The Reception of Isaac Newton in the Scottish Enlightenment:

Causation, Gravitation, and the Transformation of Natural Philosophy

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Abstract

This dissertation presents a new account of the reception of Isaac Newton (1643–1727) in Scotland centred on his readers and the texts that engage most explicitly with his example. It argues that the catalytic influence of Newton's physics – through, above all, his treatment of gravitation in the *Philosophiae Naturalis Principia Mathematica* (1687) – helped to bring about a transformation in natural philosophy during the eighteenth century. Newton has long been considered a pivotal figure in the history of science and philosophy whose revolutionary approach to natural inquiry marked the culmination of the Scientific Revolution and gave inspiration to the philosophers of the Enlightenment. Scholars have hitherto argued that the 'Newtonian Revolution' made early and enthusiastic converts in Scotland, where devoted 'Newtonians' established a new scientific orthodoxy which exerted a crucial influence on eighteenth-century Scottish philosophy. This received view is however limited by an anachronistic distinction between science and philosophy and essentialised modern readings of Newton's contribution to knowledge, obscuring both significant differences of opinion among the so-called Newtonians and important conceptual innovation in physical science that occurred in this period. By focusing on how Newton's natural philosophy was understood by his readers and the many ways his example was drawn on by both admirers and critics, this dissertation shows how Newton's reception animated and shaped important debates in the Scottish Enlightenment that cut across several fields. In so doing, it situates this reception in intellectual contexts that best reflect the interests and concerns of the actors under investigation, challenging the established narrative of the rise of Newtonianism in Scotland and typical conceptions of the Scottish Enlightenment. This study demonstrates how Scottish authors engaged with Newton's example, in service to different ends and in diverse settings, to explain why he was so admired and how Scottish natural philosophy underwent profound change following the publication of the *Principia*.

Chapter 1 shows how Archibald Pitcairne (1652–1713) and George Cheyne (1671/2–1743) drew on Newton's approach to philosophy to develop controversial reform programmes for medicine that provoked fierce debate among members of the Royal College of Physicians of Edinburgh in the 1690s and early 1700s. Chapter 2 examines how David Gregory (1659–1708) and John Keill (1671–1721) contemporaneously developed a

Newtonian pedagogy at Oxford primarily designed to introduce students to Newton's approach to explanation in physics and astronomy, emphasising its superiority over errant ancient and modern philosophical traditions. While Pitcairn and Gregory stressed Newton's causal agnosticism, Cheyne, Keill, and others soon began to characterise the law of gravitation as God's direct action in nature. Chapter 3 highlights the importance of Newtonian natural theology and traces debates over divine agency in natural philosophy through the work of Cheyne, Andrew Baxter (1686/7–1750), and Colin Maclaurin (1698–1746), in which differences of opinion are best understood in the context of broader contemporary theological debates in Scotland. Chapter 4 shows how the understanding of Newton's method of discovery shifted around mid-century under the influence of the 'Science of Man' of David Hume (1711–76) and Adam Smith (c. 1723–90) and the Common Sense philosophy of Thomas Reid (1710–96), with the power of imagination and the role of inductive inference given relatively greater weight than mathematics and deductive reasoning, leading to new theories of philosophical genius developed by Alexander Gerard (1728–1795) and William Duff (1732–1815) that took Newton as a major source. Chapter 5 argues that, following these developments, natural philosophy was redefined as a more strictly empirical enterprise, particularly in reaction to the sceptical empiricism of Hume and Henry Home, Lord Kames (1696–1782) and the perceived threat of atheism and deism to which it was connected. Newton's reputation was remade from around the 1770s, with James Burnett, Lord Monboddo (c. 1714–1799) and Edinburgh professors like John Robison (1739–1805), John Playfair (1748–1819), and Dugald Stewart (1753–1828) viewing him not as having revealed divine action in nature but as having established 'facts' or natural laws that did not, strictly speaking, describe actual physical processes. Though there were disagreements about the precise nature of Newton's own philosophical practice, his example shaped a new vision of natural philosophy established around the turn of the nineteenth century at Edinburgh by Robison, Playfair, Stewart, and others. This new ideal fed in to influential biographies of Newton written by an Edinburgh alumnus, David Brewster (1781–1868), and did much to shape the identity of the nascent natural sciences in Britain in the early nineteenth century.

Lay Summary

This dissertation examines how Scottish readers of the works of Isaac Newton (1643–1727) understood his ideas. The period under examination is from the publication of Newton's *Philosophiae Naturalis Principia Mathematica* (Mathematical Principles of Natural Philosophy) in 1687 until around 1831. This research differs from past scholarship in taking as its starting point Newton's readers rather than Newton's own works, and in primarily drawing on texts that engage most explicitly with Newton's ideas rather than works by those deemed to be the most influential or important philosophers of the Scottish Enlightenment. The thesis argues that the different ways Newton's Scottish readers understood his physics, particularly the way he pursued explanation and treated the concept of gravity, helped to transform the discipline of natural philosophy (i.e. the scientific study of nature) in Scotland during the eighteenth century.

Newton is generally understood to have been a revolutionary figure in the history of science and philosophy. His approach to the study of nature is often said to have been the culmination of the 'Scientific Revolution' and an inspiration for the philosophers of 'the Enlightenment'. Scholars have argued that Newton's influence was especially quickly and strongly felt in Scotland, where devoted 'Newtonians' embraced his science and promoted 'Newtonianism', which gave shape to Scottish Enlightenment philosophy. This dissertation breaks with the established line on the reception of Newton's ideas in Scotland by emphasising how the modern distinction between science and philosophy does not apply to the period, and by avoiding the idea that there exists a true understanding of Newton's contribution to knowledge that can now be understood by us and that the understanding of his past readers should be judged against. Some scholarship on Scottish Newtonianism suggests that Scottish Newtonians shared the same understanding of Newton and were his devoted followers. However, this thesis shows how there were important differences of opinion among these people, and that they did not all admire Newton unreservedly, nor use him as an authority figure to justify their own ideas or claims. Scholars have also argued that Newton was understood in a handful of completely different ways by the Newtonians, but here it is argued that Newton's Scottish readers actually understood him in a broadly similar way, though they had different interests and concerns at different times.

By focusing on how Newton was understood by his readers and the different ways his ideas were relevant for them, this dissertation shows how Newton's ideas influenced important debates during the Scottish Enlightenment that related to several fields, not just 'science'. By doing so, it challenges the established narrative of the rise of Newtonianism in Scotland and typical conceptions of the Scottish Enlightenment, in which science is placed in an entirely separate category to 'philosophy' and plays a minor role in the intellectual achievements of the period, if any. This thesis also challenges the notion that science did not undergo significant conceptual change in the eighteenth century by showing how Scottish natural philosophy was in a state of conceptual transformation throughout the period under study, partly due to the diversity of responses to, and understandings of, Newton's physics. Most importantly, Newton's readers disagreed about and debated how best to explain natural phenomena (i.e. occurrences in the observable universe). There was also some diversity of opinion about how Newton himself had approached causation, with his explanation of planetary motion by way of the theory of gravity of greatest interest to his readers. Despite the transformation natural philosophy underwent in this period, and the diversity of views on Newton, he was taken by most people throughout to have been an exemplary figure and an ideal natural philosopher. Newton's Scottish readers just could not agree on exactly what example he had set.

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Some material from the Introduction and Chapter 2 is reproduced in altered form in Lewis Ashman, 'David Gregory's and John Keill's Newtonian Pedagogy: Oxford and the Scottish Reception of Isaac Newton's Natural Philosophy', in *The Mind is its Own Place? Early Modern Intellectual History in an Institutional Context*, eds Alex Beeton, et al. (Oxford: Oxford University Press, 2023), 137–65.

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Contents

INTRODUCTION

I will not add to the length of so immoderately long a letter by criticising upon the passages you quote from Newton. I have a great regard to his Judgment but where he differs from me I think him wrong.

Thomas Reid to Henry Home, Lord Kames[1]

This is a study of Isaac Newton's Scottish readers and what they made of his contributions to natural philosophy. Strictly speaking, Newton's reputation was made not by his works but by those who read them, yet these readers are rarely the protagonists in the stories told of the triumph of Newtonian science. As the progenitor of 'Newtonianism', Newton (1642–1727) is widely seen as a pivotal figure in the history of science and philosophy.[2] His canonical writings are taken by many to be central to the making of intellectual modernity, and scholarly assessments of his influence are often rooted in readings of them. However, these readings are too often those of modern scholars themselves rather than those of Newton's contemporaries. This is problematic because modern conceptions of his contributions to knowledge can be quite different to what his past readers really made of them. As Newton's impact properly depended on the understanding of these readers, it is

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[1] 'Thomas Reid to Lord Kames', 16th December, 1780, in *The Correspondence of Thomas Reid*, ed. Paul Wood (Edinburgh: Edinburgh University Press, 2002), 146.

[2] See Simon Schaffer, 'Newtonianism', in *Companion to the History of Modern Science*, eds Robert C. Olby, et al. (London: Routledge, 1990), 610–26. For the history of the concept of the Scientific Revolution and Newton's role in it see H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry* (Cambridge: Cambridge University Press, 1994); and John Henry, *The Scientific Revolution and the Origins of Modern Science*, 3rd ed. (Basingstoke: Palgrave Macmillan, 2008). For the view that Newton's science was a key influence on the Enlightenment see Roy Porter, *Enlightenment: Britain and the Creation of the Modern World* (London: Allen Lane, 2000), esp. 132–8; and Ritchie Robertson, *The Enlightenment: The Pursuit of Happiness, 1680–1790* (London: Allen Lane, 2020). For an account of Newton's role in the 'narrative' constructed by Enlightenment philosophers see Dan Edelstein, *The Enlightenment: A Genealogy* (Chicago, IL: University of Chicago Press, 2010), 19–23 and 44–51. For a general account of Newton's reception and his use as a symbol in modern times see Patricia Fara, *Newton: The Making of Genius* (London: Macmillan, 2002).

essential to evaluate the consequences of the so-called 'Newtonian Revolution' first by paying close attention to how Newton's ideas were conceived in their own day, and then by tracing the development of his reception over time.[3] Looking at the Scottish context, this dissertation challenges scholarship that takes Newton's revolutionary contribution to knowledge as the basis for an influential scientific orthodoxy by placing the diverse responses to his ideas in their proper intellectual contexts.

Newton's pioneering science is thought to have found remarkably early and enthusiastic admiration in Scotland at the dawn of its celebrated Enlightenment, dislodging the theories of the French philosopher René Descartes (1596–1650) to become a local scientific orthodoxy by 1700.[4] Scotland is thus understood to have been one of the first places to witness a Newtonian revolution in natural knowledge that would eventually seize power in the whole of Europe and, from there, the world. Literature on the Scottish context has helped to establish the view that this revolution was brought about by the so-called 'Newtonians'. Early modern Scotland is believed to have been particularly fertile ground for loyal and committed partisans who successfully defended and promoted Newton's science. It is also thought that, following these efforts, Newtonianism exerted significant influence and acted as a major source of inspiration for the celebrated philosophy of the Scottish Enlightenment. Thus, Newtonian science is held to have been an important influence on the seminal works of philosophers such as Francis Hutcheson (1694–1746), Thomas Reid (1710–96), David Hume (1711–76), and Adam Smith (1723–90).[5]

This dissertation paints a quite different picture and offers an alternative account of Newton's Scottish reception to those found in the work of Tamás Demeter, Paul Wood,

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[3] This concept appeared in I. Bernard Cohen, *The Newtonian Revolution: With Illustrations of the Transformation of Scientific Ideas* (Cambridge: Cambridge University Press, 1980).

[4] For the displacement of Descartes' theories by those of Newton see Christine Shepherd, 'Philosophy and Science in the Arts Curriculum of the Scottish Universities in the 17th century' (PhD thesis, University of Edinburgh, 1975); and Christine Shepherd, 'Newtonianism in the Scottish Universities', in *The Origins and Nature of the Scottish Enlightenment*, eds R. H. Campbell and Andrew S. Skinner (Edinburgh: Donald, 1982), 65–85.

[5] For the clearest expression of this narrative see Paul Wood, 'Science in the Scottish Enlightenment', in *The Cambridge Companion to the Scottish Enlightenment*, 2nd ed., eds Alexander Broadie and Craig Smith (Cambridge: Cambridge University Press, 2019), 90–112. See also Tamás Demeter, 'Philosophical Methods', in *Scottish Philosophy in the Eighteenth Century. Volume II: Method, Metaphysics, Mind, Language*, eds Aaron Garrett and James A. Harris (Oxford: Oxford University Press, forthcoming), 53–107.

Eric Schliesser, Anita Guerrini, and David B. Wilson.[6] By placing Newton's readers at the centre of his reception and primarily using the texts that engage most explicitly with his example, this study demonstrates how Scottish Newtonians were critical readers and shows how they used his philosophy for different purposes. Newton's example was drawn on by critics and admirers in a range of important and interconnected debates throughout the eighteenth century. As the modern conception of natural science as something categorically distinct from philosophy did not yet exist at the time, this dissertation pushes against an anachronistic reading of the interplay between science and philosophy. The aim is to better integrate the reception of Newton's natural philosophy into the historiography of the Scottish Enlightenment on terms that more accurately reflect conceptions of natural knowledge held by the actors under investigation.[7]

Newton's natural philosophy was greatly influential and his discoveries widely admired but what is most interesting and important about his reception is the extent to which Newtonian philosophy stimulated new ideas, provoked productive debate, and encouraged novel solutions to old problems. This dissertation argues that the influence of Newton's philosophy in Enlightenment Scotland stemmed, above all, from his signature discovery: universal gravitation. The philosophical problematic that readers found in his treatment of gravity as an explanation of planetary motion acted as a kind of catalyst that provoked numerous important debates. As a result, natural philosophy was transformed in Scotland between 1687, with the publication of his *Philosophiae Naturalis Principia Mathematica* (Mathematical Principles of Natural Philosophy), and 1831, when David Brewster (1781–1868) published his seminal *Life of Sir Isaac Newton*. Written around the time that the Scottish Enlightenment is typically thought to have come to an end, Brewster's biography draws on several strands of Newton's Scottish reception and presents a portrait

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[6] See Tamás Demeter, *David Hume and the Culture of Scottish Newtonianism: Methodology and Ideology in Enlightenment Inquiry* (Boston, MA: Brill, 2016); Wood, 'Science in the Scottish Enlightenment'; Anita Guerrini, 'The Tory Newtonians: Gregory, Pitcairne, and Their Circle', *Journal of British Studies*, 25 (1986): 288–311; and David B. Wilson, *Seeking Nature's Logic: Natural Philosophy in the Scottish Enlightenment* (University Park, PA: Pennsylvania State University Press, 2009).

[7] For a recent call to action on this issue see Tamás Demeter, 'A Plea for an Integrated Historiography of Natural and Moral Philosophy in Enlightenment Scotland: A Programmatic Essay', *The Journal of Scottish Philosophy* 20, 3 (2022): 183–202.

of science and the proto-scientist that reflects a significant shift in the conception of natural inquiry which this reception did much to bring about.

Newton's *Principia* was swiftly understood by its readers as a new kind of natural philosophy. The explanation employed in Newton's argument for gravitation represented for many in Scotland a new approach and a major, historic departure. However, Newton's causal agnosticism regarding the origin of gravitation left open considerable interpretative space concerning even his own views on what were in themselves important questions. After its existence was thought to be established beyond doubt, the true nature of gravitational force and God's role in bringing it about remained issues of significant debate throughout the period. Defining exactly what gravity *is* and how its explanation relates to divine agency proved contentious and provoked much disagreement. These issues were subjected to a range of treatments by numerous authors attempting to get to grips with the consequences of Newton's discoveries. Newtonian philosophy was for its author's contemporaries not a ready-made scientific orthodoxy nor research programme but a stimulating, innovative, and widely admired set of propositions and arguments about the physical world. The discovery of gravity was virtually unanimously declared the most important aspect, and very often thought the most profound philosophical discovery of all time, but Newton's treatment of gravitation nonetheless presented problems that were yet in need of solutions.

By investigating attempts to provide these solutions it is possible to determine the character of Scottish natural philosophy more clearly and to trace developments in how the discipline was conceived. As natural philosophy is thought to have become 'Newtonian' in the late seventeenth century, this is important. Yet the history of science in early modern Scotland has tended to focus more on questions concerning the presence of new scientific ideas from abroad, practitioners' intellectual allegiances, scientific practices, and the relative importance of science to Enlightenment inquiry.[8] By showing how Newton's

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[8] For the presence of the latest developments in seventeenth-century European science in Scotland see Paul Wood, 'The Scientific Revolution in Scotland', in *The Scientific Revolution in National Context*, eds Roy Porter and Mikuláš Teich (Cambridge: Cambridge University Press, 1992), 263–287. For a critical reply to Wood's methodology see David McOmish, 'The Scientific Revolution in Scotland Revisited', *History of Universities* 31, 2 (2018): 153–72. For intellectual allegiances see Shepherd, 'Philosophy and Science'; and Wood, 'Science in the Scottish Enlightenment'. Scientific practices and the relative importance of science to the

example helped bring about a transformation in the conception of natural philosophy across the eighteenth century, this dissertation aims to address the question of what Newtonian natural philosophy in Scotland actually *was*.

Newton's early reception provides considerable insight into how novel his natural philosophy was thought to be, revealing the extent to which the approach to explanation exemplified by the *Principia* served as a model for a reform of the discipline. Debates involving Archibald Pitcairne (1652–1713), George Cheyne (1671/2–1743), David Gregory (1659–1708), John Keill (1671–1721), and others over what this model was exactly continued through mid-century and fed into other important debates on a range of issues, demonstrating that no settled 'Newtonianism' ever emerged in Enlightenment Scotland. The role of divine agency in effecting gravitation was a point of particular contention among authors like Cheyne, Andrew Baxter (1686/7–1750) and Colin Maclaurin (1698–1746), animating debates within natural theology, to which Newtonian physics proved considerably useful and popular.

Newton's reputation was refashioned around mid-century in response to developments in the philosophy of mind and moral philosophy (to which Newton's example itself contributed). Partly in response to the causal nescience of sceptical empiricists like Henry Home, Lord Kames (1696–1782) and David Hume, and the perceived threat of atheism and deism to which it was connected, natural philosophers followed Thomas Reid in developing a science of the mind that could justify the validity of reasoning from natural effects to their causes. This move, combined with a new emphasis on the power of the imagination, had significant consequences for how Newton's discovery of gravitation was understood, stimulating the theories of philosophical genius developed by William Duff (1732–1815) and Alexander Gerard (1728–95).

From the 1770s, 'physical' and 'metaphysical' inquiry became more consciously pulled apart and Newton's physics was increasingly seen as a particularly strict empirical enterprise directed toward the establishment of natural laws as 'facts', a view expressed by long-serving Edinburgh professors such as John Robison (1739–1805), John Playfair (1748–1819), and Dugald Stewart (1753–1828). This development, in which knowledge of such facts was considered by some to be strictly no more than the *appearance* of physical

Enlightenment are prominent themes running through contributions to Charles W. J. Withers and Paul Wood (eds), *Science and Medicine in the Scottish Enlightenment* (East Linton: Tuckwell Press, 2002).

processes, contributed to a redefinition of natural philosophy into something approximate to the modern 'science' of the 1830s, anticipating a vision of the nascent modern natural sciences as distinct from 'philosophy' that grew in influence during the nineteenth century.

In place of the standard view that the eighteenth century witnessed the consolidation of a singular, coherent Newtonian scientific tradition originating in the previous century that exerted influence on Scottish Enlightenment philosophy, the account outlined here presents eighteenth-century Scottish natural philosophy as having undergone continuous transformation in response to the persistent catalytic influence of Newton's ideas. This argument has implications for how the Scottish Enlightenment itself should be understood and suggests ways in which developments in Scottish natural philosophy gave shape to British science in the nineteenth century.

Who Was Isaac Newton?

Newton has remained a potent symbol and his legacy an issue of some debate since the 1830s, where the narrative here concludes.[9] This reputation poses a challenge for scholars seeking to understand Newton's impact, as he has attracted so much admiration and praise from many people with varying agendas, and his influence is often judged colossal in its reach and significance. However, establishing what his contemporaries actually thought helps to rein in exaggerated claims about the novelty and import of his ideas. Demonstrating the many ways his example was understood and used also has the potential to complicate essentialised readings of his works, adding greater depth to the study of Newton himself.

Newton's readers have very often lauded his ideas as transformative and modern. With the advent of the history of science as a recognised sub-discipline and the creation of the historiographical concept of the 'Scientific Revolution' in the twentieth century, Newton was cast, perhaps most influentially for the present day, as something like a

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[9] For Newton's reception in the nineteenth century see Rebekah Higgitt, *Recreating Newton: Newtonian Biography and the Making of Nineteenth-century History of Science* (London: Pickering & Chatto, 2007).

scientist *avant la lettre*.[10] Developing similar views stretching back to the early nineteenth century if not to Newton's own time, this new academic and historiographical context elevated Newton's 'scientific' reputation to new heights.[11] Newton's most celebrated modern English-language biographer, Richard S. Westfall, saw his subject as 'one of the greatest scientists of all times' who 'marked the culmination of the Scientific Revolution... that brought modern science into being', claiming that therefore few have lived 'for whom less need exists to justify a biography'.[12]

While the application of modern terminology to past ideas is not in itself anachronistic, describing Newton as a pioneering modern scientist has the potential to confuse modern conceptions of natural knowledge with past ones. One of Newton's most influential students of the twentieth century, I. Bernard Cohen, elected to render *regulae philosophandi* as 'rules for the study of natural philosophy' when producing (with Anne Whitman) only the second full English translation of the *Principia*, following Andrew Motte's in 1729.[13] Preferring this rendering to Motte's more faithful but still not entirely literal 'rules of reasoning in philosophy' (which had been retained in Florian Cajori's partial translation of 1934), Cohen and Whitman seem to have translated more than early modern Latin into modern English, turning Newton's reference to 'philosophy' into something more like a reference to 'science'.[14]

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[10] Following Herbert Butterfield, *The Origins of Modern Science, 1300–1800* (London: G. Bell, 1949), Newton played a critical role in the developments described in A. Rupert Hall, *The Scientific Revolution, 1500–1800: The Formation of the Modern Scientific Attitude* (London: Longmans, 1962). See also A. Rupert Hall, *Isaac Newton: Adventurer in Thought* (Cambridge: Cambridge University Press, 1992).

[11] Alexandre Koyré, another influential figure in the development of the history of science, did much to establish the view that Newton played a critical role in the creation of 'modern science': for his work on Newton in the 1950s and '60s see Alexandre Koyré, *Newtonian Studies* (Cambridge, MA: Harvard University Press, 1965).

[12] Richard S. Westfall, *The Life of Isaac Newton* (Cambridge: Cambridge University Press, 1994), ix. See also Richard S. Westfall, *The Construction of Modern Science: Mechanisms and Mechanics* (New York, NY: Wiley, 1971).

[13] Isaac Newton, *The* Principia*: Mathematical Principles of Natural Philosophy*, trans I. Bernard Cohen, Anne Whitman, and Julia Budenz (Oakland, CA: University of California Press: 1999), 440 – hereafter, *Principia*. (The edition quoted throughout this dissertation does not include Cohen's 'A Guide to Newton's *Principia*'.)

[14] Isaac Newton, *The Mathematical Principles of Natural Philosophy*, trans. Andrew Motte, vol. II (London: 1729), 202; Isaac Newton, *Sir Isaac Newton's Mathematical Principles of Natural Philosophy and His System*

Newton scholarship has more recently begun to view its subject in more nuanced terms, reflecting an inherent tension in the idea of Newton as a pioneer of modernity. By taking the first stride into the modern world he was always going to leave one foot in the pre-modern past. The economist John Maynard Keynes reacted to newly unearthed manuscripts detailing Newton's engagement with biblical chronology and alchemy (some of which he purchased) in a paper written for the tercentenary of Newton's birth in 1942 by describing him as

> the last of the magicians, the last of the Babylonians and Sumerians, the last great mind which looked out on the visible and intellectual world with the same eyes as those who began to build our intellectual inheritance rather less than 10,000 years ago.[15]

Towards the end of the twentieth century, Newton scholars debated the place of theology, alchemy, and the occult in his thought and questioned the 'coherence' between his supposedly scientific and non-scientific interests.[16] At around the same time, historians increasingly began to question how critical Newton's contribution to the Scientific Revolution really was, if such a revolution had even occurred at all.[17]

More recently, Newton has emerged from the literature as a more complicated figure with broad intellectual concerns. His philosophy currently attracts as much, if not more,

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of the World, ed. Florian Cajori, trans. Andrew Motte and Florian Cajori (Berkeley, CA: University of California Press, 1934).

[15] John Maynard Keynes, 'Newton, The Man', in *Newton Tercentenary Celebrations: 15-19 July 1946*, ed. F. A. E. Crew (Cambridge: Published for the Royal Society at the University Press, 1947), 27. For the history of these manuscripts see Sarah Dry, *The Newton Papers: The Strange and True Odyssey of Isaac Newton's Manuscripts* (Oxford: Oxford University Press, 2014).

[16] For a response to these debates that argues for the 'incoherence' of Newton's thought see Rob Iliffe, 'Abstract Considerations: Disciplines and the Incoherence of Newton's Natural Philosophy', *Studies in History and Philosophy of Science* 35, 3 (2004): 427–54.

[17] See Katharine Park and Lorraine Daston, 'Introduction', in *The Cambridge History of Science. Volume 3: Early Modern Science*, eds Katharine Park and Lorraine Daston (Cambridge: Cambridge University Press, 2006), 1–17; and Scott Mandelbrote and Helmut Pulte, 'Editors' Introduction', in *The Reception of Isaac Newton in Europe*, eds Helmut Pulte and Scott Mandelbrote, vol. I (London: Bloomsbury, 2019), 1-11. See also contrasting treatment of Newton in Steven Shapin, *The Scientific Revolution*, 2nd ed. (Chicago, IL: University of Chicago Press, 2018); and David Wootton, *The Invention of Science: A New History of the Scientific Revolution* (London: Penguin, 2016).

scholarly interest than his science.[18] He has been placed in intellectual contexts beyond that of the canon of scientific revolutionaries and his ideas acknowledged as responses to debates concerned with far more than modern notions of natural inquiry.[19] Currents in Newton scholarship have some influence on the study of Newton's reception, for the questions that scholars ask of his readers tend to be shaped both by what they think is most important about his influence and what they understand his ideas to be in essence. While Newton's treatment as a philosopher may serve as a useful correction to the 'great scientist' view it may also encourage a different set of scholarly priorities and assumptions related to the modern discipline of philosophy which are equally capable of distorting the historical facts.[20] It is therefore important in the investigation of Newton's reception to avoid imposing onto the source material a conception of his influence that is reduced to a specific idea, set of ideas, or single approach to philosophy and/or science.[21]

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[18] See Andrew Janiak and Eric Schliesser (eds), *Interpreting Newton: Critical Essays* (Cambridge: Cambridge University Press, 2012); Zvi Biener and Eric Schliesser (eds), *Newton and Empiricism* (Oxford: Oxford University Press, 2014); and Eric Schliesser and Chris Smeenk (eds), *The Oxford Handbook of Newton* (online ed., Oxford Academic, 2017). Cf. contributions to Rob Iliffe and George E. Smith (eds), *The Cambridge Companion to Newton*, 2nd ed. (Cambridge: Cambridge University Press, 2016).

[19] See Steffen Ducheyne, 'Newton's Training in the Aristotelian Textbook Tradition: From Effects to Causes and Back', *History of Science* 43, 3 (2005): 217–37; and Dmitri Levitin, 'Newton and Scholastic Philosophy', *British Journal for the History of Science* 49, 1 (2016): 53–77. See also Steffen Ducheyne, *The Main Business of Natural Philosophy* (Dordrecht: Springer, 2012); and Dmitri Levitin, *The Kingdom of Darkness: Bayle, Newton, and the Emancipation of the European Mind from Philosophy* (Cambridge: Cambridge University Press, 2022).

[20] See, for example, Steffen Ducheyne, 'Newton on Action at a Distance and the Cause of Gravity', *Studies in History and Philosophy of Science* 42, 1 (2011): 154–9; Andrew Janiak, 'The Three Concepts of Causation in Newton', *Studies in History and Philosophy of Science* 44, 3 (2013): 396–407; and John Henry, 'Newton and Action at a Distance between Bodies—A Response to Andrew Janiak's "Three Concepts of Causation in Newton"', *Studies in History and Philosophy of Science* 47 (2014): 91–7. See also footnote 19.

[21] Examples illustrative of this importance in the study of intellectual reception include Charles B. Schmitt, *Aristotle in the Renaissance* (Cambridge, MA: Published for Oberlin College by Harvard University Press, 1983); and Dmitri Levitin, *Ancient Wisdom in the Age of the New Science: Histories of Philosophy in England* c*. 1640–1700* (Cambridge: Cambridge University Press, 2015).

A work of reception ought nevertheless to indicate what it takes the object being received to be, and must do that by drawing on the latest scholarship.[22] It is now abundantly clear that Newton had very serious interests beyond mathematics and physics but, though this was not entirely unknown in his own time, these interests are not particularly prominent in his early reception.[23] His engagement with alchemy was, by the nature of the enterprise, kept more private than some of his other interests, and he wisely resolved not to publish or advertise many of his religious views. He rejected articles of Anglican faith that would likely have had serious practical consequences for his career, but may not have made a substantial difference to the reception of his natural philosophy.[24] That he appears to have devoted more time to, and written more words on, theology and alchemy does not in itself prove that he was more interested in these subjects, nor that they were more important to him, than his more famed public interests. That said, they clearly had great significance and our knowledge of them does enhance the understanding of his thought more generally.[25]

The views of Newton's eighteenth-century readers were inevitably shaped more by his published works than private papers and correspondence, and this dissertation therefore has more to say about the reception of the *Principia* and *Opticks* (1704) than anything else Newton wrote. Through these works, Newton became a renowned philosopher and mathematician in his own lifetime, widely acknowledged at home and

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[22] Reception studies has been particularly popular among cultural historians, literary scholars, and classicists seeking to trace the sometimes substantially divergent treatments of ideas, cultural creations, and myths across time: see Peter Burke, 'The History and Theory of Reception', *The Reception of Bodin*, ed. Howell A. Lloyd (Leiden: Brill, 2013), 21–38.

[23] Newton's *Chronology of Ancient Kingdoms Amended* was published posthumously in 1728. It presented a somewhat sanitised version of his views on the subject but nevertheless provoked controversy: see Jed Z. Buchwald and Mordechai Feingold, *Newton and the Origin of Civilization* (Princeton, NJ: Princeton University Press, 2012). For the British context and reception of Newton's religious views see Scott Mandelbrote, 'Newton and Eighteenth-century Christianity', in *Cambridge Companion to Newton*, 554–85.

[24] For Newton's alchemical interests see William Newman, *Newton the Alchemist: Science, Enigma and the Quest for Nature's "Secret Fire"* (Princeton, NJ: Princeton University Press, 2018). For his engagement with chronology see Cornelius Johannes Schilt, *Isaac Newton and the Study of Chronology: Prophecy, History, and Method* (Amsterdam: Amsterdam University Press, 2021). For his religious views and theology see Rob Iliffe, *Priest of Nature: The Religious Worlds of Isaac Newton* (Oxford: Oxford University Press, 2019).

[25] See, for example, Xiaona Wang, *Handling "Occult Qualities" in the Scientific Revolution: Disciplines and New Approaches to Natural Philosophy, from John Dee to Isaac Newton* (Leiden: Brill, 2023); and Levitin, *Kingdom of Darkness*.

abroad for the importance of his contributions to knowledge. Though no one was in any doubt that the *Principia* and *Opticks* were ostensibly works of natural inquiry, his natural philosophy was not read as science in the modern sense of a branch of knowledge separate from the rest of 'philosophy'.[26] Newtonian philosophy was a kind of natural philosophy, but its description simply as a philosophy was neither misleading nor mere shorthand. The philosophy of nature belonged to the larger enterprise of philosophy and had, by definition, implications for other areas of thought falling within the fairly capacious boundaries of that enterprise.[27] The authors under examination here made comparisons between natural philosophy and other branches of the discipline, sometimes holding physical inquiry up as a model unparalleled in its accuracy and claims to certainty. However, they also took it for granted that Newtonian natural philosophy had relevance for all philosophical inquiry. The narrative outlined here extends into the period in which a modern distinction between science and philosophy began to emerge and it traces some of Newton's influence on this development, but the focus throughout is on Newton's influence as a *philosopher* – in both the contemporary and present-day senses. In tracing Newton's influence on conceptual change within Scottish natural philosophy, this dissertation is mostly concerned with the history of what would today be considered the philosophy of science.

Mathematics bore significantly on the identity of Newtonian philosophy due to Newton's renowned mathematical abilities and the perceived success of his application of

[26] According to Ann Blair, 'Natural Philosophy', in *Cambridge History of Science*, Park and Daston, 363–406, early modern natural philosophy was 'the central discipline dedicated to laying out the principles and causes of natural phenomena' (363). See also Lynn Joy, 'Scientific Explanation from Formal Causes to Laws of Nature', in *Cambridge History of Science*, Park and Daston, 70–105.

[27] For the definition of natural philosophy in the eighteenth century as well as the influence of Newton's contribution to shaping modern scholars' notions of it see Rob Iliffe, 'Philosophy of Science', in *The Cambridge History of Science. Volume 4: Eighteenth-century Science*, ed. Roy Porter (Cambridge: Cambridge University Press, 2003), 267–84; and John Gascoigne, 'Ideas of Nature: Natural Philosophy', in *Cambridge History of Science*, Porter, 285–304. For the emergence of sub-disciplines in the eighteenth century that eventually fed into nineteenth-century ideas of science see Richard Yeo, 'Classifying the Sciences', in *Cambridge History of Science*, Porter, 241–66. For the broad interests of eighteenth-century philosophers see Aaron Garrett, 'Introduction: The Eclecticism of Eighteenth-century Philosophy', *The Routledge Companion to Eighteenth-century Philosophy*, ed. Aaron Garrett (London: Routledge, 2014), 1–27.

geometry to physics.[28] Not only was the *Principia* obviously understood to be mathematical both in its stated aims and execution, but so was *Opticks*, not least because the eponymous field was categorised as an area of mathematics and taught at universities by a mathematics professor. Newton himself taught optics as Lucasian professor of mathematics at Cambridge, a position he held between 1669 to 1702. Literary and artistic representations of Newton in the eighteenth century tended to bring together his mathematical talents with his discoveries concerning light (first published in the *Philosophical Transactions* of the Royal Society in 1671, some time before the appearance of the *Opticks*) and planetary motion, and usually emphasised how his discoveries were made possible by the application of mathematics to the study of the natural world.[29]

These depictions of Newton remain compelling into the present, but modern scholarship has encouraged the notion that the *Principia* and *Opticks* in fact represent two distinct approaches to natural philosophy. The former is often considered as a model work of mathematical physics and mechanics and the latter representative of a more experimental approach to science, associated with deductive reasoning and inductive inference respectively.[30] This is partly but not entirely to do with the apparent influence of the 'queries' Newton included at the end of *Opticks*, wherein, it has been argued, his readers found a rich natural-philosophical programme to advance his legacy and extend

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[28] For Newton's approach to mathematics see Niccolò Guicciardini, *Isaac Newton on Mathematical Certainty and Method* (Cambridge, MA: The MIT Press, 2011). For the reception of Newton's mathematics in Scotland see Niccolò Guicciardini, *The Development of Newtonian Calculus in Britain, 1700–1800* (Cambridge: Cambridge University Press, 1989); Niccolò Guicciardini, *Reading the* Principia*: The Debate on Newton's Mathematical Method for Natural Philosophy from 1687 to 1736* (Cambridge: Cambridge University Press, 1999), esp. 169–94; Niccolò Guicciardini, 'Dot-age: Newton's Mathematical Legacy in the Eighteenth Century', *Early Science and Medicine* 9, 3 (2004): 218–56; and Phillip Beeley, '"There Are Great Alterations in the Geometry of Late". The Rise of Isaac Newton's Early Scottish Circle', *British Journal for the History of Mathematics* 35, 1 (2020): 3–24.

[29] See Milo Keynes, *The Iconography of Sir Isaac Newton to 1800* (Suffolk: Boydell Press in Association with Trinity College, Cambridge, 2005) and Fara, *Making of Genius*.

[30] For an account of the distinction between Newton's philosophical enterprise in the two works see Steffen Ducheyne, 'Optical versus Mechanical Models: Newton's Failure to Construct a Satisfactory Theory of the Phenomena of Light and Colour', *Logique et Analyse* 49, 194 (2004): 199–223. For an account of how these two distinct philosophies found in each work played out in Scotland see Demeter, *Culture of Scottish Newtonianism*; and Demeter, 'Philosophical Methods'.

his achievements.[31] No Scottish authors (at least as far as this study has found) outlined this or any other distinction between the kind of philosophy Newton pursued in his corpus. Rather, several stressed the essential continuity of Newtonian natural philosophy across the *Principia* and *Opticks*. This dissertation therefore departs from some studies that take there to have been in effect two or more Newtons in eighteenth-century natural philosophy.

This study is also not as concerned as others have been to highlight responses to the German philosopher Gottfried Wilhelm Leibniz (1646–1716) and the so-called Leibnizians, who took a critical stance toward key aspects of Newton's philosophy.[32] Newton's most celebrated contribution to mathematics was the development of calculus, but Leibniz's own development of his own brand of calculus led to a bitter priority dispute over its invention.[33] Newton's Scottish supporters were prominent in the war of words between the 'Newtonians' and 'Leibnizians', which was fuelled by several factors, such as politics and religion, besides the provocative and tendentious claims over mathematical priority at its heart.[34] This clash has helped to reify the category of 'Newtonian' and has, along with Newton's own concerns and Samuel Clarke's epistolary debate with Leibniz over the correct approach to natural philosophy, suggested that Leibniz's opposition to Newtonian natural philosophy was the single most important spur to his followers' defence of their master.[35] For reasons that will be made clear in this dissertation, Newton's Scottish readers paid little attention to Leibniz's critique of the apparent 'action at a distance' involved in Newton's explanation of planetary motion by way of universal gravitation, and they tended to more or less dismiss the point. In more general terms, they saw Leibnizian philosophy as a development of, and therefore akin to, the philosophy of Descartes, with whom they typically contrasted Newton.

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[31] An influential articulation of this view can be found in Robert E. Schofield, *Mechanism and Materialism: British Natural Philosophy in an Age of Reason* (Princeton, NJ: Princeton University Press, 1970), esp. 19–87.

[32] For Leibniz's natural philosophy and his view of Newtonian gravitation see Daniel Garber, 'Leibniz: Physics and Philosophy', in *The Cambridge Companion to Leibniz*, ed. Nicholas Jolley (Cambridge: Cambridge University Press, 1994), esp. 328–55.

[33] For the priority debate over calculus see Niccolò Guicciardini, 'The Newton–Leibniz Calculus Controversy', in *Oxford Handbook of Newton*.

[34] See A. Rupert Hall, *Philosophers at War: The Quarrel between Newton and Leibniz* (Cambridge: Cambridge University Press, 1980).

[35] For the Clarke–Leibniz correspondence see Ezio Vailati, *Leibniz & Clarke: A Study of Their Correspondence* (Oxford: Oxford University Press, 1997). See Chapter 3.

The Newton who emerges from this study is one defined by his Scottish readers. The aspects of his thought that appear most frequently are those that appear from the sources to have most preoccupied and interested these readers. Newton's conception of matter, theories of light, mathematical innovations, theological views, 'queries', laws of motion, and 'rules for philosophising' all have their place. It is not (at least consciously) due to any preference or presumed importance that his treatment of gravitation is given prominence here. Nor is it simply because his readers most often cited the discovery of gravity as Newton's greatest contribution to knowledge. Most understood Newton to have proved the existence of either a real attractive force in nature or a natural law that amounted to the same thing while remaining agnostic about its precise physical origin, acknowledging only that God was its ultimate author. In the eyes of his admirers and critics alike, if universal gravitation did exist and was as profoundly significant as it appeared to be, both its conception and the argument Newton made for its existence demanded further attention.

Scholars have tended to think differently about Newton's reception and many have taken the English poet Alexander Pope's famous epitaph for Newton (in the event unused) to stand for the unanimous opinion of his contemporary admirers:

> Nature and Nature's Laws lay hid in Night.
> GOD said, *Let Newton be!* and all was Light.[36]

On examination, it seems that Pope hit upon a happy piece of verse with virtually no descriptive value for the historian seeking to trace the influence of Newton's discoveries. Newton's Scottish readers could not agree on the nature of his discoveries nor the means by which he arrived at them, but they would have agreed that two lines from Pope's *Essay on Criticism* (1711) well captured his achievement:

> Nature to all things fix'd the Limits fit,
> And wisely curb'd proud Man's pretending Wit.[37]

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[36] Alexander Pope, 'Epitaph Intended for Sir Isaac Newton', in *The Major Works*, ed. Pat Rogers (Oxford: Oxford University Press, 2006), 242.

[37] Alexander Pope, *An Essay on Criticism* (London: 1711), 6.

Newton was typically praised for his intellectual modesty and his philosophy was lauded by many precisely because he was seen to have carefully obeyed the limits placed on the human mind in its ability to account for natural phenomena. The extent to which the true nature of gravitation remained obscure and uncertain, however, encouraged Newton's readers to look more closely at the issues and continually re-examine the limits of natural inquiry.

Who Were the Newtonians?

Newton's name has been synonymous with the discovery of gravitation since 1687 and it has always been central to scholars' understanding of his influence and reception. However, this dissertation argues that the significance of Newton's discovery for his readers has been hitherto misconceived and, in fact, underestimated. The standard view of the Newtonian Revolution is that converts to Newton's science defeated the arguments of adherents to rival philosophies, chiefly the Cartesians, Leibnizians, and the remaining followers of the ancient philosopher Aristotle (384–22 BCE).[38] Consequently, historians have often told the story of eighteenth-century natural philosophy as the emergence of Newtonianism and its progressive rise to intellectual dominance over such rivals.[39] Descartes' vortex theory was explicitly countered by Newton in the *Principia* but favoured by Newton's rival Leibniz. Thus, adherence to the theory of gravitation over vortices has appeared to some scholars as signalling a commitment to Newtonianism. On this view, universal gravitation is seen less as a stimulant for fruitful debate than an article of scientific faith that determined on what side of scientific history readers stood.

There are several quite significant problems with this perspective, but these can be solved by decentring Newton himself and paying closer attention to the writings of the

[38] According to Cohen, *Newtonian Revolution*, 'the *Principia* was unfolded in 1687 to a wholly unexpectant and unprepared audience who did not, in actual fact, know what to make of it or how to use it for some time' (127), implying that the Newtonians were a mix of competent readers and devoted partisans. For a reassessment of this common view of Newton's readers' limited capacities see Mordechai Feingold and Andrej Svorenčík, 'A Preliminary Census of Copies of the First Edition of the *Principia* (1687)', *Annals of Science* 77, 3 (2020): 253–348.

[39] See, for instance, Blair, 'Natural Philosophy'; and Gascoigne, 'Ideas of Nature'.

Newtonians. Newton's admirers tend to be evaluated according to their competence and fidelity, doing little justice to their agency as scholars in their own right. Their identification as Newtonians can have the effect of distorting and obscuring what they actually thought. Cast as Newton's 'disciples' or 'followers', they are portrayed as cult-like 'devotees' motivated to evangelise the teachings of their 'master'.[40] From this point of view, Newton's own ideas appear as a reliable guide to the substance of Newtonianism, and what was most important about the Newtonians is taken to be their agreement with Newton and the extent to which they propagated Newtonian philosophy and mathematics. The success of Newtonianism has thus been presented by scholars as a victory for partisanship, the result of Newtonians' pious efforts to popularise, defend, and exposit a Newtonian 'creed'.[41]

This conception of Newtonianism runs up quite violently against the high value placed on thinking for oneself and the disdain for intellectual partisanship routinely expressed by authors in this period. Indeed, the Enlightenment is usually defined by intellectual freedom and the criticism of orthodoxies.[42] Both the motto of the Royal Society (adopted in the 1660s), 'nullius in verba', and that given by the German philosopher Immanuel Kant to the Enlightenment itself (in 1784), 'sapere aude', were lifted from the Roman poet Horace to capture the spirit of free inquiry understood by many to be characteristic of the modern age and essential to the pursuit of truth.[43] The idea that

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[40] This language has become conventional. See Guerrini, 'Tory Newtonians', where they are described as 'devotees' (288); Paul Wood, 'Science in the Scottish Enlightenment', in which 'Newton's empire' is extended by 'a phalanx of disciples and associates' (96) in Scotland; and Levitin, *Kingdom of Darkness*, in which the pioneering Newtonians David Gregory and John Keill adopted an 'aggressive Newtonianism' through a 'reverential stance toward their hero' (637).

[41] In Schofield, *Mechanism and Materialism*, the rise of Newtonianism is described as the 'diffusion of a Newtonian creed' (19).

[42] This is written into the traditional view of the Enlightenment as an intellectual project guided by Voltaire's rallying cry 'écrasez l'infâme!' which later helped to bring about the French Revolution. For a discussion of this association see Dorinda Outram, *The Enlightenment*, 4th ed. (Cambridge: Cambridge University Press, 2019), 139–56; and John Robertson, *The Enlightenment: A Very Short Introduction* (Oxford: Oxford University Press, 2015), esp. 1–14. This interpretation is also commonly applied to places where there was no such political outcome, such as Scotland, e.g. Alexander Broadie, *The Scottish Enlightenment: The Historical Age of the Historical Nation* (Edinburgh: Birlinn, 2007), esp. 1–42.

[43] *Nullius in verba* is recognised by the Society today to mean 'take nobody's word for it': 'History of the Royal Society', The Royal Society, accessed 1st Feb., 2023: royalsociety.org/about-us/history. For its adoption and

Newton's admirers were in some way dogmatically committed to his ideas has no doubt been encouraged by the high-flown and seemingly fervent praise they sometimes gave him. His achievements were a boon to poets and visual artists throughout the eighteenth century. His final resting place in Westminster Abbey was adorned with a lavish sculpture, and his image was reproduced in a variety of styles and contexts.[44] Upon Newton's death, the poet James Thomson (1700–1748) sang

> O UNPROFUSE Magnificence divine!
> O *Wisdom* truly perfect! thus to call
> From a few Causes such a Scheme of Things,
> Effects so various, beautiful, and great,
> An Universe compleat! And O Belov'd
> Of Heaven! into TH' ALMIGHTY's Councils thus
> To be admitted, and allow'd to scan
> The rising, moving, wide-establish'd Frame.[45]

Newton's Scottish readers could describe him as an 'incomparable philosopher', praising his 'sagacity', 'modesty', and 'patience', and it was often suggested that he had gained 'astonishing' and unparalleled insight into God's Creation. George Turnbull (1698–1748),

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origin see Michael Hunter, *Establishing the New Science: The Experience of the Early Royal Society* (Woodbridge: The Boydell Press, 1989), 17. For Kant's use of *sapere aude*, usually translated as 'dare to know!' see Immanuel Kant, 'An Answer to the Question: What is Enlightenment?', in *What Is Enlightenment? Eighteenth-century Answers and Twentieth-century Questions*, ed. and trans James Schmidt (Berkeley, CA: University of California Press, 1996), 58–64.

[44] For Newton's poetic and broader literary reception see Marjorie Hope Nicholson, *Newton Demands the Muse: Newton's* Opticks *and the Eighteenth Century Poets* (Princeton, NJ: Princeton University Press, 1946); Patricia Fara and David Money, 'Isaac Newton and Augustan Anglo-Latin poetry', *Studies in the History and Philosophy of Science* 35, 3 (2004): 549–71; Matthew Wickman, *Literature after Euclid: The Geometric Imagination in the Long Scottish Enlightenment* (Philadelphia, PA: University of Pennsylvania Press, 2016), 163–4; and Laura Miller, *Reading Popular Newtonianism: Print, the* Principia*, and the Dissemination of Newtonian Science* (Charlottesville, VA: University of Virginia Press, 2018). For the claim that Newton was somehow 'deified' by his contemporaries through artistic treatment see, for instance, David R. Bellhouse, 'The Deification of Newton in 1711', *BSHM Bulletin: Journal for the British Society for the History of Mathematics* 29, 2 (2014): 98–110.

[45] James Thomson, *A Poem to the Sacred Memory of Isaac Newton* (London: 1727), 8–9.

erstwhile chaplain to Frederick, Prince of Wales, hailed Newton as 'the light of the natural world'.[46] Such laudatory remarks, however, ought not to be read as signalling a form of intellectual partisanship that was widely considered unpalatable at the time and was, more often than not, the trigger for severe criticism.[47]

The notion of Newtonianism as a form of ideology originated in the 1960s and '70s and reflected contemporary thinking about the nature of scientific progress. Revolutionary change in science was thought by some to come about as a result of new ideas that successfully break with an established orthodoxy to bring about a new status quo. This may otherwise be termed a shift in 'normal science' as the result of a new 'paradigm', as most notably expressed by Thomas Kuhn in the seminal *Structure of Scientific Revolutions* (1962).[48] This shift is conceived as primarily intellectual in nature but historians have also treated revolutionary change in science as kind of a sociological phenomenon, often widening the focus beyond careful textual analysis to pay closer attention to rhetoric and scientific activities within wider social, political, and cultural contexts.[49] The Newtonian Revolution was taken by some as a prime example of such transformative change, regarding which scholars were not only interested in Newton's superior scientific method and set of resulting propositions but also the extent to which his ideas acquired currency in society more broadly through receiving credibility and assent. This approach is apparent in Robert Schofield's *Mechanism and Materialism* (1970), one of the earliest accounts of eighteenth-century Newtonian natural philosophy, which affirmed that successful scientific theories like those of Newton must become a kind of dogma.[50]

With the clear superiority (in hindsight, at least) of Newton's ideas over mostly continental-European rivals and critics, for some scholars there has appeared more to

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[46] George Turnbull, *Observations upon Liberal Education* (London: 1742), 323.

[47] See Chapter 1.

[48] Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 3rd ed. (Chicago, IL: University of Chicago Press, 1996), esp. 10–51.

[49] A major and pioneering statement of the importance of social context is Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life* (Princeton, NJ: Princeton University Press, 1985). See also Steven Shapin, *A Social History of Truth: Civility and Science in Seventeenth-century England* (Chicago, IL: University of Chicago Press, 1994). For an overview of social-constructivist historiography in the history of science see Jan Golinski, *Making Natural Knowledge: Constructivism and the History of Science*, 2nd ed. (Chicago, IL: Chicago University Press, 2005).

[50] Schofield, *Mechanism and Materialism*, 5.

Newtonianism than merely strict scientific dissent from the intellectual mainstream. From certain social-constructivist perspectives, Newton's followers appear to have been motivated less by critical judgement and philosophical debate than by the desire and to fashion a useful marker of identity and conform to a sectarian, factional or patriotic cause. Widespread admiration for Newton and the invocation of his name in connection to a range of distinct and contradictory scientific positions then only supports the view that he became a particularly flexible symbol among his admirers. For Arnold Thackray in *Atoms and Powers* (1970), Newton was a 'master' to which eighteenth-century Britain 'paid homage', during which time 'Newtonianism rapidly became many things to many men'.[51]

Extending lines of inquiry drawn earlier by Boris Hessen and other Soviet and Marxist scholars who placed Newton in the context of class conflict and industrialisation, Margaret Jacob argued in *Newtonians and the English Revolution* (1976) that Newton's ideas were embraced with particular fervour by Whigs and Low Church Anglicans.[52] The politico-religious dimension of Newton's reception has attracted considerable interest among scholars, encouraged by the explicit connection drawn by works such as the poem *The Newtonian System of the World The Best Model of Government* (1728) by English natural philosopher John Theophilus Desaguliers (d. 1744). However, the case for a special affinity with Newtonianism has been made for both sides of the period's politico-intellectual fault-line. If Newtonianism had a special affinity with both sides, it had a special affinity with neither. Jacob's argument was given something of a correction by Anita Guerrini, Simon Schaffer, and John Friesen, who have drawn particular attention to the Scottish context in order to demonstrate how Tories, Jacobites, and High Church Anglicans also found affinities between Newton's philosophy and their own confessional identities and political

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[51] Arnold Thackray, *Atoms and Powers: An Essay on Newtonian Matter Theory and the Development of Chemistry* (Cambridge, MA: Harvard University Press, 1970), 5. Thackray added that Newtonianism was nevertheless 'frequently viewed as a matter of methodology'. His concern was with the realisation of 'the Enlightenment's vision of a fully predictive Newtonian chemistry, based on mathematical laws and experimentally measured forces' – a vision that he concluded was 'not to be fulfilled' (5).

[52] For Hessen's views see Gideon Freudenthal and Peter McLaughlin (eds), *The Social and Economic Roots of the Scientific Revolution: Texts by Boris Hessen and Henryk Grossmann* (Dordrecht: Springer, 2009). For Jacob's views see Margaret C. Jacob, 'John Toland and the Newtonian Ideology', *Journal of the Warburg and Courtauld Institutes* 32 (1969): 307–31; and Margaret C. Jacob, *Newtonians and the English Revolution* (Ithaca, NY: Cornell University Press, 1976). See also Porter, *Enlightenment*, 24–47.

inclinations.[53] Along with Larry Stewart, Jacob has more recently shown how Newtonianism was adopted and adapted by various interest groups, such as industrialists and imperialists, to serve practical ends.[54] At the same time, Newton has been viewed as a powerful symbol and tool of political and philosophical conservatism, thus placing him in the so-called 'moderate' opposition that emerged to the 'Radical Enlightenment', a conceptual frame promoted most prominently in recent times by Jonathan Israel.[55]

Guerrini explicitly responded to the thesis articulated in *Newtonians and the English Revolution* by identifying the 'Scottish Tory Newtonians', but her work in fact stressed the intellectual rather than politico-religious reasons for these figures' interest in Newton. In the series of influential articles she published in the 1980s on a 'Newtonian circle' comprising Archibald Pitcairne, David Gregory, John Keill, James Keill (1673–1719), George Cheyne, and others, Guerrini was not greatly concerned to show how Scottish Episcopalianism is supposed to have played a role in these authors' admiration for Newtonian philosophy.[56] This may have been due to the paucity of evidence for the claim that Newton's Scottish readers accepted his conclusions as a result of their political views. However, even if there did exist a special affinity between Newton's philosophy and Scottish Episcopalianism at the turn of the eighteenth century, there is nothing about the Tory Newtonians' engagement with Newton that is best explained by reference to it. These authors were explicit about what they took Newton's philosophy to be and what they thought was important and

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[53] Guerrini, 'Tory Newtonians', Simon Schaffer, 'The Glorious Revolution and Medicine in Britain and the Netherlands', *Notes and Records of the Royal Society of London* 43, 2 (1989): 167–90, and John Friesen, 'Archibald Pitcairne, David Gregory and the Scottish Origins of English Tory Newtonianism, 1688–1715', *History of Science* 41, 2 (2003): 163–91.

[54] Margaret C. Jacob and Larry Stewart, *Practical Matter: Newton's Science in the Service of Industry and Empire, 1687–1851* (Cambridge, MA: Harvard University Press, 2021). See also Margaret C. Jacob, 'Newtonianism and the Origins of Enlightenment: A Reassessment', *Eighteenth-century Studies* 11, 1 (1977): 1–25.

[55] See Jonathan Israel, *Radical Enlightenment: Philosophy and the Making of Modernity* (Oxford: Oxford University Press, 2001), esp. 515–27. See also Margaret C. Jacob, *The Radical Enlightenment: Pantheists, Freemasons and Republicans* (London: George Allen and Unwin, 1981).

[56] See Anita Guerrini, 'James Keill, George Cheyne, and Newtonian Physiology, 1690–1740', *Journal of the History of Biology* 18, 2 (1985): 247–66; Guerrini, 'Tory Newtonians'; Anita Guerrini, 'Archibald Pitcairne and Newtonian Medicine', *Medical History* 31 (1987): 70–83; and Anita Guerrini, 'Isaac Newton, George Cheyne and the *Principia Medicinae*', in *The Medical Revolution of the Seventeenth Century*, eds Roger French and Andrew Wear (Cambridge: Cambridge University Press, 1989), 222–45.

admirable about it *as philosophy*. Something similar can be said for the familiar claim that Newton successfully exerted his powers of patronage to assemble followers and bring about the rise to intellectual dominance of Newtonian philosophy.[57] Not only is it unclear how exactly this patronage – which included supporting candidacies for professorships and exerting influence over the Royal Society's agenda as its president from 1703 until his death – could have ensured his ideas were not rejected but his supposed influence as a patron provides very little insight into the debates themselves.[58]

The work of historians like Schofield, Thackray, and Guerrini aimed at cutting through the widespread ideological commitment to Newton in eighteenth-century Britain to establish how exactly the Newtonians had taken their master's scientific breakthroughs forward. Acknowledging that many different positions and ideas could be projected on to him, they sought to show how a Newtonian research programme (or programmes) had nevertheless been elaborated and fruitfully pursued, particularly in new forums and social contexts amid what Larry Stewart later called the 'rise of public science'.[59] This had the effect of emphasising not just the influence of the *Principia* but the importance of the 'queries' to the *Opticks* and Newtonians' attempts to develop Newtonian matter theory.[60] Thus, scholars have not always deemed Newton's most characteristic ideas – the laws of motion, the theory of gravitation, or his conception of light – to have been the most important aspects of his reception, partly because they were least in need of further elaboration or research.[61] Guerrini, Andrew Cunningham, and others have, for instance,

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[57] Beeley, 'Newton's Early Scottish Circle' suggested that the support of Newton in Cambridge for David Gregory's bid to become Savilian professor of astronomy at Oxford was motivated by the prospect of 'Gregory's [Newtonian] circle' gathering nearby. Beeley argues that it was by way of Newton's 'tight control over his erstwhile Scottish circle', maintained 'through a complex web of support and sanction' (21), that Oxford became a hub of Newtonian activity.

[58] Evaluations of Newton's efforts to control others and wield influence through patronage are Frank E. Manuel, 'Newton as Autocrat of Science', *Daedalus* 97, 3 (1968): 969–1001; and Gerald Ellis Funk, 'Newton's Clients: Patronage in Science' (PhD thesis, University of Indiana, 1985).

[59] Larry Stewart, *The Rise of Public Science: Rhetoric, Technology, and Natural Philosophy in Newtonian Britain, 1660–1750* (Cambridge: Cambridge University Press, 1992).

[60] See Schofield, *Mechanism and Materialism*; and Thackray, *Atoms and Powers*.

[61] For the reception of Newton's optics see G. N. Cantor, *Optics after Newton: Theories of Light in Britain and Ireland, 1704–1840* (Manchester: Manchester University Press, 1993). Newton's influence on various aspects

argued that a Newtonian approach to medicine emerged in the 1690s, despite Newton having expressed no interest in the discipline and contributed very little to it.[62]

Scholarship that takes Newton to be an entirely flexible symbol or the initiator of diverse research programmes has the apparent drawback of suggesting that Newtonianism had no essential meaning or coherent definition. Generally speaking, there have been two approaches to solving this problem. Some scholars have attempted to identify the single essential Newtonianism that underlies Newton's reception. Others have embraced the diversity and attempted to categorise and catalogue the various distinct Newtonianisms at play in the period. Attempts to do the former are supported by reference to Newton's contemporary readers, but they are often rooted in a reading of Newton against which the works of Newtonians are then compared. Cohen's *Newtonian Revolution* (1981), for instance, contends that Newton completed a revolutionary shift initiated by Galileo's 'science of motion' when 'there arose' with Newtonian science

> the ideal of finding the true physical causes of [mathematical] laws, systems, constructs, and models, in a hierarchy of causes that began with the mathematical elucidation of the properties of forces causing motions and only then proceeded to the analysis of the nature and cause of such forces.

Cohen insisted that this formulation was not 'an anachronistic judgement of the twentieth century' but 'the unequivocal judgement of the Age of Newton', though his argument was advanced by first showing how Newton had, in his view, developed such a science.[63]

More recently, Dmitri Levitin has taken a quite different perspective on Newton in *The Kingdom of Darkness* (2022). There he is placed in the context of an 'emancipation' of natural philosophy from metaphysics amid a broader shift away from 'speculative philosophy' in Europe between 1500 and 1700. On Levitin's view, the 'central, defining

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of eighteenth-century natural philosophy is considered in Thomas L. Hankins, *Science and the Enlightenment* (Cambridge: Cambridge University Press, 1985).

[62] Andrew Cunningham, 'Sydenham versus Newton: the Edinburgh Fever Dispute of the 1690s between Andrew Brown and Archibald Pitcairne', in *Theories of Fever from Antiquity to the Enlightenment*, eds W. F. Bynum and V. Nutton (London: Wellcome Institute for the History of Medicine, 1981), 71–98; and David E. Shuttleton, '"A Modest Examination": John Arbuthnot and the Scottish Newtonians', *British Journal for Eighteenth-century Studies* 18 (1995), 47–62. See Chapter 1.

[63] Cohen, *Newtonian Revolution*, 35.

feature of Newtonianism was the development of anti-metaphysical, mathematical physics' and he argues that Newtonians themselves had significant influence on the development of Newton's own thought over time.[64] Cohen's and Levitin's accounts differ greatly regarding the context in which Newton is placed and the terms in which his ideas are discussed. However, the definitions of Newtonianism that emerge from them are both ultimately based on the authors' reading of Newton. The drawback of this approach is that the arguments for Newtonianism truly was are supported by the evidence of authors who are judged to be Newtonian if and when they articulate its essence. This need not be circular reasoning, but verges on being so if the Newtonians' ideas are reduced to their Newtonianism. In order to avoid exaggerating their Newtonianism, an admirer's understanding of Newton must be viewed within the context of their thought more generally and the purpose(s) of their engagement with Newton's example and works. This is made easier when Newton's admirers are taken not as Newtonians committed to a Newtonian cause but as readers who were merely persuaded by arguments they found persuasive.

