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Newton's notion and practice of unification

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Abstract

In this paper I deal with a neglected topic with respect to unification in Newton's *Principia*. I will clarify Newton's notion (as can be found in Newton's utterances on unification) *and* practice of unification (its actual occurrence in his scientific work). In order to do so, I will use the recent theories on unification as tools of analysis (Kitcher, Salmon and Schurz). I will argue, after showing that neither Kitcher's nor Schurz's account aptly capture Newton's notion and practice of unification, that Salmon's later work is a good starting point for analysing this notion and its practice in the *Principia*. Finally, I will supplement Salmon's account in order to answer the question at stake.

Keywords: Explanation; Isaac Newton; *Principia*; Unification.

1. Introduction

In this paper I try to capture Newton's *notion* of unification and the *actual practice* of unification in his scientific work. It is a *communis opinio* that Newton's unification of the terrestrial and heavenly bodies is an unprecedented achievement. In the literature on the nature and place of unification in scientific theories, philosophers of science therefore frequently refer to Newton's mechanics. Nevertheless, few attempts

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have been made to really assess what Newton wrote/thought on the matter of unification in science (Newton's notion of unification) and whether Newton actually practised what he preached (Newton's practice of unification).[1]

I will use contemporary approaches on unification as tools of analysis. In the literature on unification in philosophy of science there are broadly two positions: the bottom-up approach—defended by the causalists—and the top-down approach—defended by the unificationists. According to the first approach explanation is local; according to the second it is global. The causalists claim that unification is '*parasitic on the causal explanation of individual facts*' (Kitcher, 1985, p. 636). This approach was epitomised by Salmon (1984).[2] The unificationists, on the other hand, endorse the view that causal explanation of particular occurrences recapitulates the ordering derived from the systematisation of regularities (Kitcher, 1985, p. 635). This tradition is primarily embodied by Kitcher (1989). Recently Gerhard Schurz defended a rather different top-down approach (Schurz, 1999).

First, I will argue that Kitcher's account of unification does not provide an adequate perspective on Newton's *practice* of unification (Section 2). I will omit a comparison between Newton's *notion* of unification and Kitcher's account. The reason for this is that there are few statements in Newton's work that explicitly converge to or differ from Kitcher's account. Second, I will argue that Schurz's account is at odds with Newton's notion *and* practice of unification (Section 3). Finally, I will argue that Salmon's later synthesis of the two approaches (Salmon, 1998) is a good starting point for describing and understanding Newton's notion and practice of unification (Section 4). In this section I attempt to characterise Newton's notion and practice of unification. To sum up, in this paper I will deal with different but obviously interconnected questions. Did Newton conceive unification according to one of our contemporary approaches? Did he realise unification according to one of our contemporary approaches? Is the end product unified in the sense of one of our contemporary theories? What are the essential differences and/or similarities between Newton's conception and practice of unification and ours?

2. Kitcher and Newton

2.1. Kitcher's views on unification

Kitcher claims that behind the official view of the logical positivists, which states that explanation aims at expectability, there is also an unofficial view which regards explanation essentially as unification (Kitcher, 1981, p. 508). Kitcher tries to develop this idea. Our understanding of nature advances by increasing the degree of unification:

[1] The only exception seems to be Halonen & Hintikka (1999). I will briefly show why their account is not satisfactory in Section 4.

[2] In his later work Salmon abandoned this idea and argued that both approaches were not incompatible. See below.

> Science advances our understanding of nature by showing us how to derive descriptions of many phenomena, using the same patterns of derivation again and again, and, in demonstrating this, it teaches us how to reduce the number of types of facts we have to accept as ultimate (or brute). (Kitcher, 1989, p. 432)

Understanding amounts to seeing common (argument) patterns. Let us take a closer look (I will simplify, however). According to Kitcher a theory unifies our beliefs when it provides one (or a few) pattern(s) of argument which can be used in the derivation of a large number of sentences we accept (ibid., p. 514). He introduces *K*, the set of accepted sentences at a certain point in history; *E*(*K*) is the *explanatory store*, that is, the set of arguments acceptable as the basis for acts of explanation by those whose beliefs are exactly the members of *K* (ibid., p. 512). In Kitcher's understanding *E*(*K*) is the set of arguments that best unifies *K* (ibid., p. 434). How do we obtain *E*(*K*)? In order to understand this we need the notion of a 'generating set'. A *generating set (G) for a set of derivations (D)* is a set of argument patterns such that each argument/derivation in the set *D* is an instantiation of some pattern in *G* (ibid., pp. 519–520). A generating set *G* is said to be *complete with respect to K* if and only if every derivation that is acceptable relative to *K* and which instantiates a pattern in *G* belongs to *D*.[3] In order to determine *E*(*K*) we restrict ourselves to those generating sets that are complete with respect to *K*. Then we look for several possible bases among the set of complete generating sets. The *basis* for a systematisation is the complete generating set which is the primus according to three criteria: paucity (the amount of argument patterns it contains), stringency (which depends proportionally on of the amount of schematic letters and the level of difficulty for the filling instructions to be satisfied) and, finally, the magnitude of the set of conclusions (ibid., pp. 520–521). The quality of a generating set varies proportionally to the stringency and the magnitude of the set of conclusions; it varies inversely to its paucity. If we select from the remaining bases the basis with the best unifying power we, finally, obtain *E*(*K*). What is particularly interesting for my present purposes is that Kitcher also links his model to some extent to Newton. He quotes the following fragment from the *Principia* in favour of his account:

> If only we could derive the other phenomena of nature from mechanical principles by the same kind of reasoning! For many things lead me to have a suspicion that all phenomena may 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, p. 382)

[3] This is equivalent to saying that the generating patterns must be deductively closed, that is, everything that is derivable from it, is a member of it. Thus, a set Γ is deductively closed if and only if for every A the following holds: A is a member of the set Γ, if A is derivable from Γ.

From this Kitcher concludes:

> This, and other influential passages, inspired Newton's successors to try to complete the unification of science by finding further force laws analogous to the law of universal gravitation. . . . The passage I have quoted from Newton suggests the nature of the unification that was being sought. *Principia* had exhibited how one style of argument, one 'kind of reasoning from mechanical principles', could be used in the derivation of descriptions of many, diverse, phenomena. The unifying power of Newton's work consisted in its demonstration that one *pattern* of argument could be used again and again in the derivation of a wide range of accepted sentences. (Kitcher, 1981, pp. 513–514)

At the level of understanding unification is essential. This quote does not necessarily imply that Newton was a proto-unificationist, but it does entail that the *Principia* revealed or at least suggested the importance of using a single argument pattern. According to Kitcher, one of the basic Newtonian patterns used in treating one-body systems with a body α is:

1. The force on α is β.
2. The acceleration of α is γ.
3. Force = mass · acceleration.[4]
4. (Mass α) · (γ) = β.
5. $\delta = \theta$ [5]

(Kitcher, 1981, p. 517).

Therefore Newton's successors tried to describe a variety of phenomena with the same argument pattern in order to understand them.

2.2. A comparison with Newton

2.2.1. Introduction

As announced in Section 1, I will only compare Newton's *practice* with Kitcher's account. This amounts to analysing whether Newton's theory of universal gravitation is unified in the sense that Kitcher suggests and whether explanation for Newton is identical to using the same argument pattern. I will do so by focusing on examples of explanations in Book III of the *Principia*, namely Newton's explanation of the tides and his explanation of the motion of the moon (Section 2.2.2). Newton establishes his theory of universal gravitation in Proposition 8 of Book III. In the subsequent propositions he explains several phenomena with this theory—such as the

[4] Note that Newton's original second law states: 'A change in motion is proportional to the motive force impressed and takes place along the straight line in which the force is impressed' (Newton, 1999, p. 416).

[5] 'δ' refers to the variable coordinates of the body; 'θ' is an explicit function of time.

tides and the motion of the moon. The answer will turn out to be negative: Newton does not seem to accept some of the central tenets of Kitcher. Finally, I will argue that there are even further, more fundamental differences between Newton and Kitcher with respect to the relationship between unification and scientific explanation (Section 2.2.3).

2.2.2. Newton's explanation of the tides and the motion of the moon

The theory of universal gravitation predicts that the motions of the moon and the sun will influence the oceans. Newton starts by arguing from Corollaries 19–20 to Proposition 66, Book I (this is a three-body system) that the sea should rise and fall twice every day (Newton, 1999, pp. 582–583). The force of the sun and the moon will cause a mixed motion (ibid., p. 835). In conjunction or opposition their effects will be combined, and this will result in the greatest ebb and flood. In the quadratures the sun will raise the water while the moon depresses it and will depress the water while the moon raises it. The lowest tide of all will arise from the difference between these two effects. Next Newton considers the other parameters that are relevant for the phenomenon of the tides: for example, the distance of the moon and the sun from the Earth, the declination (or distance from the equator), and the specific way the water is transported into a harbour (ibid., pp. 836–839). Then Newton turns to the very specific case of the harbour in Batsha (then in Indochina, now Vietnam) where the water stays still on the day following the transit of the moon over the equator. This can be explained as follows. The tides in some harbours are sometimes transported through different channels and pass more quickly through some than through others. Then the tides in Batsha are explained as follows:

> Let us suppose that two equal tides come from different places to the same harbour and that the first precedes the second by a space of six hours after the appulse of the moon to the meridian of the harbour. If the moon is on the equator at the time of this appulse to the meridian, then every six hours there will be equal flood tides coming upon corresponding equal ebb tides and causing those tides to be balanced by the flood tides, and thus during the course of that day they will cause the water to stay quiet and still. (Ibid., p. 838)

Clearly this explanation is *ad hoc*: supposed contextual factors are adduced. Halonen & Hintikka (1999), p. 27 would speak of '*ad explanandum truths*'. These auxiliary premises obviously vary from case to case, that is, from harbour to harbour. They cannot be the source of any unification: each explanation involves different contextual factors. Newton does not use a standard argument pattern here to explain. Rather he first infers the causal mechanisms that are responsible for the tides from the theory of universal gravitation and next he considers relevant parameters that influence or disturb the regular tides. Newton is not explaining here along Kitcher's line of thought.

