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Gravity and *De gravitatione*: The development of Newton's ideas on action at a distance

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Gravity and *De gravitatione*: The development of Newton's ideas on action at a distance
ABSTRACT

This paper is in three sections. The first establishes that Newton, in spite of a well-known passage in a letter to Richard Bentley of 1692, did believe in action at a distance. Many readers may see this merely as an act of supererogation, since it is so patently obvious that he did. However, there has been a long history among Newton scholars of allowing the letter to Bentley to over-ride all of Newton's other pronouncements in favour of action at a distance, with devastating effects on our understanding of related aspects of his physics and his theology. Furthermore, this misconceived scholarly endeavour shows no sign of abating. The second section then offers a historical reconstruction, based on Newton's writings, of how, when and why he began to accept actions at a distance and make them one of the cornerstones of his physics. Finally, using this chronological account of Newton's use of actions at a distance, the paper re-assesses the claims of B. J. T. Dobbs that Newton's important manuscript, *De gravitatione et aequipondio fluidorum*, was written, not in the late 1660s or early 1670s as was previously supposed, but during the composition of the *Principia*, in 1684 or 1685.

KEY WORDS

Isaac Newton, action-at-a-distance, gravity, force, aether, attraction

**Gravity and *De gravitatione*:
The development of Newton's ideas on action at a distance**

In this paper I want to do three things. Firstly, I want to spend some time re-affirming that Newton did believe in action at a distance. Many readers may see this merely as an act of supererogation, since it is so patently obvious that he did. However, there have been a couple of prominent claims in the recent literature, repeating the old mistakes that Newton couldn't have believed in action at a distance because nobody in their right minds could believe in it, and besides he even said he did not believe in it. So, I'll try to counteract these claims, and along the way, say a little about the history of interpretations of Newton's attitude to *actio in distans*.

I then want to go on to look in detail at the development of Newton's ideas on action at a distance, as far as we can reconstruct it, from the late 1660s to the third edition of the *Opticks* in 1717.

Finally, I want to use this account of the development of his thought to try to help us to decide when Newton composed his *De gravitatione*. In spite of the short title, this is not a treatise on gravitational attraction—the work is named after its incipit, which translates as: “On the weight and equilibrium of fluids and of solid bodies in fluids...” The title is misleading, however, because much of the work is taken up with a digression on the nature of space and body, and this makes it a highly interesting and highly important work. It used to be believed that this was an early work, written sometime in the period from 1664 to 1673. But Betty Jo Dobbs claimed in 1991 that the *De gravitatione* was written between December and March 1684/5, and the signs are that this is now superseding the earlier dating.

1. Newton and action at a distance

Let us start by looking at an interesting quotation from John Stuart Mill's *System of Logic*, published in 1843. In Book V, Chapter III, which is devoted to what he calls “*a priori* fallacies”, Mill considers one form of this kind of fallacy which he sums up as: “Whatever is inconceivable must be false” (Mill, 1974, p. 752). He uses the rejection of action at a distance as a good example of this kind of fallacy.

Rather more than a century and a half ago it was a scientific maxim, disputed by no one, and which no one deemed to require any proof, that “a thing cannot act where it is not.” With this weapon the Cartesians waged a formidable war against the theory of gravitation, which, according to them, involving so obvious an absurdity, must be rejected *in limine*: the sun could not possibly act upon the earth, not being there. It was not surprising that the adherents of the old systems of astronomy should urge this objection against the new; but the false assumption imposed equally on Newton himself, who in order to turn the edge of the objection, imagined a subtle ether which filled up the space between the sun and the earth, and by its intermediate agency was the proximate cause of the phenomena of gravitation. “It is inconceivable,” said Newton, in one of his letters to Dr. Bentley,

that inanimate brute matter should, without the mediation of something else, which is not material, operate upon and affect other matter *without mutual contact*. . . . That gravity should be innate, inherent, and essential to matter, so that one body may act on another, at a distance, through a vacuum, without the

mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity, that I believe no man, who in philosophical matters has a competent faculty of thinking, can ever fall into it.

This passage should be hung up in the cabinet of every cultivator of science who is ever tempted to pronounce a fact impossible because it appears to him inconceivable (Mill, 1974, pp. 753-4).

Now, notice that Mill does not regard action at a distance as a fallacy—the fallacy lies in assuming that action at a distance is impossible. Indeed, Mill goes on to say

In our own day one would be more tempted, though with equal injustice, to reverse the concluding observation [of Newton's], and consider the seeing any absurdity at all in a thing so simple and natural, to be what really marks the absence of "a competent faculty of thinking." No one now feels any difficulty in conceiving gravity to be, as much as any other property is, "inherent, and essential to matter," nor finds the comprehension of it facilitated in the smallest degree by the supposition of an ether (though some recent inquirers do give this as an explanation of it), nor thinks it at all incredible that the celestial bodies can and do act where they, in actual bodily presence, are not. To us it is not more wonderful that bodies should act upon one another "without mutual contact," than that they should do so when in contact; we are familiar with both these facts, and we find them equally inexplicable, but equally easy to believe.

A few lines further on Mill says that "the ancient maxim that a thing cannot act where it is not... *probably is not now believed by any educated person in Europe*" (Mill, 1974, p. 754).

Now, there is a strange irony here, because the easy acceptance of action at a distance which Mill documents for us was in fact directly due to the influence of Newton. It was Newton's own suggestion, briefly mentioned in the Preface of the *Principia* and brilliantly illustrated in the Queries added to the *Opticks*, that all physical phenomena might be explained in terms of attractive and repulsive forces operating between the particles of matter, which shaped the physical sciences in the Enlightenment and led to what Mill saw as the wholesale rejection of the maxim that a thing cannot act where it is not (*e.g.* Rowning, 1735; Knight, 1748; Priestley, 1777; Higgins, 1786; Hutton, 1792. See also Schofield, 1970; and Thackray, 1970). Furthermore, and this is even more ironic, this Newtonian approach was about to give way, shortly after Mill wrote, to a vigorous revival of the older view that a thing cannot act where it is not. And indeed it seems likely that Mill's prominent discussion of it, in this highly influential work, usually regarded as definitive of philosophy of science in its day, was instrumental in shifting the attitudes of Victorian scientists back to a rejection of action at a distance. The authority which promoted this shift was not Mill's (indeed, as we've seen, Mill still readily accepted action at a distance), but Newton's. By quoting Newton's letter to Bentley, and presenting it as a forceful rejection of action at a distance, Mill seems to have unintentionally made Victorian physicists make a U-turn with regard to actions at a distance, so that where they once accepted them, they now vigorously dismissed them.

Certainly, as F. H. Van Lunteren has pointed out, this precise passage from Newton's letter to Bentley became the most frequently quoted statement of Newton's in the second half of the nineteenth-century (Lunteren, 1988). Michael Faraday, for example, writing in 1855, cited the letter to Bentley and noted "the strong conviction expressed by Sir Isaac Newton, that

even gravity cannot be carried on to produce a distant effect except by some interposed agent fulfilling the conditions of a physical line of force” (Faraday, 1839-55, iii, p. 532, see also p. 507). Furthermore, this single passage from Newton’s private correspondence continues to be used by historians of science to prove that Newton did not believe in action at a distance (Henry, 1994).¹

Given the very clear, and fairly numerous, statements in which Newton shows that he did believe in action at a distance, and the undeniable fact that attractive and repulsive forces acting at a distance became characteristic of Newtonianism throughout the eighteenth century (Schofield, 1970; Thackray, 1970),² it should be blindingly obvious that this single passage has been, and continues to be misinterpreted. So, we need to take a close look at it.

Richard Bentley had been appointed to deliver the first set of annual Boyle Lectures, established by the Will of Robert Boyle. Commissioned to combat atheism, Bentley decided to use Newtonian natural philosophy to fulfil that aim and entered into correspondence with Newton to make sure he made no mistakes. In Newton’s second letter to Bentley he raised an objection with which Bentley was subsequently careful to comply:

You [Bentley] sometimes speak of Gravity as essential and inherent to Matter. Pray do not ascribe that Notion to me... (Newton, 1959-77, iii, p. 240).

Now, notice that Newton is not objecting to the suggestion that gravity acts at a distance. There is not so much as a hint of that. The objection is to the suggestion that gravity is an *essential* property of matter (that is to say, that, like extension, matter cannot be imagined without gravitational attraction). Bentley was careful to check with Newton a second time to make sure that what he now intended to say in his lecture passed Newton’s scrutiny. At the end of the second numbered paragraph in his letter, Bentley wrote this:

’tis unconceivable, yt inanimate brute matter should (without a divine impression) operate upon & affect other matter without mutual contact: as it must, if gravitation be essential and inherent in it (Newton, 1959-77, iii, p. 249).

Let’s now look at Newton’s response to this very comment:

The last Clause of the second Position I like very well. It is inconceivable, that inanimate brute Matter should, without the Mediation of something else, which is not material, operate upon, and effect other Matter without mutual Contact, as it must be, if Gravitation in the Sense of Epicurus, be essential and inherent in it. And this is one Reason why I desired you would not ascribe innate Gravity to me. That Gravity should be innate, inherent and essential to Matter, so that one Body may act upon another at a distance thro' a Vacuum, without the Mediation of any thing else, by and through which their Action and Force may be conveyed from one to another, is to me so great an Absurdity, that I believe no Man who has in philosophical Matters a competent Faculty of thinking can ever fall into it. Gravity must be caused by an Agent acting constantly according to certain Laws; but whether this Agent be material

¹ For a brief account of the recent historiography see Henry (1994). To which can now be added, for example, Janiak (2008) and Kochiras (2009). Because a number of Newton specialists have taken, and continue to take, this mistaken line they infect other historians of science, who take on trust the claim that Newton didn’t believe in action at a distance, and so the rot spreads. The list of relevant citations in this regard goes on and on, but see for one recent example, Dear (2006), pp. 27-8.

² I am aware, of course, that the term “Newtonianism” covers a multitude of sins, but there is a strong case to be made (although I’m not going to do it here) that the main signification of the term was the attempt to bring about Newton’s desire to explain all the phenomena of nature by attractive and repulsive forces. See, for example, Schofield (1970) and Thackray (1970).

or immaterial, I have left to the Consideration of my Readers (Newton, 1959-77, iii, pp. 253-4).

As Emile Meyerson (1930, pp. 447-56) and I (Henry, 1994) have already pointed out, in spite of first appearances, this passage does *not* say that action at a distance is inconceivable, much less that it is impossible. What Newton is trying to do is to make sure that what he considers to be the observed reality of action at a distance can be used to prove the existence of God (natural proofs of the existence of God are, after all, the main theme of the correspondence). Newton knows that this natural theological enterprise will be undermined if it is assumed that gravity is simply essential to matter in the same way that extension is. If “Gravitation in the Sense of Epicurus” becomes generally accepted, that is to say, gravitation that is “inherent and essential in matter”, then the existence of gravitational attraction could not be used to establish the necessary existence of “something else, which is not material” which *enables* matter to “effect other matter without mutual contact.” That, he says, is why “I desired you would not ascribe innate gravity to me.” So, what “no Man who has in philosophical Matters a competent Faculty of thinking” can ever believe is *not* action at a distance *per se*, but that the observed action of “one Body upon another at a distance thro’ a Vacuum” could occur without the mediation of something beyond body—something “which is not material”.

