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The Color of Blood: Between Sensory Experience and Epistemic Significance

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Introduction: Between Anatomy and Philosophy

In his monumental *Canon*, the Persian philosopher and physician Ibn Sīnā—known in the West as Avicenna—discussed the nature and composition of blood with regard to its role in nutrition. In an important passage, he argued that blood is a humor consisting of four components, as can be ascertained by pouring the blood drawn from a patient into a vessel and observing its separation into a foamy "colera rubea," a turbid "fex" or "melancolia," a portion resembling egg white, and lastly a watery part. The first three parts are themselves humors, namely, bile, melancholia, and phlegm, whereas the last part is that which expells its excess as urine. Avicenna relied on a range of features, including color, for the identification of the blood's components. This passage attracted the attention of physicians and alchemists alike because of the importance of blood, the compound nature of the humors, and the problem of their separation. In this paper I will discuss some implications of Avicenna's passage for the nature of color and blood in the seventeenth century.[1]

In his 1651 *De generatione*, for example, William Harvey argued that blood is heterogeneous and is composed of different humors, but while the animal is alive "it is a homogeneous animate part, compounded out of soul and body"; this unity disappears in death when the soul fades away and blood decomposes into its constituents and becomes corrupted. Harvey also noticed that blood found in the lungs was especially florid, but he believed that the difference in the color of blood from arteries and veins depended on accidental circumstances, such as the size of the openings: blood squirting from a tight opening, like that in an artery, was brighter, whereas blood from a wider opening, like that in a vein, was darker. He added that between venous and arterial blood there were no physical differences and that arterial blood collected in a bowl would soon look venous.[2]

These observations and reflections on blood and its components call into question the nature of color as a tool of investigation in a number of areas ranging from chemistry to philosophy. Color is one of the most immediate sensory experiences and at the same time one of the most complex philosophical and physiological problems in sense perception. The seventeenth century was a particularly remarkable period in this regard, one that saw the crystallization of the notions of primary and secondary qualities and the publication of a number of celebrated studies and experiments on the nature of light and colors, as well as the investigation of the significance of color change in blood. This essay moves across a varied terrain conceptually and geographically: it starts by providing a brief synopsis of physical-philosophical stances on color in a few decades around midcentury, beginning with Galileo's *Assayer* (Rome, 1623) and Descartes' *Dioptrique* (Leiden, 1637). Moreover, Robert Boyle and Robert Hooke joined a chemical with a mechanistic standpoint in *Experiments and Considerations Touching Colours* (London, 1664), *The Origine of Formes and Qualities* (Oxford, 1666), and *Micrographia* (London, 1665).[3]

Anatomical investigations are particularly relevant because color enters the description of important structures and processes in the body. For this reason I will focus on a key episode, the study of color change in blood between 1659 and 1669, with special emphasis on the group around Giovanni Alfonso Borelli in Pisa, including Marcello Malpighi and Carlo Fracassati, and some scholars moving between Oxford and London, including Thomas Willis, Boyle, and Hooke. Later in his career Malpighi changed his philosophical stance on color in dramatic fashion; therefore a study of his work promises to shed light on a broad range of epistemological positions. Briefly put, at an early stage, relying on his own philosophical views and the experiments of the Cimento Academy, Borelli explained to Malpighi that color was not a useful way to explore the properties of substances. The *Saggi*, or samples of experiments of the Cimento Academy (Florence, 1667), tackled the problem of the nature of color change experimentally, discussing tests with color indicators leading Borelli to believe that colors could easily be changed and were therefore unreliable indicators of the true nature of a substance—a much more radical stance than Boyle's. As a result, in his study on lungs and respiration, Malpighi ignored color change in blood. As reported in print by Fracassati, Malpighi observed that air—among other factors, to be sure—was responsible for color change in blood, but he did not consider this change to be indicative of a corresponding transformation in its substance and therefore as a meaningful feature of respiration.

It is especially useful to contrast the works by the Pisa anatomists with the *Tractatus de corde item de motu & colore sanguinis et chili in eum transitu* [*Treatise on the Heart as well as on the Motion and Color of Blood and on the Transit of Chyle through it*] (London, 1669) by the physician Richard Lower, a treatise examining respiration—among other topics—in which color change in blood is prominently included in the title. Both Boyle and Hooke were engaged not only in philosophical and experimental reflections on color, but in anatomical investigations as well: Hooke offered a decisive contribution to Lower's work, one that Lower chose to acknowledge in print. Lower was a student and follower of Thomas Willis, a physician, anatomist, and chemist whose reflections on the nature of blood and the site where its color changed in the body proved quite influential.

In a concluding section I show that at a later stage, after having broken with Borelli and having become associated with the Royal Society, Malpighi gave increasing attention to color: not only did his description of the silkworm display a stunning sensitivity to color, but he also attributed an epistemic significance to it, since the change of color of the silkworm's eggs indicated whether they had been fertilized. I suspect that Boyle's work joined forces with Malpighi's medical background and artistic sensibility in effecting this remarkable transformation, both in the style of description and in its philosophical underpinning. This episode provides material for reflection on the nature of observation and its epistemic presuppositions and consequences.

The issue of color in philosophy, anatomy, or medicine in the seventeenth century is a huge one that cannot possibly be exhausted within the compass of a short paper, even one confined to the study of blood; therefore my aim here is limited to raising some questions and stimulating further investigations through the lens of a particularly significant episode rather than offering a comprehensive examination of the issues at stake.