However convincingly scholars may identify the true Newtonianism within Newton's corpus, defining Newtonians by way of their essential Newtonianism will always work to limit the understanding of them. This problem is no less applicable to the business of establishing multiple Newtonianisms. The most extreme example of this tendency may be David B. Wilson's *Seeking Nature's Logic* (2009), in which it was argued that Newton's legacy was spun out in various interpretive modes by each leading Scottish natural philosopher of the eighteenth century. This produces the unhappy result of making David Gregory the only 'Newtonian Newtonian', John Keill an 'Aristotelian Newtonian', Colin Maclaurin a 'Cartesian Newton' (despite acknowledgement that Maclaurin was sharply critical of Descartes' philosophy), and John Playfair a 'Leibnizian Newtonian'.[65] It is virtually needless to say that contemporaries would not have seen it this way but the same must also be said, as noted above, for the more plausible view that Newton's *Opticks* was the source for an alternative kind of Newtonianism to that of the *Principia*. Tamás Demeter has argued in *David Hume and the Culture of Scottish Newtonianism* (2016) that a 'Newton of the *Opticks'* and its 'qualitatively oriented vitalistic approach' prevalent among practitioners of the life sciences was, as evidenced in particular by Hume, an important strand of

[64] Levitin, *Kingdom of Darkness*, 500.

[65] These arguments are addressed in Chapter 2, X; Chapter 4, X; and Chapter 5, X.

Newton's influence in Scotland alongside the mathematical, mechanical philosophy derived from the '*Principia*'s dynamic corpuscularism'.[66] By applying conceptual frames to the source materials that are alien to the actors themselves, scholars are liable to reach conclusions rooted in readings of Newton (and other authors) that were not shared by contemporaries and do not reflect the terms of contemporary debates. This is not of merely semantic importance, it concerns what these authors really meant and, therefore, the historical course actually taken by Newton's ideas and influence.

Beginning not with Newton but his readers resolves this problem and sheds light on the relative importance of the concept of Newtonianism to the authors under investigation.[67] The adjective 'Newtonian' was used from time to time but did not in itself indicate anything beyond reference to Newton. The only way to know what an author meant by it exactly is to consider the context in which it was used, find out what the author thought about Newton, and to determine the relevance of Newton's example to the particular work under examination. The closest contemporaries came to defining Newtonianism concisely in general terms was through the appearance of 'Newtonian philosophy' in various encyclopaedias of the eighteenth century. Attention to the history of these entries reveals both the term's polysemy and the relative unimportance of its definition in the period. Ephraim Chambers' *Cyclopaedia* (1728) was the first to include such an entry, describing it as 'the Doctrine of the Universe, and particularly of the heavenly Bodies; their Laws, Affections, &c. as delivered by Sir *Isaac Newton*'. However, Chambers acknowledged that the term was 'apply'd very differently; whence divers confused Notions relating thereto'.[68]

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[66] Demeter, *Culture of Scottish Newtonianism*, 2 and 40. See also Demeter, 'Philosophical Methods', in which it is argued that different strands of Newton's influence helped give rise to four 'philosophical research programmes' (56): 1) 'the quest for mathematical principles' (i.e. following the *Principia*); 2) 'the programme of comparative analysis' (i.e. following the *Opticks*); 3) 'common sense foundations for inquiry' (i.e. following Thomas Reid's Common Sense philosophy); and 4) 'a programme for natural history' (i.e. following Francis Bacon rather than Newton).

[67] The word 'Newtonianism' was a rare sight in eighteenth-century English, attested by the fact that the Oxford English Dictionary records its earliest use in a letter written by Thomas Jefferson in 1814: 'Newtonianism, n.', *OED* Online, (September, 2022, Oxford University Press), accessed 30th May, 2023: www.oed.com/view/Entry/255042. See below for a much earlier example. For a brief look at the earliest uses of this terminology see Steffen Ducheyne, 'Early and Earliest Uses of the Word "Newtonian"', *Notes and Queries* 67, 4 (2020): 483–5.

[68] Ephraim Chambers, *Cyclopaedia*, vol. II (London: 1728), 628.

Chambers identified five distinct though far from mutually exclusive ways in which the term was used before giving his own account of the concept. He claimed that Newtonian philosophy was typically taken to be: 1) the '*Corpuscular*', or the '*New*', philosophy as 'reform'd' by Newton; 2) Newton's 'method', by which is meant the '*Experimental* Philosophy'; 3) '*Mechanical* and *Mathematical*' philosophy; 4) 'Physical Knowledge' as 'handled, improved, and demonstrated' in the *Principia*; and 5) the 'new Principles' Newton introduced into philosophy. The latter sense Chambers himself claimed to employ. He was of the view that Newtonian philosophy was in essence that laid down in Book III of the *Principia*, with its 'great Principle' being the '*Power of Gravity*'. The '*Newtonian System*', moreover, is constituted of 1) the 'Appearances' of nature deduced from this principle and 2) the application of the principle to the study of other natural phaenomena. By '*Newtonianism*' Chambers meant the adoption of Newtonian philosophy so defined, but he lamented that, despite its 'great Merit' and the 'universal Reception it has met with at home [i.e. Britain]', Newtonianism has 'scarce two or three Adherents' in other European nations, where '*Cartesianism*, *Huygenianism*, and *Leibnitzianism*' are 'still' dominant.[69]

This account, published a year after Newton's death, acted as a kind of truism for the rest of the century when it was reproduced in subsequent editions of the *Cyclopaedia* (1738 and 1781) and plagiarised virtually verbatim elsewhere: in the fifth and final edition of John Harris' *Lexicon Technicum* (1736), in summary form in the first edition of the *Encyclopaedia Britannica* (1771) – before being dropped, not amended, in subsequent editions, which included an entry on Newton's biography – and in Charles Hutton's *Mathematical and Philosophical Dictionary* (1796).[70] Though it is questionable how representative eighteenth-century encyclopaedias are of the general consensus of the period, other entries in these texts can reflect shifts in how Newton's ideas were understood over time.

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[69] Chambers, *Cyclopaedia*, 629.

[70] John Harris, *Lexicon Technicum, or, An Universal English Dictionary of the Arts and Sciences*, 5th ed., vol. II (London: 1736) – Harris died in 1719 and posthumous editions were amended by others. [William Smellie, et al.], *Encyclopaedia Britannica; or, A Dictionary of Arts and Sciences, Compiled upon a New Plan*, vol. III (Edinburgh: 1771), 399. Charles Hutton, *A Mathematical and Philosophical Dictionary: Containing an Explanation of the Terms, and an Account of the Several Subjects, Comprized under the Heads Mathematics, Astronomy, and Philosophy, Both Natural and Experimental*, vol. II (London: 1796), 157.

Those shifts, however, are best understood through the examination of contemporary debates and the issues and concerns that gave rise to them. By doing this it is possible to avoid the limitations of a reductivist approach to determining what Newtonianism *really was* without resorting to the compilation of an index of the many different ways Newton's example could be engaged with and treated. The only true Newtonian was Newton himself, but that does not mean each and every reading of his works must be accounted for separately to comprehend his reception. Nor does it follow that his readers were in no general agreement on what was most important about his contribution to knowledge. Newton inevitably became associated with many things, but what is most significant about his reception is how his example contributed to and shaped major developments in the philosophy of nature.

Science and the Scottish Enlightenment

These developments have been overlooked due to a tendency in the literature to view the philosophers of the Enlightenment as having been influenced by and responsive to the 'new science' of the seventeenth century only within other, non-scientific fields of philosophical inquiry. Scholars have often viewed the leading philosophical lights of the eighteenth century in the context of the major players of the Scientific Revolution, such as Newton, rather than the natural philosophy of their own time, obscuring the significance of contemporary natural-philosophical debates.[71] Eighteenth-century natural philosophy, both in Scotland and elsewhere, is typically presented as conceptually derivative of an earlier period, suggesting that the major developments and debates regarding what constitutes proper natural inquiry took place before the Enlightenment itself began.

The natural philosophy of the Scottish Enlightenment is in need of greater scholarly attention and Newton's reception offers crucial insight into it. Scholars have often evaluated

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[71] For the prominence of seventeenth-century developments in accounts of the eighteenth century, and a counter-point by way of 'Enlightenment vitalism', see Peter Hans Reill, 'The Legacy of the "Scientific Revolution": Science and Enlightenment', *Cambridge History of Science*, Porter, 21–43. Reill observed that 'if there is one characterization of the Enlightenment that appears as a truism, it is the assertion that the Enlightenment adopted, extended, and completed the intellectual and social project usually characterized as the "Scientific Revolution"' (23).

Scottish Newtonianism by tracing Newton's influence in the works of the most celebrated and influential philosophers of the Scottish Enlightenment, such as Thomas Reid, David Hume, and Adam Smith. The relatively limited explicit engagement with Newton in their writings has attracted disproportionate interest among scholars whose ostensible aim has been to understand Newton's reception in Scotland.[72] Their engagement cannot be fully understood only with reference to other aspects of their thought and the ideas of the major figures in natural philosophy of the seventeenth century but must be placed in the context of their contemporaries who engaged most with Newton's example. Establishing this context lessens the need to rely on modern readings of Newton's philosophy to substantiate eighteenth-century ones for which there is only limited direct evidence, and thus ought to reduce the tendency toward a reductivist approach to Scottish Newtonianism.[73] This dissertation is primarily concerned with what Newton's Scottish readers (including Reid, Hume, and Smith) had to say about him and therefore gives priority to material that explicitly engaged with Newton's example. A clearer picture emerges of Newton's influence in Enlightenment Scotland from an approach that first traces developments within Scottish natural philosophy with which Newton's example was bound up before examining the relevance of these developments and Newton's example to important contemporary debates in philosophy more broadly.

The idea that Newtonian science was as a model or inspiration for eighteenth-century philosophy is present in the earliest modern scholarship on the Enlightenment and can, to some extent, be traced back to the period itself. In the 'Discourse Preliminaire' to the *Encyclopédie* (1751), the French philosopher and mathematician Jean Lerond D'Alembert noted that 'our [i.e. French] scientific academists are now all Newtonians' and

[72] See, for example, Paul Wood, 'Science, Philosophy, and the Mind', *Cambridge History of Science*, Porter, 800–24; and Timothy Yenter, 'The Metaphysical Implications of Newtonianism', in *Scottish Philosophy… Volume II*, 108–43. Cf. Demeter, 'Philosophical Methods', which contextualises these leading figures with reference to several natural philosophers. See Chapter 4.

[73] For an example of this kind of scholarship see the concern to establish 'Newtonian connections' in Tamás Demeter, 'Hume's Science of Mind and Newtonianism', Schliesser and Smeenk, *Oxford Handbook of Newton*: https://doi.org/10.1093/oxfordhb/9780199930418.013.19.

proclaimed that Newton 'gave philosophy such a form as is likely to last'.[74] When the historiographical category of Enlightenment came into being in the early twentieth century, historians and philosophers gave D'Alembert's claims more substance. Ernst Cassirer argued in *Die Philosophie der Aufklärung* (1931) that a Newtonian 'methodological order characterizes all eighteenth century thought'. For Cassirer, the Enlightenment was

> not content to look upon analysis as the great intellectual tool of mathematico-physical knowledge; eighteenth century thought sees analysis rather as the necessary and indispensable instrument of all thinking in general.[75]

This 'analysis' was for Cassirer what distinguished Newton's physics from the deductivism of others, such as Descartes, whose philosophy D'Alembert had also contrasted with Newton's when welcoming the decline of Cartesianism in France. Cassirer argued that 'the goal and basic presupposition of Newtonian research is universal order and law in the material world' which could be achieved through 'mathematical determinations', 'arrangements according to measure and number', and 'observation', which 'produces the datum of science; the principle and law [being] the object of the investigation'.[76]

Cassirer's view was an influential one, but Newton has since not always played a particularly prominent role in accounts of the Enlightenment.[77] Some scholars, even while

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[74] Quoted in Jean Lerond D'Alembert, 'The Philosophical System of Des Cartes', In *Select Essays from the Encyclopedy, Being the Most Curious, Entertaining, and Instructive Parts of that Very Extensive Work, Written by Mallet, Diderot, D'Alembert, and Others, the Most Celebrated Writers of the Age*, Denis Diderot, et al. (London: 1772), 371.

[75] Ernst Cassirer, *The Philosophy of the Enlightenment*, (trs) Fritz C. A. Koelln and James P. Pettegrove (Princeton, NJ: Princeton University Press, 1951), 8 and 12. For Newton's seminal influence in other pioneering works of Enlightenment studies see Paul Hazard, *La Crise de la Conscience Européenne: 1680-1715* (Paris: Boivin et Compagnie, 1942); Gerd Buchdahl, *The Image of Newton and Locke in the Age of Reason* (London: Sheed & Ward, 1961); Norman Hampson, *The Enlightenment: An Evaluation of its Assumptions, Attitudes and Values* (London: Penguin, 1968); and Peter Gay, *The Enlightenment: An Interpretation. Vol. 2, the Science of Freedom* (New York, NY: Knopf, 1969).

[76] Cassirer, *Philosophy of the Enlightenment*, 8.

[77] Jonathan Israel, for example, has argued that the Enlightenment owes most to the influence of Baruch Spinoza: for the essentials of this influential view see Jonathan Israel, 'Enlightenment! Which Enlightenment?', *Journal of the History of Ideas* 67, 3 (2006): 523–45; and Anthony La Vopa, 'A New Intellectual History? Jonathan Israel's Enlightenment', *The Historical Journal* 52, 3 (2009): 717–38.

accepting the importance of developments in the new science to eighteenth-century philosophy, have drawn a sharp distinction between the central concerns of the Scientific Revolution and those of the Enlightenment. In *The Case for the Enlightenment* (2005), John Robertson cautioned that though the Enlightenment 'clearly owed much' to the Scientific Revolution it should not be 'conflated' with it, and his account paid little attention to the study of the natural world.[78] Robertson's view that the Enlightenment was, from the 1740s, 'characterised by... a new focus on betterment in this world, without regard for the existence or non-existence of the next' is shared by many and to some extent reflects prevailing opinion on the primary concerns and basic character of the Scottish Enlightenment.[79] According to Nicholas Phillipson's influential account, the Scottish Enlightenment was primarily concerned with an emergent 'social science' and marked by 'that remarkable inquiry' into 'the human personality and society' carried out by its leading literati.[80] Phillipson was in some agreement with another influential scholar of the period, Hugh Trevor-Roper, that science was 'peripheral' to this achievement.[81] That judgement has been challenged by Roger Emerson and Paul Wood, among others, who have

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[78] John Robertson, *The Case for the Enlightenment: Scotland and Naples, 1680–1760* (Cambridge: Cambridge University Press, 2005), 16 and 32. See also Robertson, *Enlightenment: A Very Short Introduction*, in which it is noted that the 'evident presence of traditions of [scientific] thought from the previous century [i.e. seventeenth] reinforces the conclusion that it is hard to distinguish any particular set of ideas as unique to the Enlightenment' in dismissal of 'historians of science' who have 'pressed the claims of their subject for inclusion' into the historiographical category of Enlightenment (12).

[79] Robertson, *Case for the Enlightenment*, 8. Another general account that takes a similar view of the Enlightenment is Anthony Pagden, *The Enlightenment and Why It Still Matters* (Oxford: Oxford University Press, 2013).

[80] Nicholas Phillipson, 'The Scottish Enlightenment', in *The Enlightenment in National Context*, eds Roy Porter and Mikuláš Teich (Cambridge: Cambridge University Press, 1981), 40. For Phillipson's contribution to the study of the Scottish Enlightenment see Colin Kidd, 'The Phillipsonian Enlightenment', *Modern Intellectual History* 11, 1 (2014): 175–90.

[81] Phillipson, 'Scottish Enlightenment', 40. See Hugh Trevor-Roper, 'The Scottish Enlightenment', *Studies on Voltaire and the Eighteenth Century* 58 (1967): 1635–58; and John Robertson, 'The Scottish Contribution to the Enlightenment', in *The Scottish Enlightenment: Essays in Reinterpretation*, ed. Paul Wood (Rochester, NY: University of Rochester Press, 2000), 37–62. For Trevor-Roper's contribution to the study of the Scottish Enlightenment see Colin Kidd, 'Lord Dacre and the Politics of the Scottish Enlightenment', *Scottish Historical Review* 84, 218 (2005): 202–20.

developed the work of John R. R. Christie to argue that 'scientism' and a 'culture of science' were crucial to Scotland's Enlightenment.[82]

The terms of this debate have tended to reflect modern conceptions of science and philosophy. Proponents of the scientism view have argued, against the claim that Scottish Enlightenment philosophy was essentially about non-scientific issues, that the work of scientists did indeed influence philosophers. They point out that these philosophers were interested in, and themselves sometimes practiced, science.[83] The case for an Enlightenment culture of science has been made by showing how integral Newtonianism apparently was for moral philosophers like Hume, or by demonstrating how Newton's ideas fertilised the intellectual seedbed out of which Enlightenment ideas themselves later grew. A significant limitation of these arguments is the tendency to take Newtonianism as a monolithic scientific orthodoxy. That is, treating it is a single method of natural inquiry and set of proven propositions about the natural world that may either be accepted or rejected.

On this view, expressions of admiration for Newton in Scotland have been taken as evidence that a given author was a Newtonian and, thus, someone committed to the truth of Newton's scientific discoveries rather than a critical reader of his philosophy. This approach implies that, among Newtonians, Newton's science was one thing and its philosophical interpretation another. A Newtonian may, for example, have to solve philosophical problems resulting from their apparent commitment to Newton's science. This kind of approach has been prevalent in the literature while insufficient attention has been paid to the differences of opinion among Newton's admirers. This is clear in the case of George Turnbull and Thomas Reid. Turnbull taught Reid at Marischal College, Aberdeen

[82] See John R. R. Christie, 'The Culture of Science in Eighteenth-century Scotland', in *The History of Scottish Literature. Volume 2 1660–1800*, ed. Andrew Hook (Aberdeen: Aberdeen University Press, 1987), 291–306; Roger L. Emerson, 'Science and Moral Philosophy in the Scottish Enlightenment', *Studies in the Philosophy of the Scottish Enlightenment*, ed. M. A. Stewart (Oxford: Oxford University Press, 1990), 11–36; Paul Wood, 'Science and the Pursuit of Virtue in the Aberdeen Enlightenment', in *Philosophy of the Scottish Enlightenment*, Stewart, 87–126; and Paul Wood, 'Thomas Reid and the Culture of Science', in *The Cambridge Companion to Thomas Reid*, eds Terence Cuneo and René van Woudenberg (Cambridge: Cambridge University Press, 2004), 53–76.

[83] This approach to the issue is evident in Roger L. Emerson, *David Hume, Medical Men and the Scottish Enlightenment: Industry, Knowledge and Humanity* (Farnham: Ashgate, 2009); and Paul Wood, 'Introduction', *Thomas Reid on Mathematics and Natural Philosophy*, ed. Paul Wood (Edinburgh: Edinburgh University Press, 2017), xvii–cxciv.

in the 1720s and argued that natural philosophy, above all Newton's, could serve as a direct model for moral philosophy. Reid is thought to have imbibed Newtonianism from Turnbull, however scholars have missed that Reid not only had different philosophical interests to Turnbull but came to completely disagree with his teacher, denying the applicability of natural-philosophical methodology to moral inquiry.[84] Reid therefore seems to have dissented from the Newtonian dictum apparently central to Scottish 'moral Newtonianism': 'if natural Philosophy in all its Parts, shall at length be perfected, the Bounds of Moral Philosophy will be also enlarged'.[85]

As the Scottish Enlightenment proper is often taken to have occurred around mid-century, the idea that a Newtonian orthodoxy was established by 1700, prior to the education of its leading figures, has encouraged the notion that Newtonian science was a conditioning factor for all Enlightenment inquiry.[86] Scotland's universities, learned societies, and debating clubs thus appear to have experienced a kind of institutional capture by Newtonians set on launching and establishing a particular scientific programme.[87] However, scholarship has often focused on establishing the *presence* of Newton's ideas rather than their reception.[88] The lack of attention paid to the works of figures thought to have actually established the Newtonian orthodoxy has obscured what Scottish Newtonianism really consisted of. David Gregory, John Keill, Archibald Pitcairne, George Cheyne, and Colin Maclaurin are thought to have done much to advance the Newtonian cause, but their motivations and divergent views on key questions about Newton's

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[84] See Chapter 4.

[85] Isaac Newton, *Opticks: Or, a Treatise of the Reflections, Refractions, Inflections and Colours of Light*, 4th ed. (London: 1730), 382. Hereafter *Opticks*.

[86] Following Shepherd, 'Newtonianism in the Scottish Universities', this is the perspective offered in Wood, 'Science in the Scottish Enlightenment'. See also David Allan, '"For the Advancement of Religion and Learning": University and Society in Seventeenth-century Scotland', in *Scottish Philosophy in the Seventeenth Century*, (ed.) Alexander Broadie (Oxford: Oxford University Press, 2020), 11–32.

[87] For the role of institutions in the rise of Newtonianism see Chapters 1 and 2.

[88] For alternatives to Shepherd's approach (though not applied to Newton) see Giovanni Gellera, 'The Reception of Descartes in the Seventeenth-century Scottish Universities: Metaphysics and Natural Philosophy (1650–1680)', *The Journal of Scottish Philosophy*, 13 (2015): 179–201; and Alasdair Raffe, 'Intellectual Change before the Enlightenment: Scotland, the Netherlands and the Reception of Cartesian Thought, 1650–1700', *The Scottish Historical Review*, 94 (2015): 24–47.

philosophy have been overlooked and the debates to which they contributed given insufficient treatment.

Maclaurin is best known as Scotland's Newtonian *par excellence* and his *Account of Sir Isaac Newton's Philosophical Discoveries* (1748) held up as an example of his competence and commitment to the truth of Newtonian science. However, only a handful of studies have even engaged with its arguments. In the *Account*, Maclaurin responded to important debates about the conception of gravitation and God's role in bringing it about, and produced the only detailed account of Newtonian philosophical methodology to appear in eighteenth-century Scotland.[89] Debates over gravitation and divine agency were quite critical to Newton's reception in Scotland and reconstructing them provides great insight into the so-called 'providential naturalism' or 'scientific theism' thought by some to be characteristic of the Scottish Enlightenment.[90] This providentialism has been taken as evidence of Newton's influence in Scotland, but Newton's reticence on the issue combined with the importance of gravitation actually stimulated a debate on the topic that was decisively shaped by pre-existing currents in Scottish theology and philosophy.[91]

Such debates gave Newton's Scottish reception its distinctive character. Though the Acts of Union (1706–7) incorporated its parliament into that of a new united kingdom of Great Britain, Scotland did not simply lose any semblance of independent identity, even if contemporaries liked to talk of 'North Britain' and the *Scoto-Britanni*, and sometimes put the remarkable growth of learning and politeness in Scotland down to English influence.[92] This thesis is not a comparative study and as such does not seek to reify the concept of a *Scottish* Enlightenment. It simply takes there to be enough that is distinctive and

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[89] See Chapters 3 and 4.

[90] See Paul Oslington, 'Divine Action, Providence, and Adam Smith's Invisible Hand', in *Adam Smith as Theologian*, ed. Paul Oslington (New York, NY: Routledge, 2011), 61–74; Peter Harrison, 'Adam Smith, Natural Theology, and the Natural Sciences', in *Smith as Theologian*, 77–91; Joshua Ehrlich, 'William Robertson and Scientific Theism', *Modern Intellectual History* 10, 3 (2013): 519–42; and Demeter, 'Philosophical Methods'.

[91] See Chapter 3.

[92] See Roger L. Emerson and Mark G. Spencer, 'Several Contexts of the Scottish Enlightenment', *Companion to the Scottish Enlightenment*, Broadie and Smith, 9–32; and Broadie, *Scottish Enlightenment*, 25–121; and Murray G. H. Pittock, 'Historiography', Broadie and Smith, *Companion to the Scottish Enlightenment*, 248–70.

characteristic of Scottish philosophy and theology to justify a national frame.[93] The Scottish context offers more than geographical convenience, yet the boundaries cannot be marked too definitively, not least because texts and ideas always travel with the people who create and convey them. The authors under study here must sometimes be viewed in both a British and wider European context.

Investigation of the Scottish context recommends itself partly due to the apparent zeal and enthusiasm of Newton's Scottish admirers. The concept of Tory Newtonianism has served as an explanation for this apparent phenomenon but its inapplicability to Presbyterians and Whigs, combined with other problems outlined above, weakens its explanatory value. Then there is the view offered by Rupert Hall in his study of the calculus dispute, who, observing that 'nearly all the ardent Newtonians' were Scottish, opined that 'the Scots are a people who have prided themselves upon their courage, their dogged pugnacity, and their outspoken reluctance to compromise'.[94] This dissertation offers a solution to this problem (if not a compromise) by showing precisely why, in their own words and on their own terms, these supposedly 'ardent' Newtonians admired Newton's philosophy.

That Newton's Scottish admirers produced some of the most valuable evidence for Newton's reception need not be explained by politico-religious identity nor putative national stereotypes. The geographical distribution of Britain's universities – with 5 of the 7 to be found in Scotland, though they tended to be smaller institutions than Oxford and Cambridge – the role of Edinburgh as a Scottish 'capital', and the various opportunities on offer in neighbouring England (especially London) helped people born in Scotland play a prominent role in British natural philosophy and mathematics. As careful attention to contemporary debates and their contexts reveal that Newton's Scottish readers were not so committed to a 'master' as the typical conception of a Newtonian implies (added to the fact that Newton was read with enthusiasm by many elsewhere), Scottish Newtonians had no peculiar zeal to answer for.

Scholars have in recent times been less inclined to view Newton's reception as a battle for the future of science between the Newtonians and their enemies. Greater

[93] On the distinctive character of eighteenth-century Scottish theology see contributions to David Fergusson and M. W. Elliot (eds), *The History of Scottish Theology. Volume II, from the Early Enlightenment to the Late Victorian Era* (Oxford: Oxford University Press, 2019).

[94] Hall, *Philosophers at War*, 134–5.

attention is being paid to the different ways in which Newton was read and understood both in Britain and elsewhere.[95] Literature on Newton's reception in continental Europe has revealed diverse ways in which his philosophy was understood and his example utilised.[96] J. B. Shank has argued against the 'mythistory' of the Newtonian Revolution as the invention of 'Newtonian' mathematical physics. He has argued that members of the Académie Royale des Sciences anticipated Newtonian mechanics in France and that alternative sources emerged through Leibniz and the French philosopher Nicolas Malebranche (d. 1715).[97] Steffen Ducheyne has seen Newton's influence on Dutch authors as a kind of 'appropriation' of his ideas that put them to specific ends and inevitably departed from what Newton really thought on certain issues.[98] In his work on the German context, Thomas Ahnert has questioned whether certain authors ought to be described as 'Newtonian' and challenged assumptions about which ideas were considered to be Newtonian in the period.[99] By focusing on contemporary debates, Ahnert has shown how

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[95] See Guicciardini, *Reading the* Principia; Eric Schliesser, 'Newton and Newtonianism in Eighteenth-century British Thought', in *The Oxford Handbook of British Philosophy in the Eighteenth Century*, ed. James A. Harris (Oxford: Oxford University Press, 2013), 41–64; Eric Schliesser, 'Newton and Newtonianism', in *Eighteenth-century Philosophy*, Garrett, 86–114; Steffen Ducheyne and Jip van Besouw, 'Readers of the First Edition of the *Principia* on the Relation between Gravity, Matter, and Divine and Natural Causation: British Public Debates, 1687–1713', *Centaurus* 63, 2 (2021): 381–95; and Jip van Besouw and Steffen Ducheyne, 'Characterisations in Britain of Isaac Newton's Approach to Physical Enquiry in the *Principia* between 1687 and 1713', *Early Science and Medicine*, 26 (2021): 341–72.

[96] See contributions to Elizabethanne Boran and Mordechai Feingold (eds), *Reading Newton in Early Modern Europe* (Leiden: Brill, 2017); and Helmut Pulte and Scott Mandelbrote (eds), *The Reception of Isaac Newton in Europe*, vols I–III (London: Bloomsbury, 2019).

[97] J. B. Shank, *Before Voltaire: the French Origins of "Newtonian" Mechanics, 1680–1715* (Chicago, IL: University of Chicago Press, 2018). See also J. B. Shank, *The Newton Wars and the Beginning of the French Enlightenment* (Chicago, IL: University of Chicago Press, 2008).

[98] See Steffen Ducheyne, ''s Gravesande's and van Mussheonbroek's Appropriation of Newton's Methodological Ideas', in *Reading Newton*, Boran and Feingold, 192–243. For the Dutch context see also Ernestine van der Waal, 'Newtonianism and Religion in the Netherlands', *Studies in the History and Philosophy of Science* 35, no. 3 (2004): 493–514; and Eric Jorink and Ad Maas (eds), *Newton and the Netherlands: How Isaac Newton Was Fashioned in the Dutch Republic* (Leiden: Leiden University Press, 2012).

[99] See Thomas Ahnert, 'Newtonianism in Early Enlightenment Germany, *c*. 1720 to 1750: Metaphysics and the Critique of Dogmatic Philosophy', *Studies in the History of Philosophy and Science*, 35, 3 (2004): 471–91;

German authors were often critical of Newton and his British admirers due to what they saw as the lack of a suitable metaphysical core to the supposedly systematic Newtonian philosophy practiced in Britain.

Despite the attention scholars have given the emergence of Scottish Newtonianism and its intersection with Enlightenment philosophy, no comprehensive account has tied together Newton's reception in Scotland that pays attention to the debates and diverse readings that defined the contours of this reception. It has been argued that the chief legacy of Scottish Enlightenment natural philosophy was to impart a particularly 'philosophical' quality to nineteenth-century British science through the Common Sense philosophy of Reid and others, which came to be known as 'the Scottish philosophy'.[100] For Richard Olson, Crosbie Smith, and David B. Wilson, a particular brand of Newtonian natural inquiry influenced by Common Sense fed into important developments in the nascent natural sciences.[101] On this view, Newtonian Common Sense inductivism combined with a tradition of Newtonian mathematical and mechanical philosophy to found the modern British scientific tradition. This perspective reflects and reinforces the notion that Scottish Newtonians developed a particularly 'experimental' brand of Newtonianism as opposed to a 'mathematical' tradition popular elsewhere.[102]

Tracing the reception of Newton's philosophy from the earliest readers of the *Principia* to the first few decades of the nineteenth century puts such claims in a longer-term context and makes possible the evaluation of Newton's legacy in Scotland. A comprehensive perspective also has the benefit of providing a fuller sense of what 'science' meant in this period. The explicit engagement with Newton by Common Sense theorists and natural philosophers of the later Scottish Enlightenment qualifies the view that the eighteenth century witnessed the emergence of a Newtonian Common Sense natural-

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and Thomas Ahnert, 'Newton in the German-speaking Lands' in *Reception of Isaac Newton*, Pulte and Mandelbrote, vol I. 41–58.

[100] See contributions to Charles Bradford Bow (ed.), *Common Sense in the Scottish Enlightenment* (Oxford: Oxford University Press, 2018).

[101] See Richard Olson, *Scottish Philosophy and British Physics, 1740–1870: A Study in the Foundations of the Victorian Scientific Style* (Princeton, NJ: Princeton University Press, 1975); Crosbie Smith, '"Mechanical Philosophy" and the Emergence of Physics in Britain: 1800–1850', *Annals of Science* 33, 1 (1976): 3–29; and Wilson, *Seeking Nature's Logic*.

[102] See Chapters 4 and 5.

philosophical tradition. It also makes clear that Newton never came to be seen as an experimental philosopher *rather than* a mathematical or mechanical philosopher, nor *vice versa*. Indeed, when attention is paid to diverse contemporary viewpoints it is evident that no single Scottish Newtonianism ever appeared in the eighteenth century.

Natural philosophy was transformed during the Scottish Enlightenment, in part, by debates fuelled by the diversity of responses to Newton's treatment of universal gravitation. Though he had plenty of admirers, there were also critical voices that did much to shape how his ideas were conceived. More than any other aspect of Newton's thought, gravitation posed challenging and important questions about natural inquiry that never ceased to preoccupy his readers, particularly with respect to issues of physical causation and divine agency. Newton's Scottish readers were initially most concerned with *how* his approach to philosophy had led to the discovery of gravitation. It was not long, however, before they began to pay great attention to what gravity actually *is*. By mid-century, these concerns had helped to shape new developments in the science of mind which themselves gave rise to new ways of viewing Newton's philosophical methodology. In the latter half of the eighteenth century, Newton's Scottish readers then supplied new answers to questions concerning what gravitation is and how God's agency might be said to bring it about. This dynamic between methodological, physical, and metaphysical issues drove Newton's reception and its catalytic influence on Enlightenment inquiry.

Newton's reception in Scotland did not settle into orthodoxy. His ideas were not merely the inspiration for philosophical debates but often vital aspects of them and, sometimes, their central concern. This was because the discovery of gravitation was generally understood to have been made by an 'incomparable philosopher' who had reformed the discipline of natural philosophy and made a transformative, revolutionary impact on history. Newton's Scottish readers just couldn't agree with one another as to what Newtonian philosophy was exactly nor what the transformation it brought about really amounted to.

Summary of Arguments

The account offered here begins with the consequences of an act of shared reading: Archibald Pitcairne and David Gregory first encountered the *Principia* while living together in Edinburgh in the late 1680s. They took a very similar reading of Newton's approach to philosophy with them when embarking on new positions at Leiden (Pitcairne, professor of medicine) and Oxford (Gregory, Savilian professor of astronomy) in 1691, laying out a shared vision for the reform of philosophy along Newtonian lines in inaugural addresses delivered less than a week apart.

Chapter 1 follows Pitcairne's path and shows how Newton's example was embraced as a superior approach to philosophy and taken as a model for the life sciences. It argues that Pitcairne developed an influential Newtonian reform programme at Leiden aimed at improving medical theory. Pitcairne's views fuelled the Edinburgh physic debate of the 1690s, in which his former students, George Hepburn (*c*. 1669–1759) and George Cheyne, defended his agenda. Cheyne went on to extend and develop Pitcairne's programme, arguing that gravitational attraction was a fundamental principle of nature, which James Keill (1673–1719) would later echo by arguing that a separate but equivalent attractive force could account for microscopic phenomena. These responses show how Newton's philosophy provoked debate within learned professional bodies like the Royal College of Surgeons of Edinburgh and served his admirers as a model for the reform of philosophy. The role played by Newton's example in these debates demonstrates what a 'Newtonian physician' could be in this period and reveals the extent of contemporary opposition to intellectual partisanship.

Chapter 2 examines similar contemporaneous attempts by Gregory and John Keill to reform physics at Oxford along Newtonian lines. Both Gregory and Keill left Edinburgh for Oxford in the 1690s and developed a Newtonian pedagogy there designed to introduce students to Newton's superior approach to philosophy, contrasting it with errant approaches to physical explanation both ancient and modern. The published accounts of their teaching, the chapter argues, are more fruitfully read as contributions to a debate about causation in physics than expressions of apologetic Newtonian orthodoxy. Their Newtonian pedagogy is usefully contrasted with the interests of other Scottish 'Newtonians', such as John Arbuthnot (1667–1735) and George Pirrie (fl. 1720), and ought to be read in light of Keill's contribution to a debate over the origins of the Earth, in which he was critical of contemporary approaches to explanation among both admirers of Descartes, such as the English clergyman and philosopher Thomas Burnet (*c*. 1635–1715), and Newton, such as the English mathematician and philosopher William Whiston (1667–1752). Gregory's and Keill's engagement with Newton shows how his example served particular pedagogical ends rather than simply appealing to educators as the basis for a new curriculum.

Chapter 3 traces an important yet hitherto underappreciated debate over the role of divine agency in Newtonian natural philosophy. While Gregory and Pitcairne, two of the earliest to respond to Newton's physics in Scotland, tended to emphasise Newton's causal agnosticism, readers such as Cheyne and Keill soon after began to see gravitation as a real attractive force and a natural law somehow effected directly by God himself. Cheyne developed a natural theology that responded to the English philosophers and clergymen Richard Bentley (1662–1742) and Samuel Clarke (1675–1729) by offering an account of the nature of gravitation and God's relationship to it as a causal agent. Cheyne's account was shaped by theological views akin to 'Cambridge Platonism' and two later contributions to this debate that departed from Cheyne's position, made by Andrew Baxter and Colin Maclaurin, are best understood with reference to the authors' own religious views in the context of a theological debate in Scotland over the role of reason in matters of faith. Baxter's somewhat extreme voluntarist conception of divine agency contrasts with Maclaurin's contention that a vast chain of causes leads from the Deity to natural phenomena. This debate demonstrates how Newton's Scottish readers were greatly motivated to integrate Newton's philosophy into accounts of natural theology aimed at countering atheism and deism and only popularised and defended his natural philosophy as an inadvertent or secondary result.

Chapter 4 highlights the emergence of new conceptions of Newtonian methodology around mid-century. Prior to the 1760s Newton's method of discovery was generally considered to be a combination of mathematical and experimental philosophy, though it was not until the 1740s that a systematic account of it was produced in Scotland, in the form of Maclaurin's *Account of Sir Isaac Newton's Philosophical Discoveries*. While Maclaurin held that deductive reasoning by way of mathematics was essential to Newton's discovery of gravity, Thomas Reid departed from this view by arguing that inductive inference, through the innate 'principle of common sense', was sufficient to make the discovery, with mathematics then required only to trace its effects. Reid's views of Newton's *regulae*, delivered in a paper to the Glasgow Literary Society, clarify the extent to which he disagreed with other so-called 'Newtonian moralists' and reflect greater interest in the role of the imagination in this period. The power of the imagination was essential to Adam Smith's understanding of Newton's discoveries and was central to theories of genius produced by Alexander Gerard and William Duff that used Newton's example as a major source for the notion of 'philosophical genius'.

Chapter 5 examines the reconceptualisation of natural philosophy in response to the challenge of sceptical empiricism and the perceived threats of atheism and deism. A redefinition of the discipline into a more strictly empirical enterprise is evident following a debate between the Edinburgh professor of natural philosophy John Stewart (1712–59) and Henry Home, Lord Kames, which played out in papers given to the Edinburgh Philosophical Society in the 1750s. Stewart did not provide a response to the empiricist psychology underlying Kames' and David Hume's causal nescience, whose scepticism he attempted to dismiss. In the following decades, Edinburgh professors like John Robison and John Playfair met Kames' and Hume's sceptical challenge by developing the view, along similar lines to Reid's Common Sense philosophy, that the human mind was so constituted as to acquire knowledge of physical causes from their observed effects. In this context, Newton began to be viewed as a pioneering empiricist who was entirely agnostic about the physical origin of gravity. This led some, like James Burnett, Lord Monboddo (bap. 1714–1799), to criticise the absence of metaphysics in his physics and to consider, as Dugald Stewart (1753–1828) would, his argument for gravitation to be merely the establishment of a 'fact' and not, strictly speaking, an act of philosophical explanation.

The redefinition of natural philosophy and the modification of Newton's reputation that occurred from the 1770s shaped David Brewster's influential biographies of Newton that established their subject as a proto-scientist in the image of contemporary practitioners of the nascent natural sciences. The appearance of Brewster's *Life of Sir Isaac Newton* in 1831 marks the end of a phase of Newton's reception that began in the 1690s and saw, this dissertation argues, the discipline of natural philosophy enter a period of continuous conceptual transformation that was given significant force and direction by the catalytic influence of Newton's distinctive approach to physics. For all that Newton's influence is thought to have given rise to modern science, his Scottish reception did not follow a neat linear trajectory. Views expressed in the 1690s were not necessarily more akin to those in mid-century than those articulated in the 1790s. But there were major shifts in how physical inquiry was conceived across this period.

Following the publication of the *Principia*, the ideal for physical explanation was expressed as the identification of final causes by way of the forces or powers somehow present in matter. The law of gravitation was a model for this ideal. From mid-century, this view, with its confidence that natural philosophy could reveal God's hand in nature, began to be replaced by an ideal in which the natural philosopher establishes natural laws or facts, such as universal gravitation, on a more strictly empirical basis, maintaining a degree of agnosticism regarding the physical reality underlying the phenomena. Under the pressure of sceptical empiricism, the capacity for the human mind to acquire knowledge of causes from effects became newly rooted in an empirical science of the mind. Divine agency, though never abandoned or denied by anyone but the most radically sceptical, reduced in prominence among Scottish natural philosophers who no longer believed that physical inquiry could reveal any insight into *how* God acted in nature. Throughout this period of transformation, Newton was an exemplary figure in the eyes of most. Notwithstanding the shifting and competing notions of proper natural philosophy his readers articulated, Newton's reputation remained tied to the highest ideals of natural inquiry.

CHAPTER I

ANIMAL BODIES

But ask not, to what Doctors I apply?
Sworn to no Master, of no Sect am I

Alexander Pope[1]

For his earliest Scottish readers, Newton's example promised to transform areas of natural inquiry to which he had made no direct contribution. On 26th April, 1692, Archibald Pitcairne delivered an inaugural address as the new professor of medicine at Leiden university, in which he told his audience how the discipline of medicine – 'physic' – had been corrupted since antiquity and could at long last be reformed by following the 'Method of Astronomers'.[2] His diagnosis was not entirely new but the suggested cure may have raised eyebrows.[3] 'The Business of a Physician', he said, 'is to weigh and consider the Powers of Medicines and Diseases as far as they are discoverable by their Operations, and to reduce them to Laws'.[4] He had in mind Newton's *Principia*, though he did not that day make the connection explicit. Pitcairne had read the work shortly after its publication in 1687 while lodging with David Gregory, at the time professor of mathematics at Edinburgh, and shared with his friend the hope that Newton's approach to philosophy could guide a root-and-branch reformation of natural knowledge.[5]

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[1] Alexander Pope, *The First Epistle of the First Book of Horace* (London: 1737), 5.

[2] Archibald Pitcairne, *The Whole Works of Dr. Archibald Pitcairne, Published by Himself*, tr. George Sewell, 3rd ed. (London: 1740), 11. Hereafter 'Oration' (*Whole Works*, 5–22).

[3] For the critique of philosophy among European physicians in the seventeenth century and its origins see Levitin, *Kingdom of Darkness*, esp. 25–50.

[4] 'Oration', 10.

[5] Pitcairn's lodging with Gregory at this time is mentioned in Richard Mead, *De Imperio Solis ac Lunae in Corpora Humana* (London: 1704), 47. For Gregory's own views, see Chapter 2.

Pitcairne warned his audience that they ought not 'lay out their Time and Pains in searching after Physical Causes, which can never be deduced till after the Laws of the Powers are found out; and when they [i.e. the physical causes] are found out, will be of no service to a Physician'.[6] He recommended rather the pursuit of 'Mathematical or Medical Causes' so medicine might liberate itself from the 'tyranny' of false, sectarian philosophy, both ancient and modern.[7] The reform he proposed involved approaching the philosophy of medicine like Newton did the philosophy of the heavens. In the *Principia*, Newton had eschewed the cause or origin of gravitational force itself in favour of determining the mathematical laws by which it operated and the effects thus brought about through the motion of heavenly bodies.[8] For Pitcairne, 'mathematical or medical causes' were the laws governing the powers responsible for the function (and malfunction) of animal bodies, and it was those causes, he insisted in his lecture, that 'are most useful for a Physician to know'.[9]

Pitcairne's time in the Dutch Republic was brief, but the attempt to reform medical theory he began there occupied him for much of the next decade. In the summer of 1693 he returned permanently to Scotland and, by 1695, his reform programme had helped to provoke a bitter and public feud among fellow members of Edinburgh's Royal College of Physicians, from which he was subsequently cast out. The debate among Edinburgh physicians that fuelled what has been dubbed the 'riot in the College', and which persisted through factional strife that embroiled the institution for many years, has been characterised as a struggle for the future of medicine contested by 'Newtonians' like Pitcairne against followers of the English physician Thomas Sydenham (d. 1689) and defenders of the status quo.[10] Scholars have argued that Newton's significance to Pitcairne and his fellow

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[6] 'Oration', 10.

[7] 'Oration', 22.

[8] For Newton's approach to causation and a discussion of the literature on the topic see Levitin, *Kingdom of Darkness*, 499–576. For Newton's use of 'laws' see Sergio Orozco-Echeverri, 'How Do Planets Find Their Way?: Laws of Nature and the Transformations of Knowledge in the Scientific Revolution' (PhD thesis, University of Edinburgh, 2020), 235–84.

[9] 'Oration', 22.

[10] For an account of the factionalism and personal rivalries behind the 'riot' see W. B. Howie, 'Sir Archibald Stevenson, His Ancestry, and the Riot in the College of Physicians of Edinburgh', *Medical History* 11, 3 (1967): 269–84. The 'Newtonian' valence of this dispute has been addressed in Cunningham, 'Sydenham versus

reformers lay in his scientific discoveries and in the mathematical and mechanical character of his philosophy.[11] However, Pitcairne did not think Newton's theories, such as the theory of gravitation, had much direct relevance for medicine, nor did he need Newton's example to advocate for a mechanical and/or mathematical approach to the discipline. He admired and frequently cited the Italian physicians Giovanni Borelli (d. 1671) and Lorenzo Bellini (d. 1704) as pioneers in bringing the power of mathematics and mechanism to bear on medical problems – that is, as practitioners of what is sometimes called 'iatromechanism'.[12]

It is unclear from the literature why exactly Pitcairne and others should have found support for a specifically mechanical approach to medicine in Newton's works, for the case has also been made that Newton's philosophy offered physicians a model for non-mechanical materialism and 'vitalism'.[13] This case has sometimes been made by arguing that the queries to the *Opticks* were most influential in the development of a Newtonian 'matter theory' which thereby shaped the development of medicine and the emergent discipline of chemistry in the eighteenth century.[14] Newton's influence on the life sciences thus emerges from the scholarship as ambivalent and contradictory: he was apparently considered by some as a superlative mechanist, in having provided an exemplary model for mathematical mechanical philosophy, and by others as a source for mechanism's antithesis, in having provided (or suggested through the queries) a non-mechanistic

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Newton'; Guerrini, 'Pitcairne and Newtonian medicine'; Guerrini, 'Cheyne and the *Principia Medicinae*'; and Shuttleton, 'Arbuthnot and the Scottish Newtonians'.

[11] See works cited in footnote 10 and Schofield, *Mechanism and Materialism*, 40–74; Thackray, *Atoms and Powers*, 43–82; and Demeter, *Culture of Scottish Newtonianism*, 35–45.

[12] For accounts of Borelli's and Bellini's medical theories see Anita Guerrini, 'The Varieties of Mechanical Medicine: Borelli, Malpighi, Bellini, and Pitcairne' in *Marcello Malpighi: Anatomist and Physician*, ed. Domenico Bertoloni Meli, (Florence: Leo S. Olschki, 1997), 111–28; and Fabio Zampieri, 'Giovanni Alfonso Borelli and Santorio on the Explanation of Fevers' in *Santorio Santori and the Emergence of Quantified Medicine, 1614–1790: Corpscularianism, Technology and Experimentation*, eds Jonathan Barry and Fabrizio Bigotti (Place of publication not stated: Springer, 2022), 273–87.

[13] For the diverse sources and outcomes of Newton's influence on the life sciences see: Harold J. Cook, 'Medicine', in *Cambridge History of Science*, Daston and Park, 407–34; Thomas Broman, 'The Medical Sciences', in *Cambridge History of Science*, Porter, 463–484; Jan Golinski, 'Chemistry', in *Cambridge History of Science*, Porter, 375–96; Peter Hans Reill, *Vitalizing Nature in the Enlightenment* (Berkeley, CA: University of California Press, 2005); and John H. Zammito, *The Gestation of German Biology: Philosophy and Physiology from Stahl to Schelling* (Chicago, IL: University of Chicago Press, 2018).

[14] See works cited in footnotes 10 and 11.

account of attraction and repulsion which served as a model for materialistic vitalism.[15] This is a confusing picture when the relevant material in the *Opticks* is taken to be that in which Newton speculated on inter-particulate forces and the validity of supposing the existence of a material ether, for both inter-particulate forces and a material ether are most at home *within* mechanical philosophy.

This chapter addresses this issue through a reassessment of Newton's role in the Edinburgh physic debate of the 1690s and the medical reform programmes that both developed out of it and motivated its participants. It argues that Newton's primary significance to medicine, according to readers like Pitcairne, was not the results he obtained nor the mathematico-mechanical character of his natural philosophy but his approach to causation, particularly as represented by his treatment of gravitation in the *Principia*. This argument suggests that Newton's example served the life sciences in this period principally as a model for physical explanation that was not tied to either a mechanical or non-mechanical paradigm. This view not only has the benefit of resolving the historiographical tensions outlined above. It also offers a way of bridging the otherwise puzzling gap between Newtonian projects supposed to have failed, like Pitcairne's, and those deemed more successful, such as the 'philosophical chemistry' of the physicians and chemists William Cullen (1710–90) and Joseph Black (1728–99), whose apparent Newtonianism has been connected to their pioneering contributions to major, influential developments in the life sciences.[16] While explicit engagement with Newton in the works of

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[15] According to Guerrini, 'Newtonian Physiology', Newton was a symbol of mechanical and mathematical philosophy operating at a higher level of sophistication than other mechanists to try their hand at medical theory, such as Descartes, Robert Boyle, Borelli, and Bellini. According to Golinski, 'Chemistry', a mechanical programme for the life sciences failed before a non-mechanical approach to forces, inspired by the *Opticks*, was developed in its place. For Demeter, *Culture of Scottish Newtonianism*, a Newtonian tradition based on inter-particulate forces co-existed in the eighteenth century with a separate vitalist tradition based on reasoning that can be connected to Newton's speculations on the existence of an ether.

[16] See Arthur L. Donovan, *Philosophical Chemistry in the Scottish Enlightenment: The Doctrines and Discoveries of William Cullen and Joseph Black* (Edinburgh: Edinburgh University Press, 1975); Matthew [D.] Eddy, *The Language of Mineralogy: John Walker, Chemistry and the Edinburgh Medical School, 1750-1800* (Farnham: Ashgate, 2008); contributions to Robert G. W. Anderson (ed.), *The Cradle of Chemistry: the Early Years of Chemistry at the University of Edinburgh* (Edinburgh: John Donald, 2015) and contributions to A. Doig, et al. (eds), *William Cullen and the Eighteenth-century Medical World: A Bicentenary Exhibition by the Royal College of Physicians of Edinburgh in 1990* (Edinburgh: Edinburgh University Press, 1993).

Cullen and Black is scant, scholars have argued that they saw his philosophy in essence as a model for an experimentalism directed toward the establishment of the properties of bodies and the laws that govern the forces giving rise to motion.[17] In its fundamentals, this understanding was shared by Pitcairne and his fellow reformers. Unlike Cullen and Black, however, who consciously rejected mechanical philosophy and pursued what might be described as chemical-vitalism, Pitcairne and his allies combined their view of Newton's experimentalism with optimism about the application of mathematics to a mechanistic vision of nature, to which Newton's philosophy could also be connected.

Pitcairne, along with two young physicians he appears to have mentored in Edinburgh, George Hepburn and George Cheyne, believed that taking a Newtonian approach to natural inquiry could secure the advancement of medicine by reforming medical theory and, through it, medical practice. After announcing and giving brief outline to his agenda in the inaugural lecture at Leiden, he elaborated his views further in a number of short works on medicine and natural history published throughout the 1690s.[18] His ideas were attacked by the physician Edward Eizat in the anonymous *Apollo Mathematicus* (1695) and defended by Hepburn in *Tarrugo Unmasked* (1695), an understudied text that provides some clarity on Pitcairne's influence and the significance of Newton's philosophy to the debate.[19] Pitcairne was later attacked by the physician Charles Oliphant in a work promoting the treatment of fever primarily through vomiting, prompting Cheyne to defend and develop Pitcairne's ideas about fever in *A New Theory of Continual Fevers* (1701).[20] Cheyne then took Pitcairne's agenda forward and developed his own Newtonian reform

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[17] See Donovan, *Philosophical Chemistry*, esp. 129–31 and 215–21; Demeter, *Culture of Scottish Newtonianism*; and Demeter, 'Philosophical Methods'.

[18] These works were published in Scotland and the Netherlands and first printed together as Archibald Pitcairne, *Archibaldi Pitcairneii Dissertationes Medicae, Quarum Syllabum Pagina Sequens Exhibet* (Rotterdam: 1701), later translated into English in two subsequent versions: *The Works of Dr. Archibald Pitcairn; Wherein Are Found the True Foundation and Principles of the Art of Physic*, (London: 1715); and Pitcairne, *Whole Works*, published in 1727 and 1740.

[19] [Edward Eizat], *Apollo Mathematicus, or, The Art of Curing Diseases by the Mathematicks According to the Principles of Dr. Pitcairne* (Edinburgh: 1695); George Hepburn, *Tarrugo Unmasked, or an Answer to a Late Pamphlet Intituled,* Apollo Mathematicus (Edinburgh: 1695) – hereafter *Tarrugo*.

[20] [George Cheyne], *A New Theory of Continual Fevers* (London: 1701).

programme, which he outlined in 'An Essay Concerning the Improvements of the Theory of Medicine', inserted into the second edition of his *New Theory*.[21]

Cheyne's essay was a bold manifesto advocating for the thorough reform of medical theory. He presented gravitation as evidence of a single fundamental principle that animates the natural world and claimed that Newton's calculus was the key to unlocking the secrets of nature, suggesting that this new mathematical technique ought to be applied directly to the life sciences. In Cheyne's actual work, however – as in Pitcairne's – the application of mathematics never came anywhere near the kind of technical sophistication found in the *Principia*. Imitating Newton's mathematics appears not to have been the aim of their pursuit of a 'mathematical medicine'. Primarily, Cheyne believed medicine would advance with the creation of a new system of natural philosophy developed along Newtonian lines. Following Cheyne and Newton's own remarks on the possibility of discovering attractive forces underlying microscopic phenomena in the queries to the *Opticks*, James Keill outlined a new theory of matter in the hope of advancing the discipline of medicine in *An Account of Animal Secretion* (1708).[22] Drawing on mathematical work by his brother, John Keill, he held that a principle of attraction distinct from but equivalent to gravitation was responsible for material cohesion and the interaction of all particulate matter. While Newton's discoveries and mathematical methods were offered as the basis, or possible basis, for new theories in medicine and chemistry, both Cheyne and Keill nevertheless saw Newton's approach to causation as fundamental to proper natural philosophy and, thus, central to any 'Newtonian' reform of the life sciences.

Pitcairne, Hepburn, Cheyne, and Keill believed Newton's philosophy was an antidote to the poisonous tradition of false philosophy represented by ancients like Aristotle and moderns like Descartes. They focused their critical energy on how this philosophy and the medical theories it spawned had corrupted physicians across the ages. Descartes' philosophy was for them akin to Aristotle's in that it consisted of an *a priori* system based upon speculative hypothetical 'elements' or 'principles'. Such speculative schemes characterised both the medical theories of influential ancient physicians, like Hippocrates

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[21] Originally published in [George Cheyne], *A New Theory of Acute and Slow Continu'd Fevers*, 2nd ed. (London: 1701), 1–37. Hereafter 'Essay'. Quotes from the essay are taken from [George Cheyne], *A New Theory of Acute and Slow Continued Fevers*, 6th ed. (London: 1744), 1–30.

[22] James Keill, *An Account of Animal Secretion, the Quantity of Blood in the Humane Body, and Muscular Motion* (London: 1708).

(*c*. 5th C. BCE) and Galen (*c*. 130–210 CE), and those of Descartes' modern admirers. Medical reformers like Pitcairne lamented this kind of philosophy not just for its errors and unempirical character but for its capacity to attract committed, uncritical adherents lured by the promise of systematic reasoning and the superficially plausible theories derived from it. This sectarian tendency provoked different responses, however, for while Pitcairne presented the creation of philosophical systems in general terms as negative, Cheyne advocated for the creation of a new kind of philosophical system along Newtonian lines, guided by mathematics and the proper approach to explanation, which he contrasted with bad system-building on the Cartesian model.

These Scottish medical reformers believed that the body must, as far as possible, be understood mechanically using mathematics, as had been pioneered by Santorio Santori (d. 1636), professor of medicine at Padua between 1611 and 1624.[23] They viewed the bodily machine as incredibly intricate, perhaps infinitely so, and emphasised the importance of empirical investigation into its inner-workings, such as the renowned microscopy of the contemporary Dutch naturalist Antoni van Leeuwenhoek (d. 1723).[24] They saw William Harvey's discovery of the circulation of the blood as a pivotal moment in the history of medicine but they rejected the kind of philosophy Harvey (d. 1657) in fact favoured, which involved explanation by way of qualities inherent in bodily organs and fluids.[25] A commitment to empiricism drove their critique of contemporary philosophy and they saw explanation by way of 'occult qualities', which they also described as assigning causes to the 'natures of things', as invalid. However, they did not rule out the existence of the unseen, such as corpuscles, so they sought a way of reasoning about unseen, and potentially unseeable, bodily objects and the invisible powers that animate bodily processes – such as breathing, the circulation of blood, and the operation of the nervous system – without recourse to speculative principles and so-called occult qualities. In Newton's treatment of gravitational force they found a model for theorising about animate

[23] For the work of Santori and its influence see contributions to Barry and Bigotti, *The Emergence of Quantified Medicine*.

[24] For van Leeuwenhoek's microscopy and its context see Ian M. Davis, 'Antoni van Leeuwenhoek and Measuring the Invisible: The Context of 16th and 17th Century Micrometry', *Studies in the History and Philosophy of Science* 83 (2020): 75–85.

[25] See Roger French, *William Harvey's Natural Philosophy* (Cambridge: Cambridge University Press, 1994), esp. 51–70.

beings with machine-like bodies around which fluids are somehow driven before being excreted. Such vital activity was apparently powered at least in part by the function of the heart, but Newton's admirers came to understand well that knowledge of the physical origin of such power was not required to accurately trace its effects.

Pitcairne and Cheyne have become well known to historians as committed Newtonians and are among a number of medical men in this period sometimes described as 'Newtonian physicians'.[26] It is held that such figures were 'disciples' or 'followers' of Newton who openly advocated for the authority of their master's teachings and appealed to his reputation in support of their own ideas and authority in medical matters.[27] This does much to explain why scholars have spoken of a 'Newtonian' approach to medicine when Newton's writings, unlike Descartes', offer no medical theories and contain little from which to develop a body of medical knowledge – much less from which to derive new treatments.[28] 'Newtonianism' is thought to have been a powerful presence in intellectual societies, clubs, and professional bodies, such as the Edinburgh College of Physicians, through which a 'public science' is said to have emerged that witnessed forceful appeals to Newton's authority.[29] Important developments in medicine and the life sciences in this period are understood to have taken place in an environment where Newton's intellectual authority loomed large.

Yet the idea that Newton's admirers gave dogmatic, ideological allegiance to him is out of step with the spirit and inclination of the times. To take the most famous example, the Royal Society of London, of which Newton was president between 1703 and his death

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[26] 'Newtonian physicians' have their own index entry in Anne-Marie Roos, *The Salt of the Earth: Natural Philosophy, Medicine, and Chymistry in England, 1650–1750* (Leiden: Brill, 2007), 291. See also Sebastián Molina-Bentancur, 'Newtonian Medicine and its Influence in José Celestino Mutis's *General Plan for Medical Studies*', *History of Medicine and Allied Sciences* 75, 3 (2020): 245–69.

[27] For an analysis of how expertise played in Cheyne's authority as a physician and author see Steven Shapin, 'Trusting George Cheyne: Scientific Expertise, Common Sense, and Moral Authority in Early Dietetic Medicine', *Bulletin of the History of Medicine* 77, 2 (2003): 263–97. For a discussion of issues around the label 'Newtonian' see Introduction, esp. 23–33.

[28] For Descartes' engagement with medicine see Gideon Manning, 'Descartes and Medicine', in *The Oxford Handbook of Descartes and Cartesianism*, eds Steven Nadler, et al. (Oxford: Oxford University Press, 2019), 157–77.

[29] See, for instance, Stewart, *Rise of Public Science*, Golinski, *Science as Public Culture*, 1–37; and Roy Porter, 'Medical Science', in *Cambridge History of Science*, Porter, 136–75.

in 1727, had as its motto ‘nullius in verba’. Recognised by the Society today to mean ‘take nobody’s word for it’, the line of Horace from which these words were lifted was later rendered by Alexander Pope as ‘sworn to no Master, of no Sect am I’.[30] Rather than commit themselves to Newtonian dogma, physicians such as Pitcairne, Hepburn, Cheyne, and Keill promoted and admired Newton’s philosophy because they saw it as a model for the reform of medical theory that would correct errors and advance the discipline. They derided their opponents for dogmatism and were derided in turn, making professions of commitment to Newtonianism tantamount to intellectual suicide. Their admiration for Newton was far from the near hero worship it has been made out to be, and was always rooted in a critique of the philosophy upon which they believed medical theory to have rested since antiquity. This critique, centred on the proper approach to physical explanation, demonstrates how Newton’s philosophy energised public debates in this period and shows how his readers drew primarily on his exemplary treatment of causation in their hopes of reforming natural knowledge.

This chapter follows Pitcairne’s reform agenda and the Newtonian science of properties that was central to it from its articulation in Leiden to Edinburgh, where it was defended by Hepburn within a broad debate about the role of theory in medicine. It then traces Cheyne’s own reform ideal, developed from Pitcairne’s vision and articulated in response to his Edinburgh critics, to show how Newton’s superior approach to explanation lay behind both Cheyne’s and James Keill’s hopes for a revolution in the life sciences through advanced mathematics and principles of attraction connected to Newton’s concept of gravitation. It concludes that the role Newton played in the Edinburgh physic debate suggests that these reform efforts had a more constructive longer-term impact than has typically been thought.

Archibald Pitcairne and the Liberation of Physic

Pitcairn’s admiration for Newton has long been recognised by scholars, yet the role Newton’s ideas played in his reform agenda has not been established with clarity. For Anita

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[30] ‘History of the Royal Society’, The Royal Society, accessed 1st Feb., 2023: royalsociety.org/about-us/history. Pope, *First Epistle*, 5.