To reiterate, what Newton is really saying to Bentley is that although they (he and Bentley) both know gravity is an action at a distance they shouldn’t allow this to be seen as an *essential* property of matter because to do so is to provide a hostage to atheists. They must always take pains to point out that this observed property of matter could only have accrued to matter as a result of divine intervention. For extra assurance that this is the correct interpretation of this passage, note that there is *no* suggestion that Newton is differing from the comment by Bentley (“the last Clause of the second Position”), nor that he is introducing a new and different topic. For all the convolutions of Newton’s prose, which make it look on a superficial reading as though he is rejecting action at a distance, once we see that he is agreeing with Bentley, we can be fairly confident that he is therefore trying to say, as Bentley did, that action at a distance is impossible *unless God impresses it upon matter*, because gravity is not, as is generally acknowledged by all mechanical philosophers, an “essential and inherent” property of matter.

Indeed, it is hard to see why Newton should be so concerned about the issue of “Gravity as essential and inherent to Matter” being attributed to him, if he did *not* think gravity was an action at a distance between the gravitating bodies. If he believed gravity operated by means of some physical connection between the Sun and the planets, or the Earth and an apple, then the notion of gravity as inherent in matter does not arise. Certainly, nobody would ever have accused Descartes of developing an idea of gravity inherent in matter. Descartes’s gravitational force was a force of impact, or a chain of impacts consequent upon one another, brought about not by the gravitating bodies themselves but by particles moving between those bodies. Newton’s gravity, by contrast, is something caused by an active principle in bodies, and it therefore becomes important to insist that this active principle is not simply a natural or logical concomitant of matter, but must have been put into matter by God (Henry, 1984; Koyré, 1965, pp. 154-5).

Certainly, Bentley interpreted Newton’s words in this way. In the Boyle Lecture which Bentley wrote after receiving this letter from Newton he said:

Now mutual Gravitation or Attraction (in our present acceptation of the Words) is the same thing with This; 'tis an operation or virtue or influence of distant Bodies upon

each other through an empty Interval, without any *Effluvia* or Exhalations, or other corporeal Medium to convey and transmit it (Bentley, 1693, p. 29; also in Newton, 1978, p. 341).

And he made explicit the highly convenient, even desirable, theological implications:

This Power [of gravitational attraction] therefore cannot be innate and essential to Matter. And if it be not essential; it is consequently most manifest (seeing it doth not depend upon Motion or Rest or Figure or Position of Parts, which are all the ways that Matter can diversify itself) that it could never *supervene* to it [matter], unless impress'd and infused into it by an immaterial and divine Power (Bentley, 1693, p. 29; also in Newton, 1978, p. 341).

It is perhaps also worth pointing out that Bentley's interpretation of Newton's meaning makes it clear that Newton, assuming Bentley was right, did not believe that gravity was performed directly by God, continually and directly "mediating" between all bodies. This is important because a number of scholars have interpreted this statement, in the third letter to Bentley, to imply that the link between two interacting bodies was always God himself (Westfall, 1986, p. 233; Dobbs, 1991).³

In fact, we can see from the last sentence of this famous passage that Newton believes gravity is executed by a secondary causal agent (where God, as always, is the primary cause). It must be a secondary agent because Newton says that it might be material ("whether this Agent be material or immaterial, I have left to the Consideration of my Readers"). He would never say such a thing if he had God in mind. So, Newton does not declare action at a distance to be impossible and then use this as a way of insisting that, therefore, God must continually and directly act to bring about gravitational effects. He merely insists that matter could not attract other matter at a distance unless the power to do so was imposed upon it by God. Having imposed this power on matter, it is the power which is subsequently the direct cause of gravity, not God. As Newton says later in Query 31 of the *Opticks*, the cause of gravity is an active principle in matter, and that active principle is not an essential aspect of matter (without which the concept of matter makes no sense, as non-extended matter would make no sense) but is something which must have been added to matter by God.

All these things being consider'd, [Newton wrote] it seems probable to me, that God in the Beginning form'd Matter in solid, massy, hard, impenetrable, moveable Particles... It seems to me farther, that these Particles have not only a *Vis inertiae*, accompanied with such passive Laws of Motion as naturally result from that Force, but also they are moved by certain active Principles, such as is that of Gravity, and that which causes Fermentation, and the Cohesion of Bodies (Newton, 1979, pp. 400-01).⁴

³ In particular, Westfall (1986) and Dobbs (1991). For a critique of their views in this regard see Henry (1994), pp. 123-6.

⁴ Newton, *Opticks* (1979), pp. 400-01. There has been a strong tendency to see the last sentence of the passage from the third letter to Bentley as referring to the same subject as the previous three sentences. It was this, at least in part, which led Westfall (1986) and Dobbs (1991) astray (see previous note), and it has more recently led Hylarie Kochiras (2009) astray. Assuming that all four sentences of the passage refer to the same subject, Kochiras has to explain the odd circumstance that Newton first of all says the mediating thing responsible for gravity is "not material" and then says it can be either "material or immaterial" (Newton, 1978, pp. 253-4). She suggests that "Newton states his own view in the first sentence, while in the last he describes what he did in the *Principia*, which was to refrain from stating his own view" (Kochiras, 2009, p. 268, n. 5) Certainly, Newton's reference in the last sentence to the "Consideration of my Readers" shows that he is referring there to what he wrote in the *Principia*, but the subject of this sentence is the secondary cause of gravity (the "Agent acting constantly according to certain Laws"). The subject of the three sentences before this, if Kochiras is correct,

Read in this way, Newton's letter to Bentley is by no means incompatible with all the statements he makes where he clearly favours the notion of actions at a distance. Consider, for example, the clear statements in the Queries at the end of the *Opticks*:

Do not bodies act upon light *at a distance*, and by their action bend its rays" [Query 1] (Newton, 1979, pp. 339).

Pellucid Substances act upon the Rays of Light *at a distance* in refracting, reflecting, and inflecting them, and the Rays mutually agitate the Parts of those Substances *at a distance* for heating them; and this Action and Re-action *at a distance* very much resembles an attractive Force between Bodies [Query 29] (Newton, 1979, pp. 370-71).

And:

Have not the small Particles of Bodies certain Powers, Virtues, or Forces, by which they act *at a distance*, not only upon the Rays of Light for reflecting, refracting, and inflecting them, but also upon one another for producing a great Part of the Phaenomena of Nature? For it's well known, that Bodies act one upon another by the Attractions of Gravity, Magnetism and Electricity; and these Instances shew the Tenor and Course of Nature, and make it not improbable but that there may be more attractive Powers than these [Query 31] (Newton, 1979, pp. 375-6).⁵

By the time Newton's letters to Bentley appeared in print, and in public, in 1756 (Newton, 1756, also in Newton, 1978), Newtonians in Britain and all over the Continent were fully engaged in pursuing the Newtonian dream, as expressed in the Preface to the *Principia*, of explaining all the phenomena of nature in terms of attractive and repulsive forces acting at a distance between particles (Newton, 1999, pp. 382-3). It is perfectly possible that had any eighteenth-century Newtonians read Newton's letters, in 1756 or the decades following, they would have read his statement to Bentley in the same way that Bentley did. Certainly, Daniel Bernoulli, for example, understood and subscribed to the theological underpinning. Writing to Leonard Euler in February 1744, he stated it clearly:

I cannot hide from you that on this point [action at a distance] I am a complete Newtonian, and I marvel you so long adhere to the Cartesian principles;... if God could create a soul whose nature is incomprehensible to us, so could he impress a

would have to be the same (and so, although he left things open in the *Principia*, he is now telling Bentley that he believes the secondary cause of gravity is immaterial), but in fact, these three sentences are clearly not concerned with the secondary cause of gravity, but with the issue of whether gravity can be said to be innate or essential to matter—that is to say, whether gravity can be held to be a natural (or even logical) concomitant of matter, in the way that extension is. There is a shift of focus between the first three sentences and the last, shifting from one subject to another as Newton moves on in the last sentence to make a different (though related) point. A careful reading will show that the mediating "something else" referred to in the first sentence, and the mediating "any thing else" of the third sentence, is required to enable matter to attract other matter (the unacceptable alternative would be to acknowledge matter can do this simply by its nature). This must be God, and is held to be "not material". The agent said to cause gravity in the fourth sentence, is an unknown agent and could, therefore, be either "material or immaterial"; clearly this is not God but a secondary cause.

⁵ Newton ended the *Opticks*, in 1704 with 21 "Queries". He added two new ones, numbered 21 and 23 to the Latin edition, *Optice*, of 1706. These became Queries 29 and 31 in the second English edition of 1717, when Newton added the eight so-called "aether Queries", which he interpolated as Queries 17 through to 24. It is now customary to refer to the Queries by their numbers in the 1717 edition.

universal attraction on matter, even if such an attraction is beyond our comprehension (quoted from Wilson, 1992, p. 399).

There is no doubting, anyway, that eighteenth-century Newtonians accepted actions at a distance, even those who preferred Newton's reductionist aether theories, as an alternative to the supposition that *all* atoms were endowed with attractive and repulsive forces (Schofield, 1970; Thackray, 1970). In the nineteenth-century backlash against actions at a distance, Newton's aether speculations, as discussed in the Queries at the end of the *Opticks*, were appropriated to show that he believed only in contact actions, and even today some scholars refer to this aether as a "mechanical" aether. A careful reading of Newton's ideas on aether, however, leave the reader in no doubt that all the operations of the aether depended upon the assumption that its particles were mutually repellent and stood far apart from one another because of strong repulsive forces acting across the distances between them.⁶ As Leon Rosenfeld (1969, p. 31) has pointed out, "The constitution of the aether discussed in the Queries... is that of an elastic medium of such extremely low density that its single constituent particles must be assumed to be separated by considerable spatial extensions void of every kind of matter". Indeed, as we'll see below (in Section 2), it was while speculating on an all-pervasive aether that Newton first introduced actions at a distance into his physics.

Inspired by their misreading of the third letter to Bentley, a number of scholars have sought, and believed they had found, further evidence for Newton's rejection of action at a distance. It is necessary, therefore, to point out the inadequacy of these arguments too. There are two main sources for these secondary arguments. Firstly, the various places, mostly in the *Principia* but also in the *Opticks*, where Newton makes methodological *apologia* for seeming to talk about action at a distance, when really we don't know how gravity and similar forces work. Secondly, in the *Scholium generale* added to the second edition of the *Principia* in 1713, where Newton is interpreted as saying that God can only act where he is present (and therefore, *a fortiori*, matter must also be restricted to acting only where it is).

Before going any further, it is worth pointing out that if it wasn't for the comment in the third letter to Bentley, which seemed to provide succour to those appalled by Newton's talk of distant action, it is highly unlikely that anyone would have seized on these sources in the way that they have done. Given the fact that this single comment in the letter to Bentley is directly countered by numerous other statements where Newton explicitly invokes action at a distance, it behoved those who refused to believe that Newton might accept *actio in distans* to find other statements in support of their reading of a Newton who denied this supposed absurdity. In short, without the comment in the third letter to Bentley, there is no real evidence that Newton rejected the concept of action at a distance. But let us take these two sources of argument in turn.

Firstly, there are the repeated statements like this, which follows Definition 8, at the outset of the *Principia*:

I use interchangeably and indiscriminately words signifying attraction, impulse, or any sort of propensity toward a center, considering these forces not from a physical but only from a mathematical point of view. Therefore, let the reader beware of thinking that by words of this kind I am anywhere defining a species or mode of

⁶ See, for example, Queries 21 and 22 in the *Opticks*, where Newton first of all supposes that the particles of the aether always endeavour to recede from one another, with the result that the aether is "exceedingly more rare and elastick than Air", and then tells us that aether "should be supposed 700000 times more elastic than our Air, and above 700000 times more rare". Newton (1979), p. 352.

action or a physical cause or reason, or that I am attributing forces in a true and physical sense to centers (which are mathematical points) if I happen to say that centers attract or that centers have forces (Newton, 1999, p. 408).

