Kant's dynamic theory of matter in 1755, and its debt to speculative Newtonian experimentalism

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Abstract

This paper explores the scientific sources behind Kant's early dynamic theory of matter in 1755, with a focus on two main Kant's writings: *Universal Natural History and Theory of the Heavens* and *On Fire*. The year 1755 has often been portrayed by Kantian scholars as a turning point in the intellectual career of the young Kant, with his much debated conversion to Newton. Via a careful analysis of some salient themes in the two aforementioned works, and a reconstruction of the scientific sources behind them, this paper shows Kant's debt to an often overlooked scientific tradition, i.e. speculative Newtonian experimentalism. The paper argues that more than the *Principia,* it was the speculative experimentalism that goes from Newton's *Opticks* to Herman Boerhaave's *Elementa chemiae* via Stephen Hales' *Vegetable Staticks* that played a central role in the elaboration of Kant's early dynamic theory of matter in 1755.

Keywords: Kant, repulsive force, ether, Newton, Hales, Boerhaave

1. Introduction

In 1786, in *Metaphysical Foundations of Natural Science,* Kant famously introduced attraction and repulsion as two fundamental forces in nature, within the context of his own defence of a "dynamical natural philosophy". The purpose of a "dynamical natural philosophy" is to explain natural phenomena in terms of "moving forces of attraction and repulsion originally inherent in them",[1] by contrast with the "mechanical natural philosophy" which "under the name of *atomism* or the

[1] Kant (1786); English translation (2004), p. 72.

corpuscular philosophy" retained its authority and influence from Democritus to Descartes. After having praised a "dynamical mode of explanation" as more conducive to experimental philosophy and to "the discovery of matter's inherent moving forces and their laws", Kant goes on to defend it by refuting what he calls the "postulate of the merely mechanical mode of explanation, namely, that *it is impossible to think a specific difference in the density of matters without interposition of empty spaces*".[2] There follows Kant's defence of the ether as a matter filling all space, but very subtle compared to the matter of ordinary bodies: "In the aether, the repulsive force must be thought as incomparably larger in proportion to its inherent attractive force than in any other matters known to us".[3]

The assumption of an ether endowed with repulsive force, as a way of refuting the postulate of empty space typical of corpuscular philosophy, may seem like a passing remark in the context of Kant's "General Remark to Dynamics". However, in this paper I contend that this assumption is the historical core of Kant's dynamic theory of matter, and the aim of this paper is to reconstruct the history of this assumption back to some pre-critical writings of 1755. Indeed, Kant's belief in the ether as endowed with repulsive force is an important leitmotiv in Kant's dynamic theory of matter, from *Physical Monadology* (1756) to *Opus postumum*.

In the *Opus postumum*, in the ix fascicle of "Towards an elementary system of the moving forces of matter", Kant introduces the ether as an "*originally* elastic matter" acting both as the matter of light and the matter of heat or "caloric (…) regardless of the fact that, in the latter condition, it is neither a fluid nor repulsive, but only makes fluid and expand their matter".[4]

The link between ether and repulsive force becomes explicit in a note on the left margin of sheet I of ix fascicle, where Kant says: "Repulsion can act as a superficial force, or as a penetrative force (but not one acting at a distance, like gravitation). In the latter case, the repulsion of all internal material parts of all bodies is heat. One could call the ether empyreal air (…) as an expansive matter whose penetration contains the ground of all the forms of air".[5] Given the central importance of Kant's proof of the ether in the *Opus postumum*, about which various Kantian scholars have

[2] Ibid., p. 73.
[3] Ibid. p. 73
[4] Kant (1936, 1938); English translation (1993), p. 33.
[5] Ibid., p. 33.

given different interpretive exegeses,[6] it is not irrelevant to investigate the historical origins and sources behind Kant's idea of the ether as endowed with repulsive force and as the matter of fire and light.

And the history of Kant's view of the ether takes us back to the very beginning of Kant's academic career. Indeed, as early as 1756, in *Physical Monadology* (written with the hope to get the vacant chair of Philosophy of his former teacher Martin Knutzen), Kant introduced some seminal ideas for his dynamic theory of matter that would prove central for his critical period. Not only did he introduce the two fundamental forces of attraction and repulsion; but he also expressly made repulsive force the cause of the elasticity of bodies, among whose "one may legitimately include ether, that is to say, the matter of fire".[7]

In this paper, I reconstruct the historical sources behind Kant's idea of an ethereal, all-pervasive, elastic matter as the physical seat of repulsive force, and hence of the elasticity of bodies. In particular, through an examination of both *Universal Natural History and Theory of the Heavens* (1755a), and of Kant's *Magisterarbeit On Fire* (1755b), I identify what I take to be an important—and so far overlooked —– scientific tradition behind Kant's dynamic theory of matter. Indeed, of the two fundamental forces of Kant's dynamic theory of matter, while attraction has been uncontroversially interpreted as borrowed from Newton's *Principia*, repulsive force betrays Kant's debt to another tradition, namely British and Dutch natural philosophy of the eighteenth century, which—with a firm footing in the Queries of Newton's *Opticks* (first Latin edition 1706; second English edition 1717)—–flourished in England with Stephen Hales' *Vegetable Staticks* (1727) and in Leiden with Herman Boerhaave's *Elementa chemiae* (1732) and Pieter van Musschenbroek's *Elementa physicae* (1734). The importance of this alternative experimental tradition can be found not only in Kant's analysis of repulsive force in the explanation of a variety of chemical and thermal phenomena in *On Fire*, but also in some key aspects of his cosmogony (1755a) as well as in his elaboration of causality, or better in its ancestor, i.e. Kant's principle of determining ground in *New Elucidation* (1755c), where again elastic matter is said to be the 'efficient cause' hidden within bodies.

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[6] It is not my purpose in this paper to discuss these interpretive exegeses. It suffices to mention that Förster (2000), ch. 4 criticizes a common interpretation of the ether proof in the *Opus postumum* as a way of explaining the possibility of particular properties of matter (such as cohesion) in favor of an analysis of the "ether (…) as a transcendental ideal in the critical sense" (ibid., p. 91).
[7] Kant (1756), English translation (1992), p. 66.

In this study, I explore the very idiosyncratic combination of three main sources behind Kant's early dynamic theory of matter: (I) the ether—borrowed from Newton's *Opticks*—as a *mechanical* medium for optical, thermal and chemical phenomena; (II) the repulsive force—borrowed from Stephen Hales' chymio-statical experiments—as inherent the ether and manifesting itself in the elasticity of airs and vapours; and (III) the identification of the weakly repulsive elastic ether with the matter of fire, following Herman Boerhaave's material theory of fire.

Accordingly, the paper is divided in six sections. In Section 2, I briefly revisit Kant's much celebrated conversion to Newton around 1755, by looking at a recent study by Martin Schönfeld on the philosophy of the young Kant. In Section 3, I focus on some salient aspects of Kant's *Universal Natural History* that in my view betray his divergence from the Newton of the *Principia* and his allegiance to the more esoteric and speculative Newton of the *Opticks.* To substantiate these claims, in Section 4, I give a survey of some salient aspects of speculative Newtonianism as developed by Stephen Hales' natural philosophy (to which § 4.1 is dedicated) and by Herman Boerhaave (§ 4.2). I argue that Newton's ether of the Queries of the *Opticks* as a matter of light (but also as a medium of heat and gravity) provided the blueprint for Hales' experiments on elastic airs, and I highlight Hales' debt both to Newton and to Boyle's corpuscular philosophy. In turn, the chemical role of Hales' elastic air influenced Herman Boerhaave's material theory of fire as a substance trapped in all bodies. Having clarified the conceptual link that goes from Newton's ether to repulsive force, and hence from Hales' elastic air to Boerhaave's material fire, in Section 5 I take a look at Kant's *On Fire*, with its exemplary idiosyncratic combination of Newton, Hales, and Boerhaave's views. In surprising continuity with the much later ether of the *Opus postumum* as Wärmestoffe, in *On Fire* Kant clarified the nature of the very subtle ethereal matter of *Universal Natural History*, as a weakly repulsive matter responsible for the elasticity of bodies, and identified it with the matter of both light and fire. In Section 6, I finally draw some concluding remarks about Kant's departure from Newton's physics and theology.

