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NEWTON'S MATERIAL AETHER: PROBLEMS OF INTERNAL COHERENCE AND RATIONAL RECONSTRUCTION

1. Preliminaries

In this paper an examination of Newton's "material" aether program has been undertaken with several parallel aims. First is to examine the internal coherence and unity of ideas within the "material" aether program (inter-program coherence, i.e., unity between "material" aether, "immaterial" aether, phenomenological program and *actio in distans*, would not be discussed in this paper). The search for internal coherence and unity is important, for many historians and philosophers of science believe that a "failed" research program might be very much wanting in internal coherence. Although "rationality" question cannot be entirely reduced to internal coherence and unity of ideas, these must still be regarded as important criteria. Besides Newton's texts are dense, difficult to interpret and an alternative interpretation is offered here.

Second related aim is to examine the question of relationship between "rational reconstruction" and the "descriptive" epistemology of history of science, through this reconstruction of Newton's aether program. Much discussion has gone on this topic philosophical literature, with many distinguished philosophers – e.g., Agassi, Grunbaum, Lakatos etc. – participating in it.¹ Laudan (1977) has suggested drawing a line between two types of history of science – called HOS1 and HOS2.² The distinction is useful, even though it may be challenged by many on theoretical grounds, as all such distinctions in the past have been (e.g., distinction between theory and observation etc.). Even if we accept this distinction between HOS1 and HOS2, the position is not altogether free of difficulties. An overwhelmingly large part of the HOS1 must be consisting of "failed" research program and it

will be difficult to explain many of them in the “rational reconstruction” mode. The picture gets further complicated by the fact that *pre-analytical intuition about scientific rationality* (or PI) is seen as important element of theory acceptance/rejection. HOS1 contains many situations where a “failed” research program with very string PI’s were considered along with alternative counter-intuitive programs, with well articulated modular justification. Such was the case of Newton’s “material” aether program, which had to compete for a valid explanation of transmission of gravitational forces with two alternative models, namely space-body interaction model and the *actio in distans* model, which appeared to be totally counter-intuitive. Here we see a case of post-facto development of PI and creation of a post-facto modular justification for the alternative programs. The present case study, besides highlighting the complexity of relationship between “rational reconstruction” and “descriptive” epistemology, also makes another point, which although not original, is nevertheless of some value. Physical explanations, even in absence of adequate modular justification, often strive to go beyond logically transparent inferential structure by assuming a fundamentally different nature of physical reality. That the explanations are counter-intuitive or inconsistent with intuitively acceptable logical relationships, may not have anything to do with the “truth” or the scientific worth of the implications of these explanations. Adequate modular justifications are of course eventually developed to post-facto legitimize all the successful explanations, but for obvious reasons these justifications have no profound heuristic value. Besides these conclusions, some observations are also added on the discovery/justification dichotomy in the concluding remarks.

II. Explanation and gravitation in Newton’s writings

Newton’s pre-*Principia* writings on gravitation show that he mainly used three approaches in order to explain the causes and the mechanism of operation of the phenomenon of gravitation: (a) he used the “material” aether as the “causal agent” – an approach that shared the inter-phenomenal aether with the tradition of 17th century “mechanical” philosophy, but otherwise differed substantially with this tradition, (b) he introduced the so-called “immaterial” aether hypothesis, in the paper *De gravitatione* in 1668, and (c) he used, what we shall call here, the “phenomenological” approach to develop a workable dynamics of motion of bodies under gravitation. The last approach to the problem of gravitation or (d) comprised of putting forward and testing the empirical consequence of “models” or mathematical constructions that depicted the relationship between dynamic variables of bodies in motion under gravitation. This approach unlike the other two did not attempt to describe the mechanism by which gravitational forces were

transmitted and in the “phenomenological” papers by and large, Newton refrained from offering any conjecture on the ultimate causes of gravitation. Such was the approach of the papers like *Laws of Motion* or the paper on calculation of lunar surface gravity and also the approach taken in the *Principia*.³

Obviously the aether conceptions were originally introduced into the field of physics in answer to a question that Newton tried to solve for many years, namely: how are the gravitational forces transmitted across the vast expanse of cosmic void from one body to another? The basic model or the mechanism of transmission of force in the two aether programs are very different from each other. In case of the “material” aether the transmission of forces was caused by either impact phenomenon or by “pushing” resulting from the pressure gradient of the aether. In other words, the “material” aether explanation could be reduced to some sort of *contact action* between a body and aether (which in turn also comprised of “material” substance). In case of “immaterial” aether however Newton introduced a very different species of argument – that the absolute space itself in some way “acted” on bodies to produce their inertia and their observed gravitational motion. Since absolute space, unlike the “material” aether, was not “constituted of material substance”, this action could neither be contrived as *contact action* nor as a type of mechanical interaction. What was the model of transmission of force underlying the “phenomenological” writings? With the publication of the *Principia* in 1687, Newton was almost “universally misunderstood” to be advocating the phenomenon of *actio in distans*. This however is an incorrect supposition. The “phenomenological” model was simply neutral to mechanism of transmission of forces and Newton in a number of documents – e.g., the *Rules of Reasoning* of the *Principia*, the *Bentley Letters* of 1692 etc. – expressed grave doubts about the possibility of *actio in distans*.⁴ Nevertheless there are other documents among Newton’s manuscripts in which he did argue on the basis of some observed phenomenon about the possible existence of an asymmetrically propagating “double force” *acting at a distance* on micro and macro objects.⁵