Guerrini, Newton was central to Pitcairne's agenda but in her account he led a quixotic effort to fulfil the promise of applying Newtonian science to medicine.[31] Due to the centrality of Newton's matter theory to her account, she drew particular attention to the stopover Pitcairne made to Cambridge en route to Leiden, where he met Newton and acquired a copy of the apparently seminal short essay, 'De Natura Acidorum' (On the Nature of Acids). However, Guerrini argued that, following this encounter, and 'despite his professed intentions', 'Pitcairne did not develop a Newtonian theory of medicine'.[32] It is unclear why Pitcairne failed in his apparent endeavour and Guerrini's account leaves unanswered questions about his true intentions and the role of Newtonian natural philosophy in his thought.

More recently, Jip van Besouw and Steffen Ducheyne have examined Pitcairne's engagement with Newton's approach to causation in a survey of Newton's early readers, but did not situate his reading fully in the context of his ambition to reform medicine. They argued that he was alone among the *Principia*'s British readers prior to 1713 in asserting that 'the aim of Newton's mathematical approach was to discover the forces and properties of bodies'. In their view, though, Pitcairne did not think the objects of this discovery to have causal status, for he read Newton as having 'discarded causes from natural philosophical investigation altogether', understanding Newton's philosophy as 'antithetical to approaches based on hypotheses because of its neutrality with respect to the cause of gravitation'.[33] Though Newton's approach to causation was indeed central to Pitcairne's understanding of his philosophy as a model for the discovery of forces and the properties of bodies, it will be argued here that – even if one could remain a natural *philosopher* in this period without seeking to explain natural phenomena – Pitcairne neither thought that

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[31] Guerrini, 'Newtonian physiology' argues that both Pitcairne and Cheyne wished to develop a new medical theory stemming from Newton's treatment of 'short-range forces', which 'had obvious implications for physiological explanation' in that it 'related to animal function, such as fermentation, putrefaction, and the chemical production of heat' (248).

[32] Guerrini, 'Pitcairne and Newtonian Science' observes that when 'Bellini and Newton disagreed, Pitcairne did not invariably choose Newton, at least not the Newton of "De natura acidorum"' (75) and, having 'dismissed Descartes in his Leiden lectures', Pitcairne 'did not fully welcome Newton in his place' (79). This argument may have been influenced by Schofield, *Mechanism and Materialism* and Thackray, *Atoms and Powers*, which characterised Newtonian matter theory as only a partially realised desideratum among eighteenth-century British scientists.

[33] Van Besouw and Ducheyne, 'Characterisations', 368.

philosophers should eschew causation altogether nor read Newton as having done so. When his views are set within the context of his reform programme and the debate it fuelled it becomes evident that Pitcairne was chiefly concerned to address the problematic approach to causation that physicians had followed through the ages and continued to follow in his own time.

Pitcairne's brief stint in Leiden not only provided him with a platform to advance his views but initiated an intense period of literary activity focused on medical issues. Due to the relatively sorry state of Scotland's printing industry at this time, the period he spent in the Netherlands may have been a boon to this productivity, with some of his works first published in Leiden and his collected works first appearing in Rotterdam in 1701.[34] The Dutch Republic was of considerable importance to Scottish intellectual life in this period and Leiden was a renowned centre of medicine that attracted students from across Europe.[35] Among the attendees at Pitcairne's lectures were students who would go on to become influential figures in Britain, such as Richard Mead, who later counted Newton among his patients, and John Monro, who helped establish the Edinburgh medical school in the 1720s – and whose son, grandson, and great-grandson successively occupied the anatomy professorship there until 1846.[36] It is also possible that Pitcairne taught Hermann Boerhaave, who was a Leiden student at the time and had recently begun to study medicine.[37]

Pitcairne's inaugural lecture is particularly important for understanding the connection between his reform ideas and Newton's philosophy for references to Newton are few and far between in his extant corpus. It is possible to determine the significance of Newton to Pitcairne's thinking, however, by connecting the scant explicit engagement with Newton in his works to his conception of the 'method of astronomers' (which, in this

[34] For Scotland's printing industry see Thomas Ahnert and Martha McGill, 'Scotland and the European Republic of Letters around 1700', in *Scottish Philosophy in the Seventeenth Century*, Broadie, 73–93.

[35] For the Dutch influence on Scotland's intellectual scene see Esther Mijers, *'News from the Republick of Letters': Scottish Students, Charles Mackie and the United Provinces, 1650-1750* (Leiden: Brill, 2012); and Raffe, 'Intellectual Change before the Enlightenment'.

[36] For Pitcairne's students see Guerrini, 'Tory Newtonians', 303.

[37] John C. Powers, *Inventing Chemistry: Hermann Boerhaave and the Reform of the Medical Arts* (Chicago, IL: University of Chicago Press, 2012), 21–3.

context, strongly implies he had the *Principia* in mind) and to his criticism of both Descartes' philosophy and the relationship of philosophy to medicine more generally over time.

Leiden was an appropriate place to launch an attack on Descartes' philosophy, and Pitcairne would most likely have found a receptive audience for his critique of Cartesian medicine there. Cartesian philosophy had been controversial since the 1640s and the theological faculty there supported a prohibition on teaching and reading Descartes in 1656 and later issued a condemnation of Descartes' thought in 1676.[38] This did not of course prevent any engagement with Descartes' ideas but the university actively sought professors who would teach alternatives, such as the professor of philosophy Wolfred Senguerd. In this environment, some former admirers of Descartes, like the professor of physics Burchard de Voider, abandoned the teaching of Cartesian natural philosophy.[39]

Pitcairne occupied one of two professorships in medicine, the other being held by Charles Drélincourt, whose teaching emphasised empiricism over such theoretical schemes as those developed by Descartes. Drélincourt focused much of his activity on the study of ancient texts, such as those ascribed to Hippocrates.[40] He was in fact responsible for teaching the theory of medicine, but soon after his arrival Pitcairne requested permission to teach theoretical medicine rather than the 'praxis' ordinarily the remit of the chair he had just obtained. Pitcairne acquired the Leiden professorship in 1691 with the support of Gilbert Burnet, Bishop of Salisbury and James Dalrymple, Viscount Stair, both former residents in the Dutch Republic, and his acceptance of the post was communicated on his behalf by Stair via the professor of theology, Jakob Trigland.[41]

Pitcairne was a practicing physician at the time but had so far tried and failed to get an academic career off the ground in Scotland. His medical education seems to have begun in Paris around 1675, where he travelled for his health after graduating from the university

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[38] The States of Holland forbade philosophical discussion of scripture and ordered that 'questions from the philosophy of Descartes... be left aside' – quoted in Thomas Arthur McGahagan, 'Cartesianism in the Netherlands, 1639–1676: The New Science and the Calvinist Counter-Reformation' (PhD thesis, University of Pennsylvania, 1976), 303. See also Andrea Strazzoni, *Dutch Cartesianism and the Birth of Philosophy of Science: From Regius to 's Gravesande* (Berlin: De Gruyter, 2019).

[39] Powers, *Inventing Chemistry,* 19–23.

[40] Powers, *Inventing Chemistry*, 24–5.

[41] G. A. Lindeboom, 'Pitcairne's Leyden Interlude Described from the Documents', *Annals of Science* 19, 4 (1963), 279–80.

in his native Edinburgh in 1671. He was apparently persuaded by some Scottish medical students in France to abandon law in favour of medicine and he subsequently obtained an MD from Rheims in 1680. After returning to Edinburgh, he became a founder member of the Royal College of Physicians in 1681, alongside the naturalist Robert Sibbald, with whom he then attempted to establish a medical faculty at Edinburgh in 1685. Pitcairne was supposed to serve as one of its professors but the town council did not provide the necessary backing for the initiative to get off the ground.[42]

Notwithstanding the importance of his time on the continent, Pitcairne developed the ideas behind his reform programme in Scotland, where they would later be put to the test in debate with his peers. He also developed a reputation for controversy.[43] In 1683, he issued a challenge to the acting professor of mathematics at Edinburgh, John Young, whose failure to meet it led to his replacement by David Gregory. At this time he began to publish, first with *Solutio Problematis de Historicis, seu, De Inventoribus Dissertatio* (Solution to the Problem of Historical Issues, or, Dissertation on Inventors, 1688), in which he criticised the notion that ancient authors, particularly Hippocrates, Aristotle, and Galen, were aware of Harvey's discovery of the circulation of blood. In it he outlined a scheme by which to evaluate 'inventors' and advanced the claim that Gregory, rather than Newton, had discovered the binomial theorem.[44] Pitcairne originally intended to publish another essay alongside the *Solutio*, 'Epistola Archemidis ad Regem Gelonem' (Archimedes' Letter to King Gelon), which has been read predominantly as an anti-Presbyterian satire but, in criticising philosophical sectarianism, also reflected concerns he soon raised in his inaugural lecture.[45]

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[42] Anita Guerrini, 'Pitcairne, Archibald (1652–1713), Physician', in *Oxford Dictionary of National Biography*, 2004, accessed 1st Feb., 2023: doi.org/10.1093/ref:odnb/22320.

[43] For Pitcairne's religious views see Michael Hunter, 'Pitcairneana: An Atheist text by Archibald Pitcairne', *The Historical Journal* 59, 2 (2016): 595–621; and Alasdair Raffe, 'Archibald Pitcairne and Scottish Heterodoxy, c. 1688–1713', *The Historical Journal* 60, 3 (2017): 633–657. For his political views see Guerrini, 'Tory Newtonians'; Schaffer, 'Glorious Revolution'; and Friesen, 'Scottish Origins'.

[44] Archibald Pitcairne, *Solutio Problematis de Historicis, seu De Inventoribus Dissertatio* (Edinburgh: 1688). The section on binomial theorem was subsequently dropped in the version included in his collected works.

[45] Later published as Archibald Pitcairne, *Epistola Archimedis ad Regem Gelonem, Albæ Græcæ Reperta* (Edinburgh: 1710). See Guerrini, 'Pitcairne and Newtonian Medicine'; David E. Shuttleton, 'Bantering with Scripture: Dr Archibald Pitcairne and Articulate Irreligion in Late Seventeenth-century Edinburgh', in *The Arts*

Though its printed title declared the lecture to have 'proved' physic liberated from 'sects of the philosophers', Pitcairne actually argued that medicine continued to be tyrannised by false, sectarian philosophy and denied the freedom to advance.[46] He claimed that superficially persuasive philosophy had dogged the discipline since antiquity:

> Miserable must the view of our Republic appear in those Days, when all was over-grown and choaked with Perplexities of Words and Things: Men of Parts and Genius were obliged to submit to a Tyranny over their Reason, and bear the most insolent internal Slavery, to give up a vast Stock of Human Literature, the Toils of long and sever [*sic*] Studies, to be corrupted and debauched by the Leaders of Sects.[47]

Yet he also claimed that, while learning had been reformed more generally and the hold of philosophical sectarianism over other disciplines released, physicians have in modern times scarcely managed to move the discipline forward:

> Our Ancestors were blamed for introducing a Heap of Jargon into our Art, of Things unknown to our Senses, and consisting entirely of Conjectures, and, in one Word, for too great a Fondness to Sects of Philosophy: We who have shook off this Weight of Stupidity, have, even we, been much more successful in the Improvement of our Science? Not at all.[48]

Chief among the corruptions deriving from the tendency toward sectarianism and false philosophy are 'jargon' and 'conjecture', empty terminology and speculative claims that result in a confused and obscure 'perplexity of words and things'.

Drawing his audience's critical attention to the example of glandular fermentation, Pitcairne proposed that 'we cultivate Physic, not under the Disguise of such Fictions' as the unverifiable notion of fermentation 'but upon the Trials of Experience'.[49] If this was not enough of a hint that he had Descartes and his admirers in mind, who were associated with

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of 17th-century Science, eds Claire Jowitt and Diane Watt Hunter (Aldershot: Ashgate, 2002), 72–88; Hunter, 'Pitcairneana'; and Raffe, 'Pitcairne and Scottish Heterodoxy'.

[46] The full title was 'An Oration Proving the Profession of Physic Free from the Tyranny of Any Sect of Philosophers', as rendered in Pitcairne, *Whole Works*.

[47] 'Oration', 14.

[48] 'Oration', 15.

[49] 'Oration', 17.

the explanation of bodily functions by way of fermentation, Pitcairne remarked critically on the pursuit of the 'Physical Cause or a Mechanical Origin' of medical disorders, which the physician need not ever determine in order to actually treat patients.[50] Mechanical medicine was not presented as an ideal but characterised as a vehicle for speculative accounts of bodily functions, rooted in processes for which there may be terminology but no empirical evidence.

Pitcairne's 'method of astronomers' was intended to remedy the unempirical bent typical of Cartesian mechanism, for he claimed astronomers 'never take up, and adopt into their Science such Opinions as are grateful to the Vulgar, or generally received by Orators'. In other words, astronomy had never corrupted itself with conjectural, superficially plausible philosophy.[51] What he didn't say explicitly, perhaps not needing to, was that astronomers and physicians alike ought to adopt opinions into their science only so far as they accord with empirical observation and mathematical rigour. With that thought likely in his audience's mind, he claimed that the 'business of a physician' is to 'weigh and consider the powers of medicines and diseases as far as they are discoverable by their operations', before reducing them to 'laws' and thus determining 'mathematical causes'.

In his lectures at Leiden over the course of the following year, Pitcairne was not explicitly hostile to Cartesian medicine *per se* but does seem to have indicated its limitations. He advised students 'diligently to consider the Principles of the *Cartesian* Philosophy, and to compare them with those of [the ancient atomist] *Democritus*, so far as Geometry will conduct them, especially that Part of it whereby are demonstrated the Laws of Motion'. He claimed that 'what they shall find most conformable to those Laws' – apparently Newton's *leges motus* not Descartes' *leges naturae* – 'may be reserved as of great Service in the true Theory of Physick'.[52] Whatever Pitcairne's assessment of Descartes' contribution to medicine was exactly, he was certainly committed, first and foremost, to a theory of physic grounded in empirical investigation and guided by mathematical certainty.

The final section of Pitcairne's inaugural lecture, which went on to form the basis of a short text published soon after, outlined 'an Instance of the Usefulness of Mathematics

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[50] 'Oration', 21–2.

[51] 'Oration', 11.

[52] [Archibald Pitcairne], *The Philosophical and Mathematical Elements of Physick*, trans. John Quincy (London: 1745), 7.

in Physic'. He took the example of a certain eye disorder and argued that its hypothetically assigned cause by way of corpuscles swimming on the eye's surface could be disproved by applying what has been 'demonstrated by Writers of Optics'. He observed that the laws of optics demonstrate that the symptoms could never follow from the supposed cause, due to the simple fact that the images before the sufferer's eyes would not appear as they do from the presence of corpuscles at such proximity.[53] Given this interest in applying mathematics to medical problems, it is no surprise that Pitcairne admired Newton's mathematical abilities. However, it does not necessarily follow that he intended to replicate Newton's mathematical practice in his medical works. He described Newton as one of the 'great Improvers of Geometry to so high a Pitch' and even composed a Latin poem in which Newton is lauded as a 'prince of the mathematicians'. In the poem he wished Newton as long a life as Nestor, the mythical king of Pylos, and claimed Newton's greatness to have outgrown that of the quasi-mythical ancient philosopher Pythagoras (perhaps *c*. 6th C. BCE) in the same proportion as the size of Britain exceeds that of Pythagoras' native island of Samos.[54]

Yet Pitcairne's debt was clearly, in his own mind at least, to an Italian tradition of mathematical medicine, for he most frequently drew on the works of Santori, Borelli, and Bellini, and it is unlikely that Pitcairne considered himself to have in any way replicated the mathematics of the *Principia* in the field of medicine. His use of mathematics typically consisted of a limited measure of quantification and the determination of proportional relationships between theoretically measurable quantities, such as the speed and mass of bodily liquids, and the spaces through which they travel in the body. Such quantification might establish relationships through which to determine the healthy balance between these measurable quantities but could also, via fairly simple equations, be used to investigate the forces that power bodily processes, such as those responsible for the circulation of blood.

In his *Dissertatio de Circulatione Sanguinis per Vasa Minima* (Dissertation on the Circulation of the Blood through the Smallest Vessels, 1693), for example, Pitcairne attempted to capture the circulation of blood in a simple formula in support of the claim

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[53] [Pitcairne], *Elements of Physick*, 19.

[54] Pitcairne, *Whole Works*, 56. John MacQueen and Winifred MacQueen (eds and trs), *Archibald Pitcairne: The Latin Poems* (Tempe, AZ: ACMRS, 2009), 178–9.

that the ‘heat’ of blood is the product of its velocity and the distance travelled through the veins. For this he produced the equation Ag + Ep/q + p, where A and E are apertures of the pores required for entry and exit, respectively, of corpuscles through the veins. He took bodily fluids to be composed of corpuscles and q and p to represent the numbers of times these corpuscles will pass in and out, respectively, of the pores. Believing that this relationship disproves a contemporary ‘sieve theory’ of circulation, where some larger bodies will not pass and all smaller bodies will, Pitcairne considered his own explanation, that pores must be circular and identical in figure to the corpuscles passing through them, given mathematical support.[55]

In that work Pitcairne declared his hope, having referenced Newton’s contributions to geometry, that

> by the Assistance of the Principles demonstrated by that Great Man [i.e. Newton], the Powers and Properties of Bodies serviceable to Medicinal Uses and the Comfort of Mankind, may be discovered with greater Ease, and reduced to a greater Certainty.[56]

He went on to clarify the role mathematics played in his vision of a reformed discipline of medicine:

> Nor do I disown that the Art of Physic pleases me not so on any other Account, as its being capable of bearing the Method of Geometry in the same Manner, as all those other Arts which determine the Powers of Bodies; so that I cannot help pitying those who accuse the Nature of Bodies as a mean ignoble Subject, since the Geometricians demonstrate, in the most convincing Method, such a beautiful and so infinite a Number of their Properties.[57]

Newton’s significance was as the practitioner of a philosophy that applies geometry to physics in order to discover the ‘powers and properties of bodies’. Clearly, Pitcairne had in mind universal gravitation, but it is therefore not the fact of gravitation that interested him

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[55] Pitcairne, *Whole Works*, 46–7. According to the sieve theory q would be infinite and the result therefore absurd (Q.E.D.). Pitcairne’s calculation has been considered in the light of modern statistical methods in Steven M. Stigler, ‘*Apollo Mathematicus*: A Story of Resistance to Quantification in the Seventeenth Century’, *Proceedings of the American Philosophical Society* 136, 1 (1992): 93–126.

[56] Pitcairne, *Whole Works*, 56.

[57] Pitcairne, *Whole Works*, 56–7.

as much as how Newton's treatment of gravitational force might serve as a model for the philosophy of medicine. Pitcairne was actively engaged in trying to determine how bodily powers account for bodily functions ,and it is therefore Newton's 'mathematical principles of natural philosophy' that, in his mind, may give 'assistance' to the physician, as they may do 'all other arts which determine the powers of bodies'.

For Pitcairne, Newtonian philosophy was superior in its approach to an ancient tradition of philosophy, carried forward by Descartes and his admirers, that pursues explanation by way of speculative processes, such as fermentation, that cannot themselves be detected through observation and, due to their purely qualitative nature, cannot be subject to the certainty of mathematics. In *Dissertatio de Curatione Febrium Quae per Evacuationes Instituitur* (Dissertation on the Cure of Fevers by Evacuation, 1695) Pitcairne, considering how 'many different Liquors [i.e. fluids]' come to be 'secreted out of the same Blood', observed that

> The Ancients attributed it to a different Attraction; which Opinion may be better illustrated now by such as understand *Sir Isaac Newton*'s Philosophy, than it cou'd then be by them. Since that Time a great many Physicians having thrown out the Word *Attraction*, wou'd have this performed by Ferments, which they supposed to be different in the different Glands or Strainers of different Kinds.[58]

Pitcairne was not fighting the 'battle of the books' on the side of the moderns.[59] Any philosophical sect was corrupting for imposing a flawed model of reasoning on to the discipline. In this passage, he was not claiming that Newton provided an account of attraction that may resolve the question at hand about the secretion of bodily fluids. Rather, he meant that those who 'understand' Newton's philosophy may better grasp what some ancient authors really should have been talking about when they spoke of 'attraction'.

[58] Pitcairne, *Whole Works*, 196–7.

[59] As suggested in Guerrini, 'Pitcairne, Archibald'.

‘Mathematical Medicine’ in the Edinburgh Physic Debate

The ideas Pitcairne advanced in these publications convinced some but made opponents of others. Ironically enough, his attack on philosophical sectarianism acted as fuel to the flames of factional strife back in Edinburgh. In the summer of 1693, he shocked the Leiden governors by abruptly resigning his chair and returning home, initiating a protracted dispute over pay that was not resolved until after his death. It is not known exactly what lay behind this move. It may have been influenced by his decision to marry Elizabeth Stevenson later that year, whom scholars have noted may have been reluctant to leave Scotland, though it may simply have been Pitcairne’s own preference to return.[60] Elizabeth was the daughter of Archibald Stevenson, another founding member of the Royal College of Physicians whom Pitcairne made alliance with as the organisation split into hostile camps. Rival groupings seem to have first emerged around Stevenson and Sibbald during the 1680s, with the latter blaming the ‘malice’ and ‘faction’ of Stevenson’s side for the 18-year delay in the College’s publication of *Pharmacopeia Edinburgensis* (1699). Disagreements over the process of examination for entry to the College boiled over in 1695 in the case of Edward Eizat, who sought exemption from examination on account of already having graduated MD, into what W. B. Howie has described as ‘anarchy’.[61]

Eizat’s anonymous authorship of the satirical and ill-mannered *Apollo Mathematicus*, a direct attack on Pitcairne and the ideas contained in the Leiden address, the *Dissertatio de Circulatione Sanguinis*, and the *Dissertatio de Curatione Febrium*, prompted George Hepburn to publish his own equally impolite riposte, *Tarrugo Unmasked*. Hepburn’s attack on Eizat and defence of Pitcairne’s ideas differed in one crucial respect from Eizat’s: it bore the author’s name on its title page. For this reason, it led to Hepburn’s expulsion from the College. The publication was swiftly censured and, before Hepburn himself appeared for a summons, Pitcairne delivered a partisan ‘report’ attacking the conduct of those presiding over recent College business, which was itself condemned as ‘a calumnious, scandalous, false and arrogant paper’.[62] Pitcairne and Stevenson were ejected along with Hepburn, but

[60] Lindeboom, ‘Leiden Interlude’, 280–2. Guerrini, ‘Pitcairne, Archibald’.

[61] Howie, ‘Riot in the College’, 271–2.

[62] Quoted in Howie, ‘Riot in the College’, 273.

while the two former were eventually readmitted following a general amnesty issued in 1703, Hepburn left the College for good.

Tarrugo Unmasked has received curiously little attention from scholars interested in this debate and in Pitcairne's 'Newtonian' agenda. This is curious because Hepburn engaged more explicitly with Newton's example in the work than Pitcairne did in his whole extant corpus.[63] Even if, as has been supposed, Hepburn was simply Pitcairne's mouthpiece, the work warrants serious examination, as does Eizat's satirical attack on Pitcairne as a 'mathematical Apollo', after the Greek god associated with healing. These texts and the dramatic events that followed them have been considered by historians in the context of Pitcairne's controversial Newtonian reform programme, but the debate they sparked has tended to be seen as one over the validity and desirability of mathematicising medicine in conscious imitation of Newton's *Principia*.[64] Eizat did pour scorn on the pretensions of Pitcairne's mathematical approach, but his work also contained a critique of Pitcairne's general approach to the philosophy of medicine that has hitherto escaped scholars' notice.

For Andrew Cunningham, the debate over mathematical medicine was part of a 'fever dispute' in Edinburgh which pitted admirers of Newton against those of Thomas Sydenham, the so-called 'English Hippocrates'.[65] Cunningham presented the debate over fever itself as a proxy for one more general between the Sydenhamites, committed to a mechanical 'Cartesian paradigm', and the Newtonians, for whom medical theory ought to be based on 'the twin supports of mathematics and an anatomy in which measurement was essential'.[66] The chief figures in this account are Pitcairne and a new member of the Royal College of Physicians, Andrew Brown. The positions they adopted were taken to be representative of, in the case of Brown, an 'experimental, empirical approach' (associated

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[63] Neither Cunningham, 'Sydenham versus Newton' nor Guerrini, 'Pitcairne and Newtonian Science' discuss the text in any depth. It is given slightly more attention in Stigler, 'Resistance to Quantification'.

[64] See works cited in footnote 10; and Stigler, 'Resistance to Quantification'.

[65] For the origin of this appellation see Peter Anstey, 'The Creation of the English Hippocrates', *Medical History* 55, 4 (2011): 457–78. In Cunningham's account, Edinburgh was a 'sleepy backwater' in which Newton's and Sydenham's 'followers' were 'proselytizing for converts' to their two 'revolutionary' approaches to medicine (71).

[66] Cunningham, 'Sydenham versus Newton,' 79 and 93.

with Sydenham and Whig politics) and, in that of Pitcairne, a 'physiological approach' (associated with Newton and Jacobite politics).[67]

However, the examples of Newton and Sydenham do not have central places in the texts through which this debate was played out. By situating the work of Brown, Eizat, and Hepburn in the context of Pitcairne's reform programme, it is easier to see what exactly the problem might be with the 'mathematical medicine' Pitcairne and his supporters were thought to have advanced. Moreover, when Newton's *philosophy*, rather than his science, is taken to be the focus of engagement with him it becomes clearer what relevance Newton had to the issues under discussion. Contributors argued about the role of philosophy in medicine and disagreed (though not always explicitly) about what value Newton's philosophy may have for physiology. At issue was not just what kind of philosophy may best aid the advance of medicine but whether any kind of medical theory was desirable at all. The appearance of new recommendations for the treatment and understanding of fever were flashpoints, but the debate itself was essentially over the theory and practice of physic more broadly.

All sides agreed that false philosophy had retarded the progress of the discipline since antiquity, but the critique of medical theory varied significantly between authors. Brown's *Vindicatory Schedule* (1691), a work defending the author's own treatment of fever, appears to have acted as a spark for the debate. It lauded Sydenham's 'most effectual method of cureing [*sic*] continual fevers' in its full title, but nevertheless also offered a 'new hypothesis of fevers, for establishing this method' that drew on and supported features of several theoretical medical schemes.[68] This is notable because Brown understood Sydenham as having practiced a patient, empirical methodology that represented the surest way of advancing the discipline, which might suggest abstract theory was undesirable. Brown claimed that such an experimental approach had only recently begun to loosen the grip of Galen, who liberated his own age from 'the immortal *Hippocrates*', but only for those ideas to be replaced with Galen's own, establishing 'a *Theory* agreeable to

[67] Cunningham, 'Sydenham versus Newton', 95–6. Cunningham describes Newton, without reference to evidence, as Pitcairne's 'hero' (88) but does not indicate where Newton or his ideas explicitly feature in the debate.

[68] Andrew Brown, *A Vindicatory Schedule; Concerning the New Cure of Fevers: Containing a Disquisition Theoretical and Practical, of the New and Most Effectual Method of Cureing Continual Fevers, First Invented and Delivered, by the Sagacious Dr. Tho: Sydenham* (Edinburgh: 1691).

the *Philosophy* of his time, that pester [*sic*] not only *Medicine*, but *Theology* likewise, and that to this day'. The tyranny of Galenic physiology was only now being thrown off 'with Discoveries that were not only reasonable, but demonstrably [so] by our Senses'.[69]

However, Brown was not opposed to medical theory *per se*. His own hypothesis was advanced with reference to personal experience, but he believed it supported the view that the '*animal œconomy* is founded in a *Mechanick* structure, to witt [*sic*], in matter in motion'. This structure is driven by a 'principle', which he noted Hippocrates had called 'the first *Impellent*, or *Impetum faciens*', the Flemish physician Jan Baptist van Helmont (d. 1644) called 'the *Archeus'*, and 'common' people call 'spirits'.[70] In Brown's case, Sydenham's empiricism seems to have inspired an observational approach to the discovery of active principles that power bodily functions in order to explain the origins of illness and, thus, guide treatment. Brown's work was 'vindicatory' because his patient, James Crichton, 2nd Viscount Frendraught, had died following a fever (in 1674–5), so the work's principle aim was to justify Brown's procedure. His hypothesis – that 'the fundamental cause of most, if not all, Diseases, seemes [*sic*] to be the grossness of the Humores, causing their slowness, making soon bad Impressions upon the functions' – was taken to support his favoured treatment for fever: a course of bleeding, purging, and, finally, a paregoric (tincture of opium).[71]

Brown's work gave rise to a number of anonymous pamphlets critical of his methods, including a work by another physician, James Forrest, in 1694 that rejected Brown's 'new' method as inferior to the 'old' course of procedures: bleeding, vomiting, incisions, and sweating.[72] Brown defended himself against Forrest later that year, responding to criticism of his decision to write in English by publishing a Latin revision of his case 'augmented by mechanical constructions from the principles of Bellini'.[73] Pitcairne's *Dissertatio de Curatione Febrium* was first published the following year (early

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[69] Brown, *Vindicatory Schedule*, [1–3].

[70] Brown, *Vindicatory Schedule*, [28]. For Cunningham, 'Sydenham versus Newton', these remarks indicated Brown's commitment to Cartesian medicine.

[71] Brown, *Vindicatory Schedule*, [30].

[72] James Forrest, *A Brief Defence of the Old and Successful Method of Curing Continual Fevers; in Opposition to Doctor Brown and his* Vindicatory Schedule (Edinburgh: 1694).

[73] Andrew Brown, *De Febribus Continuis Tentamen Theoretico-practicum* (Edinburgh: 1694). The full tile offered the alternative: 'seu Nova Febrium Hypothesis Mechanica Adaucta ex Principiis Bellini Constructa'.

1695), but as he did not propose a course of treatment his concern was mostly with how fevers ought to be understood. He did not side with Forrest and only rejected Brown's course of treatment implicitly, Pitcairne's case being that fevers are caused by blocked passages through which vital fluids must pass, so that the most effective cure is to be achieved through evacuation. Pitcairne engaged mostly with medical theory, and it was therefore reasonable for Eizat to subsequently criticise Pitcairne on philosophical grounds.

Though Eizat's position has been elided with Brown's due to his opposition to Pitcairne and positive assessment of Sydenham, the two authors were far from aligned on fundamental questions about medical theory. While Brown observed that Hippocratic and Galenic theoretical orthodoxies had negatively impacted the advancement of the discipline, Eizat would have rejected much of what Brown had to say about physiology because he criticised the application of philosophy to medicine altogether. Eizat claimed that philosophy had 'spoiled all' and he cast it as 'the Rock on which all the Physicians has [*sic*] split'. He lamented that physicians had 'divided into as many Sects as the Philosophers, every one setting up a different Hypothesis, according to the Philosophy he valued most, whether the Platonick, Peripatetick, or Epicurean, &c. and now of late the Cartesian', characterising philosophy as an essentially sectarian pursuit and suggesting that no philosophical system can be of use to medicine.[74]

What Eizat says of Newton, therefore – 'what this great Man may do by his Principles for the advancement of Medicine, I know not' – is not so much a comment about Newton as it is about philosophy. In a preceding passage Eizat accused Pitcairne of abject intellectual partisanship, claiming 'Philosophical Physicians' like him 'fall down before those Idols, or Nothings (for an Idol is nothing) and worship not the Works of their own Hands, but the Spawn and deformed Brood of other Mens [*sic*] Brains'.[75] He poured scorn on 'the Doctrine of Physical Causes' and therefore appears to have rejected Pitcairne's argument that Newton's approach offers a model for seeking 'mathematical causes' in favour of useless 'physical causes'.[76] The Leiden lecture in which he made this case was printed by Pitcairne's critics in Edinburgh in 1695, complete with a hostile preface and postscript attacking Pitcairne's ideas.

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[74] [Eizat], *Apollo Mathematicus,* 27

[75] [Eizat], *Apollo Mathematicus*, 94–5.

[76] [Eizat], *Apollo Mathematicus,* 27.

Eizat may have been behind that effort, and may also have been the author of *Apollo Staticus* (1695), an English translation of Pitcairne's *Dissertatio de Curatione Febrium* which bore a critical preface declaring that, by reading Pitcairne's text, 'any Body may see the vast difference that is between one that takes his Observations from Nature, and one that takes his marks by the Moon, that is between a Rational and Mathematical Physician'.[77] This would square with the basis for Eizat's attack on Pitcairne as a 'mathematical Apollo', for Eizat believed that only a patient, empirical approach like that of Sydenham could help cure the sick. Eizat believed 'nothing can be of more fatal consequence in the practice of Medicine' than Pitcairne's 'system of *Mathematical Medicine*', which was an 'idle Notion and vain Conceit'. He drew attention to the lack of certainty among mathematicians themselves and the folly of waiting in vain for consensus among them:

> since one of the charactaristick [*sic*] Marks of these Principles is, That they must be such about which the Mathematicians do agree, why are they so cruel as not to agree, and give us a printed List of them, that we may not practise any more in the Dark, and suffer Men to die after the old fashion?[78]

Beyond the lack of certainty among mathematicians themselves, Eizat categorically opposed Pitcairne's approach on the grounds that 'Any Body that understands the very first Principles of Medicine, knows that it is an establish'd Maxime among Physicians, *A juvantibus & nocentibus optima petitur Indicatio* [i.e. the best evaluation is that sought from what helps and what harms]'. This, he affirmed, 'for ever debars' medicine 'from the benefit of these Principles the Doctor [i.e. Pitcairne] pretends to find out by this Astronomical, or rather Lunatical Method'.[79]

Hepburn's defence of 'the Doctor' addressed both Eizat's argument against the application of mathematics to medicine in general and his dismissal of the value of Newtonian philosophy in particular. Its title referred to Thomas St Serfe's play, *Tarugo's Wiles* (1668), and probably indicated Hepburn's intention to 'unmask' a figure involved in the attack on Pitcairne who somehow resembled the high-born Tarugo, who in the play

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[77] [Archibald Pitcairne], *Apollo Staticus* (Edinburgh: 1695), [6].

[78] [Eizat], *Apollo Mathematicus*, 44–5.

[79] [Eizat], *Apollo Mathematicus*, 47.

disguises himself as the master of a coffee house to escape a gang of pursuers.[80] Hepburn justified the application of mathematics to medicine on the basis that the human body is part of the natural world and therefore within the remit of natural philosophy, for which mathematics has unquestionable utility. He declared that ‘we should have brought Medicine to an incredible perfection, if Mathematical methods had been used’ earlier, because ‘Mathematicks are the Theory of the effects produced in Nature by the means of Figure, Bulk, and Motion, which effects and events comprehend those also which appear to us as Diseases and the Actions of Remedies’.[81] He observed that, ‘now that the Temple of Geometry is built, the Mathematicians have both Leisure and Inclinations to assist their Neighbours’ in other disciplines, ‘and to lend them Propositions and Truths useful in bringing their Works to a greater perfection’. ‘Mr. *Newton*’, Hepburn explained, ‘has effectually helped the Philosophers; and *Borrelli* [*sic*], but above all *Bellini* has given great light in Medicinal matters, only by the help of Mathematicks’.[82]

For Hepburn, Borelli’s and Bellini’s work showed that medicine ‘must be beholden’ to mathematicians like Newton and the ancients Euclid, Apollonius of Perga, and Archimedes (all *c*. 3rd C. BCE). To support his case he echoed Pitcairne’s appeal to the ‘method of astronomers’. In astronomy, some ‘have attempted to make a Systeme, as they called it, and to draw too large consequences’ without the requisite observational data, while others, ‘for want of Geometry, that is, Reason sufficient and judgement how to use and compare the observations, have err’d and draw’n wrong consequences’. Newton, in contrast, was able to avoid such consequences ‘by bringing sufficient strength of Geometry, or right reason to be applyed to the sufficient observations’.[83] According to this astronomical model, mathematical medicine is not a radical alternative to the empiricism associated with Sydenham but the extension of an experimental approach directed toward the collection of observational data.

The approach suggested by Hepburn offered an alternative to the speculative philosophy of past ages still practiced by some. He characterised Hippocratic medicine as ‘the humor of building Medicine on the Hypothesis of Hot and Cold’, and contrasted ‘Natural Philosophy mathematically handled’ with the philosophies of Aristotle and

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[80] Thomas St Serf, *Tarugo’s Wiles: Or, the Coffee-House, A Comedy* (London: 1668) – first performed in 1667.

[81] *Tarrugo*, 2–3.

[82] *Tarrugo,* 2.

[83] *Tarrugo,* 9.

Descartes. They made the 'both equally false and useless' claim that nature operates by way of certain fundamental elements, which they established through speculation rather than experimentation.[84] Hepburn lamented the prevalence of false philosophy in his own time, observing that 'those who reject *Aristotles* philosophy as useless, hurtful to Medicine, admit *Hippocrat's* or *Des. Carte's* that is equally prejudical and uncertain [*sic*]'.[85] To illustrate the distinction between Newton's philosophy and the false philosophy beloved by his peers, he took the example of a material ether, or 'materia subtilis'. As a physical body subject to the laws of motion, Newton showed that a material ether, though invisible, 'must have weight proportional to the quantity of its matter'. Hepburn then explicitly drew a parallel between Pitcairne's work on bodily fluids – citing his treatment of the 'liquidum nervorum' (i.e. *liquidus nervorum*, literally 'fluid of the nerves') – and Newtonian celestial mechanics, indicating how Newton's treatment of universal gravitation offered the physician a superior model of reasoning about unseen powers and processes.[86]

Developing Pitcairne's remarks on causation, Hepburn quoted Newton's preface to the *Principia* in support of his claim that 'Mr. Newton thinks that physical causes are yet unknown, and are like to remain unknown till wee [*sic*] use a Mathematical method for finding them'.[87] He called the cause 'which is mainly requir'd' in medicine the 'efficient cause'. By this he meant that the physician ought to establish only what gives rise to the physical processes or changes relevant for understanding the body and developing treatments. Though Pitcairne had contrasted 'physical causes' (which otherwise might be called 'efficient causes') with 'mathematical or medical causes', he did so to reject the speculative pursuit of physical origins of no utility to the physician. Hepburn understood this quite well and, citing the Leiden 'Oration', characterised Pitcairne's position as having 'advised the Phisicians [*sic*] in their reasonings to abstain from the Sectarian Philosophy and lay aside the Investigation of Physical Causes after the manner hitherto used by the Sects'.[88]

To illustrate the alternative to unmathematical 'common Philosophy taken from a Sect', Hepburn turned from Pitcairne to Bellini. The latter had, 'from the circulation

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[84] *Tarrugo,* 11 and 14.

[85] *Tarrugo,* 14.

[86] *Tarrugo,* 21–2.

[87] *Tarrugo,* 14.

[88] *Tarrugo*, 15.

observed by Dr William Harvey', 'taught when, where, and in what case or disease blood is to be let', as well as 'how much of it at a time, and what are the effects and consequences of letting blood'.[89] Hepburn argued that in doing so Bellini 'explains and confirmes' what Newton meant in the preface to the *Principia* when he observed that 'the basic problem of philosophy seems to be to discover the forces of nature from the phenomena of motions and then to demonstrate the other phenomena from these forces'.[90]

George Cheyne's Newtonian Medical Manifesto

The physic debate cooled immediately after the climactic events that followed the publication of Hepburn's reply to Eizat. Tensions nevertheless remained and the debate flared up again a few years later with the publication of Charles Oliphant's *Short Discourse, to Prove the Usefulness of Vomiting in Fevers* (1699). As before, Pitcairne did not enter the fray himself directly, and was this time defended by another of his allies, George Cheyne. Yet Cheyne did not just offer a defence of Pitcairne's medical programme, he built upon Pitcairne's ideas to articulate his own strident reform agenda that extended and developed Pitcairne's vision considerably. Through an even more optimistic understanding of the power and potential of Newton's philosophy, Cheyne issued a manifesto in 1701 that did not repeat the call for the liberation of physic but advocated the creation of a new natural-philosophical system along Newtonian lines that would secure the continued advancement of the discipline as part of a broad reformation of natural knowledge.

Cheyne's medical reform ideal has been characterised by Guerrini, his biographer, as even more quixotic than that of Pitcairne. She has presented his project as a failure and defined him as a man of many contradictions, who crossed 'back and forth over the boundaries between the view of a world governed by God and one governed by the laws of Newtonian physics; between a medicine that intervened and one that merely observed... [and] between animistic and mechanistic views of the human body'.[91] Despite these

[89] *Tarrugo*, 17 and 30.

[90] *Tarrugo,* 31; *Principia*, 30.

[91] Anita Guerrini, *Obesity and Depression in the Enlightenment: The Life and Times of George Cheyne* (Norman, OK: University of Oklahoma Press, 2000), xiv.

contradictions, Cheyne's response to Oliphant 'echoed' the 'absolute faith in Newtonian physics as the basis of authority in both medicine and society' that Pitcairne had apparently expressed in his inaugural lecture at Leiden, suggesting that their reform programmes were in essential agreement about what Newton's example could bring to the discipline.[92] However, Cheyne was both far more specific than Pitcairne about how Newtonian philosophy might help medicine progress and adopted a quite different attitude than either Pitcairne and Hepburn regarding the potential for the discipline to form part of a wide-reaching philosophical system. By presenting Newton's discovery of a universal attractive force in nature and the advanced mathematical techniques he used to make it as the basis for this system, Cheyne turned Pitcairne's agenda somewhat on its head.

Cheyne nevertheless saw himself as following Pitcairne's lead, and took common cause against his opponents in the physic debate. Oliphant's *Short Discourse* presented a challenge because, though it did not deny the importance and validity of theory, Oliphant used the work to pour scorn on what he saw as the excessive abstraction of Pitcairne's vision of physic. In stark contrast to both the story Pitcairne told at Leiden and the one Cheyne would tell in his manifesto, Oliphant contended that '*Physick* as it hath advanced in Age, so it hath decayed in Reputation'. Modern 'Pretenders of this Science' take greatest interest in the 'mean and crafty Politicks of the Trade', attracting followers and lampooning their enemies. Thus, 'presently they throw Dirt on the whole Faculty, & proclaim Physick to be nothing else but Conjectural ill grounded Notions wrapt up in difficult and hard Terms'.[93] Though he longed for the credibility physicians supposedly enjoyed in the ages of Hippocrates and Galen, Oliphant rejected neither modern philosophy nor quantification. He urged theoretical moderation while emphasising the importance of observation.

The central contention of a *Short Discourse* was to defend the priority of vomiting as a cure for fever against the apparent dismissal of its importance by 'Apollo Mathematicus' (i.e. Pitcairne) who, in 'Impudent Ignorance', had cast Oliphant's practice as an unwelcome 'Innovation' and declared one of his patients therefore as good as dead.[94] Oliphant argued that vomiting both conforms with the 'General Rules and Maxims of *Physick*' (though he

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[92] Guerrini, *Obesity and Depression*, 62. Guerrini, 'Cheyne and the *Principia Medicinae*' 245. See also Guerrini, 'Newtonian Physiology'.

[93] Charles Oliphant, *A Short Discourse, to Prove the Usefulness of Vomiting in Fevers, by Plain Reasoning, and the Authority of the Best Physicians, Ancient and Modern* (Edinburgh: 1699), [1–2].

[94] Oliphant, *Short Discourse*, [2].

did not clarify what they are) and is 'Confirmed by the Authority of the best *Physicians*, both *Ancient* and *Modern*'. He recommended the use of 'calculation', claiming that once a fever has begun the ratio of 'humours' in the stomach may be supposed one in twenty which, after vomiting, may be reduced to one in forty. As these humours give 'Fewel to the Fever' when mixing with the blood, vomiting 'must make a vast difference in the event of a Cure'. This reasoning, Oliphant pointed out, is plain enough not to require a quotation from 'the Fifth Book of *Euclide* to prove it', and he instead cited the example of the 'the Judicious and Ingenuous [*sic*]' Sydenham.[95]

A flurry of short works followed, in which Oliphant engaged in a back and forth with anonymous critical salvos he believed were issued by Pitcairne's 'Malicious Club of little Villains', before the appearance of Cheyne's *New Theory of Continual Fevers* (1701).[96] Also published anonymously, Cheyne's work was the first substantial defence of Pitcairne's programme since Hepburn's *Tarrugo Unmasked*, though it also marked the debate's dislocation and hinted at its end. The *New Theory* was published in London, where Cheyne had recently moved, opening up the discussion to a broader audience beyond the Edinburgh medical community. Tamás Demeter has suggested that mathematical medicine became less appealing due to the political certainty provided by the Union of 1707, leaving Scottish physicians less in need of mathematical certainties.[97] However, there was no resolution to the factional strife that divided colleagues and former friends nor agreement found over fundamental questions in medical theory at this time. The disputatious intensity of the 1690s fizzled out before the Union of 1707, which provided very limited political certainty in any case. These years neither witnessed the success nor failure of quantification and the Newtonian reform of medical theory. However, in Cheyne's *New Theory*, they did receive their most elaborate and optimistic expression.

The work was motivated, Cheyne wrote, by the recent 'noice [*sic*] and bustle' on '*Vomiting in Fevers*', and aimed to demonstrate, in support of Pitcairne's *Dissertatio de Curatione Febrium*, that the 'General and most effectual cause of all Fevers, is the Obstruction or Dilations' of the glands.[98] The *New Theory* followed Pitcairne's use of

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[95] Oliphant, *Short Discourse*, [2–3] and 10.

[96] Charles Oliphant, *A Short Answer to Two Lybels Lately Published against D.O. by Drs. Cheyne and Pitcairne* (Edinburgh: 1701), 3.

[97] Demeter, *Culture of Scottish Newtonianism*, 42.

[98] [Cheyne], *New Theory*, 11. All quotes from 1744 edition.

quantification, though Cheyne went further in his discussion of fever than Pitcairne had by proposing a specific course of treatment: blood-letting, vomiting, purging, and, finally, the '*Medicaments* which encrease [*sic*] the less *Sensible Evacuations*; under which I comprehend Sweating, Perspiration, and the like'.[99] Cheyne cited Borelli, Bellini, and Pitcairne as the main sources for the work and signalled his commitment to a mechanical approach to the discipline by affirming that 'this Machine we carry about' has been 'clearly demonstrated' to be 'nothing but a Congeries of Canals'.[100] The body's ailments and disorders are analogous to a faulty watch and ought to be treated as such. He claimed, however, to be 'dreadfully afraid' few would read and 'understand' his work 'for want of the necessary Qualifications, of a moderate attention, and a smattering of the Mathematicks'.[101]

Newton barely featured in the first edition of the work, and on the surface the *Principia* may appear to have been relevant only as a source of scientific facts. Cheyne wondered aloud whether the scholium to Book II, Prop. 35 of the *Principia* related to 'Animal Bodys' before recommending its scholium be studied closely, for it is 'crouded up', like the 'admirable Book' itself, with a 'vast number (if retail'd) of most Charming and useful Truths'.[102] This proposition was concerned with, as Newton put it, the 'resistance encountered by a sphere' in a 'rare medium', so Cheyne was evidently interested at this time in what Newton's treatment of a material ether could offer the life sciences.[103] The reference alluded to Hepburn's remarks about ether, which Cheyne was surely familiar with, having also been close to Pitcairne in the 1690s. The *New Theory*'s treatment of the 'effectual cause' of fevers as that by which 'appearances' may be 'accounted for' was therefore probably aligned with Hepburn's notion of an 'efficient cause' and Pitcairne's 'mathematical or medical' cause, while likely also consciously modelled on Newton's approach to physical explanation.[104]

Newton's relevance to Cheyne's thinking became abundantly clear in the work's second edition, printed later that year, which included an undeniably Newtonian manifesto for the reform and advancement of medicine in the form of his 'Essay concerning the

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[99] [Cheyne], *New Theory*, 51.

[100] [Cheyne], *New Theory*, 1–2.

[101] [Cheyne], *New Theory*, v.

[102] [Cheyne], *New Theory*, 46.

[103] *Principia*, 377–9.

[104] 'Essay', 15.

Improvements of the Theory of Medicine'. The essay laid out Cheyne's vision of the discipline and showed that the *Principia* was for him far more than a font of 'charming and useful truths'. Echoing Pitcairne, Cheyne claimed that if physic had followed the lead of astronomy, lately brought 'almost to the highest Pinnacle of Perfection', it would have 'been above the Contempt and Reproaches which are now daily thrown upon it' and not 'the common Theme of the lowest Pretenders to Satire and Wit'.[105] He scorned the medicine of the ancients, whose science revealed only the 'names' and not the 'natures' of things, but told how the translation of, borrowing from, and commenting on ancient texts was finally abandoned following the contributions to mechanical philosophy of Galileo Galilei (1564–1642), his student Evangelista Torricelli (d. 1647), and Blaise Pascal (d. 1662). The Dutch mathematician Willebrord Snel van Royen (Snell, d. 1626) furthered the understanding of vision before Descartes, whom Cheyne claimed was the first to treat vision mechanically, 'banished effectually the *Aristotelian* Jargon, and made Men reflect upon the natural Right they had to a Freedom of Thinking'.[106]

For Cheyne, modern medicine really got going however not with Descartes but Harvey, who gave a 'fatal Shock' to prevailing theory with the discovery of the circulation of blood. This stood as a pivotal moment in the history of medicine:

> a Discovery so conformable to the Rules of Mechanism, and the Laws of Motion, and so fitted to that Geometry, the wise Director of Nature uses in all his wonderful Works; in a word, a Discovery, which has let in more Light into the *Theory* of *Medicine*, than almost all the former joined together.[107]

Since Harvey's discovery, the Danish anatomist Niels Steensen (Nicolas Steno, d. 1686), Santori, Borelli, and Bellini made important strides forward, applying the 'Doctrine of Quantity, *i.e.* Geometry and Numbers' to medicine and reducing 'pretty near to a Science, which was before but a Trade'.[108] Cheyne's story culminated with Pitcairne, whose 'manly *Laconic* Eloquence' has 'left undetailed' many 'noble Hints' to the 'sagacity of the attentive

[105] 'Essay', 4.

[106] 'Essay', 10.

[107] 'Essay', 10–1.

[108] 'Essay', 14–5.

Reader', using this history to situate both his *New theory* and Pitcairne's vision of medicine within the broader revival of learning in modern times.[109]

Despite such progress, however, 'it cannot be denied, there still remains an ample Field for the Industry of the present and future Ages', and Cheyne offered a four-point plan for making good on this potential.[110] Firstly, the discipline must go further than the 'obvious' parts of the body discovered by 'ingenious Anatomists', such as the Italian Marcello Malpighi (d. 1694) and van Leeuwenhoek, to investigate its more minute aspects with 'fine Microscopes, and a good Skill'. Secondly, Cheyne suggested, 'we evidently want a compleat *History of Nature*, i.e. the Names and Natures, the Distinctions and Properties, of the Animal, Vegetable, and Mineral Kingdoms', but he spilt little ink on this point, as with the first.[111] Cheyne was more invested in steps three and four: that medicine required a 'compleat System of Mechanic Philosophy, *i.e.* an Account of all the visible Effects of Nature upon Geometric Principles' to draw on, and that it needs a 'Principia Medicinae Theoreticae Mathematicae' to become synthesised with such a system.[112]

As the projected *Principia Medicinae* suggests, Newton and the *Principia* were uppermost in Cheyne's mind. He observed that 'all the great, visible, constant and uniform *Phaenomena* of Nature, have been attempted by the eminent Mathematicians of this age and the last Age', but have only been 'accounted for, from rigorous Geometry, by that stupendiously Great Man, Sir *Isaac Newton*'. Written before the *Opticks* appeared, Cheyne was still thinking about the *Principia* when he drew a distinction between what Newton had accounted for and 'the lesser, less obvious, less constant, and less uniform Effects of Nature... which are so absolutely necessary to a true Theory of Medicine'.[113] He not only considered Newton's philosophy as a model for any 'true' theory of medicine but that such a theory would have to range into territory beyond that which Newton himself had yet entered. Cheyne explained in some detail what any *Principia Medicinae* ought to deliver, including the 'true nature' of fluidity and elasticity, and the 'effects' of 'solid particles' and

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[109] 'Essay', 15–6.

[110] 'Essay', 16–7.

[111] 'Essay', 18–9.

[112] 'Essay', 19–20.

[113] 'Essay', 21–22.

of fluid interaction. Then it ought to deliver the 'determination or calculation' of these latter effects as well as their 'final Causes' and 'Mechanical Necessity'.[114]

Cheyne's positive remarks about the need for the creation of a 'system' of mechanical philosophy reflect a departure from the critical stance toward system-building in Pitcairne's and Hepburn's appeals to the superiority of Newtonian philosophy. For Pitcairne, 'the Decoys of a System' were intimately connected with 'the Narrowness and Uncertainty of a School-Bigotry', while for Hepburn Newton's contribution to astronomy followed from his unwillingness to systematise in favour of careful attention to the data.[115] For all the progress Cheyne pointed to, he was clear about the negative role false philosophy had played in holding medicine back, observing that philosophy had, prior to the 'restauration of letters', been overly concerned with terminology and system-building.[116] 'All Natural Philosophy', he declared, 'unless supported by Geometry, is but a pleasant *Romance*', and he presented geometry as the linchpin of any valid system: 'it is not Systems, as they are an explication of all the Effects of Nature from the same Principles, which are so justly ridiculed, but Systems, as they are ungeometrical'.[117] What is owed 'most of all' to Newton, Cheyne pointed out, is 'the only Key whereby the Secrets of Nature are unlocked, to wit, the general Way of managing Æquations, the Methods of Infinite Series's [*sic*], and of Fluxions, direct and inverse'.[118]

Descartes may have thrown off Aristotelian jargon and taught people to think freely but, despite his 'Analytical and Geometrical Improvements' in the discipline of mathematics itself, he merely proposed one 'bad System' in place of another.[119] Descartes was a 'bold' and 'impious' philosopher, 'the first (since *Prometheus* and *Democritus*'s Days) who endeavoured to create an Animal', and his system-building was, thanks to the absence of geometry, fundamentally flawed.[120] What a valid system does, for Cheyne, is explain effects from their causes mathematically by demonstrating 'mechanical necessity'. It does not account for natural phenomena through an *a priori* explanatory scheme, hypothesising

[114] 'Essay', 22–6.

[115] [Pitcairne], *Elements of Physick*, xxviii.

[116] 'Essay', 7.

[117] 'Essay', 7 and 19.

[118] 'Essay', 20.

[119] 'Essay', 10–1.

[120] 'Essay', 11.

‘mechanical origins’. By constructing his hypothetical system without the guidance of mathematics, Descartes was, like when he attempted to ‘create an animal’, playing too much like God.

The distinction Cheyne drew between good and bad philosophical system-building helps to explain why his essay included the striking claim that Newton’s philosophy has uncovered ‘the true Principle of all the effects of Nature, to wit, Attraction, or Gravitation’.[121] In Cheyne’s mind, this principle is essentially different to any of the principles one might find in Aristotle or Descartes, because it is not the product of speculation for the purposes of constructing a system but discovered through the application of geometry to philosophical problems. Gravitation, i.e. the ‘true’ attractive principle underlying all natural phenomena, was for Cheyne not established by Newton to explain appearances in nature but discovered *as a result* of the proper explanation of those appearances. This approach gives any system constructed from it a valid philosophical basis.

Though Cheyne observed a distinction between Newton’s achievements for the celestial realm and the apparently ‘less constant, and less uniform effects of Nature’ necessary for a true theory of medicine, he declared that ‘I am persuaded, that from the same Principles [i.e. Newton’s ‘mathematical principles’] the grand Appearances of Nature have been accounted for’ so that ‘these more minute ones may be so too’.[122] Rather than a partisan commitment to Newtonianism this statement reflects how Cheyne became convinced of Newton’s conclusions due to what he understood to be the superiority of Newton’s approach to philosophy over those who had come before. Though he went further than Pitcairne and Hepburn in proposing gravitation itself and Newton’s advanced mathematical methods as directly applicable to medical theory, his motivation for doing so was rooted in the view he shared with them of Newton’s philosophy as a superior model of reasoning. This philosophy was for them directed toward establishing the forces that give rise to natural phenomena and demonstrating their effects by way of mathematics, promising a route by which to advance and (in Cheyne’s eyes) perfect medical science in the modern age.

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[121] ‘Essay’, 20.

[122] ‘Essay’, 19.

In response to Cheyne's *New Theory*, Oliphant published an *ad hominem* diatribe entitled *A Short Answer to Two Lybels Lately Published against D.O. by Drs. Cheyne and Pitcairne* (1702). Cheyne's reply, *Remarks on Two Late Pamphlets Written by Dr. Oliphant, against Dr Pitcairne's Dissertations, and the* New Theory of Fevers (1702), suggests that by this time he had had enough of such disputes. Cheyne described his critics as 'Bloody minded Beasts of Prey', remarking that 'not to write at all, is the wisest thing a Man of Sense can do'. He had resigned himself to the fact that 'it is very hard to apply *Geometry* to *Physiology*, with such Accuracy and Niceness, as to exclude all possibility of Wrangling'. Cheyne was himself convinced of how to improve 'the present low Estate' of medicine and seems to have believed that he had done the best he could to convince his opponents, insisting that 'if we reason fairly... all ingenious Men will be satisfied with such Performances, since it is all can be done in the present Condition of *Medicine* and *Philosophie*'.[123]

Guerrini and others have emphasised the discontinuity between Cheyne's early medical writings and his later work, and at this point in his life he is thought to have given up hope of a reform agenda that would, in the long run, have little influence on the course medicine took in Scotland.[124] For Demeter the failure of this project exemplifies a 'flight from mathematics in Scottish physiology' and a new 'theoretical climate' following the publication of Newton's *Opticks* in 1704 and 'De Natura Acidorum' in 1710.[125] With the establishment of the medical school, he argues that Edinburgh became a centre for 'physiological vitalism' in line with the reading of Newton's philosophy David Hume and others could have found in the *Opticks*.[126] Medical theory is generally thought to have experienced a degree of pluralisation in this period, with scholars tending to recognise two overarching physiological paradigms at play in the Enlightenment: mechanical and chemical-vitalist.[127] The development of 'Enlightenment vitalism' as an alternative to

[123] George Cheyne, *Remarks on Two Late Pamphlets Written by Dr. Oliphant, against Dr Pitcairne's Dissertations, and the* New Theory of Fevers (Edinburgh: 1702), [2–3].

[124] See Guerrini, 'Cheyne and the *Principia Medicinae*'; and Demeter, *Culture of Scottish Newtonianism*.

[125] Demeter, *Culture of Scottish Newtonianism*, 41. 'De Natura Acidorum' was first published in John Harris, *Lexicon Technicum*, 2nd ed., vol. II (London: 1710).

[126] Demeter, *Culture of Scottish Newtonianism*, 2 and 42.

[127] See Cook, 'Medicine' and Broman, 'The Medical Sciences'.

mechanistic accounts of the animate creation (which first appeared in the previous century) has been seen by some as a major new departure in the fields of medicine and chemistry in the eighteenth century, and it is also thought that chemical-vitalism was increasingly favoured over the mechanical paradigm from around mid-century.

From this perspective, the apparent dead end reached by Pitcairne's and Cheyne's mechanistic medical programmes looks to be in line with broader trends. By the 1720s, Cheyne's own interests had moved on, and his and Pitcairne's reform efforts do not seem to have been considered a great success by later generations. In 1781, the physician Charles Webster delivered an oration to the Edinburgh Harveian Society celebrating the life and legacy of the 'great' Pitcairne, dedicated to his kinsman, William Pitcairne, current president of the Royal College of Physicians. Webster could not help mixing admiration for Pitcairne's evident talents with regret for how he had 'expected from geometry more than the science could grant'. For Webster, modern physicians worked according to a different paradigm: the 'supreme influence of the living principle' had since proven capable of explaining all that the 'laws of chemistry and mechanism' could not.[128] However, Pitcairne's understanding of Newtonian physics was not one that contrasted in its essentials with vitalism. He and other reformers at the turn of the eighteenth century understood Newton's philosophy not merely as an example of mathematical mechanism but as a science directed toward the discovery of powers and the elaboration of their effects.

Pitcairne and Cheyne were not, after all, concerned exclusively with the advance of medicine. Pitcairne turned his agenda against his former collaborator, Sibbald, to propose a new 'method of natural history' in his *Dissertatio de Legibus Historiae Naturalis* (Dissertation on the Laws of Natural History, 1696). The work was largely an exposition and correction of the technical and factual errors he found in Sibbald's *Scotia Illustrata* (1684), but also offered a set of four 'axioms', or 'precepts', to guide natural-historical inquiry: 1) the natural historian 'ought to be bound to no sect of Philosophers which does not support itself with Mathematical, that is, certain principles'; 2) must have visited the places they write about; 3) practice the 'same method' as that which has been 'laid out by those arts which teach and describe only the forms [*figuras*] and powers [*facultates*] of bodies'; and 4) ought not to be diverted from their subject by a problem that cannot be solved until the

[128] Charles Webster, *An Account of the Life and Writings of the Celebrated Dr Archibald Pitcairne, Delivered as the Harveian Oration at Edinburgh, for the Year 1781* (Edinburgh: 1781), 8 and 26–7.

work is complete.[129] The final point, along with much of the work itself, may have been *ad hominem* but with these 'laws' Pitcairne repeated his demand for a science guided by mathematical principles aimed at discovering and describing the 'powers and properties' of bodies.