Color in the Mid-seventeenth Century

I wish to open this short section by discussing Galileo's celebrated passages from the *Assayer* in which he introduced the distinction between what we can call "objective" and "subjective" qualities, later called primary and secondary. In section 48 Galileo discussed the nature of heat and then went on to argue that some qualities—such as size, motion, spatial relation to other bodies, and number—are inseparable in our mind from corporeal substance. Other qualities, however, such as tastes, odors, and colors reside only in the sensorium of the perceiving animal; if this were removed, they would disappear. Heat, according to Galileo, was one of those qualities; heat would consist in a multitude of tiny particles—the *ignicoli*—moving at great speed, which are the only entities existing independently of the perceiver; consequently there is no such thing in nature as heat independently of those who perceive it. Looking more closely at Galileo's text one notices a significant difference among the purely subjective qualities: in some cases, as with tastes, odors, and sounds, Galileo provided an explanation of their origin, such that tastes and odors are associated with the shape, size, and speed of particles entering the pores of the tongue or the nostrils. Galileo had already discussed sounds in the celebrated and much discussed fable of the cicada; whatever their specific forms of production, however, such as the vibration of a string, they stemmed from the motion of air. By contrast, Galileo left the issue of light and especially color open, arguing first that he understood very little about it and then that it would require a long time to explain the little he knew.[4]

Probably Borelli had Galileo's *Assayer* in mind when in the 1649 *Delle cagioni de le febbri maligne* he applied a similar reasoning to medical matters, pointing out that neither tastes, nor smells, nor colors are reliable or indeed viable ways to distinguish poisons from healthy foods: as we shall see, for Borelli those qualities could be changed without a change in substance and therefore all we can do to find a substance's properties—medical or otherwise—is to study its effects.[5]

I believe that Descartes too was familiar with Galileo's *Assayer*, which was published in Rome just before his arrival in the eternal city; several passages from the 1644 *Principia philosophiae* echo quite closely Galileo's text. Descartes retained Galileo's dichotomy between "objective" and "subjective" qualities, namely, qualities like size, shape, and motion on the one hand, and colors, tastes, and odors on the other, arguing that there is nothing in nature that corresponds to color as such independently of the perceiving subject. Light played a major part in Descartes' natural philosophy, so much so that his treatise *Le monde* was originally conceived as a treatise on light: although he treated the problem in different ways depending on the problem he was addressing, overall he understood light in terms of pressure from particles of a fluid. Already in the *Dioptrique* Descartes moved one step further than Galileo in providing a mechanical account of the corresponding quality of colored particles, namely, their spin. According to his view, the different rotational speed of light particles makes us see color: red for the greatest spin and blue for the smallest. Descartes, too, dealt with the color of blood, framing his study in a neo-Galenic fashion to try to explain how white chyle is transformed into red blood in the liver: his answer was that just as the white juice of black grapes is turned into red wine, so chyle passing through the pores of the liver "takes on the color, and acquires the form, of blood," a comparison borrowed from Galen.[6]

Moving to England, we find writings of Boyle and Hooke especially pertinent to the philosophy of color: both were engaged in anatomical experiments on respiration and the reasons for the change of color of blood. Several documents from that period testify to Boyle's interests in the matter: for example, he wished to investigate the differences between arterial and venous blood, as well as their color, taste, odor, and specific gravity. Boyle's *Experiments Touching Colour* claim that color and color changes are due to the change of the mechanical texture of bodies, especially their surfaces. Boyle's argument that color is related to the roughness of surfaces led him to accept the report by Sir John Finch that John Vermaasen, a blind man in the Netherlands, was able to distinguish colors by touch, a report savagely lampooned by Jonathan Swift in *Gulliver's Travels.* According to Vermaasen, black and white had the roughest surfaces or the "most asperous," while red and blue were the least rough or "asperous," the full range going from black to blue. It is of particular interest that Boyle reported several experiments with color indicators, much like the Cimento Academy, though he did not reach Borelli's radical conclusion that color is ultimately unrelated to the nature of substance. Rather, he showed a typically restrained attitude to formulating a general theory. Boyle, however, did surmise that colored bodies appear opaque but may in fact consist of transparent corpuscles. In *The Origine of Formes and Qualities* he argued that colors are not inherent qualities of a body due to its substantial form; rather, they derive from the mechanical texture of its minute parts and can be easily changed by changing that texture. The very first of ten experiments in his book involves the dissolution of camphor into oil of vitriol, producing a deep yellow-red color in striking contrast to the colorless ingredients; add water to the solution, however, and the solution turns colorless and camphor regains its piercing odor that it had lost in its dissolution. Boyle's *Memoirs for the Natural History of Humane Blood* (London, 1684), published twenty years later, testifies to his lasting interest in blood. The book was dedicated to John Locke, who in the mid-1660s was interested in the color change of blood and believed it was due to the niter in the air.[7]

Robert Hooke, too, indulged in speculations on light and color in several bodies, such as Muscovy glass—a mineral composed of tiny flakes with varying optical properties as they got smaller—and a diamond presented by Mr. Clayton to the Royal Society, which produced light when rubbed, struck, or beaten in the dark, a matter discussed by Boyle too. Hooke concluded from painstaking examination of the behavior of Clayton's diamond that light resulted from a very short vibratory motion. While examining the color of bodies, Hooke argued that even those appearing opaque are composed of tiny transparent elements, hence the importance of his study of Muscovy glass, which thus appeared not as a peculiar exception but as exemplary of the structure of bodies.[8]

Whatever the specific view about the color of bodies, both Boyle and Hooke, unlike Borelli and his followers, did not dismiss the significance of color and color change altogether. Rather, they adopted a more flexible approach whereby color did have some correlations to bodies, if not strictly to their material substance, at least to its arrangement in the texture and especially to the surface of bodies.

