Hume, Newton, & Maclaurin

Charles R. Twardy
School of Computer Science & Software Engineering
Building 63
Monash University, VIC 3800
AUSTRALIA
ctwardy@alumni.indiana.edu
www.csse.monash.edu.au/~ctwardy/lab.html

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Abstract

Note to readers: Originally I thought there was a stronger link between Maclaurin and Hume, however I now think it clear that Hume is not taking his mechanics out of Maclaurin's *Account*. Although I still have found Maclaurin useful in interpreting Hume, I suspect this draft suffers somewhat from ambivalence. There are still similarities, and possible avenues of influence, arguing that Hume was not ignorant of the new mechanics, but it also becomes clear that he did not understand it: although he adopts the Newtonian measure of force, he misapplies it.

David Hume grew up in a philosophical landscape dominated by Newton's philosophy, which he self-consciously imitated, hoping at least early in his career to create a "science of human nature" to parallel Newton's achievement in mechanics. Hume was of course a Newtonian: he was from England. But his Newtonianism was strongly circumscribed by his distaste for natural theology. In those few cases where Hume discussed natural philosophy directly, he apparently missed some of the finer, but more important, points which distinguished Newtonian mechanics from pre-Newtonian and rival theories. Hume did not grasp the mathematics involved, nor even their central importance in Newton's reasoning, and as a result of that failure propounded a philosophy which, as Kant saw, could not support Newtonian science.

However, I think Hume was otherwise aware of developments in natural philosophy, at least at the level of scientific popularization. In addition to taking Colin Maclaurin (1698-1746) as a model for Cleanthes in the *Dialogues*, as (Noxon, 1973, pp.102-104) has argued, there is a strong correlation between Hume's brief presentation of momentum and the definition advanced by Maclaurin. The important point to make is that what appears as a confused passage in Hume can be found in the Newtonian popularization of one of the foremost mathematical Newtonians in England at the time.

I should like to argue that Hume's understanding of Newton, or of mechanics anyway, came through Maclaurin. However, although there is enough evidence to make the claim

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plausible, it cannot rule out the possibility that their writings are both common effects of the general environment. For instance, it is clear they were both responding to Berkeley (although while Maclaurin defends Newtonian science against Berkeleyan empiricism, Hume seems to endorse Berkeley on that matter). Furthermore, a proper defense of such a hypothesis would have to evaluate its likelihood compared to those of direct influence of Descartes, Malebranche, Locke, Berkeley, Boyle, Hooke, Huyghens, Leibniz, Torricelli, *etc.* It remains, however, that Maclaurin and Hume are strongly correlated, were writing contemporaneously, and sufficiently closely related to be in the same area of the causal network. Therefore we may learn something about Hume by reading Maclaurin, and treat both as indicators of the Newtonianism of the day.

Hume's assessment of the proper interpretation and application of Newtonian science involved his theory of causality and indeed his whole skeptical apparatus. Hume's understanding of natural philosophy was clearly conditioned by his strong empiricism, and so among other things his philosophy fails to account for the centrality of mathematics in the Newtonian method. However, his empiricism is also condition by his understanding of contemporary natural philosophy, which may explain a notable change in his definition of causation between the *Treatise* and the *Enquiry*.

Causation, connection, & force

In his constructive account of causality, Hume argued that causal links are psychological additions to a world sufficiently governed by the laws of motion. Hume did not doubt that observers had an impression of causality, but only that there was some ultimate rational justification for the habitual "inference" from cause to effect. That inference or expectation remained for Hume an empirical induction from repeated experience. Observers perceived only constant conjunctions of objects or events, to which they attuned. After repeated exposure to two events regularly conjoined in space and time, the first or prior one naturally and forcefully evoked in the mind the second or consequent one. Hume accepted this as a brute fact about the action of the mind, and called the resulting forceful expectation our causal impression, much as Newton called the universal attraction a "centripetal force," which was meant to imply no more than that there was some otherwise unknown force directed toward the center.

Hume offered several definitions of causation, not all of which cohere. However, he is most famous for insisting on the triad, "priority, contiguity, and constant conjunction." Interestingly enough, as Barry Stroud (Stroud, 1977, pp.43-44) has observed, Hume dropped his insistence on contiguity between his early *Treatise* and the later *Inquiry*. Both definitions in the *Treatise* required contiguity, yet all three definitions in the *Inquiry* omitted it. Even in the *Treatise*, Hume admitted that although causation required contiguity, the causal impression did not:

> I find in the first place, that whatever objects are consider'd as causes or effects, are *contiguous;* and that nothing can operate in a time or place, which is ever so little remov'd from those of its existence. **Tho' distant objects may sometimes seem productive of each other**, they are commonly found upon examination to be link'd by a chain of causes, which are contiguous among themselves, and to the distant objects; and when in any particular instance we cannot discover this connexion, we still presume it to exist. (Hume, 1739-40, p.75, Bk.I., Pt.III, Sec.2, my boldface)

I think it probable that gravity and magnetism were some of the examples which convinced Hume to drop his insistence on contiguity in the *Inquiry*. These provided examples of apparent causation wherein no connection could be perceived, and none had yet been discovered. While Hume believed that Newton had recourse to an æther, he implicitly allowed for the

possibility of forces acting at a distance. He did not endorse the idea; he just could not insist otherwise without abandoning the metaphysical caution for which he so admired Newton.

Hume could have followed earlier Newtonians and discussed causation in reference to force, but that he abhorred metaphysical notions like "power," "force," and "energy." The question is, since Newton felt free to appeal to force and to define it quite precisely, why did Hume avoid the term so much? Perhaps he did not understand the physical meaning of the terms as applied by the Newtonians. Perhaps he took note of the contentious debate over the proper definition and measure of force, and reasonably concluded from all the noise that proponents of an immaterial force had not won the day.