2. Revisiting Kant's conversion to Newtonianism

One of the key tenets of modern studies on Kant's philosophy of nature is his unwavering Newtonianism throughout his intellectual career.[8] In a recent study on Kant's philosophy in the pre-critical period, Martin Schönfeld[9] too subscribes to the received view, and reconstructs Kant's conversion to Newton around 1755. Indeed, in his very first work *Thoughts on the true estimation of living forces* (1747), there is hardly any mention of Newton, and Kant engaged instead with the ongoing debate on *vis viva* between the Leibnizians and the Cartesians. Schönfeld identifies the first signs of a conversion to Newton in two short essays of 1754 on the Earth's axial rotation and age. It is, in particular, in the essay on the Earth's diurnal motion that Newtonian attraction is for the first time identified as "the universal driving power of nature" and Kant does not avail himself of Cartesian vortices, because—according to Schönfeld—"vortices require an ether (…) but such a cosmic medium does not exist because Kant believes now that space is empty", or better space is "filled with matter, but with infinitely thin, and accordingly 'infinitely weakly resisting matter'. Although the words are similar in *Living Forces* and the *Spin Cycle*, they express greatly different views (…). Cosmic space may be filled with some remnants of matter or gaseous traces, but (…) we can treat this diffuse impurity of a mostly empty space as if it were a void. (…) Philosophically and literally, Descartes and Leibniz had dropped out of the picture".[10]

Schönfeld's explanation of Kant's conversion to Newtonianism is based on Kant's alleged rejection of the ether as a cosmic medium and his belief that cosmic space is empty, or better *as if* it were empty (despite remnants of 'infinitely weakly resisting matter'). Here below I am going to argue that that there is no reason why conversion to Newtonianism should be signalled by the rejection of the ether, *as if* the ether belonged to the exclusive province of Cartesian physics.

Schönfeld does acknowledge the possibility for Kant to convert to Newton and to endorse the ether.[11] Indeed, he refers not only to the molecular ether advocated in Kant's *On Fire* (1755b) but also to the ether of *Physical Monadology* (1756) in conjunction with Newton's early ether-related works (*Hypothesis* 1675; *De aere et*

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[8] See Adickes (1924); Friedman (1992a), (1992b); Laywine (1993).
[9] Schönfeld (2000).
[10] *Ibid.*, p. 80–2.
[11] *Ibid.*, p. 84.

aethere 1674, and the 1717 *Opticks*). But Schönfeld falls short of drawing any conclusion from this observation, and claims that since Newton neither defended nor ruled out the ether, the ether remained an open question. As far as Kant's use of the ether is concerned, Schönfeld observes that only with *Physical Monadology*, "Kant lifted the mystery of the ether. The ether was revealed as a determinate and derivative manifestation of the elementary attractive and repulsive forces".[12]

In the following two sections, I show that there is no "mystery of the ether" and that the role assigned to the ether in *Physical Monadology* (1756) is in continuity with the role assigned to it in the 1755 *Universal Natural History* and *On Fire*. Most importantly, I stress the crucial role that Newton's *Opticks,* more than Newton's *Principia,* played in the elaboration of Kant's early dynamic theory of matter in these two crucial works of 1755, and I highlight two other main scientific sources: (i) the 'chymio-statical' experiments of Stephen Hales; and (ii) Herman Boerhaave's theory of fire. Far from being a "derivative manifestation of attractive and repulsive forces", the ether of *Physical Monadology* as the medium of attractive and repulsive forces shows instead why Kant did not embrace Newton's absolute space as the *sensorium* of God. The role of substantival space is here taken up by the ether, and this is compatible with the fact that after all Kant did not subscribe to a "substantive relative space", as Schönfeld calls it.[13] In these early 1755 works, Kant still subscribed instead to a truly Leibnizian, relational conception of space, where the reality of space was reduced to the reality of attractive and repulsive forces *acting and being acted upon* by the ether, along the lines of Newton's *Opticks*. More precisely, Newton's *Opticks* offered the *ether* as the *mechanical medium repository of attractive and repulsive forces* to explain the elasticity of the air (as per Query 21 of *Opticks*)[14], the transmission of heat (Query 18), and the origin and continuation of heat in the sun and the stars (Query 11); while Stephen Hales' 'chymio-statical experiments' provided the main source of inspiration for Kant's repulsive force.

[12] *Ibid.,* p. 174.
[13] *Ibid.,* pp. 166–7.
[14] "And so if anyone should suppose that *Aether* (like our Air) may contain particles which endeavour to recede from one another (for I do not know what this *Aether* is) and that its particles are exceedingly smaller than those of Air, or even than those of Light: the exceeding smallness of its particles may contribute to the greatness of the force by which those particles may recede from one another, and thereby making that medium exceedingly more rare and elastick than Air", Newton *Opticks*, Query 21. Edition (1952), p. 352.

In the following Section 3, I am going to highlight some passages in *Universal Natural History* that in my view betray Kant's allegiance to Newton's *Opticks* and Hales' experiments on elastic airs. In Section 4, I take a closer look at the British and Dutch natural philosophy of the first half of the eighteenth century, to clarify some of its main themes and their legacy for Kant's theory of matter. Finally, in Section 5, I analyse Kant's *On Fire* to corroborate my interpretive analysis about the key role that this tradition of natural philosophy played for the young Kant.

3. *Universal Natural History and Theory of the Heavens*

Universal Natural History is certainly one of the most important Kantian texts of the pre-critical period. In it, Kant advanced the hypothesis of the origin of the universe from a nebula, in which primordial attractive and repulsive forces were at work. Kantian scholars have been unanimous in reading this 1755 text as the manifesto of Kant's conversion to Newton. The purpose of this paper is to clarify some aspects of Kant's much celebrated conversion to Newton. Kant's dynamic theory of matter has been for long time associated with Newton's *Principia*, with its introduction of repulsion and attraction. The association is fully justified and supported by the same structure of Kant's mature dynamic theory of matter as exposed in *Metaphysical Foundations of Natural Science*, whose chapter 3 follows closely Newton's *Principia* with its three laws of mechanics, as Friedman's analysis has clarified.[15] And yet, if we look at the history of Kant's own ideas, and how thirty years earlier he came to elaborate his embryonic dynamic theory of matter in *Universal Natural History*, we get a slightly different picture of his conversion to Newtonianism. The Newton that seemed to have inspired the young Kant in identifying attractive and repulsive forces in the constitution of the universe was not much the Newton of *Principia*, but rather the more speculative Newton of the *Opticks*, who in the Queries ruminated about the ether as the physical seat of gravity and about chemical reactions with salt of tartar and *aqua regia*. Thus, investigating Kant's early dynamic theory of matter around 1755 can help us gain a more complete and accurate picture of his much celebrated conversion to Newton. Indeed, the unequivocal signs that the *Principia* are not necessarily the main source of inspiration for *Universal Natural History* can be found already in the Preface:

[15] Friedman (1992b) and Introduction to the English translation (2004) of *Metaphysical Foundations.*

> I have applied no other forces than those of attraction and repulsion to the evolution of the great order of nature: two forces which are both equally certain, equally simple (…). They are both borrowed from the Natural Philosophy of Newton. The first is a law of nature, which is now established beyond doubt. The second, which is perhaps not demonstrated by the science of Newton with so much distinctness as the first, is accepted here only in that understanding of it which no one questions, namely, in connection with the finest dissolution of matter, as for instance in vapour.[16]

Mark the last sentence of this important passage: Kant is here claiming that the best evidence for repulsive force does not come from the demonstrative science of Newton, but instead from the "finest dissolution of matter, as for instance in vapour". In my view, this sentence contains the kernel of Kant's early dynamic theory of matter as far as repulsive force is concerned, and I will come back to it and to its underlying sources in detail in Section 4. Indeed, Kant's divergence from the Newton of *Principia* can be found in his unorthodox use of the repulsive force for a quasi-mechanical explanation of the formation of planets.[17] Or better, it can be found in his unorthodox use of Newtonian forces of attraction and repulsion at work in the vortex mechanism of *Universal Natural History*.

Despite the emphasis on Newton's gravitational attraction as an original force lumping the primordial matter of the nebula to form planets and stars, Newtonian attraction per se is not sufficient to explain the origin of heavenly bodies, and by itself it would throw the world into chaos "unless the regularly distributed forces of rotation formed a counterpoise or equilibrium with attraction". It is then the combination of Newtonian attraction and of what, few lines below, Kant calls "the mechanical consequences of the general laws of resistance"[18] that explains the formation of heavenly bodies out of whirling primordial matter. The other force responsible for the formation of heavenly bodies is indeed the repulsive force, whose main role is to counterbalance the attractive force, and make the fine ethereal matter whirl in

[16] Kant (1755a), English translation (1968), p. 23.
[17] I analyse the quasi-mechanical (echoing Leibniz's *Tentamen*) explanation of the formation of planets in *Universal Natural History* in a paper co-authored with Silvia De Bianchi (in preparation).
[18] Kant (1755a), English translation (1968), p. 67.

vortices. Kant does not expressly speak of ether in *Universal Natural History*; instead in continuity with the 1754 essay on the Earth's axial rotation, he talks of a "fine stuff" diffused in celestial space. However, given the role of this fine matter as the repository of the repulsive force, and given the analysis of repulsive force that we shall see shortly, it is legitimate to identify the fine matter with an ethereal elastic medium. But how can the repulsive force, jointly with the attractive one, make the ethereal fine matter whirl?