The Pisa Scene: Borelli, Malpighi, and Fracassati

Between 1656 and 1667 Borelli held the chair of mathematics at Pisa University. Although traditionally this position was not especially highly remunerated or of very high rank, Borelli's close contacts with the Medici rulers and their academy enabled him to enjoy an unusually high standing at the university, where he was the "philosophical" and "political" leader of a group that included at different times the professors of medicine Malpighi (1656–59) and Fracassati (1663–68). Let us focus on Malpighi first: his position was especially interesting because, besides being an anatomist, he was also a professor of the practice of medicine and a physician, and this adds another dimension to the issue of color. Although the venerated practice of uroscopy—involving the careful inspection of urine, including its color—may have fallen into disuse, color remained a key feature of medical diagnosis as a meaningful indicator of health and disease: jaundice, for example, relied on the observation of a yellow tinge in some solid and fluid parts of patients. Therefore it was natural for Malpighi to pay attention to the color of body parts, as he did in a letter to Borelli in 1660 in which he commented on the changing color of some callous particles—possibly of blood—extracted from a patient and friend afflicted by pain in the articulations; he reported that those particles turned from white into a rotten color, *color di marcia*, or the color of rotten or putrid matter. In a revealing reply, Borelli stated that the change of color of those callous particles was not a matter of great interest, "knowing that the colors of things can be very easily changed."[9]

In a later letter Borelli discussed the issue of color at greater length in a medical and therapeutic context: the topic of discussion was the nature of some fevers afflicting Pisa and the search for the best therapy. Since postmortems revealed an excess of bile in the victims' cadavers, bile played a major role in his and Malpighi's reflections. Malpighi had argued that no fever arises in those cases in which bile is mixed with blood, as the example of jaundice shows. In his reply Borelli questioned whether bile is truly to be found in the arteries and veins of patients; he recalled having tested by means of a piece of paper the urine of a patient with exceedingly yellow face and eyes and found that the paper did not turn yellow. He pointed out that since nature can change colors very easily, it would be conceivable that jaundice could be due to causes other than bile. Thus in this instance Borelli still considered color as a valid symptom in that the yellow face and eyes of the patient indicated jaundice, yet he questioned the traditional causal mechanism linking the appearances to bile. At this point he embarked on a chemical-philosophical excursus on color—and taste too—arguing that colors can be changed without a corresponding change of "substance," by which he meant the constituent matter of the body. He mentioned the experiments performed at the Cimento Academy and later published in the *Saggi*. It is to these experiments that we now turn.[10]

Study of color change occupied a small part of the agenda of the Cimento Academy around 1660. Its activities aimed to promote experimental philosophy without an explicit philosophical agenda for or against novelties in order to present irrefutable experimental results and avoid sterile philosophical disputes. As in many other cases, however, it seems likely that the experiments on color indicators did follow a philosophical agenda in challenging the view that colors were related to substantial forms, in that colors could be easily changed without changing the substance generating them in any meaningful way. This way of proceeding by allusions or coded messages was standard at the Cimento. The *Saggi* of the Cimento states that, the academy truly did not wish to meddle with color changes studied by the chemists, but the members investigated some of those changes in connection with their study of the properties of mineral waters. The third experiment offers an example:[11]

> Tincture of red roses extracted with spirit of vitriol becomes a very beautiful green when mixed with oil of tartar. A few drops of spirit of sulphur make it all bubble up into a bright red foam, and it finally returns to a rose color without ever losing its scent and can no longer be changed by oil of tartar poured into it.

The text specifies that ten or twelve drops of oil of tartar and of spirit of sulphur in half an ounce of tincture of roses are enough to achieve the desired result. Although at first sight this and other similar experiments seem like neutral factual reports, Borelli's correspondence reveals a different side of the story. Borelli drew the conclusion that there was no fixed relation between color and the substance generating it: a few drops of oil of tartar or spirit of sulphur could turn a much larger amount of liquid obtained from red roses and spirit of vitriol from red to green and back to red. The red liquids, however, had such different properties that the first had a pleasant taste and was innocuous, whereas the final product could have proved lethal. Similarly, tastes too could be deceptive, as he had just experienced by noticing the similarity between two fluids with different properties, such as the brine in which olives macerate and that found in the stomach of fishes, or milk and the liquid found in the stomach of hawks: whereas the digestive fluids were very corrosive, the others were innocuous. Hence nature could easily change colors and tastes without changing a body's substance; conversely, it could make very different substances look and taste similar: changes in color or taste were unrelated to substantive transformations.[12] As we are going to see, in this tradition joining subtle philosophical thinking with the latest experimental results, the far less dramatic color change in blood from dark to bright red and back to dark seemed unworthy of serious investigation; the change may be attributed to the rearrangement of blood components in the lungs, but the investigators in Borelli's circle did not test where and in what circumstances it occurred.

These observations about color had an anatomical counterpart in the study of blood carried out by Borelli and Malpighi when they overlapped as professors at Pisa University between 1656 and 1659. At the time Malpighi planned a dialogue in Galilean form dealing with medical and anatomical issues; although in the end that work was not published and is now lost, in 1665 Malpighi incorporated portions of it into a *Risposta* he drafted against some traditionalist Galenist physicians at Messina, which was published only posthumously in 1697. The Galenists argued that even barbers know that blood contains bile, phlegm, and melancholia or black bile, as can be seen in blood let from a healthy person, a reference dating back to Avicenna's *Canon*.[13]

Malpighi disagreed with the Galenists and challenged their interpretation: both taste and odor of the various parts are intermingled and therefore they cannot be easily distinguished, so much so that even the bitterness of bile is overshadowed by the sweetness of blood. Thus color turns out to have a crucial role: the components of blood could allegedly be detected by visual inspection by taking some congealed blood, showing a bright red portion at the top and a darker, heavier portion at the bottom: the former could be identified as rich in bile—Avicenna's "colera rubea"—that is yellow and also lighter in weight and therefore rises to the top; the latter could be identified as melancholy—Avicenna's turbid "fex." It is at this point that Malpighi deployed his philosophy of color derived from Borelli, arguing that being dark or bright are "accidents" (*accidenti*) unrelated to the change of substance or its "mixing" (*temperie*). In fact, they can be repeatedly reversed since they depend on causes that have nothing to do with what the Galenists think. Malpighi went on to report a number of experiments on the caked blood intended to show that color is not a valid indicator of the nature of a substance. He started by arguing that putting some salt on the dark portion of blood will turn it very bright red; yet the earthy nature of salt ought to have turned it dark like melancholia, according to the Galenists. The simplest experiment consisted in turning upside down the caked blood and then observing the inversion of colors, the dark portion at the bottom turns bright red once it is at the top and, vice versa, the bright portion at the top turns dark once it is at the bottom. By putting the cake under water, even the bright red portions turn entirely dark. Malpighi was fully aware of the role of air in the changing color of blood: in another passage dealing with pulmonary disease, he argued that blood spits are bright red because blood is mixed with air, whereas blood in the rest of the body can be quite different in color and texture.[14]