In considering these three types of explanations we immediately see that the “material” aether program had an explanatory advantage which both the other types of explanations generally lacked. The *contact action* and mechanical interaction model had an explanatory transparency that made it immediately intelligible. Both *actio in distans* and the space-body interaction model lacked this transparency and immediacy and in general sense these explanations were counter-intuitive. Furthermore there was no modal justification for these programmes available in the 17th century. Given the criteria of *acceptability* of scientific theories in the 17th century therefore, the abandonment of the “material” aether appeared to be the abandonment of the very notion of mechanical causation of generation and transmission of the gravitational forces. At a more abstract plane the rejection of “material”

aether caused even deeper and other significant philosophical problems. If the generation and transmission of the gravitational forces were not associated with some sort of “material substance” then what were they rooted in? This placed the “theoretical” entities like “force” on a very unsound ontological and methodological footing. For this reason and others many thinkers of 17th century, like Huygens and Leibniz, preferred “material” aether explanations and struggled to develop a “material” aether explanation even after the great success of Newton’s *Principia*. Newton however choose to part ways with the “material” aether and explore other possible options. In doing so he confronted a most complex philosophical problem, which McGuire (1968) has most aptly called the “ontological problem of causation of force”.

III. Newton’s “material” aether writings

There are two distinct types of “material” aether explanatory “models” that Newton uses in order to explain gravity. In some papers he uses the *descending aether collision model* and in others a *variable density gradient of the aether* is held to be responsible for causing the gravitational phenomenon. In an important paper Rosenfeld (1969) has termed the former the “kinetic” aether and the latter the “static” aether⁶. We shall be using here the terms *kinetic aether model* as terminologically equivalent alternative for the *descending aether collision model* and the *static aether model* for the *variable density aether model*. The *kinetic aether* is predominantly used in Newton’s early pre-*Principia* papers, most notably in the *Waste Book* (the *Questiones*, therein) and in the paper *Hypothesis*. The *Questiones* gives us the basic format of the *descending aether* explanation. A corpuscular aether radially descending towards the center of earth gets into continuous inelastic collision with bodies. A part of the aether is absorbed by bodies and another part ascends upward in “lesser consistency”. The conceptual problems arising out of this descent-ascent mechanism and the problem of continual absorption of aether by bodies is elaborately discussed in the *Questiones*. The main problems are what happens to the aether that gets absorbed and what makes the aether ascend upwards again?

The paper *Hypothesis* elaborates further on all these problems and gives us the most exhaustive picture of Newton’s early aether “philosophy”. In this paper Newton attempts to develop an overall theory of aether to explain all types of natural phenomenon. The basic tenets of this theory of aether consisted of (a) a cosmic circulation of aether, (b) conversion of aether and matter through condensation and evaporation, (c) mechanism of descending/ascending aether and varying densities of aether substance surrounding matter etc., causing gravitation and other natural phenomena. The

long list of natural phenomena that Newton attempted to explain through the operation of aether mechanism in this paper is revealing. Besides gravitation, electricity, magnetism, chemical reaction, reflection and refraction of light etc., he also devised an elaborate explanation of animal motion through condensation and dilation of aether in the muscles.⁷ The last was undoubtedly an attempt to furnish a “mechanical” solution to the complex mind-body problem, which was turning out to be the bane of the 17th century “mechanical” philosophy.

Aether in this paper was seen as the fundamental “cosmic” constituent – a source of all cosmic activity – which the Sun imbibed copiously to produce the heat, light and planetary motion, which the brain directs through the nervous system in living organisms to produce the muscular movements and which through its layers of varying density etc. could produce gravitation and other attractions. As we have already suggested, this paper was definitely conceived within the framework of Cartesian “mechanical” philosophy. God was seen as the first cause, while the “mechanical” nature proceeded with its own autonomy, aided by the aether that like the Cartesian “first matter” constituted the “whole frame of nature”. The “main body of the aether” here is functionally sub-divided into electrical, magnetic, gravitational types of “aether substance”, “spirits” and “effluvia”, each having its special characteristics and each operating through distinct type of mechanism. The distinction – perhaps in anticipation of Newton’s future views – also extends to the ontological planes. The aether as a “substance”, bears the burden of performing the bodily work; condensing, evaporating, dilating, moving bodies etc. Thereafter Newton goes into its attendant “formal” characteristics: “In the *second* place it is to be supposed that aether is a vibrating medium like air, only vibrations far more swift and minute; those of air made by man’s ordinary voice, succeeding one another at more than half a foot or a foot distance; but those of aether at a less distance; but those of aether at a less distance than the hundred thousandth part of an inch...”⁸. Although the “pulses” in the “vibrating medium” is also used to explain chemical reaction and production of flames besides the optical phenomenon, the distinction clearly suggests Newton’s recognition of the “formal” or the “medium” aspect of the aether. This distinction as we shall see would become progressively more acute in Newton’s future writings, heralding with it the problem of elasticity of this medium and the philosophical problem of “ontology” of all such “theoretical” entities as “force”, to account for which the “material” aether was originally invoked.

