'The Organical Motions of Body Fluids'. Mechanical and Iatrochemical Theories in 17th-Century Physiology

Draft

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Introduction

According to the standard view of early modern science and medicine, two different approaches to human physiology dominated 17th-century physiology. One was the iatromechanical, originating from Descartes, and the other was the iatrochemical, which started with Paracelsus and was subsequently articulated by Jean Baptiste van Helmont.[1] Historians of science and medicine have drawn a firm line between iatromechanical and iatrochemical theories, emphasizing the differences of ideas and methods. The mechanists described human body and its parts in terms of matter and motion, namely by means of the shape, size and motion of particles of matter. The champion of iatromechanism was Descartes, who derived physiological processes from known mechanisms. As he put it in Traité de l'Homme " I derive all these functions from the disposition of its organs alone, just as movements of a clock or another automat follow the disposition of counterweights and wheels". For Descartes, living organisms do not differ in nature from nonliving things, and are the same as machines, their operations are performed by particles of inert matter following the laws of movement. Most iatromechanists followed a reductionist strategy, trying to deduce theories from the geometrico-mechanical properties of particles.

By contrast, iatrochemists described human body as a chemical laboratory, the main physiological operations were deemed as chemical reactions, which they conceived as qualitative change. The iatrochemists rejected deductive logic and mathematics as useless to medicine and emphasised the importance of the empirical investigations. The ultimate ingredients of bodies (the three or five chemical principles) were conceived in qualitative terms. The chemical philosophers maintained

[1] R.G. Frank Jr., *Harvey and the Oxford physiologists*, (Berkeley and Los Angeles, 1980). T.M. Brown, *The Mechanical Philosophy and the 'Animal Oeconomy': A Study in the Development of English Physiology in the Seventeenth and Early Eighteenth Centuries*, (New York, 1981).

that matter was active, or that it was activated by some spiritual agent. The Paracelsians insisted that in nature and in living bodies operated immaterial active principles: *archaei*, spirits, seeds and ferments played a central part in human body. So the knowledge of spirits, ferments and seeds was crucial for the understanding of what they called the 'living anatomy', as opposed to the anatomy of cadavers. Whereas the so-called dead anatomy provided superficial descriptions of the corporeal parts, the 'living anatomy' disclosed the incorporeal principles ruling the main organs. The insistence on the immaterial and invisible active principles did not prevent the chemical physicians from promoting experimental knowledge in medicine. For Paracelsus and his followers, the active vital principles are hidden within bodies, so he urged physicians not to stop at what is offered by immediate sensory perception. In order to attain true knowledge, one has to go beyond the surface of bodies, penetrate their inner nature and investigate their internal powers. Chemistry is the way to discover the hidden properties of bodies, to turn the invisible principles into visible substances and processes. Therefore 'the philosopher by fire' is able to break down bodies in order to discover their internal principles and to make visible what was not initially perceptible.

It would seem that there was a neat opposition between the mechanical and the chemical investigation of physiology. Yet, in the second half of the 17th century (notably in England) the boundaries between the two medical schools were blurred and a number of physicians and natural philosophers adopted both mechanical and chemical explanations in physiology. In England, Cartesian mechanism had a limited impact on physiological investigations, which in fact were based on the view of human bodies as a complex machine where both chemical and mechanical processes take place.[2] Robert Boyle spelled out this view in the *Free Inquiry into the received Notion of Nature*:

"…I look not on a human body, as on a watch or a hand-mill, i.e., as a machine made up only of solid, or at least consistent parts; but as an hydraulical, or rather hydraulico-pneumatical engine, that consists not only of solid and stable parts, but of fluids, and those in organical motion: and not only so, but I consider that these fluids, the liquors and spirits, are in a living man so constituted, that in certain circumstances the liquors are disposed to be put into a fermentation or commotion…"[3]

In the second part of the *Christian Virtuoso* Boyle unambiguously endorsed the iatrochemical 'living anatomy' :

[2] See W. Pagel, *Jan Baptista van Helmont Reformer of Science and Medicine* (Cambridge, 1982); A.B. Davis, *Circulation Physiology and Medical Chemistry in England (1650-1680)* (Lawrence, Kansas, 1973).
[3] Boyle*, Works,* 10, p. 540.