Let us turn to Newton's explanation of the motions of the moon. I will focus on Propositions 22 and 25, Book III here, since a full account of the explanation of the motions of the moon would be too technical and complex to spell out here. From the theory of universal gravitation it follows that the motions of the Earth and the sun will affect the motion of the moon. In Proposition 66, Book I Newton constructed a three-body system including the relevant forces. The first accelerative force is the force that arises from the mutual attraction between the Earth and the moon. By this force alone the moon would describe areas proportional to the times (Newton, 1999, p. 571). Then Newton introduces the accelerative force of the sun that he resolves into two components: one parallel to the force between the Earth and the moon, the other directed from the sun to the Earth. Since the first component force is not inversely proportional to the square of the distance it will disturb the moon's regular motion produced by the first force (ibid.). The second component force in combination with the two previous forces will result in a force that is no longer directed from the sun to the moon and will cause a deviation from the elliptical orbit and Kepler's second law. This explains why the moon shows irregular motions. Newton declares in the subsequent scholium that he wished '*to show by these computations of the lunar motions that the lunar motions can be computed from their causes by the theory of gravity*' (ibid., p. 869). Indeed, what truly explains the motions of the moon is the interaction between the accelerative forces of the Earth and the sun on the moon. Of course, Newton's second law or his formula of universal gravitation will enable you to obtain the direction and strength of these forces, but these formulae remain silent on the interaction between them. It is not an argument pattern that provides explanation here, but the reference to (the interaction of) several centripetal forces, i.e., causes.

In the case of the tides Newton infers from the three-body system that the sun and the moon will cause a mixed motion and that the sea should rise and fall twice every day. But explaining the tides at specific places involves knowledge of other factors: for example, the latitude of that place or the way the water is transported into a harbour. This involves the postulation of *ad hoc* causes (cf. the harbour of Batsha). For every place these factors are different and hence there is no single argument pattern for all of them. In the case of the motion of the moon Newton infers from his three-body system that the accelerative force of the sun will disturb the strict Keplerian motion of the moon. Newton assumes the forces postulated by the theory of universal gravitation (the force of the Earth and the disturbing force of the sun) and shows that an irregular motion will follow from them. The causes inferred from the theory of universal gravitation explain here, not some standard argument pattern. To sum up: Newton's practice does not correspond to Kitcher's account.

2.2.3. Some further fundamental differences

There are further substantial differences between Kitcher and Newton. To see these we must take a closer look at Newton's actual unification. Let me point out that this section can be considered as a stage setting for Section 4, where I characterise Newton's notion and practice of unification. The unification is not straightforward. Let us look briefly at how Newton establishes his famous unification. Firstly, Newton demonstrates that the circumjovial planets, the circumsaturnian planets, the primary planets and the moon[6] are (1) drawn towards their respective centres by a centripetal force, and, that (2) this centripetal force varies inversely proportional to the square of the distance from those centres (ibid., pp. 802–805). This respectively follows from the fact that (1′) they describe areas proportional to the times and (2′) that their periodic times are as 3/2 powers of their distances from their respective centre. Newton infers the causal agents that are responsible for the mathematical regularities. These 'deductions' are validated by propositions Newton proved earlier in *Book I*:

> Proposition 2:
> Every body that moves in some curved line described in a plane and, by a radius drawn to a point, either unmoving or moving uniformly forward with a rectilinear motion, describes areas around that point proportional to the times, is urged by a centripetal force tending toward that same point (ibid., p. 446).
> Corollary 6, Proposition 4:
> If the periodic times are as 3/2 powers of the radii, and therefore the velocities are inversely as the square roots of the radii, the centripetal forces will be inversely as the squares of the radii; and conversely. (Ibid., p. 451)

A first level of unification is reached in Proposition 5. We know that the primary planets are drawn towards the sun by an inverse square law, that the moon is drawn to the Earth by a similar force, and that the secondary planets are drawn to their primary planets by a similar force. These are explanatory claims. Since these revolutions are phenomena of the same kind, they must—according to rule 2[7]—'*depend on causes of the same kind*' (ibid., p. 806). The elements of its domain obviously are: the primary planets, the secondary planets and the moon.[8] I will represent this as follows:

> *(1)* $(F \sim 1/r^2)$ *for domain* D_1 (D_1 = [p = primary planets, s = secondary planets, m = moon]).
> *The force-function operates from p towards the sun, from s towards Jupiter and Saturn, and from m to the Earth.*

[6] The proof for the moon is different. This concerns the famous moon test. In Proposition 4 Newton shows that (1) terrestrial gravity extends to the moon and that it does so by an inverse square law, and (2) it is this force of gravity which causes the moon to circle about the Earth. Newton calculates the distance the moon would fall if deprived from all forward motion in 1 min. The result of that calculation is 15 1/12 Paris feet. If gravity diminishes by an inverse square law and the Earth's gravity extends to the moon, then it follows that a heavy body on the Earth's surface should fall freely in one minute through 60 times 60 the above 15 1/12 Paris feet (the moon is approximately positioned at 60 Earth-radii from the Earth's centre) (Newton, 1999, p. 205). This indeed agrees with terrestrial experiments (cf. Huygens's experiments with pendula).