Or this, from Book I, Section 11:

I now go on to set forth the motion of bodies that attract one another, considering centripetal forces as attractions, although perhaps—if we speak in the language of physics—they might more truly be called impulses. For we are here concerned with mathematics; and therefore, putting aside any debates concerning physics, we are using familiar language so as to be more easily understood by mathematical readers (Newton, 1999, p. 561, see also p. 588).

There is a long-standing tradition among Newton scholars to see such comments as (much-needed!) confirmations of Newton's supposed rejection of actions at a distance. He only uses the word "attractions" for convenience, but really it should be taken for granted that what he really means is not attraction but impulse.

Even so, Alexandre Koyré and I. Bernard Cohen have expressed their dismay at Newton's slap dash use of this kind of "convenient" talk (Koyré, 1965, pp. 149-63; Cohen, 1980, pp. 72-8). Almost inevitably, his readers failed to remember his warnings and assumed—foolishly, according to Koyré and Cohen—that Newton really did believe in occult attractions. Cohen demonstrates the confusing way Newton writes by pointing to Proposition 23 in Book II of the *Principia*:

If the density of a fluid composed of particles that are repelled from one another is as the compression, the centrifugal forces [or forces of repulsion] of the particles are inversely proportional to the distances between their centers. And conversely, that particles that are repelled from one another by forces that are inversely proportional to the distances between their centers constitute an elastic fluid whose density is proportional to the compression (Newton, 1999, p. 697).

Newton's claim to be talking only loosely when he used the word attraction was, as Koyré pointed out, "by no means convincing". Pointing out that in the Latin, as well as the passive "attractio" (attraction), Newton also wrote in much more active terms that "bodies *trahunt* each other", Koyré went on to say that:

The mathematical reader will doubtless understand – or misunderstand – Newton as asserting the existence in bodies of forces by which they act upon each other (pull each other, *trahunt*), in spite of the distance that separates them. And, *as he never encounters a mention of any medium that transmits this action*, the reader will conclude, like Huygens and Leibniz, and also Cotes, that Newton postulates action at a distance... (Koyré, 1965, p. 154, my emphasis)

Koyré and Cohen were committed to seeing Newton's apologetic escape clauses as genuine expressions of his disbelief in actions at a distance because they knew of, and had catastrophically misread, the third letter to Bentley. If they had never seen this letter, they might well have accepted that all the evidence pointed to the fact that Newton believed in actions at a distance.

Whatever Koyré and Cohen wished to believe, these passages were not written to deny the possibility of action at a distance, but merely to cover Newton's embarrassment if an explanation that did not involve *actio in distans* was forthcoming. Newton of course knew that the concept of *actio in distans* was dismissed out of hand by virtually all his

contemporaries—especially those in the thrall of Descartes. Furthermore, he was sufficiently steeped in English Baconianism and what Richard H. Popkin called the “mitigated scepticism” that went with it, to accept that an explanation of gravity might well emerge, and what’s more, that it might not have to rely on actions at a distance (Dear, 1985; Henry, 1986; Popkin, 2003). Indeed, there is even evidence to suggest that it might have crossed Newton’s mind that electricity could displace his belief in actions at a distance (Home, 1985). It was important, therefore, that Newton should be able to point to these kinds of passages scattered throughout the *Principia* and lay claim merely to talking of attractions as an interim measure. Precisely the same could be said of the Queries in the *Opticks*. It is in the Queries that Newton speaks most explicitly and most freely of interparticulate forces acting across empty space. But if somebody were to come up with a more plausible account of the phenomena without invoking actions at a distance, all Newton had to do, to save face, was to point out that he had not written dogmatically, but only tentatively and questioningly.

Be that as it may, the real point here is that—irrespective of how Koyré, Cohen, and others wanted to read these passages—they cannot be used to prove that Newton rejected actions at a distance. At best, they can be used to suggest he was noncommittal, but that is by no means the same as claiming he was opposed to distant action. Indeed, for Koyré, these passages were not non-committal enough, since they clearly led many contemporary readers, mathematical and non-mathematical alike, to believe in action at a distance. Koyré was clearly baffled as to why Newton, if he really wanted to reject attractions at a distance, didn’t simply commit himself to talking throughout of “impulses”, “*vis centripeta*”, and other straightforwardly mechanical notions (Koyré, 1965, pp. 153-4). The answer to Koyré’s problem lies in the conditional clause: “if he really wanted to reject attractions at a distance”. The truth of the matter is that Newton did *not* want to reject action at a distance. Read without the prejudice attendant on an acceptance of Mill’s fallacy, it is perfectly clear, and this will be brought-out in the following section of this paper, that Newton did believe actions at a distance provided the most likely solution to gravity and other phenomena, and this kind of “method” talk was simply a way of forestalling the “cavilling” that was an abomination to Newton (Iliffe, 1999).⁷

Following on from this kind of discussion by Koyré and Cohen, we have a new refinement offered by Andrew Janiak. Claiming a special “technical” sense of what Newton means by “mechanical”—namely a cause operating only on the surface of bodies—Janiak points out that gravity operates through to the centres of bodies, and uses this to suggest how Newton can invoke a gravity which is non-mechanical, without accepting that it acts at a distance. For Janiak, then,

The contention that gravity causes the planetary orbits does not amount to, or entail, the contention that there is no causally efficacious medium between planetary bodies that serves as the basis of their gravitational interactions. On the contrary, since Newton’s theory is neutral with respect to the physical cause of gravity, it is perfectly compatible with the discovery that some type of medium does in fact exist (Janiak, 2008, p. 77).

Here, once again, the main point being made is that Newton’s theory is noncommittal, or “neutral”, about the cause of gravity. That being so, if Janiak is allowed to say this is “perfectly compatible with the discovery that some type of medium does in fact exist”, then I

⁷ It has been forcefully pointed out by John Schuster that when scientists talk not about science but about their scientific method there are always underlying socio-political motivations. See Schuster (1986).

must be allowed to say Newton's neutral theory is perfectly compatible with the discovery that action at a distance exists. Of course, Janiak would say that this isn't a valid inference because action at a distance is inconceivable and Newton himself has said it is. To which I reply, in case it isn't obvious by now, *action at a distance wasn't inconceivable for Newton (because he believed that nothing could stop an omnipotent God from bringing it about), and nowhere did he ever say it was.*

The involvement of God in Newton's thinking is clear from the draft of a letter which Newton intended to send to the Editor of *Memoirs of Literature* in 1712. Rejecting Leibniz's claim that Newtonian gravity is "an unreasonable and occult quality", Newton writes:

And why may not the same be said of the vis inertiae & the extension the duration & mobility of bodies, and yet no man ever attempted to explain these qualities mechanically, or took them for miracles or supernatural things or fictions or occult qualities. They are the natural real reasonable manifest qualities of all bodies seated in them by the will of God from the beginning of the creation & perfectly incapable of being explained mechanically.

In case the addressee misses the theological point, Newton makes it crystal clear:

But he [Leibniz] goes on and tells us that God *could not create planets that should move round of themselves without any cause that should prevent their removing through the tangent...* But certainly God could create planets that should move round of themselves without any other cause than gravity... (Newton, 1959-77, v, p. 300, Newton's emphasis).

It is undeniable that Newton accepted that a plausible, indeed convincing, explanation of gravity which did not involve action at a distance might one day be discovered. As Janiak himself points out, Newton said so explicitly to Leibniz:

But if, meanwhile, someone explains gravity along with all its laws by the action of some subtle matter, and shows that the motion of planets and comets will not be disturbed by that matter, I shall not object (Newton, 1959-77, iii, p. 287; Janiak, 2008, p. 78).

The point, however, and Janiak seems to have missed this, is that Newton cannot imagine how such an explanation really would work. Indeed, it is worth looking at the immediately preceding few words, which Janiak does not quote:

I have myself concluded that all other causes are to be rejected and that the heavens are to be stripped as far as maybe of all matter, lest the motions of planets and comets be hindered or rendered irregular. But if, meanwhile... (Newton, 1959-77, iii, p. 287).

If Newton has rejected all other causes, then he has rejected the idea that gravity can be explained by subtle matter. Rather than endorsing the idea of an all pervasive subtle matter or aether, he expresses his belief that the heavens are constituted of empty space—notice the importance of that: the arena in which gravity operates between the Sun and the planets is empty space. Rather than accept an aether, Newton prefers to suppose, especially because it seems to him to have distinct theological advantages, that gravity acts at a distance.

Janiak misses the point again when he suggests that,

The [putative awaited] ether could not be mechanical in Newton's sense [*i.e.* Janiak's sense: acting on surfaces only], but would have to flow through material bodies, interacting somehow with their masses (Janiak, 2008, p. 78).

Yes, indeed, and it is that "somehow" which is the rub. Consider the standard objection to the Cartesian account of gravity: if bodies are pushed towards the centre of the Earth by continual streams of downward particles, why can't we shield a body from these streams

(why does a body dropped from underneath a heavy oak table, say, fall in exactly the same way as a body dropped in open air)? The standard Cartesian answer was that the particles were so fine they went through the table and affected the body just the same. To which the standard riposte was, why don't the particles also pass through the "falling" body, instead of pushing it down? Given Newton's long-standing anti-Cartesianism, it must have crossed Newton's mind that any aether which is capable of penetrating through to the innermost parts of bodies to give those parts a mechanical push, by impact, or at least by some sort of contact, would also be capable of passing through the body without making such contact. Indeed, it is hard to see how "some subtle matter" can pass through moving bodies like planets and comets so that their motions "will not be disturbed" (*i.e.* by friction or drag effects) and yet this same subtle matter is to be held responsible for the gravitational motions of planets by its contact actions. In writing to Leibniz as he did, Newton was not really conceding anything to Leibniz (Heaven forbid!), he was setting him what he took to be an unsolvable puzzle. Unsolvable that is, unless you resort to the omnipotence of God, and His ability to make one body attract, or repel, another at a distance.

It is usually the case in philosophical discourse that if we arrive at an infinite regress we assume we've gone wrong somewhere; it is astonishing, therefore, to see Janiak evidently unconcerned by the fact that his interpretation of Newton's aether leads Newton into an infinite regress. Addressing the undeniable fact that Newton's aether, as presented in the *Opticks* of 1717, invokes repulsive forces acting at a distance between the aether particles, Janiak has argued himself into a position where he has no choice but to deny the undeniable: the ether may be the physical seat – the "cause" – of gravity, and it may involve repulsive forces among its particles that, in turn, have their own physical seat, perhaps in some other medium. From the fact that the ether and its particles serve as the physical basis of gravity it does not follow that we know the physical characterization of the short-range repulsive forces that those particles may exert. Further work would be required. And of course we cannot determine *a priori* where this investigation of forces will lead us, nor where it will stop (Janiak, 2008, p. 79).

So, we now have to ask ourselves which is more likely, that Newton readily accepted the existence of an aether that would lead him into an infinite regress; or that the Newton who wrote in his *De aere at aethere* of 1679, "But if by some principle acting at a distance [the particles] tend to recede mutually from each other, reason persuades us that when the distance between their centres is doubled the force of recession will be halved, when trebled the force is reduced to a third and so on..." (Newton, 1962, pp. 223-4), preferred to believe in actions at a distance? Janiak's willing acceptance of an infinite regress notwithstanding, it seems perfectly clear that Rosenfeld was right when he wrote that "The constitution of the aether discussed in the Queries... is that of an elastic medium of such extremely low density that its single constituent particles must be assumed to be separated by considerable spatial extensions *void of every kind of matter*" (Rosenfeld, 1969, p. 31; my emphasis). It seems to me that we should accept that Newton no more believed "the ancient maxim that a thing cannot act where it is not" than did John Stuart Mill.