"For all anatomy can do, is to manifest or display the structure of the *consistent parts*, such as the bones, cartilages, nerves, arteries, veins etc., and expose to our senses the visible liquors of the body, such as blood, gall, the concreted juices, urine, etc. But it cannot show us either of the two sorts of invisible parts, viz. the *animal* and other *spirits*, and the ferments, (or principles analogous to them) that may reasonably be supposed to lodge in the stomach, kidneys, and other particular parts. And yet the influences and operations of these are so considerable, that I am apt to think, that most of the parts of the grosser body seem intended by nature, but as a kind of kitchens to dress the aliment, and make its finer parts pure and subtil enough to become animal; or if you please, hormetck or impulsive spirits, fit to actuate the brain and nerves, and thereby to become the grand instruments of sense, motion, and imagination."[4]

In the present paper I deal with the mutual interactions of chemical and mechanical theories in England in the second half of the seventeenth century, focusing on two main problems of 17th-c. physiology, namely, respiration and the composition of blood. These two subjects were part of Harvey's legacy and were investigated by English physiologists, including Francis Glisson, Walter Charleton, Thomas Willis and Robert Boyle, who formulated mechanical and chemical theories to account for physiology and performed a number of sophisticated experiments. The most famous being those made by Boyle with the air-pump. The Oxford Physiologists' experiments have been thoroughly studied by Frank, who insisted on the experimental research the Oxonians carried out in the 1650s and 1660s. However, Frank paid little attention to the Oxford physiologists' chemical theories and experiments. The Oxonians' research gave prominence to chemistry and was at variance with important aspects of Harvey's physiology. The function of respiration, according to Harvey, was refrigeration, namely cooling blood. The lungs have the function of expelling fuliginous vapours. Harvey also maintained that a vast amount of blood is brought to perfection in the lungs, but he did not expand on this subject. He rejected the idea that spirits, generated from air, were substances distinct from blood. He dismissed spirits as subterfuge of ignorance, as fac-totum that are adopted to explain all kinds of phenomena:

"With regards to spirits, there are many and opposing views as to which these are, and what is their state in the body, and their consistence, and whether they are separate and distinct from blood and the solid parts, or mixed with these. So it is not surprising that these spirits, with their nature thus left in doubt, serve as common subterfuge of ignorance. For smatterers, not knowing the causes, promptly say that the spirits are responsible (thus introducing them upon very occasion). And like bad poets, they call this deus ex machina on to their stage to explain their plot and catastrophe."[5]

[4] Boyle, *Works*, 12, p. 473. italics are Boyle's. *Hormetic* (from the Greek *ὁρμητικός*) means having the property of exciting (OED).

[5] W. Harvey, *Exercitationes duae Anatomicae*, 1648, pp. 66-7

Harvey's target was Fernel as well as the Paracelsians, who like Petrus Severinus (one of the most influential Paracelsians), put special emphasis on spirits, claiming (*Idea Medicinae,* 1571), that "ex spiritibus corpora produci et rursus in spiritus resolvi." Severinus maintained that spirits perform all the functions that traditional medicine attributed to the faculties of the soul: "spiritus sunt qui esuriunt &,,,, sitiunt, qui attrahunt, expellunt, concoquunt, consummunt, & omnes actiones naturales perficiunt."[6]. Severinus's spirits were adopted by most 17th-c. Paracelsians and were reinterpreted in chemical terms by van Helmont. Van Helmont rejected the traditional tripartition of spirits (natural, vital and animal spirits) and reduced them into one, the vital spirit, which he conceived as an alkaline volatile salt. In the *Ortus Medicinae* we find a detailed account of the chemical process generating the spirit of life. Van Helmont maintained that by means of a ferment operating in the stomach, food was transformed into what he called *cremor*, namely a highly volatile acid; this was in turn transformed into chyle - a substance rich of volatile salts.[7] In the liver chyle is turned into *cruor* (i.e., blood without spirit), which is imbued with a volatile alkaline salt. Finally, within the left ventricle of heart, vital spirit is generated from the volatile salt contained in *cruor* and by means of a local ferment.[8] It important to point out that, for van Helmont, the generation of vital spirits was not just a chemical process. Since spirits were the source of life, they ultimately depended on a divine illumination. Van Helmont's iatrochemistry had a strong impact on the physiological researches carried out in England in the second half of the seventeenth century, and in particular on the early works of Robert Boyle.