[7] Rule 2 goes as follows: 'Therefore, the causes assigned to the natural effects of the same kind must be, so far as possible, the same' (Newton, 1999, p. 795).

[8] The domain refers to those bodies that are drawn toward a centre. Therefore at this stage the sun is not an element of the domain. I will also take over Newton's distinction between the secondary planets and the moon.

In Corollary 1 Newton applies the third law of motion. He establishes that the sun is drawn back by the primary planets, that the Earth is drawn back by the moon, and that Jupiter and Saturn are drawn back by their satellites. (1) is reinterpreted as follows:

> *(2)* $(F \sim 1/r^2)$ *for domain* D_2 (D_2 = [p = primary planets, s = secondary planets, m = moon, S = sun]).
> *The force-function operates from p towards S (and conversely), from s towards Jupiter and Saturn (and conversely), and from m to the Earth (and conversely).*

Corollary 2 to Proposition 5 states that the gravity towards every planet is inversely as the square of the distance (ibid., p. 805). Thus, what is important for my present purposes here, is that Newton at this stage proves that the inverse square law is valid for all planets. In Corollary 3 he further extends his claim: all planets are heavy toward one another. And hence Jupiter and Saturn when in conjunction sensibly perturb each other's motion by attracting each other, the sun perturbs the lunar motions, and the sun and the moon perturb the sea (ibid., p. 806). (2) is again reinterpreted as follows:

> *(3)* $(F \sim 1/r^2)$ *for domain* D_2*.*
> *The force-function operates from p towards S (and conversely), from s towards p (and conversely), from m to e (and conversely), and from every p to every p.*

Next, he reinterprets Galileo's law of free fall in the following way (ibid., pp. 806–807).[9] The falling of heavy bodies takes place in equal times. Newton used experiments with pendulums to show that different materials of exactly the same weight (gold, silver, lead, glass, sand, salt, wood, water, and wheat) swing back and forth with equal oscillations. These experiments make it possible to discern the equality of the times with higher precision. The motive force of a falling body is its weight. This force is proportional to the acceleration and the mass of the body (by Newton's second law). Since the acceleration for bodies in free fall is constant, the weight of bodies in free fall is proportional to their mass. Newton generalises the outcome of the experiments with pendulums to all terrestrial bodies. In this way Newton arrives at a different unification:

> *(4)* $(W \sim m)$ *for domain* D_3 (D_3 = [t = terrestrial bodies]).

Since '*there is no doubt that the nature of gravity toward the planet is the same as toward the Earth*', this also holds for the other planets (ibid., p. 807). As he writes:

> Further, since the satellites of Jupiter revolve in times that are the 3/2 powers of their distances from the centre of Jupiter, their accelerative gravities toward

[9] Newton does not mention Galileo's name here: 'Others have long since observed that the falling bodies of all heavy bodies toward the Earth (at least making an adjustment for the inequality of the retardation that arises from the very slight resistance of the air) takes place in equal times, and it is possible to discern that equality of the times, to a very high degree of accuracy, by using pendulums' (Newton, 1999, pp. 806–807).

> Jupiter will be inversely as the squares of the distances from the centre of Jupiter,[10] and, therefore, at equal distances from Jupiter, their accelerative gravities would come out equal. Accordingly, in equal times in falling from equal heights [toward Jupiter] they would describe equal spaces, just as happens with heavy bodies on this Earth of ours. (Ibid.)

Here Newton has extended the domain of the (4). Consequently a new unification arises:

> *(5) ($W \sim m$) for domain D_4* (D_4 = [t = terrestrial bodies, bp = bodies in the neighbourhood of other primary planets]).
> The force-function operates from t to the Earth and more generally from bp to p.

In Proposition 7 Newton claims that gravity exists in all bodies universally and is proportional to the quantity of matter in each (ibid., p. 810). This follows from the fact that all parts of any planets A are heavy toward any planet B, and since the gravity of each part is to the gravity of the whole as the matter of that part to the matter of the whole, and since to every action there is always an equal reaction, it follows that planet B will gravitate in turn to all the parts of planet A, and its gravity will toward any part will be to its gravity towards the whole of the planet as the matter of that part to the matter of that whole (ibid., pp. 810–811). So we get:

> *(6) ($W \sim m$) for domain D_5* (D_5 = [b = all bodies universally]).