This brings us to the second means of establishing, independently of his comment to Bentley, that Newton must have rejected actions at a distance. Namely, Newton's alleged suggestion in the General Scholium that not even God can act where He is not. The passage in question, in the recent translation of Cohen and Whitman, reads like this:

He is omnipresent not only virtually but also substantially; for action requires substance [*lit.* for active power [virtus] cannot subsist without substance] (Newton, 1999, p. 941).

For Janiak, the meaning of this is perfectly clear: “From Newton’s point of view, then, God in fact never acts at a distance on any object, at any time in the history of the world” (Janiak, 2008, p. 38). The same interpretation has recently been laid upon this passage by Hylarie Kochiras:

Why does Newton think that, in order for God’s power to be omnipresent, the substance, God himself, must be present everywhere in space? The answer, it appears, is that Newton believes that a substance must be present where it acts (Kochiras, 2009, p. 275; but see also Schliesser, forthcoming).

Newton’s aim at this point in the General Scholium is to re-assert his cherished belief that God should not be seen as a *res cogitans* outside space (or inappropriately associated with spatiality) and therefore remote, but that he should be acknowledged to be omnipresent in something like a literal sense. As Newton says, both here and in Query 31 of the *Opticks*, echoing St Paul, “In him [God] all things are contained and move” (Acts, 17, 28; Newton, 1999, p. 941; Newton, 1979, p. 403). We need not pursue here the undeniable importance of this for Newton, or what he might have meant by it, but it is worth noting that no previous commentators on this passage have seen this as an attempt by Newton to support the view that a thing cannot act where it is not (Koyré, 1957; Copenhaver, 1980; Grant, 1981; Funkenstein, 1986; Hall, 1990). That in itself is not an argument against Janiak’s and Kochiras’s view, but it does show that there are much more obvious issues at stake in this passage—opposition to Cartesian dualism, the nature of space, the nature of existence, and the nature of God and his relationship to the world (in a wide and general sense, rather than at the level of physical causation)—and it is much more likely that the earlier commentators on this passage have discerned the more salient features of this passage, than that Janiak and Kochiras have now revealed what it is really about.

Furthermore, the Janiak/Kochiras interpretation seems completely incompatible with what follows immediately upon this quotation from the General Scholium. It is worth quoting this in full.

He is omnipresent not only virtually but also substantially; for action requires substance [*lit.* for active power [virtus] cannot subsist without substance]. In him all things are contained and move, but he does not act on them nor they on him. God experiences nothing from the motions of bodies; the bodies feel no resistance from God’s omnipresence.

It is agreed that the supreme God necessarily exists, and by the same necessity he is always and everywhere. It follows that all of him is like himself: he is all eye, all ear, all brain, all arm, all force of sensing, of understanding, and of acting, but in a way not at all human, in a way not at all corporeal in a way utterly unknown to us... (Newton, 1999, pp. 941-2).

It seems clear from the insistence that God “does not act on them nor they on him”, that Newton simply wants to reaffirm the truth of the omnipresence of God without actually involving God directly in the physics of the world system. After all, contemporary atheists evidently took delight in identifying existence with the occupation of space. In *The True Intellectual System of the Universe*, Ralph Cudworth’s monumental compendium and exposition of varieties of atheism, he had characterised the atheists’ chief principle as “whatsoever is not Extended, is Nowhere and Nothing” (Cudworth, 1678, p. 9). It seems

clear that Newton simply wants to distance himself from a Cartesian concept of God as a non-extended *res cogitans*, and to persuade the atheists that God is a real extended presence in the world. Accordingly, he not only insists that God is really physically (substantially) present everywhere, but he also tries to imply that this is a perfectly orthodox view by echoing Biblical language in his account (“In him all things are contained and move”).

However, there is no real sense here that what we are being told is that God cannot act where he is not. Indeed, it seems to me that although Newton wants to insist that God must exist in space, in order to exist at all (a metaphysical point about the nature of existence), he emphatically does *not* want his readers to infer from this that God can only act by contact. Consequently, he immediately adds that God does not act on bodies and bodies do not act on him (a physical point about the nature of causation). If Newton really had wanted to insist at this point that God cannot act where he is not, why would he then say that God’s “force... of acting” was “in a way utterly unknown to us”? If the Janiak/Kochiras interpretation was correct, then Newton would effectively be arguing that God has to conform to what is judged by humankind to be conceivable (in this case that only contact action is feasible). So, it would be an odd thing to then add that, in spite of God having to conform in this way, he operates in a way that is not at all human, and is utterly unknown to us.⁸ The Janiak/Kochiras claim that Newton’s insistence on God’s omnipresence is driven ultimately by a desire to prove that things cannot act where they are not, is at best precarious, and much more likely to be downright wrong.

It is, after all, doubtful whether God’s local presence is in any way relevant to the way gravitational attraction occurs. Although they are careful to avoid saying so, it seems hard to resist the conclusion that Janiak and Kochiras are offering us a picture of a Newton who believes in occasionalism. God has to be present everywhere because there is no such thing as action at a distance and all actions are performed by God. But, of course, Newton never hints anywhere that he subscribed to occasionalism. As we have already pointed out, Newton always assumed that God acted by secondary causes. Indeed, one of the most significant confirmations of his belief in secondary causation occurs in the General Scholium just a few lines before the comment which Janiak and Kochiras take to be further confirmation of their view that Newton could not have believed in action at a distance. Consider this well-known passage again:

He rules all things, not as the world soul but as the lord of all. And because of his dominion he is called Lord God *Pantokrator*. For “god” is a relative word and has reference to servants, and godhood is the lordship of God, not over his own body as is supposed by those for whom God is the world soul, but over servants (Newton, 1999, p. 940).

God acts through his servants, but this should not be taken to mean human (or angelic) servants; we are being informed about God’s dominion over nature—God’s servants are the myriad kinds of secondary causes in the world.

⁸ The notion of a God who has to conform to our judgements about what is possible would have been seen by Newton as characteristic of Leibniz’s theology. For Leibniz, God has to conform to what Leibniz decrees to be logically possible. Newton, a major representative of voluntarist theology, sees the Leibnizian approach as circumscribing the omnipotence of God. By contrast, the voluntarist believes that if God wishes to make matter capable of thinking, say, or capable of attracting other matter at a distance, then He can. I have discussed these matters at much greater length in Henry (2009) and Henry (2011). The similarity between Newton’s theology on the issue of action at a distance, and the theology which led John Locke to insist that God could make matter think was noticed in Koyré (1965), pp. 154-5. The differences between the Leibnizian and Newtonian theologies can be seen in Alexander (1956).

This being so, it is hard to understand how God's immediate presence can be held to be relevant to the action of gravity. God said "Let there be light: and there was light." Presumably, therefore, God could have said words to the effect: let there be an active principle in all bodies which attracts all other bodies. God no more has to be present to all bodies when he decrees this, than a king has to be present to every homeowner if he should decree that all his tax collectors are allowed to enter anyone's home even without the homeowner's permission. Much less does God have to be present when, in accordance with his omnipotent decree, an apple falls to the ground. He may *be* present, by virtue of his ubiquity, but his presence is not directly relevant to the question as to what causes the apple to fall—because that question, for Newton, had to be answered in terms of secondary causes. Furthermore, although Leibniz and others might suppose that not even God could decree that bodies should attract one another at a distance—because action at a distance is (supposedly) impossible even for omnipotency—for Newton there was absolutely nothing to prevent God from making action at a distance a physical reality.⁹

In spite of all the foregoing, there may be readers who still cannot bring themselves to believe that Newton might have accepted the possibility of action at a distance. Such recalcitrant adherents to Mill's "*a priori* fallacy" that action at a distance is impossible, are in danger of allowing their own convictions to over-ride historical evidence. They are in a similar position to David Brewster, who, regardless of the manuscript evidence in front of him, could hardly believe that Newton would have wasted so much time on alchemy (Brewster, 1855, ii, pp. 374-5). One course of action open to them, in order to defend (as they see it) Newton's credentials as a philosopher, is to claim that he only accepted action at a distance in a phenomenalistic way. Consider, for example, his famous statement in the General Scholium—arguably the most famous of all Newton's pronouncements—in which he eschews hypothesizing:

I have not as yet been able to deduce from phenomena the reason for these properties of gravity, and I do not feign hypotheses. For whatever is not deduced from the phenomena must be called an hypothesis; and hypotheses, whether metaphysical or physical, or based on occult qualities, or mechanical, have no place in experimental philosophy. In this experimental philosophy, propositions are deduced from the phenomena, and are made general by induction... And it is enough that gravity really exists and acts according to the laws that we have set forth and is sufficient to explain all the motions of the heavenly bodies and of our sea (Newton, 1999, p. 943).

What we have here, it certainly can be argued, is a clear indication that Newton believed there must be a cause of gravity, but he was not yet in a position to say what that cause might be. In the meantime, therefore, he could simply talk of gravity as something which seemed, for all we could tell from our experience of phenomena, to act at a distance. The bottom line of this way of arguing, for those who resist belief in action at a distance, is to conclude that Newton might have appeared to talk as though action at a distance existed, but really he knew this wasn't tenable and that there must be a yet undiscovered physical cause of gravity which does not involve action at a distance.

⁹ The issue of what was impossible even for omnipotency was crucial here, and had been a major focus of the debate, in 1699, between John Locke and Edward Stillingfleet about the possibility (or impossibility) of thinking matter. As Alexandre Koyré has pointed out, Locke explicitly linked his claims that God could make matter think to the parallel claim that God could make matter attract other matter at a distance. See Koyré (1965), pp. 154-55. For a fuller discussion, see Henry (2011).

On the face of it, this seems like a powerful argument. But this famous passage from the General Scholium can be seen, alternatively, as little more than another example of Newton providing himself with a face-saving escape, of the kind we have already noted, in the event that somebody should come up with a more mechanistic kind of explanation for gravity. This famous passage is, in fact, immediately followed by the short, inconclusive, paragraph on the newly discovered “electric spirit”, which may well have seemed, for a brief while, capable of providing such an explanation (Home, 1985). I would suggest, however, that these two alternative readings of this part of the General Scholium do not have to be seen as presenting us with a stark choice; they could both be equally valid interpretations.

It is important to note, however, that even if we accept that Newton was presenting here a phenomenalist approach to gravity, pending an eventual causal explanation, we have no warrant for supposing that Newton excluded action at a distance from the range of possible explanations. Certainly, he does not defend his phenomenalist approach by explicitly pointing to the necessity to avoid invoking actions at a distance. On the contrary, the evidence tends to suggest that Newton really could not see any other possibility. Consider, for example, what comes immediately before the passage in which he famously rejects hypothesising:

Thus far I have explained the phenomena of the heavens and of our sea by the force of gravity, but I have not yet assigned a cause to gravity. Indeed, this force arises from some cause that penetrates as far as the centers of the sun and planets, without any diminution of its power to act, and that acts not in proportion to the quantity of the *surfaces* of the particles on which it acts (as mechanical causes are wont to do) but in proportion to the quantity of *solid* matter, and whose action is extended everywhere to immense distances, always decreasing as the squares of the distances. Gravity toward the sun is compounded of the gravities toward the individual particles of the sun, and at increasing distances from the sun decreases exactly as the squares of the distances as far out as the orbit of Saturn, as is manifest from the fact that the aphelia of the planets are at rest, and even as far as the farthest aphelia of the comets, provided that those aphelia are at rest (Newton, 1999, p. 943).