Kant says that both attraction and repulsion are borrowed from Newton's natural philosophy. However, as mentioned above, by contrast with attraction, Kant claims that repulsion has not been demonstrated by the science of Newton, but it is accepted mainly on the basis of evidence coming from phenomena such as the dissolution of matter in vapours: "This force of repulsion is manifested in the elasticity of vapours, the effluences of strong smelling bodies, and the diffusion of all spirituous matter".[19] And references to changes of physical state from solid to gaseous feature prominently in the explanation of Saturn's rings, for example. What is the main source for Kant's repulsive force? Why does Kant say that Newton could not demonstrate repulsive force, and that the best evidence for it comes from "spirituous substances"? This could be a simple methodological remark. While Newton's analysis—the method of making experiments and observations and drawing conclusions by induction, as displayed in the *Opticks*—identified two fundamental forces in nature (attraction and repulsion); Newton's synthesis—the opposite method of starting from causes as established principles and deducing phenomena from them—as paradigmatically displayed in the *Principia*—could not mathematically derive from the two forces of attraction and repulsion all thermal, optical and other phenomena.

To reinforce this methodological remark concerning the limits of Newtonian synthesis in the *Principia* is the privilege that Kant seems to accord to Newtonian analysis as paradigmatically displayed in the *Opticks*, and especially in the speculative experimentalism of the Queries. Indeed, the best evidence for repulsion does not come from Newtonian mechanics (despite repulsion appearing already in the Preface to the I edition of *Principia*), but instead from the speculative Newtonian experimentalism of the Queries, especially in the re-elaboration of a British natural philosopher such as

[19] Ibid., p. 64.

Stephen Hales, as we shall see in the next section 4. But before I go on to substantiate this claim, let us proceed with order and take first a look at some important themes of *Universal Natural History*.

The discussion of repulsive force in Kant's *Universal Natural History* is not only central to his analysis of nebular vortices in the constitution of planets. It is also a key element for his analysis of: (i) comets; (ii) Saturn's ring; and (iii) solar heat. This is a particularly interesting area to analyse the nature of Kant's debt to the Newtonian tradition. Cometography was a popular topic at the time. Not only did Newton resort to the great eccentricities of comets to rebut Leibniz's fluid vortex theory; but, after him, Newtonians such as de Maupertuis in the 1732 *Discours* expressly used comets to explain the origin of Saturn's satellites and ring.[20] So, when in the Second Part, Third Chapter of *Universal Natural History*, Kant takes up the issue of explaining both the eccentricity of the orbits of planets and the origin of comets, he is not only engaging with a well-established Newtonian literature, but he is also trying to find his own feet in it.

Kant seemed to be at pain to explain how the "free circulatory movements of the primitive matter" require a modification to account for the eccentricities of planetary orbits. Perhaps he felt that Newton's argument from comets applied to Leibniz's fluid vortex as much as it applied to his own dynamic theory of matter (with its counterbalance between attraction and repulsion)[21] at work behind the circulatory movements of primordial matter. And since these circulatory movements in turn engendered planets' axial rotations as well as their rotations around the Sun, in the "systematic constitution" of the universe, Kant felt the need to address Newton's argument from comets.

In order to explain the eccentricities of both planetary orbits and comets, he had to "limit the hypothesis of the exact circular movement of the particles of primitive matter" so as to "allow a wider divergence from it, the more distantly these elementary particles have floated away from the Sun. (…) and the resistance of the

[20] Maupertuis (1732) explained Saturn's ring as originating from the tail of a comet attracted by Saturn, while Saturn's satellites would be the bodies themselves of the comets captured in the same way.

[21] In a paper co-authored with De Bianchi, I clarify how Kant's use of centrifugal and centripetal forces latches onto Huyghens and Leibniz, in their use of these two opposite forces to explain planetary motion. But by contrast with both the mechanical explanation of Huyghens and Leibniz (which ultimately relied on a fluid ether) and by contrast also with Newton (who considered centrifugal force as simply opposite the centripetal one), Kant tried to give a dynamical grounding to these two forces in terms of attraction and repulsion.

nearer portions of this primitive matter (…) diminishes in the proportions in which these nearer particles move away under it".[22] At large distances from the centre of the solar system, attractive and repulsive force are feeble as the particles become rarer and lighter; and this would explain the eccentricities of both planetary orbits (with the exception of Mars and Mercury which are closer to the Sun) and comets, which form out of the lightest particles in the most remote regions of space.

It is because of their constitution out of the lightest particles in the most remote regions of the solar system that comets present the "vapour heads and tails by which they are distinguished from other heavenly bodies. The dispersion of the matter of comets into vapour cannot be attributed mainly to the action of the heat of the Sun: for some comets scarcely reach as near the Sun as the distance of the Earth's orbit".[23]Thus, contra Newton, Kant explicitly defended his own view of comets as consisting of 'vapours' of infinitely weak repelling primordial matter, which would also explain their great eccentricities.

This explanation proves expedient to clarify in the following Fifth Chapter the origin of Saturn's ring. Like Maupertuis, Kant too defended the "comet-like nature" of Saturn's ring.[24] But, once again, we should not be misguided by the *prima facie* Newtonianism of this claim. While for Maupertuis, Saturn's ring was a comet tail that—by falling into the sphere of attraction of Saturn—was captured by it; for Kant, Saturn's ring originated from the very same "comet-like" vaporous state or "cometic atmosphere" consisting of the lightest and weakly resisting particles, which arose from the planet surface, and continued to float around it in virtue of the momentum impressed by Saturn's axial rotation. To support his view, Kant discussed Cassini's observations about the period of diurnal rotation of Saturn and the ensuing ratio of gravitational and centrifugal force determining its spheroidal shape, to conclude against Newton's hypothesis of uniform density, that the planet must have a varying density, increasing towards the centre and with the lightest particles arising from its surface.[25]

The varying degrees of density are in turn used by Kant to explain the problem of the origin of solar heat in the Addition to the Seventh Chapter. This section is one of the most intriguing of the whole essay, because Kant speculated about the origin

[22] Kant (1755a); English trans. (1968), p. 85.
[23] *Ibid*., p. 89.
[24] *Ibid*., p. 102.
[25] *Ibid*., p. 110.

and continued activity of the solar heat. In continuity with his previous analysis, Kant claimed that the Sun was a mixture of light and heavy particles, with a higher percentage of light particles (which are always abundant at the centre of the solar system). This would explain why the Sun has a density four times less than the Earth, and it would also explain why the Sun is a "flaming body and not a mass of molten and glowing matter heated up to the highest degree".[26] Indeed, Kant claimed that lighter, volatile, infinitely weakly resisting particles were the "most active in maintaining fire",[27] and their higher percentage in the central body of the Sun would cause the Sun to become a "flaming", "self-active" ball. And here it comes the most intriguing part of the story, about the nature of these lighter particles. Because they are active principles of fire, and because "no fire burns without air",[28] Kant concluded that there must have been air trapped inside the Sun; indeed, there must have been "elastic air" capable of "maintaining the most violent degrees of fire". And while the action of the Sun's fire consumes and burns "the elasticity of the atmosphere of the Sun", at the same time—to explain the self-activity of the Sun—Kant latched onto the experiments of Stephen Hales to claim that "fire also generates air by the decomposition of certain kinds of matter (…), we may suppose that in the bowels of the Sun there are many substances which, like saltpetre, are inexhaustible in yielding elastic air, and thus the fire of the Sun may be able to go on through very long periods without suffering in any considerable way from want of the accession of always renewed air".[29]

Two main points are worth noting here:

(I) Against the emerging geophysical studies view that all planets and the Sun originated from a hot molten state that gradually cooled down, Kant defended the idea of the Sun's self-activity, which would soon prove outmoded with the emergence of the idea of irreversibility at the beginning of the nineteenth century.

(II) The self-activity of the Sun is based on Kant's surreptitious identification of the lighter, weakly resisting particles with the elastic air as the matter of fire.

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[26] Ibid., p. 147.
[27] Ibid., p. 145.
[28] Ibid., 147.
[29] Ibid., p. 149.

And while the identification of light, weakly repulsive ethereal matter with elastic air betrays Kant's debt to Newton's *Opticks*, as we are going to show in Section 4, the emission of elastic air by decomposition of mineral substances such as saltpetre, is explicitly traced back to Stephen Hales' chymio-statical experiments in *Vegetable Staticks* (§ 4.1); whereas the further identification of elastic air with the matter of fire betrays Kant's debt to Herman Boerhaave's theory of fire, as I show in § 4.2 and 5, when I discuss Kant's essay *On Fire*. Therefore, in order to better appreciate the sources behind Kant's early elaboration of a dynamic theory of matter in 1755, we need to turn our attention to them. Once we have clarified some of the salient themes of the speculative experimental Newtonianism that goes from the *Opticks* to Boerhaave via Hales, can we be in a better position to appreciate Kant's pre-critical writings of 1755, in particular *On Fire*, with its idiosyncratic blend of these three main sources.