Soon after issuing his own medical manifesto, Cheyne published a pioneering work on calculus, *Fluxionum Methodus Inversa* (Inverse Method of Fluxions, 1703) and a wide-ranging work of natural theology, *Philosophical Principles of Natural Religion* (1705). Though these works looked beyond the immediate concerns of his reform programme they did in fact point in the direction of its ultimate aims. The *Methodus Inversa* roused Newton's ire and drew a rebuke from the Huguenot mathematician Abraham de Moivre, but Cheyne was undeterred and went on to publish another unsanctioned book on Newton's invention, *Rudimentorum Methodi Fluxionum Inversae Specimina* (Examples of the Inverse Method of Rudimentary Fluxions, 1705). As the *Methodus Inversa* was written in the form of a letter to Pitcairne, Cheyne's work on calculus might not be seen primarily as a failure to win Newton's patronage, as it often has been, but as an attempt to make good on his hopes for the development of advanced mathematical techniques that might be applied to medicine.[130] Similarly, while the *Principles* has been described as 'an altogether different project' to his medical reform efforts, Cheyne used the work to construct a philosophical system with a principle of attraction at its centre, as he had wished for in the 'Essay'.[131]

If there was a turning point in Cheyne's career it came after the *Principles* first appeared in 1705, when he suffered a mental health crisis and returned to Scotland.[132] Aside from subsequent editions of the *Principles*, which began to appear after a decade of literary inactivity, Cheyne subsequently abandoned his reform agenda. He nevertheless amassed considerable wealth as an author of popular works on health and wellbeing and through his medical practice, eventually settling in Bath where he counted the wealthy elite among his clientele. By the time he wrote *An Essay of Health and Long Life* (1725), he had

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[129] Archibald Pitcairne, *Dissertatio de Legibus Historiae Naturalis* (Edinburgh: 1696), 4–7: Rationem Naturalis Historiæ per axiomata quædam, aut si mavis, precepta… [1] Historiæ naturalis auctorem nulli Philosophorum sectae, quæ principiis Mathematiciis, hoc est, certis non nitatur, debere esse illigatum… [3] Decere ipsum iis artibus esse instructum quæ docent enarrantque rationem figuras atque facultates corporum.

[130] See Guerrini, *Obesity and Depression,* 68–71.

[131] Guerrini, *Obesity and Depression*, 72. See Chapter 3, 144–52.

[132] He addressed this episode explicitly in George Cheyne, *An Essay of Health and Long Life* (London: 1725).

lost interest in advanced mathematics and the advancement of medical theory, claiming the former often left ‘a Stiffness, Positiveness and Sufficiency on weak Minds, much more pernicious to Society, and the Interests of the great End of our Being, than all they bring them can recompense’.[133] He did not lose faith in the power of Newton’s philosophy *per se* but began to reference Newton’s works as a body of facts rather than a superior approach to philosophy. These later writings promised readers that the conclusions were drawn not from elaborate theory but primarily from Cheyne’s ‘own Experience and Observation on my own crazy Carcase and the Infirmities of others I have treated’.[134]

Cheyne was far from alone in having seen Newton’s discovery of gravitation as a pivotal moment for the understanding of the natural world. His reform programme anticipated Newton’s own printed speculation on the topic, first articulated in ‘quaestio 23’ of *Optice* (1706), in which Newton suggested that it was ‘not improbable but that there may be more attractive powers’ than gravity, magnetism, and electricity, for ‘Nature is very consonant and conformable to herself’.[135] James Keill was one of many who agreed with Newton, and, following Cheyne, he became convinced that a ‘principle of attraction’ explained the cohesion of microscopic particles that make up both bodily fluids and solid matter. In his *Account of Animal Secretion* (1708), Keill claimed it ‘can be denied by none’ that ‘there is such an attractive Power in Nature as this we have mentioned’, after ‘the Experiments and Reasons given for it by Sir *Isaac Newton*, in the Questions annexed to the Latin Edition of his Opticks’.[136] Keill’s principle was distinct from, though equivalent to, the principle of gravitation by which Newton had accounted for planetary motion, as it was likewise attractive but obeyed different mathematical laws – which his brother, John, helped to establish.[137]

Keill had left Oxford by this time, where he had taught medicine and chemistry between 1698 and 1703, and established himself as a successful physician in

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[133] Cheyne, *Health and Long Life*, v.

[134] Cheyne, *Health and Long Life*, viii.

[135] *Opticks*, 350.

[136] Keill, *Animal Secretion*, 102. Expanded as *Essays on Several Parts of the Animal Oeconomy* (1717) and translated into Latin as *Tentamina Medico-physica* (1718).

[137] John’s work was published in ‘Epistola… in qua Leges Attractionis Aliaque Physices Principia Traduntur’, *Transactions of the Royal Society* 26, 314 (1708): 97–110. For John Keill’s engagement with Newton see Chapter 2.

Northampton, where he would die a wealthy man in 1719.[138] Like Cheyne, he had left Edinburgh for a lucrative medical career in England and, though he did not participate in the physic debate, he was an undergraduate at Edinburgh in the 1690s and may at that time have been persuaded by the prospect of reforming medicine along Newtonian lines.[139] He saw that the truth of Newton's discoveries followed from the superior method he employed to make them, criticising 'the too common Method of philosophizing' practiced by Descartes, i.e. the 'laying down of Principles not drawn from the *Phaenomena* of Nature, but uncertain Fictions of the Brain'. The best that can be said of such a philosophy developed from the 'Chymerical' elements of the Cartesians, Keill thought, is that it is 'meerly [*sic*] possible'.[140] He shared with Cheyne the view that Newton's approach was an antidote to the false philosophy of Descartes and others, making possible the creation of a valid philosophical system upon principles derived from empirical data, not hypothesised for the purpose of system-building. Observation and experiment were therefore essential but alone insufficient. He insisted that 'Natural philosophy and Histories of Diseases must go hand in hand in the improving the Art of curing', and observed somewhat cryptically of the consummate empiricist Sydenham that 'by his philosophyzing [he] has evidently shewn us the Necessity of that Science, he so much decryed, and so little understood'.[141]

By the time that a *Principia Medicinae* did appear in Edinburgh in 1758, central aspects of the physic debate remained unresolved, though they could be articulated with reference to a different cast of characters. Francis Home's *Principia Medicinae*, which ran into several editions and achieved some success throughout Europe, was not an answer to Cheyne's manifesto, nor – despite the resonances of its title – did it have almost anything to do with Newton.[142] Home attended the medical school at Edinburgh and studied at Leiden during the 1730s and '40s before becoming the first professor of materia medica at Edinburgh in 1768. He later served as president of the Royal College of Surgeons between 1775 and 1777. In his *Principia*, Home credited Hermann Boerhaave for having 'reduced

[138] F. M. Valadez and C. D. O'Malley, 'James Keill of Northampton: Physician, Anatomist and Physiologist', *Medical History* 25 (1971): 317–35.

[139] See Guerrini, 'Newtonian Physiology'.

[140] Keill, *Animal Secretion*, xix–xx.

[141] Keill, *Animal Secretion*, xxiii.

[142] Iain Milne, 'Home, Francis (1719–1813), Physician', in *Oxford Dictionary of National Biography*, 2004, accessed 13th Jul., 2023: doi.org/10.1093/ref:odnb/13640.

medicine to a rational system' and, thus, having 'delivered many useful things concerning inflammatory fevers'.[143] While he acknowledged the value of systematic medical theory, Home separately stressed the importance of experience and observation, not just one's own but those of others. He cited not Sydenham but Aulus Cornelius Celsus (d. *c*. 50 CE), an ancient author renowned for his medical writings, and the German physician Friedrich Hoffman (d. 1742), declaring himself to follow their lead.[144] A rational medical system would not be one in which experimentalism played no part, yet there apparently remained in the minds of some Scottish physicians after mid-century some lingering uncertainty about the precise relationship between abstract theory and empirical observation.

Boerhaave was associated by Home with a rational system of medicine and Hoffman with careful observation, yet Boerhaave had presented himself in his own lectures at Leiden in 1702 as following in the footsteps of Hippocrates, whom he saw as an anti-metaphysical empiricist, in contrast to Cartesian mechanists who reason *a priori*.[145] Like Hoffman, Boerhaave drew partly on a mechanical understanding of the body to develop chemical theories of bodily processes. These figures defy simple classification according to strict definitions of iatrochemistry, vitalism, and mechanism, despite the fact they sometimes engaged in this kind of reductionism themselves.[146] Newton's example had served the 'Newtonian' reformers of the 1690s as the basis for a superior medical theory and, in Cheyne's case, as the basis for a brand new medical system. That Boerhaave, who admired Newton's philosophy himself, was later taken to be the author of such a system suggests that the apparent failure of their Newtonian reform agendas was at least a qualified one.

Conclusion

As subsequent chapters of this dissertation show, Newton's Scottish readers continued to draw on his approach to physical explanation as a means by which to reform and advance

[143] Francis Home, *Principia Medicinae* (Edinburgh: 1758), iv: 'Primus enim Medicinam in systema ratione... redegit; et multa de febribus inflammatoriis utilia tradidit.'

[144] Home, *Principia*, iv.

[145] Powers, *Inventing Chemistry*, 30–2.

[146] Broman, 'Medical Sciences', 469–70.

the discipline of natural philosophy for the rest of the eighteenth century. When the Edinburgh physic debate is placed in this context it becomes clear that Newton did not serve reformers merely as a source for advanced mathematics and scientific results. His example was invoked in support of attempts to reform the life sciences primarily because the approach to explanation he employed in the *Principia*, above all in the treatment of gravitation, was taken as a superior one through which to reason about quantifiable, mechanical processes by way of the forces, or powers, that drive bodily functions and microscopic phenomena. This approach was used as an alternative to the false, sectarian philosophy medical reformers like Pitcairne, Hepburn, Cheyne, and Keill thought had corrupted medicine since antiquity. This ancient tradition of theorising based on systematic, *a priori* reasoning from speculative physical elements or principles was, for them, alive and well in modern times thanks principally to Descartes and his followers.

This chapter has shown how these issues were tackled in complex and sometimes uncivil public debates. Such debates suggest that Newtonian philosophy commanded a certain authority in Britain as Newton's ideas rose to dominance over those of rivals like Descartes. However, the commitment to independent thought and opposition to intellectual sectarianism worked against the use of Newton as a flexible authority figure with which to legitimise ideas or personal and professional standing. In institutions like the Royal College of Physicians of Edinburgh, one could not gain credibility simply through an appeal to Newton's authority. Despite the parallels some contemporaries saw between Newtonian natural philosophy and certain political and religious ideas, these issues did not play a significant role in debates about the future of medicine. By the first decade of the eighteenth century Newton's discoveries and the calculus he employed to arrive at them appeared to some as the future of natural philosophy, potentially serving as a new foundation upon which the life sciences might be based. The revolution in these sciences based on principles of attraction and advanced mathematical methods that Cheyne and Keill worked toward may not have come to pass, but Newton's significance for medical reform had never entirely hung on those hopes.

CHAPTER II

HEAVENLY BODIES

The things that so often vexed the minds of the ancient philosophers
And fruitlessly disturb the schools with noisy debate
We see right before our eyes, since mathematics drives away the cloud.
Errors and doubt no longer encumber us with mist;
For the keenness of a sublime intelligence has made it possible for us to enter
The dwellings of the gods above and to climb the heights of heaven.

Edmond Halley[1]

On April 21st, 1692, less than a week before Archibald Pitcairne launched his reform agenda for medicine at Leiden, David Gregory delivered an oration in the Astronomical Auditorium at Oxford as the new Savilian professor of astronomy. That day, Gregory set out his vision for how celestial physics ought to be reformed along Newtonian lines. Newton, Lucasian professor of mathematics at Cambridge, was one of a number of eminent mathematicians consulted on the appointment, and he had recommended Gregory.[2] There is no evidence that Newton's approval was decisive for the appointment, but it is reasonable to suppose the electors listened not only due to Newton's ability as a mathematician but his growing renown as a philosopher. Gregory had been an eager reader of the *Principia* while professor of mathematics at Edinburgh but, anticipating Pitcairne's remarks at Leiden, his address drew attention not so much to the work's mathematical sophistication, nor the Newtonian cosmic system it had established, as with Newton's exemplary approach to physical explanation that made his astonishing discoveries possible.

[1] Edmond Halley, 'Ode on This Splendid Ornament of Our Time and Our Nation, the Mathematico-physical Treatise by the Eminent Isaac Newton', in *Principia*, 25–6.

[2] See P. D. Lawrence and A. G. Molland, 'David Gregory's Inaugural Lecture at Oxford', *Notes and Records of the Royal Society of London* 25, 2 (1970), 145–6.

Gregory's lecture was ostensibly concerned with 'the aids by which celestial science has increased and the thoughts and systems of reasoning to which it will owe all its advances'.[3] He saw the *Principia* – 'the immortal glory of this age' – as representative of a new era in learning, though one just dawning.[4] 'Within the memory of ourselves and of our fathers', he declared, 'philosophers began to extend the limits of geometry in order to found the kingdom of astronomy'. Men like Newton were the geometers who had fortified the seat of this kingdom – the 'astronomical city' – with a 'ditch and ramparts'. They were on course to drive all the 'ungeometrical men' into exile.[5] Gregory poured scorn on the vain speculations of late foreign philosophers and praised the English nation for its 'knowledge, peculiar to this people, of some more universal geometry'.[6] He had two specific targets: René Descartes and the German astronomer and mathematician Johannes Kepler (1571–1630), who earlier in the seventeenth century had produced explanations of planetary motion with which Newton's theory of gravity could be compared.[7] Very different in their commitment to a geometrical celestial science, for Gregory the efforts of both Descartes and Kepler nevertheless exemplified the most pressing and problematic issues in contemporary natural philosophy.

For all that Kepler had done for mathematical astronomy, he had erred in philosophy by proposing 'archetypal causes' (or 'original' causes) to explain planetary motion, designed in Gregory's mind rather to 'desire a path to Olympus' than to 'scale the heavens with the help of geometry'.[8] Gregory meant that Kepler had succumbed to a vain desire to identify the physical origins of the causes of celestial motion rather than be content to carefully trace the effects of these causes using mathematics. Descartes shared Kepler's approach to explanation but erred further in leaving the 'one narrow path' to Gregory's astronomical city altogether. Descartes wished 'to investigate the causes of things logically,

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[3] Quoted in Lawrence and Molland, 'Inaugural Lecture', 166.

[4] Lawrence and Molland, 'Inaugural Lecture', 169.

[5] Lawrence and Molland, 'Inaugural Lecture', 166–7.

[6] Lawrence and Molland, 'Inaugural Lecture', 172.

[7] For Descartes' celestial physics see Daniel Garber, *Descartes' Metaphysical Physics* (Chicago, IL: University of Chicago Press, 1992); and Stephen Gaukroger, *Descartes' System of Philosophy* (Cambridge: Cambridge University Press, 2002), esp. 145–70. For Kepler's see Rhonda Martens, *Kepler's Philosophy and the New Astronomy* (Princeton, NJ: Princeton University Press, 2000), esp. 69–98.

[8] Lawrence and Molland, 'Inaugural Lecture', 167.

or rather, sophistically', abandoning geometry in favour of 'easier and less composite laws' determined through speculative and systematic *a priori* reasoning.[9] As Savilian professor of astronomy until his death in 1708, Gregory developed a Newtonian pedagogy at Oxford designed to show, by way of contrast to the flawed philosophy of Kepler, Descartes, and others, how Newton's philosophy represented the ideal approach to physics. Gregory shared with Pitcairne and his fellow medical reformers the view that the most important lesson one could learn from the *Principia* was how to handle causation in natural inquiry.

Gregory was joined at Oxford by a former student during his time at Edinburgh, John Keill, who went on to occupy the Savilian astronomy chair himself between 1712 and his death in 1721. At Oxford, Keill had earlier delivered lectures in 'experimental philosophy' before deputising for the Sedleian professor of natural philosophy, Thomas Millington, between 1699 and 1704.[10] The works Gregory and Keill developed at this time – Gregory's *Astronomiae Physicae et Geometricae Elementa* (The Elements of Physical and Geometrical Astronomy, 1702), Keill's *Introductio ad Veram Physicam* (Introduction to the True Physics, 1701), and his *Introductio ad Veram Astronomiam* (Introduction to the True Astronomy, 1718) – have largely been of interest to historians as evidence for the adoption and promotion of Newton's science and mathematics.[11] As a result, Gregory's and Keill's own views have been obscured. They are well known as loyal and pioneering Newtonians who delivered some of the earliest lecture courses in Newtonian physics and astronomy, but they have not received scholarly attention commensurate with the importance of this

[9] Lawrence and Molland, 'Inaugural Lecture', 168.

[10] For an examination of Keill's 'experimental philosophy' teaching see Peter Anstey, 'Experimental Pedagogy and the Eclipse of Robert Boyle in England', *Intellectual History Review* 25, 1 (2015): 115–31.

[11] David Gregory, *Astronomiae Physicae et Geometricae Elementa* (Oxford: 1702) was translated as David Gregory, *The Elements of Astronomy, Physical and Geometrical*, 2 vols (London: 1715) and republished in Latin in Geneva in 1726. John Keill, *Introductio ad Veram Physicam* (Oxford: 1701) was enlarged in a second edition of 1702 before being republished in four further editions, with the sixth appearing in London and Cambridge in 1741. The English translation, John Keill, *An Introduction to Natural Philosophy* (London: 1720) reached a fifth edition in 1758. John Keill, *Introductio ad Veram Astronomiam* (London: 1718) was expanded in a second edition in 1721 and republished in 1732. Its English translation, John Keill, *An Introduction to the True Astronomy* (London: 1721) appeared in six further editions, with the final edition appearing in Dublin in 1793.

teaching and the influence of their published works.[12] Their identification as Newtonians has done little to reveal their understanding of Newtonian philosophy and they have not attracted much interest among scholars as philosophers in their own right.[13]

This chapter examines their understanding of Newton's ideas by demonstrating how his example was used in their teaching, and by situating this engagement within the context of contemporary debates about the proper approach to physical inquiry. Despite acknowledgement of the importance of Gregory's and Keill's teaching and the central place of universities in scholarly narratives of the rise of Newtonianism in Scotland, Oxford is an underappreciated context for Newton's Scottish reception. It in fact served as an environment conducive to the development of Gregory's and Keill's influential views on physical science, to which Newton's example was central.[14] Through the publications derived from this teaching, which were subsequently used in universities across Britain for much of the eighteenth century, Gregory and Keill helped to shape Newton's reputation and the teaching of physics and astronomy in Scotland and elsewhere.[15] These texts are

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[12] The presence of Newton's ideas in Gregory's teaching is discussed in Christina M. Eagles, 'David Gregory and Newtonian Science', *British Journal for the History of Science* 10 (1977): 216–25; and the 'Newtonian' character of his mathematics is treated in Guicciardini, *Reading the* Principia, 179–84. Wilson, *Seeking Nature's Logic* argues that the Newtonian 'revolution' in Scotland saw Gregory and Keill 'transform' Newton's ideas into a 'Newtonian Newtonianism' and an 'Aristotelian Newtonianism' (33), respectively, but Wilson does little to establish what drew them to Newton's ideas nor what significance Newton had for them as pedagogues. For a discussion of the concept of a 'Newtonian' see Introduction, 23–33.

[13] Gregory's and Keill's readings of Newton's philosophy have only recently attracted serious interest in Levitin, *Kingdom of Darkness*, 638–52 and van Besouw and Ducheyne, 'Characterisations'. Aspects of Keill's natural philosophy have been analysed in Carla Rita Palmerino, 'The Composition of Space, Time and Matter according to Isaac Newton and John Keill', in *The Mechanization of Natural Philosophy*, eds Sophie Roux and Daniel Garber (Dordrecht: Springer, 2013), 117–42; and Gustavo Sarmiento, 'Cartesianismo, Newtonianismo y Método: Sobre el Rechazo del Cartesianismo en la Obra de John Keill', *Episteme NS* 36 (2016): 173–98.

[14] Oxford is mentioned neither in Demeter, *Culture of Scottish Newtonianism* nor Wood, 'Science in the Scottish Enlightenment'. Its role in Newton's reception more generally has recently been emphasised in Levitin, *Kingdom of Darkness*, where Oxford is said to have witnessed 'the most important early adoption, dissemination, and development of Newtonian ideas' (638).

[15] The texts they developed at Oxford were in use at Edinburgh until at least the 1740s, as discussed in Michael Barfoot, 'Hume and the Culture of Science in the Early Eighteenth Century', in *Philosophy of the Scottish Enlightenment*, Stewart, 151–90; and at Cambridge had become part of a 'staple round of

not only relevant as teaching material, for they also served as contributions to debates about the best approach to explanation and the limits of philosophy. The polemical edge to their preoccupation with Newton's philosophy is well illustrated by Keill's contribution in the late 1690s to a debate over the origins of the Earth that followed the publication of Thomas Burnet's *Telluris Theoria Sacra* (Sacred Theory of the Earth, 1681). Keill was critical of the approach to causation taken by other contributors to this debate, some of whom he viewed as admirers of Descartes, but others he knew to be admirers of Newton.[16]

Keill took aim not only at Burnet and a defender of his *Theoria Sacra*, the English clergyman Thomas Beverly, but Newton's future hand-picked successor in the Lucasian chair, William Whiston. Burnet and Beverly were guilty, in Keill's mind, of attempting to explain inexplicable 'natural things' for which God's inscrutable activity was alone responsible. Whiston, too, transgressed the bounds of philosophy by providing purported accounts of the miracle of Creation supported by calculations of cometary orbits. Whiston's clear intention to bring Newton's physics and discoveries to bear on the subject was of little relevance, if any, for Keill had important points to make about the business of philosophy that transcended any sense of loyalty either may have had to Newton. Not all of Newton's admirers shared these interests, however. The Scottish author and physician John Arbuthnot made his own contribution to the debate over the origins of the Earth and sang Newton's praises in a work advertising the utility of a mathematical education, but he was little concerned with the technical details of Newton's approach to causation. Likewise, the Edinburgh mathematics teacher George Pirrie defended Gregory's and Newton's treatment of centripetal motion against the London mathematician George Gordon, who was sceptical about the application of mathematics to philosophy, by ignoring his antagonist's case and simply producing a restatement of the mathematical argument for the theory of gravity. Newton's admirers shared a positive assessment of his abilities and contributions to knowledge, but sometimes little else.

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undergraduate studies by the 1730s' according to John Gascoigne, *Cambridge in the Age of Enlightenment: Science, Religion and Politics from the Restoration to the French Revolution* (Cambridge: Cambridge University Press, 1989), 178.

[16] Keill's contributions to the debate over the origins of the Earth are discussed in William Poole, *The World Makers: Scientists of the Restoration and the Search for the Origins of the Earth* (Whitney: Peter Lang, 2010), 55–74.

The works produced by Gregory and Keill in Oxford should not therefore be merely taken as evidence of their apparent commitment to Newton's ideas. They were not intended simply as expositions of Newton's science for the purpose of popularising and defending Newtonianism. This chapter argues that Gregory and Keill primarily used Newton's example to articulate a critique of contemporary natural philosophy intended to guide the advancement of a discipline undergoing profound change. They put this critique to work in order to demonstrate how Newton's discoveries were made possible and, thus, to deliver a lesson in how to do philosophy. They believed physical science ought to be reformed along what they took to be Newtonian lines and were particularly interested in how mathematics could be used to disprove false theories, such as Kepler's and Descartes' accounts of planetary motion. Like contemporary Scottish readers who pursued a Newtonian reform agenda for the life sciences, both Gregory and Keill presented the defining characteristic of Newtonian philosophy as its approach to explanation by way of the properties or forces that bring about motion. As Pitcairne and George Cheyne had done, they contrasted this approach with an ancient tradition of speculative, *a priori* physics that they thought sought to assign intuitive yet empirically unverifiable physical principles as causes, or to discover the causes *of* empirically verifiable properties or forces.

Yet Gregory and Keill did not present Newton's philosophy in an identical fashion nor remain in complete alignment on the implications of Newton's approach. Around the turn of the eighteenth century, their emphasis was on Newton's causal agnosticism and contrasting his approach with those who had erred. Gregory used Newton's name and example sparingly in his *Elementa*, defining Newtonian philosophy largely implicitly through critical examination of the failures of celestial physics, ancient and modern. In his natural philosophy lectures, Keill lambasted Cartesian mechanism and outlined a composite portrait of the ideal natural-philosophical 'method' drawn from four 'eminent sects'. Though it requires some joining of dots, this portrait reveals Keill's understanding of the basic character of Newtonian philosophy. In the years following Gregory's death, with the reputation of Newton's philosophy growing in Britain at the expense of his rivals, Keill developed the view that gravitation was evidence of God's direct action in nature, from which it followed that Newton had in fact established the origin of celestial motion. As Savilian professor of astronomy in the 1710s, Keill presented Newton's philosophy as offering the deepest level of explanation that could be hoped for, implying that his approach had ironically met or even exceeded the ambitions of the speculative, *a priori* physics developed by vain philosophers like Descartes.

The Newtonian pedagogy Gregory and Keill developed at Oxford is of considerable value for understanding both how and why Newton's ideas rose to dominance in the eighteenth century, and for determining the importance of institutions of higher learning in shaping Newton's reception. Gregory's main rival for the Savilian chair, the English mathematician and astronomer Edmond Halley (d. 1742), proclaimed in his 'Ode on This Splendid Ornament of Our Time and Our Nation', published with the *Principia*, that Newton's 'sublime intelligence' had 'made it possible for us to enter / The dwellings of the gods above and to climb the heights of heaven'.[17] From what Gregory said about Kepler's 'desire' to lay 'a path to Olympus' through speculative philosophy, his inaugural address signalled some dissent from Halley's hyperbolic verse.[18] This was not merely semantics, for Gregory's remarks reflected concerns that defined his pedagogy and that of Keill.

Scholars have tended to underestimate the sophistication of engagement with Newton in this period. In their recent survey examining early readers of the *Principia*, including Gregory and Keill, Jip van Besouw and Steffen Ducheyne concluded that 'there can be no doubt that, up to the mid-1700s, characterisations of Newton's approach in the *Principia*, although they abounded, were rather underdeveloped and sketchy'.[19] They endorsed the view that it was not until the English mathematician Roger Cotes' (1682–1716) preface to the second edition of the *Principia* (1713) and Samuel Clarke's epistolary debate with Leibniz (1715–6) that Newton's British readers began to produce serious critical responses to his philosophy.[20] Gregory's and John Keill's pedagogy is evidence that Newton's Scottish readers had by 1713 produced detailed and nuanced responses to the central issues raised by what they saw as Newton's historically significant and exemplary approach to physical inquiry. While Gregory and Keill shared Pitcairne's and other medical reformers' view of the essential characteristics of Newtonian philosophy, they developed

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[17] Halley, 'Ode', 26.

[18] A less subtle critique was issued by subsequent editors of the *Principia*, who modified the poem. For an analysis of Halley's poem and its fate see W. R. Albury, 'Halley's Ode on the *Principia* of Newton and the Epicurean Revival in England', *Journal of the History of Ideas* 39, 1 (1978): 24–43.

[19] Van Besouw and Steffen Ducheyne, 'Characterisations', 361.

[20] Levitin, *Kingdom of Darkness* also challenges the typical underestimation of the importance of Gregory's and Keill's engagement with Newtonian philosophy at Oxford.

these ideas more fully in their lectures on physics and astronomy. In so doing, their pedagogy addressed questions and stimulated debates that would preoccupy Newton's Scottish readers for much of the eighteenth century.

This chapter situates Gregory's and Keill's engagement with Newton at Oxford, where Keill first developed ideas that would be central to his teaching in the context of the debate over the origins of the Earth, contrasting this engagement with that of Arbuthnot. It outlines Newton's role in Gregory's and Keill's subsequent teaching, demonstrating how they developed their ideas about Newton's philosophy in the classroom and the published accounts of this teaching. It concludes by contrasting Gregory's and Keill's Newtonian pedagogy with that of Pirrie, highlighting the importance of institutions of higher learning for Newton's reception as a philosopher.

Newton's Scottish Reception at Oxford

Though warm words are to be expected on such occasions, Gregory's inaugural address ought to be taken seriously in its characterisation of Oxford as at the forefront of mathematics, astronomy, and natural philosophy. He described his new institution as 'this renowned university' and gave it much credit for making 'physical science' in England internationally significant and the object of foreigners' envy.[21] Yet Oxford is rarely taken by scholars to have been at the cutting edge of developments in philosophy in this period. It has even served historians as a means to highlight the apparent gulf in quality between higher education in England and Scotland in the eighteenth century.[22] As a Snell exhibitioner in the 1740s, Adam Smith complained of the 'extraordinary and most extravagant fees' there and joked about how unlikely a student would be to 'endanger his health at Oxford by excessive study'.[23] In the *Wealth of Nations* (1776) he noted that 'in the university of Oxford, the greater part of the publick professors have, for these many years,

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[21] Lawrence and Molland, 'Inaugural Lecture', 172.

[22] See, for example, Porter, *Enlightenment*, 347.

[23] Adam Smith to William Smith, Oxford, 24th August, 1740, *The Glasgow Edition of the Works and Correspondence of Adam Smith, Vol. 6: Correspondence*, (eds) Ernest Campbell Mossner and Ian Simpson Ross, 2nd ed. (Oxford: Oxford University Press, 1987), 1.

given up altogether even the pretence of teaching'.[24] Another David Gregory, Regius professor of history at Oxford between 1724 and 1736, had earlier described the curriculum as 'in some measure defective, since we are obliged to adhere so much to the rules laid down by our forefathers', with 'the old scholastic learning' persistent 'because nothing else has been substituted in its place'.[25]

Smith was in good company among disgruntled Oxford alumni scornful of the university's curriculum, with the English philosophers Thomas Hobbes (d. 1679) and John Locke (d. 1704) having made similar dismissive judgements later in their lives. Mordechai Feingold has offered a correction to the impression created by such complaints, arguing that throughout the seventeenth century students at Oxford were exposed to many new developments in the mathematical and physical sciences.[26] He concluded that the university in this period had an 'essentially liberal environment' that facilitated a 'swift and largely unchecked dissemination' of 'new modes of thought among teachers and students alike'.[27] Regardless of how Oxford's general scholarly quality in this period is to be judged, Gregory and Keill found an institutional setting friendly to serious engagement with the latest ideas in mathematics and philosophy. That said, they did not need to move to Oxford to come into contact with them. Edinburgh's intellectual scene prior to the coming of Enlightenment has itself been derided as in the grip of a 'fanatical clergy', but historians have since shown that the reception of the new science had deep roots by the time Newton's *Principia* appeared.[28] Engagement with Kepler's celestial physics can be found in extant graduate theses at Edinburgh in the 1610s and Descartes' philosophy appeared

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[24] Adam Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations*, vol. II (London: 1776), 343.

[25] Quoted in Nicholas Phillipson, *Adam Smith: An Enlightened Life* (New Haven, CO: Yale University Press, 2010), 38.

[26] Mordechai Feingold, 'The Mathematical Sciences and New Philosophies', in *The History of the University of Oxford: Volume IV, Seventeenth-century Oxford*, ed. Nicholas Tyacke (Oxford: Oxford University Press, 1997), 359–448. See also several contributions to Philip Beeley, et al. (eds.), *Reading Mathematics in Early Modern Europe: Studies in the Production, Collection, and Use of Mathematical Books* (New York, NY: Routledge, 2021).

[27] Feingold, 'Mathematical Sciences', 361.

[28] Hugh Trevor-Roper's notorious description is quoted in McOmish, 'Scientific Revolution in Scotland'. See also Wood, 'Scientific Revolution in Scotland'.

in theses at Marischal College, Aberdeen as early as 1654.[29] Christine Shepherd showed that Cartesian physics became widespread in Scottish education after mid-century and that Newton's ideas found their way into the curriculums of all Scotland's universities before 1700.[30]

As his inaugural address strongly suggests, Gregory's own engagement with Newton's philosophy began prior to his appointment at Oxford. He was born in Aberdeen and educated at Marischal before studying widely in continental Europe.[31] His mathematical interests were stimulated by the work of his uncle, James Gregory (d. 1675), professor of mathematics at St Andrews and Edinburgh, whose papers were inherited by Gregory's father, David Gregory (or Gregorie). By the time the younger David Gregory read the *Principia* he had already initiated correspondence with Newton and sent him a copy of his *Exercitatio Geometrica* (1684).[32] He had also developed a firm interest in celestial physics by the 1680s, evidenced by his having introduced students to Descartes' vortex theory at Edinburgh in lectures on mathematics and mechanics.[33]

Despite these evident pre-existing interests, Gregory's Newtonianism has often been viewed as the product of politics and patronage. The move to Oxford is typically seen as a flight from Presbyterian persecution and connected to the apparent affinity between Newton's philosophy and both Episcopalianism and Jacobitism.[34] Phillip Beeley has suggested that the support of Newton in Cambridge for Gregory's bid to become Savilian professor of astronomy was motivated by the prospect of 'Gregory's [Newtonian] circle'

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[29] See McOmish, 'Scientific Revolution in Scotland', 157–8 and 170–3; and Gellera, 'Reception of Descartes', 180.

[30] See Shepherd, 'Philosophy and Science'; and Shepherd, 'Newtonianism in the Scottish Universities'.

[31] See Anita Guerrini, 'Gregory, David (1659–1708), Mathematician and Astronomer', *Oxford Dictionary of National Biography*, 2008, accessed 13th March, 2023: doi.org/10.1093/ref:odnb/11456.

[32] For this correspondence and Gregory's engagement with Newton's mathematics see Beeley, 'Great Alterations in the Geometry'.

[33] See Christina M. Eagles, 'The Mathematical Work of David Gregory, 1659–1708', (PhD thesis, University of Edinburgh, 1977), 183–229; and Eagles, 'Gregory and Newtonian Science', 218–22.

[34] The visitation commission that followed the re-establishment of Presbyterianism in the Church of Scotland as part of the Revolution Settlement of 1689 has been described as a 'purge' of the universities in Michael Lynch, 'The Creation of a College', in *The University of Edinburgh: An Illustrated History*, Robert D. Anderson, et al. (Edinburgh: Edinburgh University Press, 2003), 49. The circumstances around Gregory's move to Oxford are discussed in Lawrence and Molland, 'Inaugural Lecture', 145.

gathering in nearby Oxford. He argued that it was by way of Newton's 'tight control over his erstwhile Scottish circle', maintained 'through a complex web of support and sanction', that Oxford became a hub of Newtonian activity.[35]

While there is little evidence that the power of Newton's *patronage* influenced Gregory's views, it is clear that the *Principia* made a lasting impression on him. Shortly after reading it he began composing a commentary on the text, 'Notae in Newtoni Principia', which went unpublished but held his attention for much of the rest of his life. At least at Oxford, Gregory also began teaching Newton's theory of gravitation with the clear intention to demonstrate how it disproved vorticism and all other alternative planetary systems.[36] His 'Notae' are often cited as evidence for his competence as a mathematician and reader of the *Principia*, and manuscript evidence for his teaching at Oxford has recently received due scholarly attention. However, his *Elementa*, which contains a mature statement on celestial physics developed out of that teaching, has been largely ignored by scholars.[37]

Keill's move to Oxford and his admiration for Newton are often connected to his relationship with Gregory.[38] However, Keill is better known for his role in the calculus dispute than for his pedagogy, and he has been given much of the responsibility by some historians for the bad blood that developed between supporters of Newton and Leibniz.[39] He was born in Edinburgh and is understood to have become one of Gregory's 'most accomplished' students at the university there.[40] After Gregory's move, Keill enrolled at Oxford on a 'Scotch exhibition' and incorporated MA in 1694. After then acting as deputy professor of natural philosophy, Keill was unsuccessful in acquiring a permanent chair following the deaths of Millington (1704) and Gregory. He subsequently left Oxford but was offered the Savilian astronomy professorship in 1712, following the death of Gregory's successor, John Caswell, after only 4 years in the chair. Keill acknowledged Gregory's

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35 Beeley, 'Great Alterations in the Geometry', 21.

36 See Eagles, 'Gregory and Newtonian Science'.

37 On the apparent relative importance of the 'Notae' over the *Elementa* see Guicciardini, *Reading the* Principia, 179–84; and I. Bernard Cohen, *Introduction to Newton's 'Principia'* (London: Cambridge University Press, 1971), 189–91. Manuscript evidence for Gregory's Savilian lectures is discussed in Levitin, *Kingdom of Darkness*, 638–44.

38 See John Henry, 'Keill, John (1671–1721), Mathematician and Natural Philosopher', in *Oxford Dictionary of National Biography*, 2004, accessed 13th March, 2023: doi.org/10.1093/ref:odnb/15256.

39 See Hall, *Philosophers at War*; and Guicciardini, 'Calculus Controversy'.

40 Henry, 'Keill, John'.

influence in the *Introductio ad Veram Astronomiam*, whom he called 'my Preceptor', declaring that 'it is owing to him [i.e. Gregory] if I have made any Advances in this study'.[41] But, as will be shown below, Keill had by this time developed a new perspective on the power and pedagogical value of Newtonian celestial physics to that of his erstwhile teacher.

Keill was made Millington's deputy in the natural philosophy chair following the publication of his critical responses to Burnet, Beverly, and Whiston. His *Examination of Dr. Burnet's* Theory of the Earth (1698) and *Examination of the* Reflections on the Theory of the Earth (1699) – the latter a response to Beverly's *Reflections upon* The Theory of the Earth*, Occasion'd by a Late Examination of it* (1699) – raised issues he later pursued in his natural philosophy lectures, and composing them may have played an important role in the development of his views.[42] Burnet's *Theoria Sacra*, which he completed in 1688 by adding a second part mostly concerned with the Earth's ultimate fate, provoked considerable debate on a variety of issues, such as the scriptural basis for Burnet's claims, the purported shape of the earth in his account, and the quantity of water involved in the Biblical Flood. Burnet had held a fellowship at Christ's College, Cambridge and was interested in the philosophy of Descartes and the work of the theologian and Platonist philosopher Ralph Cudworth (d. 1688), who was master of Christ's when Burnet became a fellow there. To some extent, Burnet developed the account of the Earth's history he found in Descartes' *Principia Philosophiae* (1644) and readers were typically quite aware of this influence.[43]

Keill believed Burnet, and his defender Beverly, had succumbed to the Cartesian 'fancy of making a World, and deducing the origination of the Universe from Mechanical principles'. He was critical in particular of their efforts to provide explanations for such things as the alignment of the Earth's axis, which Burnet claimed had been different before the Flood, rather than to concern themselves strictly with the effects such facts of nature

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[41] Keill, *True Astronomy*, p. xiii. Hereafter *True Astronomy*. All quotations taken from this edition unless otherwise stated.

[42] John Keill, *An Examination of Dr. Burnet's* Theory of the Earth *Together with Some Remarks on Mr. Whiston's* New Theory of the Earth (Oxford: 1698); John Keill, *An Examination of the* Reflections on the Theory of the Earth *Together with a Defence of the Remarks on Mr. Whiston's* New Theory (Oxford: 1699). On the wider context of these publications see Poole, *World Makers*.

[43] For Burnet's views and influences see Thomas Rossetter, 'The Theorist: Thomas Burnet and his Sacred History of the Earth' (PhD thesis, Durham University, 2019); and Thomas Rossetter, 'Anti-voluntarism, Natural Providence and Miracles in Thomas Burnet's *Theory of the Earth*', *The British Journal for the History of Science* 56, 1 (2023): 1–20.

brought about.[44] He attacked Beverly on this point for 'inquiring into Physical causes, when there are none that can be known, and neglecting the final ones, which were the only real principles by which the question [i.e. why the planets were positioned and aligned as they are] was to be determin'd'.[45] A 'physical cause' was for Keill akin to Aristotle's 'efficient cause', that which is 'the original of change or rest'. A 'final cause' was essentially as Aristotle had it, 'what something is for' – though, more specifically in this case, the end for which God intended it.[46] Keill's objection to Burnet's and Beverly's philosophy was rooted in his view of the limits of the discipline due to the inscrutability of the act of Creation and God's continued activity in the world. Physical causes of certain phenomena or facts were impermissible because they purported to explain God's actions. The final causes deriving from the study of these phenomena or facts were all that could be justly pursued in philosophy.

In an appendix to *An Examination of Dr. Burnet's* Theory of the Earth, Keill addressed the handling of these issues in Whiston's *A New Theory of the Earth, from its Original to the Consummation of All Things* (1696). The centrepiece of Whiston's theory was the development of Newton's ideas about comets, in which he proposed that the planets were originally comets, that the near passage of a comet determined the rotation and shape of the Earth, and that the tail of a passing comet caused the Flood.[47] Keill acknowledged the technical competence of Whiston's calculations of cometary orbits in past times but rejected his theory outright on the grounds that the Deluge 'was the immediate work of the Divine Power' and no cause can be assigned for God's 'Omnipotence'.[48] There was much that could be established about the shape and composition of the Earth, as well as the history of cosmic activity, but Keill saw his opponents as asking several of the wrong questions on these topics.

Whiston replied to Keill in *A Vindication of the* New Theory of the Earth *from the Exceptions of Mr. Keill and Others* (1698), insisting that it was wrong to eschew the investigation of the causes of miracles. In a subsequent appendix to the *Examination of the* Reflections on the Theory of the Earth, Keill reiterated his point, claiming that 'Christians

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[44] Keill, *Examination of Dr. Burnet's* Theory of the Earth, 19.

[45] Keill, *Examination of the* Reflections on the Theory of the Earth, 32.

[46] Aristotle, *Physics*, trans. Robin Waterfield (Oxford: Oxford University Press, 2008), 39.

[47] See Poole, *World Makers*, esp. 68.

[48] Keill, *Examination of Dr. Burnet's* Theory of the Earth, 178.

have always thought' such things as the act of Creation and the Flood 'could never be produced by Laws of Motion and Mechanism'.[49] The only cause that can be assigned for these events is the free and inscrutable exercise of divine power. Quite apart from the plausibility of Whiston's appeals to the astronomical evidence, the very attempt to explain such things was bound to result in error, for the explanation of God's direct actions, such as the miracle of Creation and maintenance of natural laws, were simply beyond human reckoning. He therefore connected Whiston's enterprise to that of Burnet and Beverly, all of whom had improperly used mechanical philosophy to answer fundamental questions about the origin and formation of the universe. In his published natural philosophy lectures, Keill would lay particular emphasis on this issue and seek to outline the proper place of mechanism in the natural philosopher's toolkit.

Evidently, Keill did not see eye-to-eye with a number of his contemporaries on what constituted the 'true physics' with which these lectures were concerned. In the case of Whiston, it is clear that so-called Newtonians might not only disagree with each other on the fundamental lessons to be drawn from Newton's philosophy but could simply direct their apparent Newtonianism to different ends. Arbuthnot, who encountered Gregory and Keill at Oxford in the 1690s, was a fellow educated admirer of Newton, but one whose interests differed significantly.[50] In his *Essay on the Usefulness of Mathematical Learning* (1701), Arbuthnot heaped praise upon 'the glory of this Age, and the honour of the *English Nation...* the incomparable Mr. *Newton*'. He claimed Newton produced 'a perfection in *Philosophy*, that the boldest thinker durst hardly have hoped for', and that 'unless Mankind turn barbarous, will continue the Reputation of this Nation, as long as the Fabrick of Nature shall endure'. He asked, 'after this, what is it, we may not expect from *Geometry* join'd to *Observations* and *Experiments*?'.[51] But as he does not compare Newton's philosophy to alternatives, nor critically appraise its content, the most Arbuthnot offered by way of detail as to why expectations should be so high is that 'in all Ages and Countries, where Learning

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[49] Keill, *Examination of the* Reflections on the Theory of the Earth, 166.

[50] See Angus Ross, 'Arbuthnot [Arbuthnott], John (bap. 1667, d. 1735), Physician and Satirist', in *Oxford Dictionary of National Biography*, 2004, accessed 13th March, 2023: doi.org/10.1093/ref:odnb/610.

[51] John Arbuthnot, *An Essay on the Usefulness of Mathematical Learning. In a Letter from a Gentleman in the City, to his Friend at Oxford* (Oxford: 1701), 12–4.

hath prevailed, the Mathematical Sciences have been looked upon as the most considerable branch of it'.[52]

Arbuthnot's design in the *Essay* was to promote mathematics, not produce an exposition of Newtonian philosophy, but the finer details of Newton's example were also absent from his own philosophical work. In his *Examination of Dr. Woodward's Account of the Deluge* (1697), a response to the English naturalist John Woodward's *Essay toward a Natural Theory of the Earth* (1695), Arbuthnot made a quite different intervention in the debate than had Keill. He acknowledged the need to 'survey the Works of Nature' with geometry and 'build upon true and decisive Observations' by 'compiling Theories', but had little to say about the alternative. He did not warn his readers of the dangers of false philosophy but merely cautioned them against committing to a 'darling Hypothesis', as he claimed Woodward had done, observing that 'Mankind, in these Matters, is naturally too rash'.[53] These remarks are a reminder that there was little appetite in this period for commitment to any kind of scientific orthodoxy, especially one laid down by a single author. Great admiration for Newton's work did not imply a desire to adopt his methods and conclusions in their entirety, and certainly was not intended to signal such a desire to contemporaries.

'The Causes of Natural Things' in John Keill's Natural Philosophy Lectures

The presence and function of Newton's example in Keill's subsequent teaching reveals how the *Principia* served him not merely as source of knowledge but as a tool to develop his ideas on important philosophical issues that had preoccupied him in the 1690s. In this respect, the 1703 *Oxford Almanack* gives the historian a false impression, as the summary account presented there describes a 'Course of Mechanical and Experimental Philosophy, performed by Mr. John Keill'. He is supposed to have 'shown and proved' much of this

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[52] Arbuthnot, *Usefulness of Mathematical Learning*, 2.

[53] John Arbuthnot, *An Examination of Dr. Woodward's Account of the Deluge &c. With a Comparison between Steno's Philosophy and the Doctor's, in the Case of Marine Bodies Dug Out of the Earth* (London: 1697), 62–3. See Poole, *World Makers*, 65–68.

course 'by *Experiments'*, including a 'great variety' using an air-pump, and demonstrated the use of machines and instruments such as 'the *Magick Lanthorn*'.[54] His published lectures suggest that Keill spent more time than the *Almanack*'s account allows on abstract matters, in which Newton's example played an important, if sometimes implicit, role.

By pursuing his own philosophical interests in his lectures on natural philosophy, Keill broke from recent tradition at Oxford. During the seventeenth century, the Sedleian professor of natural philosophy and the Savilian professor of astronomy began to observe what has been called a 'silent split' in their responsibilities, whereby the former taught the life sciences and natural history and the latter physics and cosmology. This arrangement would have suited Thomas Millington, who acquired the Sedleian chair in 1675 and whose interests lay precisely in the areas he would thereby teach according to the prevailing division of labour. In reality, however, he appears to have spent little time at Oxford, preferring London, where he was a successful physician and an active member of London's Royal College of Physicians.[55] As his deputy, Keill was by statute required to lead students through an extensive Aristotelean natural-philosophical corpus, working from the *Physica* toward *De Anima*, but it was quite normal, especially by the later part of the seventeenth century, for lecturers to ignore such stipulations.[56]

Keill's lectures were therefore entirely of his own devising, and provide great insight into his priorities. The content of the *Introductio ad Veram Physicam* indicates the importance of Newton's *Principia* to this teaching, but it is Keill's critical remarks on alternative approaches to the discipline that reveal the significance of the work to his thinking about philosophy. Any reader familiar with the *Principia* would have been quite sure of its influence on the subject matter of Keill's lectures, however Newton's name was used sparingly and it was nowhere declared that the true physics being taught was 'Newtonian'. It was therefore not made explicit what Keill made of Newton's philosophy exactly. The inquisitive reader could nevertheless find clarity on this issue by connecting the scant remarks made directly about Newton himself with the correct approach to the discipline Keill outlined in the opening lecture through a composite portrait drawn from the best of the major philosophical traditions in history. While it was not described as such, the

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[54] *The Oxford Almanack for the Year of Our Lord God 1703* (Oxford: 1703), [56–7].

[55] A. J. Turner, 'Millington, Sir Thomas (1628–1704), Physician', in *Oxford Dictionary of National Biography*, 2004, accessed 14th Jul., 2023: doi.org/10.1093/ref:odnb/18764.

[56] Feingold, 'Mathematical Sciences', 390.

reader – and, presumably, the attentive student – could find in this vision a means of understanding the chief virtues of Newton's philosophy.[57]

While scholars have had little trouble identifying Keill's vision of natural philosophy as Newtonian, he has often been understood as privileging mathematical philosophy above all other kinds.[58] For Gustavo Sarmiento, Keill saw geometry as 'fundamental' to natural philosophy such that it yields knowledge of 'natural forces' and believed that the 'principles of physics' must take the form of 'mathematical expressions'.[59] Van Besouw and Ducheyne have argued that Keill was anomalous among Newton's early readers in that he 'explicitly denied that Newton was to be considered an experimental philosopher'. For them, Keill only considered Newton as a 'mathematical philosopher', his discussion of mechanical philosophy being a discussion of Cartesian mechanism.[60] This chapter argues that Keill's vision of natural philosophy combined the most useful aspects of both experimental and mathematical philosophy with proper mechanical philosophy and, somewhat idiosyncratically, what could be salvaged from Aristotle's approach to physics.

In the preface to the printed account of his lectures, Keill noted that mechanical philosophy was 'in great Repute' but lamented that in most of it 'there is scarce anything Mechanical to be found besides the Name'.[61] His central complaint was that

> Men ignorant of Geometry presume to Philosophize, and to give the Causes of Natural Things. For what can we expect but Mistakes, from such, as having neglected Geometry, the Foundation

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[57] Van Besouw and Ducheyne, 'Characterisations' argues that while 'Keill criticised the "Cartesians", he did not oppose their approach to a method that he considered to be unique to Newton' (370). For an alternative view that holds Keill contrasted Newtonian and Cartesian philosophy see Sarmiento, 'Cartesianismo, Newtonianismo y Método'.

[58] See works cited in footnote 57; E. W. Strong, 'Newtonian Explications of Natural Philosophy', *Journal of the History of Ideas* 18, 1 (1957), esp. 53; and Hall, *Philosophers at War*, 143–5.

[59] Sarmiento, 'Cartesianismo, Newtonianismo y Método', 196: John Keill presenta la geometría como fundamento de la filosofía de la naturaleza y requisito de admisión a la misma, en tanto —al hacer posible su medición— permite el conocimiento de las fuerzas naturales... De acuerdo con Keill... lo central es que los principios de la física tengan la forma de expresiones matemáticas.

[60] Van Besouw and Ducheyne, 'Characterisations', 360–1. See also Anstey, 'Experimental Pedagogy', 118–20; and Levitin, *Kingdom of Darkness*, 645–52. According to Levitin, Keill believed that 'to proceed "geometrically" in natural philosophy was to avoid essentialism and speculation on causes, and work only with empirically established *properties*' (645).

[61] Keill, *Natural Philosophy*, iv–viii. All quotations taken from this edition. Hereafter *Natural Philosophy*.

> of all Philosophy, and being unacquainted with the Forces of Nature, which can only be estimated by the means of Geometry, do yet attempt to explain its Operations, by a Method not at all agreeing with the Rules of Mechanicks?[62]

Physics ought to be, in its most fundamental form, a science concerned with the investigation of forces using mathematics, eschewing the 'causes of natural things'. Keill was repeating the point made in relation to the investigation of the origins of the Earth, insisting on the eschewal of attempts to assign causes to certain natural phenomena or facts, the explanation of which must remain outside philosophy's remit.

Keill's reference to the 'rules of mechanics' appears to follow Newton's own conception of 'rational mechanics' as offered in the preface to the *Principia.* There Newton defined rational mechanics as 'the science, expressed in exact propositions and demonstrations, of the motions that result from any forces whatever and of the forces that are required for any motions whatever'.[63] Keill therefore seems to draw directly from the *Principia* to launch a critical attack on contemporary philosophy. The preface leaves the reader in little doubt as to the importance of what Newton achieved through such an approach, with Keill remarking that Newton's 'prodigious Genius has laid open more and obstruser Mysteries of Nature, than Men could ever have hoped for'. 'What all our Predecessors from Time immemorial have handed down to us concerning the Mechanical Philosophy', he claimed, 'does not amount to the tenth part of those Things, which Sir *Isaac Newton* alone, through his vast Skill in Geometry, has found out by his own Sagacity'.[64]

Such laudatory remarks were, however, confined to the preface. While the structure of the course itself gave only faint indication of Newton's influence, its content was in places lifted directly from the *Principia*. It consisted of 26 lectures that covered general topics in physics such as the 'solidity' and 'extension' of bodies, the 'divisibility' of magnitude, 'subtility' of matter, and concepts of 'motion, place and time' (II–VI), before giving attention to 'definitions' (VII–VIII and XIII–XIV), under which heading Keill introduced Newton's *regulae philosophandi* (lecture XIII). Lectures on the 'laws of nature' (XI–XII) consisted of the 'axioms' or 'laws of motion' proposed in the *Principia*, but only lectures IX and X, on 'Theorems of the Quantity of Motion, and of Spaces passed over by Bodies in motion',

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[62] *Natural Philosophy*, viii.

[63] *Principia*, 28.

[64] *Natural Philosophy*, x.

might have looked especially Newtonian on their surfaces. The final lectures (XV and XVI) were concerned with gravitation but did not advertise the fact in their ostensible subject matter, i.e. 'the Descent of heavy Bodies on inclined Planes, and of the Motion of Pendulums', and Keill rounded the work off with extracts from the late Dutch mathematician and physicist Christiaan Huygens' (d. 1695) 'De Vi Centrifuga' ('On Centrifugal Force'). Lecture I, 'Of the Method of Philosophizing', was presumably intended to provide the student and reader with an overarching definition of physics by which to make sense of this material.

From the content of that lecture, Newton's achievements cannot be supposed, as the preface may have suggested, to belong to 'mechanical philosophy' alone. Keill laid out an eclectic conception of the discipline based on a combination of the four 'sects of the greatest Eminence in History' – mechanical, mathematical, peripatetic (i.e. Aristotelean), and experimental – for 'there is no particular one, wherein we do intirely quiesce'.[65] Mechanical philosophy was criticised as false in an extreme form but of use for the explanation of certain natural phenomena when practiced using sound principles. Descartes' 'specious' vortex theory, discussed in the preface, served as an example. Described as one of the competing 'Mechanical Explications of Gravity', vortices were criticised for handling only the surfaces of interacting bodies and not the 'quantity of matter', an idea that Keill affirmed to be contrary to experience. Vorticism also requires an aether that must move faster than the earth rotates, which is 'contrary to the true Laws of Mechanicks', for such an arrangement should bring about the repulsion of bodies from the Earth, not their attraction to it. Thus, Cartesian philosophy posits forces that are contradicted by what is evident. They simply do not exist in nature. Vortex theory therefore fails in its basic objective to explain natural phenomena mechanically, for the circular motion of vortices cannot fully account for planetary motion as it has been observed without further explanation 'by what is still more unknown'.[66]

Strictly speaking, mechanical philosophers are those who 'imagine they can explain all the Phenomena of Nature by Matter and Motion, by the Figure and Texture of the Parts, by subtle Particles, and the Actions of Effluvia'.[67] The duty of the natural philosopher,

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[65] *Natural Philosophy*, 1–3.

[66] *Natural Philosophy*, iv–viii.

[67] *Natural Philosophy*, 3.

nevertheless, is to take what they can from this approach: 'to inquire with the antient Atomists, and the Followers of the new Philosophy, what are the phenomena that may be explained by Matter and Motion, and the known and established Laws of Mechanicks'.[68] Those who 'philosophize aright' can do so when they are 'able to lay down a sure Foundation, and firm Principles of the Mechanical Philosophy, and explain the Phenomena, which are thence to be deduced'.[69] Newton's unprecedented contributions to mechanical philosophy were surely included in what was meant here, indicating that Newtonian philosophy differs from Cartesian philosophy most importantly in being directed toward explaining the right kind of natural phenomena. That is, when used along with the right principles, the laws of mechanism can provide valid explanation, making sense of Keill's designation of Newton's achievements as lying within mechanical philosophy despite his criticism of the tradition in its extreme form. Keill's rational mechanics outlined in the preface must then represent what he saw as the proper approach to mechanical philosophy.

His descriptions of the other 'eminent sects' furnish the rest of the philosophical toolkit needed to 'philosophize aright'. Mathematical philosophy, after the ancients Pythagoras and Plato (428/7–348/7 BCE), involves the 'assistance' of arithmetic and geometry to bring certainty to the discovery of causes. Descartes 'was a famous Geometer, yet that he might accomodate himself to the idle and common Herd of Philosophers, made no use of Geometry in his Philosophy', so it is little surprise that he erred in his conclusions.[70] The peripatetic tradition is that which attempts to explain natural phenomena 'by Matter and Forms, Privations, Elementary Virtues, occult Qualities, Sympathies and Antipathies, Faculties, Attractions, and the like', though when used appropriately such an approach involves only giving 'proper Names to the Things'. Thus, 'scholastic' philosophy was succinctly reduced to the practice of mistaking nomenclature for causation. This error, most obviously in applying to 'attractions', emphasised the importance of Newtonian causal agnosticism. Gravitation, Keill believed, can be called a 'Quality, whereby all Bodies are carried downwards' wherever its 'Cause' arises from. Whether gravity is 'innate to Matter itself', or arising from the 'Virtue of the central Body',

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[68] *Natural Philosophy*, 7.

[69] *Natural Philosophy*, 10–11.

[70] *Natural Philosophy*, viii.

the 'Action of the Æther', or produced 'after another manner whatever', the natural philosopher properly ought only to identify its existence in order to account for its effects.[71]

The discovery of such qualities is made possible by experimental philosophy, by which the 'Properties and Actions of all Bodies may be manifested to us, by the means of our Senses'.[72] This was essential to Keill's account of how to do philosophy, and certainly central to his understanding of Newtonian physics. He claimed that, as philosophers, 'we shall define all things by their Properties, chusing out one or more of the simplest, which by experience we are certain do really belong to the things themselves' before 'after a Geometrical manner [we shall] deduce other Properties of the same things'. In his discussion of experimentalism, Keill reiterated the importance of clear and accurate definitions, insisting that 'we shall after the Method of the Geometers, premise such Definitions, as are necessary to arrive at the Knowledge of Things'. This activity was distinguished sharply from 'Logical Definitions, which consist of the *Genus* and *Difference*' intended to 'discover the intimate Essence and the ultimate Cause of the thing defined'. This is to be avoided, for the 'intimate Nature and Causes of Things are not known to me' – nor can be to anyone, for the acquisition of such knowledge is beyond the capacity of the human mind.[73] Mathematics, rather than traditional 'logic', offers the surest means of reasoning in a science based on properties.

In lecture XV, Keill clarified that the 'Business of the true Philosophy' was the 'explaining of' and 'reviewing the Phenomena thence arising from' the 'Motions that arise from given Forces'. He recommended that the student begin with what is 'most simple', the 'force of Gravity'.[74] Elsewhere in the lectures, Keill urged against the pursuit of the causes of the fundamental properties of bodies, such as those described by the first 'law of nature' (as he rendered Newton's first 'law of motion'): 'Let the Philosophers at length leave off inquiring into the Cause of the Continuation of Motion; for there is no other besides that first Cause, which does not only preserve Motion, but every thing else in its *Being*, namely, the All-Wise and Great God'.[75] Newton's physics functioned to substantiate a critique of contemporary natural philosophy directed toward identifying the 'causes of

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[71] *Natural Philosophy*, 1–2 and 4.

[72] *Natural Philosophy*, 3–4.

[73] *Natural Philosophy*, 8.

[74] *Natural Philosophy*, 206.

[75] *Natural Philosophy*, 136.

natural things'. By Keill's reckoning, natural philosophers must cease their pursuit of the causes *of* bodily properties and cease taking properties to be causes of phenomena *in themselves*. Rather, the natural philosopher ought to conduct the business of explanation by way of Newtonian mathematical rational mechanics from the forces and other properties determined through experimentation (or, at least, a kind of experimental, inductive reasoning).

Newton's *Principia* did not just act as the basis of Keill's lectures, as if he intended only to deliver the teachings of his master to a new generation of students. Newton's example delivered a deeper and more comprehensive lesson about the 'business of true philosophy'. Keill poured scorn on Cartesian philosophy and drew on Newton's *Principia* to outline an ideal approach to the discipline, bringing together the best features he found in the major philosophical traditions in history. Newton's philosophy was so important because it proceeded from proper principles and exemplified the discovery of both the fundamental 'properties', or 'qualities', of bodies and the laws of nature, through which the causes of natural phenomena may be properly assigned. This was what distinguished Newton from those who had come before.

While each sect had its virtues it also had its drawbacks, and Keill believed the natural philosopher ought to judiciously discriminate between them. He intended to help his audience do so by carefully determining the object of the enterprise: the explanation of natural phenomena by way of the 'properties and actions of bodies', such as the force of gravity. Rational mechanics may be of great use in this enterprise, but it is not synonymous with it. Newton's *Principia* served Keill as a model not because it exemplified the discipline in its entirety but because it acted as a discrete and profound example of true physics. What it did not do, crucially, was attempt to explain the inexplicable: the causes of natural things.

Newton and the Philosophers in David Gregory's *Elementa*

Subsequent editions of Keill's lectures endorsed Gregory's *Elementa* in terms that suggest Keill approved of the work's handling of philosophical issues, an aspect of Gregory's thought that has long been underestimated by historians. He praised Gregory's monumental work, which first appeared the year after Keill originally published his natural philosophy lectures, for demonstrating how Newton's 'Mechanical Principles may be easily applied to explain the Affection of such Bodies as are at a distance from us, namely, the Motions and Inequalities of the Planets', remarking that the work 'will last as long as the Sun and Moon endure'.[76] Modern scholars have typically thought otherwise. I. Bernard Cohen gave consideration to Gregory's reading in his *Introduction to Newton's 'Principia'* (1971) but said virtually nothing about the *Elementa* beyond supposing its preface may have been written by Newton. In the preface, Gregory argued that gravitation was known to the ancients, something Newton also claimed in his 'Classical Scholia'.[77] More recently, Niccolò Guicciardini's more substantial treatment of Gregory's engagement with the *Principia* described the *Elementa* as 'ponderous', claiming Gregory 'omitted any treatment of the more abstract or theoretical parts' of Newton's work.[78]

Such treatment is rooted in the traditional classification of Gregory as a mathematician, not a philosopher, and a devoted Newtonian, a follower whose aim was to comprehend and relay his master's science rather think for himself. As with Keill's natural philosophy lectures, the *Oxford Almanack* supports a misleading impression of Gregory's interests, advertising his extracurricular 'Method of Teaching Mathematicks' as having included 'Mechanicks', the 'Principles of Astronomy', and the 'Theory of the Planets'.[79] Despite the fact that Gregory had previously taught mathematics at Edinburgh and appears, particularly in his published works, to have been predominantly interested in mathematics throughout his life, he did not treat the topics listed in the *Almanack* in exclusively mathematical terms in his lectures. Quite in line with the silent split that persisted between the occupant of the Savilian astronomy chair and the Sedleian natural philosophy professor until the arrival of Keill in the late 1690s, Gregory's teaching offered students an introduction to the business of natural philosophy as it applies to celestial physics.