Harvey ruled out the four Aristotelian elements as well as the humours of traditional medicine, but he also rejected the chemical principles. He maintained that blood was the vital principle, the source of life; it is both matter and force.

Spirits made visible

From the 1650s, spirits and fermentation became central issues in post-Harveyan physiology. The impulse came from Francis Glisson, Regius Professor of Medicine in Cambridge. In *De Rachitide*, published in 1650, Glisson had recourse to spirits in order to explain the cause of rickets, whereas the traditional Galenical explanation of this disease was usually based upon humours and tempers. In *De Rachitide* Glisson claimed that tempers depended upon the quantity and activity of vital spirits. He claimed that the sluggish intestinal motion of spirits was the cause of the cold temper and, accordingly, of rachitism.[9] Glisson's adherence to iatrochemical ideas is attested by some of

[6] Severinus, *Idea Medicinae*, pp. 26; see also pp. 58 and 105.
[7] van Helmont, *Spiritus Vitae*, ¶12-14 and *Sextuplex digestio*, *OrtusMedicinae,* 1648, pp. 197-8 and 208-225.
[8] van Helmont, *Blas Humanum*, ¶ 24, ibid, pp. 183-184
[9] Glisson, *De Rachitide, sive morbo puerili*, London 1650, Engl. tr. by N. Culpeper *A Treatise of the Rickets*, London 1651, p. 43. This work was the outcome of Glisson's collaboration with G. Bate and A. Regemorter. Cf. E. Clarke, 'Whistler and Glisson on Rickets', *Bulletin of the History of Medicine*, 36 (1962), 48-9.

his manuscripts now in the British Library. Glisson's notes contained in MS. Sloane 3308 deal with the generation of spirits. After mentioning the Galenical theory that vital spirits are produced by natural ones implanted in the liver, he gave his own account:

"there is a natural spirit in all thinges that we eat and drinke, as the arte of chymistry clearly discovers in that it can extracte those spirits from these bodys... this spirit is not generated in the liver ... but is the same spirit which was before in the meate or drinkes..."[10]

In a manuscript entitled 'De causa vitalis spiritus' Glisson maintains that vital spirits are formed by means of fermentation, which brings about their rarefaction, heating, separation from the grosser parts of matter and purification. In *Anatomia Hepatis* (1654) Glisson unambiguously adopted chemical theories as the ultimate basis of physiology and medicine: humours – he stated - like all mixed bodies, were composed of the five chemical principles.[11] For Glisson, fermentation - that he described as a combat between the grosser components of blood and spirit - brings about the passage of spirits (originally contained in the food) from the state of fixation to that of volatility.[12]

Glisson put special emphasis upon the chemical composition of the blood and claimed that vital spirit was its more active component. This view deviates from Harvey's physiology. Harvey maintained that blood was the cause of circulation and rejected the theory that spirits made arterial blood different from the venous. Actually, Harvey did not discriminate between arterial and venous blood. By contrast, Glisson gave a major role to spirits, that he conceived as the vital principle, the productive cause of blood.[13] What was commonly called vital heat (calor vitalis) is the outcome of the action of spirits (i.e., the active and volatile parts of blood) on the grosser parts. For Glisson, spirits are subtle and volatile substances (*spiritus in distillatione primus ascendit*). Their origin is in food, where they are in a state of inactivity (*fixatio*). In the body spirits undergo a series of fermentative processes: they pass from the state of *fixatio* to that of *fusio* (they are free to move). Finally, when they reach the heart they are in the state of excitation. This is the outcome of circulation, that is not just a mechanical process, but also a chemical reaction, like the circulation of fluids in the alembic. For Glisson, the difference between venous and arterial blood is the outcome of the action of spirits.