There are some evidences that Newton wanted to give a mathematical shape to this descending collision aether hypothesis. Thus in a letter to Halley written in 1686, just before the publication of the *Principia* he referred to “material” aether again and mentioned his attempts to formulate a quantitative version of the descending aether theory. He suggested that the de-

scending aether could be given a mathematical treatment and made to harmonize with the inverse square law, and consequently with the Kepler's law:

"I there suppose that the descending spirit acts upon bodies here on the superficies of the earth with force proportional to superficies of their parts; which cannot be, unless the demunition of its velocity in acting upon the first part of any body it meets with, be recompensed by increase of its density arising from that retardation. Whether this be true is not material. It suffices that was the hypothesis. Now if this spirit descends with accelerated motion, its density would everywhere diminish as much as its velocity increase; and so its force (according to the hypothesis) will be same as before, that is still reciprocally as the square of its distance from the center".⁹

Newton never really mathematically elaborated this idea, and the basic idea is not very clear. Prof. Rosenfeld has offered a simple model of the idea underlying the passage quoted above:¹⁰ N aether particles descending per unit time towards the center of Earth with radial velocity V at a distance R from the center of earth, would have a surface density of $(N/4\pi R^2 V)$. This stream will exert a force directed towards the center of Earth of magnitude $(NmV/4\pi R^2)$ on bodies that it encounters on its way, thus making the "central force" inversely proportional to the distance from the center as required by Newton's theory of gravitation. Despite this possibility of being able to mathematically harmonize the "kinetic" aether with the inverse square law, we find that Newton preferred the "static" aether approach in the post-*Principia* period. The only exception to this is the brief episode in the early 1690s when Newton is known to have approved of Fatio's "kinetic" aether explanation of the gravitational phenomenon. The Fatio episode has become somewhat of a puzzle for the history of science. Why did Newton support Fatio's explanation of gravity when in 1690s he generally harbored strong reservations against the whole "material" aether program itself? Fatio imagined a very rare aether – of an extremely low density – such that the effect of collision among the aether particles could be considered negligible. These aether particle moved rectilinearly and very swiftly and through inelastic impact with bodies they caused the gravitational motion. Obviously the random collision of aether and matter would introduce secular aberrations in the observed motion of the bodies. Fatio thought that by reducing the density of the aether suitably and simultaneously attributing higher velocity to its particles he could make the secular effects vanish. Fatio's own calculations show that he did not quite succeed in this and he certainly did not convince any of his adversaries on this point. But perhaps from Newton's point of view Fatio's system had several attractive features. Newton had never completely accepted the hypothesis of *actio in distans*. The Fatio model had rectilinearly moving corpuscles, which was in compliance with the first law of motion. It emphasized high degree of vacuum and a relative paucity of matter in the universe, which was very much in accordance with Newton's own world view. If some of this aether in inelastic impact with

the bodies had to be absorbed by the bodies, Newton, unlike Huygens, had no difficulty in accepting this. Indeed, as we have already seen, he had always entertained the possibility of absorption of aether in the “descending aether model”. Besides these the Fatio idea was novel and showed the possibility of developing further. None of these however furnish us with a complete reason and we still do not know conclusively as to why, for a brief period in early 1690s, Newton thought that “kinetic” aether model could possibly furnish an explanation of gravity consistent with his *Principia*.

Only few years after the *Hypothesis* in a *Letter to Boyle*,¹¹ Newton introduces the “variable density” or the “static” aether hypothesis. The main focus of the *Boyle Letter* was explanation of “chemical” phenomenon and gravitational phenomenon is dealt only in passing in a single paragraph at the very end of the letter. In this paragraph Newton introduces an aether of differentiated corpuscular size – comprising of aether particles of “finer” and “grosser” size – mixed in different proportion to each other such that as to result into an aether of variable density around different bodies. The interacting density gradients of different bodies produces an aether pressure and the consequent gravitational motion (or the force) of the bodies. The exact mechanism of explanation is somewhat complex. The relevant paragraph reads as follows:

