleurs," *Journal de physique* 8 pt. 2 (July 1776): 189–110; Louis-Guillaume de la Folie, "Réflexions sur la Théorie de la Teinture, Suivies d'Expériences Utiles pour les Manufactures," *Journal de physique* 12, pt. 1 (January 1778): 66–78.

Note 25: de la Folie, "Réflexions sur la théorie de la teinture," 68.

Note 26: Opoix, "Observations Physico-Chymiques sur les Couleurs," 100–116, 189–211; [Christoph] Opoix, "Des Couleurs Considérées dans la Lumière," *Journal des sçavans* (March 1777): 212–51 and *Journal des sçavans* (April 1777): 440ff.; Un simple amateur de la physique, "Propositions et Demandes sur les Couleurs des Corps au Sujet du Mémoire de M. Opoix, Publié dans le Journal de Physique, du Mois d'août 1776," *Journal de physique* 10 (July 1777): 66–72; Madame T.E.S.A.V.L.M.O.R. [Etienne Claude Marvitz], "Lettre Adressée à l'Auteur de ce Recueil," *Journal de physique* 9 (May 1777): 330–37. Christophe Opoix, *Théorie des couleurs et des corps inflammables, et de leurs principes constituents: La lumière et le feu; basée sur les faits, et sur les découvertes modernes*, (Paris, 1808).

Note 27: *Physikalisch-chemische Beobachtungen über die Farben: aus dem Französischen des Herrn Opoix übersetzt und mit Anmerkungen versehen . . .* trans. Johann Daniel Ribini (Vienna; Leipzig, 1785); Johann Beckmann, *Physikalisch-ökonomische Bibliothek* (Göttingen, 1770–79), 9:75; C. Opoix, "Ueber die Natur des Lichts, der Farben, der gefärbten Schatten, des Nordlichts, der Morgen- und Abendröthe," *Magazin für das Neueste aus der Physik und Naturgeschichte* 2, no. 4 (1784): 95–100; see also C. Girtanner, "Ueber Elementarfeuer, Causticität und die Entstehung der Farben," *Göttingisches Magazin der Wissenschaften und Litteratur* 2, no.1. (1781): 34–80.

Note 28: Pierre-Joseph Macquer, "Notes pour la course de chemie," 1779, BNF M.F. 9134, p. 128; "Sur l'art de teinture," n.d., BNF M.F. 9132, pp. 108–11.

Note 29: John Wilson, *An Essay on Light and Colours, and What Colouring Matters Are that Dye Cotton and Linen* (Manchester, 1786).

Note 30: Wilson, *An Essay on Light and Colours*.

Note 31: Wilson, *An Essay on Light and Colours*, 28.

Note 32: Wilson, *An Essay on Light and Colours*, 2. On Delaval, see also Shapiro, *Fits, Passions, Paroxysms*, 230–35, and esp. 269–72.

Note 33: Robert Dossie, "On the Nature Preparations and Use of the Several Substances Employed in Enamel Painting—Sect. 1, Of the General Nature of Enamel Painting," *The Handmaid to the Arts*, 2d ed. (London, 1764), 1:261; Pierre-Joseph Macquer, *Dictionnaire de chimie: contenant la théorie et la pratique decette science, son application à la physique, à la histoire naturelle, à la médecine & aux arts dépendans de la chimie* (Paris, 1778), s.v. "Émaux."

Note 34: Louis-Claude Cadet de Gassicourt, "Decomposition de l'Émail par l'Alun," *Mémoires de mathématique et de physique présentés à l'Académie royale des Sciences par divers sçavans, & lus dans ses assemblées [Savants étrangers]* 3 (1760); See also Macquer to [unknown] regarding Cadet's study and the problems of spotting in ceramics,

11 December 1769, BNF M.F. 9135, p. 9.

Note 35: Didier-François d'Arclais de Montamy, *Traité des couleurs pour la peinture en émail et sur la porcelaine et précède de l'art de peindre sur l'émail* . . . (Paris, 1765).

Note 36: Didier-François d'Arclais de Montamy, *Traité des couleurs*, 34–49 repeated elsewhere.

Note 37: Meeting minutes for 20 December 1768 [de la Martinière: Demonstration of some enamel paintings]. Procès-verbaux de l'Académie royale des Sciences 87 (1768); Meeting minutes for 4 February 1769 ["Rapport sur la Peinture en Émail du M. de la Martinière] Procès-verbaux de l'Académie royale des Sciences 88 (1769).

Note 38: "Details du secret de Mr. Lorient pour fixer la peinture au pastel," 8 October 1753, Extrait des registres de l'Académie royale de peinture et sculpture, AN O/1/1915 #50; "La veuve Pessechet et le secret à faire le pastel au huile inventée par son feu mari," 23 February 1767, AN O/1/1911 #14; "Lettre de le vicomte de Milleville à le comte d'Artois sur la decouverte d'une vernis pour le pastel," 5 December 1785, AN O/1/1918 #476; Nadaux, Engraver et dessinateur, son composition des crayons, [after 15 July 1780], AN F/12/2237; "Method of Painting with Fixed Crayons Considered and Revealed," 11 November 1763, Committee Minutes of the Committee on Polite Arts, [R]SA Minutes of Various Premium Committees 1763–64 [R]SA PR.GE/112/12/5; Regarding Mr. Stanley's Crayons, 25 January 1766 and 20 June 1766 [R]SA Minutes of the Committee on Polite Arts, [R]SA Minutes of Various Premium Committees 1765–66 [R]SA PR.GE/112/12/7; Regarding Crayons Invented by Mr. Pache, 4 December 1772, [R]SA Minutes of the Committee on Polite Arts, [R]SA Minutes of Various Premium Committees 1772–73 [R]SA PR.GE/112/12/14; Regarding Mrs. Keeting (Elizabeth Randall Keeting) and Her Swiss-Style Crayons, 3 May 1782, Committee Minutes of the Committee on Polite Arts, [R]SA Minutes of Various Premium Committees 1781–82 [R]SA PR.GE/112/12/23; A Collection of Recipes for Painting, etc., Belonging to Paul Sandby, Correspondence, T. and P. Sandby, 1790–1809, British Library Add. ms. 36,994 British Library.

Note 39: Johann Heinrich Müntz, *Encaustic: or, Count Caylus's Method of Painting in the Manner of the Ancients* . . . (London, 1760); see also Johann Heinrich Müntz to the Chemistry Committee, 7 April 1760, [R]SA Guard Book PR.GE/110/8/145. Other applications to the Society of Arts regarding encaustic painting techniques include: Miss E. F. Greenland to the Committee on Polite Arts, 13 December 1786, Committee Minutes of the Committee on Polite Arts, [R]SA Minutes of Various Premium Committees 1786–87 [R]SA PR.GE/112/12/28; "B" to the Committee on Polite Arts, 7 December 1787, Committee Minutes of the Committee on Polite Arts, [R]SA Minutes of Various Premium Committees 1787–88 [R]SAPR.GE/112/12/29.

Note 40: Johann Heinrich Müntz, *Encaustic*, 137.