The blood experiments carried out at Pisa between 1656 and 1659 were first reported in print by Malpighi's friend and colleague Carlo Fracassati in his 1665 treatise on the brain, *De cerebro*, with a clear attribution to Malpighi. Fracassati's treatise is a rather disorganized work covering nearly twenty double-column folio pages in the 1699 edition from the *Bibliotheca anatomica*. His report occupies just a few lines and follows closely the style of argument we have seen above, including the challenge to the link between dark blood and melancholia; Fracassati, too, explicitly mentioned the role of air in the changing color of blood from dark to bright red.[15] Yet his acknowledgment did not imply the recognition of the anatomical significance of that transformation: Borelli and his group thought that the substance of blood remained the same whether it was mixed with air or not. Indeed, in a later passage dealing with the changing color of blood mixed with various substances Fracassati explicitly warned readers not to trust colors, "*ne crede colori*," as he put it.[16] Thus it would be erroneous and anachronistic to attach great significance to Fracassati's report, as if it had claimed that Malpighi had discovered that exposure to air turns venous blood into arterial and, conversely, privation of air turns arterial blood into venous. In fact, Borelli's correspondence and the study of the Cimento experiments offer a revealing and entirely different context to interpret Malpighi's and Fracassati's claims: color is not a valid indicator of substance and—one may add—it is therefore legitimate to ignore it in the study of nature and in anatomical investigations in particular. Moreover, mixing with air was only one among several processes that turn the color of blood bright red, besides sprinkling it with salt, for example.

We are now equipped to attempt a fresh reading of Malpighi's celebrated *Epistolae* (1661) on the lungs, in which he announced the discovery of their microscopic structure. By studying the lungs of frogs, whose microstructure is easier to detect, he showed that the lungs were not spongy as was traditionally believed, but rather consisted of a series of smaller and smaller cavities or *alveoli* delimited by membranes covered by a network of blood vessels. Malpighi was able to see the anastomoses or junctions between arteries and veins, and also venous and arterial blood flowing in opposite directions. These findings provided direct visual proof of Harvey's circulation and showed that blood always flows inside blood vessels, thus closing the missing link in Harvey's system. Malpighi, however, did not stop with structure and tried to provide an explanation of the purpose of respiration, one directly influenced by Borelli. Their account has been aptly described as purely mechanical in that they did not attribute any role to chemistry. The role of the lungs was simply to mix blood with chyle so that it could nourish all the parts of the body. The motion of inflation and deflation of the lungs allows them to mix the blood better. This account soon proved grossly inadequate, since it was shown that animals could not breathe the same air but need fresh air to enter their lungs. More significantly from our perspective, in line with Borelli's views as highlighted in the contemporary correspondence and with the experiments of the Cimento, Malpighi paid no attention whatsoever to color change of blood in respiration. The finding that air changes the color of blood from dark to bright red seemed irrelevant, since Malpighi had shown that blood is never in direct contact with air but flows always inside blood vessels. Thus Malpighi did not see a connection between the color of blood in the lungs and the purpose of their structure, or to put it another way, he did not see a connection between the color of blood and respiration.

The English Scene: Boyle, Hooke, and Lower

It may seem peculiar to start a brief account of the English scene from a review of Fracassati's experimental report of Malpighi's observation; however, since there was a fundamental shift in the way the Pisan experiment was interpreted at Oxford and London, one may well argue that the same observation played a radically different role. Even the name differed: despite Fracassati's clear attribution to Malpighi, the experiment became known in England as "Fracassati's." In a brief report in the *Philosophical Transactions*, Henry Oldenburg teased out of Fracassati's disordered work the few lines dealing with color change in blood. Oldenburg reported that when blood has turned cold in a dish, the portion at the bottom is darker than at the top. The standard explanation that this observation would reveal the presence of melancholia in blood, however, was disproved by exposing blood to air, showing that blood becomes a florid red, "An experiment as easie to try, as 'tis curious."[17] As the admirable work by Robert Frank has shown, Fracassati's report reached England in the midst of a flurry of investigations on respiration and exerted a considerable impact. In a letter to Oldenburg of 26 October 1667, Boyle gave guarded approval to the truth of the experiment and Fracassati's interpretation that air plays a role in the color of blood. They differed significantly, however, in their interpretation of the significance of this observation: by now Avicenna's original report had underwent a major reconceptualization, from a proof of the composite nature of blood to evidence of the role of air in respiration.[18]

We now take a step back in time to consider a major figure, the Oxford Sedleian Professor of Natural Philosophy Thomas Willis. Willis combined medical, chemical, and anatomical interests with a sympathetic attitude to Descartes' mechanical understanding of nature, making the notion of fermentation a hallmark of modernity. In *Diatribae duae medico-philosophicae* (London, 1659), an influential treatise dealing with fermentation and the nature of fevers, Willis had provided a chemical reason for the change of color of blood, arguing that this phenomenon resulted from the combination of the sulphurous particles of blood with those of salt and spirit. In line with Descartes and other Continental investigators, he located the site where blood changes color in the heart: thus, unlike Borelli, he attributed a significant role to the change of color of blood. Willis too referred to the stratification of blood components once blood cools in a bowl, much like milk and wine; blood separates into a purer sulphureous part at the top, which in healthy individuals is bright red, and a thicker darker part at the bottom. We encounter here exactly the classical observation Malpighi and Fracassati had reported.[19]