As in the letter which Newton had written the year before to the Editor of *Memoirs of Literature*, Newton seems here to be suggesting to his readers that gravity is “perfectly uncapable of being explained mechanically” (Newton, 1959-77, v, p. 300). Indeed, if we all came at this passage with the mind-set of a John Stuart Mill, we could easily imagine Newton going on from this comment about the aphelions of the comets to conclude that, therefore, the power of gravity must be capable of acting at a distance. The fact that Newton does *not* explicitly draw this bold conclusion is hardly surprising, but it is not evidence that he has rejected the possibility of action at a distance.

If doubts still remain among those who are incapable of thinking like John Stuart Mill, we have only to turn from the General Scholium of 1713 to Newton’s so-called “aether queries”, interpolated into the second English edition of the *Opticks* in 1717. Notwithstanding the glib attempts of commentators to see the proposed aether as “mechanical” in its operation, it is impossible to deny that the aether works by virtue of strong repulsive forces operating between its particles, and those particles are (consequently) widely spread apart (Rosenfeld, 1969; Thackray, 1970). Although the aether queries, being merely queries, allow Newton a face-saving escape from embarrassment should he need one, there is no hint of phenomenalism in his discussion of the aether. Indeed, there hardly could be, since the aether itself scarcely qualifies as an indisputable “phenomenon” (that is, a fact established by the senses). That being so, Newton might have been expected to dismiss out of hand any

explanations which relied on such an aether. The fact that he did not surely suggests that he had no difficulty in believing in action at a distance as a real feature of the physical world. In the end, therefore, it seems reasonable to suppose that if Newton was willing to speculate (without recourse to a phenomenalist evasion) about an aether which could account for various physical phenomena because its particles repelled one another at a distance, he would also have been (and indeed was in the rest of the *Queries*) willing to speculate about the explanatory power of supposing actions at a distance (attractive and repulsive) between all particles of bodies.

To sum up this part of the paper: the third letter to Bentley notwithstanding, there is no evidence whatsoever that Newton believed action at a distance to be inconceivable or impossible. Indeed, in the *Principia* Newton believed actions at a distance, manifested in attractive or repulsive particles between bodies, were fundamental to all physical explanation, and said so in the Preface. Moreover, he went on to exemplify this kind of physics in the *Queries* added to the *Opticks*. Furthermore, the influence of this idea on subsequent natural philosophers was both wide and deep. So much so, in fact, that in 1843 John Stuart Mill could sneer at the Cartesian rejection, “Rather more than a century and a half ago”, of action at a distance, and insist that “the ancient maxim that a thing cannot act where it is not... probably is not now believed by any educated person in Europe” (Mill, 1974, p. 754). All the arguments of recent commentators on Newton who have insisted that he rejected action at a distance are based on a misreading of the passage in the third letter to Bentley, followed by efforts to tease out other places in Newton’s writings which might be shoe-horned to fit in with, and falsely confirm, that misreading. This scholarship, misconceived from the start and influential on successive generations of Newton scholars, now forms a massive barrier to a correct understanding of Newton’s attitude to action at a distance and the nature of force, continuing every day to lead new readers astray. While this continues, much Newton scholarship is at best a waste of scholarly time and effort, and at worst seriously misleading—as the poet Philip Larkin said of the baleful influence of your mum and dad: “They fill you with the faults they had/And add some extra, just for you”, and so the misunderstanding “deepens like a coastal shelf” (Larkin, 1974).¹⁰

2. The historical development of Newton’s ideas on action at a distance

Needless to say, Newton was not born believing in action at a distance. Like every other natural philosopher, he was schooled under the influence of the Aristotelian rejection of actions at a distance, and in the early part of his career undoubtedly tended to take for granted the Cartesian reiteration that a body could not act where it was not (Westfall, 1980, pp. 66-104; Ducheyne, 2005). So, how did he come to develop the idea that actions at a distance were fundamental in the natural world?

It is often supposed that Newton became acquainted with the explanatory use of actions at a distance in the course of his alchemical studies. Certainly, when Newton’s alchemical studies began to be taken seriously for the first time, by Pyo Rattansi and R. S. Westfall, it was suggested that they were the source of his ideas on interparticulate forces (Rattansi, 1972;

¹⁰ See Philip Larkin’s “This be the Verse”, perhaps written in 1971, it was first published in his *High windows* (Larkin, 1974). It is worth noting, since the list won’t detain us long, the exceptions among recent Newton scholars who have understood Newton’s comment to Bentley correctly: Schliesser (in press) and Ducheyne (2009).

Westfall, 1972; Dobbs, 1988). I cannot find any hint of attractive and repulsive forces, however, in what is generally taken to be one of his earliest alchemical compositions. This is “Of nature’s obvious laws & processes in vegetation”, often simply called *The Vegetation of Metals*, and usually agreed to have been written about 1670 (Dobbs, 1991, pp. 258-70; Iliffe, 2007, pp. 56-61).¹¹

Seeking to understand how chemical transformations take place, Newton sees the process as analogous to putrefaction and the emergence of new vegetable matter out of the putrefaction. A principle of vegetation in things can change things, in the way that a protoplast can change into a tree. But this raises the question as to what is this “principle of vegetation”—what, Newton asks, is “Natures universall agent, her secret fire” (Dobbs, 1991, p. 264)?

In what is surely the most famous passage in the *Vegetation of Metals*, Newton suggests that all bodies are composed of “Aether congealed and interwoven into various textures”, and that this material aether is itself “but a vehicle to some more active spirit”. This more active spirit “perhaps is the body of light”. What we have here, then, are the beginnings of Newton’s life-long belief that matter is not passive and inert, but is endowed (by God) with what he calls “active principles”, and which can be called upon to account for the various activities of matter. Indeed, he refers to the body of light, and this aether, as both having “a prodigious active principle” (Dobbs, 1991, p. 265).

It is clear, however, that this aether is not the aether that I have already mentioned, and which appears in its final form in Queries 17 to 24 of the *Opticks*. There is no suggestion here that Newton has in mind an aether composed of particles that are widely distanced from one another due to forces of repulsion operating between them. For one thing, ordinary bodies are said in this early alchemical work to be “concreted” out of the aether—there is no hint of this in the later aether which depends upon actions at a distance between its particles.

The aether of the *Vegetation of Metals* appears once again, however, in a more carefully considered form in Newton’s “Hypothesis explaining the Properties of Light”, which he wrote for a meeting of the Royal Society in 1675. The similarities between this aether and the aether of the earlier alchemical work are unmistakable:

Perhaps the whole frame of nature may be nothing but various contextures of some certain aetherial spirits, or vapours, condensed as it were by precipitation, much after the manner, that vapours are condensed into water, or exhalations into grosser substances, though not so easily condensable; and after condensation wrought into various forms; at first by the immediate hand of the Creator; and ever since by the power of nature; which by virtue of the command, increase and multiply, became a complete imitator of the copies set her by the protoplast. Thus perhaps may all things be originated from aether (Newton, 1978, p. 180).¹²

There are, however, some major differences between this aether and the earlier one. It is here for the first time that the aether is invoked to explain the observed phenomena of electricity, magnetism, and the “gravitating principle”. Even so, Newton does not yet think in terms of

¹¹ Dibner Library of the History of Science and Technology, Dibner MSS 1031 B. Conveniently edited in Dobbs (1991), pp. 258-70. I have used her edition.

¹² Isaac Newton, “An Hypothesis explaining the properties of light, discoursed of in my several papers” [1675], in Newton (1978), pp. 178-99.

interparticulate forces. The movements of small pieces of chaff, paper, and so on which can be observed when glass is rubbed and held over them gives rise to the speculation that some kind of subtil matter lying condensed in the glass, and rarefied by rubbing, as water is rarefied into vapour by heat, and in that rarefaction diffused through the space round the glass to a great distance, and made to move and circulate variously, and accordingly to actuate the papers till it return into the glass again, and be recondensed there (Newton, 1978, p. 180).

In short, the phenomena of static electricity are explained not by interparticulate forces but by what Newton calls “an aetherial wind”.

Similarly, “the gravitating attraction of the earth”, it is suggested, may be caused by the continual condensation of some other such like aetherial spirit, not of the main body of phlegmatic aether, but of something very thinly and subtilly diffused through it, perhaps of an unctuous or gummy, tenacious, and springy nature... (Newton, 1978, p. 181).

Newton also suggests that the aether might account for the phenomena of light and heat by assuming it is in a state of incessant “swift and minute” vibration. He then extends this to suggest that such vibrations can explain the continued motions of “fermenting or putrifying substances, fluid liquors, or melted, burning, or other hot bodies.” All of these phenomena can be seen, he suggests, as analogous to a ship being “shaken asunder... by waves” (Newton, 1978, p. 181).

What we have here, therefore, is an aether which operates in an entirely mechanical way, by blowing things about, or by sticking to things and carrying them back, as it returns to where it emerged, or by shaking them about.

This is also true of another explanatory speculation Newton provides, even though this clearly foreshadows the aether that will depend on interparticulate forces. Here, Newton draws upon a supposed variation in the density of the aether:

as the air can pervade the bores of small glass pipes, but yet not so easily as if they were wider; and therefore stands at a greater degree of rarity than in the free aerial spaces, and at so much a greater degree of rarity as the pipe is smaller, as is known by the rising of water in such pipes to a much greater height than the surface of the stagnating water, into which they are dipped; so I suppose aether, though it pervades the pores of crystal, glass, water, and other natural bodies, yet it stands at a greater degree of rarity in those pores, than in the free aetherial spaces, and at so much a greater degree of rarity, as the pores of the body are smaller (Newton, 1978, p. 182).

The implication here is that the aether is rarer inside glass, say, because the pores in the glass do not allow the aether in. It won't be long before Newton begins to suppose that the particles of aether are rarer inside other bodies because the aether particles *repell* other particles. At the moment, however, he is not thinking that way. He now merely supposes that “the denser aether, which surrounds these bodies, must crowd and press their parts together, much after the manner that air surrounding two marbles [i.e. flat slabs of marble] presses them together, if there be little or no air between them” (Newton, 1978, p. 182). The adherence of two marble slabs in this way used to be explained in terms of *fuga vacui*—the slabs had to remain together to prevent the formation of a vacuum between them (even if only momentarily) as they separated. By Newton's day, thanks to the work of Torricelli, Boyle and others, the

phenomenon could be glibly attributed to the “spring of the air”, or the pressure of the atmosphere.¹³ Newton’s aether also operated by means of its “spring”.

The next piece that is relevant to our story, seems to be (although we’ll have to come back to discuss the sequence of this and other relevant documents) the letter Newton wrote to Robert Boyle early in 1679. The phrase “at a distance” occurs three times in this letter, and it is possible that Newton was already thinking in terms of actions at a distance, but if so, he is avoiding saying this outright to Boyle.

Let’s consider, the way the phrase “at a distance” appears in the letter. On one occasion Newton is discussing how “gross compact substances” can be turned into “aereal” substances by heat, and he writes this:

as fast as the motion of heat can shake off the particles of water from the surface of it, those particles, by the said principle, will float up and down in the air at a distance from one another, and from the particles of air, and make that substance a vapour (Newton, 1978, p. 252).¹⁴

It would be easy for Boyle to assume that what is being suggested here is that the particles float at a distance from one another simply by virtue of having been thrown in the air by the heat. There is no necessary implication that interparticulate forces are at work—if I throw a basketful of balls in the air, the chances are the balls will not cleave together but will fly up in the air, and subsequently descend, at a distance from one another.

