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NEWTONIAN EXPLANATORY REDUCTION AND HUME'S SYSTEM OF THE SCIENCES

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In the Introduction to his *Treatise of Human Nature*, the young David Hume makes a rather remarkable claim. He informs readers that what they are about to read is “a compleat system of the sciences,” which will provide the sciences with an entirely new foundation, and place them on a solid footing for the first time. As he writes:

There is no question of importance, whose decision is not compriz'd in the science of man; and there is none, which can be decided with any certainty, before we become acquainted with that science. In pretending therefore to explain the principles of human nature, *we in effect propose a compleat system of the sciences, built on a foundation almost entirely new, and the only one upon which they can stand with any security.*¹

Fourteen months after publishing these lines, Hume returns to this theme in an anonymously published abstract of the *Treatise*, in which he again writes that “This treatise . . . of human nature seems intended for a system of the sciences.” And he adds (in the third person): “[W]ere his philosophy receiv'd, we must alter from the foundation the greatest part of the sciences.”²

That Hume goes to the trouble of repeating these extraordinary claims more than a year after the publication of the *Treatise* suggests that the ambitions to which he gives voice in the Introduction were no passing whim. Hume really did take the *Treatise* to be “a compleat system of the sciences,” and he really did believe the existing sciences

¹ Hume ([1739] 1978, xvi). Emphasis added. Books I and II of the *Treatise* were published in January 1739. Book III was published in November 1740, together with the corrections to books I and II that are now called the “Appendix.” The “Abstract of a Book Lately Published” appeared in March 1740.

² Hume ([1740] 1978, pp. 646, 643).

would have to be more or less reconstructed in its wake. But most of Hume's readers, in his own time and in ours, have declined to give these claims much weight. Even Norman Kemp Smith, whose scholarship contributed so much to the present high regard for Hume as a philosopher, considered the *Treatise* too haphazard and eclectic a work to be anything like a "system of the sciences."³ And the same may be said of other interpreters of Hume who have followed his lead.⁴

My purpose here will be to present a new interpretation of Hume's aims in his *Treatise* based on the supposition that the ambitions described in the Introduction were meant to be read literally, and that this work was indeed intended to present a new system of the sciences. But I argue that to understand what Hume was after, we have to consider these ambitions in light of the methods and achievements of the Newtonian philosophy.

My argument will be in three parts: (i) First, I examine Hume's claim to have proposed "a compleat system of the sciences" in light of Descartes' very similar claims.⁵ Descartes' system consists of conclusions deduced from first principles thought to be self-evident.⁶ Hume, however, argues that knowledge is derived principally from

³ Kemp Smith ([1941] 2005) argues that Hume is excessively distrustful of parsimony and simplicity, "accept[ing] with an all too easy conscience the loose ends of doctrine in which his 'experimental' method was repeatedly landing him." On this view, Hume invokes a morasse of different fundamental principles, with new ones being introduced on an ad hoc basis whenever his argument runs into trouble. As Kemp Smith writes: "How numerous and motley a collection of ultimates he would recommend to our acceptance! All impressions of sensation, and as regards impressions of reflexion, the various appetites and passions moral and aesthetic, approvals and disapprovals, custom as an agency capable of generating a quite new feeling, the propensity of the mind to spread itself over external objects, these—with sympathy in the moral sphere and belief in the theoretical sphere standing ready to yield support to one and all of them—are the sorts of factors which Hume was prepared to regard as ultimate, and to which he freely resorted in circumventing the obstacles that beset his path." Kemp Smith does acknowledge Hume's commitment to parsimony in principle, but maintains that his "practice" is not in keeping with this commitment (p. 59).

⁴ See, for example, of John Passmore's appraisal of Hume as "a philosophical puppy-dog, picking up and worrying one problem after another, always leaving his teeth-marks in it, but casting it aside when it threatened to become wearisome" (Passmore 1968, pp. 87–88). Passmore does try to figure out what Hume means by a "system of the sciences." But he doesn't get very far, and ends up concluding that Hume's foundational enterprise isn't meant to be taken seriously: "[Hume] is deliberately arousing expectations, in order the more effectively to show that they cannot be fulfilled" (Ibid., p. 42).

⁵ Readings of Hume that have tried to make sense of Hume's foundationalist aspirations have been relatively rare. Focused treatments are found in Passmore (1968), Boehm (2008, and *forthcoming*), and Schliesser (2009, pp. 6–14).

⁶ Descartes does not use the term "deduction" in the formal, Scholastic-Aristotelian sense. His is a much looser use of the term, roughly equivalent to what we mean by an "inference" (Normore 1993, pp. 437–454; Owen 1999, pp. 12–29). Much of early modern thought follows Descartes on this point, including Newton. Compare Samuel Johnson's dictionary, which has as its first entry

experience. So a "system of the sciences" must, for him, be empirical. But what is an empirical "system of the sciences"? I argue that (ii) by the time Hume wrote the *Treatise*, English natural philosophy had indeed developed the tools for the construction of a hierarchical system of sciences derived empirically. The key to the construction of an empirical hierarchy of the sciences is provided by Boyle's conception of a step-wise "reduction" or "resolution" of the respective sciences to a small set of fundamental terms derived from physics.⁷ Such explanatory reduction then appears in a new and much more powerful form in Newton's *Principia*. Finally, I show that (iii) Hume consistently presents his method in terms almost identical to those Newton uses to describe his own explanatory reductions.⁸ Hume differs from Newton in claiming that all of experience can be reduced to psychological "elements" that he takes to be simpler and more general than those provided by physics.⁹

6.1 WHAT IS A 'SYSTEM OF THE SCIENCES'?

What does Hume mean when he speaks of a "system of the sciences"? We know from the Introduction to the *Treatise* that he conceives of all of the sciences as being inter-related—and, more specifically, that this interrelationship derives from the fact that all of the sciences are "dependent" on the study of human nature. As he writes:

'Tis evident, that all the sciences have a relation, greater or less, to human nature.... Even *Mathematics, Natural Philosophy, and Natural Religion*, are in

for 'deduce': "to draw in a regular connected series, from one time to another." See Baier (1991, p. 302, n. 8).

⁷ I will be using the term "reduction" to mean something rather different from what it is usually taken to mean in recent philosophy. I discuss this term and its meaning in the context of early modern philosophy in Section 2 below.

⁸ But Hume is not to be taken as a straightforward Newtonian. Hume in fact has a dual agenda with respect to Newton. On the one hand, Hume's aims and methods in the *Treatise* are strongly influenced by Newton. On the other hand, Hume's *Treatise* is deeply subversive with respect to Newtonianism. The subversive character of the Hume's philosophy with respect to Newton is a theme that has been raised in past work by Noxon (1973), Jones (1982), and Barfoot (1990, pp. 151–190). However, these works fail to recognize the profoundly Newtonian character of Hume's work. More balanced works that treat the anti-Newtonian aspects of Hume's philosophy alongside recognition of Newton's influence are Hazony and Schliesser (2014), Schliesser (2007, 2008, 2009), and Boehm (2008, 2012, and *forthcoming*). See also Garrett (1997, pp. 56–57), Casini (1988, pp. 45–48).

⁹ Hume (1739, p. 13). In this analysis, I am extending and elaborating a trend in recent Hume scholarship that sees explanatory reduction as playing an important role in Hume's philosophy. Versions of this view have been advanced by Loftson (1998, pp. 318–321), Garrett (1997, pp. 36–38), Waxman (1994, p. xiii), Laird ([1932] 1967, p. 41), and others.

some measure dependent on the science of *Man*; since they lie under the cognizance of men, and are judged of by their powers and faculties. 'Tis impossible to tell what changes and improvements we might make in these sciences were we thoroughly acquainted with the extent and force of human understanding, and could explain the nature of the ideas we employ, and of the operations we perform in our reasoning.¹⁰

It is this “dependence” of the other sciences on the science of human nature, and especially of the human mind, that underwrites Hume’s claim, quoted above, that there is “no question of importance, whose decision is not compriz’d in the science of man.” Similarly, when Hume writes that his system will be built on “a foundation almost entirely new, and the only one upon which [the sciences] can stand with any security”; and when he writes, a little later, that “[T]he science of man is the only solid foundation for the other sciences”—he is suggesting an architectural metaphor in which the science of human nature serves as the foundation for a structure that is made up of the other sciences.¹¹ Just as the higher reaches of the building stand secure only if they are built atop firm foundations, so too in the sciences: the other sciences are to be seen as being built up on top of the science of human nature, which alone can provide the “solid foundation” that is “the only one upon which they can stand with any security.”

This manner of speaking about the sciences is not original to Hume, and it seems clear that when he speaks of his philosophy as a “system of the sciences” based on foundations that are “secure” and “solid,” he is inviting comparison with other, earlier systems. Indeed, he opens the *Treatise* with a reference to these other “systems, which have obtained the greatest credit, and [have] carried their pretensions highest to accurate and profound reasoning,” and explicitly derides them for the “weakness” of their “foundations.”¹²

What systems did Hume have in mind? One of the principal ones must have been Descartes’ *Principles of Philosophy*, which purports to “deduce” physics and the other sciences from metaphysics. Indeed, Descartes’ writings are riddled with well-known allusions to the “weakness” or “solidity” of the “foundations” upon which the edifice

¹⁰ Hume (1739, p. xv).