Scholars have recently acknowledged Gregory's interest in philosophy, but the *Elementa* is yet to receive substantial examination. Nor has the work been considered

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[76] *Natural Philosophy*, x.

[77] Cohen, *Introduction*, 188–9. Newton's authorship need not be assumed need be assumed and his views are not entirely reflected in Gregory's text. For Newton's own ideas about ancient notions of gravitation see Levitin, *Ancient Wisdom*, 435–446.

[78] Guicciardini, *Reading the* Principia, 187–8.

[79] *Oxford Almanack*, [52–5].

within the context of his wider pedagogical aims and duties at Oxford. As the product of a decade of teaching, the *Elementa* provides considerable insight into his views and, as the origin of the lectures upon which it was based predated Keill's own lecture course, the work offers a revealing point of comparison with Keill's pedagogy. Van Besouw and Ducheyne argued that Gregory, following Newton, departed from Keill in believing that 'the search for causes was to be abandoned entirely', though they did not address what this would have meant for the basic identity of celestial physics, to which explanation was deemed central.[80] Dmitri Levitin has taken a different view and, drawing on manuscript evidence of Gregory's lectures, has characterised his approach to explanation as 'the subsumption of physics under geometry', contextualised within a shift toward 'anti-metaphysical natural philosophy' in the wake of Newton's *Principia*.[81] The *Elementa* does not contradict the manuscript evidence but it is certainly worthy of detailed treatment for, in having been published and subsequently used as both teaching material and an (admittedly weighty) introduction to the lay reader, the presentation and function of Newton in the text reached a broader audience than Gregory found in the lecture hall.

According to the statutes, the Savilian astronomy professor did not technically need to concern himself with celestial physics or philosophy *per se*, but should 'explain the whole mathematical economy of Ptolemy… applying in their proper place the discoveries of [Nikolaus] Copernicus, Geber [the Arab astronomer and mathematician Jabir ibn Aflah (*c*. 1100–1160)], and other modern writers'.[82] Though the *Elementa* indicates that Gregory took a different view of his responsibilities, the work's considerable length is some evidence that he took the comprehensive intent of such a (plainly antiquated) remit seriously. The latest discoveries in astronomy took precedence in Book I, before Book II introduced the reader to the terminology and concepts of traditional astronomy. That is, according to Gregory, the discipline as practiced by those who believed in the 'doctrine of the sphere' and understood the heavens intuitively from the viewpoint of what appears to be a stationary planet. The sequence of these books was important, he explained, because 'we must speak with the common People', but only after clearly outlining the true system so as not to confuse students nor 'make our Reason and Philosophy perpetually offer violence to our

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[80] Van Besouw and Ducheyne, 'Characterisations', 355. On the general definition of philosophy and physics in this period see Introduction, 18–20.

[81] Levitin, *Kingdom of Darkness*, 641.

[82] Quoted in Feingold, 'Mathematical Sciences', 379.

Sight and other Senses'.[83] Books III–V expanded on 'the true and genuine Foundations of Physical Astronomy' laid out in Book I to treat, respectively, planetary motion, lunar motion, and comets in greater depth.[84] Book VI then rounded off the work by considering what can be learned by placing an imaginary observer on various extra-terrestrial bodies.

If the work's readers hoped for an introduction to Newtonianism, they were to be disappointed, for the *Elementa* offered neither a definition of Newtonian philosophy nor an explicit account of Newton's physics. The wide-ranging astronomy textbook comprises, in English translation, almost 900 pages across two volumes. However, a reader keen to understand Newton's contribution to the discipline needed only turn to Book I ('Of the System of the World') for an account of the 'true system' of the heavens as contained in the *Principia*, which consisted largely of mathematical demonstrations in support of Newton's account of planetary motion. Yet Gregory did not describe this system as Newtonian nor do much to indicate his debt to the *Principia* beyond noting in the preface that its author brought celestial physics 'to such a pitch as surprises all the World'.[85] Newton's name appears in only a handful of places in the text, but Gregory nevertheless offered the attentive reader firm guidance on how – and why – to proceed in natural philosophy along Newtonian lines. Gregory did this through careful and critical treatment of those who have erred and his vision of the proper approach to physics is mostly elaborated in the negative. It is therefore through the polemic aimed at ancient and modern celestial physics that the importance of the *Principia* to the *Elementa* becomes clear.

Newton primarily functioned in the text as a counterpoint to the false philosophers who have come before. The penultimate section of Book I, concerned with the 'Causes and Reasons of the Motions of the Planets Assigned by the Philosophers', provides greatest insight into Gregory's views and is a valuable guide to decoding the few explicit remarks about Newton found throughout the work. The reader saw that by 'the philosophers' Gregory meant Kepler, Descartes, and Leibniz, all of whom he criticised, implying that all the 'causes and reasons' yet assigned for celestial motion were false.[86] Moreover, Newton not appearing among them implies that he was not, in Gregory's eyes, a philosopher who

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[83] Gregory, *Elements*, 200. All quotations taken from this edition unless otherwise stated. Hereafter *Elements*.

[84] *Elements*, 466.

[85] *Elements*, i. Only Newton's essay, 'Lunae Theoria' (Theory of the Moon), included in Book IV, is described as 'Newtonian', and only in the Latin edition: Gregory, *Elementa* (1702), 332.

[86] *Elements*, 133.

had supplied an explanation of celestial motion. It is argued here that Gregory did present Newton as a philosopher in this sense, but that he also wished to differentiate him from others by portraying him not as the progenitor of a new system but as a different kind of philosopher altogether. Newton was different because his commitment to the application of geometry to celestial physics had guided him toward a new approach to explanation. After all, if the title of the section on 'philosophers' was meant literally then Gregory would have been claiming that a centripetal force did not in any way *explain* planetary motion, contradicting what had been clearly demonstrated in the preceding sections of Book I.

Newton's triumph was put in sharpest relief in comparison with Descartes' vortex theory, but the significance of Newtonian philosophy was made most evident in contrast to Kepler's celestial physics. Gregory clearly admired Kepler and respected his achievements. He was presented alongside Newton in the preface as 'most sagacious', and a man who had 'got the scent of' Newton's discoveries.[87] In the main body of the text, Gregory lavished praise on Kepler's 'force of Genius' and claimed he was the first since the time of Pythagoras to treat 'Celestial Physics in a Mathematical manner'.[88] In the preface, Gregory also seemed to diminish the significance of Newton's authorship of the true system by arguing that it was 'both known and diligently cultivated by the most ancient Philosophers'.[89] Newton's achievement was made to look more modest still as Kepler not only showed 'what Laws a Planet must move by' but discovered the cause of the tides and demonstrated the 'gravity of a given body toward any other universally'.[90] Kepler's greatest mistake seems to have been that he simply forgot the 'true Doctrine of Gravity' after hitting upon it in his *Astronomia Nova* (1609).[91] His example was therefore particularly instructive because, despite his discoveries, 'genius', 'sagacity', facility with geometry, and application of mathematics to celestial physics, Newton was the one who had raised celestial science to its highest 'pitch'.

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[87] *Elements*, i.

[88] *Elements*, 145.

[89] *Elements*, iii.

[90] *Elements*, 375. Gregory, *Elementa*, 384: 'cujusvis corporis Gravitatem in quodvis universaliter ostendit [Kepler]', rendered in the 1715 English edition, 'he [Kepler] has shown the Gravity or Gravitation of all bodies towards another' (*Elements*, 668).

[91] *Elements*, 149.

The difference between Kepler's and Newton's approaches to *philosophy* was what determined the latter's success. Despite all of his merits and accomplishments, Kepler proposed a false explanation of celestial motion rooted in an ancient philosophical tradition that Newton rejected. For Gregory, Kepler's works contain an overly complicated account of attraction as the explanation of planetary motion and employ a false conception of the inherent 'Virtue' of bodies – related too much to 'Animal Power' and not enough to 'Mechanism'.[92] Thus, he will be 'Immortal' only 'among the common System-makers or hunters after Physical Causes'.[93] It is not immediately clear why this should be, but becomes so in light of Gregory's subsequent discussion of Descartes. With Kepler having already shown that a physical vortex could only result in perfectly circular (i.e. not elliptical) orbital motion, Descartes' vortex theory was patently developed without the guidance of mathematics.[94] Descartes was rather 'resolved to frame a World' and simply drew on Kepler's discussion of a celestial vortex without paying attention to the 'niceties' of Kepler's treatment – nor any astronomical observations. In so doing, Descartes also drew on an ancient notion, dating back 'long before... even *Epicurus*'s Time', that the planets must be moved by the Sun or both by 'one common Cause'. This primitive notion of an 'Æther, whirl'd about the Sun by a Vortex or Whirl-pool' provided, in Gregory's view, the basis for Descartes' reasoning.[95]

Using this approach, Descartes supposed that fundamental 'elements' were formed long ago from the stirrings of matter in this universal ether, from which bodies appeared over time and set off on courses that would, if unimpeded, trace perfect circles around the Sun.[96] In Gregory's account of Kepler's system elaborated in the previous subsection, it was shown to Kepler's discredit that he had developed a philosophy from 'principles' that resemble Descartes' later 'elements'. Gregory outlined Kepler's vision as that of a 'gyrating' Sun 'carrying about the immateriated Species of its own Body thro' the vast Spaces of the World... like a Leaver'.[97] It was from this image that Kepler derived his false notion of the inherent 'virtue' of planetary bodies. Though this point was made implicitly in the *Elementa*,

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[92] *Elements*, 148.

[93] *Elements*, 145.

[94] *Elements*, 150.

[95] *Elements*, 151.

[96] *Elements*, 150–63.

[97] *Elements*, 135.

Kepler was therefore also framing a world – just one less fanciful than Descartes'. Newton's singular triumph, therefore, was to resist the urge toward vain explanation and adopt *mathematical* principles as the basis for his philosophy. Kepler's and Descartes' approach to philosophy shared an ancient simplicity, though not that of Pythagoras, who had actually known of the true system. Kepler may have followed Pythagoras in applying mathematics to celestial physics but his approach to explanation followed an errant tradition of reconstructing the universe according to intuitive physical principles, producing an *a priori* system that amounts to the fabrication of a world.

Gregory may have claimed that modern celestial physics was both 'known and diligently cultivated' by the ancients, but by that he did not mean the discipline was common knowledge throughout antiquity. Pythagoras promoted the 'true System of the World' and knew of the inverse-square 'theorem' of gravity, but Gregory's survey of ancient authors argued that only the mere notion of universal gravitation remained by the time of the poet Lucretius (i.e. 1st century BCE), whose Epicurean philosophy (i.e. after the philosopher Epicurus, 341–271 BCE) contained only remnants of the true system and, as noted later in Gregory's discussion of the Epicurean universe in relation to Cartesian physics, was not itself based upon mathematical principles.[98] His brief overview of ancient celestial physics implies a corruption of Pythagorean wisdom over time, accelerated by flawed works such as Plato's *Timaeus*, until knowledge of gravitation was entirely lost and had to be rediscovered through the 'industry and skill of the Moderns'.[99]

Beyond rejecting his antiquated approach, Gregory detailed a litany of technical and philosophical errors in Descartes' arguments, leaving the reader in no doubt about its invalidity. His system was deemed unsustainable in tending toward 'rest and its dissolution' without an 'active' and 'immechanical Principle' superadding motion from the centre outwards in order to stop all matter simply coalescing in a central lump.[100] Vortex theory was presented as a mess and, according to Gregory, ''tis evident, that this Hypothesis of Vortices is entirely disagreeable with the Phaenomena of Astronomy, and conduces not so much to the explaining as the disordering of the Celestial Motions'.[101] Nevertheless, Gregory's critical engagement with Cartesian philosophy was driven in part by a concern

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[98] *Elements*, iv and ix.

[99] *Elements*, xii.

[100] *Elements*, 165.

[101] *Elements*, 172.

that others might succumb to human vanity and become 'intoxicated' by 'easier and less composite laws', as he had put it in his inaugural lecture. Gregory had good reason to enumerate Descartes' failings, for he knew well that vortex theory still had admirers, even though he played down the threat, claiming that attempts by Cartesians to establish the laws governing vortices have only shown his 'cosmic system, which he jokingly called his fable of the world... to be a fable indeed'. [102]

The danger of vorticism was represented by Gregory's contemporary Gottfried Wilhelm Leibniz, whose adherence to vorticism persisted, Gregory noted, despite the discovery of the true system. Acknowledging Leibniz to be a 'most acute Philosopher' and 'a name so celebrated among Geometricians', his commitment to vortex theory served as a reminder that skilled geometers and talented philosophers have a stubborn tendency to err.[103] Thus, in his discussion of Leibniz, Gregory returned to the demolition of vortex theory elaborated in the previous subsection, adding that in the wake of Newton's *Principia* vortices are simply unable to account for what is now known about comets. Moreover, in requiring a separate vortex for each planetary orbit they offend against simplicity, leading Gregory to wonder aloud why Leibniz doesn't just accept the 'Law of Gravity'.[104]

Gregory did not present Newton as having provided an explanation of planetary motion as emphatically as he might, but he did clarify the point if any clarification was needed. Newton was described twice as 'an incomparable philosopher' and, at the start of Book IV, Gregory noted that astronomers had tried to 'save' the phenomena of lunar motion through hypotheses, rather than explain them 'by the physical causes of the Philosopher', before 'they looked to the most happy Newton'. This implies that Newton supplied the proper explanation 'philosophers' like Kepler and Descartes could not.[105] It is the pursuit of *physical* causes that Gregory presented as improper and a source of error. In his inaugural lecture, he had referred to Newton's physics as a 'new philosophy' and praised his causal agnosticism, observing approvingly that he investigated the 'measure' of centripetal forces

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[102] Lawrence and Molland, 'Inaugural Lecture', 171.

[103] *Elements*, 173.

[104] *Elements*, 182.

[105] Gregory, *Elementa*, 282: 'Astronomi Hypothesibus salvare potius quam Philosophi ex Causis Physicis explicare, ante felicissimum *Newtonum*, sperabant', rendered in the 1715 English edition, 'such Unequalities as the Astronomers hop'd to account for by their Hypotheses, sooner than the Philosophers cou'd explain them from Physical Causes, till *Sir Isaac Newton* was so happy as to do it' (*Elements*, 466).

in orbital motion 'from whatever cause that force may arise, be it from a deeper mechanical one or from a law imposed by the supreme creator of all things'.[106]

For Gregory, it is Newton's approach to causation that makes him an incomparable philosopher. Newtonian philosophy demonstrates the mathematical laws governing the forces that bring about motion and thereby *explains* that motion without seeking the actual origin of such forces – i.e. their physical causes. The philosopher need not determine the cause of gravitation for gravitation to itself serve as a cause. Gregory could find explicit support for this view in the *Principia*, where Newton had insisted that the forces his philosophy dealt with ought to be considered 'not from a physical but only a mathematical point of view', and that, having not done so, 'philosophers have hitherto made trial of nature in vain'.[107] Gregory described the causes which he dealt with in Book I as 'such as we experience about us, and can calculate their Forces, and Geometrically investigate their Properties, as we do of any other Quantities'. These causes were not to be mistaken, he warned, for 'the ultimate Causes, or such as have no Causes of themselves'.[108] In other words, the causes of natural things.

Gregory wanted to highlight the difference between Newton and his rivals if not spell it out. He did so by emphasising how certain philosophers, despite their talents, had reached too far in what they sought to explain and therefore fell short in their attempts to establish the true celestial system. Newton had rejected primitive ancient notions of causation by way of intuitive physical principles, in favour of explanation through the forces that bring about motion according to mathematical principles of natural philosophy. In this profound move lay the basis for the success of Newtonian celestial science.

Nature's Mysteries Revealed

Keill evidently shared Gregory's view of Newton's principal contribution to physical inquiry, and was therefore well placed to carry Gregory's lectures forward after his death. In the event, he had to wait four years before he could do so, and may never have got the chance.

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[106] Quoted in Lawrence and Molland, 'Inaugural Lecture', 169–70.

[107] *Principia*, 54 and 29.

[108] *Elements*, 134.

Prior to the death of Gregory's successor John Caswell in 1712, Keill left Oxford in 1709 to serve as 'Treasurer of the Palatines', accompanying Protestant refugees from the Palatinate to the American Colonies. After returning to Europe in 1711, he was offered the role of court 'decipherer' for Queen Anne and could have become a mathematician serving the Republic of Venice, before being given the chance to take up Gregory's old chair. The lectures he gave as Savilian professor of astronomy have received even less attention than his natural philosophy lectures, and it has therefore been overlooked how Keill's presentation and understanding of Newton shifted over time.[109]

By at least 1718, when the *Introductio ad Veram Astronomiam* first appeared, Keill was apparently far less concerned with the threat of false philosophy than he had been previously. Descartes is conspicuous by his absence in the astronomy lectures, which suggests that Keill believed the influence of Cartesianism to have waned, at least among his audience, and Newtonian philosophy to be secure in its ascendency. His views on what constituted false philosophy had not changed but he had developed a new confidence in the potential of Newton's physics to reveal nature's innermost workings, which conditioned his mature treatment of causation. By the 1710s, Keill was no longer so concerned to highlight the dangers of pursuing physical causes in the manner of Kepler and Descartes and sought to emphasise the explanatory power of Newtonian celestial physics by characterising the law of gravitation as God's direct action in nature. This marked a significant shift because Keill now presented Newton as having taken philosophy as far as the capacity of the human mind allows. In this way, Keill made Newton's achievement look like it had equalled or even surpassed the vanity of false philosophers working in the ancient *a priori* tradition.

Much had transpired in the field of physical science since Keill first took aim at Cartesian world-making in the 1690s. He had declared in his natural philosophy lectures that Newton had 'laid open more and obstruser Mysteries of Nature, than Men could ever have hoped for', but did little to substantiate the claim prior to taking up Gregory's old chair. In the intervening years, the priority dispute between Newton and Leibniz over the invention of calculus had flared up (thanks in part to Keill himself) and fizzled out after Leibniz's death

[109] E.g. Guicciardini, *Reading the* Principia, 186–7.

in 1716.[110] Newton's *Opticks*, and its Latin translation, *Optice*, appeared in which queries (or *quaestiones*) addressed the issue of gravity's 'occult' status, among much else. In the queries, Newton responded to critics and clarified somewhat how he saw his own philosophical practice by insisting that 'hypotheses based on occult qualities, or mechanical, have no place in experimental philosophy'.[111] A second edition of the *Principia* appeared in 1713 which, besides amendments to the text itself, featured Newton's 'Scholium Generale' ('General Scholium') and a preface by the editor, Roger Cotes, the Plumian professor of mathematics and experimental philosophy. In that preface, Cotes was concerned with 'the method of [Newton's] philosophy' and expanded on Newton's remarks regarding hypotheses, occult qualities, and experimental philosophy.[112]

Cotes was dismissive of the peripatetics, claiming that 'they affirm that individual effects arise from the specific natures of bodies', which 'do not tell us the causes of those natures, and therefore they tell us nothing'. He distinguished the experimentalists, by which he meant the Newtonians, from the corpuscularians, by which he meant Cartesians. He observed that while the latter 'too hold that the causes of all things are to be derived from the simplest possible principles, they [i.e. the experimentalists/Newtonians] assume nothing as a principle that has not yet been thoroughly proved from phenomena'.[113] Cotes further clarified that experimentalists like Newton 'do not contrive hypotheses, nor do they admit them into natural science otherwise than as questions whose truth may be discussed'. Rather than hypothesise, they pursue a method of analysis and synthesis, in which 'they deduce by analysis the force of nature and the simpler laws of those forces, from which they then give the constitution of the rest of the phenomena by synthesis'.[114] In this latter remark, Cotes appears to have followed Newton's advice in the final *queastio* of *Optice*:

> As in Mathematicks, so in Natural Philosophy, the Investigation of difficult Things by the Method of Analysis, ought ever to proceed the Method of Composition [i.e. synthesis]. This Analysis

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[110] For Keill's role in the dispute and a connected debate over the application of mathematics to natural philosophy see Guicciardini, 'Calculus Controversy'.

[111] *Opticks*, 588.

[112] Roger Cotes, 'Editor's Preface to the Second Edition' in *Principia*, 31.

[113] Cotes, 'Editor's Preface', 31.

[114] Cotes, 'Editor's Preface', 32.

> consists in making Experiments and Observations, and in drawing general Conclusions from them by Induction, and admitting of no Objections against the Conclusions, but such as are taken from Experiments, or other certain Truths. For Hypotheses are not to be regarded in Experimental Philosophy.[115]

Van Besouw and Ducheyne have argued that there was 'very little precedent' for how Cotes 'presented Newtons' natural philosophy as a clear and definitive break with the past and as a serious competitor to the existing natural philosophies of the Scholastics and Cartesians'.[116] As argued above, Gregory and Keill had laid out the superiority and transformative power of Newton's philosophy, especially in contrast to Descartes, both in print and the classroom in the two decades before Cotes' preface appeared. Cotes' originality with respect to Gregory and Keill seems to lie in his adoption of conceptual language that Newton himself, who taught Cotes at Cambridge, used to describe his own practice, though this language only appeared in print in the years after Gregory and Keill had published their earliest accounts.

Cotes' preface sought to defend the theory of gravitation against the charge of it being an 'occult quality'. While neither Gregory nor Keill expressed the issue in this way, they addressed the matter through attention to the role of 'qualities', or 'properties', more generally in Newton's philosophical practice.[117] Cotes admitted that gravity was indeed an occult quality in the literal sense – i.e. a 'hidden' quality – but was not one in the sense of being a quality and causal agent for which there is no direct evidence. Cotes and others associated this latter kind of occult quality with Aristotle and Descartes. However, the issue had also been central to the criticism of Newton's *Principia* made by Leibniz in his 'Tentamen de Motuum Coelestium Causis' (Essay on the Causes of Celestial Motion), published in the *Acta Eruditorum* in 1689. Leibniz's argument rested on the assertion that proper physics involved mechanical explanation and physical interaction, both of which appeared to be lacking in the identification of an invisible gravitational force as the causal agent in planetary motion, for such a force appeared to 'act at a distance' – a physical impossibility.[118] As Newton's remarks in the *Optice* indicate, he affirmed that no such

[115] *Opticks*, 380.

[116] Van Besouw and Ducheyne, 'Characterisations', 370.

[117] For occult qualities in the context of medicine see Chapter 1.

[118] For Leibniz's criticism of Newton and his views on physics see Garber, 'Physics and Philosophy'.

mechanical explanation was required in his brand of experimental philosophy. Samuel Clarke agreed and defended Newton's view in the famous epistolary debate with Leibniz later in the 1710s.[119]

By this time, Keill seems to have considered the argument won, if he ever even thought the matter open to question. Gregory and Keill not only handled the issue in slightly different terms but do no appear to have been as concerned by Leibniz's argument as were Newton, Cotes, and Clarke. Neither Gregory nor Keill attempted to answer Leibniz's charge directly, but the matter was nevertheless fairly central to their treatment of Newtonian philosophy. They recognised the importance of Newton's causal agnosticism and rejected the pursuit of physical causes to account for gravitation itself, which was precisely what Leibniz thought critically lacking in Newton's argument. They clearly rejected the identification of speculative occult qualities and physical principles as causal agents – as these had appeared in the works of both Aristotle and Descartes – but the reason for their insouciance about action at a distance is not immediately obvious from their writings.

Keill's treatment of divine agency is, however, suggestive of a reason. While Gregory's and Keill's cases against speculative explanation in their lectures rested mostly on the inaccurate results of the theories which resulted from it, in the 1690s Keill had gone further in the debate over the origins of the Earth by advancing views on the limitations of the human mind to acquire knowledge of divine activity in nature. In his natural philosophy lectures, he had identified God as the cause of the laws of motion and the continuity of motion. Perhaps as a result of Newton's burgeoning renown since that time, Keill returned to the issue of divine agency in his lectures as Savilian astronomy professor and modified his presentation of Newtonian physics and the role of physical causes in philosophy. In the 1710s he apparently came to believe that the discovery of gravitation was in fact the discovery of a physical cause in that it was evidence of God's action in the world through divine legislation. With gravitation conceived as direct divine activity in nature, there is no physical impossibility in what appears to be action at a distance and no need for demonstrable mechanical interaction in physical explanation, so long as God is conceived as an all-powerful and completely free agent. Keill's debate with Whiston suggests that he

[119] See Vailati, *Leibniz and Clarke*.

did conceive of divine agency in this way, and Gregory's similar lack of concern with Leibniz's critique suggests he may have held the same conception.[120]

Keill did not outline a clear position on these issues, but the language he employed in the published account of his astronomy lectures provides valuable insight into his views. The course was divided into thirty lectures, but the printed account is less than half the length of the *Elementa*. Unlike Gregory's text, the true 'system of the World' is introduced in lecture III, only after lectures on the 'visible and apparent motion' of the heavens. This suggests that Keill worried less than his predecessor about causing confusion among his students, perhaps due to there being a greater familiarity with the true cosmic system by this time. The preface stridently celebrated Newton's achievement and, rather than draw attention to the errors of vortex theory, presented a story of progress in the fields of astronomy and philosophy. Newton was the grand final chapter of a narrative beginning in the mists of time with the god Neptune and his son Belus, an Egyptian astronomer. According to Keill, astronomy thrived in the east before being brought to Greece by the ancient philosophers Thales of Miletos (*c*. 6th century BCE) and Pythagoras, 'not only the first, but the greatest Philosophers that Greece produc'd', when 'no Body was esteem'd as a Philosopher, but who was well acquainted with the Mathematical Sciences'.[121] With the neglect and resulting demise of mathematical science among subsequent ancient philosophers, only scant remnants survived in Italy and Egypt for moderns to eventually recover and augment, leading to the revival and eclipse of ancient astronomy through the work of Polish astronomer Copernicus (d. 1543), the Danish astronomer Tycho Brahe (d. 1601), and Kepler, aided by the innovations of Galileo and others in mathematical philosophy.[122]

Kepler's achievement is clearly distinguished from Newton's in Lecture IV, where Keill explained that the former discovered the law of gravitation ('this great Law of Nature') in only a qualified sense: 'only by Computation, comparing the Distances of all the *Planets* with their Periods'. The 'physical cause of the law' was, however, 'unknown' to him.[123] 'The

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[120] For a fuller discussion of theological voluntarism among Newton's Scottish readers and its connection to action at a distance see Chapter 3.

[121] *True Astronomy*, ix–x.

[122] *True Astronomy*, viii–xii.

[123] Keill, *Introductio ad Veram Astronomiam*, 37: 'Regulæ causa Physica', rendered in the 1720 English edition 'the reason of this Law' (*True Astronomy*, 33–4).

Glory of investigating it [i.e. the law of gravity] from its proper Cause [i.e. the physical cause]', and 'demonstrating the Physical Necessity of this Law, was reserved for the Great *Sir* ISAAC NEWTON'. Thus, Newton 'has demonstrated, that without a total Subversion of the Laws of Nature, no other Rule could take place in the Circulations of the Heavenly Bodies'.[124] Keill saw Newton's approach to philosophy as having established the physical causes that both he and Gregory previously presented Newton as having strictly eschewed. Keill even recommended Gregory's *Elementa* to his readers on the basis that they may 'learn the Physical Causes of the Celestial Motions from thence'.[125]

For Keill, Newton reigned supreme and his philosophy could scarcely go further in revealing nature's mysteries:

> ... our Times, and this Country of *Britain*, have had the Happiness to produce a *Genius* of a Divine Nature and extraordinary Qualities; I mean the Great Sir ISAAC NEWTON, who, besides his innumerable other wonderful Inventions, has discovered the Fountain and Spring of all the Celestial Motions, and the Great Law which is Universally diffused through the whole System of Nature, which the Almighty and Wise Creator has commanded all bodies to observe, *viz*. That every Particle of Matter attracts each other in a reciprocal duplicate Proportion of its distance.[126]

Newton's superior approach yielded virtually all that could be hoped for from physical inquiry. He had, for Keill, actually determined the 'fountain and spring' of celestial motion in a 'great law' laid down by God himself that applies to 'every particle of matter'. Keill turned to Psalm 148 to emphasise the point:

> *It is He who spoke the Word, and the Heavens were made. He commanded and they were created. He hath made them fast for ever and ever. He hath given them a Law which shall not be broken*.[127]

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[124] *True Astronomy*, 34.

[125] *True Astronomy*, xv.

[126] *True Astronomy*, v.

[127] *True Astronomy*, vi. Keill, *Introductio ad Veram Astronomiam*, vii: 'Qui dixit, & facti sunt cæli, ipse mandavit & creati sunt. Statuit eos in æternum, iis legem dedit, quam transgedi [sic] nequeunt' – a printed marginal note identifies this as Psalm 148, and it is clearly modelled on verse 6.

In the preface to these lectures, Keill indicated that he saw gravitation as an attractive force that permeated the entire natural world. He thus signalled dissent from his brother James, who had earlier argued for the existence of a separate microscopic attractive force governed by a different mathematical law.[128] Keill's characterisation of gravity marks a shift in his thinking but was by no means new. Arbuthnot had earlier articulated a similar view in the *Usefulness of Mathematical Learning*, crediting Newton for the discovery of 'the grand secret of the whole Machine', which 'proves to be (like the other contrivances of Infinite Wisdom) simple and natural, depending upon the most known and most common property of matter, viz. *gravity*.'[129] Keill, unlike Arbuthnot, had developed a philosophical underpinning to support such claims. Gravitation was, for Keill, a physical quality or property established by experimental reasoning that accounted not just for planetary motion but the cohesion of bodies, suggesting to him that it was fundamental to Creation. George Cheyne had recently taken a similar view supported by his own understanding of the power and potential of Newtonian philosophy, and he made it central to the natural theology he developed in his *Principles of Religion* (1705).[130] There Cheyne addressed at some length questions about divine agency that followed from this position for which Keill did not attempt to provide answers.[131]

Keill's description of gravity as God's 'great law' brought his Newtonian pedagogy full circle. Having started out as a tool with which to critique contemporary philosophy and its pursuit of physical causes, toward the end of his life Keill saw Newtonian physics as the apogee of physical inquiry, capable of revealing the deepest of mysteries. He did not need to revise the fundamentals of his understanding of Newton to get there, for his mature view of physics followed from his original presentation of what Newtonian philosophy was all about. It may have taken the decline of Descartes' influence in Britain to make him see it, but Keill eventually realised that the right mixture of the mechanical, mathematical, peripatetic, and experimental philosophies was capable of establishing true physical causes and revealing God's hand in nature. In this way, it boasted as much explanatory power as any speculative system had hoped for, definitively superseding rival approaches

[128] See Chapter 1, 86–7.

[129] Arbuthnot, *Usefulness of Mathematical Learning*, 13.

[130] See Chapter 1, 75–86.

[131] See Chapter 3, 144–52.

to the study of the heavens and setting a new standard for the discipline of natural philosophy.

Institutions of higher learning did not make Keill a Newtonian, nor were they strictly necessary for himself and Gregory to arrive at their understanding of Newton's achievement. However, first Edinburgh and then Oxford provided environments in which their views could be developed and elaborated, first in the classroom and then in printed textbooks. These texts were important, for others could sing Newton's praises and defend his conclusions without articulating good reasons for lauding Newtonian physics above its rivals. One example is George Pirrie, whose *Short Treatise of the General Laws of Motion and Centripetal Forces* (1720) was issued as a defence against critics of both Newton's *Principia* and Gregory's *Elementa*, which together comprise 'the incomparably best System of natural Philosophy that ever the World was blest with'.[132] In particular, Pirrie took aim at George Gordon, whose *Remarks upon the Newtonian Philosophy* (1719) had argued that the attractive force at the heart of the theory is an 'unintelligible' cause. Gordon followed Leibniz's thinking by charging that the argument for gravitation did not demonstrate physical interaction, lacking an account of the action of 'Natural Agents' upon the 'surfaces of Bodies'.[133]

Gordon went further and criticised the 'Advantage of handling Natural Philosophy it self, in the same Method as Mathematicks.'[134] His *Remarks* consists of a detailed rejection of the argument for gravitation on two bases: 1) that its mathematical demonstrations are faulty and 2) that nature cannot be reduced to mathematical abstraction in the first place, in that it cannot be justly handled quantitatively. Pirrie's reply was a restatement of the mathematical argument for gravitation in silent defiance of Gordon's conceptual objections. He took specific issue with Gordon only in the appendix, where Pirrie argued that Gordon's mathematical objection to Newton's argument for centripetal force completely falls down when in Gordon's demonstration – modelled on Prop. 31, Prob. 23 of the *Principia* – the

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[132] George Pirrie, *A Short Treatise of the General Laws of Motion and Centripetal Forces* (Edinburgh: 1720), xi.

[133] George Gordon, *Remarks upon the Newtonian Philosophy, as Propos'd by Sir Isaac Newton, in His* Principia Philosophiae*, &c. and by Dr. Gregory, in His* Principia Astronomiae Physicae, 2nd ed. (London: 1719), 2.

[134] Gordon, *Remarks*, 6.

proportion between certain lines is taken to be simple rather than duplicate.[135] Having passed over the actual substance of Gordon's philosophical arguments, Pirrie concluded with some confidence that 'the incomparable *Newton*'s general Law of centripetal Forces, and consequently his particular Laws deduc'd from thence, stand strong and firm like a brasen Pillar, and will, I believe, do so to the World's End'.[136]

Conclusion

Such convictions obscure more than they reveal about an author's engagement with Newton. The few laudatory remarks in Gregory's and Keill's textbooks give a quite misleading impression of their engagement with Newton's example and the role it played in their pedagogy. Their reputation as committed Newtonians has not helped to recover their intentions and it has often obscured what they actually thought about physics and astronomy. Examining the presence and function of Newton in their pedagogy is instructive in several respects. It demonstrates how Newton's science did not merely serve them as a new orthodoxy with which to indoctrinate their students. So-called Newtonians did not always aim to popularise, defend, and exposit the ideas of their master. Newton's example could serve a variety of purposes, and his admirers often disagreed with each other when they were not simply pursuing quite different ends. Above all, Gregory's and Keill's Newtonian pedagogy illustrates what they thought about natural philosophy and Newton's impact on it. They saw him as breaking with a flawed ancient philosophical tradition, not as having merely discovered the true cosmic system. That had been known in ancient times and the moderns, Kepler chief among them, had more or less worked the system out and reduced it to mathematical certainties. Through the concept of gravitation, Newton supplied the *physical explanation* that finally made sense of it all, making it possible to sweep away false theories and fortify the new science. At Oxford, Gregory and Keill attempted to do just that. They presented Newton's example as vital to the further advancement of natural philosophy, and sought to encourage the reform of the discipline along Newtonian lines.

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[135] Pirrie, *Short Treatise*, 181–90.

[136] Pirrie, *Short Treatise*, 190.

For Gregory and Keill, philosophers had since antiquity pursued the wrong kind of explanation, attempting to discover physical causes through speculation and assign causes to 'natural things' that were beyond the bounds of human knowledge. Newton eschewed this enterprise and sought instead to demonstrate how bodily properties and forces, such as gravitation, give rise to natural phenomena. Gregory and Keill shared this conception of the essence of Newtonian philosophy, but they sometimes articulated it only through implication, evidently unwilling to pass Newton off as a mere authority figure. Newton's significance was for them best expressed through polemic, his achievements captured through critical differentiation from those who had come before, and erred. They presented the merits of his philosophy in different ways and their views were not static. Keill's estimation of Newton's pivotal contribution to the history of celestial physics appears to have shifted over time. With his concern over Descartes' influence having subsided, he began to present Newton as having taken physical explanation to its greatest conceivable extent. By associating the physical cause of gravitation with divine legislation, Keill raised issues regarding divine agency that he seems to have been unwilling to tackle fully. Several of Newton's readers, including Cheyne, were more than willing to do so, however. By the 1710s, a debate was already under way over the true nature of gravitation and God's role in bringing it about. Though Gregory and Keill largely avoided the issue of divine agency, their pioneering engagement with Newton's physics raised fruitful questions that invited further critical discussion and remained at the centre of debates about natural philosophy for the rest of the eighteenth century.

CHAPTER III

GOD AND GRAVITY

When I wrote my treatise about our Systeme I had an eye upon such Principles as might work with considering men for the beliefe of a Deity & nothing can rejoyce me more then to find it usefull for that purpose.

Isaac Newton to Richard Bentley[1]

In the summer of 1723, Andrew Baxter found himself overcome by frustration and thus put an end to a brief epistolary debate that, despite its obscurities, had both fascinated and compelled him. His correspondent, Henry Home (later Lord Kames), wrote to Baxter at Duns Castle, Berwickshire in late May from his family estate at nearby Kames with a view to discussing the laws of nature. By 13th June, Baxter had observed of their otherwise cordial exchange that 'it seems we shall never understand each other enough in our way of expressing our meaning to come through the Expressions to the meaning it Self'.[2] 'In truth, Sir', he sighed, 'the very best natur'd construction I can put on this, and which is yet abundantly ill-natur'd if I cou'd admit of a Better, is that you are Bamboozling & jesting me'. After Home had proposed a ceasefire, Baxter suggested that, if his own letters had not yet been destroyed, they 'burn them and our philosophical Heats together'.[3] Judging from Baxter's later publications, his correspondence with Home marked not the end but the

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[1] Isaac Newton to Richard Bentley, 10th December, 1692, quoted in Andrew Janiak (ed.), *Newton: Philosophical Writings* (Cambridge: Cambridge University Press: 2004), 94.

[2] All quotations from this correspondence are from Ian Simpson Ross, *Lord Kames and the Scotland of His Day* (Oxford: Clarendon, 1972), 63–6.

[3] Thankfully, the suggestion was not taken up: these letters survive in 'Correspondence between Henry Home, Advocate (later Lord Kames) and Andrew Baxter, Philosophical Writer', 28th May–13th July, 1723, National Records of Scotland.

beginning of serious engagement with profound questions about natural philosophy and divine providence that would he would pursue for the rest of his life.

Home, newly admitted to the Faculty of Advocates, had initiated the exchange by offering Baxter, who resided at the castle at Duns as tutor to the Hays of Drumelzier, critical reflections on how Samuel Clarke had treated a 'law of nature' as divine legislation imposing moral obligations. He then switched focus from Clarke, with whom Home was also engaged in epistolary debate, to Newton's first law of motion (which he called 'the first Law of nature'), and drew his correspondent's attention to John Keill's *Introductio ad Veram Physicam*, which in Home's opinion treated the law 'very unsatisfactorily'.[4] He claimed that Keill 'considers Motion as ane Accident or Modification, which like a certain Colour or a certain Figure being once impressed, must perpetually remain or continue without a new cause to induce an alteration'. This conception was 'very weak' for it did not resolve the problem of how a body remains in a state of motion without assuming a contradiction: that matter is simultaneously both active and passive.

The problem for Home was that the 'Hand' by which motion might be 'impressed' could no longer be said to act on a body following the moment of impression itself. Some further cause would be required to account for the continuation of the motion brought about by the initial impression on that body. This could not be resolved by appeal to an 'active power' by which 'the Substance or Agent puts itself into Action', for 'no Being can be said to put itself into Action, because that is the same as to be active and passive at the same Instant and with respect to the Same effect produced'. Home believed that 'a continual change of Place is a continuall new Effect which must require as constant a Cause', but 'seeing [that] a Hand that has once set the Body in motion can produce no effects longer than it acts, of consequence it still remains to know what is the Cause of Motion continuing even after the Hand ceases to act'. Home was sceptical about how a momentary impulse can itself be said to continually produce or maintain motion in impacted bodies. From the empirical data we gather through sensory experience, it appears that continual action – in other words, an unceasing series of discreet causes – is required to maintain continual motion.

Baxter complained that 'if I shou'd offer such arguments as, to me, seem conclusive against a multiplicity of causes... or the renew'd impulse of the same cause... ye tell me the

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[4] See Chapter 2, 104–10.

Foundation of my mistake (or Sophism) is the considering Motion as an effect produc'd by some cause'. Within a decade Baxter's bamboozlement had given way to a conviction that the natural passivity of matter, its *vis inertiae* (power of inertia), is best described not as a power but as the inherent quality of 'resistance', and that inanimate objects, such as planets orbiting the Sun, remain in motion only as a result of God's unceasing direct action: his 'constant and universal Providence'.[5] This distinctive conception of divine agency informed Baxter's contributions to natural theology and drew him into important debates about the role of reason in religion. Home also engaged in debates on these topics, but began publishing his views only after Baxter's death in 1750. Though the broader conclusions he drew shifted later in his life, Home always held to the sceptical empiricist position he articulated in his letters to Baxter and was never happy with Newton's first law of motion and his conception of inertia. He could not accept Baxter's solution to the problem because he did not believe the human mind was capable of so comprehending God's activity in the universe.[6]

Home and Baxter were responding to a problem in Newton's physics that had challenged readers of the *Principia* since its first appearance: how do the forces or powers that give rise to motion relate both to matter and to God?[7] It was not the first law of motion that most exercised minds in this period, but the law of gravitation. The issue was important because if active powers like gravity were thought to be *inherent* to matter then God might seem to no longer play a role in Creation, rendering him little more than a 'divine clockmaker'.[8] Worse still, this position might encourage a purely materialistic natural

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[5] [Andrew Baxter], *An Enquiry into the Nature of the Human Soul: Wherein the Immateriality of the Soul Is Evinced from the Principles of Reason and Philosophy*, 2nd ed., vol. I (London: 1737), 36. Hereafter *Enquiry*. All quotations taken from the 1737 edition. It is sometimes claimed that this revised and expanded, but the text is actually (and mercifully) just in a larger font size.

[6] See Chapter 5, 223–30.

[7] See John Henry, 'Primary and Secondary Causation in Samuel Clarke's and Isaac Newton's Theories of Gravity', *Isis* 111, 3 (2020): 542–61; John Henry, 'Newton, the Sensorium of God, and the Cause of Gravity', *Science in Context* 33 (2020): 329–51; Patrick J. Connolly, 'Causation and Gravitation in George Cheyne's Newtonian Natural Philosophy', *Studies in History and Philosophy of Science* 85 (2021): 145–54; Ducheyne and van Besouw, 'Readers'; Levitin, *Kingdom of Darkness*; and Yenter, 'Metaphysical Implications'.

[8] This concern was articulated by Clarke in debate with Leibniz: 'The notion of the worlds' being a great machine, going on without the interposition of God as a clock continues to go without the assistance of a

philosophy. On the other hand, if the force of gravity was thought to be entirely extrinsic to matter, how was the Deity's role in so effecting it to be conceived? The God that merely provides nature with an animating power might appear too detached from the material realm, an *anima mundi* (world soul) unbefitting the Author of the universe.[9]

Newton's theory of gravitation thus raised a series of knotty questions. Is gravity directly effected by God (the 'first' or 'primary cause') or brought about by some intermediate agent (a 'secondary cause') placed by God in nature?[10] If it is conceived as an expression of God's *will*, how can the stability and law-like regularity of voluntary divine activity in the universe be accounted for? Is God's will to be understood as his purely free action, determined from moment to moment in the here and now, or as expressed at the point of creation and somehow bound by the strictures of rationality through which an ordered universe appears to be governed?[11] Newton was not taken to have explicitly

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clockmaker, is the notion of materialism and fate, and tends (under the pretence of making God a *supramundane intelligence*) to exclude providence and Gods' government in reality out of the world' – quoted in Connolly, 'Causation and Gravitation', 146.

[9] In the 'Scholium Generale', Newton pushed back against this notion: 'He rules all things, not as the world soul [*anima mundi*] but as the lord of all. And because of his dominion he is called Lord God *Pantokrator* [Newton's note: 'That is, universal ruler']. For "god' is a relative word and has reference to servants, and godhood [*deitas*] is the lordship of God, not over his own body as is supposed by those for whom God is the world soul, but over servants. The supreme God is an eternal, infinite, and absolutely perfect being; but a being, however perfect, without dominion is not the Lord God' (*Principia*, 586–7). For the concept of *anima mundi* in the early modern period see Alison Peterman, 'The World Soul in Early Modern Philosophy', in *World Soul: A History*, ed. James Wilberding (Oxford: Oxford University Press, 2021), 186–222.

[10] The framework of primary and secondary causation is sometimes distinguished from forms of 'occasionalism' in which God is said to be the only real agent in all causal interactions. For these concepts as they relate to Descartes, his admirers, and the 'Scholastic' tradition which his approach responded to see Tad M. Schmaltz, 'Primary and Secondary Causes in Descartes' Physics', in *Causation and Modern Philosophy*, eds Keith Allen and Tom Stoneham (London: Routledge, 2010), 31–47; and Steven Nadler, *Occasionalism: Causation among the Cartesians* (Oxford: Oxford University Press, 2011).

[11] Theological 'voluntarism' that emphasises the freedom of God's causal agency is sometimes contrasted with the view that divine agency must conform to certain rational strictures, which may be called 'rationalism', 'intellectualism', or 'necessitarianism'. For these concepts as they relate to experimentalists like Robert Boyle, Cambridge Platonists like Henry More, Leibniz, and Leibniz's readers see John Henry, 'Henry More Versus Robert Boyle: The *Spirit of Nature* and the Nature of Providence', *Henry More (1614–1687): Tercentenary Studies*, ed. Sarah Hutton (Dordrecht: Kluwer, 1990), 55–76; Catherine Wilson, 'The Reception of Leibniz in

addressed all of these questions, much less answered them definitively, with his characterisation of the material universe as 'Sensorium Dei' (God's sensorium) in the *quaestiones* of *Optice* (1706), and of the Deity as 'universorum Dominus' (Lord of all things) in the 'Scholium Generale' of the second edition of the *Principia* (1713).[12] This left room for his readers to develop their own ideas both about what Newton meant and about what gravitation really is.

Theological questions raised by Newton's philosophy were pressing because his discoveries soon became integrated into accounts of natural theology and their answers were contingent upon theological problems authors sometimes disagreed about, such as the role of reason in acquiring knowledge of God.[13] The theological debates that conditioned how Newton's readers treated gravitation were important because they were provoked by real concerns about the rise of deism and atheism, and about the boundaries of religious orthodoxy.[14] Many of Newton's Scottish readers held competing notions of gravitation and adopted distinct – sometimes directly opposed – positions on the theological consequences of Newtonian natural philosophy. This chapter argues that Scottish authors who have been thought motivated primarily to popularise, extend, and defend Newton's philosophy *as philosophy* (or 'science') engaged to a significant extent with Newton's ideas in order to contribute to religious debates and to integrate his philosophy into accounts of natural theology, often with an explicit emphasis on

the Eighteenth Century', *Companion to Leibniz*, Jolley, 442–74; and Michael V. Griffin, *Leibniz: God and Necessity* (Cambridge: Cambridge University Press, 2012).

[12] See Larry Stewart, 'Seeing through the Scholium: Religion and Reading in the Eighteenth Century', *History of Science* 34, 2 (1996): 123–65. See also Henry, 'Sensorium of God' and Levitin, *Kingdom of Darkness*, 703–65.

[13] See Scott Mandelbrote, 'Early Modern Natural Theologies', in *The Oxford Handbook of Natural Theology*, eds John Hedley Brooke, et al. (online ed., Oxford University Press, 2013), 75–99; John Henry, 'Early Modern Theology and Science', in *The Oxford Handbook of Early Modern Theology, 1600–1800*, eds Ulrich L. Lehner, et al. (online ed., Oxford Academic, 2014); and contributions to Ann Blair and Kaspar von Greyerz (eds), *Physico-theology: Religion and Science in Europe, 1650–1750* (Baltimore, MD: Johns Hopkins University Press, 2020).

[14] See Thomas Ahnert, *The Moral Culture of the Scottish Enlightenment: 1690–1805* (New Haven, CO: Yale University Press, 2015); and Jeffrey R. Wigelsworth, *Deism in Enlightenment England: Theology, Politics and Newtonian Public Science* (Manchester: Manchester University Press, 2009).

pedagogy.[15] Different readings of Newton are often best understood in light of readers' religious views rather than exclusively through their philosophical priorities. This case is made primarily through treatments of gravitation in the works of George Cheyne, Andrew Baxter, and Colin Maclaurin, professor of mathematics at Edinburgh from 1725 until his death in 1746. Much has been made of Scottish Newtonians' efforts to evangelise the unconverted, but popularising Newtonianism was not these authors' foremost intention. The extent to which they did so was, to a significant degree, an unintentional result of their efforts to promote and defend their understanding of true Christianity.

Scholars have not paid sufficient attention to the intersection between natural philosophy and theology in early-modern Scotland. It has yet to be established whether well known English authors who engaged with the theological consequences of Newton's physics, such as Samuel Clarke and Richard Bentley, shared the same concerns as their Scottish peers. The literature on 'Scottish Tory Newtonianism' has argued that Newton's science gained adherents in Scotland among Episcopalians and Jacobites, but the primary aim of this scholarship was to show how some figures were drawn to Newton's work due to their religious and political allegiances, not to demonstrate how these figures' politico-religious sympathies shaped their understandings of Newton's philosophy.[16] Literature on Newton's influence on Scottish philosophy more generally has not contextualised this influence by reference to contemporary religious debates.[17] This has obscured the relevance of Scotland's distinctive religious environment and the theological currents peculiar to it to Newton's reception. It is often thought that eighteenth-century Scottish philosophy was infused with a Calvinistic conception of divine providence, and it has been suggested that Newton's influence was responsible for a certain cast of this providentialist

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[15] Cf. Connolly, 'Causation and Gravitation'; Paul Russell, *The Riddle of Hume's* Treatise*: Skepticism, Naturalism, and Irreligion* (Oxford: Oxford University Press, 2008), esp. 35–46; Wilson, *Seeking Nature's Logic*, esp. 53–9; Wood, 'Science in the Scottish Enlightenment'; and Yenter, 'Metaphysical Implications'.

[16] See Introduction, 23–3.

[17] E.g. Schliesser, 'Newton and Newtonianism' (2013); and, equally, Schliesser, 'Newton and Newtonianism' (2014); Demeter, *Culture of Scottish Newtonianism*; Wood, 'Science in the Scottish Enlightenment', esp. 102–3; and Yenter, 'Metaphysical Implications'.

thinking in Scotland.[18] This latter suggestion is plausible when Newton is believed to have had loyal followers principally concerned to reproduce his views. Once the diverse engagement with theological issues connected to Newton's physics are recovered, it becomes clear that Newton's Scottish readers interpreted him using various pre-existing conceptions of providence and developed ideas about divine agency in response to his discoveries.

In their attempts to grasp the nature of gravitation, Scottish authors probed its possible origin and reflected on the capacity of the human mind to comprehend it. Cheyne's *Philosophical Principles of Religion* (1705), revised and expanded as *Principles of Religion, Natural and Revealed* (1715), followed efforts made by Bentley and others to develop a Newtonian natural theology in the sermons known as 'Boyle lectures'.[19] Cheyne proposed that the force of gravity is 'impress'd' upon bodies in such a way that it is neither inherent to matter nor entirely extrinsic to it, so that God acts continuously and directly in nature but has also to some extent endowed matter with gravitation. His work was later praised by the Jacobite sympathiser and Catholic convert Andrew Michael 'Chevalier' Ramsay (1686–1743), who produced his own *Philosophical Principles of Natural and Revealed Religion* (1748–9).

Ramsay was less impressed by the work of Baxter, who took against the idea that the force of gravitation was in any way present in bodies themselves. Baxter proposed an extreme form of voluntarism with his conception of God's 'constant and universal Providence', outlined in *An Enquiry into the Nature of the Human Soul* (1733) and later made central to his pedagogical dialogue *Matho* (1738).[20] In response to Baxter, Maclaurin argued in his posthumous *Account of Sir Isaac Newton's Philosophical Discoveries* (1748) that the ultimate origin of gravitation could only be traced through a 'chain of causes' back to God,

[18] See Oslington, 'Adam Smith's Invisible Hand'; and Ehrlich, 'Robertson and Scientific Theism'. Harrison, 'Smith, Natural Theology, and the Natural Sciences' does not mention Newton but stresses the emergence of the 'new science' before placing Smith in a broad European and British context, though with little reference to developments in Scotland.

[19] For the origin and early life of these sermons see John J. Dahm, 'Science and Apologetics in the Early Boyle Lectures', *Church History* 39, 2 (1970): 172–86.

[20] Andrew Baxter, *Matho; Sive, Cosmotheoria Puerilis, Dialogus* (London: 1738). Translated as Andrew Baxter, *Matho: Or, the* Cosmotheoria Puerilis*: A Dialogue*, vols I–II (London: 1740).

its author and the 'first cause'.[21] Though he emphasised how 'natural philosophy is subservient to purposes of a higher kind, and is chiefly to be valued as it lays a sure foundation for natural religion and moral philosophy', Maclaurin did not recommend, nor adopt a particularly optimistic stance toward, the tracing of this chain back to its origin.[22]

These responses were, naturally, shaped by the authors' religious views. Cheyne's Neoplatonist principle of attraction appears to owe something to his Episcopalianism and the distinctive theology of north-east Scotland, while Baxter and Maclaurin were on opposing sides of a debate within the Presbyterian Church of Scotland over the role of reason in matters of faith.[23] In this debate the causal nescience and sceptical empiricism of Home and his kinsman David Hume are fairly extreme positions among heterodox thinkers who opposed the relatively optimistic view about the capacity of reason to comprehend God's actions held by orthodox Presbyterians in Scotland, like Baxter.[24] Though Maclaurin did not agree with the kind of causal nescience articulated by Hume, both men shared a certain scepticism toward the potential for philosophy to reveal the effects of God's hand in nature. These views were typical of a set of heterodox Presbyterians, to which Maclaurin seems to have belonged and with which Hume was on famously friendly terms, whose ideas anticipated those of the 'Moderate' faction that emerged within the Kirk from the 1750s.

The authors under investigation here developed earlier engagement with Newton's approach to causation and, prompted by theological issues related to Newton's treatment of gravitation, asked new questions about physical explanation. They developed responses to the theological implications of these questions that were intended to resolve contemporary religious controversies and defend the faith. In so doing, these authors brought natural philosophy into constructive dialogue with theology in Scotland in a way

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[21] Colin Maclaurin, *An Account of Sir Isaac Newton's Philosophical Discoveries* (London: 1748), 22. Hereafter *Account*.

[22] *Account*, 3.

[23] For connections between Cambridge Platonism and theological currents distinctive to north-east Scotland see Sarah Hutton, 'From Cudworth to Hume: Cambridge Platonism and the Scottish Enlightenment', *Canadian Journal of Philosophy* 42, 1 (2012): 8–26.

[24] Ahnert, *Moral Culture* and Thomas Ahnert, 'Philosophy and Theology in the Mid-eighteenth Century', *Scottish Theology*, Fergusson and Elliot, 56–68. See also M. A. Stewart, 'Religion and Rational Theology', in *Companion to the Scottish Enlightenment*, Broadie and Smith, 33–59

that was both reinforcing and contentious. Newton's natural philosophy was drawn on by authors, such as the notorious 'deists' John Toland and Matthew Tindal, who were seen to undermine the veracity of scripture and orthodox doctrine.[25] This gave rise to fears over the influence of natural philosophy on religion and threatened philosophers' credibility.

This period therefore gave rise to controversies in Scotland regarding divine agency and causation that would, particularly through the sceptical empiricism of Home and his namesake Hume, present a significant challenge for natural philosophers in Scotland as the century progressed.[26] Questions around Newton's approach to causation continued to energise debates that cut across philosophy and religion into the nineteenth century. These debates are an important and hitherto underappreciated context for Hume's views on causation, which have been widely celebrated as one of the most influential products of the Scottish Enlightenment and a major development in the history of philosophy.[27] In this context, Hume can be viewed not only as interpreting Newton but responding to ways in which Newton's other Scottish readers engaged with and understood Newtonian physics in the eighteenth century.

This chapter begins by setting Scottish responses to the role of divine agency in Newtonian physics in the context of the Boyle lectures and fears over the rise of atheism and deism, to which the mathematician and clergyman John Craig (1663–1731) responded with his *Theologiae Christianae Principia Mathematica* (1699). It then examines the treatment of providence and gravitation in Cheyne's *Principles*, before considering Cheyne's influence on Ramsay's *Principles* and the critique of Newtonian natural philosophy Ramsay articulated. Baxter's and Maclaurin's treatments of these issues are placed in the context of debates over the role of reason in religion and the importance of written doctrine within the Church of Scotland. This context sheds light on the alleged commitment of Duncan Forbes of Culloden (1685–1747) to the anti-Newtonian ideas of the English author John Hutchinson, demonstrating the great variety of theological purposes Newton's example could serve in this period.

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[25] On the 'deists' and their engagement and contemporary association with Newton see Wigelsworth, *Deism*.

[26] See Chapters 4 and 5.

[27] See Walter Ott, *Causation and Laws of Nature in Early Modern Philosophy* (Oxford: Oxford University Press, 2009); Lynn S. Joy, 'Dispositional Explanations: Boyle's Problem, Newton's Solution, Hume's Response', in *Interpreting Newton*, 320–41; and P. J. E. Kail, 'Causation', in *Routledge Companion to Eighteenth-century Philosophy*, 188–202.

Defenders of the Faith: Gravitation in the Boyle Lectures

Newton supported attempts to demonstrate the compatibility of his philosophy with Christianity, as well as efforts to use it in defence of true religion. Writing to Bentley in December, 1692, he claimed that in composing the *Principia* he 'had an eye upon such Principles as might work with considering men for the beliefe of a Deity', and added that 'nothing can rejoyce me more then to find it usefull for that purpose'.[28] These remarks followed the first of what come to be known as the Boyle lectures that Bentley had given earlier that year. These 'lectures' were established by an endowment in the natural philosopher Robert Boyle's will to support London clergymen 'preach eight sermons in the year for proving the Christian religion against notorious Infidels, *viz*. Atheists, Theists [i.e. deists], Pagans, Jews and Mahometans'.[29]

Boyle (d. 1691) himself argued in *The Christian Virtuoso* (1690) that a philosopher could 'make such reflections, as may (unforcedly) be applied to confirm and encrease in him the sentiments of natural religion, and facilitate his submission and adherence to the Christian religion'.[30] He explored the relationship between theology and philosophy in a number of works written between 1660 and 1690, and was greatly interested in the kind and extent of natural knowledge that could be acquired through philosophy. He believed that God had endowed humans with a limited capacity to comprehend nature's innermost workings through reason, meaning that the natural philosopher ought to aim to supply, at best, 'Good and Excellent Hypotheses' which are 'clearly Intelligible'.[31] Boyle opposed coreligionists whom he believed attempted to explain or comprehend the inexplicable and mysterious through philosophy.[32] This conviction, outlined in Boyle's *Inquiry into the Vulgarly Receiv'd Notion of Nature* (1686), was supported by a voluntaristic conception of

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[28] Newton to Bentley, 10th Dec. 1692, in *Philosophical Writings*, Janiak, 92.

[29] Quoted in Dahm, 'Science and Apologetics', 172.

[30] Quoted in Jan W. Wojcik, *Robert Boyle and the Limits of Reason* (Cambridge: Cambridge University Press, 1997), 4.

[31] Manuscript material quoted in Wojcik, *Limits of Reason*, 166–7.

[32] Wojcik, *Limits of Reason*, 95–117.

divine agency, wherein ‘God is a most free as well as a most wise agent, and may in many things have ends unknown to us’. He criticised philosophers who ‘ascribe to the agency of nature’ what ought only to be ascribed to ‘the wisdom of God’. By this he meant to attack the ‘interpositions’ so often fabricated by philosophers as agents *between* God and Creation in order to explain both ‘anomalies’ and the ordinary ‘course of things’.[33]

Many agreed with Boyle in thinking that natural philosophy ought not only combat explicit irreligion, such as atheistic materialism, but also oppose any ideas that served to undermine true Christianity, whether or not irreligious by design. Bentley’s eight sermons for the inaugural Boyle lecture of 1692 were given in support of these aims and within a year were published in three parts entitled *A Confutation of Atheism* (1693) and in a single volume, *The Folly and Unreasonableness of Atheism* (1693). Their engagement with Newton has long been considered pioneering and influential. Henry Guerlac and Margaret C. Jacob argued that Bentley was the ‘first expositer of the religious significance of Newton's natural philosophy’, and Patrick J. Connolly has more recently described him as ‘one of the first public defenders of Newtonianism as well as one its most influential popularizers’.[34] From his sermons readers gained an introduction to the problems facing the natural theologian in reckoning with Newton’s relatively new discovery of gravitation. They would also have come across the pitfalls on the way to accounting for God's relationship with the force of gravity.

In Sermon 4, Bentley observed that the atheist might claim ‘this Catholick Principle of Gravitation is essential to Matter without introducing a God’ and, in Sermon 7, stated that gravitation cannot be ‘inherent and essential to Matter’ unless it is ‘impress’d and infused into it by a Divine Power’. Doubts could be raised over the issue, however, from Bentley’s claim elsewhere in Sermon 4 that gravity ‘*may* be prov’d [my emphasis]’ to be ‘but the immediate *Fiat* and Finger of God, and the Execution of the Divine Law’.[35] He did not definitively say whether or not he believed it had been, and also noted that the

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[33] Robert Boyle, *A Free Inquiry into the Vulgarly Receiv’d Notion of Nature Made in an Essay Address’d to a Friend* (London: 1686), 10–13.

[34] Henry Guerlac and M[argaret]. C. Jacob, ‘Bentley, Newton, and Providence (The Boyle Lectures Once More)’, *Journal of the History of Ideas* 30, 3 (1969), 307; and Patrick J. Connolly, ‘Metaphysics in Richard Bentley’s Boyle Lectures’, *History of Philosophy Quarterly* 34, 2 (2017), 155.