“I shall set down one conjecture more, which came into my mind now, as I was writing this letter. It is about the cause of gravity. For this end I suppose aether to consist of parts differing from one another in subtlety by indefinite degree; that in the part of bodies there is less of the grosser aether, in proportion to the finer, than in the open spaces; and consequently, that in the great body of earth there is much less of the grosser aether, in proportion to the finer, than in the regions of the air: and that yet the grosser aether in the air affects the upper regions of the earth, and the finer in the earth the lower regions of the air, in such a manner, that from the top of the air to the surface of the earth, and again from the surface of the earth to the center thereof, the aether is insensibly finer and finer. Imagine now any body suspended in the air or lying on the earth: and the aether being by the hypothesis grosser in the pores which are on the upper parts of the body than in those which are in the lower parts and that grosser aether being less apt to be lodged in those pores, than the finer aether bellow, it will endeavor to get out and give way to the finer aether below, which cannot be without the bodies descending to make room above for it to go out into.”¹²

The *Boyle Letter* is perhaps the last full-length paper on “material” aether of the pre-*Principia* period of writings on “material” aether or of the first phase of “material” aether writings. It is generally agreed by the Newton scholars that between 1678 and 1707. Newton harbored strong reservations against the “material” aether program. During this period he authored several documents and texts summarizing his objections against the “material” aether hypothesis. When Newton finally returned to the theme of “material” aether again around 1707, we find that he preferred the “static” aether or the “variable density hypothesis” to the “kinetic” version. His interests were pre-

sumably rekindled by Francis Hauksbee's electrical experiments before the Royal Society around 1706–07. Inspired by this Newton once again started considering the possibility of “short-range forces” between particles being of electrical nature. This led him to postulate the existence of an electrical “subtle spirit” much like he had done thirty years earlier in the *Hypothesis*. In two draft versions of *Queries* of the *Opticks*, published later in 1717–18 – titled *Quaest* 24 and 25 and widely quoted in all important studies of Newton's aether – Newton asks if the “force by which small particles of bodies cohere and act upon one another at small distance” may not be of electrical origin? In a tentative answer to this he conjectures if “particles of all bodies may abound with electric spirit” which when “rarefied” or “agitated by friction” may produce various natural phenomena. He summarizes the *Quaest* 24 thus:

”And if there be such an universal electric spirit in bodies, certainly it must very much influence the motions and actions of the particles of bodies amongst one another, so that without considering it, philosophers would never be able to give an account of the Phenomenon arising from those motions and actions. And so far as these phenomena may be performed by the spirit which causes electrical attraction it is *unphilosophical to look for any other cause*”.¹³

Newton's renewed conviction that no complete description of natural “phenomenon” without involving the aether is possible is evident from this passage. This was the spirit in which Newton added the “new” *Queries* to the different editions of *Opticks* between 1707 and 1717. Many of the new *Queries* therefore, e.g., *Query* 17, 18, 19, 21, 22, 23, 24 etc., dealt with the “material” aether, reviving anew almost the entire aether problematic that Newton had dealt with in his earlier papers like the *Hypothesis*. These *Queries* once again postulated the vibration of the aetherial medium, differential densities of the aetherial medium, to explain the same phenomenon that Newton had attempted to explain in the *Hypothesis* some forty years earlier, namely, optical effects, gravitation, electricity, and propagation of sensation etc. Radically differing from the position vis a vis the “material” aether in the *Principia*, the *Query* 22 suggested that the planetary bodies would encounter almost negligible amount of resistance from an aetherial medium.

The “material” aether of the new *Queries* however differed from the previous one in many ways. The variable aether particle size hypothesis, introduced in the *Boyle Letter*, was omitted once for all (in fact in the 1690s Newton had discarded the hypothesis on a number of interlinked considerations), instead a homogeneous aether with uniformly varying density around bodies was ascribed the task of causing the phenomenon of gravitation. Even this homogeneous “static” aether differed remarkably from the robust “kinetic” aether of the earlier writings. All through the 1690s Newton had emphasized a number of interlinked basic characteristic of matter and universe, e.g., extreme paucity of matter in the universe and the presence of a high degree of disseminate and interstitial vacuum. At the end of this period

when Newton once again returned to the “material” aether, the aether itself had become much more rare and vacuous entity. The “medium” aspect of this aether and the conjoint characteristic of high degree of “elasticity” of the aether medium is repeatedly stressed, as opposed to the ontological and kinetic characteristics of the aether of the *Waste Book*.