Not that he needed encouragement, but Hume apparently took advantage of a revisionist interpretation of Newton. As A.R. Hall has noted, Newtonian popularizers after 1744, including Maclaurin,

> were much affected by the publication of Newton's letter to Boyle in the edition of Robert Boyle's *Works* of that year. These made plain Newton's early evolution of an aetherial conjecture, in 1679. Whereas earlier expositors[1] ... accepted the existence of physical forces and of the motions of attraction and repulsion caused by these forces as empirically justified elements in natural philosophy, even though the nature and *modus operandi* of such forces could not be further resolved or accounted for in any way (unless by the direct action of the deity), many exponents of the Newtonian philosophy after 1744 ... started from the assumption of a Newtonian aether as the fundamental *explicans* of every phenomenon in nature. (Hall, 1993, p.233)

Hume seized on that information to shore up his argument against the tendency to make God the cause of everything. In an out-of-place footnote at the very end of Section VII, part I, Hume claimed,

> It was never the meaning of Sir Isaac Newton to rob second causes of all force or energy, though some of his followers have endeavored to establish that theory upon his authority. On the contrary, that great philosopher had recourse to an ethereal active fluid to explain his universal attraction, though he was so cautious and modest as to allow that it was a mere hypothesis not to be insisted on without more experiments. (Hume, 1739-40, p.84, VII, pt.I, n.11)

The fact that Hume placed this defense in a footnote, at the very end of the section, and somewhat out of place at that argues that it was an opportunistic insertion. [2]

It is worth reading Maclaurin on the same matter:

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[1] Such as Pemberton and 'sGravesande, who were staunchly against æther theories.

[2] Hume was, after 1744, becoming preoccupied with other matters. There was the public controversy over his attempt to seek the chair about to be vacated by Pringle at Edinburgh, which remained unresolved until 1745. There was the Jacobite uprising in 1745 which resulted in the capture of Edinburgh and the severe distress of one of Hume's friends in public office there. After failing to receive the chair, Hume soon took a position as a tutor, being dismissed after just over one year. Just before returning to Ninewells from the unsuccessful tutorship, Hume accepted a spontaneous offer to accompany General St Clair as his secretary on an expedition originally slated for Canada. After some truly comical mismanagement, the much-delayed expedition was ordered instead to harrass the coast of France in order to distract the French from other conflicts which, it turned out, they had already won. St. Clair's expedition was unable to return to England until the end of March, 1747. Hume was in London by early April where, after some dawdling in search of another career, he returned to Ninewells in July. (Mossner, 1980, pp.180-206)

Within five months Hume revised the manuscripts for the *Philosophical Essays concerning Human Understanding*, *Three Essays, Moral and Political*, and a third edition of *Essays Moral and Political*, in addition to publishing some smaller work. However, by January 1748, Hume was back in London, and joined with St. Clair on a mission of military envoy which sailed from England 16 February, 1748. The *Philosophical Essays* were published in April, 1748, while Hume was between the Hague and Turin, not to return until about Christmas 1748.

> Possibly some unskillful men may have fancied that bodies might attract each other by some charm or unknown virtue, without being impelled or acted upon by other bodies, or by any other powers of whatever kind ; and some may have imagined that a mutual tendency may be essential to matter, tho' this is directly contrary to the *inertia* of body described above ; but surely Sir *Isaac Newton* has given no ground for charging him with either of these opinions : he has plainly signified that he thought that those powers arose from the impulses of a subtile ætherial *medium* that is diffused over the universe, and penetrates the pores of grosser bodies. It appears from his letters to Mr. *Boyle* [footnote to "the life of Mr. *Boyle*"], that this was his opinion early ; and if he did not publish it sooner, it proceeded from hence only, that he found he was not able, from experiment and observation, to give a satisfactory account of this medium, and the manner of its operation, in producing the chief phænomena of nature. (Maclaurin, 1968, p.111)

Immaterial, instantaneous forces had proven very difficult to defend, at least without invoking God for everything. It was not clear to anyone how an æther could do the required work, but it was apparently more agreeable to consider the possibility of material (if instantaneous) forces than to defend immaterial ones.

Even if the new Newtonians accepted a Newtonian æther, they were still too committed to the ideas of active force and power for Hume's comfort. Hume was crucially concerned with distinguishing actual causation from mere coincidence, but would not avail himself to Newtonian tools such as force and inertia. I think the main reason is that Hume could find no way to endorse a methodology which allowed inference to active forces without also sanctioning Newtonian natural theology.

Hume's use of Newton

> The claim that Hume's philosophical development was profoundly affected by the Newtonian method is as probable as any assertion of an unacknowledged influence can be. (Noxon, 1973, p.76)

This section quickly reviews the few direct indications of Hume's use of Newtonian thought. Hume's brief autobiography tells us little about his influences, and it has been observed that his letters mention neither Newton (except once, incidentally and facetiously), nor other philosophers with whom he is known to have been familiar. (Noxon, 1973, p.75) That Hume was familiar with Newton is clear, but his sources are more difficult to discern. Barfoot (Barfoot, 1990) has argued persuasively that Hume received a good dose of natural philosophy at Edinburgh, including some Newton but probably focussing on Boyle. In his opinion mucch of Hume's natural philosophy came from Keil and Rohault. Any further knowledge of Newton could have come from Pemberton, 'sGravesande, Maclaurin, or others depending upon the date.

On the one hand, Hume's goal of extending the experimental method to the moral sciences sounds very Newtonian—compare the following from Newton's *Opticks*:

> And if natural philosophy in all its parts, by pursuing this method, shall at length be perfected,the bounds of moral philosophy will be also enlarged. (Question 31, in Thayer, 1953, p.179)

On the other hand, the only direct *citation* of Newton occurs in the *Enquiry Concerning the Principles of Morals* in a footnote at the end of section III (Hume, 1966, p.111). The selection, including Hume's own footnote, reads:

> It is entirely agreeable to the rules of philosophy, and even of common reason; where any principle has been found to have a great force and energy in one instance, to ascribe to it a like energy in all similar instances. This indeed is Newton's chief rule of philosophizing.[a]
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> [a]Principia, Lib.iii.