¹¹ *Ibid.*, p. xvi.

¹² Hume writes: “’Tis easy for one of judgment and learning, to perceive the weak foundation even of those systems, which have obtained the greatest credit, and having carried their pretensions highest to accurate and profound reasoning. Principles taken on trust, consequences lamely deduced from them, want of coherence in the parts, and of evidence in the whole, these are everywhere to be met with in the systems of the most eminent philosophers.” (*Ibid.*, p. xiii). This seems to be directly aimed at Cartesians, Spinoza, and others who accepted an independent faculty of the intellect. See Garrett (1997, pp. 20–23).

of the sciences supposedly stands.¹³ In light of this striking similarity between Hume's declared aims and those of Descartes, it is worth asking what it is that makes Descartes' philosophy a system of the sciences.

Three aspects of Descartes' system immediately stand out. First, there is Descartes' understanding, inherited from Scholastic philosophy, of the various sciences being hierarchically ordered like a tree, with metaphysics as its base and the other sciences branching above it.¹⁴ As Descartes writes:

The first part of philosophy is metaphysics, which contains the principles of knowledge, including the explanation of the principal attributes of God The second part is physics, where, after discovering the true principles of material things, we examine the general composition of the entire universe, and then, in particular, the nature of this earth and all the bodies that are commonly found upon it Next, we need to examine individually the nature of plants, of animals, and, above all, of man Thus the whole of philosophy is like a tree. The roots are metaphysics, the trunk is physics, and the branches emerging from the trunk are all the other sciences¹⁵

In addition, this hierarchical ordering can be seen as consisting of two parts: the "foundations," which are a set of first principles "so evident that the human mind cannot doubt their truth"; and the rest of human knowledge, which is held in place in the hierarchy of knowledge by chains of deductions that are "very manifest." As Descartes explains:

[For] knowledge to be perfect it must be deduced from first causes . . . or principles. These principles must satisfy two conditions[:]

- [i] First, they must be so clear and so evident that the human mind cannot doubt their truth when it attentively concentrates on them¹⁶; and
- [ii] second, the knowledge of other things must depend on them [I]n deducing from these principles the knowledge of things which depend

¹³ Descartes ([1641] 1984, p. 12); Descartes ([1637] 1985, p. 115). Descartes' own philosophy, on the other hand, is said to be built on "very solid foundations." See Descartes ([1644] 1985, p. 189).

¹⁴ See also Bacon's ordering of human knowledge as a tree in Bacon ([1605] 2001, pp. 68–204), illustrated on two pages prior to 1. For the relationship with Scholastic systems of the sciences, see Biener (2008).

¹⁵ Descartes (1644, p. 186).

¹⁶ Compare *ibid.*, pp. 203, 207.

on them, we must try to ensure that everything in the entire chain of deductions which we draw is very manifest.¹⁷

For Descartes, a system of the sciences was thus a hierarchical ordering of the sciences, in which a set of indubitable first principles serves as the “foundation,” and the other sciences are shown to follow from these by means of chains of deductions.¹⁸ Descartes’ actual method of discovery was in fact more complicated than this, relying on a procedure for discovering these first principles, as well as on observation and experiment to fill out the tree of knowledge.¹⁹ Nevertheless, the belief that knowledge gleaned through these efforts would be easily assimilated into a single system of the sciences held together by necessary deductions was an unmistakable feature of the Cartesian philosophy.

In what sense can Hume see his own philosophy as resembling a system of the Cartesian type? Hume doesn’t have much use for self-evident first principles established a priori. And even the chains of deductions that are supposed to follow from these first principles are, for Hume, not terribly reliable, no matter how “very manifest” they may seem at first.²⁰ So what kind of a system of the sciences can Hume have in mind?

John Passmore has suggested that Hume’s description of his system as providing a new “foundation” upon which the sciences can be built indicates that his system of the sciences, like Descartes’, is intended to be hierarchical, although for Hume human psychology—the “true metaphysics”²¹—replaces a priori metaphysics as the base of the structure.²² Moreover, the higher reaches of Hume’s system can be convincingly pieced

¹⁷ Ibid., pp. 179–180. Line breaks added.

¹⁸ See also *ibid.*, pp. 183–184, 188–189.

¹⁹ Descartes’ presentation of his system of the sciences in the *Principles* strongly resembles the Scholastic systems with which it was competing, but his deductive structure obscures a more complicated method of discovery that is used to attain the knowledge ordered by this structure. Descartes was apparently committed to a method of discovery that consisted of (i) the reduction of all known effects to irreducible “simple natures” known by intuition; and (ii) deduction (“inference of something as following necessarily”) from these intuitions. It was this method that was used to construct the more general parts of Descartes’ deductive system of the sciences. The more specialized parts of the system, on the other hand, relied on observations and experiments, whose results were then supposed to fit into the deductive system for presentation as part of an integrated whole. See, especially, Descartes (1985 [1628], pp. 14–15); Descartes (1637, pp. 143–144). For discussion see Raftopoulos (2003); Gaukroger (2005); Garber (1993); Marion (1992).

²⁰ David Hume ([1748] 2008, pp. 22–23, 53), Hume (1739, pp. 180–183).

²¹ David Hume (1748, p. 8). Hume also uses the term “metaphysics” to describe his explorations of human psychology in Hume (1739, p. 185). Compare: “the reasonings of true philosophy; which, showing us the original qualities of human nature . . .” (*Ibid.*, p. 562).

²² Passmore (1968, p. 12) writes: “Hume sets out to show that the theory of human nature, not metaphysics, is the roots. . . . Metaphysics, he argues, is in part nonsense, in part psychology in disguise—it is nonsense when it talks about essences, occult qualities and the like; it is

together from comments in the *Treatise* and subsequent writings, as Miren Boehm has shown.²³ Her argument is as follows: Hume tells us in the Introduction that “all the sciences have a relation, greater or less, to human nature,” and then goes on to name the various sciences, dividing them into two groups. First he tells the reader (in the passage quoted above) that “even mathematics, natural science, and natural religion” are “dependent” on the powers of the human mind. He then proceeds to distinguish this group of sciences from a second group, which he says have a “more close” relationship with human nature:

If, therefore, the sciences of Mathematics, Natural Philosophy, and Natural Religion, have such a dependence on the knowledge of man, what may be expected of the other sciences, whose connexion with human nature is more close and intimate? . . . In these four sciences of *Logic, Morals, Criticism, and Politics*, is comprehended almost every thing, which it can any way import us to be acquainted with. . . .²⁴

In an advertisement published in 1739 with Books I and II of the *Treatise*, Hume explicitly says that the plan for the work is described in the Introduction, but that “all the subjects I have there plann’d out to myself, are not treated of in these two volumes.” If Books I and II are successful, Hume says he will “proceed to the examination of *morals, politics, and criticism*.” Additional volumes on these subjects “will compleat this *Treatise of human nature*.”²⁵

In Hume’s abstract of the *Treatise*, he explicitly describes his “system of the sciences,” and places those sciences most closely related to human nature in a clear relation one to another:

The sole end of *logic* is to explain the principles and Operations of our reasoning faculty, and the nature of our ideas; *morals* and *criticism* regard our tastes and sentiments and *politics* consider men as united in society. . . . This treatise

psychology when it concerns itself with causality, substance, identity. . . . Hume’s analysis of causality is a paradigm of philosophy as he would like it to be; *true* metaphysics—the science of human nature, the genuinely fundamental science—replaces false, or visionary, metaphysics.” Eric Schliesser (2009, pp. 6–14, 47) rightly argues that this foundationalism is part of Hume’s “general attempt to resurrect the prestige and independence of a reinterpreted (and constrained) first philosophy (metaphysics).”

²³ Boehm (2008, pp. 13–20).

²⁴ Hume (1739, pp. xv–xvi).

²⁵ *Ibid.*, p. xii.

therefore of human nature seems intended for a system of the sciences. The author has already finished what regards logic, and has laid the foundation of the other parts in his account of the passions.²⁶

From this it is evident that Book I, which “explain[s] the principles and Operations of our reasoning faculty, and the nature of our ideas,” is in fact that part of the *Treatise* that treats the science of logic; whereas the sciences of morals, criticism, and politics are themselves to be constructed on top of the foundation that is laid in Book II with Hume’s account of the passions. Returning to Hume’s discussion in the Introduction, we find that this supplies us with the rest of the hierarchy of the sciences: Hume tells us there that mathematics, natural philosophy, and natural religion are dependent on the science of man since they are conducted by means of man’s powers and faculties; and could be improved if we “could explain the nature of the ideas we employ, and of the operations we perform in our reasoning.”²⁷ This description of that science on which mathematics, natural philosophy, and natural religion depends is thus clearly seen to be referring to what Hume calls *logic*. We can therefore conclude that Book I, which treats logic, is to serve as the foundation for those sciences that are less closely connected to the study of human nature, just as Book II provides the foundations for the other sciences that are more intimately connected with it.²⁸

The only thing missing from Boehm’s reconstruction of the hierarchical structure of the Hume’s system of the sciences, then, is the common foundation for Books I and II. Such a foundation is needed, for otherwise there would not be one system of the sciences, but two. This common foundation, as Passmore correctly suggests, is the science of human psychology, which provides Hume’s equivalent of metaphysical first principles, or “true metaphysics.” Once psychology takes its place as the most fundamental level in the hierarchy, Hume’s system of the sciences is seen to have the form of a tree, as depicted in Figure 6.1.