4. Kant reader of Newton's *Opticks*, Hales' *Vegetable Staticks*, and Boerhaave's *Elementa chemiae*

Newton's philosophy of natural science has been the subject of important studies that in various ways have illuminated its complex and multifaceted nature. Despite the "hypotheses non fingo" of *Principia*, Isaac Bernard Cohen[30] in his monograph on the legacy of Newtonianism for theories of electricity in the seventeenth century, has re-evaluated the importance of the hypothesis of the ether, within the methodological framework of speculative experimentalism typical of the Queries of *Opticks*. Through a careful historical analysis of the sources available at the time (especially scientific lexicons), Cohen has concluded that the *Opticks* (much more than the *Principia*) influenced generations of British and Continental natural philosophers throughout the eighteenth century. One of the distinctive features of the *Opticks,* especially evident in the Queries, is Newton's speculation about the ether as the medium for a variety of optical, thermal and electric phenomena, by contrast with the first edition of *Principia.*

Newton was not in fact new to the hypothesis of the ether. In his early years, before the *Principia,* he had already speculated about an ethereal medium responsible

[30] See Cohen (1956).

for electricity, gravitation, and optical phenomena. In a famous letter to Boyle on 28 February 1678/9, he even ventured an explanation of gravity in terms of different ethereal densities, which re-appeared again in *De aere and aethere.* Newton's letter to Boyle was first published in Thomas Birch's (1744) edition of Boyle's works, and by the mid-eighteenth century, mainly thanks to the enormous influence of the *Opticks* in the meantime, Newton's speculations on the ether were no longer regarded as simple speculations: they became an essential part and parcel of Newtonian natural philosophy.

In this section, I draw on a well-established secondary literature to survey briefly some of the salient points of speculative Newtonian experimentalism that thrived in England and in the Netherlands, with particular reference to Stephen Hales (§ 4.1) and Herman Boerhaave (§ 4.2). I also look at the primary sources of *Opticks* and Hales' *Vegetable Staticks* to back up my previous claim that Kant's unorthodox use of attraction and repulsion in *Universal Natural History* betrays his debt to this tradition of speculative experimentalism more than to the *Principia*. In this way, the following discussion paves the way to the final part of this paper (§ 5), where we encounter again some of the themes of speculative experimentalism, in an even more paradigmatic form, in Kant's essay *On Fire* (1755b).

In a monograph on British natural philosophy in the eighteenth-century, Robert Schofield introduces a distinction between what he identifies as two main traditions: mechanism and materialism.[31] According to mechanism, the causes of all phenomena have to be found in particles and in their attractive and repulsive forces. According to materialism, on the other hand, the causes of all phenomena have to be found in a unique substance, the ether as a substantial medium of heat, electricity, vital spirit, etc. Both traditions originate from Newton's *Opticks*, in particular the Latin edition of 1706 and the second English edition of 1717, with the new sets of Queries (Qu. 17-23 added to the Latin edition, and 24-31 added to the second English edition). In particular, Query 31, with its discussion of the ether and chemical speculations about salts, had a direct influence on the development of what Schofield called the materialistic culture of the first-half of eighteenth-century natural philosophy; while Queries 20–23, with their speculations on phenomena due to attraction and repulsion (from gravity, to electricity, from evaporation, to

[31] Schofield (1970).

fermentation and elasticity) largely inspired the mechanical tradition of natural philosophy, which, as Schofield presents it, is instead the natural consequence of Boyle's and Newton's dynamic corpuscolarity.

It was mainly via John Keill's *Introductio ad veram physicam* (translated into English in 1720 as *Introduction to Natural Philosophy*) that the Boyle–Newton dynamic corpuscolarity spread as the official academic credo.[32] Although Keill did not mention the ether or repulsive force, he was the first one that in a 1708 paper for the *Philosophical Transactions 26,* latching onto Queries 23-24 of the *Opticks,* suggested that the principles of dynamic corpuscolarity could be usefully applied to explain the ascent of sap in plants and trees, opening in this way the door to Stephen Hales' subsequent work,[33] to which I now turn.

4.1 Stephen Hales on 'elastick' repelling air: in between Boyle and Newton

Stephen Hales' *Vegetable Staticks* (1727) brought the Boyle–Newton dynamic corpuscolarity to the next level, making full use of attractive and repulsive forces for the explanation of vegetable, animal, and mineral fermentation processes. Stephen Hales was a central figure of British natural philosophy of the first half of the eighteenth-century. His primary research interests were plant physiology and medicine (his other book, *Haemostaticks,* 1733, influenced a new generation of Oxford and Cambridge iatro-chemists including John Friend and James Keill, the brother of John Keill). *Vegetable Staticks* had a great resonance also in the Continent,[34] where it was soon translated in French by Buffon, and from the French into German in 1748 with a Preface by Christian Wolff. Kant had in his library a copy of this 1748 German edition (Warda 1922: 03012. Exemplar: <4> IX B 1169 m.); and, no wonder references to Hales' *Vegetable Staticks* feature prominently in all Kant's works of 1755 (*Universal Natural History, New Elucidation, On Fire*). So, we should try to clarify some salient aspects of Hales' work that influenced the young Kant. As we shall see here below, there is an important theme that runs from Newton's *Opticks,* via Hales' *Vegetable Staticks,* to Boerhaave's *Elementa chemiae*

[32] Not only had Kant in his library a copy of the Leiden 1739 edition of Keill's Latin textbook (Warda 1922: 05019. Exemplar <1a> FR/MV 9407), but he also explicitly refers to Keill in the geometrical proof of the infinite divisibility of space in *Physical Monadology*.
[33] See Schofield (1970), p. 42-3.
[34] See Guerlac (1951).

(1732), and that provides—if my analysis is correct—the background for Kant's early dynamic theory of matter around 1755.

In Chapter 6 of *Vegetable Staticks*, Hales latched onto Boyle's experiments on the production of air from the fermentation of "Grapes, Plums, Gooseberries, Cherries, and Pease".[35] He used an experimental device consisting of a small retort connected to a glass vessel with a hole at the bottom and immersed in a large vessel of water. By placing the retort (containing different kinds of vegetable or mineral substances) on a stove, Hales could observe the effects of combustion, with the "expansion of the Air and the matter which was distilling". Hales could measure—through the changing level of water rushing through the hole—the quantity of air either absorbed or released via the fermentation of vegetable or mineral substances. The long series of very detailed experiments that occupy Chapter 6 are meant to provide a proof for Newton's analysis of air absorption and release as explained in Query 31 of the *Opticks*, where Newton claimed that "true permanent Air arises by fermentation or heat, from those bodies which the chymists called fixed, whose particles adhere by a strong attraction, and are not therefore separated and rarified without fermentation. Those particles receding from one another with the greatest repulsive force, and being most difficultly brought together, which upon contact were most strongly united".[36]

Indeed, in Query 31 of *Opticks*, Newton famously advocated attractive and repulsive forces as two fundamental Qualities in nature, whose causes were however unknown. Evidence for them comes from chemical reactions such as Salt of Tartar (potassium carbonate) attracting the "water which float in the Air in the form of Vapour", or *Aqua fortis*—i.e. solution of nitric acid obtained by distilling at high temperatures vitriol (sulphuric acid), saltpetre (potassium nitrate), and sand—dissolving iron filings and liberating their particles into water. Newton believed that all bodies abound more or less with oily sulphuric particles and that those particles were so attractive to be responsible for optical phenomena such as reflection, as well as for the different refractive indexes of bodies. Moreover, "sulphureous Steams abound in the Bowels of the Earth and ferment with minerals and sometimes take fire with a sudden Coruscation and Explosion" as in mines.[37] From these various

[35] Hales (1727); English translation (1961), p. 89.
[36] Ibid., p. 94-5. Quoted *verbatim* from Newton, *Opticks*, Query 31, ed. (1952), p. 396.
[37] Newton, *Opticks*, Query 31, ed. (1952), p. 379.

examples, Newton drew the following conclusion about fundamental principles in nature:

> Seeing therefore the variety of Motion which we find in the World is always decreasing, there is a necessity of conserving and recruiting it by active Principles, such as are the cause of Gravity, by which Planets and Comets keep their Motion in their Orbs, and Bodies acquire great Motion in falling; and the cause of Fermentation, by which the Hearth and Blood of Animals are kept in perpetual motion; (…) the Caverns of the Earth are blown up, and the Sun continues violently hot and lucid, and warms all things by his Light.[38]

If attraction, or better the "cause of Gravity", is one of the fundamental principles, what is the other principle, i.e. the "cause of Fermentation", animal heat, natural explosions, and the Sun's heat? It is at this point of Query 31 that in addition to attraction, Newton introduces repulsion, whose evidence for comes from "the Production of Air and Vapour. The Particles (…) are shaken off from Bodies by Heat or Fermentation, so soon as they are beyond the reach of the Attraction of the Body, receding from it, and also from one another with great strength".[39] And he refers implicitly to Boyle's discussion of "Particles of Air to be springy and ramous, or rolled up like Hoops" to conclude critically that none of these ingenious mechanical hypotheses could explain the vast contraction and expansion of aerial particles—'fixed' or released from bodies—unless we assume "a repulsive Power".[40]

We can now better appreciate why in the Preface to *Universal Natural History* Kant says that repulsive force "is accepted here only in that understanding of it which no one questions, namely, in connection with the finest dissolution of matter, as for instance in vapour".[41] This is precisely the way Newton introduced repulsive force in Query 31 of *Opticks*, and also the way in which repulsive force entered in the common vocabulary of British natural philosophy in the first half of the eighteenth century. And more than anyone else, it was Stephen Hales, who by building up on Newton's chemical ruminations in the *Opticks*, picked up on the theme of repulsive

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[38] *Ibid*., p. 399
[39] *Ibid*., p. 395.
[40] *Ibid*., p. 396.
[41] Kant (1755a), Engl. trans. (1968), p. 23.

force at work in vapours, fermentations, and animal heat to bring the discussion to the next level.