[35] Richard Bentley, *The Folly and Unreasonableness of Atheism* (London: 1693), Sermon IV, 5–6; and Sermon VII, 20–1.

materialist atheist would be wrong even if gravitation was found to be essential to matter, further suggesting the issue was as yet unresolved. Bentley characterised gravitation as 'the secondary Agent' through which the 'first and real Cause' acts. If this 'secondary agent' was deemed to be a power with which matter was by definition endowed, this could be seen not only as contradicting Bentley's other remarks but offering too much to the materialist. Read one way, such a secondary agent might be construed as a philosopher's 'interposition' of the kind Boyle had rejected in his *Free Inquiry*, rather than the 'fiat and finger of God' to which Boyle may have given assent.[36]

The following January, Newton protested to Bentley that 'you sometimes speak of gravity as essential & inherent to matter: pray do not ascribe that notion to me, for ye cause of gravity is what I do not pretend to know, & therefore would take more time to consider of it'.[37] Newton may have had in mind possible association with the materialistic atheism of Lucretius' *De Rerum Natura*, which apparently followed the philosophy of Epicurus in positing a universe made of uncreated, self-motive atoms. The influence of Epicureanism might be strengthened if gravity was deemed essential or inherent to matter.[38] The Irish philosopher John Toland soon confirmed such fears with his *Christianity not Mysterious* (1696) and *Letters to Serena* (1704). Toland, who was educated in Scotland in the 1680s, argued that matter contained the power to initiate motion and questioned the immortality of the soul. He claimed that no authentic knowledge could be acquired of immaterial substances and that the soul could not therefore truly be said to live on without the body.[39] Toland held that these views were in line with Newton's philosophy, asserting in *Letters to Serena* that Newton's remarks on space and time in the *Principia* were 'capable of receiving an Interpretation favourable to my opinion'.[40]

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[36] Bentley, *Folly and Unreasonableness*, Sermon IV, 5.

[37] Isaac Newton to Richard Bentley, 17th January 1693, quoted in *Philosophical Writings*, Janiak, 100.

[38] For the reception of Lucretius and Epicurean atomism in this period see Catherine Wilson, *Epicureanism at the Origin of Modernity* (Oxford: Oxford University Press, 2008); and Alan Charles Kors, *Epicureans and Atheists in France, 1650–1729* (Cambridge: Cambridge University Press, 2016). See also Eric Schliesser, 'On Reading Newton as an Epicurean: Kant, Spinozism and the Changes to the *Principia*', *Studies in History and Philosophy of Science* 44, 3 (2013): 416–28.

[39] See Wigelsworth, *Deism*, 74–101.

[40] John Toland, *Letters to Serena* (London: 1704), 183.

A decade after Bentley, another attempt was made to provide a pious interpretation of Newton's words by Samuel Clarke, who delivered sixteen sermons in both 1704 and 1705 as the twelfth and thirteenth instalments of the Boyle lectures. They appeared as *A Demonstration of the Being and Attributes of God* (1704) and *A Discourse concerning the Unchangeable Obligations of Natural Religion* (1705), before being published together later in 1705. Clarke addressed the issue of gravitation by abandoning the characterisation of God's actions through the notion of secondary causation. With somewhat more clarity than Bentley had achieved, Clarke avoided any affinity with Toland or Epicurean materialism by arguing that active powers like gravitation could only be effected directly by an immaterial agent, either by God himself or through subordinate spirits like angels. This ruled out the possibility that bodies could themselves initiate motion.[41]

Scholars have tended to agree with Ezio Vailati that Clarke's Boyle lectures were 'the clearest and most interesting statement of the theological and metaphysical views circulating within the Newtonian circle'.[42] Combined with scholars' high estimation of the importance and influence of Clarke's epistolary debate with Leibniz, this judgement supports the notion that Clarke attracted 'followers' and 'disciples' among Newtonians in Scotland.[43] Paul Wood has suggested that 'it is arguable that the exchanges between Leibniz and Samuel Clarke over the philosophical foundations of Newtonian natural philosophy... set many of the parameters for metaphysical debate in Scotland for the remainder of the century'.[44]

While Clarke was read and discussed, and may have been particularly influential among these Newton's Scottish readers, the idea that his correspondence with Leibniz set the terms of their debates about Newtonian philosophy can be misleading. It is widely observed that an important issue in the Clarke-Leibniz correspondence was 'action at a distance', which posed the question of whether gravitation could serve as a physical

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[41] See Henry, 'Primary and Secondary Causation'.

[42] Ezio Vailati, 'Introduction', in *Samuel Clarke:* A Demonstration of the Being and Attributes of God *and Other Writings*, ed. Ezio Vailati (Cambridge: Cambridge University Press, 1998), xxxi.

[43] See Paul Wood, 'Baxter, Andrew (1686/7–1750), Natural Philosopher and Metaphysician', in *Oxford Dictionary of National Biography,* 2004, accessed 22nd June, 2022: doi.org/10.1093/ref:odnb/1728; Russell, *Riddle of the* Treatise, 40; and Yenter, 'Metaphysical Implications', in which Baxter is said to have 'cast himself as the intellectual heir of Clarke' (118).

[44] Wood, 'Science in the Scottish Enlightenment', 102.

explanation without an account of the physical interaction between the bodies involved. It has consequently been thought that this issue was one central to Newton's reception in Britain and the defence of his natural philosophy against its critics.[45] Yet action at a distance was of little interest to Scottish authors, who more or less dismissed the point. They did this for a number of reasons but their insouciance is best explained by unanimity about the fact that God can unquestionably (appear to) act at a distance, leaving no need to account for the precise physical interaction involved in planetary motion.

Timothy Yenter has recently described the existence of a material ether as one of the 'key debates' within the reception of Newton's philosophy in Scotland, and argued that one of the 'ontological claims' made by Newton's Scottish readers more broadly was that 'gravitational forces [*sic*] are conveyed through an ethereal medium'.[46] This chapter demonstrates why Newton's eighteenth-century readers did not in fact positively endorse the idea that gravitation was conveyed by an ether, and why they gave it such short shrift. Despite their confessional differences and theological disagreements, Newton's Scottish readers held to a broadly voluntaristic notion of divine agency.[47] Unlike Boyle and Clarke, who also took this view, they were not in critical dialogue with authors who denied this position, and so evidently felt little need to consider the case of its opponents at any great length in their treatment of Newton's physics.

As Newton's Scottish readers said themselves, bringing a material ether into the explanation of planetary motion would add unnecessary and empirically dubious complexity to a perfectly sound argument. They were sometimes respectful of Newton's speculations about a material ether in the *Opticks*, though Baxter was critical of Newton on

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[45] According to Henry, 'Primary and Secondary Causation', Leibniz was Newton's 'most dangerous critic' (543). See also Brian Copenhaver, 'The Occultist Tradition and its Critics', in *The Cambridge History of Seventeenth-century Philosophy*, eds Daniel Garber and Michael Ayers, vol. I (Cambridge: Cambridge University Press, 2000), 454–512.

[46] Yenter, 'Metaphysical Implications', 111.

[47] For the importance of theological voluntarism and the debate over its relationship to the development of modern science see Francis Oakley, 'Christian Theology and the Newtonian Science: The Rise of the Concept of the Law of Nature', *Church History* 30, 4 (1961): 433–57; Peter Harrison, 'Voluntarism and Early Modern Science', *History of Science* 40, 1 (2002): 63–89; John Henry, 'Voluntarist Theology at the Origins of Modern Science: A Response to Peter Harrison', *History of Science*, 47, 1, (2009): 79–113; Francis Oakley, 'Will and Artifice: The Impact of Voluntarist Theology on Early-modern Science', *History of European Ideas* 45, 6 (2019): 767–84.

this score. Others were respectful of Newton's curiosity about the issue, but they did not believe it was his firm position. They grasped very well the difference between the arguments of the *Principia* and the queries appended to the *Opticks*. In any case, the aim for them was not to defend Newton against Leibniz, but to determine how exactly gravitation is best understood as the product of God's voluntary action in nature. They did this primarily in order to defend the Christian faith against its enemies.

The 'Principles of Natural Religion'

Confidence that philosophy and mathematics could counter the perceived threats of atheism and deism is evident in John Craig's *Theologiae Christianae Principia Mathematica*. Craig (or 'Craige'), was born in Dumfries in the 1660s and attended the university at Edinburgh in the 1680s, during which time he met Newton in Cambridge and pursued serious mathematical interests that he held until his death in 1731. He was the first British author to publish on calculus, contributed mathematical writing for other works, including William Wotton's *Reflections upon Ancient and Modern Learning* (1694) and Cheyne's *Principles*, and was an active member in epistolary networks that tied Newton together with David Gregory, the mathematician and clergyman Colin Campbell, and others.[48] From the late 1680s, Craig settled in the diocese of Salisbury, where he held various ecclesiastical positions under the authority of the Bishop of Salisbury, Gilbert Burnet (d. 1715), who had himself left his native Scotland for a career in the Church of England.[49]

The title of Craig's *Principia* pays obvious homage to Newton's *Principia*, but the former only has a superficial affinity with the latter.[50] The work was an attempt to determine when the perceived veracity of the gospel would decrease to zero, such that the 'probability' of belief in the story of Jesus Christ, as related by those who first witnessed it,

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[48] See Beeley, 'Great Alterations'.

[49] For an overview of the biographical material on Craig and the religious context of his *Principia* see Jeff[rey R.] Wigelsworth, 'The Deist Controversy and John Craig's *Theologiae Christianae Principia Mathematica* (1699)', *History of European Ideas* 49, 4 (2023): 654–75.

[50] Superficial resonances with Newtonian physics include Craig's deployment of terms like 'Ius naturale' (natural law) governing belief, 'velocitas suspicionis' (the velocity of distrust) of testimony, and 'conatus sapientum' (the endeavour/tendency of the wise) toward truth.

will have 'vanished' from the Earth, necessitating the Second Coming.[51] He calculated that this should occur in 3150 AD. Besides the obvious attraction of this exercise for a pious mathematician, the ultimate point of establishing 'mathematical principles of Christian theology' was to fend off the 'serious attacks of Atheists and Deists against the truth of our religion'.[52] Craig described Plato as a 'Divine' and praised his reputed exclusion of those ignorant of geometry from his Academy: 'vain is that Philosophy toward which we do not deduce the knowledge of Nature and of its Author'.[53] For Craig, mathematics was responsible for the 'extraordinary advances of the Natural Sciences' in modern times, when it has been taken to a 'boundless Extent' through, among other things, the expression of curves as equations and the determination of the 'Infinities' of curvilinear space.[54]

Craig's efforts to shore up the true faith by calculating Christ's return did not meet with great sympathy in his own time and have often been derided since, but only recently has his *Principia* been placed in the context of contemporary religious debates.[55] This context has also been underestimated in the case of Cheyne, with whom Craig collaborated in the years following the publication of the work. Scholars have tended to use Cheyne's *Principles* to shed light on his Newtonianism, but this has had the effect of obscuring his intentions and the views articulated in the work.[56] Rather than simply reflect a commitment to Newton's ideas, the work demonstrates precisely how Cheyne used Newton's

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[51] John Craig, *Theologiae Christianae Principia Mathematica* (London: 1699): '... illum [i.e. the Second Coming] non priùs venturum, quàm ferè evanuerit historiae suae [i.e. Christ's] probabilitas' (24). For Craig's work in the context of early-modern probability theory see Lorraine Daston, *Classical Probability in the Enlightenment* (Princeton, NJ: Princeton University Press, 1988), 64, 82–3, and 110.

[52] Craig, *Principia*: '... graviores iam contra Religionis nostræ veritatem sunt Atheorum & Deistarum impetus' (6).

[53] Craig, *Principia*: 'Divinus ille Plato Philosophus: & proinde ex Scholis suis Philosophicis omnes Geometriæ ignaros jure merito exclusit. Vana enim est illa Philosophia quæ nos ad Naturæ ejusque Autoris cognitionem non deducit' (5–6).

[54] Craig, *Principia*: 'Cum vero serio mecum perpenderem quam egregia Scientiarum Naturalium incrementa ex Geometriâ deduxerint & demonstraverint tum veteres tum recentiores Mathematici' (5). For his remarks on modern calculus and 'infinities' see William Wotton, *Reflections upon Ancient and Modern Learning* (London: 1694), 161–8.

[55] See Wigelsworth, 655–6.

[56] According to Guerrini, *Obesity and Depression*, Cheyne may have written the work to 'reingratiate himself with Newton' (72). She notes that Clarke was an influence but that otherwise Cheyne's specific aims are obscure (85–7). See also Demeter, *Culture of Scottish Newtonianism*, 94.

philosophy as a support for natural-theological aims.[57] Patrick J. Connolly has argued the other way around, viewing the work primarily as natural philosophy and suggesting that Cheyne developed a 'delegated powers model' to account for gravity's operation in order to solve the problem of divine conservation while both avoiding occasionalism and ensuring Newton's philosophy could serve 'physico-theological ends'.[58] Similarly, Steffen Ducheyne and Jip van Besouw have argued that through his reading of the *Principia* Cheyne thought 'gravity was a property that was endowed on matter by God at the time of creation', in contrast to the 'occasionalism' of fellow readers Bentley and William Whiston.[59] They acknowledge the importance of religious concerns and argue that Cheyne drew primarily on Newton's argument against a plenum in Cor. 3, Prop. 6, Lib. III of the *Principia* in order to counter materialists like John Toland, though they do not outline the religious dimension of these debates.[60]

Dmitri Levitin has argued that where Cheyne 'really innovated', particularly with respect to Clarke, was in connecting natural theology 'so strongly to the denial of the natural conservation of motion in the universe'. He has drawn attention to Cheyne's treatment of the circulation of blood, and suggested that Cheyne's views were a major influence on Newton's subsequent thinking about the relationship between God and nature. He argued that Cheyne's work shaped what Newton, a subscriber to the first edition of the *Principles*, wrote about divine agency and causation after 1705, including his discussion of the 'sensorium dei' and the 'Scholium Generale'. Levitin denies, however, that Cheyne intended to resolve thorny issues around divine activity and the relationship between force and matter, for 'Newtonians [at this time] simply did not care about such questions... their only aim was to show that gravitation *qua* empirical phenomenon could not arise from matter itself'.[61]

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[57] For the natural-theological context of Cheyne's engagement with 'principles' see Peter R. Anstey, 'Experimental Philosophy and the Principles of Natural Religion in England, 1667–1720', in *The Idea of Principles in Early Modern Thought*, ed. Peter R. Anstey (London: Routledge, 2017), 246–70. See also Levitin, *Kingdom of Darkness*, 679–87.

[58] Connolly, 'Causation and Gravitation', 145.

[59] Ducheyne and van Besouw, 'Readers', 389.

[60] Ducheyne and van Besouw, 'Readers', 383–5.

[61] Levitin, *Kingdom of Darkness*, 685.

Cheyne's aims and the relevance Newton had for the work are best understood by determining why the *Principles* were written. The work's subtitle promised to deliver 'the Elements of *Natural Philosophy*, and the Proofs for Natural Religion Arising from them'.[62] Cheyne revised and expanded the work in 1715 (reissued in 1716) and three further editions formally appeared in 1724, 1733, and 1736. Though some contemporary British readers were dismissive of the work, the *Principles* enjoyed a favourable reception in continental Europe, particularly in the Netherlands.[63] The text also found its way onto curricula at Oxford and Cambridge, as Cheyne had explicitly hoped in the preface to the 1715 edition, and at universities in Scotland.[64] He complained that students were only taught about the '*Appearances of Nature* from the Modern Discoveries', and desired that through his work the '*Principles* of *Natural Religion*' would be 'insensibly instill'd into them at the same time'.[65] Cheyne noted that 'some part of the Matter was furnished me from Mr. *Newton*'s Store' and observed that he did not need to cite Newton's works, for 'his Inventions have such peculiar Marks, as will distinguish them, even in my rude Dress'.

These 'peculiar Marks' are central to the work, but Cheyne's aim was not simply to promote Newton's philosophy. The *Principles* were written partly to defend against the malign influence of Aristotelean, Epicurean, and Cartesian philosophy. Cheyne took aim at those who professed Christianity but either espoused ideas friendly to atheistic doctrines and arguments or, as deists, held the truth of revelation to be dependent upon the dictates of human reason. These antagonists could be found close to home, but their ideas were attacked through ancient and modern proxies like Epicurus and Descartes.. The work was dedicated to John Ker, Earl (later Duke) of Roxburgh, whose son Cheyne tutored and whom he had served as a physician in the early 1700s. Apparently, the genesis of the work lay in the Earl's 'Command and Conversation'. Like Bentley and Clarke, Cheyne wished to integrate gravitation into natural theology without giving succour to a 'corrupt Generation

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[62] George Cheyne, *Philosophical Principles of Natural Religion* (London: 1705). Subsequent quotations are, unless otherwise indicated, from George Cheyne, *Philosophical Principles of Religion, Natural and Revealed* (London: 1715).

[63] See brief discussions in Connolly, 'Causation and gravitation', 146; and Levitin, *Kingdom of Darkness*, 680–1.

[64] David E. Shuttleton, '"My Own Crazy Carcase": The Life and Works of Dr. George Cheyne (1672–1743)', (PhD thesis, University of Edinburgh, 1972), 101–5.

[65] *Principles*, 'Preface to the First Part', [i].

of Men', such as those who, 'being Prone to *Atheism*, have vainly pretended, *Oracles of Reason* to be on their side'.[66] Here he referenced the *Oracles of Reason* (1683) by the English author and notorious deist Charles Blount, signalling that his true opponents were not long-dead philosophers but contemporary freethinkers.[67]

It is unclear whether Cheyne had either attended or read either of Clarke's Boyle lectures before composing the 1705 edition of the *Principles*, as he seems to reference Clarke's position only in the 1715 edition.[68] Like Clarke, nevertheless, he departed from the characterisation of gravitation as a secondary agent. Rather than speaking of secondary causes that may be misconceived as implying matter itself to be capable of motion, Cheyne characterised God as acting directly in nature, without mediation, through a principle of attraction. Confusingly, however, he sometimes presented this attractive principle as residing in matter, and used a variety of terms to describe the relationship between God and nature that did not always enhance the clarity of his position. Notwithstanding this disclarity, the *Principles* demonstrates that Cheyne held a voluntaristic notion of divine action and believed that gravitation must be continuously present in matter without being intrinsic to matter as matter.

This position avoided reducing divine agency to a technicality, as was supposed of those understood by modern scholars to have been occasionalists, such as Descartes. Occasionalists' claims that causal interaction was by definition divine activity did not convince authors like Cheyne.[69] His position also answered the materialist and addressed the issue of the conservation of motion, but Cheyne's ambitions were grander still. His conception of a fundamental attractive principle was used to develop an alternative philosophical system to those that had come before. This system would counter what Cheyne saw as the flawed metaphysics and problematic conceptions of divine action in nature found in major works of natural theology and philosophy.

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[66] *Principles*, 'Epistle Dedicatory'.

[67] See Michelle Pfeffer, 'Paganism, Natural Reason, and Immortality: Charles Blount and John Toland's Histories of the Soul', *Intellectual History Review* 31, 4 (2021): 563–83.

[68] *Principles*: he noted that gravitation might be effected by 'subordinate spirits' (4), but did not name Clarke.

[69] According to Connolly, 'Causation and Gravitation', occasionalism was sub-optimal because it answered the materialist atheist but did not dispense with the 'need for immediate and continuous divine intervention in the created world' (146).

Cheyne framed his account as a departure from the 'metaphysics' of Plato, Aristotle, Hippocrates, the French scholar and Protestant convert Joseph Scaliger (d. 1609), and the English philosopher Henry More (d. 1687), who is often placed among the so-called Cambridge Platonists. For Cheyne, these authors proposed merely 'allegorical' principles, or 'Beings', to account for divine activity. In order for principles to do this, they must be endowed with 'Powers and Faculties above the Dignity of such secondary Agents' as these authors imagined, for otherwise principles are 'derogatory from the Wisdom and Power of the *Author* of *Nature*'. Cheyne promised the reader 'more intelligible and less indirect Principles' and a more authentic account of the Deity, befitting the true nature of his unlimited providential power and unconstrained will.[70] Cheyne's 'principle [*sic*] Design' was to show that 'without his [i.e. God's] continual Influence and Support, the whole Movement [of the universe] would fall to Pieces'. The 's*cheme* of *Nature* which seems most Agreeable to the Wisdom of its Author', he observed, is one that has 'settled Laws', but – despite the resemblance of the universe to a machine – we must not overlook the fact that 'he [i.e. God] has reserv'd to himself the Power of dispensing with these Laws, when he pleases'.[71]

Cheyne uses the term 'principle' in two senses. One is general and loose, such as when referring to the principles of 'geometry' and 'mechanism'. The other is formal and extremely important to his account. He introduced just one of these formal principles in the 1705 edition, 'the Principle of the Universal Law of the *Gravitation* of Bodies upon one another'.[72] This single principle may account for all natural effects, as Cheyne had announced in his medical manifesto of 1701.[73] When he mentioned an 'extrinsick principle' necessary for the 'subsistence' of the universe, the principle of gravitation is what he meant.[74] He described this principle as 'annex'd' to matter by God and also employed the concept of 'impression' used by Bentley, characterising gravitation as 'impress'd on Matter by the *Creator* of the World'.[75] Cheyne developed this fundamental principle of attraction in

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[70] *Principles*, 3–4.

[71] *Principles*, 5–6.

[72] *Principles* (1705, Part I), 50. According to Anstey, 'Experimental Philosophy', Cheyne stands out among his contemporaries in natural theology for using 'determinate Newtonian principles' (248).

[73] See Chapter 1, 75–82.

[74] *Principles*, 42.

[75] *Principles*, 16–7.

the 1715 edition, proposing an analogous ‘Principle of Re-Union’, by which souls are conducted back to God (or cast away from him) after the death of the body.[76]

Cheyne was categorical that matter, by its very essence and definition, was inactive. He pointed out that Newton’s first law of motion proves this by establishing that nothing is essential to matter except its fundamental features as matter, which are limited to ‘the particular Texture, Figure and Disposition of Bodies’.[77] The laws of nature (i.e. Newton’s laws of motion) most likely arise from these features but the law of gravity did not. Both Newton and David Gregory had demonstrated, for Cheyne, that gravitation is the ‘source and Origin of the Celestial Motions’, so gravitation must therefore be traced back to Creation itself.[78] During the act of Creation, the universe operated according to different ‘laws and principles’ than in the present, because those evident in the here and now cannot account for both the creation and maintenance of the universe. In support of this view he cited Whiston’s *Theory of the Earth*, which Cheyne saw as having proven that the laws of nature are incapable of accounting for Creation as it is detailed in scripture.[79] For Cheyne, it was impossible to account for the constitution of the universe as understood through both philosophy and scripture without distinguishing between the present-day ‘laws of nature’ and the ‘laws of creation’ which preceded them. If gravitation is the ‘source and origin of celestial motions’ it cannot be counted among either the ‘laws of nature’ (which cannot account for the *origin* of motion) nor the ‘laws of creation’ (which no longer exist), and therefore transcends them. Distinct from such laws, Cheyne’s ‘principle of attraction’ is lawlike in appearance but technically the animating force through which God freely powers his machine.

Armed with this principle of attraction, Cheyne worked through a number of natural-philosophical arguments that might lead the Christian astray and undermine true religion. The Epicurean account of the origin of the universe was certainly a real and present danger in Cheyne's mind, for he saw the Cartesian ‘mechanical hypothesis’ as sharing with Epicureanism the basic notion of a universe composed of self-moving particles. Cheyne did not dwell on the extent of (nor evidence for) Descartes’ materialism, but he

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[76] *Principles*, 47.

[77] *Principles*, 50.

[78] *Principles*, 48.

[79] *Principles*, 64–5.

characterised Cartesian mechanism as a kind of atomism, predicated on the existence of indivisible particles endowed with self-motive power.[80] He argued that Cartesian mechanical philosophy could, however, provide no good account of why such particles have cohered to produce the universe as it is, observing that 'we all know how wretchedly *Des Cartes* (the ablest *Patron* that ever this Opinion had) has blunder'd on these Heads, and his followers have not mended the matter much'.[81] Mechanism had its limits.

Cheyne's single divine principle of attraction offered philosophical simplicity, and the supposition of an ether to account for gravitation mechanically overcomplicated the issue. A material ether required the philosopher not just to factor in the gravitational attraction of the ether itself but account for where the ether's own gravitation arises from. The problem would not only remain unsolved but multiply. However, for Cheyne, there was no problem to speak of, for we cannot know more of the origin of certain things than they are the product of God's activity in nature.

> When we are capable to explain how our Souls and our Bodies act mutually upon one another, we may come to be able to conceive how Matter acts at a Distance without any *Medium*; but till then it is sufficient to know, that such a Quantity [as gravity] is actually lodg'd in Matter, and that it is the Cause of all the Great and Uniform Appearances of Nature.[82]

The phrase 'lodged in matter' was not meant to imply that gravitation was intrinsic or essential to matter, as Cheyne had already ruled that out. The point was that while the capacity of the human mind to comprehend nature is limited, God's power and range of action is infinite. It followed that the conception of gravitation as an attractive force operating between physically dislocated bodies was quite unproblematic without the supposition of a material ether through which such force interactions might be conveyed.

Cheyne shared many of the preoccupations of other natural theologians such as Bentley, Clarke, and Whiston, but the distinctive features of his account appear to derive from influences that can be traced to his background and personal religious sympathies. Though he criticised the metaphysics of Plato and More, Cheyne's desire to identify a single fundamental principle with God strongly resembles Neoplatonic ideas, such as those of the

[80] *Principles*, 30–3.

[81] *Principles*, 118.

[82] *Principles*, 45.

ancient philosopher Plotinus (3rd century CE) and figures like More who have been labelled Cambridge Platonists.[83] Cheyne's work strongly suggests the influence of the theologian Henry Scougal (d. 1678), who described true religion as the 'union of the soul with God' and spoke of the 'real participation of the divine nature'.[84] Scougal, like Cheyne, was an Episcopalian native to north-east Scotland, and his *Life of God in the Soul of Man* (1677) was in fact edited for the press by Gilbert Burnet, the brother of Cheyne's maternal grandmother. Burnet was sympathetic to the views of Cambridge Platonists such as More and John Smith (d. 1652), who are thought to have influenced Scougal along with the so-called 'Aberdeen Doctors', who operated in the north-east and elsewhere in seventeenth-century Scotland.[85]

Cheyne did not seriously revise the central arguments of the *Principles* in later editions, aside from pluralising the principle of attraction into one of 'union' and 're-union', the natural and the spiritual. Revisions made for the edition of 1715 consisted mostly of augmenting the discussion and editing the work's structure. He did add the qualification that gravity might be called a 'primary quality' as long as it not be understood as 'materia prima' (i.e. prime matter).[86] This was intended to clarify Cheyne's position as one in which gravitation resided in but was not essential to matter. He presumably did not know of Newton's private displeasure at Roger Cotes' characterisation of gravity in the preface to the second edition of the *Principia* as 'among the primary qualities' of matter. For Newton, Cotes' use of the term 'quality' unfortunately suggested that gravity might be somehow essential to matter.[87] Whether or not Newton was persuaded by Cheyne's account of

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[83] For Plotinus' philosophy see Dominic J. O'Meara, *Plotinus: An Introduction to the* Enneads (Oxford: Clarendon, 1993). For the Cambridge Platonists see contributions to G. A. J. Rogers, et al., *The Cambridge Platonists in Context: Politics, Metaphysics, and Religion* (Dordrecht: Kluwer, 1997).

[84] Quoted in Aaron Clay Denlinger, 'The Aberdeen Doctors and Henry Scougal', in *Scottish Theology*, Fergusson and Elliot, 291.

[85] See Denlinger, 'Aberdeen Doctors'; and Hutton, 'Cudworth to Hume'.

[86] *Principles*, 41.

[87] Newton's displeasure is evident from Roger Cotes to Samuel Clarke, 25th June 1713, in *The Correspondence of Isaac Newton. Volume 5, 1709–1713*, eds A. Rupert Hall and Laura Tilling (Cambridge: Cambridge University Press, 1975), 412–3. Cotes, 'Editor's Preface', 41. In 'Rule 3' of the *regulae philosophandi* introduced to the 1713 edition, Newton discussed the 'qualities of bodies' but drew a firm distinction between inertia and gravitation, clarifying that 'I am by no means affirming that gravity is essential to bodies. By inherent force I mean the force of inertia' (*Principia*, 442).

gravitation, in the *Principles* Cheyne had gone to great lengths to avoid this unhappy conclusion.

'Constant and Universal Providence': Andrew Baxter and Presbyterian Orthodoxy

In the preface to the second edition of the *Principles*, Cheyne also acknowledged William Derham, whose Boyle lectures of 1711 and 1712 were published as *Physico-theology* (1714), as a major influence.[88] However, Cheyne can't have been thinking about the principles he had proposed for Derham went to no great lengths to define gravitation, and he addressed divine activity in nature through the language of primary and secondary causes that Cheyne eschewed. Derham offered in a footnote only that 'the Cause of *Gravity*' is 'that universal Law of Matter, imprinted on it at it's [*sic*] Creation by the infinite Creator, namely *Attraction*'. Though he cited numerous authors for his reader to consult for gravity's 'Properties and Proportions', including Galileo, Evangelista Torricelli, Newton, Clarke, Edmond Halley, and the English clergyman and mathematician John Wallis (d. 1703), Cheyne's name did not appear.[89] Cheyne may not have had the influence on his peers that he hoped for, but his *Principles* does seem to have served as a model for Andrew Michael Ramsay's own *Philosophical Principles of Natural and Revealed Religion*.

Ramsay was born in Ayr in 1686 and studied at Edinburgh in the early 1700s, apparently with a view to entering the Episcopal ministry. He abandoned these plans and, due partly to his interest in the writings of the French mystic Antoinette Bourignon (d. 1680), gravitated toward others interested in mystical theology, including Cheyne, with whom he corresponded for many years.[90] Ramsay continued his education in London and the Netherlands before studying under the French theologian François Fénelon, Archbishop of Cambrai, during which time he converted to Catholicism. After a brief and unhappy

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[88] *Principles*, 'Preface to the First Part'.

[89] William Derham, *Physico-theology* (London: 1714), 31–3.

[90] Scott Mandelbrote, 'Ramsay, Andrew Michael (Jacobite Sir Andrew Ramsay, baronet) (1686–1743), Philosopher and Jacobite Sympathizer'. In *Oxford Dictionary of National Biography*, 2004, accessed 19th Jul., 2023: https://doi.org/10.1093/ref:odnb/23077.

experience as tutor to Charles Edward, the ‘Young Pretender’ to the British throne, at the Jacobite court-in-exile in Rome in the 1720s, he left for Paris and London and embarked on a successful literary career.

His *Voyages de Cyrus* (1727) engaged with the ideas of the Dutch philosopher Baruch Spinoza (d. 1677), Descartes, and Newton, and one of its aims was to promote the Platonistic view that humanity existed in the three states : innocence, fallen, and restored.[91] Despite sharing many interests with Cheyne, Ramsay’s *Principles* was critical of the voluntaristic conception of divine agency held by Newton and his ‘disciples’, such as Cheyne and Clarke.[92] Ramsay believed that God's infinite *potential* to act was ‘absolutely incompatible with the perfection of the divine nature which must be infinitely, eternally and essentially active’. He associated Newton and the Newtonians with various errant, anti-Trinitarian groups who had underestimated the necessity of unceasing divine activity:

> The Deists, the Sabellians, the Unitarians, and the Socinians, yea the great Sir Isaac Newton with his learned disciple Dr. Clarke, maintain that all action is free, both in the first and second causes. If this were so, then God would be active only by creation, he would not be active by essence, he would not be necessarily but freely active.[93]

The point was not only to repeat the allegation that Newton and Clarke had denied the Trinity but to assert that God must be thought necessarily active in nature without interruption.[94] This truth is neither expressed in Spinoza's ‘monism’ nor the ‘ingenious fiction of occasional causes’ proposed by Nicolas Malebranche (d. 1715), the French priest and admirer of Descartes.[95] For Ramsay, these notions merely collapse the concepts of God and nature together, or identify God in nature without establishing his separate

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[91] See Mandelbrote, ‘Ramsay, Andrew Michael’. See also Doowahn Ahn, ‘From Greece to Babylon: The Political Thought of Andrew Michael Ramsay (1686–1743)’, *History of European Ideas* 37, 4 (2011): 421–37.

[92] Andrew Michael Ramsay, *The Philosophical Principles of Natural and Revealed Religion*, vol. I (London: 1748), 269.

[93] Ramsay, *Principles*, 75.

[94] See Mandelbrote, ‘Newton and Eighteenth-century Christianity’.

[95] For Spinoza's monism see Steven Nadler, *Spinoza's* Ethics*: An Introduction* (Cambridge: Cambridge University Press, 2006), 143–6. Malebranche is usually held to be the occasionalist *par excellence*: see Nadler, *Occasionalism*.

existence. 'Spirits and bodies are united [only] when the one acts upon the other by a real, physical, and immediate influence'.[96]

Ramsay's attack on voluntarism was also aimed at Andrew Baxter, whose own conception of 'constant and universal providence' had been published over a decade before Ramsay's death. Ramsay believed that Newton had in fact departed from the idea that 'the great law of attraction is an immediate effect of the divine action', a view he took probably on the basis of his reading of the queries. Yet Ramsay was quite sure that Baxter maintained a position that 'despoils all material agents of active force', which is 'entirely subversive of all natural philosophy'.[97] He did not hold orthodox views according to the Presbyterian Church of Scotland, though this was not due to the optimism he displayed about the capacity of reason to acquire knowledge of God's purposes. In this respect Ramsay was not unlike Baxter and some others in the Kirk, who were committed to the idea that divine agency was not restricted by the dictates of reason. They associated such rationalism with deists, who were believed to hold that the truth of revelation depended on its compatibility with human reason. Deists were, however, often common enemies of Scottish Presbyterians who disagreed on one of the major issues of debate in the eighteenth century: the importance of written doctrine and the capacity of reason alone to determine correct moral action.[98]

Baxter's 'Newtonianism' is a predominant feature of the literature on his philosophy, but this label does not clarify his position in the major religious and philosophical debates to which he contributed. He has been described by Paul Wood as 'one of Britain's leading exponents of Newtonian metaphysics', though, if this is right, he has received relatively scant scholarly attention.[99] In what work there is on Baxter, his ideas tend to be detached from their philosophical and theological contexts. Yenter, for example, has claimed that Baxter 'stood out among his contemporaries for being so thoroughly *metaphysical* in a *natural philosophical* age'. For Yenter, 'Baxter is boldness, reason, argument, a priori', and his account presents him as both committed to the truth of Newton's science and willing

[96] Ramsay, *Principles*, 268.

[97] Ramsay, *Principles*, 269.

[98] See Ahnert, *Moral Culture*.

[99] Wood, 'Baxter, Andrew'.

to take it to metaphysical extremes.[100] Baxter's first substantial engagement with Newton in his published work, however, was a discussion of his treatment of the concept of inertia as part of a broader argument about the relationship between the soul and the body.[101] Baxter was critical both of things he understood Newton to have thought and the way that Newton wrote about certain concepts, like inertia. These views do not, most likely, have their ultimate origin in Baxter's reading of Newton, but in his religious sympathies, to which he was presumably far more committed than he was to Newton's scientific views.

Baxter set out his views on reason and religion in his first publication, the anonymous *Some Reflections on a Late Pamphlet, Called, the* Moral State of the World Considered (1732), which took aim, as advertised, at the philosopher William Dudgeon's *State of the World Consider'd* (1732). Dudgeon had promoted the view that 'experience' was more important than written doctrine for, with 'every Thing coming to pass according to the Fore-knowledge and Decree of God', humans have no need for 'Accountableness and positive Punishment' by earthly authorities. Simply living is 'doing nothing but what God designed we should'; that is, 'being in a State of Discipline, or training up to Virtue'.[102] He made these claims in the wake of the (anonymous) publication of Tindal's scandalous *Christianity as Old as Creation* (1730), and Dudgeon had written in support of Tindal's contention that religious truths must conform with reason in another work, *The Necessity of Some of the Positive Institutions of Christianity Consider'd* (1731). For Tindal, the 'Scriptural and Philosophical Account of natural things seldom agree', and he had sided in all cases with the latter.[103]

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[100] Yenter, 'Metaphysical Implications', 118–9. The case is made by contrasting Baxter with Maclaurin, who is 'caution, observation, experiment, a posteriori'. See also Fred Ablondi, 'Newtonian vs. Newtonian: Baxter and Maclaurin on the Inactivity of Matter', *Journal of Scottish Philosophy* 11, 1, (2013): 15–23, in which Baxter's 'occasionalism' (21) is said to be justified with reference to queries 25–31 of the *Opticks*.

[101] For the debate to which this broader argument contributed see Christopher Fox, *Locke and the Scriblerians: Identity and Consciousness in Early Eighteenth-century Britain* (Berkeley, CA: University of California Press, 1988); and John W. Yolton, *The Two Intellectual Worlds of John Locke: Man, Person, and Spirits in the "Essay"* (Ithaca, NY: Cornell University Press, 2018).

[102] William Dudgeon, *The State of the Moral World Consider'd; or, a Vindication of Providence in the Government of the Moral World* (Edinburgh: 1732), 3.

[103] [Matthew Tindal], *Christianity as Old as the Creation: Or, the Gospel, a Republication of the Religion of Nature* (London: 1730), 185. See Wigelsworth, *Deism*, 48–70 and 167–95.

Dudgeon's views led to his prosecution in the presbytery of Chirnside (Berwickshire), and Baxter's attack may well have contributed something to his fate.[104] Baxter lambasted Dudgeon, Tindal, and others who either implied or alleged that Christian doctrine was unreasonable or dispensable: '*surely* they must think their Maker a very *foolish* Being, who gave *them* a Reason superior to his *own*, so that they might discover a Want of it in him!'. For Baxter, such theorists rejected the truth of scripture out of cowardice, for they claimed that God is necessarily good and the universe he created entirely rational because they shied away from 'telling God, he is a capricious, tyrannical, arbitrary Being'.[105] In Baxter's view, the gift of reason is bound up with human liberty, through which we make choices that may or may not contravene 'the *Law* of our Nature as reasonable Beings' and 'our *Duty* as [God's] Dependents'. It was an 'Abuse of Liberty' to take rational determination too far and 'bring ourselves under a *Necessity* and *Slavery of our own procuring*'.[106]

Yet, in Baxter's estimation, liberty and reason were what made natural theology both possible and valuable, so it did not follow from his opposition to freethinkers like Dudgeon that he held a particularly low estimation of the capacity to acquire knowledge of God through philosophy. His optimistic attitude toward the acquisition of religious truth through reason is evident in his argument for the immortality of the soul and the conception of divine agency from which it followed. In the anonymous *Enquiry* (1737), Baxter began by making a case for the passivity of matter because, in his view, the common treatment of the issue did not properly reflect how God truly operates in nature. He believed that Newton's *vis inertiae* is less a 'power' or 'force' – i.e. 'vis' – but the innate 'resistance' essential to matter as matter, the truth of which was demonstrated beyond doubt by 'the most general, certain *phænomena* of motion, agreeable to universal experience, the common sense of men, and to reason itself'.[107] He outlined Newton's laws of motion approvingly but did not note Newton's authorship, and was by implication critical of Newton in his criticism of the term *vis*, which Newton had introduced in the *Principia*.

Baxter's interpretation of inertia as 'resistance' is highly relevant to the relationship between the soul and the body because he believed this essential feature ruled out the

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[104] Paul Wood, 'Baxter, Andrew'.

[105] [Andrew Baxter], *Some Reflections on a Late Pamphlet, Called, the* Moral State of the World Considered (Edinburgh: 1732), 36.

[106] Baxter, *Reflections*, 37 and 39.

[107] *Enquiry*, 7.

possibility that matter could be inherently endowed with any active power. What had been proven and observed – 'agreeable to universal experience, the common sense of men, and to reason itself' – was inconsistent with any such inherent material 'vis' or 'conatus' (i.e. endeavour or inclination).[108] Pointing to authors like Derham and the English natural philosopher Henry Pemberton (d. 1771), editor of the third edition of the *Principia* (1726) and professor of physic at Gresham College, Baxter complained of the tendency to characterise gravitation as essential or inherent to matter, noting the unhappy parallel with Epicurean atomism. He was also quite critical of Newton himself and others for supposing that gravity might be effected via an ethereal medium.

In a characteristically prolix footnote (k) that stretches from page 33 to page 50 in volume I of the 1737 edition, Baxter rejected all attempts by Newton's readers to account for gravitation by way of a 'mechanical cause'. He also dismissed Newton's remarks in the queries on electricity, magnetism, and an ethereal medium – quoting them in full – as 'impossible and contradictory'.[109] Baxter summed up efforts to explain gravitational force with reference to material interaction as 'contending that one effect may be *mechanical*, because another is *not mechanical*'.[110] An ethereal medium does not properly account for gravitation because such powers can only be explained by an active providential God: 'to account for the gravity of bodies by a vibrating elastic medium, is to account for one power of matter by another unaccounted for power of it, whence of consequence neither is accounted for'.[111]

Though Cheyne's name does not feature in the text (except in the list of subscribers), Baxter may well have had in mind Cheyne's description of gravity as 'lodg'd' in matter when he wrote that 'to say [God] hath lodged in matter, certain powers whereby events are to be directed, is but one degree removed from Epicurean necessity'. 'To say [God] still superintends the execution of these powers himself', he continued, 'though it is more pious, is scarce better philosophy'.[112] Baxter insisted that God must be a completely free agent who actively and directly brings about all natural phenomena through active powers on essentially passive matter:

[108] *Enquiry*, 26.

[109] *Enquiry*, 47.

[110] *Enquiry*, 49.

[111] *Enquiry*, 106–7.

[112] *Enquiry*, 100.

> for besides the impossibility of planting powers in matter inconsistent with the nature and essence of it, a Being, who by the excellency of his nature, is necessarily every where present, all-knowing and almighty, doth not want to be relieved of a part of the task.[113]

This view was supported by his belief that modern philosophy could not reduce the cohesion of matter nor celestial motion to regular laws. He argued that the centripetal and centrifugal forces driving planetary motion do not actually account for the movement of the planets precisely, therefore requiring a 'constant agent' for their maintenance.[114] One instance of this was the irregularity of lunar motion, which for Baxter was particularly instructive evidence for the voluntary character of God's providential activity.[115] Considering the cohesion of material substances, he also argued that water displayed greater cohesive force when lesser in mass, a contradiction that is 'an irrefragable instance of Almighty Power'.[116] Baxter's contention was that effects which appear to flow from powers inherent to matter are, in all cases, God's 'constant and universal Providence in the material world'.[117] 'Constant' and 'universal' not such that God is synonymous with Creation nor merely the technical cause of all effects, but such that he is an authentic voluntary agent, whose occasionally irregular and inconsistent actions can even be detected.

The only limitation to divine agency Baxter was willing to accept was in regard to souls, the active powers animating creatures. The soul must be a distinct 'Being', he thought, but one clearly subordinate to the being that is God, the 'first Cause' of everything – including other beings.[118] All creatures have such souls, but only humans are endowed with rationality, which provides them with liberty and entails moral responsibility in the eyes of their Creator. As beings, souls are incapable of self-annihilation, from which it follows

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[113] *Enquiry*, 100–1.

[114] *Enquiry*, 103.

[115] Andrew Baxter, *An Appendix to the First Part of the* Enquiry into the Nature of the Human Soul*, Wherein the Principles Laid Down there, are Cleared from Some Objections*, (London: 1750), esp. 238–80.

[116] *Enquiry*, 113.

[117] *Enquiry*, 'The Contents', [1].

[118] *Enquiry*, 157–61.

that the soul is incapable of any kind of death following the death of the body.[119] Baxter was satisfied that his account disproved any possibility that either matter could contain rationality (*contra* John Locke) or that the soul could in any sense be material (*contra* Epicurus/Lucretius). He believed this position ruled out materialism and, as he took the Anglo-Irish philosopher George Berkeley (1685–1753) to have argued, the opposite extreme: immaterialism, the notion that matter did not, or could not, exist at all. Everything Baxter said about God was, he clarified, founded upon the inherent activity of matter, 'this *impossible thing*', which was in itself sufficient to answer Berkeley's case.[120]

He nevertheless discussed Berkeley's supposed immaterialism at some length, remarking that there would have been 'nothing in it' had it been written as 'an *exercise* in a university' rather than published by a 'person of great capacity and learning'.[121] Baxter published these views not only because he wished to participate in serious philosophical debate, but because pedagogy was his vocation, with which came sensitivity not just to truth but moral propriety. His ideas about God were not philosophical exercises but reflected what he deemed to be religious truth. His interest in natural philosophy was in part a vehicle for his religious ideas and could serve the end of moral as well as philosophical instruction. Baxter served as tutor to numerous noble families throughout his life and was buried alongside members of the Hay family, his long-time employers, at their Wittingehame estate in East Lothian upon his death in 1750.[122]

His natural-theological *Matho* (1739) had put the ideas he developed in the *Enquiry* in a form better suited to the young students with whom he spent so much of his time. The work advertised itself as containing the 'first Principles of Philosophy and Astronomy' and the 'Principles of Natural Religion' deducible from them, 'accommodated to the Capacity of young Persons, or such as have yet no tincture of these Sciences'. Baxter's intentions are clear enough from the dedication to one of his tutees, a Master Glover, to whom he assures that the 'Pursuit of Knowledge' and the 'Practice of Virtue' are 'naturally allied to

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119 *Enquiry*, 219–27.

120 *Enquiry*, vol. II, 260. For the text Baxter was most likely responding to directly see Adam Grzeliński, '*Alciphron: Or, the Minute Philosopher*: Berkeley's Redefinition of Free-thinking', in *The Bloomsbury Companion to Berkeley*, ed. Bertil Belfrage (London: Bloomsbury, 2017), 174–95. See also Chapter 4, 180–6.

121 *Enquiry*, vol. II, 259.

122 Wood, 'Baxter, Andrew'.

each other'.[123] Written in the form of a dialogue, the work began with the character Matho asking his interlocutor, Philon, to explain 'some Things in Philosophy' which are 'necessary' and 'pleasant'.

In reply, Philon described the shape of the earth and the 'Nature of Gravity'.[124] Baxter presented the reader with Matho's realisation that the effects of gravitation 'must proceed from the immediate Power of the Deity' and used the work to characterise mechanism and the 'eternal Succession of [mechanical] *Causes and Effects*' he associated with it, as 'a groundless and unphilosophical Supposition'.[125] Matho and Philon discovered that the forces required to effect planetary motion are 'constantly impressed (or at least successively renewed) by an *immaterial Power*, and not owing to one original impulse'.[126] From this, they realise that the universe has been designed precisely for the habitation of rational beings, from which they can deduce the proper conception of the soul as eternal and immaterial.[127]

Tracing the 'Chain of Causes': Colin Maclaurin and Presbyterian Heterodoxy

In *Christianity as Old as the Creation*, Tindal had attempted to exploit what he took to be an inconsistency in this kind of position. He argued that it is 'a Contradiction' to 'suppose a Creature to have Reason to direct him, and that he is not to be directed by it' but, rather, by the literal truth of scripture. 'What is the Religion of all rational Beings', he asked, 'but what the scripture terms it, *a reasonable Service?*'[128] For some, the answer to Tindal was quite clear: scripture was necessary for salvation due to the incapacity of human reason to acquire knowledge of a future state and, ultimately, to tell right from wrong. The former

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[123] Baxter, vol. I, *Matho*, 'To Master Glover'.

[124] Baxter, *Matho*, vol. I, 1.

[125] Baxter, *Matho*, vol. I, 157 and 239.

[126] Baxter, *Matho*, vol. II, 1.

[127] Baxter, *Matho*, vol. II, 222,

[128] [Tindal], *Christianity as Old as Creation*, 168.

regent at Marischal College, Aberdeen, George Turnbull, who had since been working as a tutor to noble families, replied to Tindal with *Christianity neither False nor Useless, tho' not as Old as the Creation* (1732). For Turnbull, people could simply not be expected to act morally without the scriptural exemplar of Jesus Christ.[129]

In his *Philosophical Enquiry concerning the Connexion between the Doctrines and Miracles of Jesus Christ* (1731), Turnbull had argued that revelation has at least equal status to whatever might be deduced from nature, so that 'samples of power to raise the dead, prove the power to raise the dead... in the same way that samples of gravity prove gravity'.[130] Natural theology need not be reconciled with scripture for reason and philosophy were incapable of proving or disproving the truth of divine revelation. Scripture could be validated only against itself, for what can be 'fetched from the nature of GOD, and what we are able to comprehend of his government and providence, contribute not a little to render these doctrines probable, but it is only testimony; testimony from GOD himself... [that] is able to prove these doctrines to be actually true'.[131]

Others were not so sanguine and worried a great deal about the reconciliation of philosophy with revelation. One was John Hutchinson (1674–1737), the son of a Yorkshire yeoman who combined estate management for the Duke of Somerset with an unlikely literary career. Hutchinson, who stands out in the literature as one of the few anti-Newtonians of eighteenth-century Britain, read Newton's God as no more than an *anima mundi*, breathing life into nature but not suitably responsible for effecting physical phenomena.[132] His admirers, the so-called 'Hutchinsonians', were sympathetic to his ideas and, like Hutchinson, feared that the incompatibility between contemporary natural philosophy and scripture dissuaded Christians of the veracity and authority of revelation. Somewhat audaciously, Hutchinson declared in *Moses's Principia* (1724) that the Hebrew

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[129] George Turnbull, *Christianity neither False nor Useless, tho' not as Old as the Creation* (London: 1732), 52.

[130] George Turnbull, *Philosophical Enquiry concerning the Connexion between the Doctrines and Miracles of Jesus Christ* (London: 1731), 34.

[131] Turnbull, *Christianity*, 8.

[132] See John C. English, 'John Hutchinson's Critique of Newtonian Heterodoxy', *Church History* 68 (1999): 581–97; Nigel Aston, 'From Personality to Party: The Creation and Transmission of Hutchinsonianism, *c.* 1720–1750', *Studies in History and Philosophy of Science* 35, 3 (2004): 625–44; and Derya Gürses Tarbuck, *Enlightenment Reformation: Hutchinsonianism and Religion in Eighteenth-century Britain* (London: Routledge, 2016).

Bible had been corrupted through inaccurate translation, and argued that a more faithful rendering of the Old Testament yields the true physics. He proposed an alternative account to that of Newton, based directly on scripture, in which God was not merely the animating spirit of passive matter but immanently expressed through a universal material ether with three modes: fire, light, and air.[133]

Duncan Forbes of Culloden was a concerned reader of *Moses's Principia* and attempted to tidy up and broadcast Hutchinson's argument in *A Letter to a Bishop, concerning Some Important Discoveries in Philosophy and Theology* (1732).[134] Forbes, Lord Advocate and an MP for Inverness, has been designated a Hutchinsonian, apparently the only one in Scotland, and has therefore been taken to be a critic of Newton.[135] His *Letter to a Bishop* betrayed some anxiety over the potential for contemporary philosophy to undermine belief in scripture, particularly in the tendency to propose 'any improbable, or, as they [freethinking philosophers] will call it, incredible or absurd Relation'.[136] Forbes was sympathetic to Hutchinson's attempt to recover a perfect Mosaic physics and admired his ideas to some extent, but he showed little interest in his criticism of Newton. Forbes apologised on Hutchinson's behalf for his attacks on Newton and Clarke. He wrote that 'the Zeal for the Honour of Religion, which in him seems to be very strong and sincere' is the only thing that can excuse the 'degree of Bitterness and Severity' in Hutchinson's *Of Power Essential and Mechanical* (1732), which Forbes acknowledged 'must be disagreeable to many'.[137]

Neither Newton nor gravitation are mentioned in Forbes' subsequent *Thoughts concerning Religion, Natural and Revealed* (1735), which is concerned with the limits of natural theology.[138] With deists and freethinkers in mind, Forbes insisted 'the light of NATURE does in no way show that this perfect being [i.e. God] is merciful to sinners, or

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[133] English, 'Hutchinson's Critique', 586.

[134] Duncan Forbes, *A Letter to a Bishop, concerning Some Important Discoveries in Philosophy and Theology* (London, 1732).

[135] Derya Gürses Tarbuck, 'Duncan Forbes of Culloden (1685–1747), Presbyterian Whig and Hutchinsonian: Towards a Reinterpretation of the History of Ideas in Eighteenth-century Britain', *Eighteenth-century Thought* 3 (2007): 331–48.

[136] Forbes, *Letter*, 2.

[137] Forbes, *Letter*, 64.

[138] Duncan Forbes, *Some Thoughts concerning Religion, Natural and Revealed* (London, 1735).

that his clemency or beneficence can have for its object the offender against immutable justice'.[139] Rather than challenge scriptural authority, contemporary natural philosophy actually demonstrates the limits of reason, for 'we, from our reason, have discovered nothing of the first principles of MOTION, and that MECHANISM which supports our selves and this system'.[140] His defence of revelation was motivated by the fear that some might be led astray by influential desist such as Tindal. Forbes concluded his *Thoughts concerning Religion* by insisting on the primacy of scripture over philosophy, declaring that 'Christianity is very near as old as Creation' – that is, it is as old as revelation.[141]

Forbes may not have engaged directly with Newton's physics in his published works, but he was certainly interested in the philosophical issues it raised. He was listed as a subscriber for five copies of Maclaurin's *Account of Sir Isaac Newton's Philosophical Discoveries* when it first appeared in 1748, and clearly had a strong view of the limits of natural-philosophical endeavour. Maclaurin has been widely identified as the consummate Newtonian and presented as an author committed to popularising and defending his 'master', Newton, suggesting that he and the apparently anti-Newtonian Forbes disagreed about the veracity of Newtonian physics.[142] However, Maclaurin shared Forbes' relatively low estimation of the capacity of reason to acquire knowledge of God, and they might both be usefully contrasted with Baxter on this point. Scholars have recognised that Maclaurin disagreed with Baxter on the nature of providence and the limits of natural philosophy, but his views have not been connected to the religious sympathies that shaped them, obscuring the position he actually took with respect to Baxter.

Maclaurin wrote in the *Account* that 'the higher we rise in the scale of nature, towards the supreme cause, the views we have from philosophy appear more beautiful and extensive'. In light of this remark, Fred Ablondi has argued that Maclaurin's case against Baxter was expressed as three charges against the latter's occasionalism: '(1) impairing the beauty of nature, (2) putting an end to enquiries into the most sublime part of philosophy, and (3) hurting the very interests he (that is, the occasionalist [Baxter]) seeks to

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[139] Forbes, *Thoughts concerning Religion*, 47.

[140] Forbes, *Thoughts concerning Religion*, 51.

[141] Forbes, *Thoughts concerning Religion*, 125.

[142] On Maclaurin's Newtonianism see Wood, 'Science in the Scottish Enlightenment'; Wilson, *Seeking Nature's Logic*; Judith V. Grabiner, 'Newton, Maclaurin, and the Authority of Mathematics', *The American Mathematical Monthly* 111, 10 (2004): 841–52; and Guicciardini, 'Dot-age'. See also Chapter 4, 172–94.

promote', i.e. demonstrating God's providence.[143] In reply, Patrick J. Connolly pointed out, that both men in this apparently 'internecine Newtonian dispute' agreed on the passivity of matter and the inability of mechanism to account for gravitation, but he did not supply an alternative account of their disagreement about divine agency.[144] Timothy Yenter has since argued that Maclaurin is 'less bold than many others' and only 'considers and tentatively endorses metaphysical positions', which he explains through Maclaurin's caution regarding 'theoretical commitments that go beyond experiments' and his opposition to system-building.[145] Like Baxter and others, Maclaurin did not consider issues of divine agency to be purely philosophical concerns, and his position must be understood in the context of contemporary religious debates and controversies in Scotland.

In light of the apparent rise of deism and atheism, some of the rhetoric of this period can obscure what was at stake in debates over natural theology. In the 1710s and 1720s, John Simson was formally accused of unsound teaching as professor of divinity at Glasgow, where Maclaurin studied between 1709 and 1713. Legal proceedings were twice opened against Simson and he was brought before the General Assembly of the Church of Scotland for allegedly giving 'too much to natural reason' and placing too much emphasis on 'Good Works and Obeidence'. On the second attempt to sanction him in 1729, Simson was suspended from teaching, though without the loss of his professorial chair.[146] Simson was thought to give 'too much to natural reason' in moral matters, and his views were part of a broader emphasis, associated with 'New Licht' (New Light) opinion, on moral conduct and good works over the importance of orthodox written doctrine, such as the Westminster Confession of Faith.[147]

Scripture remained essential for salvation for New Light thinkers, but their views tended to place greater emphasis on the importance of 'experience' for shaping moral character. This emphasis related to interest in the concept of 'moral sense', the innate capacity and natural tendency humans have toward 'beneficence' and sociability. Turnbull

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[143] *Account*, 387. Ablondi, 'Baxter and Maclaurin', 18.

[144] Connolly, 'Maclaurin on Occasionalism', 133.

[145] Yenter, 'Metaphysical Implications', 115–7.

[146] Quoted in Ahnert, *Moral Culture*, 32–3. See also Anne Skoczylas, *Mr. Simson's Knotty Case: Divinity, Politics and Due Process in Early Eighteenth-century Scotland* (Montreal: McGill-Queen's University Press, 2001).

[147] Ahnert, *Moral Culture*, 26.

and Francis Hutcheson, professor of moral philosophy at Glasgow from 1729 until his death in 1746, were influential proponents of these views who developed the ideas of Anthony Ashley Cooper, 3rd Earl of Shaftesbury.[148] These ideas were controversial in the eyes of many Scottish Presbyterians for much of the eighteenth century. Archibald Campbell, a student of Simson and later professor of divinity and church history at St Andrews from 1733, was charged in 1735 with an unsound focus on the importance of works for achieving salvation. In *An Enquiry into the Original of Moral Virtue* (1733), Campbell associated himself with Simson and developed ideas about the primacy of moral conduct. Later, in *The Necessity of Revelation* (1739), he argued that the primary purpose of doctrine was 'to teach us to *deny ungodliness, and worldly lusts, and to live soberly, righteously, and godlily*'.[149] In 1735, Campbell had been investigated by the Committee for Purity of Doctrine but escaped punishment, being instructed only to take greater care with his pronouncements.

These new ideas about moral character and natural sociability are often considered to be what ultimately defined the Scottish Enlightenment. Yet Turnbull and Hutcheson were heterodox thinkers in the eyes of men like Baxter and, later, John Witherspoon, minister of Beith (Ayrshire), who connected their ideas to those of Matthew Tindal and William Dudgeon.[150] In *Ecclesiastical Characteristics* (1753), Witherspoon poured scorn on the heterodoxy of members of the emerging 'Moderate' faction in the Kirk, such as William Robertson, a future Moderator of the General Assembly and principal of Edinburgh's university, accusing 'moderate men' of 'altering Christianity' through selective, distorted use of scripture, in order 'to reconcile it to moderation and common sense'.[151] Maclaurin seems to have held similar views to some of the late recipients of Witherspoon's ire, such as Hutcheson, with whom Maclaurin was a student at Glasgow. Several influential heterodox Presbyterians were members of the Edinburgh Rankenian Club, and the later generation of Moderates that emerged in the 1750s held similar views to the Rankenians

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[148] For Shaftesbury's notion of 'moral sense' see Gideon Yaffe, 'Earl of Shaftesbury', in *A Companion to Early Modern Philosophy*, ed. Steven Nadler (London: Blackwell, 2002), 423–36.

[149] Archibald Campbell, *The Necessity of Revelation; or an Enquiry into the Extent of Human Powers with Respect to Matters of Religion* (London: 1739), 51. For Campbell's views see Ahnert, *Moral Culture*, 35–40.

[150] For an articulation of this view of the Scottish Enlightenment see Phillipson, *Adam Smith*.

[151] [John Witherspoon], *Ecclesiastical Characteristics* (Glasgow: 1754), 22.

on doctrine, moral character, and natural theology.[152] For these heterodox thinkers, the rational interpretation of nature was, like the rational interpretation of written doctrine, limited in its capacity to reveal knowledge of God's purposes and the moral imperatives he has set for humankind, relative to the views of orthodox Presbyterians in Scotland.

This tendency among the heterodox helps to make sense of Maclaurin's position on divine agency and natural theology. He joined the Rankenian during his time in Edinburgh. In a letter sent to Hutcheson in 1728, he referred to 'moral sense' as 'our philosophy' and Newtonian philosophy as 'our Doctrine'.[153] As a recent graduate from Glasgow, the young Maclaurin had produced an essay, 'De Viribus Mentium Bonipetis' (On the Good-seeking Powers of the Mind), in which he attempted to produce a quantitative analysis of innate 'good-seeking' or 'beneficent' powers, drawing on Newton's method of fluxions and the physics of the *Principia*.[154] 'De Viribus' has typically been treated as a precocious mathematical novelty, and cited as support for the claim that Maclaurin was utterly committed to Newton from an early age.[155] However, notwithstanding Maclaurin's reference to 'our doctrine', he is not best understood as intellectually committed to Newton, and the essay represents not just his early interest in mathematical physics but his interest in new ideas about the natural capacity for moral conduct and the tendency toward the good that Hutcheson later developed into an influential moral philosophy.[156]

Maclaurin's youthful exuberance did not translate into an optimistic view of the capacity of the human mind to fathom God's purposes. 'As a blind man knows not colours and has no idea of the sensation of those who see', he insisted in the *Account*, 'so we have

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[152] For the Rankenian Club in this context see Ahnert, *Moral Culture*, 35–7; and, for the Moderates, Ahnert, *Moral Culture*, 66–93. Maclaurin's brother John, minister in Glasgow, appears to have been on Witherspoon's ('evangelical') side the debate according to the account of his views in Jonathan Yeager, 'Nature and Grace in the Theology of John Maclaurin', *Scottish Journal of Theology* 65, 4 (2012): 435–48.