Having this ordering before us sheds much light on Hume’s ambitions in the *Treatise*. But it helps us very little in understanding what makes this hierarchy even conceivable in an empirical philosophy such as Hume’s. How can the results of any empirical science serve as the basis for a “tree of the sciences”? After all, on the Cartesian view, the tree is a metaphor whose aim is to capture the logical dependence of a given area of knowledge upon the science from which it is deduced. Thus if one

²⁶ Hume (1740, p. 646).

²⁷ Hume (1739, p. xv).

²⁸ It is interesting to note that the natural philosophy club of which Hume was a member when a student at the University of Edinburgh saw itself as committed to the study of four subjects: natural history, natural philosophy, mathematics, and religion. See Barfoot (1990, p. 156).

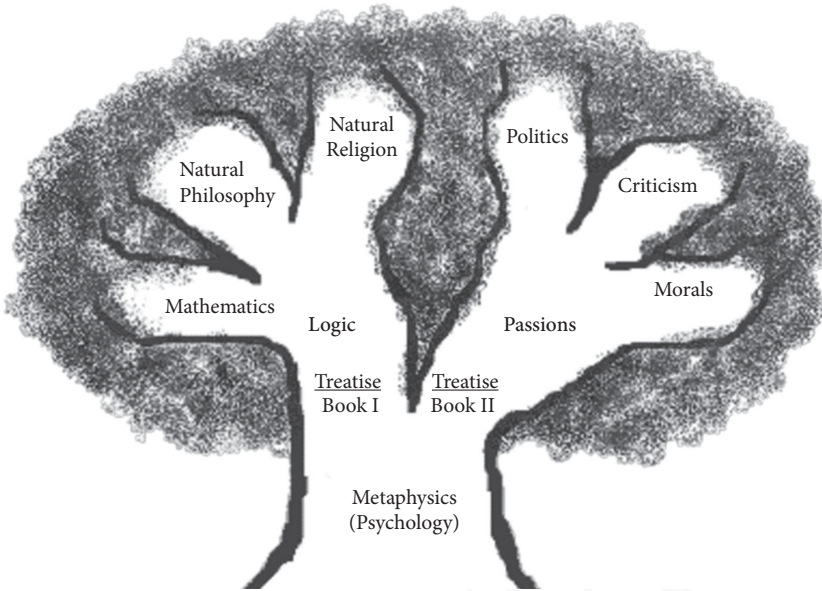


FIGURE 6.1 Hume's System of the Sciences

gets the metaphysical principles right, everything after follows of necessity.²⁹ And while Descartes' deductions do not follow necessarily in accord with traditional Scholastic syllogism, he is nevertheless so certain of his results that he promises in his *Principles of Philosophy* that disagreement and debate in the sciences is about to come to an end.³⁰ But remove the deductive nature of the structure, whether from the Scholastic systems or the Cartesian one, and the hierarchy collapses.

For Hume, as for Newton before him, this picture is deeply troubling. It makes no difference whether one adopts first principles congenial to Aristotelians or those preferred by Cartesians. Either way, the result is a hodgepodge of what Hume calls "[p]rinciples taken upon trust, consequences lamely deduced from them, want of coherence in the parts, and of evidence in the whole," bringing "disgrace upon philosophy itself." If one wants to know the nature of the world, one will have to draw this knowledge from experience, for "None of [the sciences] can go beyond experience, or

²⁹ This was at any rate the picture Descartes projected for his completed system, even if constructing it does depend on experiment to fill in things the human mind can't work out through necessary inferences. See note 19 above.

³⁰ Descartes believed his system of the sciences to be such that "the truths contained in these principles, because they are very clear and very certain, will eliminate all ground for dispute...." (Descartes 1644, 188).

establish any principles which are not founded on that authority.”³¹ Yet Hume’s talk of establishing a system of the sciences on new foundations is almost indistinguishable from Descartes’. In what sense is it possible for the natural sciences, if based solely on experience, to resemble a “tree”? If knowledge of physics cannot be deduced from metaphysical principles, and if knowledge of the special sciences cannot be deduced from physics, why should the sciences resemble any kind of tree at all?

This question may be posed in a slightly different fashion as follows: we know what Hume’s system of the sciences looks like. We have discovered its *shape*. But we still have no idea what holds its disparate parts in place, making of them a system rather than a collection of unrelated bodies of knowledge. So we are still left with the question: What does Hume mean in saying that the *Treatise* is a *system* of the sciences?

6.2 EXPLANATORY REDUCTION IN BOYLE AND NEWTON

As it turns out, one does not have to be a builder of deductive systems from a priori premises to see the sciences as being related to one another in a hierarchical structure. The idea that the sciences form such a structure has survived the emergence of modern experimental science and has, in fact, flourished, although with some modifications. First, in contemporary accounts of the sciences as a hierarchy, physics is commonly taken to be foundational science, with all other sciences constructed on top of it.³² Second, instead of being held together by a series of *deductions* from first principles as in Descartes’ science, the natural sciences are today usually said to proceed to more fundamental levels of explanation by means of one or another kind of *reduction* of the more specialized sciences to the simpler and more general terms provided by the more basic sciences.³³ In the present section, I will look at

³¹ Hume (1739, xiii, xviii). See also the opening of Roger Cotes’ Introduction the *Principia*, which distinguishes Newton’s philosophy from all that had come before it in this regard. Cotes ([1713] 1999, 385–386).

³² Jaegwon Kim (2005, p. 149–150) speaks for many others when he writes in support of a philosophical position he calls physicalism: “On the overall shape and makeup of the world in essential outlines, we must depend on what physics, our fundamental science, tells us. . . . A philosophical worldview that has been inspired and fostered by an appreciation of the foundational position of physics among the sciences is physicalism. . . . The core of contemporary physicalism is the idea that all things that exist in the world are bits of matter and structures aggregated out of bits of matter, all behaving in accordance with the laws of physics, and that any phenomenon in the world can be physically explained if it can be explained at all.”

³³ Contemporary philosophers often see reduction as existing only where there is a necessary logical deduction in the opposite direction as is the case in mathematics. It is not obvious that such a requirement is appropriate in characterizing the thought of the philosophers I will be treating here.

the emergence of *explanatory reduction* as a strategy for establishing an empirically derived system of the sciences in the thought of Robert Boyle and Isaac Newton. In the next section, I will turn to the impact of this emerging understanding of the sciences on Hume's *Treatise of Human Nature*.

The term *reduction* (in Latin, *reductio*; or *analysis* in Greek) or *resolution* has a long and complex history in philosophy and mathematics, grounded in the suggestion that the key to epistemic advancement is the reduction of complex things to a scheme of simpler ones. Even Descartes, despite his consistent emphasis on the deductive structure of the sciences, argues in his *Rules for Direction of the Mind* that scientific discovery must begin with a reductive step that precedes the deductive one. As he writes, we first "reduce complicated and obscure propositions step by step to simpler ones," until we reach certain "pure and simple natures" that are known to the intellect as being irreducible. It is from these "most simple and primary things"—the awareness that one is a thinking being is a famous example—that all other things can be deduced.³⁴ Descartes' *Rules*, however, remained incomplete and unpublished during his lifetime, and how, precisely, he intended for us to distinguish these "most simple and primary things" from everything else in our experience remains obscure.³⁵

A more useful discussion of explanatory reduction is found in the philosophy of Robert Boyle. Boyle is often mentioned together with Descartes as an architect of the mechanistic physics overthrown by Newton's *Principia*, and in fact there are important similarities in their depiction of the fundamental character of the physical world. But Boyle's understanding of the hierarchy of the sciences is quite remote from Descartes'. Indeed, in Boyle's discussion of what constitutes a credible scientific hypothesis in *About the Grounds and Excellency of the Mechanical Hypothesis* (1674), we find no reference to self-evident foundations and no effort to proceed deductively from them. Rather, Boyle describes successful scientific explanation strictly in terms of the greater simplicity and explanatory power afforded by one hypothetical scheme of fundamental terms in comparison with its competitors. The chemical theory of Paracelsus, for example, suggested that the properties of the physical world were reducible to those of three primary substances—salt, sulfur, and mercury.³⁶ Boyle, on the other hand, proposed that all of natural philosophy should ultimately be reducible

³⁴ Descartes ([1628] 1985, pp. 20–24).