IV. Elasticity of Aether

If the aether particles were separated from each other by large stretches of cosmic void then how could this aether behave like a continuous elastic medium? On what basis did this medium get its attendant characteristics of “elasticity”? This interesting question has not been given its due attention in the historical literature. Rosenfeld (1969) observes that “the origins of aether’s elasticity raised a problem whose solution lay beyond Newton’s conceptual horizon”.¹⁴ Other important studies have by and large ignored this question, supposedly implying thereby that Newton never gave much thought on this problem. I would like to differ with this supposition. Newton was in the habit of deliberately and very carefully considering the implication of any hypothesis that he adopted and it seems hardly likely that he did not ponder upon this important point before writing the passages in the *Queries* and the *Boyle Letter*. Besides it seems that during the “aether-less” period of 1678–1707, Newton made several observations on the nature and composition of matter which were *primarily* aimed at resolving the question of elasticity of aetherial medium. A “medium” had to be continuum. But as we know Newton from his very early writing had very strongly rejected the Cartesian and other *plenum* theories. If however the aether corpuscles (as well as other elementary micro-particles of matter) could *act at a distance* on each other in such a way that the total system could come to a springy pulsating medium. The first suggestion towards this we find in the paper *De aere et aether* in which micro-corpuscles of “air” agitated by heat and *acting upon each other at distance* by a “force of repulsion”, produce such a pulsating and springy medium.¹⁵ In the following paragraph this springiness of the medium is used to explain the transmission of the sound waves also. Newton’s attitude to *actio in distans* however is very complex and we shall not be in a position to examine it in greater detail here. Suffice it to say here that in the 1690s Newton made an imaginative attempt to construct an “elastic” aether out of two tentative properties of “substances”: (a) the existence of micro-structural “double forces” between elementary particles and, (b) the property of extreme porosity of matter. In another separate paper (yet unpublished) I have argued that the “double force” hypothesis was not entirely an autonomous line of argument nor a byproduct of alchemical

beliefs, but was a composite part of gravitational research program, rooted very largely in explanation of “elasticity” of “material” aether.

V. Refutation of the “Material” Aether Hypothesis

What were the considerations that motivated Newton to drop the hypothesis of “material” aether between 1678 and 1707 and later after 1717 to generally abandon it altogether? This has been the direct or indirect focus of inquiry of a number of historical work. We can begin by examining all those basic problems that Newton had to overcome in order to develop the “material” aether program.

If the aether substance continuously moved “downwards”, towards the center of the earth, than what moved the aether itself in the first place? The 17th century “mechanical” philosophy generally overcame this paradoxical question in an orthodox Cartesian way. A “first motion” was imagined to have been imparted on the universe by its creator, which was later continued by the Cartesian “Law of Conservation of Motion”. This Law, originally formulated by Descartes, was widely upheld in the 17th century. It proclaimed that all motion in the universe was perpetually conserved by a general concourse of God, such that the total motion in the universe at all time remained a constant. It appears from Newton’s early writings that he did not quite clearly answer this tantalizing question as to what makes the aether move downwards. In the *Hypothesis* he explained away all the aether functions e.g., descent, ascent, condensation and evaporation etc., by declaring that nature was a perpetual circulatory “worker”: “for nature is a perpetual worker, generating fluids out of solid, and solids out of fluid, fixed things out of volatile, subtle out of gross and gross out of subtle, some things to ascend and by consequence, others to descend to requital to the former”¹⁶. In the *Boyle Letter* however he produced an entirely different line of argument as we have already seen. Here the “static” aether moved “downwards” owing to its variable density gradient. But what kept the aether in this state of variable density? Why didn’t the aether everywhere get mixed up into a uniform mass of average density? In his early papers Newton furnished a “mechanical” answer to this question. Bodies of all types were full of minute pores. Aether in these extremely narrow pores stood rarer than the aether in the “free spaces”. This, Newton thought, was demonstrated by various natural and “experimental” evidences, e.g. by Grimaldi’s effect, by the fact that well-polished pieces of flat glass got stuck together when pressed strongly, by the cohesion of bodies, by “filtration” process, and most strongly by the phenomenon of capillary action, where the fluid rose up in the tubes because, as Newton writes, “aether may stand rarer, not only in insensible pores of bodies, but even in the very sensible cavities of these pores (capillaries)”¹⁷.

So while the aether density inside a body dropped, the outer aether density gradually increased forming a halo of uniformly varying aether density around all bodies. Newton however was not very comfortable with this mechanism as it is apparent from the hesitant approach of the *Boyle Letter* where this mechanism is discussed at some length. Prof. Westfall has also persuasively argued that the incomplete paper *De aere* – which most likely was written around the same time as the *Boyle Letter* – marked the crucial turning point in Newton's thinking, when he finally parted ways with the "material" aether.

The next objection to the "material" aether, which appears to be the most sustained of all the objections, appeared in the *Principia*. If the mediating "material" media were to have its own "inertia" ("inertia" being an "essential" property of all matter), then it would hamper the motion of bodies through it in such a way that the laws of motion would not be valid for them. This argument actually stood at the core of Newton's disagreement with the "material" aether. We see it for the first time being introduced in 1668 in the *De grav*, then repeated in the *Principia* and later in the 1690s in a number of documents connected with the revision of the *Principia*¹⁸. In the *Principia* Newton estimated, how much the circulation of aether would hinder the motion of the planets in a Cartesian vortex and finds it to be considerable¹⁹. The ostensible target of this calculation in the *Principia* is the Cartesian "theory of vortex", but it basically applies to the hypothesis of "material" aether. In a Draft paper written in connection with the projected second edition of the *Principia* written in the 1690s, Newton linked up this supposed non-inertial characteristic of the "material" aether with other aspects of his theory of matter and with his doctrine of "essential" qualities to form a generalized refutation of the "material" aether hypothesis.²⁰