Glisson's view of spirits as the vital principle in blood was adopted and developed by Thomas Willis and Walter Charleton.[14]

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[10] British Library, MS. Sloane 3308, f.132r.
[11] Glisson, *Anatomia Hepatis* (2nd ed. 1659), p. 37.
[12] Glisson, *Anatomia Hepatis*, p. 366
[13] Glisson, *Anatomia Hepatis*, p. 367. See R. French, *William Harvey's Natural Philosophy* (Cambridge, 1994), pp. 304-5.
[14] T. Willis, *Diatribae duae medico-philosophicae quarum prior agit de Fermentatione, sive de motu intestino particularum in quovis corpore, altera de Febribus, sive de motu earundem in sanguine animalium. His accessit*

Following Glisson, Charleton explained the origin of blood by the action of the vital spirit, which, according to him, is the outcome of a transformation of the spirits contained in food. But unlike Glisson and Charleton combined chemistry with the corpuscular theory of matter. He interpreted the five chemical principles in corpuscular terms. Though Charleton's medical works have received comparatively little attention, they testify to his adoption of iatrochemical views. The generation of vital spirits is the outcome of a series of chemical reactions: separation, sublimation, exaltation. As he put it in *Natural History of Nutrition* (1659):

"…this we conceive to be the true progress of Nature, from the first reception of the spirits contained in the Aliment, to their eduction into the Chyle, their sublimation in the heart, their gradual exaltation to the highest degree of volatility".[15]

The corpuscles of spirits are in constant movement, as they are endowed with an internal source of activity. In their "effort to expand themselves, and to dilate their bounds, while the other grosser elements, or ingredients of the blood, oppose them", the particles of the vital spirit produce the vital heat, as well as the contraction and dilatation of the heart.[16] According to Charleton, blood has two distinct movements: circulation and 'mication', namely a kind of vibration, that is produced by the vital spirits. Charleton went so far as to claim that the vital spirits communicate life and sensation to all parts of bodies.[17] Both Charleton and Glisson gave air a marginal role in the production of vital spirits.

Thomas Willis' *De fermentatione* was published in 1659, the same year as Charleton's work on nutrition. This tract was meant to be the introduction to his theory of fevers, which in fact he explained as the outcome of a vitiated fermentation of blood. Like Charleton, Willis combined chemistry and corpuscular philosophy, Willis' corpuscles were not endowed with mechanical properties, but with chemical ones. Willis extolled the mechanical philosophy as

"it undertakes mechanically the unfolding of things, and accommodates nature with working tools; as it were in the hand of an Artificer, and without running to occult qualities, sympathy, and other refuges of ignorance."

Dissertatio Epistolica de urinis (London, 1659); W. Charleton, *Natural History of Nutrition, Life and Voluntary Motion*, (London, 1659). See also H. Power, *Experimentall Philosophy* (London, 1664).

[15] W. Charleton, *Natural History of Nutrition, Life, and Voluntary Motion*, London 1659, p. 65. For an intellectual biography of Walter Charleton - which however does not investigate Charleton's iatrochemical ideas properly - see S. Fleitmann, *Walter Charleton (1620-1707),"Virtuoso". Leben und Werk* (Frankfurt, 1986).

[16] Charleton, *Natural History of Nutrition*, pp. 64-65.

[17] Ibid., pp. 53, 125.

Nonetheless, he cast doubts on the mechanical philosophy, preferring the chemical theories:

"but because it rather supposes, than demonstrates its principles, and teaches of what figure those elements of bodies may be, not what they have been, and also induces notions that are extremely subtle and remote from the sense, and that do not sufficiently conform with the phenomena of nature, when we descend to particulars, it pleases to me to give my sentence to the … opinion of Chymists… affirming all bodies consist of Spirit, Sulphur, Salt, Water and Earth." Their motions and proportions can explain "the beginnings and endings of natural things." [18]