But you may ask what Newton means when he says “by the said principle”? Could this be a reference to an earlier statement, invoking a principle of repulsive forces? It isn’t entirely clear to me which “said principle” Newton is referring to here, but the most likely contender is his fifth “supposition”. Before looking at this let’s consider the only other use of the phrase “at a distance” in the letter.

Speaking of the formation of vapours, Newton writes,
 that the particles of vapours, exhalations and air, do stand at a distance from one another, and endeavour to recede from one another, as the pressure of the incumbent atmosphere will let them: for I conceive the confused mass of vapours, air, and exhalations, which we call the atmosphere, to be nothing else but the particles of all sorts of bodies, of which the earth consists, separated from one another, and kept at a distance, by the said principle (Newton, 1978, p. 251).

This might look much more like an explicit statement that the particles of vapours, and air, are endowed with repulsive forces. After all, as well as suggesting the particles stand at a distance from one another, he also explicitly states that they “endeavour to recede from one another”. But we need to be careful of reading such things with the benefit of our hindsight. We know that Newton would soon be talking about interparticulate forces operating across the distances between particles, but would a reader like Boyle, in 1679, have read this into what Newton says in this letter? Certainly, Newton never mentions interparticulate forces here. What he does suggest, once again, is that the particles are kept at a distance in accord with an aforementioned “principle”.

¹³ The fullest treatment is Grant (1981), but for recent studies of the background to Newton’s concerns see, for example, Clericuzio (1997), Clericuzio (1998), and Fazzari (1997).

¹⁴ Letter from Newton to Boyle dated February 28, 1678/9, reprinted in Newton (1978), pp. 250-53.

Let's look now at the fifth supposition, which I take to be what he means when he refers to the "said principle". It is introduced like this:

5. Now from the fourth supposition it follows, that when two bodies approaching one another, come so near together, as to make the aether between them begin to rarefy, they will begin to have a reluctance from being brought nearer together, and an endeavour to recede from one another... (Newton, 1978, p. 251).

The fourth supposition, mentioned here, is that the aether in between two bodies is rarer than it is in uncluttered space. This is familiar to us from the "Hypothesis of Light", and as there, it does not necessarily imply the rarefaction of the aether is due to the action of repulsive forces. The reader seems to be invited simply to assume that the rarefaction is a necessary consequence of a lack of room—there isn't enough room between the proposed two bodies for aether to enter at its usual density, so it can only occupy the restricted space between the bodies in an attenuated form (Newton, 1978, p. 250-51).

According to the fifth supposition, then, as two bodies approach one another, they will first of all resist approaching one another because of the aether, at its usual density, in between them. If they are nonetheless moved closer to each other, eventually the aether in between will be successively squeezed out, so that it rarefies. Newton now assumes that the difference in density between the aether surrounding the two bodies, and the rarified aether between the two bodies, will result in the two bodies being pushed together by the denser surrounding aether. Newton wrote:

there will arise from the excess of density of the surrounding aether a compressure of the bodies towards one another... (Newton, 1978, p. 251).

It would have been perfectly possible, therefore, for Boyle, or anyone else reading the letter at the time, to suppose that Newton's aether was a continuous fluid which acted in an essentially mechanical way, to resist compression, and then, when forcibly rarefied (seemingly by continued compression!), to act in a way to even out any density gradients, and to restore (as much as possible) its uniformity. The suggestion in the letter "that the particles of vapours, exhalations and air, do stand at a distance from one another, and endeavour to recede from one another, as the pressure of the incumbent atmosphere will let them", could simply have been taken to mean, by a contemporary reader, that the particles could not come closer together because to do so they would have to have sufficient mechanical force to rarefy, or squeeze, the aether (Newton, 1978, p. 251). Unable to overcome the resistance of the aether to its own rarefaction, the bodies would stand apart, and indeed might even try to recede further from one another (due to the resistance of the aether), were it not for the "compressure" of the atmosphere which also surrounded them.

I hope this reading can be confirmed simply by reading the third passage where the phrase "at a distance" is used (notice that the phrase "*action* at a distance" is never used). Here again, density gradients in the aether are invoked, but the aether itself could easily be envisaged as a continuous fluid. Newton is trying to explain how a particle separated from its parent body, and so contributing to a vapour surrounding that body, eventually returns, to the parent body:

And if the particle were divided from the body, and removed to a distance from it, where the aether is still denser, the aether within it must proportionally grow denser. If you consider this, you may apprehend, how by diminishing the particle, the rarity of the aether within it will be diminished, till between the density of the aether without, and the density of the aether within it, there is little difference; that is, till the cause be almost taken away, which should keep this and other such particles at a distance from

one another. For that cause, explained in the fourth and fifth suppositions, was the excess of density of the external aether above that of the internal. This may be the reason then, why the small particles of vapours easily come together and are reduced back into water, unless the heat, which keeps them in agitation, be so great as to dissipate them as fast as they come together (Newton, 1978, p. 253).

Given the fact that the ideas expressed in both the “Hypothesis” and the letter to Boyle depend upon rarefaction, it is hardly surprising that Newton should turn his attention to the phenomenon of rarefaction, and how it occurs. Indeed, we might even say that it was a very obvious next move for Newton to make. This brings us to the short, incomplete, manuscript entitled *De aere et aethere*.¹⁵ It seems to me that Newton might well have written this very shortly after sending his letter to Boyle, and that his original intention was to expound further on the way vapours dissipate themselves under the influence of a supposed aether and a surrounding atmosphere of air.

Accordingly, the *De aere* opens by pointing to rarefaction and condensation as the most remarkable properties of the air. Almost immediately, he draws upon the illustrative example, familiar to us from both the “Hypothesis” and the letter to Boyle, of water ascending in “a very narrow pipe whose lower end is immersed in stagnating water.” The aim of this and other experimental examples is to show that there are three chief causes of the rarefaction and condensation of the air, namely “expansion, compression, [and] heat and the proximity of bodies.” Having listed these three causes, however, Newton immediately suggests that “The former [expansion] accounts for the rest, and for the whole nature of air” (Newton, 1962, p. 221) But what is the cause of this supposed expansion? Here, for the first time in any of his writings, Newton invokes interparticulate forces.

He is a bit coy at first, simply writing that “those who philosophize rightly know that... the air seeks to avoid the pores or intervals between the parts of... bodies” (Newton, 1962, p. 221). A little later he is a bit more bold: “Moreover air does not only seek to avoid bodies, but bodies also tend to fly from each other” (Newton, 1962, p. 222). Notice also, the shift here from air to bodies in general. More experimental or at least experiential examples follow. These are again familiar from the letter and the “Hypothesis” but this time the clear implication is that there is a repulsive force operating between bodies. Before stating his theory explicitly, however, Newton points to the remarkable expansion which air is able to accomplish.

The whole weight of the incumbent atmosphere by which the air here close to the Earth is compressed is known to philosophers... and conversely that under a half or a third or even a hundredth or a thousandth part of that weight [the air] is expanded to double or treble or even a hundred or a thousand times its normal space, which would hardly seem to be possible if the particles of air were in mutual contact... (Newton, 1962, p. 223).

Newton now moves to what he evidently regards as an inevitable conclusion:

But if by some principle acting at a distance [the particles] tend to recede mutually from each other, reason persuades us that when the distance between their centres is doubled the force of recession will be halved, when trebled the force is reduced to a third and so on... (Newton, 1962, p. 223-4).

¹⁵ Cambridge University Library, MS. Add. 3970, fols 652-3; reprinted in Newton (1962), pp. 214-28. The Halls (Newton, 1962, pp. 187-9) date this to between 1673 and 1675. R. S. Westfall and I are committed to a later date, 1679; I discuss this below.

It is in the *De aere*, then, written between 1675 and 1679, that Newton first puts forward the idea that physical phenomena might be explained by forces acting at a distance between the particles of bodies. It is important to note that we can say “bodies” here; the forces were not confined to particles of air. Newton evidently believed that any particle which was broken away from a solid, or a liquid, would necessarily display the same tendency to “fly from each other”:

nothing else is required [he wrote,] save a certain action or motion which tears apart the small parts of bodies; since when separated they mutually flee from one another... (Newton, 1962, p. 226).

All this appears under the heading “De aere” and there follows a new section entitled “De aethere”, but after only a few lines Newton breaks off the composition. Presumably, Newton was going to go on to discuss the even more remarkable capacity of the aether for rarefaction, but perhaps realised that he could then explain everything simply in terms of an aether with mutually repellent particles (as later appears in the so-called “aether” Queries in the *Opticks*—Queries 17 to 24 in the 1717 edition), rather than assuming repulsive forces between all bodies.

Be that as it may, it is important to note that at this point Newton is thinking only in terms of *repulsive* forces operating between bodies. There is no mention here (or of course anywhere else) of attractive forces. The condensation of the air is caused by other things pressing upon it; it is only the expansion or rarefaction of the air that is caused by its own interparticulate forces—of repulsion. Furthermore, Newton seems to have been led to this belief in the reality of repulsive forces not by alchemical considerations, but by speculating about the nature and causes of rarefaction.

Before going any further, perhaps I should acknowledge that I have followed R. S. Westfall’s proposed sequence for the writing of the “Hypothesis”, the letter to Boyle, and *De aere et aethere*. Westfall differs here from the Halls who believe the *De aere* was written before the “Hypothesis” (Westfall, 1980, pp. 374-77).

The Halls took this line because they believed there was a consistent progression over these three documents from a claim that particles of air are endowed with repulsive forces (in *De aere*), to a claim in the “Hypothesis” that both air and aether have repulsive forces, to the final position of the letter to Boyle in which only the aether has repulsive power (Newton, 1962, pp. 188-89). I have to assume here that the Halls were reading into the “Hypothesis” and the letter to Boyle the repulsive forces which they knew would be the distinctive feature of Newton’s mature speculations on an aether. Try as I might, I cannot find any unequivocal suggestion in the “Hypothesis” that the aether or air operate by repulsion between particles. Variations in density of the aether are invoked but this is never explicitly equated with differences in distance between the particles (greater as the aether gets rarer, lesser as the aether condenses). On the contrary, the impression throughout is of an aether which is conceived, or at least presented, as a continuous fluid.

For me, therefore, we have a progression, as I have already suggested and which matches Westfall’s assumptions, from the “Hypothesis of Light”, in which the aether operates in an entirely mechanical way, through the letter to Boyle, to the *De aere* in which explanations explicitly invoke, for the first time, interparticulate forces operating at a distance.

When I say for the first time, I mean the first time for Newton. He was not the first to introduce actions at a distance into the mechanical philosophy. In 1674 Sir William Petty had already published his *Discourse made before the Royal Society* in which he supposed that the atoms or corpuscles whose behaviour accounted for all physical phenomena were tiny spherical magnets. While Cartesians were trying to explain magnetic phenomena in terms of streams of invisibly small non-magnetic particles, Petty simply supposed the invisibly small particles were magnets and invoked their attractive and repulsive forces to explain cohesion, elasticity, contraction and expansion, and everything else. It was also in that year that Robert Hooke (1674) announced, in his *Attempt to Prove the Motion of the Earth*, his system of the world, based on the supposition that all celestial bodies “do also attract all other Coelestial Bodies that are within the sphere of their activity” (Henry, 1986).