Theory of matter and the doctrine of "essential" qualities got hitched up with the critical consideration simply because the aether being "material" substance had to conform to these standards. In the *De grav* Newton differentiates between "space" and "body"²¹, by using among other characteristics such as "resistance to penetration" and "hardness" etc. – that bodies offer some sort of resistance, albeit in varying degree depending upon their internal construction. In the *Rule III* of the *Rules of Reasoning in Philosophy* of the second edition of *Principia*, Newton once again includes "hardness" and "impenetrability" among the five "universal qualities of the bodies".²² The "universal qualities" or the "essential qualities" are themselves defined here as those properties of bodies that are given to "neither intensification nor remission of degree, and which are found to belong to all bodies within the reach of our experiments".²³ Here was the "material" aether that penetrated all bodies with ease, seeped into the Boyle's apparatus when everything else was emptied out of it and was not supposed to offer any hindrance to bodies travelling through it. In not having "inertia" and not offering any sort of

resistance to penetration, the “material” aether violated some of “essential” traits of matter. Besides Newton’s much maligned Conversion Hypothesis or the theory that all matter had a common “material” substratum, was fundamentally based on the aether-matter convertibility hypothesis. If the “material” aether substance was itself devoid of these “essential” traits of “matter” then could the Conversion Hypothesis be justified? Could aether that itself lacked “impenetrability” and inertial characteristic, condense into common matter? It has become almost a convention to attribute the origins of Newton’s conversion hypothesis to his belief in alchemy. Yet we see that the aether-matter conversion hypothesis – which probably was at the root of the “common material substratum” – belief – emerging from the demands of the gravitational explanations in his early writings in the *Waste Book*. What happened to the great quantity of aether that was perpetually converging on the bodies? We see Newton’s discomfort in handling this question in the *Questiones* – the bodies would “swell” up or do they have hidden cavities?²⁴ And we see this same question looming up again when in 1690s Huygens considered Fatio’s “material” aether explanation of gravity.²⁵ It had to be absorbed into these bodies, at least a large part of it, if it has to be reflected back in a lesser “consistency”. It is possible that this hypothesis of continuous absorption of aether by bodies was what caused Newton to postulate the hypothesis of aether-matter conversion and subsequently led him to the generalized conversion hypothesis. At least from the earliest texts onwards, like the *Questiones* we see that the “material” aether was the “material substratum” that condensed into matter. In the *Hypothesis* and in the *Oldenberg Letter* it became the elemental prop to the frame on nature, for, as Newton says, the “frame of nature may be nothing but various contextures of some certain aethereal spirits or vapours condensed as it were by precipitation”.²⁶ It also explains why Newton linked up the conversion hypothesis with the refutation of the “material” aether hypothesis in the 1690s. A *Draft Revision* of the *Corollary III, Proposition VI* of *Book III* of the *Principia*, that Newton wrote in 1690s in connection with the planned but later abandoned second edition of the *Principia*, Newton interlinked all the objections against the “material” aether hypothesis to form an unified critique:

“If anyone should deny these hypothesis and have recourse to a third hypothesis, namely that one admits more matter with no gravity by which gravity of perceptible matter may be explained: it is necessary for him to assert two kinds of solid particles which cannot be transmuted into one another: the one (kind) of denser (particle) which are heavy (have gravity) in proportion to the quantity of matter, and out of which all matter with gravity and consequently the whole perceptible world is compounded and other (kind) of less dense particles which have to be the cause of the gravity of the denser one but themselves have no gravity, lest their gravity might have to be explained by a third kind and that (again by fourth and) so on to infinity. But these have to be very much less dense so as by their action shake apart and mutually scatter the dense ones: by which means all bodies composed of the denser one

would be quickly dissolved. And since the action of the less dense upon the denser will have been proportional to surface of the denser, while gravity arises from that action and is in proportion to the matter of which the denser ones consist, it is necessary that the surface of the denser ones must be in proportion to their solid content, and therefore that all those particles must be equally dense and that they can neither be broken nor worn away nor in any manner destroyed: or else the ratio of the surface to the solid content, and consequently the ratio of the gravity to the quantity of matter would be changed. Therefore one must altogether determine that the denser particles cannot be changed into less dense ones, and thereupon there are two kind of particles, and these cannot pass into one another".²⁷

The hypotheses that Newton is alluding to in the first sentence are the well-known *Hypothesis III* – or the “transmutation” hypothesis of the first edition of the *Principia* and another hypothesis of the *Draft* which later became the *Rule III* of the second edition of the *Principia* which we have quoted above. The passage has been variously interpreted. What Newton is pointing out here is that a conceptual disharmony exists between various components of “material” aether explanation, e.g., the “physical” characteristics of the “material” aether, the “essential” qualities doctrine of the *Principia*, the conversion hypothesis etc. That this leads to an anomalous epistemic situation within the network of theories used for explanation of gravitation is obvious. The passage shows that even if the “essential” qualities doctrine is abandoned, the variable density aether hypothesis still leads to an infinite regress and comes into conflict with the conversion hypothesis on considerations independent of “essential” qualities doctrine.