³⁵ Descartes says that these natures are characterized by being "independent, a cause, simple, universal, single, equal, similar, straight, and other qualities of this sort" (Descartes 1985 [1628], p. 21). It is a matter of some dispute to what extent Descartes' later philosophy reflects this method. See Garber (1988).

³⁶ For a discussion of Boyle and the chemists, see Boas (1952, pp. 415–422).

to a small number of fundamental terms drawn from his “corpuscularian” physics—these terms being *matter* and *motion*, together with certain basic properties of matter such as *shape* and *size*.³⁷ In comparing the two proposed schemes of fundamental terms, Boyle presents the “chief advantages” of his hypothesis over its competitors as follows:

If the principles proposed be corporeal things, they will then be fairly reducible or reconcilable to the Mechanical principles, these being so general and pregnant that among things corporeal there is nothing real... that may not be derived from, or brought to a subordination to, such comprehensive principles. And when the chemists shall show that mixed bodies owe their qualities to the predominancy of this or that of their three grand ingredients, the Corpuscularians will show that the very qualities of this or that ingredient flow from its peculiar texture and the mechanical affections of the corpuscles it is made up of... [B]ecause of the great universality and simplicity of [our principles], the new ones proposed must be less general than they, and therefore capable of being subordinated or reduced to ours.³⁸

In this passage, Boyle is not arguing for the falsity of Paracelsian chemistry. Rather, his interest is to show that whatever truth there may be in the chemists' claim that “mixed bodies owe their qualities to... their three grand ingredients,” it will still be possible to “reduce” these ingredients to the more “general” and “comprehensive” principles derived from his physics. For Boyle, this means that there is a hierarchical relationship between the science of the chemists and what would later be called physics, with physics being the more fundamental science.³⁹

³⁷ For further discussion of explanatory reduction in Boyle, see Anstey (2000, pp. 50–58). In *Things Above Reason*, Boyle explicitly identifies the unexplainable with that which cannot be reduced to the familiar. See *ibid.*, p. 56. McGuire associates this view with a nominalist ontology that sees physical laws as categories imposed by the mind. See McGuire (1972).

³⁸ Boyle ([1674] 1991, pp. 150–151, 154). Emphasis removed from the word *Corpuscularian*. In this essay, Boyle refers to a *Dialogue about a Good Hypothesis*, which was apparently never written. See *ibid.*, p. 138. Manuscript notes, apparently for this dialogue, state that “the qualities and conditions of an excellent hypothesis” include that it be “the simplest of all the good ones we are able to frame”; that it be the best at explaining known phenomena; and that it enable the prediction of new phenomena, especially under conditions of experiments devised to test it. Boyle ([undated] 1991, p. 119).

³⁹ The distinction between chemistry and physics is admittedly anachronistic in this context. But I do think these terms help clarify where Boyle's hierarchy among empirical sciences was leading.

Like Descartes and many other writers of his time, Boyle does think of the sciences in terms of a hierarchy of explanations—a hierarchy in which some explanations are more fundamental than others. This is evident, for example, from the following passage:

[T]hough chemical explanations be sometimes the most obvious and ready, yet they are not the most fundamental. . . . [T]his may be illustrated by what happens in artificial fireworks. For though . . . gunpowder be a main ingredient, and divers of the phenomena may be derived from the greater or less measure wherein the compositions partake of it, yet . . . gunpowder itself owes its aptness to be fired and exploded to the mechanical contexture of more simple portions of matter—*nitre*, *charcoal*, and *sulphur*—and sulphur itself . . . owes its inflammability to the convention of yet more simple and primary corpuscles. . . .⁴⁰

Here, Boyle gives us an example of the way he understands explanatory reduction, addressing himself to four different levels of explanation: the levels represented, respectively, by fireworks, gunpowder, sulfur, and “more simple corpuscles.” Boyle asserts that at each of these four levels, the qualities that are observed (such as “aptness to be exploded”) can be seen to derive from qualities evident at the next lower level of explanation. It is therefore the case that, ultimately, “chemical explanations” are reduced to explanations deriving from the most fundamental level, that of physics.

But Boyle’s argument that his physical explanations are more fundamental than the theories of the chemists involves no a priori apprehension of what must be the most fundamental natures that can be known to the human mind, nor on any deduction from these, as is supposed in Descartes’ *Rules for the Direction of the Mind*. What structures Boyle’s hierarchy of the sciences is nothing other than his theory of what constitutes the “excellency” of a scientific hypothesis—which focuses on two qualities of a scientific theory: the simplicity of its terms, and their generality. As is evident from his discussion of fireworks quoted above, Boyle is using the term *simple* in a very straightforward sense. Any compound that can be reduced “by a row of decompositions” to its physical “ingredients” is thereby reduced to terms that are “more simple and primary.” In this sense, the simplest terms are just those that cannot be reduced any further because they are not further divisible into components of different kinds.⁴¹

By *comprehensiveness* or *generality*, on the other hand, Boyle refers to the range of the phenomena that can be reduced or subordinated to the scheme of terms and laws

⁴⁰ Ibid., 147.

⁴¹ Ibid., p. 150. As Boyle writes, “Neither can there be any physical principles more *simple* than matter and motion, neither of them being *resoluble* into any things wherof it may be truly . . . said to be compounded” (Ibid., 141). Emphasis added.

in question. A more excellent hypothesis will be one that can embrace a broader range of phenomena—and indeed, his argument against the chemists is that their fundamental terms “can reach but to a small part of the phenomena of nature,” and that a much broader range of phenomena must be “taken in” if the terms in question are to be seen as foundational.⁴² That is, Boyle sees a reduction to chemical terms as being based only on “narrow principles” (or “confined hypotheses”)⁴³ reaching “but to a small part of the phenomena of nature,” and “leav[ing] the greatest part of the phenomena of the universe unexplicated.” And these chemical elements will in any case be found to be “reducible or reconcilable” to a more “general and pregnant” scheme of terms, which are the fundamental principles of the mechanical philosophy: “These principles... being so simple, clear and comprehensive, are applicable to all the real phenomena of nature... ”⁴⁴

By focusing scientific discussion on the comparative simplicity and generality of competing schemes of explanatory terms, Boyle succeeds in articulating the aim of natural philosophy in terms of explanatory reduction. He thereby provides empirical science with a way of understanding the “system of the sciences” to be hierarchical. For Boyle, there is one fundamental science that can be seen as providing the foundations for the hierarchy of the sciences—the science we today call physics—and the other sciences will be held in their places in the hierarchy of the sciences by means of a reduction of their schemes of simplest causes to that provided by physics.⁴⁵

Let us compare this achievement with Descartes’ attempts at understanding what holds the system of the sciences together. For Descartes, the effort at reducing complex things to simplest natures is an effort at discovering things that are implanted in the human mind by God, and that, once found, cannot be mistaken. From these, the known phenomena can be deduced, and once they have been so deduced, one need

⁴² “[I]f the *chemists* or others that would deduce a complete [I] natural philosophy from *salt, sulphur* and *mercury*, or any other set number of ingredients of things, would well consider what they undertake, they might easily discover that the material parts of bodies, as such, can reach but to a small part of the phenomena of nature, [so long as] these ingredients are considered but as quiescent things... [S]o that the chemists... must (as indeed they are wont to do) leave the greatest part of the phenomena of the universe unexplicated by the help of the ingredients... of bodies, without taking in the mechanical and more comprehensive affectations of matter, especially local motion” (Ibid., pp. 146–147).

⁴³ Ibid., p. 149.

⁴⁴ Ibid., p. 153.

⁴⁵ On Boyle’s willingness to replace the Scholastic system with an empirical “system,” see Anstey (2000, pp. 4–6). Boyle believed that empirical systems are desirable, but that they must be regarded as “temporary”: “I would have such kind of superstructures looked upon only as temporary ones; which though they be preferred before any others, as being the least imperfect, or, if you please, the best in their kind that we yet have, yet are not entirely acquiesced in, as absolutely perfect, or incapable of improving alterations.” See Boyle ([1657] 1744, p. 303).

not suspect that the causal explanations discovered in this way could be false.⁴⁶ What holds the whole thing together is Descartes' confidence in the ability of the philosopher to clearly and distinctly intuit the truth of the first principles and of his chains of deductions. Boyle, on the other hand, makes no mention either of the clarity and distinctness with which one recognizes one's first principles, or of the clarity and distinctness with which deductions proceed from them. What interests him is a different test: it is the simplicity and explanatory power of a scheme of fundamental terms compared with its competitors that determines the excellence of a scientific hypothesis. In other words, Boyle rejects the supposition that a scientific theory can be known to be true by inspecting it. Instead, what makes a scientific theory worth attending to is that it is simpler than its competitors, and that the range of what can be explained by means of it is far greater.