Finally, he generalises the inverse square law for all bodies universally (ibid., p. 811). He firstly argues that the force of the whole is the resultant of the forces of the constituting parts. Next, he shows that the gravitation toward each individual part is inversely as the square of the distance, which follows directly from Proposition 74, Book I (ibid., pp. 593, 811). By composition—'*componendo*'—of forces, the sum of the attractions will come out in the same ratio. Hence, all parts gravitate toward each other and this force varies inversely as the square of the distance from their centres.

> *(7) ($F \sim 1/r^2$) for domain D_5.*

So what he does is basically this: he extends the proportionality of weight and mass valid for bodies in free fall to celestial bodies, and subsequently he extends the inverse square law for celestial bodies to all bodies universally. The final result is the law of universal gravitation. The extension from one domain to another is an essential feature of Newton's unification in Book III. Newton already offered causal explanations before he established his theory. Kitcher's account does not incorporate the dynamics described above, since he assumes that generating sets are *deductively closed*. If a generating set is deductively closed, or 'complete' as Kitcher

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[10] In modern terminology this can be demonstrated as follows. Huygens published the result that a body travelling in a circle needs a force proportional to v^2/r to keep it in orbit: $F = k \cdot v^2/r$. Since v equals $2.\ \pi \cdot r/t$: $F = k \cdot 4 \cdot \pi^2 \cdot r^2/t^2 \cdot r$. Multiplied by r/r: $F = k \cdot 4 \cdot \pi^2 \cdot r^3/t^2 r^2$. Since r^3/t^2 is a constant according to Kepler's third law, we can write: $F = (\text{constant})/r^2$. See Newton (1999), p. 451.

calls it, this necessarily means that the domain must remain fixed, since the initial tenet is that every derivation acceptable relative to K must already belong to the set of generated derivations. Newton, however, extends the formulae '$W \sim m$' and '$F \sim 1/r^2$', respectively, to the celestial bodies and the terrestrial bodies. The corresponding generating sets are incomplete with respect to K. When Newton applies a generating set (including: (1) a = constant, (2) $W = F$ and (3) $F = m \cdot a$) in order to derive $W \sim m$, he uses the domain of terrestrial bodies. If, however, we extend our knowledge—in this case the observation that the satellites of Jupiter are equally urged—and combine this with some creative thought, we can derive the same formula for celestial bodies by a similar pattern. The result is that K as well as its consequences is extended. It may very well turn out that certain formulae can be applied to different domains which we beforehand neglected. Solely extending our knowledge is not enough to apply a pattern to a new domain. Due to this, he portrays our knowledge and inferences from it as far more static than they really are. Unification in this example is not generated by choosing from a set of complete generating patterns and bases and applying them to an invariable domain. It is established rather by extending our knowledge, and—via creative thought—applying it to new contexts and domains.

It took someone of Newton's calibre to do so. A similar thing can be said for the derivation of $F \sim 1/r^2$. Kitcher's problem seems to be that he focuses too much on the result and not on the context of discovery. I guess that Kitcher would reply that he is not talking about the unificatory act but about the understanding provided by an accomplished theory. I agree that this is what Kitcher talks about. But what is more crucial, Kitcher claims that at the level of scientific understanding unification is essential. It seems to me that a lot of understanding is provided in the way Newton unifies, that is, unifying by identification of causal agents. I think that Newton would have agreed here. This understanding is provided by Newton's bottom-up approach. When Newton infers instances of centripetal forces and uses the second *regula philosophandi* to identify them, he generates a first level of unification: the same inverse-square force pulls the primary planets towards the sun, the secondary to the moon, and the moon towards the Earth. These causal explanations help to understand step (1). If we look somewhat further in Newton's deduction a similar thing happens. The motive force of a falling body is its weight. According to the second law of motion this force is jointly proportional to the acceleration and its mass. Since the acceleration is constant, weight is proportional to its mass. We further know that gravity extends to the moon (cf. the moon test), and that the same inverse-square force acts on the primary and secondary planets and the moon. Here Newton again uses his second rule: the nature of gravity toward the planets is the same as toward the Earth. Therefore we can apply the proportionality of weight and mass to bodies near the planets as well. The identification of causal agents again explains step (5). That all parts of a planet gravitate to another planet explains step (6). The composition of forces in Proposition 74 explains why all parts gravitate toward each other and that the relevant force is an inverse-square law (step (7)). My feeling is that the dynamics Kitcher neglects really is important to Newton. So Newton and Kitcher seem to disagree on this point. The road Newton uses to arrive at universal gravitation enlightens, as does the result—to a lesser extent.

3. Schurz and Newton

3.1. Schurz's ideas on unification

In my presentation of Schurz's ideas I will mainly focus on two propositions concerning unification and explanation which Schurz argues for and which can be considered as the core of his view. The four elements of an explanation, according to Schurz, are:

(i) the why-question ('Why P?');
(ii) the cognitive state C of the questioner;
(iii) the answer A, and finally;
(iv) the expanded or revised cognitive state C + A after receiving the answer.