It is at any rate Newton's second rule of philosophizing:

> Therefore, to the same natural effects we must, as far as possible, assign the same causes. (Thayer, 1953, p.5)

So we know that Hume at least glanced at parts of the *Principia*. We have already examined Hume's footnote where he claims to understand Newton's metaphysics better than prominent Newtonians. In addition, in the appendix to the *Treatise*, Hume concludes his discussion of a vacuum with another strong claim for his superior understanding:

> If *the Newtonian* philosophy be rightly understood, it will be found to mean no more. A vacuum is asserted: That is, bodies are said to be plac'd after such a manner, as to receive bodies betwixt them, without impulsion or penetration. The real nature of this position of bodies is unknown. We are only acquainted with its effects on the senses, and its power of receiving body. Nothing is more suitable to that [*i.e.* Newtonian] philosophy, than a modest scepticism to a certain degree, and a fair confession of ignorance in subjects, that exceed all human capacity. (Hume, 1739-40, Appendix, p. 639)

This reference indicate a familiarity with parts of the *Opticks*, which was far more accessible and more popular than the *Principia*. It also was much richer philosophically, and more amenable to Hume's experimental emphasis.

However, it would not do to be wholly ignorant of Newton's mechanics and gravitational theory. Hume was not ignorant of them, although it is not clear how well he understood them, a matter to which we shall turn later. Here, note briefly that in footnote 11 of the *Inquiry* he dismissively reduces inertia to a set of empirical facts about collisions, an interpretation which puts him at odds with Maclaurin and other Newtonians. I expect that Hume read at most Book III of the *Principia*, and probably got most of his understanding of Newtonian mechanics from popularizers.

However, any use of Newton almost compelled a reassessment of natural philosophy, and perhaps other branches as well. Locke had been forced by Newton's theory to recant his prior position that action was communicated solely by contact. Perhaps Hume's growing familiarity with Newton also explained why Hume had dropped his insistence on contiguity of cause and effect between the *Treatise* and the *Inquiry*? Whatever he might ultimately think, as an empiricist he could not insist that cause was conveyed by contact, because gravity and magnetism as well as optical phenomena like diffraction were to all appearances the operation of attractive or repulsive forces acting at a distance.

Hume certainly borrowed ideas from Newtonian science as well as experimental philosophy more generally. Boyle and others also emphasized experiment, downplayed speculation, but Hume's idea of attraction of ideas in the mind for one another seems to have a very Newtonian sound. In particular, Hume's insistence that such were the phenomena, although he could not discern the ultimate cause, was exactly Newton's defense of universal gravitation. In summarizing scholarship on the ties between Newton and Hume, Casini offered the following five points of comparison (Casini, 1988, 111):

• In the introduction to the *Treatise*, Hume "insisted on the need for universal principles, for the limitation of human knowledge to experience, and for the practice of 'careful and exact experiments'."

• In the same, "He forcibly rejected all 'presumptuous and chimerical hypotheses' from the domain of psychological inquiry. . . ."

• "Hume considered attraction as the clue to psychology and morals. He spoke of a 'gentle force' uniting the ideas, and defined this principle of association as 'a kind of attraction, which in the mental world will be found to have as extraordinary effects as in the natural. . . '."

• Hume's eight rules of causal inference display an "unmistakable echoing of Newton's *Rules of philosophizing.*"

• In the *Inquiry,* Hume wrote, "But as to the causes of these general causes, we should in vain attempt their discovery," echoing Newton's own distinction.

Most of Casini's points do refer to methodology. Hume belonged to that large group of Enlightenment thinkers who looked to the experimental philosophy espoused by the Royal Society as a way out of endless metaphysical disputes. Although in practice Hume's program was not very experimental, it was at least observational. If most of the observation was introspection, at least Hume was consistent in trying to find the empirical core of his introspections. In addition, he thought in terms of the mechanical philosophy, with some Newtonian influences. Before examining one of Hume's brief references to natural philosophy, we will review likely avenues whereby Hume encountered natural philosophy, and the potential for a Newtonian influence.

Hume's exposure to Newton

We have already mentioned the possibility that Hume had attended Colin Maclaurin's lectures while at Edinburgh. Even before Maclaurin however, Edinburgh was a stronghold of Newtonian thought. It was, outside of Cambridge of course, the foremost center of Newtonianism in England, and had begun to adopt Newtonian ideas even before 1700 (Shepherd, 1982). Kemp Smith (Smith, 1960, p.53,n.1) noted that Robert Stewart, the Chair of Natural Philosophy at Edinburgh from 1708 to 1742,

> is reported to have been in his earlier years a Cartesian, and later a Newtonian. Hume probably attended his class in the Session 1724-5. What Stewart's teaching then was, we can only conjecture.

Barfoot (Barfoot, 1990) has analyzed some contemporary lecture notes from students of Stewart and found his course to concentrate on experimental philosophy, especially that of Boyle.

If Maclaurin himself was not yet teaching the mathematical side of natural philosophy when Hume attended that lecture, then the elder Gregory or Gregory's lecturer Robert Wallace would likely have presented Newton and Locke with similar enthusiasm, although more likely amalgamating particular experiments into a more traditional curriculum. Likewise, Colin Drummond, the professor of logic and metaphysics, was one of the early subscribers to Pemberton's 1727 *View*, although before its publication he was also presumably mixing Newton in with Descartes. All told, it is almost certain that Hume received solid training in the new experimental philosophy, and at least an acquaintance with some of Newton's work. (Mossner, 1980, p.43)

Adding to the circumstantial evidence, Hume said he conceived his idea of an experimental philosophy of the moral sciences while he was of university age. Several biographers have speculated that it was Hume's contact with Newtonian thought (or at least the experimental philosophy) which sparked this idea, and in an early letter Hume did mention a "new scene of thought," which sounds like a reference to this philosophy, although it

could just as well be to Hutcheson (see Noxon (Noxon, 1973)). We should also note that many of the professors who might have introduced Hume to Newtonian thought were also members of the Rankenian club, which carried on an active correspondence with Berkeley, who himself claimed, "that no persons understood his system better than this set of young gentlemen in North Britain." (Mossner, 1980, p.48)

Whether Hume encountered Maclaurin while a university student or not, he almost certainly read Maclaurin in his later life: many of the arguments for natural theology bear striking resemblance to those which appear in the *Dialogues*, although it is always possible that both Maclaurin and Hume were relating well-rehearsed positions. It is less certain that Maclaurin represents an influence on the *Inquiry*. Maclaurin's *An account of Sir Isaac Newton's philosophical discoveries* was published in 1748, the same year as Hume's *Inquiry*, while Hume was traveling through Europe. However, apparently the *Account* was substantially completed before 1730, allowing for the possibility that Hume had seen it prior to publication, or as suggested above, even encountered its substance at university. At any rate, Hume's library passed on (via his brother first) to the philosopher's favorite nephew, who became a legal scholar of some renown in the area of Scottish criminal law. At the nephew's death an inventory of his estate was made, including the library. In the Hume library at that time was a 1748 quarto edition of Maclaurin's book. (Norton & Norton, 1996, p.111) The philosopher Hume is the most likely of the three to have had a use for the book. That edition also listed subscribers, of whom the Earl of Home (then William Hume, succ.1720, d.1761) is listed, but sadly the connection between the noble branch of the family and the Humes of Ninewells is tenuous at best.