Following his teacher Thomas Willis, Lower attached great importance to blood, its fermentation, and color change. In a letter to Boyle of June 1664, Lower discussed the reason for the difference of color between arterial and venous blood, arguing that arterial blood is bright red, whereas blood that has circulated through the muscles and thereby lost many particles before reaching the veins is darker. Unlike Harvey, Lower could confirm that blood let from the artery of a dog and kept in a "porrenger" or a small bowl remained bright red for one or two days, whereas blood let from a vein of the same dog remained dark, except for a thin layer at the top.[20]

In October and November 1664 the Royal Society debated whether air enters the body through the lungs. The fact that during the vivisection of a dog it was possible to revive the heartbeat by blowing air into the *receptaculum* *chyli*, whence it reached the heart through the thoracic duct, suggested a role for air in heart pulsation. On November 7, Hooke, together with Oldenburg and Jonathan Goddard, a former student of Francis Glisson at Cambridge, inserted a pair of bellows into the trachea of a dog and inflated its lungs. Opening the thorax and cutting the diaphragm, Hooke observed the heart beating regularly for over one hour as long as air was in the lungs. Hooke could not determine whether air entered the lungs, but he could establish that the motion of the heart was related to the inflation of the lungs, even though the two were not synchronous.[21]

The English anatomists soon elaborated on this experiment and went beyond this initial result relying on Lower's skill with vivisection. Emphasis on experimentation was a hallmark of both the Royal Society and the Italian Cimento Academy, but in this case the English investigators asked questions about issues the Italians had deemed of no significance, such as the color of blood. Initially, in *De febribus vindicatio* (London, 1665), a defense of Willis's *Diatribae* against the attack by the Bristol physician Edmund Meara, Lower had claimed that blood changes color in the heart as a result of a ferment in the left ventricle and also that blood in the lungs was venous, probably also because in his early trials the animal's lungs had collapsed and were empty of air; but regardless of where the color of blood changed, the very fact that it changed was deemed significant. Lower described his experiment in the same year in which Fracassati reported Malpighi's observations on the role of air in changing the color of blood—a finding still unknown to Lower.[22] But additional experiments refuted his initial view.

On 10 October 1667 Hooke and Lower performed an experiment at the Royal Society analogous to that of 1664, but this time they relied on two pairs of bellows instead of one, producing a continuous airflow. An incision in the pleura allowed air to exit the lungs, which thus remained inflated. In this way the animal was kept alive without motion in the lungs, thus showing that their motion was not required to keep the animal alive. By cutting a portion of the lungs, they could observe the blood moving through the lungs whether they were inflated or not.[23] This experiment refuted the purely mechanical view of respiration put forward by Malpighi and Borelli and later adopted by others in England.

Lastly, Hooke and Lower performed yet another two-part experiment on a dog. First, in the initial vivisection, they closed the trachea and showed that the blood coming from the cervical artery, after the blood had gone through the left ventricle of the heart, was venous. Thus the change of color of blood did not occur in the heart. Then the animal died, and they performed the insufflation experiment with the two pairs of bellows mentioned above, managing to obtain arterial blood from the pulmonary vein. Thus it was not the motion of the lungs, or a ferment in the heart, or the animal's heat that was responsible for the change of color of blood in the lungs, but only air, in line with Fracassati's report but against the view of Malpighi, Borelli, and Fracassati himself. This experiment strikes me as being especially significant in showing that the change of color of blood was not due to the soul or one of its faculties, because the animal was dead; although Hooke and Lower followed Harvey with respect to their acceptance of the circulation and emphasis on vivisection experiments, in this respect one wonders what they would have made of Harvey's belief in the soul and its location and role in blood.[24]

Thus in Borelli's group the experimental evidence with color indicators and the anatomical evidence that blood flows always inside blood vessels joined forces in denying a meaningful role to the change of color of blood, even after the realization that air was one of the factors responsible for this change. By contrast, in the group around Willis and Boyle the medical and chemical traditions joined forces in attributing a significant role to color and the change of color of blood, a phenomenon that anatomical experiments located in the lungs.

Finale: Malpighi and the Colorful Silkworm

Matters did not end there for Malpighi. Based on a range of sources, he revised his views on respiration, eventually accepting that a portion of air enters the blood through the lungs and plays a chemical—as opposed to a purely mechanical—role in respiration. In *De polypo cordis*, for example, first published in 1668, Malpighi studied the composition of blood starting from pathology, notably the polyps found during postmortems in the heart of deceased patients. In this work he dealt with the color of blood from a different perspective: observing blood through the microscope, Malpighi noticed that the red coloration was due to a large number of "red atoms," while the rest consisted of a network of whitish fibers. Malpighi put his finger on the color dichotomy between the macroscopic and the microscopic world, whereby what appeared on unaided visual inspection as a homogeneous red humor was shown by the microscope to be quite different; he then commented on the stratification of coagulated blood. Thus he relied on microscopic observations to reassess his own 1659 experiment and observation based on Avicenna and reported by Fracassati in 1665. He attributed the black color at the bottom not to melancholia—as some had believed—but to the great abundance of those particles he had called "red atoms," which he claimed returned to purple by a mere change of position. In a later passage of *De polypo* *cordis*, Malpighi spelled out that the lungs filter from the air a "salt of life" that awakens—"*suscito*"—the red potion of blood: thus the changing color of blood emerged as a significant feature of respiration.[25]