Schurz further proposes a necessary condition (U) for explanation. This condition is:

> (U):
> The explanatory premises Prem must be *less in need of explanation* (in C + A) than the explanandum P (in C). (Schurz, 1999, p. 97)

Schurz gives the following example (I have made some minor adjustments). Suppose Peter is flying past the window in the third floor. When someone would declare that Peter is flying past the window in the third floor because one second ago he was flying past the window in the fifth floor, few of us would agree that this is an adequate explanation. A good explanation could be that Peter is falling because of the gravity of the Earth. This illustrates, according to Schurz, that in all explanations the premises should be unproblematic, that is, they are less in need of explanation than the explanandum. One cannot understand something by means of some other thing which one has not understood (ibid., p. 98). If a phenomenon P is assimilated in the premises in C + A, then the de-coherence of P in C is removed (in C + A) but at the same time new information units may itself produce new decoherence with respect to other parts of C + A (ibid.). Condition (U) warrants that the loss of coherence due to the addition of the premises to C must be smaller than the gain of coherence due to the assimilation of P to the premises C + A. In order to establish a proper explanation one needs to refer to coherent or unified premises from which P can be derived. This leads to a top-down approach. Unification is decisive and fundamental; causal explanation is derived from it. Hence causality is not an *a priori* notion, but is it theory-relative. Causal explanation is a by-product of unification at the level of theories or laws (ibid., p. 100). Once a theory unifies phenomena originating from two or more different domains, the next step will be to causally structure that domain by means of a Causality Theory (CT). As Schurz writes:

> only because these theoretical laws have this overall unification power, our belief in real causal processes as opposed to non-causal correlations is rationally justified. . . . it is a result of the search for unification at the theoretical level that we introduce the distinction between reasons of being and reasons of believing at the singular event level. (Ibid., p. 101)

Each set of fundamental laws is, as mentioned above, accompanied by such a CT. A CT is a group of highest-level theories that puts constraints on the way real events may influence each other and consists of:

> (CT):
> 1. principles which concern the decomposition of macrophysical objects into smaller parts;
> 2. principles describing the propagation of 'causal' forces, of fields, momentum and/or of energy, in space and time. (Ibid.)

3.2. *A comparison with Newton*

In this subsection I will look at Newton's practice as well as his notion of unification. I will treat them together since they are closely related. Are Schurz and Newton kindred souls with respect to unification and explanation? I think not. The reason is that Newton at a crucial moment violates Schurz's necessary condition for explanation (U). At the end of the second edition of the *Principia* (1713), Newton claims to have explained the motions of the heavenly bodies and the flux and reflux of the sea. The cause of these phenomena is the force of gravity. However Newton did not assign a cause to gravity—hence he did not explain the *explanans* and he did not provide a causality theory.

Let us take a look at the General Scholium of that second edition—hereby we are already exploring Newton's notion of unification:

> 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. . . . And it is enough that gravity really exists and acts according to certain laws that we have set forth and is *sufficient to explain* all the motions of the heavenly bodies. (Newton, 1999, p. 943; my emphasis)

So Newton accepted an *explanans*—the force of gravity—that was in equal (or perhaps in more) need of explanation as the *explanandum*—the heavenly motions and the tides. Obviously no causality theory was provided: Newton did not specify a physical *modus operandi* for the force of gravity in his scientific practice. Newton explicitly warned his readers:

> Moreover, I use interchangeably and indiscriminately words signifying attraction, impulse, or any sort of propensity toward a centre, 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 action of a physical cause or reason, or that I am attributing forces in a true and physical sense to centres (which are mathematical points) if I happen to say that centres attract or that centres have forces. (Ibid., p. 408; see also p. 588)

As is well known, Leibniz and Huygens regarded gravity as a *qualitas occulta*.[11] The target of their criticism was the fact that gravity was used in explanations, while nothing was said about the nature and further functioning of gravity itself. Newton replied to their criticism with the following analogy—and here we are entering Newton's notion of explanation/unification:

> And to understand this without knowing the cause of gravity, is as good a progress in philosophy as to understand the frame of a clock & the dependence of ye wheels upon one another without knowing the cause of the gravity of the weight which moves the machine is in the philosophy of clockwork, or the understanding the frame of the bones & muscles by the contracting or dilating of the muscles without knowing how the muscles are contracted or dilated by the power of ye mind is [in] the philosophy of animal motion. (Newton, 1959–1977, Vol. V, p. 300)

The point Newton wants to make is that it is very well possible that certain phenomena are explained by an *explanans*, whose further cause is unclear. But there is no reason not to consider it as a proper explanation. He has explained the motion of celestial and terrestrial bodies. It works, *satis est*. One might add one thing here. When we look at Newton's unification as described in the previous section, it turns out that (causal) explanation is not a by-product of unification. Newton for instance already provided explanations—centripetal forces varying inversely as the square of the distance cause Kepler's second and third law—in order to establish (1).