Hume did not often discuss natural philosophy in any direct way, which has led to the impression that he was unfamiliar with natural philosophy in general and Newton in particular. [3] Although that position is no longer tenable, it remains that Hume's interest in natural philosophy did not extend to things mathematical. Noxon wrote,"I doubt that Hume had mathematics enough to read the *Principia*, if 'reading' includes following the geometrical demonstrations." (Noxon, 1973, p.69) While true, there were many natural philosophers who also could not have followed all of Newton's demonstrations, and one could read the *Principia* without delving into the mathematics. Even after pointing out eleven explicit references to Newton in Hume's writings, James Force noted that they indicated only an interest in "Newton's methodological principles," not his "mathematics and mechanics." (Force, 1987).

Hume appears not to have been interested in the demonstrations, and there is no evidence that he could have followed all of them, although there is reason to believe his undergraduate instruction in geometry should have enabled him to follow at least some of them. Clearly from what we have seen Hume was above all interested in the methodology. However, even without the demonstrations there was more to the *Principia* than methodology, and Hume had absorbed some notions of attraction, inertia, and force, even if he was to interpret them much more empirically than most Newtonians. In addition, we have seen that Hume felt compelled to discuss the nature of a vacuum, including reference to Newtonian arguments for a vacuum.

Whatever Hume's training or ability in geometry, his use and understanding of that field was severely limited by his insistence in the impossibility of infinite division. According to Hume, we cannot imagine infinitesimal points, and therefore we cannot reason with them. Hume's geometry seems to have been deeply confused in the area of infinites and infinite divisibility, although Frasca-Spada has made progress in untangling the mess. (Frasca-Spada, 1998, p.96) Frasca-Spada traced the arguments in some detail, and while not absolving Hume of error, pointed out that his error was not greater than that of his sources. Hume

[3]It has led some to assert that Hume was *completely* unfamiliar with and uninterested in the Newtonian system. See (Force, 1987) for references as well as an argument against that position.

disagreed with Newton and Barrow, but so did several of Hume's sources such as the great encylopædist Bayle, whose entry on Zeno contained just those crude atomistic dismissals of infinite divisibility that Barrow had shown to be fallacious. By adopting such views, Hume effectively ruled out mathematical science, and cast aside any geometric or mathematical defenses of the idea of a vacuum, and failed to appreciate the importance of quantitative methods in Newtonian reasoning.

Hume and Mechanics

Hume's brief discussion of the laws of motion in the *Inquiry* seems at first to confirm the notion that he did not understand or know about Newtonian mechanics.

> Thus it is a law of motion, discovered by experience, that the moment or force of any body in motion is in the compound ratio or proportion of its solid contents and its velocity, and consequently, that a small force may remove the greatest obstacle or raise the greatest weight if by any contrivance or machinery we can increase the velocity of that force so as to make it an overmatch for its antagonist. (*Inquiry*, Sec.IV, pt.I, p.45 (Hume, 1748/1955))

It is difficult at first to tell just what kind of mechanics Hume has in mind. I will first describe what appear to be the problems with this paragraph, and then explore what it would have meant to eighteenth-century philosophers.

The passage can be split into sections.

> Thus it is a law of motion, discovered by experience, (A)
>
> that the **moment** or **force** of any **body in motion** is in the compound ratio or proportion of its **solid contents** and its **velocity**, (B)
> and consequently,
>
> that a **small force** may remove the greatest obstacle or raise the greatest **weight** if by any contrivance or machinery we can increase the **velocity** of **that force** so as to make it an overmatch for its antagonist. (C)

Section A states a core Humean theme: knowledge comes originally from experience, not reason. Later in the same paragraph Hume explained,

> the discovery of the law itself is owing merely to experience; and all the abstract reasonings in the world could never lead us one step toward the knowledge of it (p.46)

That is the main point of the paragraph. What I am concerned with here, however, is the idea of mechanics underlying Hume's example.

Section B is more troublesome. If Hume was summarizing Newton, he seems to have been confused, or at least imprecise. It seems more likely that he is using a more Cartesian scheme which had not entirely separated dynamics from statics. Using the symbol '$\propto$' for "proportional to," we can render section B as:

- moment $\propto$ (solid contents)$\times$(velocity)
- force $\propto$ (solid contents)$\times$(velocity)

Hume has implied that moment and force are synonymous. Now what is interesting is that although this strikes one as an error, we find the same statement in Maclaurin.

> 12. The quantity of motion in a body being the sum of the motions of its parts, is in the compounded ratio of its quantity of matter and of the velocity of the motion." (Maclaurin, 1748, p.105)

After a quick example Maclaurin continued,

> There appears to be no ground for making a distinction between the *quantity of motion* and the *force* of a body in motion; as all the power or activity of body arises from and depends upon its motion. (Maclaurin, 1748, p.106)

For convenience, we can write that the quantity of motion is as mv. It then becomes apparent that something seems amiss, since taken together the two statements appear to imply $F = mv$ rather than $F = ma$. It is worth noting[4] that Newton did not write $F = ma$, but rather, "the change of motion is proportional to the motive force impressed," or at best $F \propto m\Delta v$. If the body started from rest ($v = 0$), then the motive force impressed in the body would in fact be $m\Delta v = m(v_f - 0) = mv$, yielding $F = mv$, leaving aside for the moment how to distinguish between relative and absolute rest.

So Hume's apparently erroneous equation of moment and force is found in the text of one of the foremost mathematical Newtonians of the time, and can be justified by appeal to Newton's own definition. In fact, by taking the force of a body in motion to be mv, Hume was at least implicitly siding with the Newtonians over opponents who favored measuring force by mv^2. However, if Hume read that far in Maclaurin, he read no farther in that section. Hume's understanding of mv was in fact more Cartesian. The fact is that while Maclaurin extracted a careful Newtonian account of mechanics from this start, Hume seems to have been confused.