The theme of a repulsive force at work in chemical reactions (especially those involving combustion or fermentation processes) became central to Stephen Hales' work. He was the first one that building up on Newton, theorised the 'elasticity' of the air—due to highly repelling air particles—normally 'fixed' by strongly attracting sulphureous oily particles (which would allegedly abound in all bodies) and lodged among the pores of all animal, vegetable, and mineral substances. So, going back to Hales' aforementioned experiments, their purpose was to use water displacement in the sealed bolthead (upon fermenting various substances in the retort), in order to quantify the amount of air released or absorbed in each process. I want to draw attention to three main points of Hales' experiments in Ch. 6 of *Vegetable Staticks*, which will hopefully clarify both the continuity with the Boyle–Newton tradition of dynamic corpuscolarity, as well as the influence that Hales' himself exercised on another central figure of the time, i.e. Herman Boerhaave and the Leiden school of medicine.

First, through these experiments, Hales meant to defend and champion Newton's idea of particles of elastick air being 'fixed' in animal, vegetable and mineral bodies, and released upon combustion and fermentation. And yet, Hales is more radical than Newton in defending the elastick, weakly repelling state of aerial particles. In fact, if anything, we find significant traces of Boyle in Hales' view of elasticity, in relation this time to saltpetre and gunpowder explosions. By latching onto Boyle's experiments on nitre,[42] Hales noted that *Aqua fortis* poured on a solution of salt of tartar "did not shoot into fair crystal of salt-petre, till it had been long exposed to the open air; whence he suspected that the air contribution to that artificial production of salt-petre".[43] This is the reaction whereby the corrosive nitric acid (HNO_3—known at the time as *Aqua fortis* or 'spirit of nitre') combines with potassium carbonate (K_2CO_3—known as "salt of Tartar") to produce potassium nitrate (KNO_3—or saltpetre), which is a fundamental component of gunpowder. And interestingly enough, Hales provides a speculative explanation of the "intense burning of Fire" and explosions in terms of quantity of elastic aerial particles present in various substances. Thus, 'spirit of Nitre' has little elastic air in it, and indeed, if

[42] Hales quotes Boyle, Vol. I, p. 302 and Vol. III, p. 80.
[43] Hales (1727). Edition used (1961), p. 103.

poured on coals, it dies out; but when mixed with salt of tartar, it is reduced to nitre, and will flame, if thrown in the fire, because salt of tartar abounds with elastic aerial particles. If this point illustrates well, I think, Hales' debt to Boyle's experiments, on the other hand, Hales owed a debt to Newton's hypothesis of the ether too.

It is true that in Chapter 6 of *Vegetable Staticks*, we hardly find any reference to the ether.[44] And yet, there is one passage, which also Schofield notices, where Hales explicitly quotes both Query 18 and Query 21 of the *Opticks*, in assuming that sulphur and air are acted by "that ethereal medium 'by which (the great Sir Isaac Newton supposes) light is refracted and reflected, and by whose vibrations light communicates heat to bodies'. (…) And is not this medium exceedingly more rare and subtle than the air, and exceedingly more elastick and active?'".[45] I do not think that this reference to the ether is marginal. The repelling elastic air of Hales is indeed perfectly consonant with Newton's ether as the repository of repulsive force, and as the medium of both light and heat, as per Query 18 of *Opticks*.[46] Moreover, if we consider that by the time Kant picked up on Hales in 1755, Newton's famous letter to Boyle in 1678/9 about the ether had been published by almost 11 years (in 1744 with Thomas Birch's edition of the *Works* of Boyle), and that—as Schofield also points out—this edition helped reinstating the ether hypothesis, we can easily see that—from the point of view of the young Kant writing in 1755—there should have been a small step from Newton's elastic and repelling ether (medium of light and heat) to Hales' ether (medium of 'elastick' repelling air and sulphureous attracting particles). The central interpretive hypothesis of this paper is that the young Kant, in his pre-critical writings of 1755, was following Hales' path and exploring possible ways to expand on it via his dynamic theory of matter.

No wonder then Kant mentioned Stephen Hales in *Universal Natural History*, where he speculated about the bowels of the Sun abounding of substances such as

[44] Robert Schofield (1970) classifies Hales under the mechanical tradition of Newton's attractive and repulsive forces, and contrasts him with the materialism of Herman Boerhaave's theory of fire, according to which fire would be an elemental substance. According to Schofield, not only did Hales believe that the heat of fire was a mechanical "brisk vibrating action and reaction between the elastick repelling air, and the strongly attracting acid sulphur" (*ibid*. p. 77); he did not either support the hypothesis of the ether, which was a stronghold of materialism.

[45] Hales (1727). Edition used (1961), p. 162.

[46] "Is not the Heat of the warm room conveyed through the *Vacuum* by the vibrations of a much subtiler Medium than Air, which after the Air was drawn out remained in the *Vacuum*? And is not this Medium the same with that Medium by which Light is refracted and reflected, and by whose vibrations Light communicates Heat to Bodies, and is put into Fits of easy Reflexion and easy Transmission?" Newton *Opticks*, Query 18, ed. (1952), p. 349.

saltpetre that could release enough elastic air to aliment the combustion inside the 'flaming' Sun. And references to Hales' experiments on gunpowder feature also prominently in *New Elucidation* (1755c) to back up Kant's principle of causality, or determining ground. Indeed, in Proposition X of *New Elucidation*, where Kant exposes some corollaries of the principle of determining ground such as "(1) *There is nothing in that which is grounded which was not in the ground itself*", as an illustration of this corollary, Kant mentions once again Hales' experiments on elastic air and fire:

> Very frequently we see enormous forces issue from an infinitely small initiating cause. How measureless is the explosive force produced when a spark is put to gunpowder? (…) In these cases (…) the efficient cause of the enormous forces is a cause that lies hidden within the structure of bodies. I refer namely to the elastic matter either of air, as in the case of gunpowder (according to the experiments of Hales), or of the igneous matter, as is the case with all inflammable bodies whatever. The efficient cause is, in these cases, unleashed, rather than actually produced, by the tiny stimulus. Elastic forces which are compressed together are stored within; and if these forces are stimulated just a little, they will release forces which are proportionate to the reciprocal pressure exercised in attraction and repulsion.[47]

Thus, Kant's very same criticism of Leibniz's principle of sufficient reason in *New Elucidation* and its substitution with a new principle of determining ground can be regarded as informed once again by the young Kant's scientific interests in speculative Newtonian experimentalism, no less than by his Pietist background, as Eric Watkins have persuasively argued.[48]

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[47] Kant (1755c). English translation (1992), p. 33.

[48] Watkins (2005), ch. 2, nicely reconstructs the philosophical background of the young Kant's work on the metaphysics of causality in *New elucidation*, in particular the influence of both his teacher Martin Knutzen and of the other leading exponent of the Pietist movement, Crusius, in their attack against Leibniz-Wolff's principle of sufficient reason and pre-established harmony. However, Watkins argues, the final result is Kant's elaboration of a metaphysics of causality that is equidistant from Wolff's pre-established harmony and Crusius' physical influx theory. Kant rejected the Leibnizian-Wolffian distinction between derivative active and passive forces and in particular, the "Wolffian idea that active forces could be understood as grounds of changes" (p. 123), in favor of a physical monadology, where points are physical and endowed with attractive and repulsive forces. But he also rejected Crusius' physical influx view of causality as emanating from the mere existence of substances. Instead with his new principle of determining ground, by endowing physical particles with attractive and repulsive

To sum up and conclude this subsection, Kant's idea of repulsive force at work in the production of airs and vapours is deeply rooted in Newton's *Opticks*, and in the ensuing tradition of speculative Newtonian experimentalism of Stephen Hales, as opposed to the rigorous mathematico-deductive method of the *Principia*. As we have showed in this section, Kant's claim in *Universal Natural History* that Newton could not prove repulsive force and that the best evidence came from vapours and fermentation processes clearly betrays, in my opinion, his allegiance to the tradition of 'chymio-statical' experiments of Hales.