Despite Boyle's success in articulating the aim of natural philosophy in terms of the reduction of the diversity of physical phenomena to a small number of simplest and most comprehensive terms, it was Newton's *Mathematical Principles of Natural Philosophy* (1687), published thirteen years after Boyle's essay, that demonstrated what a truly compelling reduction of the phenomena to a scheme of fundamental physical terms looks like. In the *Principia*, Newton proposes a handful of fundamental concepts regulated by a few fundamental laws, and uses these to explain projectile motion, the orbiting of the planets and their moons, the trajectories of comets, the shape of the earth, and the tides. This breathtaking capacity to explain the movements of objects on earth, the movements of the heavens, and the effects of the heavenly bodies on movements on earth—all in terms of a few fundamental concepts—did indeed seem to provide a solid foundation, almost entirely new, for the sciences.⁴⁷ And in a sense, this achievement rests on an understanding of the aim of science as explanatory reduction that had been advanced by Boyle.

Still, it is hard to say that Boyle's account of explanatory reduction serves as a description of what takes place in Newton's *Principia*. In his *Grounds and Excellency of the Mechanical Hypothesis*, Boyle's discussion of explanatory reduction in the sciences emphasizes examples in which a physical compound is reduced to another by breaking

⁴⁶ Thus in the *Principles*, Descartes says that philosophy must begin when we "attend in an orderly way to the notions that we have within us, and we must judge to be true all and only those whose truth we clearly and distinctly recognize..." (Descartes 1644, p. 221). This judgment he considers impossible of error, in that "we will never mistake the false for the true provided we give our assent only to what we clearly and distinctly perceive" (Ibid., p. 207). Regarding the reliability of the deductions, Descartes writes that "if it turns out that the results of such deductions agree with all natural phenomena, we would seem to be doing God an injustice if we suspected that the causal explanations discovered in this way were false" (Ibid., p. 255).

⁴⁷ Cotes (1713, p. 386), Feingold (2001, p. 87).

it down into its “ingredients,” as when gunpowder is decomposed into niter, charcoal, and sulphur. Such examples misleadingly suggest that in an empirical science, explanatory reduction necessarily involves the decomposition of physical objects into their constituent parts. Boyle must have been aware of the problem, for he does invoke other kinds of examples. He argues, for instance, that when attending to a patient, the goal of the doctor is to explain what is happening to the patient by “reducing” the various symptoms to a known cause such as epilepsy or convulsions.⁴⁸ Of course, in reducing the patient’s symptoms to a cause such as epilepsy, the doctor is not in any respect supposing that epilepsy is a physical component or ingredient of the symptoms. Rather, the phenomena are here reduced to a more abstract term that is not a physical component or ingredient at all. And this suggests the need for a more general articulation of explanatory reduction than Boyle is able to provide.

Newton himself offers his most cogent description of the explanatory reduction⁴⁹ at the heart of the *Principia* in his famous Query 31, a postscript to his *Opticks* first published in 1717.⁵⁰ There Newton describes the method of explanatory reduction as follows:

As in mathematics, so in natural philosophy, the investigation of difficult things by the method of analysis, ought ever to precede the method of composition [i.e., synthesis]. The analysis consists in making experiments and observations, and in drawing general conclusions from them by induction. . . . 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. . . . 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. This is the method of analysis: And the synthesis consists in assuming the causes discover’d, and establish’d as principles, and by them explaining the phaenomena proceeding from them, and proving the explanations.⁵¹

⁴⁸ Boyle (1991 [1764], p. 144).

⁴⁹ Newton uses the term *reduction* as well, and when it appears, it is used in the manner of Boyle or Hume. For example, in a letter to Cotes, Newton writes: “Experimental philosophy *reduces* phenomena to general rules and looks upon the rules to be general when they hold generally in phenomena” (Newton 2004, p. 121, emphasis added).

⁵⁰ Query 31 appears in the 1706 Latin Edition of the *Opticks* as Query 23. It receives its final numbering as Query 31 only with the Second English Edition, published in 1717. My quotations are from this later edition, which appeared four years after the Second Edition of the *Principia*.

⁵¹ Newton [1730] 2003, pp. 404–405. In this and other quotations from Newton, I have changed capital letters at the beginning of nouns to lower case to make the texts easier to read.

Newton here describes proper scientific method as consisting of two phases, which he calls *analysis* and *synthesis*.⁵² Analysis is for Newton the inference from particular experiments and observations to a set of causes that are the "most general" that can be seen as explaining these phenomena. Synthesis consists of assuming this set of most general causes, and then deriving from them the explanations of other phenomena that were not considered in the original experiments and observations. A parallel formulation is provided in the Introduction to the Second Edition of the *Principia* (1713) by Newton's editor Roger Cotes, who offers a direct comparison between Newton's analytic and synthetic method in the *Principia* and the scientific methods of predecessors. Without directly naming them, Cotes praises Descartes and Boyle for their concern to "set up a progression from simpler things to more compounded ones." But he derides them for "drifting off into dreams," attributing properties to their proposed simple causes that are not derived from phenomena. Newton alone, he argues, has escaped this trap, belonging to a new type of natural philosopher who proceeds only by way of the method of analysis and synthesis.⁵³

Let's look more closely at Newton's description of analysis and synthesis. The "way of analysis," Newton tells us, "may proceed from compounds to ingredients, and from motions to the forces producing them." Thus Newtonian analysis subsumes the decomposition of compounds into their ingredients that figures prominently in Boyle's discussion. But Newton understands the ingredients that make up chemical compounds as being analogous to the forces that together make up the visible motions of objects. Both the ingredients that together make up chemical compounds and the forces that make up movements, Newton says, are to be considered as causes: thus gunpowder is to be seen as an effect, of which niter, charcoal, and sulphur are the causes; and in the same way, the orbital motion of a planet is to be seen as the effect, of which the

Compare this text to the similar programmatic statement in the preface to Newton ([1726] 1999, p. 382).

⁵² Newton's use of *analysis* and *synthesis* is part of a broad seventeenth-century debate over the meaning of these terms spurred by the publication in 1588 of a Latin translation of Pappus' *Collection*, Book VII. For discussion, see Guicciardini (2009, pp. 31–38); Behboud (1994). For the roots of these concepts in Plato and Aristotle, see Cornford (1932); Goodman (2001, pp. 191–198).

⁵³ "Although they [i.e., Newton and his followers] too hold that the causes of all things are to be derived from the simplest possible principles, they assume nothing as a principle that has not yet been thoroughly proved from phenomena.... Therefore, they proceed by a twofold method, analytic and synthetic. From certain selected phenomena they deduce by analysis the forces of nature and the simpler laws of those forces, from which they then give the constitution of the rest of the phenomena by synthesis" (Cotes 1713, p. 386). Thus Cotes, too, argues that the "causes of all things" can be known only by reaching "the simplest possible principles." He says that

inertial movement of the planet and the centripetal force pulling it toward the sun are to be seen as the causes. Of course orbital motion is not a compound object in the same sense that gunpowder is. Gunpowder is actually created by mixing ingredients together, whereas the orbit of the moon around the earth seems to be a single thing until the invention of the concepts of rectilinear inertial motion and the centripetal pull of the earth make it possible to conceive of it, for the first time, as a compound. Yet Newton insists on this parallel: in all sciences, there is to be, at the outset, a reduction “from effects to their causes, and from particular causes to more general ones, till the argument end in the most general”—even where these causes appear at first to be entirely theoretical.

The later synthetic movement in Newton's method is quite different. Here, Newton says that we begin by “assuming the causes discover'd, and establish'd as principles,” and then proceed to “explaining the phaenomena proceeding from them, and proving the explanations.” Newton says that most of the *Principia* is synthetic.⁵⁴ And he does in fact begin the *Principia* with a set of definitions and axioms (the three “laws of motion”) as had been accepted in synthetic geometric treatises since Euclid. These provide the simplest and most general terms that are assumed throughout the treatise, and that are ultimately used to explain the phenomena.

This having been said, the *Principia* does not proceed like any other treatise in geometry, and how exactly it fulfills its synthetic mission is not so straightforward. Book I of the *Principia* does proceed from Newton's axioms and those of geometry to derive general principles governing the motion of bodies subject to centripetal forces under different conditions. But as Newton explains, these principles are strictly “mathematical”—meaning that they are ideal depictions of hypothetical conditions, and are not necessarily those that apply to the known phenomena gathered from experience. For example, Newton derives the principles of orbital motion not only for our world, in which centripetal forces fall off in proportion to the square of the radius, but also for cases in which centripetal forces fall off in proportion to the cube of the radius, or for any other power. Determining which forces in fact apply to our world is left to Book III, which could easily be described as beginning once more with the method of analysis before proceeding to synthesis: in Book III, Newton begins with real-world

Newton's method of analysis is used to “deduce” (using this term in its loose seventeenth-century sense) the “forces of nature and the simpler laws of these forces” from “certain selected phenomena.” And he too argues that once these are established, it is possible to move to “the rest of the phenomena by synthesis.”