4. Newton's views positively described

In order to get a grasp on Newton's notion and practice of unification I will focus on the analytic and the synthetic moment in Book III, the *systema mundi*, of the *Principia*. As Newton put it, the basic difficulty of natural philosophy is '*to discover the forces of nature from the phenomena of motions and then to demonstrate the other phenomena from these forces*' (Newton, 1999, p. 382). The first conjunct refers to analysis, the second to synthesis. The analysis in the *Principia* consists in deriving '*from celestial phenomena the gravitational forces by which bodies tend toward the sun and the individual planets*', the synthesis consists in the deduction of '*the motions of the*

[11] Larry Laudan sees gravitation as an external conceptual problem, that is, a case 'where a scientific theory is in conflict with any component of the prevalent *world view*' (Laudan, 1977, pp. 61–62). Lakatos states that in the 17th and 18th centuries people were accustomed to approach a theory primarily with metaphysical criticism. Therefore, they essentially criticised Newton for the 'unintelligibility' of his theory and did not care whether it was valid or not according to Newton's proposed criteria (Lakatos, 1978, p. 213). In the mechanistic metaphysics the only interaction between entities was by direct contact.

planets, the comets, the moon, and the sea' from these forces (ibid.). We will firstly consider the analysis. The analysis consists in

> making Experiments and Observations, and in drawing general Conclusions from them by Induction, and admitting of no Objections against the Conclusions, but such as are taken from Experiments, or other certain Truths. For Hypotheses are not to be regarded in experimental Philosophy. And although the arguing from Experiments and Observations by Induction be no Demonstration of general Conclusions; yet it is the best way of arguing which the Nature of Things admits of, and may be looked upon as so much the stronger, by how much the Induction is more general. And if no Exception occur from Phænomena, the Conclusion may be pronounced generally. But at any time afterwards any Exception shall occur from Experiments, it may then begin to be pronounced with such Exceptions as occur. By this way of Analysis we may proceed from Compounds to Ingredients, and from Motions to the Forces producing them; and in general, from Effects to their Causes, and from particular Causes to more general ones, till the Argument end in the most general. (Newton, 1979, p. 404)

Newton testifies here that the pillars of scientific enterprise are observations and experiments—apart from '*other certain Truths*'. From these, general conclusions are drawn by induction. The more general a conclusion the stronger. In the analysis in the *Principia* Newton infers from the observation that Kepler's second and third law hold for the primary and secondary planets that these motions are caused by inverse-square centripetal forces. The analytic phase of science typically consists in inferring causal agents. This is carried out from Propositions 1 to 5. In Proposition 5 Newton concludes that since these phenomena are of the same kind they depend on causes of the same kind (Newton, 1999, p. 806). This is where unification comes in: by identifying causal mechanisms. But the method of analysis doesn't stop here. The following step consists in generalising the results of the experiments and observations—as Newton puts it, '*drawing general Conclusions from them by Induction*' (Newton, 1979, p. 404). This again involves unification. Since Newton has demonstrated that the nature of gravity is the same for the primary and the secondary planets, we can use experiments here on Earth to gather further information concerning this force of gravity. In Proposition 6 Newton uses pendulum experiments to show that the weight of a body is proportional to its mass. From this he concludes that this proportionality also applies to other planets and their satellites. Underlying these inductive steps is a deep belief in the contiguity of nature. This is expressed in the third *regula philosophandi*:

> Those qualities of bodies that cannot be intended or remitted [*i.e., qualities that cannot be increased and diminished*] and that belong to all bodies on which experiments can be made should be taken as qualities of all bodies universally. (Newton, 1999, p. 795)

In Proposition 7 he extends the same proportionality to all bodies universally. Finally, in Proposition 8 he extends the inverse proportionality between gravity and the square of the distance to all bodies universally. That gravity exits in all bodies universally and is proportional to their mass and inversely proportional to the square of the distance from their centres is a proposition rendered general by induction. In the following phase of synthesis it is investigated whether phenomena that were not included in the original selection on which the general conclusion was based conform to this proposition or whether exceptions occur:

> In experimental philosophy, propositions gathered from phenomena by induction should be considered either exactly or very nearly true notwithstanding any contrary hypotheses, until yet other phenomena make such propositions either more exact or liable to exceptions. (Ibid., p. 796)

The method of synthesis consist in

> assuming the Causes discover'd and establich'd as Principles, and by them explaining the phaenomena proceeding from them, and proving the Explanations. (Newton, 1979, p. 405)

The synthesis starts after Proposition 8 and stretches out to the very end of Book III. Newton there shows that the motion of the planets, the motion of the moon, the tides, the motion of comets can be deduced from the causes proposed by the theory of universal gravitation. The phase of synthesis concerns the testing of the generality of the general principles. If no problems occur, the principle can by stated as truly universal—which is the case in the *Principia*. If problems occur then the principle needs to be 'de-unified'. Ultimately, the synthesis consists in testing the general principles obtained in the analysis.