At this point, rather than following Malpighi's attempts to salvage what he could from his earlier views, I wish to shift to another topic. In 1669, the same year in which Lower published *De corde*, the Royal Society published Malpighi's treatise on the silkworm, *De bombyce*, and elected its author a fellow. By that point Malpighi had broken off his friendship and correspondence with Borelli and had departed in key respects from his former mentor's philosophical stance, notably with respect to color. His publications show a growing interest in color, but it is with *De bombyce* that Malpighi let his sensitivity to color burst forward in dramatic fashion. The reader of *De bombyce* is struck by a different Malpighi from that of the *Epistolae* on the lungs: now color—including many shades of gray—takes on a significant epistemic role in the description of silkworms, revealing an author with a striking sensitivity to nuanced shades and a remarkable ability to describe color in words. Color had become an integral part of Malpighi's descriptions, not only as a source of pleasure but also as a philosophical feature of the object under investigation. The fact that Malpighi was an art collector and enthusiast is related to his ability to observe and describe nature.[26] From the first pages of *De bombyce* we read of eggs turning from *violacea* to *caerulea* or light blue, then *sulphurea* and thereafter *cinerea* or ash-colored. Nor are Malpighi's identifications of color approximate: on one single page we find him distinguishing between *cinereus* or ash-colored and *fuliginosus* or soot-colored in describing the color of the just born silkworm, a color that soon turns into *perlatus* or pearl; the head is *coracinus* or raven black; the hairs and legs are *ziziphini* or jujube-colored. Elsewhere Malpighi describes the color of the silkworm as *achatis* or agate in those parts free of folds, and *argenteum* or silvery elsewhere. The silk thread is *luteus* or *auratus*, yellow or golden, or also *subalbus* or whitish with *sulphuris tinctura* or sulphur shade. Malpighi's sheer delight in describing and his remarkable sense of color are striking. Only in this way can we explain his extraordinarily nuanced descriptions. We are also reminded of his artistic interests, in which color played a major role. In an exactly contemporary letter of 24 November 1668 to the noted Sicilian collector Antonio Ruffo, who owned paintings by Rembrandt including *Aristotle with a Bust of Homer*, now at the Metropolitan Museum in New York, and *Homer*, now at the Mauritshuis in The Hague, Malpighi provided a rich account of artistic news about recent acquisitions and prices. He regretted that a fever—probably the same that in his *Vita* he attributed to excessive work on the silkworm—had prevented him from going to Parma and Correggio to see works by "Correggio e Parmigianino"; he did go to Mirandola, however, where he saw a nude Venus by Titian with "mezze tinte di Paradiso," or heavenly halftones. These observations on Malpighi's language and artistic interests, especially about color, go hand in hand with Matthew Cobb's attribution of the watercolor of the silkworm now at the Royal Society to *De bombyce*, since the drawing and especially the color range correspond remarkably to a development stage described in the text: Cobb included the color reproduction of the watercolor in his article. It is reasonable to surmise either that Malpighi himself was responsible for the watercolor, or that the artist who executed it worked directly under his supervision. Here too the letter to Ruffo proves useful, since Malpighi states that in the summer of 1668 he had employed a young painter "per dessegnarmi alcune cosette," to draw for me a few little things, and also to make copies of paintings by members of the Carracci family—Ludovico, Agostino, and Annibale. The young painter executed a few little things for Malpighi exactly at the time of his most intense work on the silkworm; thus it seems plausible that Malpighi used the same painter to help him draw and color the silkworm and make copies of paintings by the Carraccis.[27]

Color was not just a pleasurable appendage to the treatise: Malpighi identified the significance of color differences of eggs from *violacea* or purple to *sulphurea* or pale yellow as an indication of whether fertilization has occurred. He also made an attempt at artificial insemination by sprinkling male semen on the eggs, but his experiment failed and the eggs remained sterile, as testified by the lack of color change.[28]

This brief excursus has uncovered profound links among views about color and rival philosophical, anatomical, medical, and chemical perspectives. Sense perceptions and observations were mediated by deep-rooted and radically different philosophical positions in the process of observation: Borelli and his group—notably Fracassati and, for a while, Malpighi—downplayed the role of color, while Fracassati went so far as to warn readers not to trust color, "*ne crede colori*." By contrast, Willis, Boyle, Lower, and Hooke adopted an approach according to which color appeared related to at least some properties of a substance and was therefore worthy of attention.

Even such an apparently straightforward and simple observation as the change of color in blood has required unraveling a complex web of philosophical opinions and chemical experiments. Malpighi's stance is especially revealing because he crossed boundaries in dramatic fashion: his initial tendency—probably stemming from his medical training—was to consider color as a significant diagnostic sign; following Borelli's prodding, color was then ignored in his investigations of the structure of the lungs and respiration, only to reemerge following his break with Borelli around 1667–1668. Malpighi's attention to color burst forth in all its esthetic nuances and philosophical significance in the study of the silkworm and the fertilization of its eggs, published by the Royal Society in 1669, and remained a feature of his views on nature until the end of his life as pontifical archiater.

Notes

1. Avicenna, *Canon* (Venice: In edibus Luce Antonij Junta, 1527), 7r; William R. Newman, "An Overview of Roger Bacon's Alchemy," in *Roger Bacon and the Sciences*, ed. Jeremiah Hackett (Leiden: Brill, 1997), 317–36.

2. William Harvey, *Exercitationes de generatione animalium* (London: Typis Du Gardianis, impensis Octaviani Pulleyn, 1651), trans. with an intro. and notes by Gweneth Whitteridge as *Disputations Touching the Generation of Animals* (Oxford: Blackwell, 1981), 254–55; Robert G. Frank, *Harvey and the Oxford Physiologists* (Berkeley: University of California Press, 1980), 40–41, 205–6.

3. Alistair C. Crombie, "Le proprietá primarie e le qualitá secondarie nella filosofia naturale di Galileo," in *Galileo*, ed. Adriano Carugo and Paul Tannery (Milan: ISEDI, 1978), 207–37. Surprisingly, William F. Bynum and Roy Porter, eds., *Medicine and the Five Senses* (Cambridge: Cambridge University Press, 1993), ignores color.