⁵⁴ For example, in an unpublished draft preface to the *Principia*, Newton writes that “in the following treatise I have demonstrated by synthesis the propositions found by analysis.” Quoted in Cohen (1999, p. 50).

phenomena such as astronomical tables and measurements of terrestrial gravity made with a pendulum, and from these, in light of the principles derived in Book I, establishes the actual centripetal forces acting on orbiting bodies and the actual law of gravitation (Propositions 1–7).⁵⁵ Having established the law of gravity as a general cause, Newton then proceeds synthetically, assuming this law as a given, and from there using it to explain other phenomena such as the trajectories of comets, the shape of the earth, and the rising and falling of seas (Propositions 8–42).⁵⁶

For present purposes, we do not have to delve further into the synthetic method of the *Principia*. But a better view of Newton's method of analysis would be helpful. We know that this method of analysis is rooted in gathering phenomena by means of experiment and observation because Newton tells us so. But as to the manner by means of which one proceeds "from effects to their causes, and from particular causes to more general ones," or how one gets from experiments and observations to "general conclusions," Newton's pronouncements are remarkably terse. In the passage quoted above from the *Opticks*, Newton says simply that one proceeds from effects to causes "by induction," and strives to make this induction "stronger" by rendering it as "general" as possible:

[A]lthough 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.⁵⁷

In other passages, Newton says that in his natural philosophy "propositions are deduced from the phenomena and are made general by induction"; or that "the main business" of natural philosophy is to "argue from phenomena" and "to deduce causes from effects."⁵⁸

⁵⁵ Newton (1726, pp. 797–811).

⁵⁶ On Book III of the *Principia* as an example of the method of analysis and synthesis, see Guicciardini (2009, pp. 322–323), Ducheyne (2005, pp. 73–75).

⁵⁷ Newton (1730, p. 404).

⁵⁸ Newton (1726, p. 943), Newton (1730, p. 369). These statements are notoriously vague, and a long tradition in the philosophy of science has struggled to understand what stands behind them. In recent years, much work has been invested in elucidating Newton's "deduction" of the universal law of gravity from the phenomena in Book III of the *Principia*. See Stein (1990); Harper (1990, 2002a, 2002b). However, this literature says little if anything about the relationship between this deduction and Newton's method of analysis and synthesis, or the parallel Newton draws in the General Scholium to the *Principia* between the derivation of the law of gravitation and that of Newton's laws of motion and essential properties of matter. For an alternative view of deduction and induction in Newton, see McGuire (1970, pp. 12, 25–26).

Newton's most significant published attempt to clarify what is involved in the method of analysis is his "Rules for the Study of Natural Philosophy," which were inserted at the opening of Book III in the Second Edition of the *Principia*, together with short comments on each. This brief discussion initially consisted of three Rules, with a fourth added in the Third Edition of the *Principia* (1726), as follows:

Rule 1. No more causes of natural things should be admitted than are both true and sufficient to explain their phenomena.

Rule 2. Therefore, the causes assigned to natural effects of the same kind must be, so far as possible, the same.

Rule 3. Those qualities of bodies that cannot be intended or remitted [i.e., added or removed] and that belong to all bodies on which experiments can be made should be taken as qualities of all bodies universally.

Rule 4. 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.

How are the Rules for the Study of Natural Philosophy related to the method of analysis and synthesis? Newton's Rules should be seen as guides to the method of analysis, whose purpose is to articulate what is involved in the step-wise reduction of the phenomena to ever more general causes.⁵⁹ Rule 2, in particular, describes how one goes about eliminating extraneous causes by unifying disparate effects under a single overarching cause.⁶⁰ Newton's gloss on this rule offers four examples of the aim of unification in science, as follows:

Examples are the cause of [i] respiration in man and beast, or [ii] the falling of stones in Europe and America, or [iii] of the light of a kitchen fire and the sun, or [iv] of the reflection of light on our earth and the planets.⁶¹

⁵⁹ Rule 4 has been read as reflecting a revolution in the way theoretical principles can be used to force the phenomena to point to ever more precise explanations of just how they have been produced, thereby initiating a "research program" generating ever-improving measurements intended to support or disconfirm Newton's laws. See Smith (2001, 2002); Harper (1997). This seems to suggest that Rule 4 should be seen as being related in some way to the method of synthesis Newton describes in Query 31 of the *Opticks*. But a more careful comparison of the two texts suggests that Rules 1–4 all correspond to aspects of Newton's method of analysis as described in Query 31.

⁶⁰ See Ducheyne (2005), Harper (2002b, 182–185).

⁶¹ Newton (1726, p. 795).

Of these, Newton's first two examples—that the cause of respiration should be the same in men and animals, and that the cause of falling stones should be the same in Europe and America—are apparently selected so as to appear plausible to just about anyone. But his third and fourth examples are designed to be more difficult. Newton here asks his readers to understand that when he speaks in Rule 2 of uniting “effects of the same kind,” he has in mind a “sameness” that extends so far as seeking a single cause behind the production of light in a kitchen fire and in the sun; or that will treat the cause of reflection in terrestrial objects as being the same as that which makes the planets visible in the night sky. These examples turn Rule 2 into something more radical than it seems at first, because they suggest that the heart of successful explanatory reduction consists in bringing together under a single cause effects that are as widely scattered as the phenomenal world permits, and that may not at first glance (or to most observers) appear to be “of the same kind” at all. Rule 3 then enlarges these results even further, suggesting that a cause established by Rule 2 can, by means of a form of enumerative induction, be seen as operative in microscopic bodies too small to be detected and in celestial bodies outside of the range of our instruments.

In the General Scholium at the end of the Second Edition, Newton explicitly names those points in the *Principia* that “have been found by this method,” telling us precisely what it is that he believes he has discovered by deducing propositions from the phenomena and making them general by induction. As he writes:

In this experimental philosophy, propositions are deduced from the phenomena and are made general by induction. [i] The impenetrability, mobility, and impetus of bodies, and [ii] the laws of motion and [iii] the law of gravity have been found by this method.⁶²

That these three aspects of the *Principia* are the result of the successful application of Newton's Rules 1–3 is not equally evident in each case. The point is clearest with respect to (iii) the universal law of gravitation, which is derived in Book III, Propositions 1–7, amid explicit references to Newton's Rules. Of these, perhaps most dramatic is his declaration in Proposition 4 of the identity between terrestrial gravity and the force holding the moon in its orbit, which is repeated in the Scholium immediately thereafter:

Therefore, since both forces—namely those of heavy bodies [on earth] and those of the moons—are directed toward the center of the earth and are similar to each other and equal, they will (by Rules 1 and 2) have the same cause.⁶³

⁶² Newton (1726, p. 943).

⁶³ Newton (1726, p. 804).

This is followed, in Proposition 7, by Newton's conclusion that "[g]ravity exists in all bodies universally,"⁶⁴ as required by the application of Rule 3. Here the application of Newton's Rules, as well as their identity with his other descriptions of his method, is plain.⁶⁵

Nor is it very difficult to see Newton's Rules at work in his establishment of (ii) the laws of motion that serve as the axioms at the beginning of the *Principia*.⁶⁶ For example, Newton's First Law states that "[e]very body perseveres in its state of being at rest or of moving uniformly straight forward, except insofar as it is compelled to change its state by forces impressed." What follow are three examples of what seem to be objects obeying the First Law: projectiles continue in their motion until stopped by air resistance and gravity; spinning tops are held together by a cohesion that prevent their parts from flying off in rectilinear motion; and planets and comets continue their motions seemingly indefinitely due to lack of resistance as they travel.⁶⁷ But these and the other similar examples appearing in the Definitions do not have to be viewed as examples of applications of the First Law. Instead, we should see them as the phenomena from which the law was "deduced" under Newton's Rule 2, and then "made general by induction" under Rule 3. And the same may be said for the other laws of motion.⁶⁸

Least straightforward is Newton's claim that the very same method is used to derive (i) essential properties of matter. This derivation takes place in his gloss on Rule 3, a famously obscure text that asserts, among other things, that "nature is always simple and ever consonant with herself" so that we are permitted to conclude that "because extension is found in all sensible bodies, it is [to be] ascribed to all bodies universally." The supposition that all bodies are extended is here applied to bodies at the ends of the

⁶⁴ *Ibid.*, p. 810.

⁶⁵ Howard Stein (1990, pp. 210, 219–220) argues that Newton cannot be properly said to have completed the deduction of the law of gravitation from the phenomena with the announcement of universal gravitation in Proposition 7. But Newton would certainly have said that his deduction of the law of gravitation was completed by Proposition 7, since it is this proposition in which the cause of the phenomena discovered and formulated in Propositions 4–6 is "made general by induction." The fact that additional phenomena can be explained by the law of gravity using the method of synthesis—and that these explanations serve to strengthen the laws initially deduced from phenomena by the method of analysis—does not suggest that Newton regarded his deduction as being in any way incomplete.

⁶⁶ For a more skeptical view, see McMullin 1985.

⁶⁷ Newton (1726, 416).