We saw also how the elasticity of the air, due to repulsive force and chemically 'fixed' in bodies, can be released via combustion and fermentation, and how both in Newton's Queries and in some passages of Hales, the ethereal medium is considered not just as the medium of light but also as the medium of heat and fire as well as the medium for the action and reaction of elastic repelling particles and sulphureous attracting ones. This remark is important because in another significant pre-critical work of this period, *On Fire,* Kant defended once again the idea of an elastic ether as the matter of both *light* and *fire*. And I would like to make the point that the materiality of fire that we still find in Kant's *On Fire* is just the natural consequence of the material ether of Newton's Queries, via its re-elaboration through Hales' chymio-statical experiments *and* via Herman Boerhaave's theory of fire.

Indeed, as Schofield rightly notes, "physicians were, for the next half-century, to carry much of the burden in Britain of developing a materialistic experimental natural philosophy".[49] This is mainly down to the enormous influence that Herman Boerhaave's materialistic theory of fire, as opposed to the Bacon–Boyle–Newton's overall non-materialistic theory of fire,[50] played in the advent of materialism in Britain as well as in the Continent (in the Netherlands and in Germany, in particular). The Leiden faculty of medicine, which flourished at the very beginning of the seventeenth century with De Volder first, and Herman Boerhaave later, became a

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forces so that bodies would be capable of unleashing large quantities of weakly repulsive elastic air (as per Hales' experiments), Kant was defending a new metaphysics of causality as grounded in nature's dynamic forces, without the need to resort either to the pre-established harmony, or to the mere passive existence of substances. His dynamic theory of matter, patterned upon Newton and Hales' experimentalism, provided then the blueprint for his metaphysics of causality; or, so I would like to suggest.

[49] Schofield (1970), p. 132.

[50] With some important caveats as far as Newton is concerned—i.e. Query 18 and 21, where heat is indeed related to a material vibrating ether.

famous international centre, where generations of Continental and British physicians and chemists were educated, before going back to their own countries and lay the foundations of the following pneumatic chemistry. So we need to look briefly at this further important tradition and its legacy for Kant's early dynamic theory of matter.

4.2 Herman Boerhaave on fire and the Newtonianism of Leiden

Stephen Hales exercised a deep influence not only on British natural philosophy, but also on Dutch natural philosophy, which flourished in Leiden in the first half of the seventeenth century thanks to a series of key figures, from Herman Boerhaave to William Jacob 'sGravesande, and Pieter van Musschenbroek. 'sGravesande's textbook *Physices elementa mathematica* (1720-1) defended Newtonianism and had two English translations by Jean Theofile Desaguliers and John Keill. Pieter van Musschenbroek's *Elementa physicae* (1734) became a central textbook in experimental philosophy and in 1741 was translated into English, while a German translation appeared in 1747 (Kant had a copy of the German translation—Warda 1922:05022. Exemplar: <4> X C 163 d.).

The importance of the Leiden school for spreading Newtonianism in the Continent has rightly received historians' attention, and it is not my aim here to add anything original to already existing authoritative studies on it.[51] Instead, my more modest aim is to illustrate some points of continuity with both the *Opticks* and Hales' *Vegetable Staticks* that in my view are salient to appreciate the origins of Kant's early dynamic theory of matter. Like Newton and Hales, both 'sGravesande and Musschenbroek believed in repulsive force and explained the elasticity of the air accordingly (although there is no mention of the ether in either of these two authors).

There is one theme that—in my view—runs through the three figures of 'sGravesande, Musschenbroek, and Boerhaave with a certain continuity, and that is important for the influence that Dutch Newtonianism exercised on Kant: the materiality of fire. Schofield sees in 'sGravesande and Musschenbroek's defence of the materiality of fire one of their most significant departures from Newtonian mechanics.[52] 'sGravesande regarded fire as subtle, fast moving, and contained in all

[51] See again Schofield (1970), ch. 7; Cohen (1956), ch. 7; Ruestow (1973), ch. 7; Metzger (1930).
[52] See Schofield (1970), p. 43ff. on which I draw here.

bodies, while light was the 'Newtonian archetype for material fire';[53] Musschenbroek, on his side, took fire as a fluid substance, occupying space, and adhering to bodies. He also identified the matter of light with the matter of fire, and thought that they were differing only in direction of motion.[54] Both authors clearly picked up the theme of the materiality of fire from the most important figure of Dutch natural philosophy of the time, Herman Boerhaave.

Boerhaave began his career by succeeding De Volder as Professor of Medicine and Botany in Leiden in 1709, he soon became Prof. of Chemistry in 1718, post which he retained until his death in 1738. He was one of the greatest physicians of his time, and taught several iatro-mechanists and chemists that from all over the Continent, England, and Scotland came to Leiden to study under him. His text *Elementa chemiae* (1732)—originating from a previous series of unauthorized students notes (*Institutiones et experimenta chemiae*, ca. 1724)—became a classic textbook for the chemistry of the time, underwent 80 editions and several translations in English. More than anyone else, Boerhaave contributed to spreading Newton's natural philosophy in the Continent, despite the fierce opposition of part of the French and German establishment, on the one side, and despite the reluctance of Newtonians such as Euler and the Bernoullis, on the other side.[55]

Some historians have argued that the publication of *Elementa chemiae* in 1732, just five years after Hales' *Vegetable Staticks,* allowed Boerhaave to incorporated elements of Hales' chymio-static experiments in his textbook. Milton Kerker, for example, has argued against Hélène Metzger's (1930) authoritative study on Boerhaave that she omitted mention of the conspicuous discussion of Hales' work in Boerhaave's text, and how Boerhaave did support Hales' views on the chemical role of air.[56] Indeed, not only did Boerhaave build up on Newton's speculations in the *Opticks* to defend the idea of an ethereal medium penetrating all bodies and diffused in space.[57] He also built up on Hales to defend the chemical role of air in the section "On Fire", first volume of his *Elementa chemiae*. So, what really matters for our

[53] *Ibid*., footnote 91.
[54] *Ibid*., footnote 91.
[55] *Ibid*., p. 134.
[56] Kerker (1955), p. 40.
[57] To this purpose, Cohen (1956), p. 223, gives a quote from Shaw's 1741 English translation of Boerhaave's text where Boerhaave presents Newton's hypothesis of a fine, subtle, elastic ether not just as a speculation but as a convincing demonstration, and adds "These notes reinforce the view that the Newtonian scientists of the eighteenth century were convinced that Newton's positive views were to be read in the Queries of the *Opticks*".

purpose here, is to clarify how Boerhaave gave a new twist to Hales' experiments, and how the end product of this re-elaboration of Hales via Boerhaave influenced Kant's early dynamic theory of matter.

Stephen Hales' elastic air, as the repository of repulsive force, became, in Boerhaave's hands, the elastic fluid of fire. Like Hales' air—which was an elastic matter chemically 'fixed' in the pores, and released upon combustion and fermentation—, similarly, Boerhaave's fire was an elastic matter penetrating all bodies and expanding them.[58] Boerhaave saw in the ability of heat to expand bodies and to operate transitions of state the hallmark of fire as an elemental substance trapped in all bodies and being released in various degrees. And in trying to establish the nature of fire, Boerhaave entered into discussions about combustible substances (primarily, charcoal and other vegetable substances), and about the role of air (especially atmospheric pressure as measured in Torricelli's experiments) in alimenting fire. Indeed, fire and air are strictly connected in Boerhaave's exposition, although obviously he was a long way from identifying combustion processes with chemical combinations with air. Boerhaave believed instead that air, like fire, was a fluid, having a mass and gravity, and most importantly elasticity.

And as Hales presupposed a subtle elastic medium, rarer than air itself, namely the ether of Newton's Queries, as the medium of light and heat; similarly, Boerhaave thought that heat was caused by the material fluid of fire lodged in all bodies, although he did not explicitly identify the matter of fire with the matter of light, by contrast with both 'sGravesande and Musschenbroek.

Metzger, in her classic 1930 study on Boerhaave, quotes Duhem in identifying Boerhaave's material fire as the ancestor of Boscovich's dynamic theory of matter, whereby matter is endowed with attractive and repulsive forces, the former understood in terms of gravitation and the latter in terms of imponderable fluids such as caloric.[59] This is also the interpretive line that I would like to suggest here below: behind Kant's early dynamic theory of matter around 1755 (elaborated independently of Boscovich's) lays the interpretation of repulsive force as a subtle elastic fluid surrounding particles of matter (among which gravitational attraction acts). The 'sphere of activity' of Kant's physical monads is not that different from the sphere of

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[58] Incidentally, Boerhaave's view anticipated in this way Lavoisier's imponderable fluid of *caloric* (no wonder Lavoisier paid tribute to Boerhaave in his treatise on chemistry).

[59] Metzger (1930), p. 56.

activity of imponderable fluids such as the electric fluid or the caloric fluid. And it derives from Boerhaave's defence of the materiality of fire as a subtle, elastic, and weakly repulsive fluid at work in all transitions of physical state.