Maclaurin later made his discussion of force more precise, and clearly separated proper from improper measures of force, a distinction important to Newtonians and not followed by their opponents or by Berkeley and Hume.

> 22. The principle, "that the cause is to be measured by its effect," is one of those that will be very apt to lead us into error, both in metaphysics and natural philosophy, if applied in a vague and indistinct manner, without sufficient precautions. Force is defined [by others] to be that power of acting in a body which must be measured by its whole effect till its motion be destroyed, by those who favour the new opinion, or some of of [sic] them at least, and by some who would represent this dispute as merely about words. (Maclaurin, 1748, p.136)

However, Maclaurin argued that Newton had the antidote to such muddy definitions:

> ...the impressed force being considered as the cause, the change of motion produced by it is the effect that measures the cause; and not the space described by it against the action of an uniform gravity, nor the hollows produced by the body falling into clay. (Maclaurin, 1748, p.136)

More precisely, Maclaurin had already earlier (p.106) warned that while we might make no distinction between "the *quantity of motion* and *force* of a body in motion,"

> We are not, however, to expect that all the effects of the motion of bodies should be proportional to the quantity of motion, **unless a due regard be had to the time of the motion, and to the direction in which it acts**.... (my boldface)

On the same page, Maclaurin specifically advises against comparing pressure to the force of a body in motion. This is the distinction between statics and dynamics, and Hume's main error I believe was the failure to appreciate this distinction. Indeed, the main difficulty plaguing the development of a science of dynamics was the problem of reconciling accounts of gravitational motion, simple machines, and collisions. According to Maclaurin, "pressures

[4]There is also a nice discussion of this matter in I.B. Cohen (Cohen, 1979).

are considered as infinitely small forces." (Maclaurin, 1968, p.130), so that forces are the sums of such pressures continued for a finite time. The correct measure of the intensity of a pressure like gravity is then $\frac{m\Delta v}{\Delta t}$, not just $m\Delta v$:

> the intensity of the power [pressure] that generates motion in any body, is proportional to the augment of force [momentum] which it generates in a given time, and the intensity of the power that resists or destroys motion, is measured by the decrement of force produced in a given time.... (Maclaurin, 1968, p.131)

Hume's mistake was therefore not in equating force with mv, but in how he went on to apply it.

In section C Hume talks about both removing an obstacle (collisions) and raising a weight, in a rather muddled way. To be fair, he is not being very technical, and the intuitive idea is clear enough: if the force is compounded of the solid contents and the velocity, then a less massive object which is moving faster can have the same force as a more massive object moving more slowly. But Hume does not elaborate the intuition successfully.

If we consider first the case of removing an obstacle, we may read Hume this way:

> a less massive object may remove the greatest obstacle if we can sufficiently increase the velocity of that less massive object.

Well, this is clear enough. A massive ball may be moved by colliding a less massive, but rapidly moving ball with it. However, we have already had to reconstruct Hume's wording. According to the definition of force he gave in section B, section C would be flatly inconsistent since after raising the velocity of the smaller object sufficiently, it would no longer have a "small force".

Where Hume has in section C used "force," we would write "mass," and he seems to have meant "weight" in the sense of some heavy object, as he immediately set about using the "force" to raise a "weight".

Hume appears to have been using ideas more common to Descartes and several post-Cartesian but pre-Newtonian philosophers. Descartes wrote:

> The contrivance of all these machines is based on one principle alone, which is that the same *force* which can raise a weight, for example, of a hundred pounds to a height of two feet can also raise one of 200 pounds to the height of one foot or one of 400 to the height of a half foot, and so with others, provided it is applied to the weight. (Westfall, 1971, p.73)

Perhaps following suit, Huygens [5] wrote, "What I mean by forces is the power ... of raising a weight." (Gabbey, 1980, p.177). Similarly, Torricelli thought it was possible to equate the "forza" of a 1,000 lb object with that of a 100 lb object dropped from a great enough height. From analyses such as these sprung many debates involving live and dead forces, and paradoxes about the infinities involved in converting one to another. (Westfall, 1971)

The problem is that this measure of force is not consistent with the formulation that $F = mv$. Hume has claimed to believe $F = mv$ but violated Maclaurin's warning against measuring force solely by the height to which an object can be raised, without regard to the times involved. Consider Descartes' example. If the same force can raise a 100-pound object 2 feet can raise a 200-pound object 1 foot, then the force acquired by the fall of the 100-pound object through 2 feet should be the same as that acquired by the 200-pound object falling 1 foot. However, as we can see in table 1, mv is not the same in each case.

[5] Eric Schliesser (personal communication) reports that his search has uncovered no evidence that Hume had read Huygens. I mention Huygens and Torricelli here to indicate that the example was widespread. Schliesser thinks that Hume's discussion of modern philosophy in the *Treatise* refers to Boyle.

Weight Lbs	Dist. ft	Time s	Vel. ft/s	mv lb-ft/s	mv^2 lb-ft^2/s^2
100	2	$\frac{1}{2\sqrt{2}} \approx 0.35$	$\frac{16}{\sqrt{2}} \approx 11.31$	≈ 1131	12800
200	1	0.25	8.00	1600	12800

Table 1: Comparing mv and mv^2 in Descartes' example.

Hume had, like many before Newton, erroneously carried his thinking in the realm of collisions over into an example involving gravity. In so doing he had of course, and apparently unawares, stepped into the middle of the mv-versus-mv^2 dispute raging between Newtonians and Leibnizians. Leibniz of course thought the forces were equivalent, but he measured force with mv^2.

It is hard to figure out just what picture Hume had in mind when he asserted in section C that

> a small force may ... raise the greatest weight if by any contrivance or machinery we can increase the velocity of that force so as to make it an overmatch for its antagonist.

However, his reference to using "machinery" to increase the velocity matches Descartes' explicit reference to simple machines. If we forget for the moment about the reference to velocity, Hume is addressing problems in statics: a large weight may be raised by a smaller weight if they are both put on a lever, with the smaller weight farther out. With regard to velocity, it seems Hume might still have been thinking in terms of statics, using some kind of "virtual" velocity, perhaps velocity times lever-arm, but the other possibility is that Hume had in mind the picture in his mind was that shown in figure 1.