4. Galileo Galilei, *The Assayer*, sections 21 and 48, translated by Stillman Drake and Charles D. O'Malley in *The Controversy on the Comets of 1618* (Philadelphia: University of Pennsylvania Press, 1960), 234–48 and 308–14. Susana Gómez López, "Marcello Malpighi and Atomism," in *Marcello Malpighi, Anatomist and Physician*, ed. Domenico Bertoloni Meli (Florence: Olschki, 1997), 175–89; Pietro Redondi, *Galileo Heretic*, trans. Raymond Rosenthal (Princeton: Princeton University Press, 1987).

5. Giovanni Alfonso Borelli, *Delle cagioni delle febbri maligne della Sicilia. Negli anni 1647 e 1648* (Cosenza: Gio. Battista Rosso, 1649), 143.

6. René Descartes, *Treatise on Man* (Cambridge, Mass.: Harvard University Press, 1972), 9, see also n.19; it is noteworthy that Descartes uses the Aristotelian notion of "form" here. Galen, *On the Usefulness of the Parts of the Body*, 2 vols., trans. and intro. by Margaret Tallmadge May (Ithaca: Cornell University Press, 1968), 1: 205–6; A. I. Sabra, *Theories of Light from Descartes to Newton*, 2nd ed. (Cambridge: Cambridge University Press, 1981), 65–68; John Cottingham, "Descartes on Color," *Proceedings of the Aristotelian Society* 90 (1989–90): 231–46; Stephen Gaukroger, *Descartes: An Intellectual Biography* (Oxford: Oxford University Press, 1995), 158–64, 262–69, 345–46.

7. Robert Boyle, *Works*, ed. Michael Hunter and Edward B. Davis, 14 vols. (London and Brookfield, Vt.: Pickering & Chatto, 1999–2000), 4: 40–42, 50–51, 150, 5: 395–96; Laura Keating, "Un-Locke-ing Boyle: Boyle on Primary and Secondary Qualities," *History of Philosophy Quarterly* 10 (1993): 305–23; Frank, *Harvey and the Oxford Physiologists*, chap. 7, especially 184–88; Boyle, *Memoirs for the Natural History of Humane Blood*, in *Works*, vol. 10; Alan E. Shapiro, *Fits, Passions, and Paroxisms* (Cambridge: Cambridge University Press, 1993), 99–105; Harriet Knight and Michael Hunter, "Robert Boyle's *Memoirs for the Natural History of Humane Blood* (1684): Print, Manuscript and the Impact of Baconianism in Seventeenth-Century Medical Science," *Medical History* 51 (2007): 145–64; William R. Newman and Lawrence Principe, *Alchemy Tried*

in the Fire: Starkey, Boyle, and the Fate of Helmontian Chymistry (Chicago: University of Chicago Press, 2002), 276–77; William R. Newman, *Atoms and Alchemy* (Chicago: University of Chicago Press, 2006), 182–85.

8. Robert Hooke, *Micrographia* (London: John Martyn and James Allestry, 1665), 47–79. Sabra, *Theories of Light from Descartes to Newton*, 187–95; Shapiro, *Fits, Passions, and Paroxisms*, 99–105.

9. Borelli to Malpighi, Pisa, 5 March 1659 [*more pisano* = 1660], cited in Domenico Bertoloni Meli, "Additions to the Correspondence of Marcello Malpighi," in Bertoloni Meli, *Marcello Malpighi, Anatomist and Physician*, 275–308, on 281–82. On the role of the senses in medical diagnosis, see Bynum and Porter, eds., *Medicine and the Five Senses*; Tobias Heinrich Duncker, "'Wie nämlish könnten diese einander gleich sein . . . ?' Zur Hermeneutik farblicher codierung in der antiken Medizin," *Farbe, Erkenntnis, Wissenschaft. Zur epistemischen Bedeutung von Farbe in der Medizin*, ed. Dominik Gross and Tobias Heinrich Duncker (Berlin: Lit Verlag, 2006), 29–38.

10. Borelli to Malpighi, Pisa, 20 Dec. 1661, in Marcello Malpighi, *Correspondence*, ed. Howard B. Adelmann, 5 vols. (Ithaca: Cornell University Press, 1975), 1: 105–9, on 107–8; in reply to Malpighi's undated letter, 1: 104–5. See also Nicolaus Steno, *Observationes anatomicae* (Leiden: Apud Jacobum Chouët, 1662), paragraphs 33–34.

11. W. E. Knowles Middleton, *The Experimenters* (Baltimore: Johns Hopkins University Press, 1971), 234–37, on 234–35; see also 362, 364. As to Aristotle's views on color, see *Categories*, 9b10–32; *Metaphysics*, 1007a31–3; Boyle, *Works*, 4: 150, 152; Domenico Bertoloni Meli, "Authorship and Teamwork around the Cimento Academy," *Early Science and Medicine* 6 (2001): 65–95; William Eamon, "Robert Boyle and the Discovery of Chemical Indicators," *Ambix* 27 (1980): 204–9.

12. Borelli to Malpighi, Pisa, 20 Dec. 1661, in *Correspondence*, 1: 105–9, on 107–8.

13. The author of the tract by the Galenists, *Galenistarum triumphus* (Cosenza: Apud Io. Baptistam Russo, 1665), is Michele Lipari. The text is reproduced from a manuscript by Corrado Dollo, *Modelli scientifici e filosoofici nella Sicilia spagnola* (Naples: Guida, 1984), 290–304, on 296; the unique copy of the printed version is described in Rosario Moscheo, "The *Galenistarum triumphus* by Michele Lipari (1665): A Real Edition, Not Merely a Bibliographical Illusion," in Bertoloni Meli, *Marcello Malpighi, Anatomist and Physician*, 331–35.