The passage quoted above shows us the complex variety of factors that together determined the unacceptability of the “material” aether hypothesis. In what sense was it correct to assume the aether substance was “material” if it violated most of the known “essential” characteristic of “matter”? Could this aether that lacked the ability to offer any resistance to bodies be visualized to “mechanically” interact with bodies? These were weighty considerations, going far beyond the operational – mechanistic aspect of the explanations and, although discussed in terms of “internal consistency”, they actually touched upon larger questions dealing with the basic domain of all the gravitational explanations. What was to be considered *natural and legitimate mode of interaction between “physical entities”*, and what was the meaning of “mechanical” action in this context? Newton surely did not satisfy himself entirely on all the points, for as we know he abandoned this “refutation” of the “material” aether and went back to the “universal electrical aether” after 1707. Perhaps, as Prof. Guerlac has suggested, owing to Hauksbee’s and Desaguliers’ electrical experiments Newton once again started entertaining the possibility that aether could be considered as an “experimental” entity. There were certainly some aspects in these experiments which convinced Newton that the “electrical spirits”, however unsubstantial and intangible, may be treated as a “mechanical, experimental, phenomenon.”

A complete abandonment of the “material” aether came much later, somewhere around late 1716, at the end of the second phase of aether writings, when Newton penned down some *Observations* on the electrical experiments as a revision of the texts intended for inclusion in the 1717–18 edition of the *Opticks*. There is also another document written during 1716 and meant to be published with the *Book III* of the third edition of the *Principia*, which further substantiates the view that Newton at this period not only abandoned the “material” aether, but also considered aether as such outside the realms of “phenomenon”. In two very important studies of Newton’s gravitational writings McGuire (1966 & 1968) has examined both these documents. Following important points emerge from these two documents: (a) Newton once again makes a strong distinction between “body” and “space” (or aether) on the grounds of essential qualities of impenetrability, (b) remarks on the highly speculative character of the conversion hypothesis and, (c) places the aether outside the limits of “phenomenon”. In one part of the *Observation I* Newton writes: “To distinguish this medium from the bodies which flote in it, & from their effluvia & emanation & from Air, I will henceforth call it Aether & by the word bodies I will understand bodies which flote in it, taking this name not in the sense of the modern metaphysician, but in the sense of common people & leaving it to the metaphysicians to dispute whether the aether and bodies can be changed into one another”²⁸. In a similar spirit the other document goes on to define “body” as everything that can be “moved”, “touched” and offers “resistance to tangible things”. The gulf between “aether” and “matter” are now unbridgeable and Newton notes in this document: “The subtle matter in which planets flote, and in which bodies move without resistance is not a phenomenon.”²⁹

VI. Concluding Remarks

The original purpose with which we set upon this rather long examination of Newton’s text may now be recalled again: (a) to reconstruct the conceptual unity within the “material” aether program, and (b) to explore the relationship between “descriptive” epistemology and “rational reconstruction”. As a subject of case study Newton’s “material” aether program has some interesting features. “Material” aether program being essentially a degenerate program – in the sense that the entire program was eventually refuted and banished out of physical explanation – poses a special challenge for forward-looking character of philosophical reconstruction. Can we learn some methodological lessons of general value from this defunct structure? I would be taking this up presently. On the other hand, *contact action*, which lay at the foundation of the “material” aether program was the only mechanism that was transparent, immediately intelligible and intuitively acceptable

among all the alternative explanations. Yet we find that the counter-intuitive programs generally flourished. While the *actio in distans* found much favor in the 17th & 18th century and a very devious justification from Kant and Priestley, and the basic presupposition of the other program – that space can be considered an active determinant of motion – eventually found incorporation into our contemporary physics. This rather well demonstrates the limit to which the intuitive criteria of logicity and of logical transparency/immediacy can be considered a factor of validity of hypotheses in physical sciences. We will be elaborating on this point a little later. Three main conclusions that I would like to draw from our study, having bearing on the question of “rational reconstruction” as well as on the problem of “discovery” are presented below.

(1) One of the greatest difficulties in philosophical reconstruction of Newton's texts is to make explicit the implications of different concepts and to establish conceptual linkages between different theoretical entities. In this being totally faithful to Newtonian texts is not very helpful, as Newton uses a number of these ideas in a “tacit” way, not always elaborating on all the implications. A number of examples can be cited to illustrate this difficulty. In Newton's writings on absolute space, for instance, terms like “frame of reference” and “inertial system” do not occur – this terminology was created by further elaboration of the implicit aspects of Newtonian absolute space. Yet reading between the lines of the *Scholium* on absolute space in the *Principia*, and of the texts of *De gravitatione*, we see a number of implications as well as alternative formulations of what was “discovered” later in the *post facto* analysis. A philosophical clarification of the significance of the idea of absolute space in Newton's system therefore calls for an imaginative conceptual reconstruction of the meaning of the texts and not mere dogmatic faithfulness to the texts. This, I believe, in a way distinguishes the philosophical reconstruction or the “rational reconstruction” from the historical “descriptive” epistemology where it is customary to attach great significance to textual comparison.