Figure 1. Interpretation of Hume's idea of force

In figure 1 a smaller weight w is dropped onto a lever set up to raise the larger weight W. The total "force" associated with w increases with its downward speed. Hence, to raise a heavier W, using lighter w, one need only increase the speed with which w is projected onto the lever. This will increase the force and the moment, as Hume defined those terms, and possibly raise W. However, there is no easy equation of forces here, as w is likely to ricochet off the lever, which will begin to rotate but also to decelerate in its rotation under the pull of gravity on W. If w sticks to the lever, its own weight now contributes to help raise W.

So far as this brief mention of mechanics is concerned, Hume's notion of "force" lies somewhere between momentum mv and impulse Fdt. Although Hume's use of mv to measure force is justified by reading Newton and Maclaurin, his examples make it more likely that Hume was thinking more along Cartesian lines, even if he was drawing his technical definitions from more recent sources.

Inertia: Maclaurin versus Hume

The *Inquiry* provided a more direct and dismissive reference to Newtonian natural philosophy in the previously-examined footnote 11 at the end of Section VII, part I.

> I need not examine at length the *vis inertiae* which is so much talked of in the new [Newtonian] philosophy, and which is ascribed to matter. We find by

> experience that a body at rest or in motion continues forever in its present state, till put from it by some new cause; and that a body impelled takes as much motion from the impelling body as it acquires itself. These are facts. When we call this a *vis inertiae*, we only mark these facts, without pretending to have any idea of the inert power, in the same manner as, when we talk of gravity, we mean certain effects without comprehending that active power. (Hume, 1748/1955, p.84,fn.11)

This footnote is in direct opposition to Maclaurin. Even though Hume could not have read the *Account* in time, I suspect that because of his insistence on the importance of inertia, Maclaurin may have been one of the targets.

I can hardly understate the importance of inertia for Maclaurin. In his *Account*, Book I is a history of natural philosophy. Book II is, "Of the theory of motion, or rational mechanics." On the first page Maclaurin introduces inertia as that which distinguishes animate from inanimate objects, such that inertia is a property of passivity.

> This passive nature, or *inertia*, is what chiefly distinguishes the second class of external objects, which is called *body* or *matter* ; as the former is called *mind* or *spirit*. (Maclaurin, 1968, p.97).

Because of inertia, bodies resist any change to their motion, and

> This force with which it [the body] endeavours to persevere in its state, and resists any change, is called its *vis inertiæ* ; and arises from the *inertia* of its parts, being always proportional to the quantity of matter in the body ; insomuch that it is by this *inertia* only we are able to judge of the quantity of matter. (Maclaurin, 1968, p.99).

Furthermore, it is inertia which distinguishes matter from space. Both can be divided infinitely, although Maclaurin acknowledges that there are minimum *sensible* magnitudes of time, space, body, *etcetera*, a nod to Berkeley which is also applicable to Hume.

Following Newton, Maclaurin argued that inertia alone allowed philosophers finally to distinguish between relative motion and real or absolute motion through absolute space.

> A real circular motion, for example, is always accompanied with a centrifugal force, arising from the tendency which a body always has to proceed in a right line [*i.e.*, its inertia]. (Maclaurin, 1968, p.101)

The reality of the earth's circular motion can be demonstrated by the slower motion of pendulums at the equator compared to the poles. Furthermore, "the diurnal revolution of the heavenly bodies about the earth must be apparent only," since otherwise the heavens would fly apart under an immense centrifugal force. Similarly, were one to stop the earth from spinning, which would require a measurable force, the stars would stop moving, though no force had been applied to them; therefore their motion was apparent: they changed their position with respect to "bodies that appear to us to be at rest," (p.101) namely the earth. All of these phenomena were, "consequences of the real motion of the earth upon its axis." (Maclaurin, 1748, p.102)

Insofar as Maclaurin is arguing that it is the earth rotating, not the heavens, he is correct. However, it seems that he wants to argue that these demonstrations prove the absolute rotation of the earth in space. Specifically addressing "some metaphysicians of great character [who] condemn the notion of absolute space," Maclaurin asserts

> that it is not in relative or apparent motion in which it [a body in motion] perseveres, in consequence of its *inertia*, but in real and absolute motion. (Maclaurin, 1968, p.102)

Maclaurin supports this argument with reference to objects placed on spinning tops and in ship's cabins. A body on a spinning top does not preserve its state of rest with respect to the top, but flies off, preserving its "real" state of motion. If a ship is stopped, an body in the cabin continues in its previous direction because, "it endeavours to persevere, not in its state of rest in the ship, but in its state of motion or rest with regard to absolute space." (p.103)

Maclaurin's defense of real motion motion in absolute space is a bit overzealous[6], but they give some indication of how central the concept of inertia was to Maclaurin. He also used it to argue against nonmechanical interpretations of gravity, and of course it figured in his discussion of the laws of motion.

By denying the special status of inertia and absolute space, Hume undermined the Newtonian appeal to the reality of forces and thereby set limits on the nature of causal inference in natural philosophy. Hume had a special interest in cutting off the Newtonian argument at this point: if Newtonians could appeal to inertia to grant the reality of forces in absolute space, they had available a number of arguments for natural theology. First, an omnipresent Deity made sense of the otherwise baffling notion of absolute space. Second, universal gravity was unlike any conceivable mechanical principle in extending infinitely and in proportion "to the quantity of solid matter in bodies, and not to their surfaces, as is usual in mechanical causes : this power, therefore, seems to surpass mere mechanism," (Maclaurin, 1968, p.387) suggesting that God's work was more closely at hand in universal gravity. Third, even granting the special status of gravity as a force, it could not account for the order and existence of the solar system: the coplanar circular orbits, the erratic orbits of the comets, and indeed the continued existence of a system which should have run down by now.