Indeed, it is only with Boerhaave that fire is classified among material elements: in the preceding corpuscular philosophy of Boyle and Descartes, fire was only a phenomenon, i.e. the consequence of the vibratory motions of particles. And Newton himself held contradictory views on heat (sometimes described as a brisk motion of particles, and other times, notably in Query 18, as the vibratory motion of the same ethereal medium of light, as we mentioned above). Although Boerhaave fell short of identifying the matter of fire with the matter of light,[60] his criticism of Boyle's experiments against the ponderability of fire, betrays his allegiance to Newton's Queries, rather than to Boyle's or Descartes' corpuscular philosophy.

It is precisely in this historical and cultural context at the end of the 1740s and beginning of 1750s that the young Kant began to use Newton's ether of the Queries as the medium of both light and fire, in a short but significant Latin essay entitled *De igne,* to which we now finally turn.

5. *Succint Exposition of Some Meditations on Fire*

Kant wrote the short Latin essay *De igne* in the spring 1755 as his *Magisterarbeit*. Lewis W. Beck, who translated it into English for the 1986 edition of Kant's Latin writings, notes that Kant is here defending a "mechanical natural philosophy" which only a year later in *Physical Monadology* he replaced with a "dynamical natural philosophy" that he maintained for the rest of his life.[61] There is indeed a lot of continuity between the quasi-mechanical approach of whirling particles championed in *Universal Natural History*[62] and the mechanical natural philosophy exposed in *On Fire*. In the latter, Kant spells out the chemistry underlying the mechanism envisaged for his cosmogony, and clarifies the nature of the primordial fine matter "widely diffused in the celestial space". *On Fire* is indeed entirely dedicated to the *ether* as the medium of light and heat: most of the

[60] As Metzger (1930), p. 213, pointed out, Boerhaave did not identify fire and light because he thought that there are phenomena where fire is mostly present (as a hot poker) which nontheless do not emit light, and vice versa optical phenomena such as moonlight where no fire can be found.
[61] Kant (1755b), English translation L. W. Beck *et al.* (1986), Introduction p. 12.
[62] For a discussion of the quasi-mechanical nature of Kant's cosmogony and the Leibnizian influence on it, see De Bianchi and Massimi (in preparation).

phenomena discussed in *Universal Natural History*, from the elasticity of the atmosphere of the Sun to the formation of Saturn's rings, find their ultimate explanation in Kant's analysis of changes of physical states and combustion in *On Fire*.

Hence, this short Latin essay occupies a central role in understanding the development of Kant's early dynamic theory of matter in the period 1755–6. By contrast with Lewis Beck's remark, I think that the kernel of Kant's early "dynamical natural philosophy" originates from this important short Latin essay, and from the "mechanical natural philosophy" championed in it. Indeed, the "mechanical natural philosophy" Beck refers to should be understood, in my view, as a reference to the central role that the ether plays in *On Fire* as the *medium of attractive and repulsive* forces at work in optical and thermal phenomena. And, as we shall see, Kant's view on the ether beautifully exemplifies the idiosyncratic combination of the various sources we have discussed so far: from Newton's *Opticks*, to Hales' chymio-statical experiments, to Boerhaave's theory of fire.

Kant's "mechanical natural philosophy" should not be conflated with Descartes' mechanical philosophy. Indeed, against Descartes and the atomists, right at the outset of *On Fire* Kant argues that the fluidity of bodies cannot be explained by the division of matter into smooth minute particles, but it requires instead a "mediating elastic matter, by means of which they communicate the force (*momentum*) of their weight equally in all directions" (I, 372). Elastic matter has to be intermixed with the corpuscles that according to dynamic corpuscolarism compose all bodies, in order to explain the elasticity of solid bodies: e.g., why they resist weights attached to them without easily breaking; or elastic properties of springs as per Hooke's law. Section I of *On Fire* is dedicated to the nature of solid and fluid elastic bodies, with a series of demonstrations *more geometrico* of how any kosher mechanical philosophy *à la* Descartes cannot explain the elasticity of solid bodies, even less so their rarefaction and change of physical state.

Like Boerhaave, Kant too sees the force of fire as being manifested primarily in the expansion and rarefaction of bodies (I, 371 and 376). And as Boerhaave attacked Cartesian corpuscolarism to defend the materiality of fire, similarly Kant takes the distance from Descartes by identifying the elastic matter lodged in the interstices of bodies with the matter of heat (I, 372) and more explicitly, only a few pages down, with the matter of fire:

> Proposition VII. The matter of fire is nothing but the elastic matter (…) which holds together the elements of bodies with which it is intermixed; its undulatory or vibratory motion is that which is called heat.[63]

And as evidence for the elastic matter of fire, Kant analyses the phenomenon of boiling as due to the elastic matter trapped in the liquid body, which would acquire enough force to overcome the attraction of the corpuscles, and would be released in the form of elastic bubbles.

From the identification of the elastic matter of bodies with the matter of fire, to the subsequent identification of the matter of fire with the ether itself, the step is short: "Proposition VIII. The matter of heat is nothing but the aether (the matter of light) compressed by a strong attractive (adhesive) force of bodies into interstices".[64] This is a remarkable proposition in which the ether / elastic matter is effectively identified both with a Boerhaavian *matter of fire*, whose undulations are heat, *and* with the Newtonian *matter of light*. If we consider that more than forty years later, in the *Opus postumum*, Kant still identified the ether as the 'matter of heat' or Wärmestoffe, and thought that it was responsible for all changes of physical state as well as for light transmission, we can get an idea of the scientific origins of Kant's peculiar view as rooted in his idiosyncratic combination of Boerhaave's theory of fire, Hales' view on elastic air, and Newton's *Opticks*.

Indeed, after Proposition VIII, to support the view of the ether as the matter of light and fire, Kant refers to Newton's *Optics*, in particular to the Queries on the ether (Qu. 17–23) added to the Latin edition, whose second edition Kant had in his library (Warda 1922: 05024. Exemplar <37> 4 Phys/152). In particular, he refers to Newton's study of optical refraction and reflection to claim that bodies with a higher density have a greater capacity to refract light as well as to absorb heat; and hence that the attraction of oily sulphurous particles responsible for light refraction is also responsible for holding the matter of fire trapped in the interstices of bodies:

> For oils (for instance, oil of turpentine) which according to the experiments of Newton and many others, reflect rays of light (i.e. attract them) much more than

[63] Kant (1755b), Engl. trans. (1986), p. 23.
[64] *Ibid.*, p. 24.

> can be explained by their specific gravity, likewise have a boiling point far higher than can be explained by their specific gravity. Oils are the true fuels of flames, and in this state they scatter light in all directions. Thus is shown that the matter of heat and the matter of light agree as closely as possible, or rather, that they are not different.[65]

Newton believed that the different refractive powers depended on different proportions of sulphurous oily particles inside bodies. He also believed that sulphurous matter was important for combustion—i.e. it can easily be ignited—and hence for chemistry. Indeed, he expressly linked "fat sulphurous unctuous bodies" to both refraction and combustion in Book II, Part III, Prop. X of *Opticks*.

But Newton, like Boerhaave after him, fell short of identifying matter of heat with matter of light. Although in Query 19, he resorted to the ether as an optical medium, whose different densities explained the refraction of light, and in Query 18 even took the ether as the medium whose vibrations transmitted heat to bodies, Newton never identified fire as the "matter of heat", i.e. as a material substance. The materiality of fire betrays instead Kant's debt to Herman Boerhaave's *Elementa chemiae*.

So, effectively, Kant is here operating an idiosyncratic combination of Newton's optical ether (responsible for light reflection, refraction, and thin films) with Boerhaave's material fire, although neither Newton identified fire as a substance nor Boerhaave identified fire with light. But what evidence did Kant have for identifying the ether as both the matter of fire and the matter of light?

Kant latches onto Euler's *Nova theoria lucis et colorum* 1746 "according to which light is not the effluvium of shining bodies but is the propagated pressure of the aether which is dispersed everywhere" (I, 378),[66] and links Euler's use of the ether for optical phenomena to his own use of the ether as the matter of fire, via the example of the transparency of glass. Given the transparency of glass and its ability to refract light, since glass is obtained by fusing at high temperatures potash with sand, Kant concludes that the matter of fire or heat—which must be largely dispersed among the glass' solid elements—must be one and the same as the ether, or the matter of light.

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[65] *Ibid*., p. 24.
[66] *Ibid*., p. 24.

And as further evidence for the matter of fire being trapped in the interstices of solid bodies, Kant refers to Guillaume Amontons' 1703 report in the *Mémories de l'Académie Royale des Sciences* about measuring the force of fire that manifests itself in the rarefaction of bodies. Even more explicitly, Kant refers to Hermann Boerhaave's *Elementa chemiae* (1, 172-3), and reports experiments by Fahrenheit about the changing boiling points of liquids depending on the atmospheric pressure, followed by a reference to Pierre Charles le Monnier's experiments using a Reaumur thermometer to measure different boiling points of water in Bordeaux and Pic du Midi, and similar experiments by Jean-Baptiste Baron de Secondat.