We can now see—from Newton's utterances and his actual practice—that the role of unification is mainly connected with the analytic phase. We start with singular causal explanations. When these phenomena are sufficiently similar we can infer that they are produced by causes of the same kind. This is where unification comes in: when we identify causal mechanisms, we unify. This type of unification I refer to as *unification*$_1$. Given the fact that nature is very consonant with herself and has a preference for the same mode of operation, it is very likely that we will encounter similar causal agents when we study nature. Then a further level of unification is reached: qualities that cannot be diminished nor increased that pertain to all bodies on which we can perform experiments can be taken as universal qualities. This inductive generalisation is based on a selected set of phenomena (ibid., p. 386). This type of unification I refer to as *unification*$_2$. Since Halonen and Hintikka only focus on the '*inductio*'-side of unification they miss out on the first type of unification (Halonen & Hintikka, 1999, pp. 38–40). But there are further problems for their interpretation. The first phase of scientific inquiry according to Newton is the analysis where we proceed from the phenomena to (singular) causes. The motions of the secondary planets, for example, are explained by centripetal forces. It is clear from this that explanation is part of theory formation. This is a problem for the account of Halonen and Hintikka: they claim that for Newton explanation only involves 'synthetic' derivations of an already established theory and is not part of the 'analytic' process of theory formation (ibid., p. 40).

Neither Kitcher's nor Schurz's proposal is an adequate description of Newton's views on unification and scientific explanation. I think that a start towards a better (contemporary) description of Newton's view can be found in the later work of Wesley Salmon. Salmon moved to the position that there are at least two intellectual benefits that scientific theories can offer us: (1) a unified world picture and insight into how various phenomena belong to the same domain, and (2) knowledge of the underlying mechanisms. These two accounts are by no means incompatible, both are interconnected:[12]

> In the process of searching out the hidden mechanisms of nature, we often find that superficially diverse phenomena are produced by the same basic mechanisms. *To the extent that we find extremely pervasive basic mechanisms, we are also revealing the unifying principles of nature*. (Salmon, 1998, p. 90; my emphasis)

This seems more apt to apply to Newton's views and practice. More precisely, it agrees with what I have called *unification$_1$*: unification established through identification of causal agents. Newton started Book III by inferring several inverse-square law centripetal forces. Since the constellations in which these forces are discovered are similar, we are allowed to infer—by the second rule for natural philosophy—that these phenomena are produced by one and the same cause. In this case Newton establishes a first level of unification by identifying causal agents—centripetal forces. This agrees very well with Salmon who claims we will often find that diverse phenomena are produced by the same basic mechanisms since the set of causal agents is fairly restricted. When we realise this we automatically unify. This is because a limited set of causal mechanisms pervades the physical world:

> Since there seem to be a small number of fundamental causal mechanisms, and some extremely comprehensive laws that govern them, the ontic conception has as much right as the epistemic conception to take the natural phenomena as a basic aspect of our comprehension of the world. *The unity lies in the pervasiveness of the underlying mechanisms* upon which we depend for explanation. (Salmon, 1984, p. 276)

Newton agreed to this.[13] Nature after all is '*simple, and is normally self-consistent throughout an immense variety of effects, by maintaining the same mode of operation*'. (Newton, 1959–1977, Vol. II, p. 418)

[12] See also Salmon (1989), pp. 183–184. I focus here on his fourth essay entitled 'Scientific explanation: Causation and unification' in Salmon (1998), pp. 68–78.

[13] Newton's motivation for this view is primarily theological. This is clear from the following statement: 'Truth is ever to be found in simplicity, and not in the multiplicity and confusion of things. As the world, which to the naked eye exhibits the greatest variety of objects, appears very simple in its internal constitution when surveyed by a philosophical understanding, and so much the simpler by now much the better understood, so it is in these [prophetic] visions. It is the perfection of God's work that they are all done with the greatest simplicity. He is the god of order and not of confusion. And therefore as they that would understand the frame of the world must indeavour to reduce their knowledge to all possible simplicity, so must it be in seeking to understand these visions' (quoted from Manuel, 1974, pp. 48–49).

5. Conclusion

Neither Kitcher's not Schurz's account seem to shed light on Newton's notion and practice of unification. Of all modern alternatives Salmon's later work on unification and causal explanation seems to be the closest to Newton's way of conceptualising and performing unification. There are two notions of unification in Newton's work that succeed each other:

(1) *unification*$_1$ refers to unification which is established by identification of causal mechanisms (this is based on the premise that nature maintains the same *modus operandi* as much as possible);
(2) *unification*$_2$ refers to generalising a conclusion to phenomena that were not originally included in the set of data used to establish this conclusion (this is based on the premise that nature is contiguous).

The first type is highly similar to Salmon's later thought on the non-incompatibility between an unificationist and a causalist approach of explanation. By now it should also be clear that Newton's way of conceiving unification and his actual practice correspond. Ultimately, he practised what he preached.

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