⁶⁸ On the derivation of the laws of motion, see also Newton's 1713 correspondence with Cotes in Newton (2004). Newton refers Cotes to his derivation of the Third Law of Motion for attraction in the Scholium on the Laws of Motion. See Newton (1726, pp. 427–428); Newton (2004, p. 118).

universe, no less than to the microscopic parts of bodies beyond the reach of experiments. And the same is said for the "hardness, impenetrability, mobility, and force of inertia" of all bodies universally. Newton sees these as general causes known to be present universally, which are to be regarded as "the foundation of all natural philosophy."⁶⁹ Newton draws a direct parallel between his derivation of these essential properties of matter by way of Rules 2 and 3, and his establishment of the laws of motion and the law of gravitation by means of these same Rules. This means that Newton believes the source of scientific knowledge of essential properties of matter such as extension, hardness, and the inertial mass of bodies derives from the discovery of sameness in widely disparate objects as well.

What all this means is that Newton's Rule 2 is not just an elaboration of Boyle's thesis that the excellence of an explanatory reduction relates to the greater generality of the terms to which the phenomena are reduced. Nor is it a mere repetition of Newton's own Rule 1, which, like Ockham's razor, suggests that extraneous causes be dispensed with. Rather, when Newton writes in Rule 2 that the causes assigned to natural effects must be *so far as possible* the same, what he is in fact saying is that the reduction of the phenomena to ever more general causes that is the heart of his method involves a struggle to discover whether sameness is possible among phenomena that would otherwise appear to be vastly different from one another. It has frequently been noted that Newton's method of analysis resembles what, following Peirce, is now often called *abductive* inference—an inference from observed effects to their proposed causes.⁷⁰ However, Peirce's version emphasizes the hypothetical nature of what is inferred by abduction, in striking contrast to Newton's characterization of the results of the method of analysis as yielding, not hypothesis, but a very high degree of certainty. Moreover, Peirce's accounts of abductive inference offer no parallel to Newton's Rule 2: the central role played by the effort to discover sameness in widely disparate effects appears to be virtually irrelevant to Peirce's view of science.⁷¹

The Newtonian version of inference from phenomena to causes, then, focuses on the discovery of sameness among disparate effects as the engine driving the movement "from effects to their causes, and from particular causes to more general ones, till the argument end in the most general"—to an extent that was unprecedented before Newton and has been uncommon since. This distinct form of explanatory reduction

⁶⁹ Newton (1726, p. 795–796).

⁷⁰ McMullin (1985, pp. 56–58), Smith (2002, pp. 161).

⁷¹ Fann (1970), Anderson (1986). On Peirce and Ockham's Razor, see esp. Fann (1970, pp. 48–50).

must therefore be regarded as a unique Newtonian contribution to science. It was, however, adopted and closely followed by Hume as the cement that holds together his system of the sciences.

6.3 EXPLANATORY REDUCTION AND HUME'S SYSTEM OF THE SCIENCES

In the Introduction to his *Treatise of Human Nature*, Hume describes what he takes to be the appropriate method for the study of human nature. These passages are well known, and Hume is widely noted for arguing that the science of man must be a form of “experimental philosophy,” which is to be founded on “experience and observation” just as natural philosophy had been. As he writes:

[T]he essence of the mind being equally unknown to us with that of external bodies, it must be equally impossible to form any notion of its powers and faculties otherwise than from careful and exact experiments, and the observation of those particular effects, which result from its different circumstances and situations.⁷²

Less attention has been paid to the fact that for Hume, experience and observation are not, in and of themselves, science. They only provide the materials for science,⁷³ which in fact advances only with our attempts to construct a scheme of simple, general concepts (“principles” or “causes”) in terms of which the phenomena can be understood. In this, Hume’s view is largely indistinguishable from that of Newton as described above, and especially in the passage quoted from Query 31.⁷⁴ This passage is parallel to a number of similar ones in Hume’s works, all of which suggest that Hume sees the aims of his philosophy as nearly identical to Newton’s. This similarity

⁷² Hume (1739, xvi–xvii).

⁷³ Hume writes that experience and observation “are the only solid foundation we can give this science” (Ibid., p. xvi).

⁷⁴ I have been able to locate almost no discussion of the fact that the central aim of Hume’s science, like that of Newton, is the tracing of the results of experiment to a scheme of “simplest and fewest causes.” The principal exception is Demeter (2012). See also Cohon (2008, p. 129). Particularly strange is Capaldi, who correctly identifies parallel passages in Newton and Hume, but seems unable to extract the plain meaning from the texts. His six-step “Newtonian program” seems to have no basis in the texts studied above (Capaldi 1967, pp. 63–69).

of aims and methods is already evident in the Introduction to the *Treatise*, where Hume writes:

[W]e must endeavour to render all our principles as universal as possible, by tracing up our experiments to the utmost, and explaining all effects from the simplest and fewest causes...⁷⁵

Like Newton, Hume explains that the aim is "tracing up our experiments" until one arrives at "the utmost," namely, those "simplest and fewest causes," or "principles as universal as possible," by means of which one can then go about "explaining all effects." In the Abstract to the *Treatise*, Hume repeats this description, directly comparing his method to that which has been so successful in natural philosophy:

[T]is at least worth while to try if the science of man will not admit of the same accuracy which several parts of natural philosophy are found susceptible of... If, in examining several phenomena, we find that they resolve themselves into one common principle, and can trace this principle into another, we shall at last arrive at those few simple principles on which all the rest depend.⁷⁶

Note that in this passage, Hume makes direct reference to a principle like Newton's Rule 2, arguing that his aim is to find that "several phenomena... resolve themselves into one common principle..." The hierarchical ordering of causes that is familiar from Newton also appears here in Hume's hope that the common principle to which the several phenomena are reduced, can then be traced into another principle, and so forth until "we shall at last arrive at those few simple principles on which all the rest depend."

⁷⁵ The passage continues: "[I]t is still certain we cannot go beyond experience; and any hypothesis, that pretends to discover the ultimate original qualities of human nature, ought at [once] to be rejected as presumptuous and chimerical" (Hume 1739, pp. xvii). Compare: "Here, therefore, moral philosophy is in the same condition as natural, with regard to astronomy before the time of *Copernicus*. The antients, tho' sensible of that maxim, *that nature does nothing in vain*, contriv'd such intricate systems of the heavens, as seem'd inconsistent with true philosophy, and gave place at last to something more simple and natural. To invent without scruple a new principle to every new phenomenon, instead of adapting it to the old; to overload our hypotheses with a variety of this kind; are certain proofs, that none of these principles is the just one, and that we only desire, by a number of falsehoods, to cover our ignorance of the truth" (Ibid., p. 282). As Capaldi points out, Hume compares himself here not to Newton, but to Copernicus (Capaldi 1967, p. 81).

⁷⁶ He continues: "And tho' we can never arrive at the ultimate principles, 'tis a satisfaction to go as far as our faculties will allow us" (Hume 1740, p. 646).

Almost a decade later, in his *Enquiry Concerning Human Understanding*, (1748) Hume repeats much the same description, now calling this the aim, not only of science, but of “human reason” in general:

[T]he utmost effort of human reason is to reduce the principles, productive of natural phenomena, to a greater simplicity, and to resolve the many particular effects into a few general causes, by means of reasonings from analogy, experience, and observation.⁷⁷

A similar discussion, which includes a reference to the hierarchical ordering of the causes derived from observation and experiment, appears in the *Enquiry* as well:

It is probable, that one operation and principle of the mind depends on another; which, again, may be resolved into one more general and universal: And how far these researches may possibly be carried, it will be difficult for us, before, or even after, a careful trial, exactly to determine.⁷⁸

In these passages, we have a clear presentation of what Hume sees as the scientific method of the *Treatise*. Hume's science does indeed begin with experiment and observation. But the real work—that which Hume says “requires the utmost stretch of human judgment”⁷⁹—is that of explanatory reduction, which begins with experiment and observation, but then moves up to the common causes, or principles, that can be said to explain the phenomena under consideration. By means of additional such reductions, one establishes causes or principles that are yet simpler and more general, and this procedure continues until one has reached “the utmost,” which is those few causes or principles that are capable of explaining “all effects.” This is for Hume the heart of the enterprise of science—as well as what he believes he is trying to do in the *Treatise*.

That this is essentially a recapitulation of Newton's method is, I think, difficult to deny. But Hume's description of this method is considerably more straightforward, dispensing with the cumbersome categories that make Newton's discussion of his science so confusing. Gone are the convoluted attempts to describe the Newtonian method in

⁷⁷ Hume (1748, p. 22). Compare: “Moralists have hitherto been accustomed, when they considered that vast multitude and diversity of those actions that excite our approbation or dislike, to search for some common principle, on which this variety of sentiments might depend. And though they have sometimes carried the matter too far, by their passion for some one general principle; it must however be confessed that they are excusable in expecting to find some general principles, into which all of the vices and virtues were justly to be resolved” (p. 10).

⁷⁸ *Ibid.*, p. 10.