[153] Colin Maclaurin to Francis Hutcheson, October 22nd, 1728 (Old System), *The Collected Letters of Colin MacLaurin*, (ed.) Stella Mills (Nantwich: Shiva, 1982), 25–7.

[154] Colin Maclaurin, 'De Viribus Mentium Bonipetis', 1714, Colin Campbell Collection, MS 3099.15, Edinburgh University Library Special Collections. See Ian Tweddle, 'An Early Manuscript of Colin Maclaurin's: Mathematical Modelling of the Forces of Good; Some Remarks on Fluids', accessed 20th Jul., 2023: mathshistory.st-andrews.ac.uk/Publications/tweddle_maclaurin.pdf.

[155] See Grabiner, 'Authority of Mathematics'.

[156] For Hutcheson's moral philosophy and its relationship to Newton's ideas see Chapter 4, 198–9.

no notion of how the Deity knows and acts'.[157] For Maclaurin, God's attributes, as 'the *Contriver*, *One*, an *Almighty Power* (capable of creating the whole universe)', '*active* and *present* every where' with 'consummate *Wisdom*' and 'unbounded *Goodness'*, can be deduced from creation. So can the fact that God '*governs*, and that he endowed humans with sense'. However, he warned, natural theology requires 'the utmost caution and soberness of thought'.[158] He criticised the rationalism of Descartes, Spinoza, and Leibniz as a 'monstrous' overreach and overextension of the 'doctrine of absolute necessity, extending it to the Deity himself, of whom our ideas are so inadequate, and whom it so much concerns us not to misrepresent'.[159] God's existence may be deducible from nature but not in the same way as one might 'deduce the necessity of an eternal truth in geometry, or the property of a figure from its essence, nor is it even with that direct self-evidence which we have for the necessary existence of space'.[160]

Maclaurin was nevertheless certain that 'the great mysterious Being... has set a part of the chain of causes in our view', through which 'our veneration for the supreme author is always increased, in proportion as we advance in the knowledge of his works'.[161] He defended Newton's characterisation of God in the 'Scholium Generale' and *Opticks*, arguing that by 'sensorium' and 'Lord of all' Newton clearly meant to better express God's omnipotence and omnipresence. Newton's remarks were 'rational and worthy of the Deity, and as well founded in true philosophy'. His caution had made him wary of rationalist theology, leading Newton to treat God justly as 'the only independent cause' and the 'source and foundation' of a great chain of causes.[162] Yet, while Maclaurin did not actually criticise Newton's 'conjectures' regarding a material ether, he gave no serious credence to the notion that an ethereal medium was needed to account for gravity's operation.[163] Maclaurin protested that 'the whole efficacy of this [ethereal] medium must be resolved into

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[157] *Account*, 385–6.

[158] *Account*, 381.

[159] *Account*, 380.

[160] *Account*, 386.

[161] *Account*, 22.

[162] *Account*, 386.

[163] Maclaurin's remarks have been interpreted in a number of places as supportive of the existence of an ethereal medium to explain gravitation: e.g. Russell, *Riddle of Hume's* Treatise; Ablondi, 'Baxter and Maclaurin'; and Yenter, 'Metaphysical Implications'.

his power and will, who is the supreme cause', therefore rendering it unnecessary.[164] He did not explicitly rule it out, and politely supposed that better knowledge of such an ethereal medium may be of use, but also clearly stated that the notion had no (known) empirical basis: 'as for a more subtitle medium than the air, no experiments nor observations shew that there is any here, or in the celestial spaces, from which any sensible resistance can arise'.[165] More generally, he was critical of Leibniz for questioning the term 'attraction' as a description of the motion of bodies, suggesting that Maclaurin simply saw no case to answer for in explaining gravity's physical transmission.[166]

Maclaurin's view of God's freedom to act in nature was quite different from Baxter's, for in Maclaurin' opinion 'mechanism has its share in carrying on the great scheme of nature'. For Maclaurin, the powers which animate this 'great scheme' are 'as instruments' made by God, not 'mere immediate volitions of his', though they 'derive their efficacy from him'.[167] His position not only ruled out rationalism and necessitarianism but also Baxter's extreme brand of voluntarism, which was predicated on being able to see in natural phenomena the one, supreme cause itself. Maclaurin therefore sat somewhere between Baxter and the bamboozling Henry Home on a spectrum of scepticism regarding the potential for natural theology to acquire knowledge of God. Had he known of them, Maclaurin would have disagreed with the views Home published in the 1750s, which rejected traditional natural theology altogether on epistemological grounds and denied that the human mind can acquire knowledge of causes from observed effects. Though people in the Moderate party rejected such views, some were sympathetic with Home and Hume when their ideas got them into trouble, and they both managed to avoid any serious repercussions for voicing them.[168]

Maclaurin may well not have read Hume's *Treatise of Human Nature* (1739) either, for by its author's admission the work did not make much of an immediate impact.[169] More commercially successful works that laid out Hume's critical remarks on contemporary

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[164] *Account*, 387.

[165] *Account*, 294.

[166] *Account*, 110.

[167] *Account*, 388.

[168] See Chapter 5, 215–30.

[169] See James A. Harris, *Hume: An Intellectual Biography* (Cambridge: Cambridge University Press, 2015), 118.

philosophy in the form of essays appeared in the 1750s (after Maclaurin's death). Hume's reading of Newton was at the extreme end of the sceptical spectrum, for rather than believe Newton's treatment of providence to have been 'rational and worthy of the Deity', as Maclaurin did, Hume took Newtonian physics as a support for his own brand of empirical scepticism and causal nescience that supported his rejection of natural theology. In a footnote included in the appendix to the third volume of the *Treatise*, Hume noted that we ought to 'confine our speculations to the appearances of objects to our senses, without entering into disquisitions concerning their real nature and operations'. 'If the *Newtonian philosophy* be rightly understood', he added, 'it will be found to mean no more'.[170] His views on natural theology were made clear in the posthumous *Dialogues concerning Natural Religion* (1779), but these revelations were a surprise to few. Hume went to his deathbed in 1776 notorious for unbelief.[171]

Conclusion

Hume's understanding of Newton was thus both something of a new departure and part of a broad debate about the philosophical implications of Newton's physics. This was a debate that did not just include 'philosophers' but those, like Maclaurin, with apparently merely 'scientific' interests. Nor was it one in which authors simply rejected or accepted Newton's conclusions. Newton's Scottish admirers were not motivated to defend him against Leibniz's critique of action at a distance, nor did they line up in support of Samuel Clarke as the foremost apologist for Newton's physics against continental anti-Newtonianism. They dismissed Leibniz's objection and the philosophical value of a material ether because their conceptions of divine action did not, despite their disagreements, suggest that Newton's argument for universal gravitation was insufficiently mechanical. The authors discussed here were primarily concerned to show how gravitation operated in order to demonstrate its compatibility with their own views on God's voluntary activity in nature. Their views on this matter were shaped less by natural-philosophical priorities than their own genuine religious sympathies, which were conditioned by contemporary religious

170 [David Hume], *A Treatise of Human Nature*, vol. III (London: 1739), 310.

171 Harris, *Hume*, 461–72.

debates and controversies. These authors developed their own Newtonian natural theologies in line with these sympathies and the needs of their audience, which they claimed included students at risk of being led astray by errant philosophical opinion.

The debates over providence and gravitation outlined here are easier to decipher when Newton's Scottish readers are not taken to be primarily motivated by the desire to defend their master as a figure of intellectual authority, or to promote his ideas as if a new scientific gospel. Readers like Cheyne, Baxter, and Maclaurin feared, more than anything, how false conceptions of gravitation could lend support to deists, atheists, and others who might undermine true Christianity. Their engagement with Newton in the context of natural theology and in relation to questions about divine agency had important consequences beyond the positions they outlined, for it stimulated further interest in the kind of knowledge Newton had uncovered and the wider implications of his discoveries. This led, in turn, to more detailed engagement with the finer details of his mathematical and philosophical methodologies and further reflection on their significance for historical and intellectual progress. After mid-century, Newton's reputation was remade through these inquiries and his example drawn on to support several innovative philosophical projects. Under this influence, natural philosophy would continue to be transformed by those who shared the conviction that the discipline was the product of a reformation of natural knowledge Newton had done much to bring about.

CHAPTER IV

DISCOVERY

The man who first discovered that cold freezes water, and that heat turns it into vapour, proceeded on the same general principles, and in the same method, by which Newton discovered the law of gravitation and the properties of light. His *regulæ philosophandi* are maxims of common sense, and are practised every day in common life; and he who philosophizes by other rules, either concerning the material system, or concerning the mind, mistakes his aim.

Thomas Reid[1]

Newton's death in March, 1727 prompted his admirers to take stock of his achievements. John Conduitt, Newton's nephew by marriage, soon devised a literary project designed to honour an extraordinary life. In February, 1728 he drafted a letter to which he planned to attach a 'very imperfect attempt' at Newton's biography, Bernard de Fontenelle's 'Éloge de Newton', recently published in the *Histoire de l'Académie Royale des Sciences*.[2] Conduitt thought Fontenelle, by then an influential figure in France, had 'neither abilities nor inclination to do justice to that great man who had eclipsed the glory of their Hero Descartes'. The life of such a 'national man' as Newton, Conduitt supposed, ought rather to be honoured in work composed by his fellow countrymen, and especially by those who had enjoyed 'so great a share in his esteem' as had the intended recipients of his circular.[3] Colin Maclaurin apparently received the final version of Conduitt's letter. By his own admission, he was prompted by 'M^{r} Conduit's desyre' to begin work on what would later

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[1] Thomas Reid, *An Inquiry into the Human Mind, on the Principles of Common Sense* (Edinburgh: 1764), 3–4.

[2] For an account of the 'Éloge' see Simon Schaffer, 'Fontenelle's Newton and the Uses of Genius', *L'Esprit Créateur* 55, 2 (2015): 48–61. For Conduitt's biographical activities see Rob Iliffe, 'Introduction', in *Early Biographies of Isaac Newton: 1660–1885*, eds Rob Iliffe, et al., vol. I (London: Taylor & Francis, 2006), xi–lxx.

[3] John Conduitt, 'Draft of a Circular Letter Soliciting Material for Conduitt's Life of Newton, dated 16 February 1728', Keynes MS.131a, King's College, Cambridge, accessed 30th September, 2022: https://www.newtonproject.ox.ac.uk/view/texts/diplomatic/OTHE00005.

become his *Account of Sir Isaac Newton's Philosophical Discoveries*.[4] Conduitt said of an early version of Maclaurin's contribution that he read it 'over and over' with 'infinite pleasures'. He told him the draft 'raised in me a great expectation & impatience for the continuation'.[5]

Conduitt's death in 1737 brought to an end his efforts to compile Newton's biography, but Maclaurin was undeterred and continued work on his part until his own death in 1746. Maclaurin's contribution, as its eventual title suggests, was not an account of Newton's life but his philosophy, and he took such interest in 'speculations' on the topic that he admitted to becoming 'so immerged' that he 'could not leave them'.[6] The *Account*, which finally appeared two years after its author's death, is often cited as one of the eighteenth century's most influential and authoritative expositions of Newtonian natural philosophy, but it is rarely acknowledged that Maclaurin placed greatest emphasis on Newton's philosophical method.[7] Casting Newton as 'cautious' and 'modest', Maclaurin presented the method of analysis and synthesis that he practiced as having completed a reform of philosophy underway since the revival of learning in Europe.[8] Universal gravitation was the focus of Maclaurin's interest, and he characterised the method Newton used to discover it as the result of an ideal combination of experimentalism and applied mathematics. Virtually two decades in the making, the *Account* represents what Maclaurin believed to be Newton's greatest contribution to philosophy.

In more recent times, scholars have argued that Newton was indeed a decisive influence on the philosophical methodology of Maclaurin's day. However, unlike Maclaurin, they have tended to view Newton's pioneering 'scientific' method as a major influence on Enlightenment philosophy, rather than Newtonian methodology as a kind of *philosophical* methodology in the first place.[9] Newton's methodological influence is thought to have been

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[4] 'Colin Maclaurin to Lord Hamilton of Dalzell', 13th March, 1731 (Old System), in *Collected Letters*, 30.

[5] 'John Conduitt to Colin Maclaurin', 12th July, 1732 (Old System), in *Collected Letters*, 41.

[6] 'Maclaurin to Lord Hamilton'.

[7] See Alan Gabbey, 'Newton, Active Powers, and the Mechanical Philosophy', *Cambridge Companion to Newton*, Iliffe and Smith, 421–53, in which the *Account* is described as the 'best' of its kind and written by one of the 'leading Newtonians' (421); Wood, 'Science in the Scottish Enlightenment', 96–9; Wilson, *Seeking Nature's Logic*, 53–9; Demeter, 'Philosophical Methods', 74–7; and Yenter, 'Metaphysical Implications', 115–9.

[8] *Account*, 10.

[9] For Newton's modern reception as a 'scientist' and 'philosopher' see Introduction, 14–22.

particularly strong in Scotland, yet Maclaurin's *Account* has received relatively scant scholarly attention among Scottish Enlightenment scholars.[10] Figures like Francis Hutcheson, George Turnbull, Thomas Reid, David Hume, and Adam Smith have been the focus of literature on the topic for having apparently either applied Newton's scientific or natural-philosophical methodology to moral inquiry or used methods directly 'inspired' by Newtonian natural philosophy.[11] On this view, Newton's remark in the *Opticks* that 'if natural Philosophy in all its Parts, shall at length be perfected, the Bounds of Moral Philosophy will be also enlarged' was taken quite literally as encouragement for new philosophical projects like Hume's 'Science of Man' and Reid's Common Sense.[12]

Natural philosophy in the eighteenth century did not signify inquiry as distinct from moral philosophy as science is from philosophy today, as has been sometimes implied by the literature on this topic. This chapter argues that Newtonian methodology was primarily of interest as a method of philosophical discovery more generally rather than a 'scientific method' that might be applied or transferred to moral philosophy. It contends that Newton's methodological example may be best understood not as inspiration for several Newtonian methods but as informing different ideas about philosophical discovery and methodology which, in turn, led to his example being interpreted and used in different ways. These new ideas were not just methodological in nature but related to new ways of understanding how the mind operates and new perspectives on the progress of civilisation. The discovery of gravitation was of particular interest, as it was taken by many to be historically unprecedented in its depth of insight and transformative for the discipline of natural philosophy. Yet Newton's method was informative rather than singularly inspirational because it was not seen as a completely separate kind of philosophical discovery. Rather, it was understood as a product of important methodological innovation among the moderns. For some, Newtonian method was not even really original to Newton but the

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[10] For this scant attention see footnote 7.

[11] For a brief discussion of 'moral Newtonianism' see Wood, 'Science in the Scottish Enlightenment', 91 and 102–3. See also Jacqueline Taylor, 'The Human Mind and its Powers', *Companion to the Scottish Enlightenment*, Broadie and Smith, 60–71; and Demeter, 'Philosophical Methods'.

[12] *Opticks*, 382. For what Newton himself meant see John Henry, 'Enlarging the Bounds of Moral Philosophy: Why Did Isaac Newton Conclude the *Opticks* the Way He Did?', *Notes and Records of the Royal Society* 71 (2017): 21–39.

revival of a methodology practiced in the most ancient times and temporarily lost following its utter corruption during antiquity.

Scholars have addressed the question of Newton's methodological influence through prominent figures like Hume and Smith due to the importance of their contributions to the philosophy of the Scottish Enlightenment. However, with the notable exception of Reid, there is little evidence that engagement with Newton and the new science was actually central to these figures' thinking. Their engagement with Newton was sometimes fleeting, leaving their views on the matter difficult to determine. The intention signalled by the title of Hume's *Treatise of Human Nature*, for instance, 'to introduce the experimental method of reasoning into moral subjects', does not in and of itself imply any particular reading of Newton.[13] The experimentalists Hume himself cited in connection with his enterprise were 'Mr. [John] *Locke*, my Lord *Shaftsbury* [*sic*] , [the Anglo-Dutch philosopher] Dr. [Bernard] *Mandeville*, Mr *Hutchinson* [i.e., Francis Hutcheson], [the English bishop and philosopher] Dr. [Joseph] *Butler*, &c.'. He may well have had in mind the kind of experimentalism associated with figures like Robert Boyle and Newton because he explicitly connected the experimentalists previously cited with the English natural philosopher Francis Bacon (1561–1626), but he did not advertise the fact.[14] Hume had access to their writings as a student at Edinburgh in the 1720s, when he was a member of the professor of natural philosophy Robert Stewart's Physiological Library.[15] Yet, to better understand how such remarks about experimental method may have related to Newton and the new science, they must be placed in the context of contemporary thinking about natural-philosophical methodology more generally and the reception of Newton's method in particular.

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[13] Hume, *Treatise of Human Nature*, title page. For an overview of the literature on Hume's Newtonianism and an assessment of how he read Newton see Eric Schliesser and Tamás Demeter, in 'Hume's Newtonianism and anti-Newtonianism', *Stanford Encyclopedia of Philosophy*, 2020, accessed 22nd June, 2022: plato.stanford.edu/entries/hume-newton.

[14] Hume, *Treatise*, 6. See Harris, *Hume*, 83–5. Scholars have argued that the *Treatise* does refer to Newton implicitly: e.g. according to Yenter, 'Metaphysical Implications', Hume 'frames the *Treatise* as modelled on Newton… in his claims to offer "a science of man", in his calling the association of ideas "attraction", and his reliance on "experiment" in drawing conclusions about human nature' (129), though it is not established how these terms are exclusively Newtonian.

[15] See Barfoot, 'Hume and the Culture of Science'.

By the time Hume published his *Treatise*, several of Newton's Scottish readers had characterised his approach in print as a combination of experimental and mathematical philosophy.[16] The work that did this most explicitly, John Keill's *Introductio ad Veram Physicam* (1701), was also in the Physiological Library that Stewart established in 1724.[17] Members would not have found a detailed and systematic treatment of Newtonian philosophical methodology in these works, however. Maclaurin was both the first and only Scottish author to publish such an account of Newton's method in the eighteenth century. Unlike earlier Scottish authors, Maclaurin followed Newton's own characterisation of his method as a form of analysis and synthesis, and also adopted Newton's description of his philosophy as 'experimental'. This was despite Maclaurin's own view that mathematics was not just vital for tracing the effects of gravitation but had been essential to the discovery of gravitation itself. This view ran counter to those of authors like John Theophilus Desaguliers and Henry Pemberton, who privileged the experimental character of Newtonian natural philosophy in accounts written in the 1710s and 1720s.

Maclaurin's understanding of Newton's philosophical method was shaped by his views on Newtonian mathematical methodology, which were developed partly in response to George Berkeley's criticism of the method of fluxions (i.e. Newton's calculus) articulated in *The Analyst* (1734). Berkeley's anti-abstractionist critique of calculus posed tricky questions about the validity of mathematical philosophy, which connected to the empirical scepticism he had elaborated in earlier works such as *De Motu* (On Motion, 1721). Neither Maclaurin nor most other Scottish authors were at all persuaded by Berkeley's sceptical conclusions, but he was a respected author and his arguments encouraged them to articulate their views on the issues he had raised in his works. Berkeley's empiricist psychology was part of an increased interest in the philosophy of mind in the period, and developments in this area reshaped Newton's reception in Scotland around mid-century.[18] Reid's Common Sense philosophy was developed in response to what he called the 'system of scepticism' developed by Berkeley, Locke, Hume, and others. This 'system' had

[16] See Chapters 1 and 2.

[17] Barfoot, 'Hume and the Culture of Science', 151–60.

[18] For an account of these developments see Paul Wood, 'Science, Philosophy, and the Mind'.

been constructed through psychological theories he categorised as the 'theory of ideas'.[19] The emphasis Reid placed on the role of an innate inductive principle in the acquisition of knowledge had great influence on subsequent thinking about Newton's discoveries.

In the *Inquiry into the Human Mind* (1764) with which Reid launched his Common Sense philosophy, he described Newton's *regulæ philosophandi* as 'maxims of common sense' and declared that 'he who philosophizes by other rules, either concerning the material system, or concerning the mind, mistakes his aim'.[20] Despite the apparent importance of Newton to his project, Reid's explicit engagement with Newton and understanding of his methodology have received relatively little scholarly attention.[21] Reid was in fact the only other Scottish author to produce a detailed exposition of Newton's method in this period, but the paper he gave to the Glasgow Literary Society – most likely between 1779 and 1790 – in which it can be found was not published until the 1990s.[22] In this paper, entitled 'Some Observations on the Modern System of Materialism' and ostensibly aimed at the materialism of the English natural philosopher Joseph Priestley (d. 1804), Reid departed from Maclaurin and claimed that inductive inference alone, as expressed in Newton's *regulae*, was sufficient for the discovery of universal gravitation. Though Reid was not original in claiming that Newton's discoveries could have been made

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[19] Reid, *Inquiry into the Human Mind*, 4–5. See Nicholas Wolterstorff, *Thomas Reid and the Story of Epistemology* (Cambridge: Cambridge University Press, 2000); and Paul Wood, 'Thomas Reid and the Common Sense School', in *Scottish Philosophy in the Eighteenth Century, Volume I: Morality, Politics, Art, Religion*, eds Aaron Garrett and James A. Harris (Oxford: Oxford University Press, 2015), 404–52.

[20] Reid, *Inquiry into the Human Mind*, 3–4.

[21] See L. L. Laudan, 'Thomas Reid and the Newtonian Turn in British Methodological Thought', in *The Methodological Heritage of Newton*, eds Robert Butts and John Davis (Toronto: University of Toronto Press, 1970), 103–131 in which Reid is identified as a major influence on the introduction of Newtonian 'empiricism' into 'the mainstream of British philosophical thought on epistemology and the philosophy of science' (105–6); and Steffen Ducheyne, 'Reid's Adaptation and Radicalisation of Newton's Natural Philosophy', *History of European Ideas* 32 (2006): 173–89, in which it is argued that the radical 'Reidian adaptation' of Newton's methodology heralds the 'beginnings of the anti-causal trend that would become so popular in the age of positivism' (188).

[22] Despite its publication in Paul Wood (ed.), *Reid on the Animate Creation: Papers Relating to the Life Sciences* (Edinburgh: Edinburgh University Press, 1995), Ducheyne, 'Reid's Adaptation and Radicalisation' does not refer to this paper. See Paul Wood, 'Thomas Reid's Critique of Joseph Priestley: Context and Chronology', *Man and Nature / L'Homme et la Nature* 4 (1985): 29-45.

without the assistance of mathematics, Common Sense philosophy provided a completely new epistemology and broader theoretical underpinning for this position.

Reid's understanding of Newton's method reflects a new emphasis placed by contemporaries on the nature of particular mental faculties, such as the imagination, and their role in the pursuit of knowledge and the development of new ideas. Adam Smith's only substantial explicit engagement with Newton is found in an essay on the history of astronomy which explored the role of the imagination in philosophical discovery.[23] Smith's essays on the history of astronomy and other scientific disciplines, thought to have been written between 1749 and 1758 and revised and developed in the 1770s, were not published until the 1790s, after his death. These essays were concerned with the progress of learning in history, and they reflect a broader interest in Scotland in how the science of the mind could shed light on the progress of civilisation. Two authors based in Aberdeen, William Duff and Alexander Gerard, developed theories of genius addressing these issues in the 1760s and 1770s which elevated the faculty of imagination in new conceptions of 'poetic' and 'philosophical' genius. Literature on these theories has revealed their origins in debates about ancient poetry and placed them in the context of eighteenth-century aesthetic theory and the emergence of Romantic literature, but scholars have so far overlooked their innovative treatment of scientific or philosophical genius, for which Newton's example was a major source.[24]

Through the work of Reid, Smith, Duff, and Gerard, this chapter demonstrates how emphases on inductive inference and the role of the imagination brought about a new vision of Newton as a genius of superior mental capacity, which is a prevalent view of him today.[25]

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[23] Accounts of Smith's Newtonianism include Broadie, *Scottish Enlightenment*, 191–8; Leonidas Montes, 'Newton's Real Influence on Adam Smith and its Context', *Cambridge Journal of Economics* 32 (2008): 555–76; and Eric Schliesser, *Adam Smith: Systematic Philosopher and Public Thinker* (Oxford: Oxford University Press, 2017), 274–87.

[24] See Bernhard Fabian, 'An Early Theory of Genius: Alexander Gerard's Unpublished Aberdeen Lectures', in *Studies in the Eighteenth Century II: Papers Presented at the Second David Nichol Smith Memorial Seminar, Canberra 1970*, ed. R. F. Brissenden (Toronto: University of Toronto Press, 1973), 114–42; Ronnie Young, 'James Beattie and the Progress of Genius in the Aberdeen Enlightenment', *Journal for Eighteenth-century Studies* 36, 2 (2013): 245–61; and Dabney Townsend, 'On Genius: The Development of a Philosophical Concept of Genius in Eighteenth-century Britain', *Journal of the History of Ideas* 80, 4 (2019): 555–74.

[25] For the modern view of Newton's genius and its origins see Darrin M. McMahon, *Divine Fury: A History of Genius* (New York, NY: Basic Books, 2013), esp. 96–150; and Fara, *Making of a Genius*.

This vision differed from the previously more common characterisation of Newton as the possessor of superior virtues, such as 'modesty', rather than mental faculties, and from the notion that the *regulae philosophandi* were procedural rules that Newton had carefully followed in order to make his discoveries, rather than rules by which the mind naturally operates. Neither of these alternatives to the 'genius view' disappeared by any means, and they are present to different degrees in both Maclaurin's and Reid's treatment of Newton and others that followed them. More than anything, these different ways of understanding how Newton made his extraordinary discoveries demonstrate that he was not viewed by his readers as an experimental *or* mathematical philosopher.[26] He was always both, but interpretations of Newtonian methodology tended to turn on the relative importance readers accorded to inductive and deductive reasoning in Newton's discoveries. Induction and deduction were associated, respectively, with experimentalism and the application of mathematics, but no one proposed that natural philosophy might do with one and not the other.[27]

This chapter first outlines the debate over fluxions initiated by Berkeley's *Analyst* and shows how Maclaurin tried to answer Berkeley's challenge in *A Treatise of Fluxions* (1742). It then shows how Maclaurin's treatment of mathematical philosophy in the *Treatise of Fluxions* was later complemented by his posthumous *Account*, which delivered a comprehensive exposition of Newton's method. The chapter then examines Thomas Reid's treatment of Newton's *regulae* in his paper to the Glasgow Literary Society to show how Reid's emphasis on the importance of induction departed from Maclaurin's understanding of Newton's method. Reid's interests are finally shown to be representative of a wider emphasis on the imagination represented by Smith's history of astronomy and Duff's and Gerard's theories of genius, which took Newton's reception in influential new directions.

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[26] For how the Principia and Opticks are seen to represent different philosophies see Introduction, 31–2. For an argument for Newton's 'failure' to apply the method of the *Principia* to the *Opticks* see Steffen Ducheyne, 'Optical Versus Mechanical Models: Newton's Failure to Construct a Satisfactory Theory of the Phenomena of Light and Colour', *Logique et Analyse* 49, 194 (2006): 199–223.

[27] It has been claimed that in Britain Newton was received more as an experimentalist than a mathematical philosopher, in contrast to his reception in France: e.g. Montes, 'Newton's Real Influence'. Also, Newton's Scottish reception has been seen as peculiarly experimental in focus vis-à-vis that of England: see Chapter 5, 215–22.

The Fluxions Debate and George Berkeley's Challenge to Mathematical Physics

Since the publication of the *Principia* in 1687, Newton's Scottish readers had generally seen his application of mathematics to physics as not only unproblematic but exemplary. Faith in Newton's mathematical natural philosophy was so strong among these readers that not even George Gordon's explicit challenge to the validity of mathematical abstraction prompted a response from his interlocuter, George Pirrie, nor anyone else in Scotland.[28] George Berkeley eventually broke this silent consensus and forced Newton's Scottish admirers to address the issue of abstraction in greater detail. Even then, he did so only decades after first raising explicit objections to abstraction in physical science in *De Motu* (1721).

It was Berkeley's *Analyst* (1734) that finally provoked a substantial reaction, a work that not only cast doubt on the logical rigour of Newton's calculus, the validity of its assumptions, and the permissibility of its application to philosophy but accused Newton's admirers of intellectual partisanship and religious infidelity.[29] The 'immaterialist' conclusions Berkeley was thought to have drawn from the philosophy of mind he outlined in earlier works like *An Essay Towards a New Theory of Vision* (1709) and *A Treatise Concerning the Principles of Human Knowledge* (1710) were not always taken as seriously by contemporaries as in modern times, though these works seem to have won Berkeley considerable respect as an author.[30] Maclaurin's rigorous reply to the attack on calculus nevertheless addressed Berkeley's scepticism regarding whether nature can be said to conform to mathematical laws.

Maclaurin was among the target audience for Berkeley's *Analyst*. He had been professor of mathematics at Marischal College, Aberdeen from 1719 before becoming

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[28] See Chapter 2, 127–8.

[29] See Douglas M. Jesseph, De Motu *and* The Analyst*: A Modern Edition, with Introductions and Commentary* (Dordrecht: Kluwer, 1992), esp. 3–44 and 111–58; Lisa Downing, 'Berkeley's Natural Philosophy and Philosophy of Science', in *The Cambridge Companion to Berkeley*, ed. Kenneth P. Winkler (Cambridge: Cambridge University Press, 2005), 230–65; and Richard Brook, '*De Motu*: Berkeley's Philosophy of Science', in *Bloomsbury Companion to Berkeley*, 158–73.

[30] For the *Theory of Vision* and its varied readings in the eighteenth century see Margaret Atherton, 'Berkeley's *Theory of Vision* and its Reception', in *Cambridge Companion to Berkeley*, 94–124. E.g., see Chapter 3, 160.

professor of mathematics at Edinburgh in 1725.[31] He had become a member of the Royal Society in 1719, and the following year he published a work of mathematics, *Geometria Organica* (1720), dedicated to its President, Newton. Maclaurin's appointment at Edinburgh was complicated, because James Gregory (David Gregory's brother, who succeeded him at Edinburgh in 1692) already held the post, though he did not teach. Newton eased Maclaurin's appointment as Edinburgh's second concurrent mathematics professor by offering to cover some of his salary on the town council's behalf.[32] Along with the vast majority of Newton's admirers, Maclaurin paid little attention at this time to the focus of Berkeley's forthcoming attack, the role of infinitely small quantities in Newtonian calculus.[33] Later, while weighing up whether and how to respond to *The Analyst*, Maclaurin admitted to a friend, the mathematician James Stirling, that he had been 'an admirer too of infinites'.[34]

Maclaurin's *Treatise of Fluxions* is typically seen as having played an important role in establishing Newton's fluxional method, rather than Leibniz's 'analytical' or 'differential' approach to calculus, as the dominant approach in Britain to the most powerful mathematical tool of the eighteenth century.[35] Niccolò Guicciardini has characterised the work as 'the manifesto of the fluxionists' and 'representative of the Newtonian tradition' of British mathematics.[36] Both Guicciardini and Judith V. Grabiner have drawn attention to the progressive character of the work in response to George Davie, for whom Maclaurin and others in Scotland displayed an 'excessive preoccupation' with Newton and ancient geometry.[37] Their 'mathematical Hellenism', Davie alleged, was responsible for the stagnation of British mathematics relative to continental Europe, where (Leibnizian) analytical calculus had led to significant advances.[38]

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[31] See Erik Lars Sageng, 'Maclaurin, Colin (1698–1746), Mathematician and Natural Philosopher', *Oxford Dictionary of National Biography*, 2004, accessed 11th Dec., 2020: doi.org/10.1093/ref:odnb/17643

[32] See Mills, *Collected Letters*, 171–3.

[33] See Guicciardini, *Newtonian Calculus in Britain*, 11–52.

[34] Colin Maclaurin to James Stirling, 16th November, 1734 (Old System), *Collected Letters*, 251.

[35] See Craig Fraser, 'Mathematics', *Cambridge History of Science*, Porter, 305–27.

[36] Guicciardini, *Newtonian Calculus in Britain*, x; Guicciardini, 'Dot-age', 222.

[37] Guicciardini, 'Dot-age'; and Judith V. Grabiner, 'Was Newton's Calculus a Dead End? The Continental Influence of Maclaurin's *Treatise of Fluxions*', *The American Mathematical Monthly* 104, 5 (1997): 393–410.

[38] George Elder Davie, *The Democratic Intellect: Scotland and Her Universities in the Nineteenth Century* (Edinburgh: Edinburgh University Press, 1961), 111–2. See also George Elder Davie, 'Berkeley's Impact on Scottish Philosophers', *Philosophy* 40, 153 (1965): 222–34.

Maclaurin's *Fluxions* has received less attention on its own terms.[39] Maclaurin could have had no insight into the longer-term trends with which this scholarship was primarily concerned. He acknowledged that Berkeley's *Analyst* first 'gave Occasion to the ensuing Treatise', but also noted that 'several Reasons concurred to induce me to write on this Subject'.[40] Maclaurin's intention was not only to answer Berkeley, and to defend both Newton and himself against the charges levelled in the *Analyst*, but to provide a comprehensive account of Newton's mathematical methodology in historical and philosophical context. He described the *Fluxions* as primarily a text for 'beginners', introduced his account with a history of calculus, and defended the method with reference to ancient methodological principles, such as those employed by Archimedes, and modern empirical psychology, such as that of Locke.[41] Maclaurin composed the *Fluxions* while working on the *Account*, but the connections between these texts have been overlooked in part due to modern disciplinary formations that have tended to isolate the history of mathematics from the rest of intellectual history. The concern of the former with technical matters may also have obscured the clarity with which Maclaurin defended and justified algebraic differential calculus in writing.

Berkeley clarified for the 'analysts' to whom he addressed *The Analyst* that 'I have no Controversy about your Conclusions, but only about your logic and Method'. His observation that 'Error may bring forth Truth, but cannot bring forth Science' offered cold comfort to its readers. The analyst mentioned in the work's title was also an 'infidel mathematician', and the work drew an explicit parallel between unscientific methods and religious infidelity.[42] He claimed that analysts' 'inconsistent way of arguing... would not be allowed of in Divinity'.[43] This inconsistency was, as Berkeley saw it, the assumption of either

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[39] See Erik Lars Sageng, 'Colin Maclaurin, *A Treatise of Fluxions* (1742)', in *Landmark Writings in the History of Mathematics 1640–1940*, ed. Ian Grattan-Guinness (Oxford: Elsevier, 2005), 143–58; and Guicciardini, *Newtonian Calculus in Britain*, 38–51.

[40] Colin Maclaurin, *A Treatise of Fluxions*, vol. I (Edinburgh: 1742), i. Hereafter, *Fluxions*.

[41] *Fluxions*: 'beginners' are described as those 'for whom this treatise is chiefly intended' (3).

[42] George Berkeley, *The Analyst; Or, a Discourse Addressed to an Infidel Mathematician* (London: 1734), 30–1. Hereafter, *Analyst*. See Claire Marie Moriarty, 'The *ad Hominem* Argument of Berkeley's *Analyst*', *British Journal for the History of Philosophy* 26, 3 (2018): 429–51; and Claire Marie Moriarty, 'Ructions over Fluxions: Maclaurin's Draft, *The Analyst* Controversy and Berkeley's Anti-mathematical Philosophy', *Studies in History and Philosophy of Science* 96 (2022): 77–86.

[43] *Analyst*, 23.

fluxions or differentials as finite quantities only to dismiss them from the demonstration or calculation at a later stage on the basis of their being infinitesimal and therefore approximate to nothing.

Berkeley rejected the possibility that Newton himself had never assumed such quantities to be infinitely small yet finite, citing the 'Quadratura Curvarum' and the *Principia.*[44] In Lib. II, Lem. II of the *Principia*, Berkeley insisted, Newton exhibited faulty reasoning by expanding the function x^n for $x + o$ (o being an increment) to produce an infinite series, before then removing the o terms from the series. Emphasising how Newton had retained all the other terms that were also derived from the original presence of the o, Berkeley lamented the 'manifest Sophism' of retaining 'the Consequences, or any part of the Consequences of your first Supposition so destroyed'.[45]

Berkeley argued that both Newton's method of fluxions and the differential method practiced by 'foreign Mathematicians' offend against logic and therefore stand as illegitimate means of proving the conclusions they purport to deliver.[46] His chief conceptual concern was with the unintelligibility of fluxions or differentials as objects of reasoning. He claimed that 'the further the Mind analyseth and pursueth these fugitive Ideas, the more it is lost and bewildered; the Objects, at first fleeting and minute, soon vanishing out of sight'. 'As our Sense is strained and puzzled with the perception of Objects extremely minute', he explained, 'even so the Imagination, which Faculty derives from Sense, is very much strained and puzzled to frame clear Ideas of the least Particles of time, or the least Increments generated therein'.[47]

The idea that an infinitesimally small increment of abstracted motion could serve as a valid object for mathematics struck Berkeley as illegitimate because it contradicted his conception of proper mathematics and its potential applications. Geometry, for Berkeley, was described as an 'excellent Logic' only:

> ... when the Definitions are clear; when the Postulata cannot be refused, nor the Axioms denied; when from the distinct Contemplation and Comparison of Figures, their Properties are derived,

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[44] 'De Quadratura Curvarum' was first published as an appendix to the first edition of *Opticks* (1704).

[45] *Analyst*, 24.

[46] *Analyst*, 10.

[47] *Analyst*, 8.

by a perpetual well-connected chain of Consequences, the Objects being still kept in view, and the attention ever fixed upon them.

Practiced in this way, 'there is acquired an habit of reasoning, close and exact and methodical: which habit strengthens and sharpens the Mind, and being transferred to other Subjects, is of general use in the Inquiry after Truth'.[48]

The Analyst focused on the problem of infinitesimals and did not expand on the points raised in *De Motu*. Similarly, *De Motu* had not expanded on the sceptical immaterialism laid out in the *Principles of Human Knowledge*, *Three Dialogues between Hylas and Philonous* (1713), and the *Theory of Vision*. Readers familiar with these texts would have understood Berkeley's position as a rejection of, or at least objection to, physical science that reasoned through immaterial powers abstracted from matter. Berkeley claimed that the true nature of these powers could not be determined and that no valid logical steps could be taken from these powers as supposed causes to their supposed physical effects. Nor even, for Berkeley, could sensory data provide the means to determine the reality of absolute space. These claims followed from his belief that knowledge was restricted to the contents of the human mind, which did not provide authentic access to the material realm and were confined to an immaterial plane of reality in which only the mind of God could be known (to a limited extent).[49] Geometry was an 'excellent logic' that could be 'transferred to other subjects', but these did not apparently include Newtonian physics.

The Analyst was at times a quite personal attack on Newton's admirers, which had the (presumably) desired effect of provoking them to respond. Berkeley observed that 'nothing but the obscurity of the Subject could have encouraged or induced' faulty reasoning on Newton's part, while 'nothing but an implicit deference to Authority could move' his followers to accept it.[50] The replies came swiftly and, eventually, in substantial numbers: it has been estimated that approximately 18,000 copies of works on fluxions were sold in Britain between 1734 and 1777.[51] These responses came in several shapes and sizes, from fairly short replies like the English physician James Jurin's *Geometry No Friend*

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[48] *Analyst*, 5.

[49] See works listed in footnote 42.

[50] *Analyst*, 16.

[51] Guicciardini, *Newtonian Calculus in Britain*, 55.

to Infidelity (1734) and the English Presbyterian minister Thomas Bayes' *Introduction to the Doctrine of Fluxions* (1736), to textbooks that addressed the issues Berkeley raised indirectly, such as Benjamin Martin's *Πανγεωμετρια* [Pangeometria]*; Or, the Elements of All Geometry* (1739), which argued that the fluxionary method of calculus was grounded upon the secure foundation of Euclidean geometry. Bayes, who attended Edinburgh university in the 1710s, spoke for many when he wrote that the 'best way of answering' Berkeley was not to 'follow him in all the objections' but to 'assist persons in understanding the subject itself'.[52]

Maclaurin mostly followed Bayes in this respect, though while Bayes' *Introduction* ran to fifty pages Maclaurin's two-volume *Treatise* weighed in at a total of 754, with 351 additional figures in appendices. Maclaurin also followed Martin and others in attempting to demonstrate that Newton's fluxions were founded upon principles employed by the most celebrated ancient geometers. He did not take up the issue of religious infidelity, but this had been his original concern upon reading Berkeley's attack. In a draft letter, apparently to Berkeley, he had written that 'true Science and true Religion are united', and claimed 'there is not any order or Class of Learned Men that has produced fewer writers on the side of Infidelity, or fewer adversarys to natural or revealed Religion than that of the Mathematicians'.[53] He eventually realised, however, that if what Newton had called 'fluxionum quantitatem' was liable to be so misread by 'a Person of his [i.e. Berkeley's] Abilities' then the methodological foundations of the fluxional method had clearly not been sufficiently established.[54]

Maclaurin's aim was to end any debate about the issue by identifying the incontestable principles upon which Newton's calculus was based.

> When the certainty of any part of geometry is brought into question, the most effectual way to set the truth in a full light, and to prevent disputes, is to deduce it from axioms or first principles of unexceptionable evidence, by demonstrations of the strictest kind, after the manner of the ancient geometricians.

[52] [Thomas Bayes], *An Introduction to the Doctrine of Fluxions, and Defence of the Mathematicians* (London: 1736), 8.

[53] Mills, *Collected Letters*, 425–35.

[54] *Fluxions*, i.

In order to do this Maclaurin adopted the 'method of exhaustion' he claimed was characteristic of Archimedes, in preference to the method employed by Newton himself, whose 'conciseness' and 'very short' treatment of the topic had anyway proved insufficient to indicate its foundations.[55] Maclaurin thus stated four axioms consisting of what he meant by velocity before introducing fifteen theorems and two lemmas, which he attributed to Archimedes, concerning the proper geometrical treatment of motion by way of the method of fluxions.[56]

Maclaurin countered Berkeley's central assertion against calculus by showing that fluxions do not need to be considered infinitely small. Maclaurin believed Archimedes provided a model for, even in his 'Measurement of a Circle', Archimedes 'treats of a progression whose terms decrease constantly' without supposing 'this progress to be continued to infinity, or mention the sum of an infinite number of terms; though it is manifest, that all which can be understood by those who assign that sum was fully known to him'.[57] Despite the fact that one *can* treat fluxions as infinitesimal quantities, Archimedes' works exemplify how a fluxion may justly be taken as a valid object for mathematics when considered as a real 'flowing quantity' – that is, 'the velocity at which a quantity flows, at any term of the time while it is supposed to be generated'. Archimedes was also Maclaurin's favoured model because he was particularly 'solicitous' in showing how his methodology conformed to the universally accepted principles of his day, and rigorous in always using a *reductio ad absurdum* to prove his results, a technique Maclaurin went to great lengths to apply throughout the work.[58]

Newton's notion of fluxions as 'last and ultimate ratios' was, Maclaurin claimed, 'more agreeable to the strictness of geometry' than Leibniz's method of infinitesimals, but the latter's results were nevertheless equally valid.[59] The results of these methods differ 'without even an infinitely small error', meaning the 'computations' of the differential method must somehow be in essential agreement with the method of fluxions. This was a boon for both mathematics and philosophy, for Maclaurin recognised the role of analytical calculus in recent advances and claimed that 'the improvements that have been made by

[55] *Fluxions*, 2–3.

[56] *Fluxions*, 59–108.

[57] *Fluxions*, 34.

[58] *Fluxions*, 34–7. For Maclaurin's application of the *reductio* see Sageng, 'Colin Maclaurin'.

[59] *Fluxions*, 2.

it [i.e. calculus in general], either in geometry or in philosophy, are in great measure owing to the facility, conciseness, and great extent of the method of computation, or algebraic part'.[60] Despite Berkeley's dismissal of differentials as 'an infinite Difficulty to any Man whatsoever', Maclaurin was confident and quite clear that his exposition of Newtonian mathematical methodology established the validity of their application.[61]

Maclaurin admitted that 'Philosophy probably will always have its mysteries', but insisted that 'these are to be avoided in geometry'. However, he had no doubts about the validity of mathematical physics. He rejected Berkeley's anti-abstractionist argument that velocity cannot be clearly conceived, affirming that in the mathematical sciences 'we inquire into the relations of things, rather than their inward essences'. Drawing on Locke's *Essay Concerning Human Understanding* (1691), Maclaurin argued that 'we may have a clear conception of that which is a foundation of the relation, without having a perfect idea of the thing it is attributed to', so that 'our ideas of relations' – such as the relation between time and space, i.e. velocity – 'are often clearer and more distinct than of the things to which they belong'.[62] Geometry was a science of relations between measurable quantities and Maclaurin was quite convinced that the physical world was measurable and could thus be subject to mathematics. In the *Account*, he took the opportunity to expand on this issue and outline his vision of natural philosophy as an experimental and mathematical discipline through which one can reason justly about the immaterial powers that animate the natural world.

Colin Maclaurin's Analysis and Synthesis

In the final passage of Book I of the *Fluxions*, Maclaurin claimed that 'however obscure the cause of gravity may be, there is hardly any proposition in experimental philosophy established on better evidence, than that there is such a power in nature, and that it observes the laws we have supposed'.[63] The *Fluxions* was devoted to establishing the

[60] *Fluxions*, vol. II, 575.

[61] *Analyst*, 10.

[62] *Fluxions*, 51–2.

[63] *Fluxions*, 573.

validity and ancient pedigree of the modern mathematical methods by which the laws governing gravitation were established and made certain. It skirted questions of how exactly Newton's signature discovery had been made, and what made gravitation a proposition of 'experimental philosophy'. Maclaurin's *Account* was written with a view to providing the answers.

There were two obvious but dissimilar starting points in Newton's own work for supplying them. One was the *regulae philosophandi* with which Book III of the *Principia* opened. The other was the remark Newton made in the queries that 'as in Mathematicks, so in Natural Philosophy, the Investigation of difficult Things by the Method of Analysis, ought ever to proceed the Method of Composition'.[64] Maclaurin preferred the latter, which both explicitly addressed mathematics, the discipline to which Maclaurin devoted much of his life, and the issue of 'philosophical discovery'. Analysis and synthesis – in Latin, *resolutio et compositio* – was a core part of the philosophy curriculum in Scotland, as elsewhere. It was understood to first involve the 'analysis', or *resolutio* (literally 'dissolution'), of something into its component parts in order to arrive at more general truths before 'synthesis', or *compositio*, the 'composition' of such component parts or general truths into more specific ones. As a 'method', analysis and synthesis was, in formal terms, the fourth and final part of 'logic' – following 'apprehension', 'judgement', and 'syllogistic reasoning'.[65] Method in this technical sense generally referred to the process of philosophical discovery, i.e. how new knowledge or previously unknown truths are acquired.

Maclaurin's reputation as a Newtonian devotee and a mathematician has obscured the extent to which he engaged seriously with technical aspects of philosophical methodology. This, in turn, has led some scholars to overlook the lens through which he viewed Newton's philosophy and misinterpret his position.[66] David B. Wilson has argued that the *Account* exhibits Maclaurin's 'Cartesian Newtonianism' in that he 'agreed with Descartes that consciousness established knowledge of oneself and of one's ideas' and used this 'Cartesian beginning' to construct a 'Newtonian world'.[67] Wilson nevertheless

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[64] *Opticks*, 380.

[65] See Thomas Ahnert, 'The Philosophy Curriculum at Scottish Universities in the Eighteenth Century', in *Scottish Philosophy... Volume II*, Garrett and Harris, 12–3.

[66] An exception to this is the brief treatment of Maclaurin in Demeter, 'Philosophical Methods', 75–6.

[67] Wilson, *Seeking Nature's Logic*, 55–6.

judged Maclaurin's treatment of Descartes in the *Account* to be a 'fundamental attack', but his broader point was that Maclaurin took a '"Cartesian" basis for empiricism' even if he used it to undermine Descartes' 'deduction of nature's essence from knowledge of God'.[68] Eric Schliesser has described Maclaurin's method as 'mathematical-experimental' and an instance of the 'authority' of Newton's philosophy being used to 'settle debate over proper method'. Maclaurin's engagement with analysis and synthesis was not addressed in this account, and his 'empirical' mathematical-experimental method was contrasted with Newton's own 'method of experimental series', Hume's 'method of inspecting ideas', and the French naturalist George-Louis Leclerc de Buffon's 'method of natural history'.[69]

For Timothy Yenter, Maclaurin's understanding of Newton's 'experimental philosophy' was captured in three 'guiding principles': 1) 'we should be suspicious of complete systems' (especially ones that 'begin at the summit'); 2) '"Plain experience" trumps "metaphysical considerations"'; and 3) the fact that 'Newton distinguished the certainty produced by his demonstrations from the less certain queries [i.e. in the *Opticks*]'.[70] These accounts provide limited insight into Maclaurin's views because they do not fully reflect the terms of contemporary debates and the concerns central to them. They also pass over the basic question Maclaurin was addressing: how did Newton's experimental philosophy and application of mathematics to the study of nature lead him to the discovery of gravitation? To understand how he answered this question it is important to establish what Maclaurin thought experimental philosophy was, how he thought mathematics could be applied to physics, and what he wrote about the actual process by which Newton made his discovery.

The scholarship on Maclaurin's *Account* has tended to view the work as in dialogue with seventeenth-century natural philosophers like Descartes and Spinoza as well as contemporary philosophers like Hume. However, the authors most directly relevant to Maclaurin's work were those who had produced accounts of Newton's philosophy in preceding decades which Maclaurin is either known or very likely to have read. These works also reveal the extent to which Maclaurin broke new ground in the exposition of Newtonian

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[68] Wilson, *Seeking Nature's Logic*, 58–9.

[69] Eric Schliesser, 'Four Methods of Empirical Inquiry in the Aftermath of Newton's Challenge', in *What Does it Mean to Be an Empiricist? Empiricisms in Eighteenth Century Sciences*, eds Siegfried Bodenmann and Anne-Lise Rey, (online ed.: Springer, 2018) 16–7.

[70] Yenter, 'Metaphysical Implications', 115.

philosophy. There were several models available to him when he began drafting what would become his *Account* beyond those produced by Scottish authors such as David Gregory, John Keill, and George Cheyne earlier in the eighteenth century.[71]

There were accounts of natural philosophy based predominantly or partly on Newtonian physics, such as Desaguliers' *System of Experimental Philosophy: Prov'd by Mechanicks* (1719) – substantially revised to become *A Course of Experimental Philosophy* (1734) – and the professor of mathematics and astronomy at Leiden Willem Jacob 's Gravesande's *Physices Elementa Mathematica, Experimentis Confirmata; Sive Introductio ad Philosophiam Newtoniam* (Mathematical Elements of Physics, Confirmed by Experiments; Or an Introduction to Newtonian Philosophy, 1719).[72] There were also single works focused exclusively on Newton's philosophy. Henry Pemberton's *A View of Sir Isaac Newton's Philosophy* (1728) and the French philosopher Voltaire's *Elémens de la Philosophie de Neuton* (Elements of Newton's Philosophy, 1738) offered models directly equivalent to what Maclaurin produced.[73]

The emphasis Maclaurin placed on methodology was both a natural development of and a break from these models. Newton's approach and methodology were always considered historically significant and exemplary in themselves but claims to this end, often made at or near the beginning of these works, were never backed up by anything like the extensive treatment Maclaurin provided. While, for Desaguliers, 'it is to Sir *Isaac Newton*'s application of geometry to philosophy, that we owe the routing of [an] Army of *Goths* and *Vandals* in the philosophical World', his *System of Experimental Philosophy* acknowledged how mathematics had 'frighted a great many from the *Newtonian philosophy*' and thus

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[71] See Chapters 2 and 3.

[72] Works by Desaguliers and 's Gravesande on experimental philosophy were in Edinburgh's Physiological Library: see Barfoot, 'Hume and the Culture of Science', 157. The *Physices Elementa Mathematica* became almost instantly available in English translation, with two rival versions produced by Desaguliers and John Keill published in London in 1720. The work was cited in Colin Maclaurin, *A Treatise of Algebra* (London: 1748), 110 and Desaguliers' *Course* cited in *Account*, 138.

[73] Maclaurin's name is in the 'List of... the Subscribers Names...' included in Henry Pemberton, *A View of Sir Isaac Newton's Philosophy* (London: 1728). He would probably have had easier access to Voltaire's discussion of Newton in the *Letters Concerning the English Nation* (1733) than the *Elémens*, but Maclaurin may well have read the latter. He had several French correspondents, travelled to Paris and submitted a prize-winning essay to the *Academie Royale* in 1724, and addressed himself in a letter to Voltaire in 1745 as a 'lover of the true philosophy and works of M. Voltaire': Mills, *Collected Letters, 125*.

sought to show how experiments 'Step by Step bring us to the same conclusions'.[74] He did not offer an explicit discussion of methodology in either the *System* or the later *Course of Experimental Philosophy*, however. In the latter, he merely affirmed that the 'spirit of Disputing' may be quelled by clear and accurate definitions and, in the former, observed that things with the 'Appearance of Falsehood' may be 'found contrary to Experiments and Mathematical Demonstrations'.[75]

The *Physices Elementa Mathematica* offered a brief but more formal treatment of Newtonian philosophical methodology. 's Gravesande (1688–1742) quoted Newton's *regulae* (as they appeared in the 1713 edition of the *Principia*) and took them to encapsulate 'the Method' to be followed in physics.[76] His commentary clarified that physical knowledge is acquired in three stages: 1) judgement, made by way of the senses, i.e. 'of the agreement that there is betwixt things and our Ideas'; 2) 'analogical' or inductive reasoning, employed to acquire general truths; and 3) mathematical demonstration, which is essential in order to avoid falling 'into Uncertainties at least, if not into Errors' when 'comparing Motions' or 'Quantities'. 'In Physics then', he wrote in summary, 'we are to discover the Laws of Nature by the Phænomena, then by Induction prove them to be general Laws; all the rest is to be handled Mathematically'.[77]

Though the accounts of both Pemberton and Voltaire (1694–1778) were singularly focused on Newton, they evidently had a less formal pedagogical readership in mind. This seems to have recommended against outlining Newton's methodology in detail, though they may equally have simply not been interested to do so. Pemberton offered a lengthier

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[74] John Theophilus Desaguliers, *A Course of Experimental Philosophy*, vol. I (London: 1734) [i–ii].

[75] Desaguliers, *Course*, [iii–iv]; John Theophilus Desaguliers, *A System of Experimental Philosophy: Prov'd by Mechanicks* (London: 1717), 1–2.

[76] Willem Jakob 's Gravesande, *Mathematical Elements of Natural Philosophy, Confirm'd by Experiments: Or, an Introduction to Sir Isaac Newton's Philosophy*, trans John Theophilus Desaguliers, vol. I (London: 1720), xiii and 3. See Steffen Ducheyne, ''s Gravesande's Appropriation Newton's Natural Philosophy, part II: Methodological Issues', *Centaurus* 56 (2014): 97–120; and Peter R. Anstey, 'Willem Jacob 's Gravesande's Philosophical Defence of Newtonian Physics: On the Various Uses of Locke', in *The Philosophy of Locke: New Perspectives*, ed. Peter R. Anstey (London: Routledge, 2003), 58–72.

[77] 's Gravesande, *Mathematical Elements*, xv–xvi. This treatment of method in the lectures at Leiden upon which 's Gravesande's book was based were later followed quite closely by his successor, Peter van Musschenbroek, and published as *Elementa Physicae* (Elements of Physics, 1734): see Ducheyne, 'Appropriation of Newton's Methodological Ideas'.

discussion of Newton's method than past authors but presented it primarily as the application of methodological principles first developed by Francis Bacon. He explained that Bacon was the first to write against the 'custom... to frame conjectures' in his *Novum Organum* (New Organon, 1620), advocating instead that philosophers 'proceed cautiously, to advance step by step, reserving the most general principles for the last result of our inquiries', in contrast to a conjectural method of making 'a hasty transition from our first and slight observations on things to general axioms'.[78] Newton was said to have followed Bacon 'by slow and cautious steps; to search gradually into natural causes'.[79]

Pemberton quoted the *regulae* alongside a brief commentary, but he nevertheless fell short of actually offering an explicit account of Newtonian methodology besides characterising it as an extension of Baconian method. Voltaire's work on Newton, however, probably did the least of all to clarify how his discoveries were actually made. He claimed in the *Elémens* there is 'but one Way that leads to Truth', though this 'way' was described only as following 'the Light of Experiments' rather than mere 'Hypotheses' or propositions 'founded only upon accidental Explications'.[80] The work did not even contrast Newton's approach with Descartes', as had Voltaire's *Letters Concerning the English Nation* (1733). Perhaps this was because the *Elémens* was written, as Voltaire put it, to make Newton's philosophy 'easy and intelligible to those, who know no more of *Newton* and Philosophy than their Name'.[81]

By supplying a comprehensive account of Newton's methodology, Maclaurin's *Account* therefore offered what expositions of Newtonian philosophy had hitherto lacked. The structure of the work makes his central concern quite evident. Book I, 'Of the Method of Proceeding in Natural Philosophy, and the Various Systems of Philosophers' defined Newtonian analysis and synthesis and placed Newton's method in historical context. Books III and IV, respectively 'Gravity Demonstrated by Analysis' and 'The Effects of the General Power of Gravity Deduced Synthetically', outlined this method in the case of gravitation. Newton's mechanics, including the laws of motion, which typically comprised the bulk of previous accounts of Newtonian philosophy, were confined to Book II, 'Of the

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78 Pemberton, *View*, 5.

79 Pemberton, *View*, 13–4.

80 "Voltaire" [François-Marie Arouet], *The Elements of Sir Isaac Newton's Philosophy*, trans John Hanna (London: 1738), 2.

81 Voltaire, *Elements*, 3.

Theory of Motion, or Rational Mechanics'. Newton's discoveries and work in the field of optics, which both Pemberton and Voltaire had placed at the beginning of their accounts, was virtually absent from the work.

However, Maclaurin did not believe there to be any methodological discrepancy between Newton's physics and optics: his method was applied in both his 'two incomparable treatises', the *Principia* and the *Opticks*. In the former, analysis was 'the more easily conceived', for it was based upon the 'best astronomical observations' which the 'constancy and regularity of the celestial motions had contributed, with the observations of some thousands of years, to render astronomy the most exact part of the history of nature'. Yet, on the other hand, Newton's 'admirable discoveries' in the field of optics were 'rather more nice and difficult, because of the inconceivable minuteness of the agents, and the subtilty and quickness of the motions'. Thus, Newton 'performed, himself... with the greatest address, the experiments by which he was able to pry into the more secret operations of nature, amongst the minutest particles of matter'.[82]

More generally, Newton's significance in the history of philosophical method lay in how he proposed that 'the methods of *analysis* and *synthesis* should be both employed in a proper order'. Maclaurin claimed that 'by distinguishing these so carefully from each other, he has done the greatest service to this part of learning, and has secured his philosophy against any hazard of being disproved or weakned [*sic*] by future discoveries'. The first of these, analysis, is concerned with the investigation of 'the powers of causes that operate in nature' from the phaenomena, or 'effects', in order to arrive at general truths. Having identified these 'powers' from their effects the philosopher may first identify 'particular' causes and then more 'general' ones, 'till the argument end in the most general'.

Synthesis is to 'descend in a contrary order' once in possession of these causes, and so must come after analysis. Working backwards from the causes identified through analysis, the philosopher's task is to explain the phenomena 'as established principles', and thus to 'prove our explications'.[83] Here, 'principles' are general physical truths like the existence of gravitation and the laws of motion. This definition includes Descartes' (false) principles, from which Spinoza wrongly believed 'that matter is not only infinite and

[82] *Account*, 19–21.

[83] *Account*, 8–9.

necessary, but also that it is one and indivisible'.[84] Synthesis is a crucial stage of the process and is required to prove the existence of causes that have been, through the *proper* application of analysis, identified from natural phenomena. The goal is to apply this method to arrive at causes that are as general as possible. In this way, Newtonian methodology constitutes the surest means by which a philosopher can deal with the 'business of natural philosophy', which is 'to describe the phenomena of nature, to explain their causes, to trace the relations and dependencies of those causes, and to enquire into the whole constitution of the universe'.[85]

For Maclaurin, the method of analysis and synthesis was 'the only one by which certainty can be acquired in this science', and certainty was found through the application of mathematics to philosophy.[86] He affirmed that 'by the principles of geometry and mechanics, we are enabled to carry on the *analysis* from the phaenomena to the powers or causes that produce them' and then to 'innumerable phaenomena' that can be 'deduced by *synthesis*'.[87] Experiment and observation were not sufficient on their own. Maclaurin was clear that 'a sublime geometry was [Newton's] guide in this nice and difficult enquiry' and he noted approvingly that it was hard to say 'whether he shewed greater skill, and been more successful, in improving and perfecting the instrument, or in applying it to use'.[88]

Analysis did not in itself require more than vision, so an experimenter with eyes to see could perhaps get a sense of universal gravitation by witnessing its effects. However, gravitation could not actually have been *discovered* this way. Not only was geometry required to prove the existence of gravitation beyond doubt, as Maclaurin had shown in the *Treatise of Fluxions*, but it was essential in order to actually discover the *universal* attractive force operating in nature, 'this one principle... flowing from *one cause* equally active and potent every where'. For Maclaurin, the universal reach of gravitation was simply beyond what 'undisputed observations' could deliver. Newton's 'unexceptionable calculations' of celestial and terrestrial motion were strictly essential, in combination with these observations, to arrive at such a general, extraordinary, and certain discovery.[89]

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[84] *Account*, 175.

[85] Account, 3.

[86] *Account*, 223

[87] *Account*, 222.

[88] *Account*, 8.

[89] *Account*, 287–8.