Spirits, sulphur and salts are the active principles, while earth and water are passive. Spirits are the most active corpuscles, the agent of almost all the physiological phenomena investigated by Willis.[19] Particles of spirits, being endowed with activity, put grosser particles into motion and make them more active and subtle. In addition, they convert fixed salts into volatile ones, open earthy corpuscles and help them to combine with other kinds of corpuscles. Because of their **affinity** with the corpuscles of sulphur, spirits produce with them a sweet, stable and lasting compound, which is the main component of both vital and animal spirits and the agent of fermentation.[20] The vital spirits originate from a small particle of spirit, which is activated in the heart by a ferment and can keep blood in constant fermentation. Willis maintained that, when spirits are 'ripe' (moderately active), healthy constitution follows as a consequence; when they are exceedingly active - or, on the contrary, when they are sluggish - various kinds of pathological affection occurs. Like Glisson and Charleton, Willis gave a marginal role to air in the production of vital spirits. In 1670 Willis changed his view of spirits, adopting the theory of aerial nitre as the source of life and thoroughly investigated the chemical components of blood. The current research on nitre had provided him with new theories about vital heat. As a result, this was no longer interpreted as the outcome of fermentation, but as the consequence of the chemical reaction of corpuscles of nitre, contained in air, with the sulphurous ones contained in blood.

Respiration and the chemical composition of air

In 1654 the Oxford physician and divine Ralph Bathurst lectured on the use of respiration. His lectures contain a combination of chemical and mechanical theories and introduced a new line of inquiry, namely the investigation of aerial nitre as the vital principle contained in air - a topic which attracted the attention of numerous scientists, including Boyle, Willis and John Mayow. According

[18] Willis, *De Fermentatione*, 1659, p. 4.
[19] Ibid., p. 4
[20] Ibid., pp. 4-7.

to Bathurst, spiritus nitrosus, i.e., a volatile salt contained in air, was necessary to the life of plants and animals – not for the refrigeration of blood, but because it was the food of vital and animal spirits. Bathurst describes the way corpuscles of aerial nitre penetrate blood as a chemical process, similar to distillation:

"Spiritus hic nitrosus per branchias juxta positas illabens, sanguinem copiosus imbuat; non aliter fere quam in alembico illo tortuoso quod serpentinum vocant, liquor stillatitius per multas ambages ascendit..."[21]

Nitre, otherwise known as saltpetre (potassium nitrate) had a special place in practical chemistry and in the chemical philosophy. It was a reagent, it was employed to dissolve metals, for the preparation of fertilizers, medicines and gunpowder. Several chemical philosophers, notably Michael Sendivogius, saw nitre as the vital substance (of celestial origin) contained in the air. Bathurst and his fellow physiologists in Oxford rejected the old view that the use of respiration was refrigerating blood and carrying off fumes, and maintained that the use of particles of aerial nitre was to transform blood. Bathurst made aerial nitre integral part of the reinterpretation of pulmonary function and of the composition of blood. It is no surprise that aerial nitre became the focus of Oxford physiological investigations for nearly two decades and is of no little interest to examine Boyle's view of the nitre theory.

Bathurst's lectures spurred the research of John Mayow, a physician and a Fellow of the All Souls' College, first in *Tractatus duo* (1668) and then in the *Tractatus Quinque* (1674). Mayow maintained that aerial nitre is necessary to both combustion and respiration and discussed the composition of this volatile salt. Salnitrum – Mayow states – is composed of three parts, an extremely fiery and volatile acid salt (the aerial part – that could be identified as nitric acid), an alkaline salt (potassium carbonate), and a saline volatile salt (ammonium carbonate). He reached the conclusion that part of the air is necessary to combustion and that this part is present in nitre. The volatile component of nitre provides 'food for fire' and also passes into the blood of animals by respiration. This brought about Mayow's rejection of the idea of the supposedly omnipotent spirits, which he replaced with nitre. He unambiguously rejected spirit as an obscure notion:

"With regard to the spirit of the chemists, which usually leads their band of elements, I am quite unable to understand what they mean by the very grand word spirit."[22]

[21]T,. Warton, *The Life and Literary Remains of Ralph Bathurst* (London, 1761), p. 208. Cf. H. Guerlac, "John Mayow and the Aerial Niter", *Actes du VIIe Congrès International d'Histoire des Sciences* (Paris, 1954), pp. 332-349 and R.G. Frank Jr., *Harvey*, pp. 115-139; 221-245.