Natural Theology

Newton and other followers may have waffled about the status of causes, but Maclaurin was clear on his interpretation. Natural philosophy was about explaining the causes of the phenomena of nature, and most definitely in the service of natural religion. It was important to get things right, because "false schemes of natural philosophy may lead to atheism," as Maclaurin thought it had in Lucretius' "monstrous system" and in Descartes and Spinoza. (pp.3-4) Maclaurin argued that through the method of analysis and synthesis, Newton had gone beyond hypotheses to demonstrably true causes, which could be distinguished by appeal to the real forces acting in the world. However, contemplation of universal gravity and the lawful order of the whole system led Maclaurin inevitably to God, and with Newton, to the idea that God was behind universal gravity, although Maclaurin took more seriously than earlier defenders Newton's ætherial hypothesis as a secondary cause, subjected to "like laws as other elastic fluids" but "the whole efficacy of this medium must be resolved into his power and will, who is the supreme cause." (Maclaurin, 1968, p.389)

For instance, Willem Jacob 'sGravesande's very influential Newtonian textbook from 1720 is markedly less cautious about forces than Newton was. According to Hall,

> The result is a more straightforwardly physical account of natural phenomena than Newton had provided;... Newton had not declared *why* there are laws of motion; 'sGravesande confidently asserts that the laws of nature were laid down by God and immediately depend upon his will. (Hall, 1993, p.220)

Furthermore, 'sGravesande apparently dimissed or ignored Newton's ætherial Queries, taking a very strong stand against æther theories.

[6]Schliesser points out that Huygens and Newton were aware that "the fact that the pendulums retard at the equator is consistent with relative and absolute conceptions of space." (personal communication).

> Now let a Mathematician consider, whether a Fluid so subtile as freely to penetrate the Pores of all Bodies, and so rare, as not sensibly to hinder the Motion of Bodies . . . can impel vast Bodies towards one another with so much Force [as gravity does]? ('sGravesande, in Hall 1993, p.222)

Maclaurin claimed the orthodoxy of the æther hypothesis on the strength of Newton's letter to Boyle. But 'sGravesande (and Pemberton) had a point.

The letter to Boyle is from 1678, and Westfall has pointed out that even in that letter Newton discussed "endeavours to recede". (Westfall, 1971, pp.369-377) There is no doubt that Newton wanted to find a physical cause for gravity, but nothing he thought of worked.

> Newton again and again sought for some explanation of how universal gravity might act. That is, he attempted to reduce universal gravity to the action of something else: a shower of aether particles, electrical efluvia, or 'spirits emitted,' variations in the density of an all-pervading aether. All of these attempted 'explanations' or reductions of universal gravity to some accepted kind of mechanism failed. None could fulfill two major requirements: that the resultant force vary inversely as the square of the distance and that this force act mutually on every pair of bodies so as to attempt to bring them together. (Cohen, 1988)

Westfall has argued persuasively that Newton ultimately abandoned the æther hypothesis, ascribed the ultimate *physical* explanation of motion to attractive and repulsive forces, and searched for another level of explanation. Having found no material qualities which would do, and perhaps thinking that in Book II of the *Principia* he had removed the possibility of *any* material æther, he looked to an immaterial æther, a Deity who could supply the active power needed for attractions and repulsions. Westfall quoted,

> For two planets separated from each other by a great expanse of void do not mutually attract each other by any force of gravity or act on each other in any way except by the mediation of some active principle that stands between them by means of which force is propagated from one to the other. . . . Therefore the ancients who grasped the mystical philosophy more correctly taught that a certain infinite spirit pervades all space, and contains and vivifies the entire world; and this supreme spirit was their numen; according to the poet cited by the Apostle: In him we live and move and have our being. Hence the omnipresent God is recognized. . . . (*Add.MS* 3965.6, f.269, in Westfall, 1971, pp.397-8)

On this view, forces were the ultimate court of appeal for natural philosophy, but beyond that God provided a way out of the paradox of action at a distance. God was in some way the cause of the forces, or at least gravity, which required the instantaneous action at a distance Newton found so hard to reconcile with natural philosophy. Yet, convinced that he was right in his description of gravity's action, Newton concluded that he could infer directly to an omnipresent, omnipotent deity who pervaded infinite space, without being identified with the same.

Cohen's reading of Newton is a bit more temperate. According to Cohen, Newton allowed a span of causes between the raw assertion of forces and the action of the Deity. This reading makes sense of Newton's Queries on elastic and electric ethers, and his method of proceeding "from effects to their causes and from particular causes to more general ones, till the argument end in the most general." In the end, the most general was always God, but the Queries seem more hopeful that philosophy had not reached the limit where God must be invoked directly. Maclaurin clearly interprets Newton in this way, although with an overly strong emphasis on the æther hypothesis.

On either reading, however, Hume would object that it was not possible to infer from physical principles to an omnipotent Deity, and that the proper attitude was to press as far

as possible, and then just to stop, and admit that one had reached the end of reason. *Any* step beyond that, even and indeed especially to God, was too much.

Hume thought such a move made the Newtonians into occasionalists like Malebranche, whom he had soundly criticized. Apparently referring to the famous letter to Boyle, Hume boldly accused Newtonians of failing to understand Newton in the previously referred-to footnote 11 (Hume, 1748/1955, Sec. VII, pt. I, p.84), which closely follows Maclaurin's own defense of Newton.

Hume and Maclaurin may be forgiven for not knowing Newton's other unpublished works which suggest that Newton's ætherial fluid was at best a half-hearted attempt, and probably put in just to appease mechanists by suggesting that something like an æther might be found to explain gravity. But the argument served its purpose. Both Maclaurin and Hume argued against interpretations which made Newton into an occasionalist.

> Whereas they who hastily resolve those powers into immediate volitions of the supreme cause, without admitting any intermediate instruments, put an end to our enquiries at once; and deprive us of what is probably the most sublime part of philosophy, by representing it as imaginary and fictitious: by which means, as we observed above [footnote to Book I. Chap. 5. Sec. 3], they hurt those very interest which they appear so sanguine to promote; for the higher we rise in the scale of nature, towards the supreme cause, the views we have from philosophy appear more beautiful and extensive. (p.389)

However, I am not sure that Hume would have absolved Maclaurin of the occasionalist sin. For Hume the matter was straightforward: Newton had proposed a sensible mechanical æther. Maclaurin knew the matter was not so easy, and had to elaborate how such an æther could be under the dominion of the Deity while still, from its regular behavior, counting as a natural cause. And of course Maclaurin was probably more aware of the large gap between the task set before the æther theory and what it could likely deliver.