Another example of this distinction is also well illustrated by the question of elasticity of the “material” aether, we have dealt with in our text briefly. Is it possible that Newton, who – as it is generally known – was really fussy about details, did not ponder over the question that if aether particles merely floated around in void than wherefrom the composite “medium” got its characteristic elasticity? Prof. Rosenfeld is perfectly right in suggesting that the answer to this question lay beyond the conceptual horizons of Newton and of the 17th century physics. This however did not detract Newton from attempting to solve the problem and considering various possibilities. However the possibilities Newton considered can only be worked out by carefully considering the implications of interconnection of various hypothesis/ideas Newton introduced around 1690s, when he attempted to

grapple with this complex question. In the text of this paper I have already outlined a framework which inter-connects the different key ideas that Newton emphasized in the 1660s, e.g., the “double force”, the vacuity of the universe, the connection between the internal architecture of matter and its physical properties etc. Yet we do not see all the links in the chain very clearly until we refer back to the texts of *De aere et aether*, where Newton uses the concept of *actio in distans* to develop a pulsating and springy aerial medium.

But why were these aspects considered implicitly? Historians have often suggested that it was customary of Newton to treat speculative aspects of material aether and of theory of matter with extreme caution – example: Newton’s treatment of “double force” hypothesis in the *Conclusio* and the eventual withdrawal of the *Conclusio* from publication. The same can be said of the hypothesis of “immaterial” aether – the idea that space could be considered an “active” participant in determining motion of the bodies was so radical and so much against the accepted tradition that Newton chose to articulate it only with some reservations. But his is not all. Many of the ideas/concepts that Newton treated implicitly were pregnant with possibilities and the discussion often apprehend future lines of investigations including future discoveries – e.g., treatment of absolute space in the *De gravitatione*, the speculations on nature of light in the many versions of the *Queries* of the *Opticks*. This “latent” or the “tacit” aspect is, I think, a basic feature of all types of creative scientific activity. The philosophical “reconstruction” being much more forward-looking enterprise attempts to capture this dimension, often without sticking to the texts dogmatically and seldom with any regards for the chronology.

(2) We have made an attempt to trace the long chain of arguments through which Newton tried to establish and later refute the “material” aether hypothesis. In dealing with this we see that in our contemporary methodological literature an exaggerated amount of importance has been given to the forms of inference, i.e., if the inference could be reduced to an induction (among others Reichenbach’s program) or if a valid inference it should fit the hypothetic-deductive form. Newton’s arguments are usually elegant. In establishing the generalized characteristics of the aether, he usually argues from the “known” and “observed” to a certain general conclusions and then, under the supposition of “consistency of nature”, applies these general conclusions to develop the models and mechanisms of unobservable micro-phenomenon (the “invisible realm”). In case of refutation of the “material” aether we see a different pattern of argumentation. Here a whole ensemble of concepts are put to test by assuming a thesis to be correct and then demonstrating that (a) it leads to logical absurdity, e.g., infinite regress, (b) that it results in incompatibility with observed results, and (c) it leads to inconsistency among supporting hypotheses. Looking at the nature of argu-

mentation, one would be hard put to say, even for this case of a “degenerate” research program, that the process of argumentation was faulty and it does not seem very relevant to ask if it would fit the hypothetic-deductive or the inductive pattern. We therefore feel that in dealing with broader methodological questions and in dealing with the issues of theory assessment, the criteria of “form of argumentation” should not be given the central position that it occupies today. The emphasis should rather shift on actual examination of premises of arguments, with the implicit heuristic and with the modular articulation of the “logic of the situation”.

(3) Lastly, an interconnected issue is that of counter-intuitive hypothesis, which – as we have already mentioned – demonstrates the limitations of applicability of methodological *regulae* in physical sciences rather well. Formal methodological *regulae* mostly tend to take for granted logical transparency and immediacy. If, however, the empirical results tend to support a generally counter-intuitive solution the situation is either judged (a) as anomalous and totally unintelligible (Huygens’ and Leibniz’s response to the possibility of *actio in distans*), (b) as an incomplete description, needing further elaboration (Newton’s attitude to the “phenomenological” program), and (c) or a situation needing a critical review and a new modular logic (Kant’s examination of Newtonian mechanics and Reichenbach’s (Putnam’s plea for a three valued logic for Quantum Mechanics etc.). The developments in physical sciences have shown that there are no special reasons why an absolute preference must be given to transparent and immediately intelligible hypothesis. This is also one strong reason why the “discovery machine” or the algorithm of discovery approaches are untenable. General reason is of course that we cannot have any prior logic for prediction of *all possible empirical results*; it is even more difficult to imagine that we will ever have prior modular justification of something that we have never encountered. A counter-intuitive hypothesis therefore, is a point of asymmetry in the explanatory complex, which bifurcates the predictive logic, changing its character fundamentally.

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