⁷⁹ Hume (1739, p. 175).

terms of deduction and induction from phenomena—indeed, these terms disappear almost entirely from Hume’s *Treatise*.⁸⁰ Gone, too, are the terms analysis and synthesis, although it is at times quite obvious that Hume sees his philosophy in terms of a method of analysis and synthesis like that of Newton.⁸¹ Instead, Hume prefers to speak, as Boyle does, of the *reduction* or *resolution* of the various phenomena to simpler and more general principles or causes.⁸² Thus if we are interested in identifying passages in which Hume is “tracing up”⁸³ from particular phenomena to the simpler and more general principles or causes that explain them, it is best to look for instances in which he says that one thing reduces or resolves into another. For example, Hume speaks of “resolving” phenomena or effects into more general principles or causes in three of the four methodological passages cited above, from which it appears that “resolution” is his preferred term for what I have called explanatory reduction:

[T]he utmost effort of human reason is . . . to *resolve* the many particular effects into a few general causes. . . .⁸⁴

If, in examining several phenomena, we find that they *resolve* themselves into one common principle. . . .⁸⁵

It is probable, that one operation and principle of the mind depends on another; which, again, may be *resolved* into one more general and universal. . . .⁸⁶

Perhaps the most striking example of this usage occurs in the first sentence of the *Treatise*, in which Hume asserts that:

All the perceptions of the human mind *resolve* themselves into two distinct kinds, which I shall call *impressions* and *ideas*.⁸⁷

⁸⁰ If I am not mistaken, the terms *deduction* and *deduced* appear only three times in the entire *Treatise*, and the term *induction* twice. This is as opposed to dozens of occasions in which Hume speaks of inference in terms of *resolution*, *reduction*, and *tracing up*.

⁸¹ For example, Hume writes in the *Enquiry* that by means of observation and experience of human behavior, “we mount up to the knowledge of men’s inclinations and motives, from their actions, expressions, and even gestures; and again descend to the interpretation of their actions from our knowledge of their motives and inclinations” (Hume 1748, p. 61). For further discussion of parallels between Newton’s method and that of Hume’s *Treatise*, see Hazony and Schliesser (2014).

⁸² This manner of speaking does appear rarely in Newton’s writings. See note 49 above.

⁸³ Many of Hume’s uses of the term “tracing” also involve tracing up to principles, as in the following quote from his discussion of sympathy: “So remarkable a phaenomenon merits our attention, and must be *trac’d up* to its first principles” Hume (1739, p. 317, emphasis added).

⁸⁴ Hume (1748, p. 22, emphasis added).

⁸⁵ Hume (1740, p. 646, emphasis added).

⁸⁶ Hume (1748, p. 10, emphasis added).

⁸⁷ Hume (1739, p. 1, emphasis removed from the word *all* and added to *resolve*).

Having understood that Hume takes impressions and ideas to be instances of the simplest and most general principles or causes to which the phenomena can be reduced, it becomes clear that Hume means this sentence to be taken literally as an instance of explanatory reduction.

Hume also speaks of *reducing* to the simplest and most general principles, as in the following passages, including one of the four methodological passages cited above:

[T]he utmost effort of human reason is to *reduce* the principles, productive of natural phenomena, to a greater simplicity....⁸⁸

It may, therefore, be ask'd, by what theory we can explain these variations, and to what general principle we can *reduce* them.⁸⁹

We shall now proceed to enquire how we may *reduce* these principles to a lesser number, and find among the causes something common, on which their influence depends.⁹⁰

Reduction and explanation are explicitly tied here:

It may, therefore, be ask'd, by what theory we can *explain* these variations, and to what general principle we can *reduce* them.⁹¹

From these passages and many others like them, it is evident that Hume uses Boyle's terms reduction and resolution to refer to the kind of inference to the simplest and most general principles or causes, which he describes as being the entire aim of his scientific method; and which Newton similarly describes as the aim of his own method.

Why the change in terminology? Hume does not say, and we are left to guess. My own feeling is that Hume's desire to avoid undesirable Aristotelian connotations led him to bypass "deduction" and "induction"—terms that Newton used and that have in subsequent centuries led to a great deal of confusion as to his intentions, even where these are relatively clear. As to analysis and synthesis, the meaning of these terms was not evident in Newton's day either. Newton uses them in the passages cited above in a manner that is perhaps not even consistent with his own mathematical usage, and is certainly quite dissimilar from the way in which these terms are used by Descartes or Leibniz.⁹² Indeed, in Peirce's account

⁸⁸ Hume (1748, p. 22, emphasis added).

⁸⁹ Hume (1739, p. 441, emphasis added).

⁹⁰ *Ibid.*, p. 282, emphasis added.

⁹¹ *Ibid.*, p. 441.

⁹² In the mathematics of the seventeenth century, the term "analysis" was frequently used to refer to algebraic equations (common analysis) and to infinite series and infinitesimals (the new analysis). Why the term analysis came to be used in this way, and what its relationship really was

the meaning of the terms analysis and synthesis appears to have been reversed, with Peirce referring to deductive inference, which in Newton is the method of synthesis, as "analytic"; and to inference from phenomena to their causes, which in Newton is the method of analysis, as "synthetic."⁹³ Hume seems to have seen both the language of deduction and induction and that of analysis and synthesis as confused and extraneous.

But the acceptance of Boyle's less technical terminology is not accompanied by a reversion to a less sophisticated understanding of the aims and methods of science. On the contrary, Hume embraces and refines Newton's highly abstracted use of methodological concepts such as "resolution," "cause," and "simplicity," even as he clarifies the methodological picture by discarding the terms that had cluttered Newton's presentation of his method. In this sense, Hume's philosophy of science can be seen as improving upon Newton's, while maintaining an almost complete continuity with the central features that made it the most formidable in early modern science.

These conclusions permit us to recognize that Hume owes a much greater debt to Newtonian philosophy than is commonly supposed. In particular, Hume's *Treatise of Human Nature* is seen as adopting the aims and methods of Newtonian science, not merely with respect to experiment and observation, but especially with regard to the heart of the *Principia's* method. The purpose of Newtonian science is to achieve a reduction of the phenomena to a scheme of simplest and most general causes, and with them to explain the phenomena. And precisely this is the aim and purpose of Hume's *Treatise* as well.

We can now also answer a riddle that has emerged in the Hume literature in recent years. A number of scholars have recognized that explanatory reduction plays an important role in Hume's philosophy. Don Garrett, for example, points to at least two examples of such reduction (in Hume's analyses of the self and of causation)⁹⁴; and Wayne Waxman speaks more broadly of Hume "effectively reducing to associative imagination everything philosophers had formerly attributed to intellect."⁹⁵ A more complete picture is presented by Peter Loftson, who explicitly connects Hume's reductions to his scientific aspirations and his quest to discover the simplest "elements" out of which our experience is constituted. As he writes:

[Hume] reduces... a macro-phenomenon of everyday life to elements held to make it up.... Hume's *reductionist analyses* of psychological facts are central

to Pappus' method of analysis and synthesis in geometry, remains a subject of speculation to this day. For discussion, see the essays in Otte and Panza (1997), Guicciardini (2009).

⁹³ Fann (1970, p. 7).

⁹⁴ Garrett (1997) treats Hume's analyses of the self and of causation as examples of "reductive empiricism," which he traces back to Locke and Berkeley (36–38). See also pp. 28, 115, 170.

⁹⁵ Waxman (2003, p. xiii). See also more specific instances in which Hume's reductionism is mentioned on pp. 77, 90, 104, 108, 336n.

and pervasive in the *Treatise* and both *Enquiries*. Hume means them seriously and they are offered as creative contributions to a science of human nature. They are also *radical* analyses that, if successful, would exhibit psychological complexities as built out of a relatively simple stock of states of imagination. . . . Hume's reductionist analyses are meant to be substantive theories, *contributions* to scientific advance.⁹⁶

Scholars have thus recognized that Hume reduces certain phenomena to a scheme of basic psychological elements, and that he sees these reductions as a contribution to a broader scientific enterprise. But the centrality of this attempt to reduce the sciences to a small set of fundamental terms has been consistently underestimated: these facts have not been examined within the broader context of Hume's declared aim of establishing a "compleat system of the sciences," his explicit statements concerning his own philosophical method, and his relationship to Newton's method. Once these factors are brought into view, we have a clear explanation as to why explanatory reduction is, in Loftson's phrase, "central and pervasive" in the *Treatise*: when Hume writes in the Introduction of the *Treatise* that his aim is to "render all our principles as universal as possible, by tracing up our experiments to the utmost, and explaining all effects from the simplest and fewest causes," he means that his aim is to explain all phenomena by *reducing* them to the simplest, fewest, and most universal principles or causes. Explanatory reduction is central and pervasive in the *Treatise* because it is what the *Treatise* is all about, just as it is what Newton's *Principia* is all about.

Moreover, it is these reductions that establish Hume's "system of the sciences" in its hierarchical ordering, since it is explanatory reduction that ties a given science to that which is below it in Hume's tree of the sciences. And it is these reductions, too, which provide the "foundation almost entirely new" upon which the system is built. This new foundation for the sciences is the scheme of simplest and fewest causes, drawn from human psychology, to which Hume's entire system of the sciences can ultimately be reduced.

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⁹⁶ Loftson (1998, original emphasis).

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