14. Marcello Malpighi, *Risposta*, in *Opera posthuma* (London: A. & J. Churchill, 1697), 32, 40–41.

15. Carlo Fracassati, *De cerebro*, in Daniel Le Clerc and Jean-Jacques Manget, eds, *Bibliotheca anatomica*, 2 vols., 2nd ed. (Geneva: Johan. Anthon. Chouët & David Ritter, 1699), 2: 76b: "sed tenes etiam quam male ad oculorum fidem provocent, nam inter alia color saturatus, & nigricans in sanguine, quia fundum scyphi occupavit, & ideo sanguis melancholicus habetur statim ac in lancem projicitur, & aëri inde miscetur, mutatur; scis, quomodo confertim melancholia abeat, & debeant spectatores huic insulsae operationi, quam superciliose aggrediuntur, ludibrium, si parum morentur; etenim color non idem manet, clarior, ac nitentior redditur; nonnes Achilles hic in Thersitem degenerat? Sed de his alias, dum (ne me plagii arguas) fateor tuum hoc esse inventum, & te praeunte hoc didicisse; de natura tamen sanguinis, si aliquid ab obsitis jam situ suo sententiis expectamus, decipimur."

16. Fracassati, *De cerebro*, 2: 79a, emphasis in the original: "Si arbitrarer ex colore nos posse in indicia naturae sanguinis mutuari, non omitterem, quomodo purpureus color ex digestione salium volatilium cum oleis emicet sola etiam coctione, ut in succis symphyti, pyrorum etc. quomodo ab acido hoc in sanguine contingat; sed hic recte admoneor, *ne crede colori*."

17. [Henry Oldenburg], "An Experiment of Signior Fracassati upon Bloud Grown Cold," *Philosophical Transactions* 2 (1667): 492; Frank, *Harvey and the Oxford Physiologists*, 205–6.

18. Boyle to Oldenburg, 26 October 1667, in Robert Boyle, *Correspondence*, ed. Michael Hunter, Antonio Clericuzio, and Lawrence M. Principe, 6 vols. (London and Brookfield, Vt.: Pickering & Chatto, 2001), 3: 357–59, on 357.

19. Thomas Willis, *Diatribae duae medico-philosophicae* (London: Tho. Roycroft, impensis Jo. Martin, Ja. Allestry, & Tho. Dicas, 1659), separate pagination: *De fermentatione*, 1, 10; *De febribus*, 13–15, 20; Frank, *Harvey and the Oxford Physiologists*, 165–68.

20. Lower to Boyle, 24 June 1664, in Boyle, *Correspondence*, 2: 282–91, on 288–89.

21. Frank, *Harvey and the Oxford Physiologists*, 157–59. The insufflation experiment whereby air is blown into the heart was already known to Galen and is mentioned by Harvey and Malpighi.

22. Richard Lower, *De febribus vindicatio* (London: Jo. Martyn & Ja. Allestry, 1665), 117–18; Frank, *Harvey and the Oxford Physiologists*, 188–92 (at 190), and 206.

23. Robert Hooke, "An Account of an Experiment of Preserving Animals Alive by Blowing through Their Lungs with Bellows," *Philosophical Transactions* 2 (1667): 509–16; Frank, *Harvey and the Oxford Physiologists*, 330–31.

24. Richard Lower, *Tractatus de corde* (London: Typis Jo. Redmayne impensis Jacobi Allestry, 1669), 165–67; Frank, *Harvey and the Oxford Physiologists*, 189, on Willis and Lower on Harvey and the soul, 214–15.

25. Marcello Malpighi, *Vita*, in *Opera posthuma*, 16, idem, *Opere scelte* (Turin: UTET, 1967), 193, 200–1, 212–14, 533; Domenico Bertoloni Meli, "Blood, Monsters, and Necessity in Malpighi's *De polypo cordis*," *Medical History* 45 (2001): 511–22; John M. Forrester, "Marcello Malpighi's *De polypo cordis*: An Annotated Translation," *Medical History* 39 (1995): 477–92, on 483–84; Howard B. Adelmann, *Marcello Malpighi and the Evolution of Embryology*, 5 vols. (Ithaca: Cornell University Press, 1966), 1: 196–97.

26. On physicians and art collecting in this period, see Pamela H. Smith, *The Body of the Artisan* (Chicago: University of Chicago Press, 2004), chap. 6 on Sylvius de le Boë, and "Science and Taste: Painting, the Passions, and the New Philosophy in Seventeenth-Century Leiden," *Isis* 90 (1999): 420–61.

27. Marcello Malpighi, *De bombyce*, in *Opera omnia*, 2 vols. (London: Thomas Sawbridge and others, 1686–87), vol. 2, 2 (wrongly numbered 66), 7, 20; Matthew Cobb, "Malpighi, Swammerdam, and the Colorful Silkworm: Replication and Visual Representation in Early Modern Science," *Annals of Science* 59 (2002): 111–47, on 119–21; Malpighi to Antonio Ruffo, 24 Nov. 1668, in Malpighi, *Correspondence*, 1: 388–89; Martin Kemp, *The Science of Art* (New Haven: Yale University Press, 1990), part 3; Trevor Lamb and Janine Bourriau, eds., *Colour: Art and Science* (Cambridge: Cambridge University Press, 1995); John Gage, *Color and Meaning: Art, Science, and Symbolism* (Berkeley: University of California Press, 1999); and idem, *Color and Culture: Practice and Meaning from Antiquity to Abstraction* (Berkeley: University of California Press, 1993).

28. Marcello Malpighi, *De bombyce*, in *Opera omnia*, 2 vols. (London: Thomas Sawbridge and others, 1686–87), 2: 37, 42–43; idem, *Dissertazione epistolare sul baco da seta*, in *Il bacofilo italiano*, vol. 2 (1860), 1–90, on 77–78, 87–88; Howard B. Adelmann, *Marcello Malpighi and the Evolution of Embryology*, 5 vols. (Ithaca: Cornell University Press, 1966), 2: 856–58.