So Hume is right that Newton allowed that even "second causes" of gravity would have power, but contrary to Hume, Newton did put God very close to the nature of gravity. Hume's swift move to exclude inference to attractive and repulsive forces or inertia were in line with the mechanical philosophy, but in fact undercut pieces of Newtonian science which the Newtonians at least considered crucial to a proper understanding of mechanics and motion.

Ultimately Maclaurin's natural theology was more general than the appeal to the reality of forces. In fact they bear a striking resemblance to two arguments advanced by Cleanthes in Hume's *Dialogues*, which was begun around 1750. Noxon has already argued that Hume lifted passages from Maclaurin to give voice to Cleanthes. (Noxon, 1973, pp.102-104) Here I quote one passage from Maclaurin at length to demonstrate the correlation. All italics are in the original:

> 6. The plain argument for the existence of the Deity, obvious to all and carrying irresistible conviction with it, is from the evident contrivance and fitness of things for one another, which we meet with throughout all parts of the universe. There is no need of nice or subtle reasonings in this matter: a manifest contrivance immediately suggests a contriver. It strikes us like a sensation; and artful reasonings against it may puzzle us, but it is without shaking our belief. No person, for example, that knows the principles of optics and the structure of the eye, can believe that it was formed without skill in that science; or that the ear was formed without the knowledge of sounds; or that the male and female in animals were not formed for each other, and for continuing the species. All our accounts of nature are full of instances of this kind. The admirable and beautiful structure of things for final causes, exalt our idea of the *Contriver:* the unity of

> design shews him to be *One*. The great motions in the system, performed with the same facility as the least, suggest his *Almighty Power*, which gave motion to the earth and the celestial bodies, with equal ease as to the minutest particles. The subtility of the motions and actions in the internal parts of bodies, shews that his influence penetrates the inmost recesses of things, and that He is equally *active* and *present* every where. The simplicity of the laws that prevail in the world, the excellent disposition of things, in order to obtain the best ends, and the beauty which adorns the works of nature, far superior to any thing in art, suggest his consummate *Wisdom*. The usefulness of the whole scheme, so well contrived for intelligent beings that enjoy it, with the internal disposition and moral structure of those beings themselves, shew his unbounded *Goodness*. These are the arguments which are sufficiently open to the views and capacities of the unlearned, while at the same time they acquire new strength and lustre from the discoveries of the learned. (Maclaurin, 1968, p.381)

Maclaurin was a straightforward realist. Our internal consciousness, he said, convinced us "that there are objects, powers, or causes without us, and that act upon us" (Maclaurin, 1748, p.97) and produce ideas, including ideas of cause and effect, mind, spirit, and God. (Maclaurin, 1748, pp.97-99) Hume argued that all such inferences were ultimately unjustified, and that while certain rules of reasoning made causal inferences permissible in natural philosophy, in no case did they warrant inferences to mind, spirit, and God. (Force, 1987; DePierris, forthcoming) And by the same arguments against those inferences, Hume also undermined the inference to real forces, attractive or repulsive.

Newtonians appealed heavily to the Design argument. Hume allowed that the mind was compelled to make the inference to God, but argued that the analogy was a poor one. Even granting that like effects require like causes, as Hume's fourth rule of reasoning in natural philosophy required (Hume, 1739-40, I.III.XV, p.173), was it really true that the works of nature resembled the works of humanity? Hume thought the creation of planets and stars was so far beyond human art to be a dissimilarity. Conversely, the closer the resemblance, the closer God must be to human, which was also absurd. As we have seen, Hume's fourth rule of reasoning was Newton's second. The Newtonians thought it underwrote the Design argument, but Hume sought to preserve its use in natural philosophy while denying its application to theological ends.

"A fair confession of ignorance"

By inferring without a doubt the existence of a designer, Newton was, according to Hume, guilty of going beyond his own modest rules of reasoning. It was Newton's adherence to these rules elsewhere in his natural philosophy that made Hume esteem Newton above all others, and to which Hume attributed Newton's great success.

> If we carry our enquiry beyond the appearances of objects to the senses, I am afraid, that most of our conclusions will be full of scepticism and uncertainty. . . . If *the Newtonian* philosophy be rightly understood, it will be found to mean no more. . . . Nothing is more suitable to that philosophy, than a modest scepticism to a certain degree, and a fair confession of ignorance in subjects, that exceed all human capacity. (Hume, 1739-40, Appendix, pp.638-9), noted in (Force, 1987, p.170)

By applying Newton's methodology to aspects of Newton's system itself, Hume undermined some of the tenets of the whole metaphysical package held by Newton and his followers, as exemplified by Maclaurin. Even though "same cause same effect" was a judicious (although unjustifiable) rule for reasoning in natural philosophy, its scope did not extend beyond the

proper domain of that science, and could not license metaphysical inferences about God, nor even inferences from a universal generalization to a natural law.

However, Hume's failure to appreciate the role of mathematical reasoning in Newtonian philosophy led him to lump too much into the category of metaphysics. Hume was right to suspect that some metaphysics were sneaking in somewhere: mechanics proceeds very well with only relative motion, and even anthropic arguments do not refer to real space and inertia as grounds to infer a Deity. But like many of his time, Hume suspect that the leak was down at the level of force, and created an epistemology insufficient to support the inference of theoretical entities such as forces.

Impressed by the success of the experimental philosophy and convinced of its promise in advancing beyond metaphysical dispute, Hume attempted to extend its success to the moral sciences. The essence of the experimental philosophy, as Hume saw it, was a careful and explicitly Newtonian caution about mixing conjectures with certainties. As part of his project, Hume searched for an epistemology which endorsed empirical science and rejected theological metaphysics, which subject Hume believed must remain beyond human reason.

One problem was that the best example of the experimental philosophy was rife with natural theology. Hume tried to sift the core of Newtonian philosophy from its metaphysical attachments, using a very Newtonian wariness of ultimate explanations. In removing the potential for theological inference, Hume also reduced force, gravity, and inertia to merely names marking empirical facts, which is all he thought they were. No doubt this extends in part to his incomplete appreciation of Newtonian mechanics, as evidenced by his apparent use of a Newtonian measure of force, mv, but within a Cartesian context.

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