In order to avoid mistakes in the assessment of Mayow's theory of nitre, it is important to point out that John Mayow did not maintain that combustion occurred because some corpuscles of air combined with the combustible substance. He believed that spirit of nitre contained in air was consumed.

In 1668, the same year as Mayow published his *Tractatus duo*, Willis issued *Pathologiae Cerebri*, adopting the aerial nitre. He explained the origin of muscular motion by means of aerial nitre and maintained that muscular motion was produced by an explosion caused by the encounter of the spirito-saline particles of animal spirits - coming from the nerves - and the nitro-aerial ones contained in the blood.[23]

In *De Sanguinis Incalescentia* (1670) Willis developed the notion of nitre and presented a recantation of the theory he had earlier put forward in the *De Fermentatione*. In his work on fermentation Willis maintained that the heat of blood was generated by fermentation, namely, the motion of its component particles, which were activated by spirits. In his work of 1670 Willis denied that fermentation could produce heat in liquids. Having stated that fermentation was not the cause of the warming of blood, Willis suggested instead that heat was generated by the reaction of particles of nitre coming from air with those of sulphur contained in the blood.[24] Thus, in 1670 Willis had replaced undifferentiated and omnipotent spirits with nitre particles as the active component of air. Whereas in *De Fermentatione* Willis had seen the source of life in vital spirits (spirits + sulphur), in *De Sanguinis Incalescentia* he explained life as a flame without fire generated by nitre and sulphur. This flame he called the vital part of the soul of brutes.[25] Willis' abandonment of his former idea of spirit as the source of life can be explained by considering his concern to provide detailed accounts of the chemical processes occurring in the blood. The latter was a topic Boyle investigated for many years and dealt with in the *Memoirs for the History of Human Blood, Especially the Spirit of that Liquor* (1684).

Boyle on respiration

Boyle started his work on respiration and on the composition of blood at an early stage of his career. His investigations with the air-pump are well known and I will not refer to them in this paper. I want to call the attention on Boyle's investigations of respiration and blood. At the

[22] J. Mayow, *Tractatus Quinque* (Oxford, 1674), p. 48, Engl. tr.: *Medico-Physical Works*, (Oxford, 1926), p. 34.
[23] Willis, *Pathologie Cerebri*, in *Practice*, p. 3
[24]Willis, *De Sanguinis Incalescentia*, in *Practice*, pp 21-23.
[25]Willis, *Cerebri Anatome*, 1664, p. 134.

beginning of his career he became interested in nitre. In the late 1640s Boyle and other members of the Hartlib Circle prepared schemes for the artificial generation of nitre. His friend Benjamin Worsley wrote a tract on 'Saltpeter as the cause of life and vegetation', that circulated among the Hartlib circle. In the *The Usefulnesse of Natural philosophy*, published in 1663, but largely written in the early 1650s, Boyle - following van Helmont - maintained that the knowledge of the spirit of blood was crucial for both physiology and pharmacy.[26] In 1655 Boyle read Bathurst's lectures on respiration and wanted to have them published, but Bathurst did not agree. In 1654-56 Boyle wrote an *Essay on Nitre*, that he included in *Certain Physiological Essays* (1661). This essay is well known for it prompted a series of objections from Spinoza. Boyle stated that nitre is composed of two chemically distinct substances, of different nature, that can be obtained by chemical analysis. In his view, each of two components - and nitre itself - had distinctive chemical properties. Spirit of nitre is an acid spirit, "a kind of *Acetum Minerale*", fixed nitre "is of an Alkalizate nature and participates qualities belonging generally to lixiviate salts", finally, nitre - Boyle continues - "is a peculiar sort of salt, discriminated by distinct properties both from those salts, that are eminently acid…, and from those, that are properly alkalizate". The different natures of the two ingredients of nitre are recognized by their tastes and colours as well as by the chemical effects produced by their operations on the same bodies: those minerals that spirit of nitre dissolves, fixed nitre precipitates, those sulphureous bodies which fixed nitre dissolves, spirit of nitre precipitates.[27]