This brings us to the next, and crucial, development of Newton’s ideas on action at a distance. As is well known, Hooke wrote to Newton in November 1679 to ask his opinion of Hooke’s theory about planetary motions, which depended upon “attractive motions”. I won’t go into the details of this tale again—the short version is that Hooke handed the universal principle of gravitation, including the inverse square law, to Newton on a plate (Westfall, 1980, pp. 382-88; Gal, 2002; Guicciardini, 2005). All Newton had to do was provide the mathematical proof. The up-shot for Newton’s natural philosophy is nicely summarized by Westfall:

What we do know is that Newton had recast his entire philosophy of nature by 1686-7. In papers composed with the *Principia*, first a proposed “Conclusio” then the same material in a proposed “Preface” neither of which appeared in the published work, Newton applied action at a distance to virtually all the phenomena of nature (Westfall, 1980, p. 388).

So, Newton had been led by his own speculations on a mechanical aether, and his realisation that the necessary extreme rarity of the aether demanded that its particles be standing apart from one another in space, to the idea of repulsive forces acting between particles. Now, later that same year, he was made aware of the possibilities if attractive forces were also thrown into the mix.

As Newton wrote in the “Conclusio”:

Whatever reasoning holds for greater motions, should hold for lesser ones as well. The former depend upon the greater attractive forces of larger bodies, and I suspect that the latter depend upon the lesser forces, as yet unobserved, of insensible particles. For from the forces of gravity, of magnetism and of electricity it is manifest that there are various kinds of natural forces, and that there may be still more kinds is not to be rashly denied (Newton, 1962, p. 333).¹⁶

Later, he pointed out that “just as magnetic bodies repel as well as attract each other, so also the particles of bodies can recede from each other by certain forces.” Although the “Conclusio” was not included in the first edition of the *Principia*, much of the material appeared later in the Queries in the *Opticks* (Newton, 1962, p. 336).

It seems, then, that 1679 was another *annus mirabilis* for Isaac Newton. Having arrived at the notion of an aether which worked as a result of short-range forces of repulsion operating between invisibly small particles, his ideas were extended and reinforced as a result of learning about Hooke’s theory of attractive forces operating between vast bodies and over

¹⁶ Cambridge University Library, MS. Add. 4005, fols 25-8, 30-7; reprinted in Newton (1962), pp. 320-47.

vast distances. Newton had finally arrived at his own distinctive philosophy of nature, in which, as he wrote in the Preface to the *Principia*, all the phenomena of nature depend on certain forces by which the particles of bodies, by causes not yet known, either are impelled toward one another and cohere in regular figures, or are repelled from one another and recede (Newton, 1999, pp. 382-3).

Although the “Conclusio”, and a longer version of the Preface giving more details of how attractive and repulsive forces could be used in physical explanations (Newton, 1962, pp. 302-08 and pp. 320-47), never appeared in the *Principia*, all of the material in them subsequently appeared in the Queries. It is true to say, therefore, that Westfall was right, and that from this point on, “Newton applied action at a distance to virtually all the phenomena of nature.” For the most part, these actions at a distance were both attractive and repulsive. It is worth noting two important exceptions, however. Newton reverted to the more reductionist aether—reducing interparticulate forces down to repulsive forces only, operating not between all particles but only between the aether particles and other particles—in a block of eight Queries (numbered 17 to 24) which he introduced into the second English edition of the *Opticks* in 1717. We will return to these later. The other exception to the use of both attractive and repulsive forces appeared in a short piece called *De natura acidorum*, which Newton wrote in 1692.¹⁷ Here, Newton only invokes attractive forces.

It is possible that Newton was trying in this short work to explore the reductionist possibility that only attractive forces were required, not a combination of attractive and repulsive. If so, we have to conclude, from the subsequent appearance of the Queries, that Newton gave up on the idea. For the most part, therefore, it remains true to say that after 1679 Newton explained all those physical phenomena which could not easily be understood in straightforwardly mechanist ways (of motion and impact) in terms of attractive and repulsive forces acting across the distances between the constituent particles of bodies.

3. *Where does the De gravitatione fit into all of this?*

It was generally assumed since the beginning of modern Newton scholarship in the 1960s, that the *De gravitatione* was written around 1668 or perhaps a few years later,¹⁸ but Betty Jo Dobbs’s suggestion in her *Janus Faces of Genius* of 1991 (pp. 139-46), that the *De gravitatione* must have been written early in 1685 (as part of the preparations for the *Principia*), has gradually been gaining adherents (e.g. McGuire, 2000; Newton, 2004; Iliffe, 2007, p. 64). In view of what has gone before, it might be worth considering whether we have learned anything which can throw more light on this issue. After all, the *De gravitatione*, in spite of being ostensibly about fluid mechanics, digresses into a prolonged discussion of space and body. Potentially, therefore, it seems likely to include discussion not just of weights but also of gravitational attraction.

Before going any further it is worth pointing out that we can now say with some confidence that the *De gravitatione* could not have been written before 1668. Thanks to the careful research of Alan Gabbey (2011, note 19), it is now clear that the reference Newton makes to a letter of Descartes’s to Mersenne must be to the Latin edition of Descartes’s

¹⁷ First published in John Harris, *Lexicon technicum: Or, an universal English dictionary of arts and sciences* (London, 1710), Harris notes its date of composition as 1692. It is conveniently reprinted in Newton (1978), pp. 255-8.

¹⁸ Cambridge University Library, MS. Add. 4003; reprinted in Newton (1962), pp. 89-156.

correspondence published in Amsterdam and in London in 1668. Indeed, it seems certain that Newton had this open in front of him as he wrote the passage in which he refers to it. But if *De gravitatione* was written no earlier than 1668, we still need to know whether it was written in this year or shortly after, or much later, as Dobbs (1991) suggested. Is there anything in Newton's discussion of the nature of body and of hydrodynamics, which allows us to place the *De gravitatione* in the sequence we have been trying to define?

On the immediate face of it, the answer ought to be no. While the discussion of space in *De gravitatione* shows marked and detailed similarities with other pronouncements and discussions of space from different parts of Newton's career, the discussion of body is a unique one-off. Famously, Newton suggests that a body might be nothing more than a part of space which God, by an act of will, has made impenetrable. If God should exercise this power, Newton wrote,

and cause some space projecting above the Earth, like a mountain or any other body, to be impervious to bodies and thus stop or reflect light and all impinging things, it seems impossible that we should not consider this space to be truly body from the evidence of our senses (which constitute our sole judges in this matter); for it will be tangible on account of its impenetrability, and visible, opaque and coloured on account of the reflection of light, and it will resonate when struck because the adjacent air will be moved by the blow.

As far as I know, Newton, who was given to recycling and re-presenting ideas throughout his career, never discussed such an idea of body anywhere ever again (but see Gabbey, 2011). In principle, therefore, such a unique speculation, bearing no relation to any other part of his work can be slotted in anywhere in his career. Speaking personally, however, I'm inclined to infer from its uniqueness that it was more likely to be an early work, which he completely abandoned, rather than an idea he came up with while preparing the *Principia* and never returned to, not even as the hint of a suggestion in the *Queries*. But, this is just my hunch, and fortunately we do not have to rely on it. Let us press on, therefore.

Expanding on his idea, Newton insisted that bodies could be nothing more than concreted space:

If we may further imagine that that impenetrability is not always maintained in the same part of space but can be transferred hither and thither according to certain laws, yet so that the amount and shape of that impenetrable space are not changed, there will be no property of a body which this does not possess. It would have shape, be tangible and mobile, and be capable of reflecting and being reflected, and no less constitute a part of the structure of things than any other corpuscle... (Newton, 1962, p. 139).

It is difficult to formulate an argument based on a negative, but I can't help noticing that Newton's list of the properties of bodies here is repetitive, it adds nothing to the list of properties in the previous quotation except the motion which is now being introduced in to the discussion. If this work was conceived to provide material for the *Principia*, surely Newton would have taken the opportunity to add to the properties of body, their ability to attract and repel other bodies—and at a distance?

Consider also the discussion following Newton's proposed new definition of body:

we can define bodies as *determined quantities of extension which omnipresent God endows with certain conditions*. These conditions are, (1) that they be mobile... (2)

that two of this kind cannot coincide anywhere; that is, that they may be impenetrable, and hence that when their motions cause them to meet they stop and are reflected in accord with certain laws; (3) that they can excite various perceptions of the senses and the fancy in created minds... (Newton, 1962, p. 140).

Again, the opportunity is missed to add interparticulate forces as one of the conditions which God endows upon the “determined quantities of extension”.

But we do not have to confine ourselves to this kind of speculation about whether Newton *would* have said this, or that, in 1685. Eventually, Newton tears himself away from his digression on the nature of space and body and returns to what he calls the “main theme” of *De gravitatione*.¹⁹ Continuing, therefore, to set up the proposed discussion of fluid dynamics, Newton defines force:

Definition 5. Force is the causal principle of motion and rest. And it is either an external one that generates or destroys or otherwise changes impressed motion in some body; or it is an internal principle by which existing motion or rest is conserved in a body, and by which any being endeavours to continue in its state and opposes resistance (Newton, 1962, p. 148).

In the following five definitions, Newton considers the different kinds of “internal” forces: *conatus* or endeavour, *impetus*, *inertia*, pressure, and gravity. The first three are entirely mechanical and derive essentially from Cartesian physics. The same is true of pressure, but it is worth comparing this with the account of pressure given in the *De aere et aethere* of 1679.

Definition 9. Pressure is the endeavour of contiguous parts to penetrate each others’ dimensions. For if they could penetrate the pressure would cease. And pressure is only between contiguous parts, which in turn press upon others contiguous to them, until the pressure is transmitted to the most remote parts of any body, whether hard, soft or fluid. And upon this action is based the communication of motion by means of a point or surface of contact (Newton, 1962, p. 148).

There is nothing original here, but in the *De aere* Newton first points to the link between pressure and heat and explains this in terms of increased vibrations of the particles of air when agitated by heat. Furthermore, the account he gives of the transmission of vibrations through the air does not depend on their contiguity, or their coming into contact. Thanks to the repulsive forces which in *De aere* he supposes between the particles of air, a particle only has to begin to move towards another particle for that particle to begin its own motions away from it. Vibrations are transmitted at a distance (Newton, 1962, p. 224):

Suppose A, B, C, three particles in a state of rest, and if B is set in motion by heat towards A, as far as the point R, it drives A away to a greater distance and, by the same action in reverse springing back towards S, drives away C and so on, B alternately repelling A and C with a vibrating motion and A and C similarly repelling their neighbouring particles...

A R · · · · B · · · · S C

It seems odd that Newton should move from this original account of pressure in 1679 to a bland and unoriginal account in 1685. I believe the definition of pressure in the *De gravitatione* makes it highly probable that it was written before the *De aere*.

¹⁹ For a full comparison of the mechanics in *De gravitatione* with that in the *Principia*, see Steinle (1991).

It is also odd that in 1685 he should provide a definition of gravity which is certainly compatible with, if not actually derived from, the Cartesian account:

Definition 10. Gravity is a force in a body impelling it to descend. Here, however, by descent is not only meant a motion towards the centre of the Earth but also towards any point or region, or even from any point. In this way if the *conatus* of the aether whirling about the Sun to recede from its centre be taken for gravity, the aether in receding from the Sun could be said to descend. And so by analogy, the plane is called horizontal that is directly opposed to the direction of gravity or *conatus* (Newton, 1962, p. 148).²⁰

This aether seems just like the swirling whirlpool of “second matter” which Descartes deploys in his vortex physics (Aiton, 1972; Gaukroger, 2002). Accordingly, it seems entirely out of keeping with the theory of gravity that Newton developed after his correspondence with Hooke in 1679.