It is here that Kant's debt to Boerhaave becomes manifest in the specific ways in which Kant devises an explanation for the change of physical state of water from liquid to vapour. As Boerhaave in his Vol. 3 of *Elementa chemiae* referred to Torricelli's experience about atmospheric pressure as compressing the force of fire and preventing the flame from dissipating through some sort of action and reaction; similarly, Kant claims that it is via the action and reaction between the weight of the atmospheric pressure and the undulatory motion of the particles of fire that the elastic ethereal matter is stably lodged in the pores of bodies. As soon as either the attraction among the corpuscles decreases or the weight of the atmospheric pressure diminishes (as it happens on the mountains), the "aether by its elastic force at the boiling point succeeds in its striving to escape from its connection with the water".[67]

Thus, the best evidence for the elastic ethereal matter of fire seems to come from changes of physical state, especially from the nature of vapours, where again Kant (I, 380) refers to Newton's *Opticks* to explain the "wonderful elasticity" of all vapours in terms of a strong repelling force.[68]

Kant's analysis of the elasticity of water vapour and the ensuing proof *more geometrico* of water bubble formation (in terms of water containing the repulsive ether compressed in its mass) is hence germane to Newton's ether of *Opticks* as much as is germane to Boerhaave's view of fire as a material substance. But recall that Boerhaave—and Kant after him—did not defend only the *physical role* of air as dissolved in liquids. Under the influence of Hales, Boerhaave defended also the

[67] Ibid., p. 26

[68] Lewis Beck in his English translation adds here a footnote referring to Query 31, in particular to the passage we analysed above concerning Newton's defence of a 'repulsive power' against Boyle's hypothesis of 'springy or ramous' particles of air.

chemical role of air as an elastic matter ‘fixed’ in animal, vegetable, and mineral substances.

Like Hales, Kant too mentions “all plants, the spirit of wine, animal stone, and many kinds of salts, especially nitre, [that] release an immense amount of elastic air when strongly affected by fire, as Hales in his *Vegetable Staticks* instructs us with wonderful experiments”.[69] Kant refers here once more to chapter 6 of Stephen Hales’ 1727 work, of which Kant had the 1748 German translation with Christian Wolff’s preface, to argue that “Air is an elastic fluid, almost a thousand times lighter than water”, and to conclude: “It is self-evident that air extracted from these bodies by the force of fire did not have the nature of air (i.e. was not an elastic fluid possessing elasticity proportional to its density) as long as it was a part of their mass. Thus the matter expelled from the interstices of the body (…) shows elasticity only when liberated”.[70]

Via Boerhaave’s material fire, Kant finally gets to Hales’ elastic air as being ‘fixed’ in bodies and liberated under the action of heat. But by contrast with Hales, who considered water vapour as one of a kind compared to other types of vapours released from vegetable, mineral, and animal substances, Kant advances what he himself calls “an opinion…worthy of their [physicists] most accurate investigation: whether air is anything but the most subtle exhalation of the acid disseminated through all nature which manifests elasticity at any degree of heat, however small”.[71]So, the elastic air released under the action of fire and present in all vapours (including water vapour) would only be an exhalation of the acid as “the most active and strongest principle by the attraction of which the aether is held together”; that is, the “true magnet of aetherial matter which holds all bodies together”.

Building up on Newton’s claim about sulphurous oily particles being highly attracting and on Hales’ similar view about acid sulphurous fumes attracting and ‘fixing’ elastic, repelling aerial particles, Kant goes on to identify acid as the “true magnet” of the elastic, repelling air of Hales, now suitably reinterpreted as an “ethereal matter” lodged in the pores of all bodies and acting both as Boerhaavian matter of fire and as a Newtonian matter of light. Indeed, Kant even ventures to explain why nitre, when burns, releases an immense quantity of elastic air, and even

[69] Kant (1755b), English translation (1986), p. 29.
[70] *Ibid*., p. 30.
[71] *Ibid*., p. 30.

more so does tartar of Rhenish wine (the acid being what is mostly given off from the materials which are the most resistant to fire). And while Hales was hesitant about the identification of elastic repelling air with the ether—as we saw in § 4.1—Kant happily proceeded to such an identification via his idiosyncratic combination of Newton's optical ether and Boerhaave's material fire. But where does all this discussion leave us? And what good is it to appreciate Kant's early dynamic theory of matter around 1755?

6. Concluding remarks

Kant's dynamic theory of matter can receive a complete new light if we consider carefully the scientific background against which Kant came to elaborate his own view very early on in his academic career. It was not my goal to provide a definition of dynamic theory of matter—especially given the evolution of the idea from Kant's pre-critical writings around 1755 analysed in this paper, to the critical period, especially *Metaphysical Foundations* and *Opus postumum*. Instead, my more modest goal was to identify some key aspects of Newton's speculative experimentalism behind Kant's early dynamic theory of matter in 1755, and to investigate how he came to elaborate his very own brand by extensively drawing on a popular tradition of speculative experimentalism. What we have found is that Kant borrowed and adapted Newton's optical ether and Hales' elastic air and employed them in ways in which neither Newton nor Hales envisaged. In the mid-eighteenth century, chemistry provided the most insightful source of knowledge for optical, thermal, and electrical phenomena. Kant's idea of physical monads consisting of attractive and repulsive forces is deeply rooted in Newton's *Opticks,* and in the ensuing tradition of experimental Newtonianism that thrived both in England and in the Netherland.

The authors quoted and their specific experimental researches leave hardly any doubt about Kant's engagement with speculative experimental Newtonianism that flourished at the time, especially in the British and Dutch natural philosophy of Hales and Boerhaave. This important experimental tradition—which dealt with the matter of fire, wondered about the elasticity of airs, and believed in an ethereal fluid as the ultimate cause of elasticity—is at quite a distance from the Newtonian mathematical physics that we are so accustomed to associate with Kant's philosophy of natural science. It causes almost a sense of embarrassment in Kant's commentators to the point that Lewis Beck, in the Introduction to the English translation of *On Fire*, felt the need to clarify that Kant's dissertation is the end of a long tradition that was about to be overthrown by Priestley, Lavoisier, and Rumford. However, we should not forget the pivotal role that speculative Newtonian experimentalism played for the chemical revolution at the end of the eighteenth century. Stephen Hales and Hermann Boerhaave paved the way to Joseph Priestley, Joseph Black, and Henry Cavendish's pneumatic chemistry. The seeds of the chemical revolution can be found in the experimental Newtonianism that flourished in Leiden, Cambridge, and Oxford.

Kant seems to have arrived at his early dynamic theory of matter around 1755 following a very idiosyncratic path: building up on Hales and Boerhaave's chemical experiments, Kant began to elaborate a dynamic view of nature as governed by two fundamental forces, attraction and repulsion, as the *causal agents* at work in the formation of planets and stars from an original ethereal fine matter. The link between forces, ether, and chemical phenomena reveals the real nature of Kant's much celebrated conversion to Newton. The Newton Kant owed a debt to was not necessarily or exclusively the Newton of the first edition of *Principia*, i.e. the Newton that championed the new mathematical physics; but instead the much more esoteric and controversial Newton of the *Opticks*, who ruminated on chemistry and on the possible ether-mechanism behind chemical phenomena. If we further consider that again in the *Opus postumum* Kant tried to prove a priori the existence of the ether in conjunction with his speculations on chemistry (this time prompted by Lavoisier's chemical revolution at the turn of the eighteenth century), we can clearly identify an important leitmotiv in the evolution of Kant's dynamic theory of matter from the 1750s to the 1790s.

Apropos of Newton's ether, Westfall famously observed that "composed of particles repelling each other, the aether embodied the very problem of action at a distance which it pretended to explain". In particular, Westfall argued that Newton's ambiguity on the ether (against which he had abundantly written in Book II of first edition of *Principia*) can be explained by bearing in mind that there was another candidate in Newton's natural philosophy for the semi-mechanical and semi-dynamical role of the ether, namely God himself as an "incorporeal aether who could move bodies without offering resistance to them in turn",[72] which is perfectly

[72] Westfall (1971), p. 397.

germane to Newton's idea of absolute space and time as the *sensorium* of God. If Westfall's analysis is right, it would also explain why the young Kant, by rejecting the Newtonian absolute space as the *sensorium* of God, had to resurrect the idea of a material ether as the medium of attractive and repulsive forces, which otherwise would look like occult qualities to a generation accustomed to the mechanical view of nature. Newton's God as an 'incorporeal aether' was simply precluded to the young Kant. No wonder, he expressly took the distance from Newton's theological stance in *Universal Natural History*, and repeatedly begged to differ from Newton on the role of divine intervention in the creation of heavenly bodies. If my interpretive analysis is correct, Kant's stance on the ether in the 1755 writings would then not only illuminate the nature of his debt to Newton, but also their parting of the ways as far as theology is concerned. But this is another story that I leave for future investigation.

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