In the *New experiments about the relation betwixt flame and air, and particularly betwixt air and the flamma vitalis of animals* (1672) Boyle claimed that the so-called vital flame and the common flame are both maintained by distinct substances or parts of the air- but he was cautious about the nature of this component of air and the way it kept vital flame. I do not share Frank's view that Boyle was reluctant to establish the way vital flame depended on air because "[he] tended to conceive the role of the air in physical, rather than chemical terms."[28] Boyle thoroughly investigated the chemical properties of air and made experiments on the relationship between human blood and air. He rejected nitre as the vital principle of air because he deemed the chemical properties of spirit of nitre as incompatible with the role it was given by the Oxford physiologists.

Boyle on Blood and Air

Boyle started working on the *Memoirs for the History of Human Blood* in the 1660s, when he was in Oxford. As attested by extant notes, the stimulus to pursue a natural history of blood came from

[26] Boyle, , *Works*, 3, p. 386.
[27] Boyle, *Works*, 2, pp. 105-6.
[28] Frank, *Harvey and the Oxford Physiologists*, p. 255.

Locke, to whom Boyle addressed the Preface to the work. At the outset, Boyle adopted the chemical philosophers' stance, stressing the importance of chemistry to disclose was is not visible, but is hidden in bodies. He pointed out that current work on blood "consist much more of observations than experiments; being suggested far more by the phenomena that nature her self has afforded physicians, than by trials industriously made, to find what she will not, unsolicited by art, discover".[29] Boyle's main goal in this work was to establish, by chemical experiments, the compoition and properties of blood. In addition, he thoroughly investigated the chemical change produced by respiration in blood.

A look at some titles of the chapters shows Boyle's way to investigate blood, namely, combining research based on sense perception with more sophisticated chemical analysis:

1. Of the Colours of human blood, arterial and venal.

2. Of the taste of human blood

3. Of the odours of human blood

4. Of the heat of the freshly emitted human blood

6. Of the aerial particles naturally mixed with human blood

7. Of the specific gravity of human blood entire

8. Of the specific gravity of the two obvious parts of hman blood, the red (and fibrous) and the serous

11. Of the liquors and salts that coagulate human blood

13 Of the liquors that preserve human blood

15. Of the spontaneous or natural analysis of human blood into a serous and a fibrous part.

18. Of the artificial or chymical analysis of humane blood, and first to its spirits.

19. Of the volatile salt of human blood, and its figures

22. Of the fixed salt of human blood

24. Of the proportion of the differing substances chymically obtain'd from human blood

25. Of the fermentation or putrefaction of human blood[30]

Boyle's tract on blood was evidently a response to some of his Oxford colleagues' views on blood, air and respiration. He also dealt with the aerial nitre and its supposed role to keep life. Though Boyle paid special attention to fermentation, he was not convinced that one could explain most physiological processes as the outcome of fermentation, as Wiillis did in his tract of 1659. Boyle ruled out Willis' 'applauded' theory of fermentation as it was based on the analogy between blood

[29] Boyle, *Works*, 10, p. 5. Boyle states that he had suggested a physician to write a history of the fluid parts of the body, including of spirits. (Ibid., p. 6)

[30] Boyle, *Works*, 10, pp. 12-13

and other liquors, as for instance wine, which he did not accept: “I am not much encouraged to expect from human blood a vinous or ardent spirit – wrote Boyle – though that be the usual product of fermentation in liquors, and I am the less encouraged to expect this, because I am not sure that there is any fermentation truly and properly so called in human blood, either within, or out of the body...”[31]

The composition of blood was central to Boyle’s enquiry. He recorded that from the distillation of blood he had obtained, besides oily and phlegmatic parts, a clear liquor which, “though probably it contains some phlegm, might be called spirit, because it contains saline and volatile parts”. He pointed out that the spirit distilled from human blood was no simple and homogeneous substance. The distinctive aspect of Boyle's view of the spirit of human blood was his rejection of the chemical notion of spirit, as employed by Glisson, Charleton, Willis, among others. Boyle ruled out the chemists’ view that spirit was a simple and homogeneous substance as follows:

“As for what the Chymists call spirit, they apply the name to so many differing things, that this various and ambiguous use of the word seems to me no mean proof that they have no clear notion of the thing. Most of them are indeed wont to give the name of spirit to any distilled volatile liquor, that is not insipid, as is phlegm, or inflammable, as oil. But under this general term they comprehend liquors that are not only of a differing, but must be of, according to they principles, of a quite contrary nature.”[32] It was Boyle’s constant preoccupation to distinguish substances chemists were used to grouping together under the same name.[33] Boyle recognized two classes of spirits: acid ones, such as spirit of niter, spirit of salt and spirit of vinegar; and alkaline ones, such as spirit of urine, spirit of hartshorn and spirit of blood.

He argued that spirit of blood was a compound substance, whose chemical properties he was keen to investigate in details. Following van Helmont, Boyle stated that spirit of blood was alkaline volatile salt, having much in common with spirit of urine, of hartshorn, sal armoniac.[34] Boyle paid special attention to the relation between human blood and air, notably of spirit of blood with aerial nitre. He had no doubt that there was “a great cognation or affinity between spirit of blood and air.” This he inferred from the following experiment: he put some filings of copper in a vial, then he poured in some spirit of human blood. After stopping the vial, the solution “because of the quantity of air, that was contained in the vial, did within few hours acquire a rich blue colour; and this, after a day or two, began to grow more faint, and continued to do so more and more until it came to be almost lost.” Boyle went on to say that when he opened the vial he perceived that in a few minutes

[31] Boyle, *Works*, 10, p. 42.
[32] Boyle, *Experiments and Notes about the Producibleness of Chymical Principles*, *Works*, 9, p. 52
[33] Cf. A. Clericuzio, *Elements*..., p. 134.
[34] Boyle, *Works*, 10, p. 39.

the blueish colour reappeared. This colour, when the vial was stopped again, began again to fade away.[35]

Boyle, as we have seen, was keen to test the theory that aerial nitre was the source of life. He stated that the chemical properties of aerial nitre were not understood properly yet. In *General History of Air* (published posthumously in 1692), containing notes which he had been collecting for more than twenty years, Boyle came to the conclusion that spirit of nitre was not the vital part of the air. For Boyle, spirit of nitre was an 'exceedingly corrosive' substance, which could scarcely be conceived as 'refreshing to the nature of animals.' In addition, he conceived of spirit of nitre as an acid spirit, whereas he classified spirit of blood as an alkaline volatile salt. These two substances – he said - were of opposing natures.[36] For Boyle, there was 'hostility' between spirit of blood and acids, including spirit of nitre. This is attested by a number of experiments Boyle performed with spirit of human blood and spirit of nitre (or other acids) - that he recorded in the *Memoirs for the History of Human Blood*. He noticed that the two substances produced "a confused agitation accompanyed with bubbles...; great commotion, not only with froth, but with noise."[37] Boyle refrained from giving a mechanical explanation of this 'hostility' between spirit of blood and aerial nitre, he produced chemical experiments to investigate the properties of blood and of the substances he obtained by analysis. Boyle was cautious about the component of air responsible for life, as he believed that the experimental evidence he produced was adequate to question the view that aerial nitre was the vital principle contained in air, but was not able to establish what was the substance maintaining 'vital flame'. Boyle refrained from formulating general hypotheses on air and respiration, like those propounded by the Oxord physiolgists (especially Willis and Mayow). He also made little or no use of the contrivance of biological structures to explain physiological phenomena. Indeed, references to mechanisms of living bodies occurr in a number of Boyle's work, but he referred to them to stress the Artificer's admirable design, majesty and wisdom, rather than to explain 'animal oeconomy'.

[35] Boyle, *Works*, 10, pp. 62-63.
[36]Boyle, *The General History of Air*, *Works*, 12, p. 32.
[37] Boyle, *Works*, 10, p. 64.