Dobbs believed that *De gravitatione* had to be written between what she calls the “augmented” *De motu*, written around December 1684, and what she calls the “initial revise” of *De motu*, written by the early spring of 1685 (Dobbs, 1991, p. 141). She drew this conclusion because the later version of *De motu* assumed “the mutuality of gravitational influence” and she evidently saw this as an advance on anything found in the *De gravitatione* (Dobbs, 1991, p. 141). But I would say the same is true of the definitions of force even in the very first version of *De motu*, written after Halley visited Newton in Cambridge and set the composition of the *Principia* in motion.

Compare the definition of gravity we have just looked at (as it appeared in *De gravitatione*) with the definition in Draft A of *De motu* (which the Halls date to the summer of 1684):

The centripetal force is any action or potential by which a body is drawn, impelled or in any way tends towards any point as to a centre. Of this kind is gravity, by which a body tends towards the centre of the earth: the magnetic force, by which iron goes towards the centre of the magnet, and that force, whatever it may be, by which the Planets are preserved in their orbits and perpetually confined there, lest they go astray along the tangents to those [orbits] (Newton, 1962, p. 242).

It is easy to see that this is written after Newton’s exchange with Hooke, in which he was made aware of Hooke’s theory of the tangential motions of planets being bent into orbit by an attractive force. This is definitely not true of the definition of gravity in *De gravitatione*, which only shows the influence of Descartes.

It is also worth noting that in the *De gravitatione* Newton does not suggest that the particles of individual bodies are held together by gravitational attraction, or any other kind of attraction, be it magnetic, electrical, or an as yet unknown active principle responsible for cohesion, as we might have expected him to do in 1685. He talks instead, albeit figuratively, of glue:

I suppose that the parts of hard bodies do not merely touch each other and remain at relative rest, but that they do besides so strongly and firmly cohere, and are so bound together, as it were by glue, that no one of them can be moved without all the rest being drawn along with it... (Newton, 1962, p. 151).

²⁰ The concept of *conatus* is used here in an entirely Cartesian sense. Although *conatus* also appears in the discussion following Definition 5 at the outset of the *Principia* it is there seen as a tendency opposed by gravity, not constituting gravity, as here.

Furthermore, immediately after this he even dispenses with an atomistic account of solid bodies. Favouring his speculation that solid bodies are parts of space made impenetrable by God, he presumably thought it unlikely that God would choose to make innumerable atom-sized bits of impenetrable space and then arrange them to form a rock, when he could simply make one rock-shaped bit of impenetrable space. This is how he continues:

...that no one of them can be moved without all the rest being drawn along with it; or rather that a hard body is not made up of conglomerate parts but is a single undivided and uniform body which preserves its shape most resolutely, whereas a fluid body is uniformly divided at all points (Newton, 1962, p. 151).

Surely, this has to be an early speculation, written even before Newton became committed to the atomist theory of matter (applied even to hard or solid bodies) which is unquestioningly assumed in almost everything else he wrote?

Finally, let us consider what Newton says in the *De gravitatione* about the aether. The starting point for the discussion is clearly the Cartesian “aether” of plenist vortex physics. Newton spends time arguing that such an aether would offer resistance to comets and other projectiles moving through it, and if it did not do so, then it could not be a plenum. The argument goes like this:

For if the aether were a corporeal fluid entirely without vacuous pores, however subtle its parts are made by division, it would be as dense as any other fluid, and it would yield to the motion of bodies through it with no less sluggishness; indeed with a much greater, if the projectile should be porous, because then the aether would enter its internal pores, and encounter and resist not only the whole of its external surface but also the surfaces of all the internal parts. Since the resistance of the aether is on the contrary so small when compared with the resistance of quicksilver as to be over ten or a hundred thousand times less, there is all the more reason for thinking that by far the largest part of the aetherial space is void, scattered between the aetherial particles (Newton, 1962, p. 147).

To the modern reader it would probably seem more apposite to speak of aetherial particles scattered through the void, but the notion of a “scattered void” was a fairly standard way of referring to an extended void space, as opposed to the kind of void spaces which necessarily remain in between close-packed spherical atoms.²¹ Anyway, there are two points to notice in the discussion of aether in *De gravitatione*. Firstly, that there is no mention of an endeavour among the particles to recede from one another, much less any mention of repulsive forces (and yet, as we’ve seen, if this was written in 1685, such ideas had already been discussed by Newton). Secondly, in spite of Newton’s scepticism about the aether as it appeared in Cartesian physics, he does not conclude that the aether does *not* exist. The closest he gets to denying the existence of the aether is merely another attempt to throw doubt on the Cartesian aether:

If there were any aerial or aetherial space of such a kind that it yielded without any resistance to the motions of comets or any other projectiles I should believe that it was utterly void. For it is impossible that a corporeal fluid should not impede the motion of bodies passing through it, assuming that (as I supposed before) it is not disposed to move at the same speed as the body... (Newton, 1962, p. 146).

²¹ On this see Grant (1981). Newton himself refers to a “scattered vacuum” shortly before this: Newton (1962), p. 146.

Although it might look as though Newton comes close here to denying the existence of the aether, we can see from the subsequent discussion that he merely concludes that the resistance of the aether is extremely small compared to the resistance of quicksilver, and therefore, if the aether does exist it cannot be like the Cartesian aether (filling all space) but must consist of particles widely dispersed through otherwise void space.

In view of this, we might be tempted to jump to the conclusion here that Newton's aether particles were held apart in the void by repulsive forces operating between them. It is important to note, however, that he does not say this. If he had said it in this document, this would constitute strong grounds for supposing the *De gravitatione* was written after 1679. But Newton did not say it, and so we have to accept the possibility that he is thinking here of an aether whose particles are widely dispersed simply because it is highly rarefied, and by definition (if you are an atomist), rarefaction implies increased distances between particles.²² Of course, this does implicitly raise the question as to what keeps the particles apart, but those committed to atomist philosophies were used to turning a blind eye to this problem, or at least to not taking it seriously. As we have seen in Section 2 above, before the *De aere* of 1679 Newton effectively avoided the issue, and there is no reason to suppose that he was not also avoiding it here in *De gravitatione*, and that therefore, the *De gravitatione* pre-dated 1679.

The fact that Newton did *not* deny the existence of the aether in the *De gravitatione* is another reason for supposing that it was unlikely to have been written after 1679. According to Westfall, Newton effectively abandoned the belief in an aether shortly after he broke off writing the unfinished *De aere et aethere* in 1679 (Westfall, 1980, pp. 376-7).²³ It was at this time that Newton performed elaborate pendulum experiments, comparing the number of oscillations of solid and hollow pendulum bobs. The aim was to determine how an all pervasive aether, supposedly capable of acting not just on the surface of a body but also on its inner parts, affected these different kinds of pendulum. The up-shot was that Newton came to believe that there was no aether, and began to favour the idea expressed in the Preface of the *Principia*, that physical phenomena could be explained by forces of attraction and repulsion operating between the particles of all bodies (Newton, 1999, pp. 382-3). After all, it was at just this time that Hooke introduced him to the idea that gravity could be understood, without recourse to an aether, as an attractive force capable of acting across vast distances of empty space.

Certainly, speculative explanations of physical phenomena that depended on an aether dropped out of Newton's writings after 1679, until 1717 when they reappeared in the so-called "aether Queries" (nos 17-24), in the second English edition of the *Opticks*. Presumably he reverted to them at this time in response to Continental dismay that he did not offer a mechanical account of the action of gravity—it was also, of course, an opportune moment because his most astute, persistent, and annoying critic, Leibniz, had just died. In these Queries Newton used density gradients to provide a quasi-mechanical explanation and played

²² We noted earlier that in the *De gravitatione* Newton seemed to deny atomic structures when dealing with hard or solid bodies, but even there he admitted the atomist view that fluid bodies are "uniformly divided at all points" (Newton, 1962, pp. 151).

²³ Westfall (1980), p. 377, writes that "Now he had demonstrated to his own satisfaction that the aether, the *deus ex machina* that made mechanical philosophies run, does not exist". I believe this remained true even in 1717 when Newton included the aether Queries into the *Opticks*. In my view, Newton introduced these Queries to silence "cavilling" from mechanical philosophers, but his own belief was that the aether was not necessary and did not exist. The fact is, for all his caution in expressing the idea openly (as discussed in Section 1), after 1679 Newton believed in interparticulate forces acting at a distance between the particles.

down the fact that the density gradients were generated by the repulsive forces operating at a distance between the particles of the aether and the particles of all other matter. Leibniz might have made an issue of these unexplained, occult, repulsive forces operating at a distance between the particles, but Newton had made sure that his nemesis had been silenced before he put these ideas in the public domain.

The evidence from Newton's writings, therefore, suggests that Westfall was right, and that after 1679—when he arrived at the existence of repulsive forces as a result of his own speculations in *De aere*, his experiments on solid and hollow pendulums, and his awareness of Hooke's use of cosmic attractive forces—Newton assumed that all physical phenomena could be explained in terms of attractive and repulsive forces operating between all particles. If the *De gravitatione* was written in 1685, its assumption that a highly rarefied aether was a reality would represent an inconsistency in the historical development of Newton's thought.

So, although much of *De gravitatione* is devoted to dismissing Cartesian ideas (Descartes's theory of matter as extension, the plenum, the relativity of motion, and so on), and it is undoubtedly the locus for Newton's first ruminations on what will later become his theory of absolute space, the theory of body it offers is nonetheless entirely mechanical in the strict sense (that is, it deals with body which is passive and inert, endowed only with inertia, and capable of acting only through its motion and force of impact). There is no hint of bodies deploying interparticulate forces capable of operating across empty space. Furthermore, there aren't even any suggestions that matter might be infused with active principles, as we can see in the *Vegetation of Metals* of about 1670. All in all, then, it seems to me that the internal content of the *De gravitatione* favours the early dating which the Halls gave it—1668 (even before the *Vegetation of Metals*)—and seems to make Dobbs's suggestion that it was written in 1685 virtually untenable.

It is perhaps also worth pointing out that one of the fullest arguments Dobbs provides for her revised date is that the *De gravitatione* bears many resemblances to the *Principia*. She has no trouble in showing how earlier Newton commentators, in spite of assuming it was written around 1670, acknowledge the close similarities between the two works (Dobbs, 1991, pp. 139-41).²⁴ But this in itself is not a reason to conclude that the two writings were composed close together. The *Vegetation of Metals* shows many close similarities to the "Hypothesis of Light", and both of them, dating from the 1670s, show close similarities to the Queries in the *Opticks* of 1717. Dobbs does not offer the kind of close reading of the *De gravitatione* that I have presented here. It is my conviction that I could go through the *De gravitatione* and show that those aspects of it which Newton recycles in the *Principia* are irrelevant to, or unaffected by, the chronological development of Newton's thought on actions at a distance and interparticulate forces. I could do this, but this paper is long enough already. I hope I have shown, anyway, that by reconstructing Newton's thinking on these matters, we can conclude that the *De gravitatione* must have pre-dated his commitment, from 1679 onwards, to actions at a distance.

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²⁴ To the major works dealing with the *De gravitatione* which Dobbs cites, we can now add Steinle (1991). Steinle also favours the early date of composition of *De gravitatione*, about 1670; Steinle (1991), pp. 9-11, and 124-5.

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