Thomas Reid's *Regulae Philosophandi*

Maclaurin's view of Newton's achievement was shaped by his understanding of the interconnected history of philosophy and mathematics. For him, a natural tendency toward 'speculation' has always vied with a proper, grounded approach to the discipline in which experimentalism is combined with, and complemented by, mathematics. This proper approach, represented and perfected by Newton, led to the realisation among the moderns that the 'true philosophy' is 'the consideration of final causes'.[90] Its antithesis, represented by Descartes, who tried to 'banish' final causes from philosophy, is the building of a speculative system from one 'first cause', the creation of nothing but a 'human fiction'.[91]

The origins of learning were for Maclaurin 'uncertain and obscured with fables', but he believed that geometry was invented to deal with the consequences of the flooding of the river Nile before passing into Greece with Thales of Miletos where it 'received great improvements' and was held in 'high esteem'.[92] Yet, the lack of experimentalism and excess of speculation limited what could be achieved at that time, for 'geometry can be of little use' in philosophy 'till *data* are collected to build on'. Maclaurin argued that a fruitful combination of empirical data and philosophical speculation was probably found by Pythagoras in the 'eastern nations' for him to have had knowledge of the true celestial system. In Greece the story was increasingly one of unbridled speculation. Despite the philosopher Socrates' (d. 399 BCE) ability to see that 'imaginary knowledge was the greatest obstruction to true science', the ancients succumbed to the 'unintelligible mystical doctrines' of Plato, the 'dangerous' atomism of the philosopher Democritus (*c*. 5th–4th C. BCE), and Aristotle's sheer 'force of genius'.[93]

Thereafter, European learning was dominated by sects devoted to these speculative doctrines and the systems developed from them, until learning was itself virtually lost, preserved only by the Muslim world – the 'Saracens' – to whom the world is therefore

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[90] *Account*, 29.

[91] *Account*, 76.

[92] *Account*, 34 and 92.

[93] *Account*, 31–5.

indebted. With the reintroduction of this learning into Europe and advances in astronomy ‘the cloud was, at length, lifted’.[94] Notwithstanding the false philosophy of Descartes and his followers, above all Spinoza and Leibniz, speculation gradually gave way to experimentalism as ancient mathematics was restored. Copernicus and Kepler espoused abstract physical ‘principles’ and ‘hypotheses’ with too much ‘liberty’, but opinion increasingly followed Bacon, the founder of experimental philosophy. He showed that natural philosophy is a ‘vast pyramid’, the base of which is ‘history’, upon which is laid ‘an account of the powers and principles that operate in nature’ (derived from the data of ‘history’) before, finally, is laid ‘the metaphysical part, that treats of the formal and final causes of things’.[95] At the same time, Galileo, in addition to making observations and conducting experiments himself, made the first progress in ‘applying geometry to the doctrine of motion’ since ‘the time of the incomparable *Archimedes*’.[96] Ever since, ‘the evidence of geometry began to take place in philosophy, while all things were examined by number, weight, and measure’.

Maclaurin observed that Bacon’s *Novum Organum* was primarily intended to ‘shew how to make a good *induction*’.[97] According to some scholars, it would be this remark that associates Maclaurin with the story of natural philosophy, if not all philosophy, favoured during the Scottish Enlightenment.[98] It has been observed that Bacon was held to be the founder of a proper inductive philosophical methodology by George Turnbull, who taught Thomas Reid in the 1720s as a regent at Marischal College, Aberdeen. Reid is believed to have shared Turnbull’s view, as did a later towering figure of Common Sense philosophy, Dugald Stewart, professor of moral philosophy at Edinburgh for over two decades from 1785.[99] Newton, it is thought, was held by these men to have followed in Bacon’s footsteps as a practitioner of an essentially inductivist experimental natural philosophy.[100] In the light of Maclaurin’s little-studied story of philosophy, however, this view seems incomplete. As

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[94] *Account*, 41.

[95] *Account*, 56–9.

[96] *Account*, 54–5.

[97] *Account*, 59.

[98] See, for example, Alexander Broadie, ‘Reid in Context’, in *Companion to Thomas Reid*, 1–30; Wood, ‘Reid and the Common Sense School’; and Demeter, ‘Philosophical Methods’.

[99] For the longer-term influence of Common Sense philosophy in Scotland see Chapter 5.

[100] Wood, ‘Reid and the Common Sense School’.

Turnbull, Reid, and Stewart were surely well aware that Bacon produced nothing like Newton's mathematical physics, scholars appear to have overlooked what these figures took to be the difference between Bacon's and Newton's achievements. If there was in fact thought to be no fundamental distinction between their philosophies, then Newton's application of mathematics would for them have been of little consequence to the proper study of nature, a radical departure from Newton's past readers – and a remarkable if not bizarre conclusion in itself.

The case that Reid followed Turnbull's views on Bacon and Newton is rooted in the fact that at Marischal he would have been exposed to Turnbull's claim that Newtonian methodology owed a debt to Bacon. This is supported by the centrality of induction to both Common Sense philosophy and Reid's view of Newton. Due to the prominence of Newton in works through which Reid then contributed to moral philosophy, it has been argued that he hoped, following Turnbull, that moral laws akin to Newton's laws of motion may be found to bring to ethics the kind of certainty delivered through Newtonian physics.[101] However, if Turnbull *was* responsible for shaping Reid's views on Newton then he inspired his pupil to take a completely different position on Newton's significance for moral philosophy.

The title page of Turnbull's *Principles of Moral Philosophy* (1740) bore two quotations indicative of Newton's place in his thinking: '*And if Natural Philosophy, in all its Parts, by pursuing this Method, shall at length be perfected, the Bounds of Moral Philosophy will also be enlarged*', from the *Opticks*; alongside '*Account for Moral, as for Natural Things*', from Alexander Pope's *Essay on Man* (1733).[102] Turnbull commented on Newton's *regulae* and characterised his philosophical method as a process of analysis and synthesis directed primarily toward the discovery of general physical laws from 'experience'. He argued that 'when natural philosophy is carried so far as to reduce phenomena to good general laws, it becomes moral philosophy'. This reflected Turnbull's broad vision of the discipline of philosophy:

> when it [i.e. philosophy] stops short of this chief end of all enquiries into the sensible or material world… it hardly deserves the name of philosophy in the sense of *Socrates*, *Plato*,

[101] See Wood, 'Reid and the Common Sense School', 405–12.

[102] George Turnbull, *Principles of Moral Philosophy*, vol. I (London: 1740).

Lord Verulam [i.e. Bacon], *Boyle*, *Newton*, and the other best moral or natural philosophers.[103]

Reid explicitly rejected this vision by drawing a strict and fundamental distinction between physical and moral inquiry.

Reid's critical engagement with authors who attempted to use natural philosophy for moral-philosophical purposes prompted his first published work, 'An Essay on Quantity'.[104] An early draft of this essay, which was eventually delivered to the Royal Society in 1748 on Reid's behalf (he wasn't a member), was entitled 'Essay Concerning the Object of Mathematicks Occasioned by Reading a Piece of Mr Hutchesons [*sic*] wherein Virtue is Measured by Simple & Compound Ratios', indicating how Reid had protested at Francis Hutcheson's so-called 'moral calculus'.[105] Hutcheson's calculus was predicated on the notion that moral properties may be handled mathematically in the same manner as physical properties. In his *Inquiry into the Original of our Ideas of Beauty and Virtue* (1725) Hutcheson claimed:

> In the search of *Nature* there is the like *Beauty* in the Knowledge of some great Principles, or universal Forces, from which innumerable Effects do flow. Such is *Gravitation*, in Sir ISAAC NEWTON's Scheme: such also is the Knowledge of the Original of *Rights*, *perfect* and *imperfect*, and *external*; *alienable* and *unalienable*, with their manner of *Translations*; from whence the greatest Part of moral Dutys may be deduc'd in the various Relations of human Life.[106]

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[103] Turnbull, *Principles*, 53.

[104] Thomas Reid, 'An Essay on Quantity; Occasioned by Reading a Treatise, in which Simple and Compound Ratios are Applied to Virtue and Merit, by the Rev. Mr. Reid…', *Philosophical Transactions of the Royal Society* 45, 489 (1748): 505–20.

[105] Wood, *Reid on Mathematics*, 34.

[106] Francis Hutcheson, *An Inquiry into the Original of our Ideas of Beauty and Virtue: In Two Treatises* (London: 1725), 29–30.

His wider point was that humans are naturally inclined toward beautiful things, including beautiful theorems.[107] Hutcheson argued that 'in order to regulate our Election among various Actions propos'd, or to find which of them has the greatest *moral Excellency*, we are led by *our moral Sense of Virtue*'. Through his suggestion of 'applying a *mathematical Calculation* to *moral Subjects'* he claimed that the '*moral Qualitys* of Actions' may in some way resemble physical qualities for the purpose of drawing philosophical conclusions with the aid of mathematics, as he believed natural philosophers had done with great success.[108]

Reid decided not to name Hutcheson in his paper and he instead offered more general thoughts on quantification before considering the so-called '*vis viva* controversy', concerning whether Newton or Leibniz (and their respective followers) had provided the correct 'measurement' of force. His view on the validity of Hutcheson's moral calculus is clear, for he argued, citing Aristotle, that only 'proper' quantity, i.e. that 'which is measured by its own Kind', may be reduced to 'Extension, Duration, Number, and Proportion'.[109] Any 'improper' quantity, such as velocity, may be made proper if it is conceived as a compound of proper quantities, but this in Reid's eyes this is not what Hutcheson did, or could do, for moral inclinations.[110] The paper also revealed Reid's interest in the importance of definitions for mathematics and its application to philosophy, such as when he recommends that 'the Measure of an improper Quantity ought always to be included in the Definition of it; for it is the giving it a Measure that makes it a proper Subject of mathematical Reasoning'.

Reid took Newton as an exemplar of proper quantification, claiming

> that Great Man [i.e. Newton], whose clear and comprehensive Understanding appears, even in his Definitions, having frequent Occasion to treat of such improper Quantities, never fails to define them, so as to give a Measure of them, either in proper Quantities, or in such as had a known Measure.[111]

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[107] Hutcheson used gravitation as a metaphor for an innate, sentimental human attraction toward things. This should not be confused with the claim that the moral sense is actually like gravitation in any more than metaphorical terms. In Phillipson, *Adam Smith*, Hutcheson's 'moral sense' is said to be a 'Newtonian principle which explained the principle of moral order in the universe in exactly the same way that the principle of gravity had explained the principles of order in nature' (35).

[108] Hutcheson, *Inquiry*, 163–4.

[109] Reid, 'Essay on Quantity', 507.

[110] Reid, 'Essay on Quantity,' 508.

[111] Reid, 'Essay on Quantity', 509.

He was quite sure that Newton's natural philosophy was elaborated in proper quantities that may justly be handled mathematically. Reid's deep interest in mathematics led him to reflect on the definitions and axioms (i.e. postulates) of Euclidean geometry, which informed his ideas about philosophical methodology. In a paper drafted for submission to the Glasgow Literary Society on issues he had been studying since the 1750s, Reid claimed that 'Mathematical Definition ought to give such a Conception of the thing defined, as that all its properties may be deduced by mathematical reasoning from the Definition', and he argued that by showing greater attention to Euclid's definitions any weakness of the axioms derived from them, such as the notorious fifth axiom, or 'parallel postulate', may be remedied.[112]

Neither Reid's understanding of Newton nor his Common Sense philosophy has been fully contextualised with reference to these interests in mathematics and mathematical philosophy.[113] Following his early work on quantification he became a regent at King's College, Aberdeen in 1751, leaving in 1764 for Glasgow to succeed Adam Smith as professor of moral philosophy. The Common Sense philosophy he developed at King's was in that same year given expression in the seminal *Inquiry into the Human Mind*, in which Reid proclaimed that Newton's *regulae* were 'maxims of common sense'. In so doing, he was drawing an explicit parallel between the everyday exercise of inductive inference and Newton's celebrated philosophical discoveries, claiming that 'the man who first discovered that cold freezes water, and that heat turns it into vapour, proceeded on the same general principles, and in the same method, by which Newton discovered the law of gravitation and the properties of light'.[114]

This reflected Reid's view that Newton's discoveries were primarily the result of induction. His remarks in the *Inquiry* suggest he placed particular emphasis on the 4th *regula*, added to the *regulae philosophandi* in the 3rd edition of the *Principia* of 1726, in which Newton stated that '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

[112] Quoted in Wood, *Reid on Mathematics*, 16. For the dating of Reid's writings on Euclid and their possible preparation for the Glasgow Literary Society see Wood, *Reid on Mathematics*, 164–5.

[113] This has been partially remedied through Wood, *Reid on Mathematics*.

[114] Reid, *Inquiry into the Human Mind*, 3–4.

propositions either more exact or liable to exceptions'. However, this late addition to the *Principia* does not indicate what the relationship between inductive reasoning and either deductive reasoning or mathematics should actually be. Newton explained that the rule 'should be followed so that arguments based on induction may not be nullified by hypotheses', but nothing indicates that Newton meant to suddenly downgrade the mathematics of the *Principia* by asserting the sufficiency of inductive inference alone for determining the 'exactly or very nearly true' propositions regarding planetary motion the work contained.[115]

The unpublished paper given by Reid to the Glasgow Literary Society under the misleading title 'Some Observations on the Modern System of Materialism' provides crucial insight into Reid's understanding of Newton and his reading of the *regulae*. Reid did not discuss Priestley's 'modern system of materialism' but responded to methodological claims he had made when articulating it .[116] Priestley's *Disquisitions Relating to Matter and Spirit* (1777) had naturally come to Reid's attention following critical remarks against Common Sense philosophy made by Priestley in his *Examination of Thomas Reid's* Inquiry into the Human Mind (1775). Priestley had also rejected Reid's ideas in his *Hartley's* Theory of the Human Mind (1775), which drew on the English philosopher David Hartley's *Observations on Man* (1749) to promote a psychological theory predicated on the 'association' of ideas in the mind, against which Reid's whole Common Sense project had been aimed. Nevertheless, Reid's paper took issue principally with the claim Priestley made in the opening pages of the *Disquisitions* – to have maintained a 'uniform and rigorous adherence' to Newton's *regulae* throughout the work – and Reid gladly took Priestley up on his insistence that 'my own reasoning' be 'tried by this, and by no other test'.[117]

Reid charged Priestley with having produced a 'loose paraphrase' that omitted the words 'natural' and 'true' from Newton's first *regula*, making it: 'that we are to *admit no more causes of things than are sufficient to explain appearances*'.[118] This was important for

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[115] *Principia*, 442.

[116] For the disagreement between Reid and Priestley see Aaron Garrett, 'In Defence of Elephants: Priestley on Reid on How to Be a Newtonian of the Mind', *Journal of Scottish Philosophy* 2, 2 (2004): 137–53; and Pascal Taranto, 'Joseph Priestley as an Heir of Newton', *Intellectual History Review* 30, 1 (2020): 87–107.

[117] Joseph Priestley, *Disquisitions Relating to Matter and Spirit* (London: 1777), 2.

[118] Thomas Reid, 'Some Observations on the Modern System of Materialism', 1738–88, Thomas Reid Papers (MS 3061/1/4), Aberdeen University Library, 12. Hereafter 'Observations'.

Reid because natural philosophy must aim at establishing 'laws of Nature', which are 'physical' laws 'essentially different' to 'moral' ones. Moral laws 'ought always to be obeyed, but, in fact, are often transgressed'. Physical laws are, in contrast, 'the rules by which the Deity himself acts in his government of the world', and can never be transgressed. In Reid's view, ethics, being concerned with 'the voluntary actions of men' who are endowed with 'free will', was a fundamentally different endeavour to natural philosophy, meaning that he rejected Turnbull's assertion – and Newton's suggestion – that physics may extend the frontiers of moral philosophy.[119]

By omitting the word 'true' and leaving Newton's first rule as advocating only 'sufficient' causes, Priestley missed the point of what Newton had achieved in philosophy. Reid believed natural philosophy was in a state of 'maturity' following its 'Reformation', a condition he described in the *Essays on the Intellectual Powers of Man* (1785) as one in which the discipline boasts 'principles... so firmly established' that among the learned 'there remains no doubt about them'. The discipline is therefore 'no more subject to revolutions' but 'carried on by the accession of new discoveries'.[120] Bacon was a crucial figure in its final revolution, who 'at great length, and with wonderful sagacity laid down the rules of just induction'.[121] Newton, 'treading in the steps of this great Reformer in Philosophy, has given two of the first and noblest examples of this chaste induction [the *Principia* and the *Opticks*]' and 'has likewise comprehended the substance of Lord Bacons' rules in three selfevident Axioms, which he calls the Rules of Philosophizing'.

Reformed inductivist natural philosophy could for Reid be contrasted with a 'conjectural' or 'hypothetical' method in which the philosopher surveys a 'certain class of phenomena' before speculating about what might cause them. 'By his sagacity', he would then conclude that he has discovered the 'secret of Nature' and build an explanatory system from it, 'which is fondly embraced and believed by his admirers'.[122] In explaining only the 'appearances', however, this system only briefly 'triumphs' before being replaced by another in a non-progressive, cyclical process of false revolutionary discovery, based each time upon a merely 'sufficient' explanation. Conjectures, properly made, are not

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[119] 'Observations', 16.

[120] Thomas Reid, *Essays on the Intellectual Powers of Man* (Edinburgh: 1785), 62 and 457.

[121] 'Observations', 14.

[122] 'Observations', 18.

explanatory but, like Newton's discussion of a material ether, intended 'to be useful [and] to lead to experiments by which their truth might be proved or disproved, but ought never to be relied upon'. In response to what he saw as Priestley's attempt to justify his own speculations, Reid insisted that Newton never engaged in such speculative philosophy, for 'his conjectures are always clearly distinguished from his principles, so that no attentive reader can mistake the one for other'.[123]

Priestley appeared to Reid quite ignorant of the central methodological lesson embedded in the *regulae*. Priestley's rendering of Newton's second rule – '*That to the same effects we must, as far as possible, assign the same causes*' – misses their ultimate purpose due to the insertion of 'as far as possible'. For Reid, 'Men are naturally more prone to observe the similitude of effects, which may lead to the belief of their being the same kind'.[124] Newton's rule works to guard against the natural human inclination toward 'wit and invention', with which philosophers tend to ascribe different effects to the same cause – not different causes to the same effects, as Priestley's rendering would seem to address.[125] Priestley's omission of Newton's third rule (neither Reid nor Priestley mention the fourth) highlighted for Reid his underestimation of the 'inductive principle' the *regulae* so succinctly and significantly capture, and to which 'no philosopher ever kept more strictly' than Newton himself.[126] Reid believed that the greatest danger for natural philosophy is 'that men are prone to draw the general conclusion from too few instances', carrying out 'a lame and imperfect induction, which is more apt to lead into error than truth'.[127]

Newton's *regulae* are therefore 'maxims of common sense' both to the extent that they express and represent Reid's Common Sense psychology, in which an innate inductive principle is of crucial importance for the acquisition of authentic knowledge about the world, but also as procedural rules with which to discipline the mind and guide philosophical practice. Misunderstanding them begets error. Priestley's conception of matter was, for Reid, not as 'that inert, solid and impenetrable Substance which it has commonly been supposed to be', but that which 'has no properties but those of extension

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123 'Observations', 45.

124 'Observations', 19.

125 'Observations', 20.

126 'Observations', 35.

127 'Observations', 21.

and inherent powers of Attraction and Repulsion'.[128] This was plainly contradicted by Newton's laws of motion, which were established according to his rigorous adherence to the *regulae*, as was the law of gravitation: 'undoubtedly, the greatest discovery ever made in Natural Philosophy'.

Reid explained that Newton established gravitation 'by a proper induction from facts', which 'prove the truth' of this law. 'Mathematical Reasoning' was then required for Newton to show what motion must take place according to this and the laws of motion – which he together labelled 'Axioms' – through a 'train of consequences demonstratively deduced'.[129] Deduction can do no more, and does not actually play a role in discovering nature's laws. This method is the only means by which natural laws can be comprehended: induction is 'the only proof we can have' of physical laws, for their true nature is 'quite beyond the Reach of human Knowledge'.[130] Philosophers have attempted to employ deductive, demonstrative reasoning to *establish* the 'efficient causes' (i.e. 'physical causes') of these laws, but in vain. This is because any 'original' notion of causation implied for Reid the 'power' and 'will' of God, which are beyond the scope of natural philosophy.

Physical inquiry gives no insight into the agency – i.e. 'voluntary actions' – either of human beings, following Reid's view of the distinction between moral and natural laws, or God, whose purposes are *per se* inscrutable.[131] He rejected causation in natural philosophy to this extent only: the explanation of natural laws that are, strictly speaking, God's actions in nature. The philosopher can, as Newton did, demonstrate the necessary consequences of natural laws by way of mathematical or deductive reasoning. These consequences are in a sense *causally* determined by natural laws, not as agents themselves but as final causes. When Reid says that the laws of nature Newton discovered through inductive inference 'carry us not a step toward the discovery of the cause of gravitation', he means that they do not provide insight into divine agency, i.e. the *first* cause.

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[128] 'Observations', 1.

[129] 'Observations', 13–4.

[130] 'Observations', 20.

[131] 'Observations', 13.

Genius and the Progress of Civilisation

Reid believed that the natural philosopher would always be tempted to wonder about the origins of natural laws and how they are implemented. However, by straying beyond the proper bounds of the discipline the philosopher would operate in a 'state of darkness', able only to 'grope' around 'til they hit upon some conjecture or hypotheses' to explain the phenomena to their own satisfaction.[132] The *regulae* help restrain this ambition and serve as an expression of Newton's own exemplary approach to causation. Newton, 'that wonderful Genius' was by inclination so restrained and modest in ambition as to eschew the improper pursuit of physical causes.

Though Reid disagreed with Maclaurin about the means by which philosophical discoveries like gravitation could be made, they were aligned on their estimation of Newton's virtues. For Maclaurin, he stood out from men like Descartes and Leibniz because he was naturally averse to controversy and dogmatism. Newton took time to release his ideas to the public for he 'weighed the reasons of things impartially and coolly', a tendency which 'fitted him in a particular manner for penetrating far into nature and unfolding her harmony'.[133] In the eyes of his Scottish readers, Newton had often seemed suited by nature to make his philosophical discoveries, endowed with characteristics that helped to explain his achievements. For John Keill, he was nothing less than a '*Genius* of a Divine Nature and extraordinary Qualities'.[134] Even when Newton wasn't described in this way, such virtues might still be associated with the discoveries he made. For David Gregory, the 'most sagacious' Kepler discovered gravitation through his 'Force of Genius'.[135] Though Maclaurin blamed Aristotle's 'force of genius' for the pernicious influence of his speculative philosophy, it is most likely he thought this genius was not a negative quality, in itself and would have been better directed by proper combination of experimental and mathematical philosophy.[136]

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[132] 'Observations', 41.

[133] *Account*, 13.

[134] *True Astronomy*, v.

[135] *Elements*, i and 145.

[136] *Account*, 35.

Reid did not compose a brand-new psychological portrait of Newton, but the Common Sense science of the mind he developed could encourage one. His emphasis on an innate inductive principle implied that someone like Newton might by nature have an enhanced or superior mental capacity for philosophical discovery. This view was further encouraged by the emphasis placed by a number of authors around mid-century on the importance of the faculty of 'imagination' for philosophical discovery. These ideas were combined in the work of William Duff and Alexander Gerard in theories of genius they produced in the 1760 and '70s, in which philosophical genius was conceived as a superior or outstanding combination of the faculties of imagination and judgement. These theories are striking and important because the eighteenth century is thought to have witnessed the emergence of a modern or 'Romantic' notion of genius out of early modern ideas around 'ingenuity'.[137] The concept of genius was not transformed during the eighteenth century from a particular aptitude someone might *possess* to something someone *is*, but genius became associated above all with the power of the mind. This brought the notion more or less into line with the present meaning of the English word 'genius' as applied to a superior mental capacity, a person for whom that capacity is inherent, or a product of that capacity.[138]

Newton's example is thought to have played an important role in this development, particularly as a discoverer of previously unknown facts about nature and an innovator in both mathematical and philosophical (or 'scientific') methodology.[139] Writing in the 1780s, the German philosopher Immanuel Kant described his own work as an attempt to bring about a 'change in point of view' potentially equivalent to that brought about by the pathbreaking discovery of the 'essential laws of motion' and 'the Newtonian attraction'.[140] Kant famously described being awoken from his 'dogmatic slumber' by the philosophy of Hume, and he also engaged critically with Reid's Common Sense philosophy and read

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[137] See Alexander Marr, et al., *Logodaedalus: World Histories of Ingenuity in Early Modern Europe* (Pittsburgh, PA: University of Pittsburgh Press, 2019); and McMahon, *Divine Fury*, xi–xxii.

[138] See senses 7–9 of 'genius, n. and adj.', in *OED Online* (Oxford University Press, Mar. 2023), accessed 9th April, 2023: www.oed.com/view/Entry/77607?.

[139] See, for instance, Schaffer, 'Fontenelle's Newton'; Fara, *Newton*; and McMahon, *Divine Fury*, 96–150.

[140] Immanuel Kant, *Critique of Pure Reason*, ed. Marcus Weigelt, trans. Marcus Weigelt and Max Müller (London: Penguin, 2007), 21.

Gerard's *Essay on Genius* (1774).[141] While Kant has been a focus of scholarship on eighteenth-century notions of genius as they relate to aesthetics, the literature on philosophical genius is relatively limited.[142]

In Scotland, the science of the mind was often of great interest for the insight it was thought to provide into the progress of civilisation through so-called ‘philosophical’ or ‘conjectural’ history.[143] Duff’s and Gerard’s use of Newton as an example of philosophical genius is best understood within this context, in which his virtues and the power of his imagination were highlights in a progressive vision of intellectual history.[144] Hume used the conception of the human mind he developed through his Science of Man to develop new ideas about the progress of civilisation and the formation of concepts that appear universal or ‘natural’ but are in fact historically contingent.[145] Newton was of little relevance to Hume’s successful six-volume *History of England* (1754–61) because the account terminated in 1688, but the place he accorded him in the nation’s story – one of only a few brief remarks he made about Newton – reflects contemporary thinking and provides useful insight into Hume’s own view of Newtonian methodology.[146]

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[141] Quoted in Ronald E. Beanblossom, ‘Kant’s Quarrel with Reid: the Role of Metaphysics’, *History of Philosophy Quarterly* 5, 1 (1988), 53. For Kant’s take on Reid and Common Sense see Etienne Brun-Rovet, ‘Reid, Kant and the Philosophy of Mind’, *The Philosophical Quarterly* 52, 209 (2002): 495–510. Kant’s engagement with Gerard is discussed in Paul Guyer, ‘Gerard and Kant: Influence and Opposition’, *Journal of Scottish Philosophy* 9, 1 (2011): 59–93. See also contributions to Elizabeth Robinson and Chris W. Surprenant (eds), *Kant and the Scottish Enlightenment* (London: Routledge, 2017).

[142] See works listed in footnote 25; and Bryan Hall, ‘Kant on Newton, Genius, and Scientific Discovery’, *Intellectual History Review* 24, 4 (2014): 539–56.

[143] See Aaron Garrett, ‘Anthropology: The “Original” of Human Nature’, in *Companion to the Scottish Enlightenment*, 74–89; Pittock, ‘Historiography’; and Silvia Sebastiani, *The Scottish Enlightenment: Race, Gender, and the Limits of Progress* (Basingstoke: Palgrave Macmillan, 2013).

[144] See Francesco Bottin, ‘The Scottish Enlightenment and “Philosophical History”’, in *Models of the History of Philosophy. Vol. III: The Second Enlightenment and Kantian Age*, eds Gregorio Piaia and Giovanni Santinello (Dordrecht: Springer, 2015), 383–472.

[145] For an account of Hume’s historical thinking and its parallels in contemporary France see Christopher J. Berry, ‘Hume on Rationality in History and Social Life’, in *Essays on Hume, Smith and the Scottish Enlightenment* (Edinburgh: Edinburgh University Press, 2018), 146–62.

[146] Better known as the *History of England* for its combined six volumes, the first two works to appear, published in 1754 and 1757, were entitled *The History of Great Britain*. See Nicholas Phillipson, *David Hume: The Philosopher as Historian* (London: Penguin, 2012).

Hume wrote:

> In Newton this island may boast of having produced the greatest and rarest genius that ever arose for the ornament and instruction of the species. Cautious, in admitting no principles but such as were founded on experiment; but resolute to adopt every such principle, however new or unusual... less careful to accommodate his reasonings to common apprehensions... While Newton seemed to draw off the veil from some of the mysteries of nature, he showed at the same time some of the imperfections of the mechanical philosophy; and thereby restored her ultimate secrets to that obscurity, in which they ever did and ever will remain.[147]

In his remarks about nature's 'ultimate secrets', Hume was likely referring to the causal nescience he believed Newtonian philosophy to have represented, though it is unclear from this passage what Hume thought Newton's mechanical philosophy to be exactly. It is nevertheless clear that Hume understood the products of Newton's experimentalism to have contributed in some way to his historically significant natural philosophy. Nothing about the passage, however, nor anything else Hume says about Newton, suggests that he is to be taken as *the* exemplar of experimental reasoning. In the previous paragraph, Hume had expanded on a reference to Boyle, whom, alongside Newton, he considered to have 'trod, with cautious, and therefore more secure steps, the only road, which leads to true philosophy'.[148]

Writing around the same time, Adam Smith painted a fuller picture of Newton's methodology in historical context as he considered the nature of intellectual progress in an essay on the history of astronomy, later published in the posthumous *Essays on Philosophical Subjects* (1795).[149] In this essay, Smith presented philosophical discovery and the progress of learning as driven by a natural inclination toward the pursuit of truth

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[147] David Hume, *The History of Great Britain. Vol II* (London: 1757), 452.

[148] Hume, *Great Britain*, 451.

[149] The essay on astronomy is thought to have been written between 1749 and 1758 and revised in 1773, after which the essays on ancient physics and ancient logic and metaphysics were written. See W. P. D. Wightman, et al., 'General Introduction', in *The Glasgow Edition of the Works and Correspondence of Adam Smith, Volume 3: Essays on Philosophical Subjects with Dugald Stewart's Account of Adam Smith*, eds W. P. D. Wightman, et al. (Oxford: Oxford University Press, 1980), 5–27.

and natural knowledge shaped by the sentiments of 'Wonder, Surprise, and Admiration'.[150] In his view, this inclination, with the establishment of 'law and order' and the opportunity for 'leisure', led humans to be 'more attentive to the appearances of nature, more observant of her smallest irregularities, and more desirous to know what is the chain which links them all together'.[151]

For Smith, the history of astronomy was particularly revealing of humans' desire to connect natural appearances in a causal chain, for 'of all the phaenomena of nature, the celestial appearances are, by their greatness and beauty, the most universal objects of the curiosity of mankind'.[152] In this history, Newton stood out as the possessor of a particularly powerful imagination and Smith presented his discoveries and philosophical system as the result of an extraordinary natural capacity to link factual information by way of a convincing causal connection. Newton's contribution was of singular importance because he broke a cycle of system-building following the revival of learning in Europe and the appearance of the Copernican system. This cycle was for Smith progressive but Newton's intervention sped things up considerably, having rejected and surpassed the approach of Descartes who merely connected 'together the real motions of the heavenly bodies... more happily than had been done before'. Newton joined 'together the movements of the Planets by so familiar a principle of connection', i.e. gravitation, 'which completely removed all the difficulties the imagination had hitherto felt in attending to them'.[153]

The real veracity of Newton's insight, as opposed to its mere appearance of truth, only became clear after later developments proved unable to overturn his account. The new phenomena 'persevering industry and more perfect instruments of later Astronomers have made known to us', Smith explained, have been 'either easily and immediately explained by the application of his principles, or have been explained in consequence of more laborious and accurate calculations from these principles, than had been instituted before'.[154] The Newtonian system, though its author did not set out to construct one, 'now

[150] Adam Smith, 'The Principles Which Lead and Direct Philosophical Enquiries; Illustrated by the History of Astronomy', in *Essays on Philosophical Subjects* (London: 1795), 3–4.

[151] Smith, 'Astronomy', 20.

[152] Smith, 'Astronomy', 24–5.

[153] Smith, 'Astronomy', 77–81.

[154] Smith, 'Astronomy', 84–5.

prevails over all opposition, and has advanced to the acquisition of the most universal empire that was ever established in philosophy'.[155]

The creation of the Newtonian philosophical system was the result of Newton's extraordinary powers of insight and imagination, even if to gain absolute ascendence it required the assistance of 'laborious and accurate calculations'. Newton's discoveries were presented by Smith as both a methodological break with the past and simply the most successful application of the human mind to the age-old problem of explaining celestial motion. 'The superior genius and sagacity of Sir Isaac Newton', he wrote, 'made the most happy, and, we may now say, the greatest and most admirable improvement that was ever made in philosophy'.[156] However, he believed Newton's success had actually obscured the crucial role played by the imagination in philosophical discovery, as well as the essential similarity between Newton's endeavour and those of his predecessors since antiquity. Smith asked whether it is any wonder that Newton's system, having 'gained the general and complete approbation of mankind... should now be considered, not as an attempt to connect in the imagination the phaenomena of the Heavens, but as the greatest discovery that ever was made by man'.[157]

Smith presented the discovery of gravitation less as the result of the careful application of philosophical methodology than as a triumph of the power of the human mind. Newton's 'genius and sagacity' had finally uncovered a truth evident to all but so long out of reach, 'the discovery of an immense chain of the most important and sublime truths, all closely connected together, by one capital fact, of the reality of which we have daily experience'.[158] On this view, Newton's historical contribution is rooted more in nature than in art. He represented to Smith the almost inevitable appearance, given the right conditions, of a superior mental capacity capable of resolving the great philosophical problems that humans are naturally inclined to pursue.

This way of thinking about Newton was first articulated in print not by Smith and not as part of a debate over advances in science but following debates over 'primitivism' and ancient poetry. Duff and Gerard were both Aberdonian clergymen and Marischal alumni, where the professor of Greek (from 1728) and principal (from 1748) Thomas Blackwell had

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[155] Smith, 'Astronomy', 84.

[156] Smith, 'Astronomy', 97–101.

[157] Smith, 'Astronomy', 85.

[158] Smith, 'Astronomy', 85.

advanced controversial ideas about the relative merits of ancient and modern literature, the influence of bards in shaping culture, and the extent to which primitive cultural achievements were shaped by historical conditions and the individual 'character' of the bard. James Macpherson, the author of 'translations' of the ancient Scottish bard Ossian (first published in 1761) and the clergyman and professor of rhetoric and belles lettres at Edinburgh Hugh Blair contributed to this debate in the 1760s.[159] Duff explained in his *Essay on Original Genius* (1767) that his intention had been to write about 'poetic' genius before the project expanded into a more general account of the phenomenon. For Duff, 'to explore unbeaten tracks, and make new discoveries in the regions of Science; to invent the designs, and perfect the productions of Art, is the province of Genius alone'.[160]

Technically speaking, for Duff, genius is a combination of three mental attributes: 'imagination', 'judgement', and 'taste'. The 'original' of his title referred to an important distinction he saw in the quality and kind of genius. 'We allow MACLAURIN, who has explained the Principles of NEWTON's Philosophy' to have been a man 'of Genius' though not one 'of original Genius', he explained, for Maclaurin 'did not possess that COMPASS of IMAGINATION, and that DEPTH of DISCERNMENT, which were necessary to discover the doctrines of the *Newtonian* System'.[161] Maclaurin was no Newton. Philosophical genius is least about the 'internal sense' of taste, which relates more to poetry and artistic achievement, and most about the balance between the 'faculties' of imagination and judgement.[162] Descartes may have had 'the honour of first reforming the Philosophy of his country' but 'inherited from nature a strong and vivid Imagination', which he 'too freely indulged'. Bacon, on the other hand, 'possessed that nice temperature of Imagination and Judgement, which constitute truly original Philosophic Genius'. 'Perhaps', Duff suggested, 'no age or nation can boast of having produced a more comprehensive and universal Genius' than Bacon.[163] Yet Newton, too, was 'doubtless in Philosophy an original Genius of the first rank'.

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[159] See Young, 'Progress of Genius'.

[160] William Duff, *An Essay on Original Genius; And its Various Modes of Exertion in Philosophy and the Fine Arts, Particularly in Poetry* (London: 1767), 5. Hereafter *Original Genius*.

[161] *Original Genius*, 75.

[162] *Original Genius*, 5.

[163] *Original Genius*, 115–9.

Newton's cosmology and optics 'are the most astonishing efforts of the human mind' that 'shew the prodigious compass of that imagination, which could frame and comprehend such sublime conceptions' as universal gravitation and white light as a composite of coloured rays. These discoveries for Duff 'clearly evince the profound depth of penetration and strength of reason, which, by a kind of divine intuition, could discern and demonstrate their truth'.[164] These achievements were also lauded by Gerard in his *Essay on Genius*, in which the 'intellectual power' of genius was divided into four parts: 'Sense, Memory, Imagination, and Judgement'. Gerard defined genius as 'properly the faculty of *invention*; by means of which a man is qualified for making new discoveries in science, or for producing original works of art', and followed Duff in emphasising the combination of imagination and judgement.[165] 'A man can scarce be said to have invented till he has exercised his judgement', though while 'it is imagination that produces genius; the other intellectual faculties lend their assistance to rear the offspring of imagination to maturity'.[166] 'Many of the facts on which Newton founds his theory of gravitation', Gerard explained, 'and that of light and colours, require no great degree of imagination to bring them into view, and have actually been observed by many'. That no one else drew the conclusions he did can be put down 'partly to a defect of imagination' on their collective part, and 'partly to the want of such depth of judgement as was sufficient for deducing them'.[167]

Newton followed to some extent in Bacon's footsteps, his philosophical discoveries contributing to a 'body of philosophy' Bacon 'had conceived entire'. Yet, not only were Newton's mathematical discoveries beyond the scope of Bacon's foresight, but his imagination was 'more correct' than Bacon's, and 'more constantly under the control of judgement'.[168] Judgement was quite central to Gerard's view of certainty and proof in philosophy. He claimed that 'only a judgement... can be the occasion of suggesting what is called an *experimentum crucis*', and believed that Newton's optical experiments 'required the nicest judgement, as well as the most comprehensive imagination, to conduct them in such a manner that every succeeding one should confirm and extend the

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[164] *Original Genius*, 119–22.

[165] Alexander Gerard, *Essay on Genius* (Edinburgh: 1774), 6–8. Hereafter *Essay on Genius*.

[166] *Essay on Genius*, 36–7.

[167] *Essay on Genius*, 371–2.

[168] *Essay on Genius*, 82.

conclusions to which the preceeding ones had given rise'.[169] For Gerard, Newton's philosophical discoveries were not the result of experimentalism and inductive inference any more than they were that of deduction or the application of mathematics. Not even his work on light was strictly experimental philosophy, for his optical research demonstrates 'the most vigorous power of abstraction, and the most piercing judgement of mathematical truth'.[170]

Conclusion

Newton's example fed in to late eighteenth-century conceptions of genius through the work of Duff and Gerard, as well as that of James Beattie, a fellow Marischal alumnus and successor to Gerard as professor of philosophy and logic at Marischal in 1760. Beattie's poem *The Minstrel; Or, the Progress of Genius* (1771–4) was a commercial success and has been seen as an influence on Romantic literature and, more broadly, the Romantic cultural movement.[171] Newton's example both helped to shape the Romantic notion of genius and was, in turn, made into one of quintessential scientific genius in the Romantic mould. Enlightenment Scotland's role in this development is not best described as having painted a portrait of Newton as the consummate experimentalist. Newton was never seen by anyone as exclusively an experimental philosopher, as if inductive inference was the only feature of his philosophy that really mattered. Experimentalism and induction may have concerned some authors more than others at certain times and in certain contexts, but deduction and mathematics were always bound up with Newton's reputation and always understood to be necessary for tracing the effects of his discoveries, such as the law of gravitation and the true nature of light. Mathematical and experimental philosophy were not necessarily separable. Deduction played an important role in reasoning from the findings of experiments. Mathematical demonstration could only proceed from axioms determined by some form of inductive reasoning.

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[169] *Essay on Genius*, 87.

[170] *Essay on Genius*, 312.

[171] See Young, 'Progress of Genius'.

If there was a turning point in the reception of Newton's methodology it was not the publication of the *Opticks* but the emergence of Enlightenment science of the mind. Berkeley's scepticism encouraged Newton's readers to question their epistemological assumptions and articulate how the conclusions of Newtonian natural philosophy could be justified. This did not lead Colin Maclaurin to stray too far from the hitherto typical view of Newton's discoveries as the result of a combination of experimental and mathematical philosophy. Yet Thomas Reid's own Common Sense philosophy led him to conclude that inductive inference alone was capable of discovering universal gravitation. Reid's views were contemporaneous with a new emphasis on the role of the imagination, something that decisively shaped Adam Smith's understanding of Newton's role in history. This emphasis also gave rise to William Duff's and Alexander Gerard's theories of genius, in which the imagination could not lead to philosophical progress on its own without guidance from other faculties – above all, judgement.

Newton's Scottish readers thereafter tended to acknowledge the power of his imagination alongside his other virtues and personal attributes. The influence of Reid's Common Sense philosophy to some extent reshaped Newton's reputation as the eighteenth century wore on, but in combination with more unsettling and controversial readings of Newton. The causal nescience and sceptical empiricism articulated by Henry Home, Lord Kames and David Hume in the 1750s was felt to be a greater threat by Scottish natural philosophers than the ingenious scepticism of Berkeley. Debates over divine agency and the role of reason in religion never went away. It was in response to continued anxiety over the influence of deism and atheism, together with the scepticism that was seen to support them, that Scottish natural philosophy began to take new shape as a forerunner to the nascent natural sciences of the early nineteenth century. These developments prepared the ground in Scotland for the advent of modern science, and the establishment of Newton as its hero and icon.

CHAPTER V

LEGACY

Formerly, the 'learned' embraced in their wide grasp all the branches of the tree of knowledge; the Scaligers and Vossiuses of former days were mathematicians as well as philologers, physical as well as antiquarian speculators. But these days are past; the students of books and of things are estranged from each other in habit and feeling.

William Whewell[1]

On 13th March, 1805, Edinburgh town council voted unanimously to elect John Leslie (1766–1832) professor of mathematics at the city's university. This decisive result belied the controversy that swirled around the appointment. Accusations of impiety had followed Leslie around for some time and he had previously been unsuccessful in bids for professorships in natural philosophy at St Andrews (1795 and 1804), Glasgow (1796), and Edinburgh (earlier in 1805). In May, he was brought before the General Assembly of the Church of Scotland accused of atheism. The Assembly was divided on the issue, but the electors resolved not to pursue the case by a vote of 96 to 84. Leslie duly became and remained professor of mathematics at Edinburgh until 1819, when he was successful in a bid for the newly vacant professorship of natural philosophy, a position he then held until his death in 1832. The so-called 'Leslie Affair' has been viewed as an episode of greater political than intellectual significance but it in fact highlights a momentous shift that had occurred in the conception of natural philosophy in Scotland since mid-century.[2]

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[1] [William Whewell], 'Art. III.—*On the Connexion of the Physical Sciences*. By Mrs. Somerville', *The Quarterly Review* 51, 101 (1834): 59.

[2] For a detailed account of the contemporary politics and institutional rivalries behind the Affair see J. B. Morrell, 'The Leslie Affair: Careers, Kirk and Politics in Edinburgh in 1805', *Scottish Historical Review* 51, 1 (1975): 63–82. See also Charles Bradford Bow, 'In Defence of the Scottish Enlightenment: Dugald Stewart's

Leslie's opponents seized on remarks he made in *An Experimental Inquiry into the Nature and Propagation of Heat* (1804) endorsing the causal nescience of David Hume, whom he believed to be 'the first, as far as I know, who has treated of causation in a truly philosophical manner'.[3] Hume had argued that we do not have authentic knowledge of the 'necessary connexion' between physical causes and their effects, the mind only becoming habitually expectant of the one following the other. For some, this was an impious and dangerous position that undermined knowledge we might have of God and worked to weaken faith in orthodox doctrine, such as the belief in divine providence and human free will.[4] Hume had himself been unsuccessful in the pursuit of the professorship in pneumatics and moral philosophy at Edinburgh in 1744, with petitions sent to Edinburgh's town council from clergymen opposing his appointment on the grounds of atheism. Any chance Hume had of succeeding Adam Smith as professor of moral philosophy at Glasgow in the 1760s was snuffed out for similar reasons.[5]

Leslie's successful bid to become professor of mathematics at Edinburgh in 1805 was the result not only of the institutionalisation of 'Enlightenment values' and a shift in church politics with the rise of the Moderate faction since mid-century.[6] The Affair was also shaped by a redefinition of natural philosophy brought about during the second half of the eighteenth century partly in response to Hume's ideas about causation. Hume's position would have struck authors like John Keill, George Cheyne, Andrew Baxter, and Colin Maclaurin, as well as many others besides, as extreme and absurd.[7] Even Newton's readers

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Role in the 1805 John Leslie Affair', *The Scottish Historical Review* 92, 1 (2013): 123–46; and, for an account of the role natural philosophy played, John G. Burke, 'Kirk and Causality in Edinburgh, 1805', *Isis* 61, 93 (1970): 340–54.

[3] John Leslie, *An Experimental Inquiry into the Nature and Propagation of Heat* (London: 1804), 521.

[4] For the context and reception of Hume's ideas about religion see Stewart, 'Religion and Rational Theology'; and Ahnert, 'Philosophy and Theology in the Mid-eighteenth Century'. See also Chapter 3.

[5] See Roger L. Emerson, 'The "Affair" at Edinburgh and the "Project" at Glasgow: The Politics of Hume's Attempts to Become a Professor', in *Hume and Hume's Connexions*, eds M. A. Stewart and J. P. Wright (University Park: Pennsylvania State University Press, 1995), 1–22; and Ahnert, *Moral Culture*, 94–121.

[6] For the 'values' of the Scottish Enlightenment see definitions given in Broadie, *Scottish Enlightenment*, 6–42; and Charles Bradford Bow, *Dugald Stewart's Empire of the Mind: Moral Education in the Late Scottish Enlightenment* (Oxford: Oxford University Press, 2022). For the theological context of the rise of Moderatism and the church politics around the Leslie Affair see Ahnert, *Moral Culture*, 122–40.

[7] See Chapter 3.

who were approving of his causal agnosticism but wrote little about its epistemological implications, like Archibald Pitcairne and David Gregory, gave no hint that they believed this agnosticism followed from the impossibility of determining the causes that give rise to physical effects.[8] By the turn of the nineteenth century, however, Leslie's endorsement of Humean causal nescience was, for many, a basic and uncontroversial assessment of the limits of physical inquiry.

This chapter argues that natural philosophy was given new definition in the second half of the eighteenth century in response both to the sceptical empiricist causal nescience of Hume and Henry Home, Lord Kames and the perceived threat of atheism and deism to which it was connected. In technical terms, the redefinition of the discipline followed from a new epistemological basis upon which natural philosophers grounded their explanations. That is, how they claimed to acquire knowledge of causes from observable effects. After mid-century, influential figures such as John Robison, professor of natural philosophy at Edinburgh between 1773 and 1805, argued that the human mind had been so constituted by its author as to acquire such knowledge to a limited extent. This was similar to the move made by Thomas Reid in proposing an innate inductive principle of 'common sense' to counter Hume's sceptical psychology based upon the existence of discrete ideas in the mind, to which knowledge he believed is restricted.[9] More generally, natural philosophy began to be viewed principally as a practical and useful endeavour rather than as the handmaiden to theology, as Maclaurin appears to have viewed the discipline in the 1740s when he declared it 'subservient to purposes of a higher kind' and 'chiefly to be valued as it lays a sure foundation for natural religion and moral philosophy'.[10] The chief purpose of the enterprise in later decades was still to discover and identify the laws of nature, but these

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[8] See Chapters 1 and 2.

[9] For Reid's Common Sense philosophy as a reply to Humean scepticism see Wood, 'Reid and the Common Sense School', 415–28.

[10] *Account*, 3. Many scholars have sought to identify a turning point in the secularisation of science or the decline of natural theology at some point between 1687 and the 1830s. For an overview of some of this historiography see John Hedley Brooke, *Science and Religion: Some Historical Perspectives* (Cambridge: Cambridge University Press, 1991). For the persistence and variety of natural-theological argument in nineteenth-century Britain see Matthew D. Eddy, 'Nineteenth-century Natural Theology', in *Handbook of Natural Theology*, Brooke, et al., 100–17. For an argument for the decline of Newtonian natural theology in the second half of the nineteenth century see John Gascoigne, 'From Bentley to the Victorians: The Rise and Fall of British Newtonian Natural Theology', *Science in Context* 2, 2 (1988): 219–56.

were increasingly characterised as 'facts' of nature rather than divine legislation or action, and these facts could even be described as merely the evident appearance of things rather than authentic physical reality.

This more strictly empirical vision of physical inquiry was a reaction against the perceived impiety of Humean scepticism. Figures who shared Leslie's views about causation did not believe that they were refuting or undermining orthodox Christian doctrine in any way. Nor did they believe that these views denied that natural philosophy could yield knowledge of God. They simply believed that humans had been endowed by their creator with a limited capacity for physical inquiry. As Leslie's admiring remarks about Hume indicate, Newton was not always considered to be the pioneer of this proper attitude to physical causation, but Newton's example was nonetheless important in the debates that brought about the redefinition of natural philosophy after mid-century. Not only that, but Newton's philosophy began to be viewed in line with the more strictly empirical vision of physical inquiry that emerged in this period, and his philosophy was sometimes distinguished from the 'Newtonian philosophy' that had developed since his own time. It is argued here that, through the influence of the Edinburgh professoriate which Leslie joined in 1805, these developments modified Newton's reputation and established a new vision of his philosophical practice that exerted great influence on the self-identification of the physical sciences in the early nineteenth century, particularly through the biographies of David Brewster, a student at Edinburgh in the 1790s.

For modern scholars, Newton is often the protagonist in the move from 'natural philosophy' to 'science', a pivotal figure in the transition from premodern philosophising to scientific modernity. For the editors of *The Cambridge Companion to Newton* (2016), he 'occupies a singular place in the history of science, having contributed far more than any other single individual to the transformation of natural philosophy into modern science'.[11] Much ink remains to be spilled over the origins of the modern natural sciences, but most historians would agree that by the first half of the nineteenth century their institutional, professional, and disciplinary foundations had been laid, during what has been called the

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[11] Rob Iliffe and George E. Smith, 'Introduction', *The Cambridge Companion to Newton*, eds Rob Iliffe and George E. Smith, 2nd ed. (Cambridge: Cambridge University Press, 2016), 12.

‘second Scientific Revolution’.[12] The coining of the term ‘scientist’ in the 1830s, in conscious opposition to ‘philosopher’, in order to reflect the single, shared enterprise of a new self-conscious body of practitioners of the natural sciences, has come to support the view that this period witnessed the birth of modern science.

The English polymath and educationalist William Whewell (1794–1866) was the first to write about this neologism in a review of the Scottish natural philosopher/scientist Mary Somerville’s *Connexion of the Physical Sciences* (1834). He believed his generation might need a word like scientist due to a great intellectual shift that had occurred in modern times. He pointed out that in the past ‘the “learned” embraced in their wide grasp all the branches of the tree of knowledge’, while in modern times ‘the students of books and of things are estranged from each other in habit and feeling’. In his telling, members of the British Association for the Advancement of Science discussed the term scientist, among many others, in pursuit of a ‘general term’ for those who pursue natural science. The term philosopher would not do for it ‘was felt too wide and too lofty’.[13] Interest in Newton’s biography and legacy in this period, spurred on by the availability of new primary source material, is seen to have made him into an icon for a modern age in which the *scientist* could see something of themselves.[14] Since then, the distinction between science and philosophy, between the scientist and the philosopher, has done much to mark out Newton’s place in history and shape the historiography of science.

Scholars have often thought that eighteenth-century natural philosophy supplied the following century with a kind of Newtonian orthodoxy, as delivered by Newton himself, out of which a new modern scientific enterprise was forged.[15] Those who have complicated this view have proposed that not one but several Newtonianisms emerged in the eighteenth century. Scottish philosophy, particularly through its supposed Newtonian character, is

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[12] See Mary Jo Nye, ‘Introduction’, *The Cambridge History of Science. Volume 5: The Modern Physical and Mathematical Sciences*, ed. Mary Jo Nye (Cambridge: Cambridge University Press, 2002), 1–18; and Richard Yeo, *Defining Science: William Whewell, Natural Knowledge, and Public Debate in Early Victorian Britain* (Cambridge: Cambridge University Press, 1993).

[13] [Whewell], ‘Art. III’, 59.

[14] See Higgitt, *Recreating Newton*; and Richard Yeo, ‘Genius, Method and Morality: Images of Newton in Britain, 1760–1860’, *Science in Context* 2, 2 (1988): 257–84.

[15] For an overview of the scholarship on eighteenth-century natural philosophy and Newton’s reception see Introduction.

thought to have played an important role in giving shape and definition to nineteenth-century British science, though scholars have disagreed on the precise function of the Scottish contribution. One view, proposed by Paul Wood, is that a coherent Newtonian natural-philosophical tradition broke down with the creation of new disciplinary formations within the natural sciences, though with these new disciplines inheriting something of the conceptual foundation of Enlightenment Newtonianism which is difficult for the historian to accurately discern.[16] Another, advanced by Richard Olson, Crosbie Smith, and David B. Wilson, has it that inductivist and experimental Scottish natural philosophy combined with an English mechanical and mathematical natural-philosophical tradition to create a successful British scientific synthesis.[17] This suggests that the Scottish Enlightenment injected a particularly *philosophical* spirit into this mix. Wilson, for instance, has argued that Scotland's peculiarly 'philosophical' and 'theological-philosophical' scientific tradition combined with English mathematical natural philosophy to produce a new British scientific tradition with a 'distinctive Scottish accent'.[18]

This chapter contends that there is more continuity than the literature suggests in the basic definition of physical inquiry between the late eighteenth and early nineteenth centuries. Natural philosophy in Scotland at the turn of the nineteenth century was an experimental and mathematical (i.e. both 'inductivist' and 'deductivist') enterprise directed toward the establishment of the laws or facts of nature and the tracing of their effects. It was therefore fairly approximate to the basic definition of 'modern' British science that emerged in the 1830s.[19] This, at least, was the form in which Scottish natural philosophy

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[16] Wood, 'Science in the Scottish Enlightenment', 103.

[17] For the view that Common Sense moral philosophy and epistemology passed into British physics by way of Scottish natural philosophers of the eighteenth century see Olson, *Scottish Philosophy*. *Contra* Olson, it was argued that John Robison's 'mechanical philosophy' had already served as an influential meeting point between Common Sense philosophy and Newtonian physics in Smith, 'Emergence of Physics'. These lines of thinking have been developed in Wilson, *Seeking Nature's Logic*, in which it is the argued that a Scottish Newtonian natural philosophy heavily influenced by Common Sense philosophy merged with a mathematico-mechanical conception of Newtonianism developed at Cambridge.

[18] Wilson, *Seeking Nature's Logic*, 307.

[19] For what modern British science that emerged from the 1830s was see, for example, Nancy Cartwright, et al., 'Theories of Scientific Method', in *Cambridge History of Science*, Nye, 19–35; and James A. Secord, *Visions of Science: Books and Readers at the Dawn of the Victorian Age* (Oxford: Oxford University Press, 2014). See also works listed in footnote 17.

had been institutionalised in Edinburgh from around the 1770s. By the outbreak of the Leslie Affair, this conception had broad and influential support at the university. Dugald Stewart, professor of moral philosophy at Edinburgh between 1785 and 1820, wrote in Leslie's defence that his endorsement of Humean causal nescience 'contained nothing (nothing at least connected with the alleged charge [i.e. of atheism against Leslie]) but what I myself, and many others much better and wiser than me, had openly avowed as our opinions'.[20] Stewart claimed that Hume's 'doctrine' had been 'completely anticipated by authors of a more early date, in the essential principle' and argued that, since Francis Bacon, this doctrine had been taken as a '*cardinal principle*' upon which 'the whole logic of the Experimental or Inductive Philosophy of the moderns hinges'.[21]

This would have been news to John Stewart (no close relation of Dugald), professor of natural philosophy at Edinburgh between 1742 and 1759, who opposed the causal nescience of Hume and Kames in a paper given to the Edinburgh Philosophical Society in the early 1750s in response to one given by Kames on Newton's laws of motion. Stewart's confident rejection of sceptical empiricism underestimated the force and subsequent influence of Hume's and Kames' arguments. From the 1770s, Robison and James Gregory, professor of medicine at Edinburgh from 1776 until his death in 1821, instituted a form of natural philosophy at Edinburgh that countered this scepticism through an appeal to the human mind's natural capacity to acquire limited knowledge of causation from the evidence of natural phenomena. Kames himself later revised his views in order to justify knowledge of both physical causes and divine agency by way of an appeal to the constitution of the human mind. Partly under the influence of Robison and Gregory, physical inquiry at Edinburgh was reconceptualised as an enterprise restricted to the establishment of the laws or facts of nature and the tracing of their effects, with the caveat that such laws and facts only appear as such to the human mind. The mind had only been designed to perceive the existence of such laws or facts, not their true nature – that is, the mind had no access to the authentic physical reality behind the phenomena.

Robison, Gregory, and others were troubled by the threat of deism and atheism, and they believed that a strictly empirical conception of physical inquiry could most effectively

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[20] Dugald Stewart, *A Short Statement of Some Important Facts Relative to the Election of Professor Leslie* (Edinburgh: 1805), 31.

[21] Stewart, *Short Statement*, 52–4.

counter it. This was because they believed that confusion between unempirical science and proper physical inquiry was a boon to the irreligious. In *Proofs of a Conspiracy against All the Religions and Governments of Europe* (1797), written in response to events in Revolutionary France, Robison argued that Newton's conjectures about an invisible material ether were being perverted to support atheistic materialism. Others, however, took a different approach to the threat of contemporary irreligion and scepticism by advocating for a more pronounced theism in natural philosophy. For James Burnett, Lord Monboddo, Newtonian natural philosophy lacked a proper theistic metaphysics, and in his *Antient Metaphysics; Or, the Science of Universals* (1779–99) he advocated for the incorporation of ancient Greek philosophy into modern physics to correct this failing. On both sides of the debate, Newton's own approach to philosophy was conceived, notwithstanding his conjectural queries to the *Opticks*, as a particularly empirical enterprise.

Under the influence of figures like Dugald Stewart, Robison, Gregory, the natural philosopher and mathematician John Playfair, and Leslie, who occupied chairs in natural philosophy, moral philosophy, medicine, and mathematics at Edinburgh for around half a century, both Newton's reputation and physical inquiry were redefined. The influence of these men went beyond the university itself through their publications and former students. Their interpretation of Newton's own philosophical practice did much to shape how his legacy was understood. During a more general biographical turn in Scottish philosophy and mathematics, Robison and Playfair integrated biographical details into their accounts of Newton's intellectual contributions, presenting him in terms that David Brewster would later follow in his influential biography, *The Life of Sir Isaac Newton* (1831), which he expanded into *Memoirs of the Life, Writings and Discoveries of Sir Isaac Newton* (1855). Brewster's presentation of Newton as a proto-scientist and pioneer of the more strictly empirical natural philosophy of his own day went on to influence readings of Newton well into the twentieth century.

This chapter begins by examining John Stewart's response to the causal nescience and sceptical empiricism of Hume and Kames in the 1750s, before comparing it with how Robison and Gregory sought to justify explanation in natural philosophy from the 1770s. It then reconstructs a debate over how natural philosophy should best respond to irreligion with reference to Monboddo's *Antient Metaphysics*, Robison's *Proofs of a Conspiracy*, and Dugald Stewart's defence of Leslie. It then examines how Robison and Playfair presented Newton's philosophical practice and connected it to his biography, before comparing their assessments of Newton with that of their colleague Dugald Stewart. Finally, it shows how these developments fed in to the work of Somerville and Brewster at a time when Newton was being established as an icon and pioneer of modern science.

Causes of Controversy: David Hume's and Lord Kames' Sceptical Challenge

Evidence for how the bold and controversial ideas of Hume and Kames began to pull at the limits of mid-century Scottish physics can be found in the activities of a body established to promote and facilitate the advancement of natural knowledge: the Society for Improving Arts and Sciences and particularly Natural Knowledge. Better known as the Edinburgh Philosophical Society, and later to become the Royal Society of Edinburgh in 1783, the Society was founded in 1737 but nearly abandoned altogether before it was given a new lease of life in the late 1740s by a heterogenous constituency of practically minded improvers and deep thinkers.[22] Kames, an important figure in the Society, was both of these things, but a paper he gave on the laws of motion in the early 1750s inclined very much toward the abstract. He aired views recently set out in his *Essays on the Principles of Morality and Religion* (1751), which his respondent, John Stewart, had no trouble connecting to the ideas advanced in Hume's *Treatise* and *Philosophical Essays concerning Human Understanding* (1748). Scholars have observed that Stewart reacted forcefully against Kames' views, but their exchange has not been outlined in detail and placed in the context of debates over physical causation and divine agency.[23]

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[22] See Roger L. Emerson, 'The Philosophical Society of Edinburgh, 1737–1748', *The British Journal for the History of Science* 12, 2 (1979): 154–91; and Roger L. Emerson, 'The Philosophical Society of Edinburgh, 1748–1768', *The British Journal for the History of Science* 14, 2 (1981): 133–76.

[23] According to Ross, *Lord Kames*, Kames' and Hume's views were 'roughly handled' by Stewart, a 'confirmed Newtonian' (174). According to Yenter, 'Metaphysical Implications', Kames' paper is an example of 'Scottish philosophers appealing to the qualities of bodies to account for gravity' in which Kames 'valorizes experiment... and downplays "theory"' (113), whereas Stewart argued that 'God's continued activity' best explains gravity, a 'power' that is not 'mediated by ether or the powers of bodies' (121). See also Michael Barfoot, 'James Gregory (1753-1821) and Scottish Scientific Metaphysics, 1750-1800' (PhD thesis, University

Kames argued, much as he had done in correspondence with Andrew Baxter in the 1720s, that our inability to perceive the origin of motion contradicted the concept of inertia upon which Newton's laws of motion were partly predicated.[24] He insisted that matter in motion be viewed as no more the necessary result of an extrinsic actor than a self-motive power inherent to matter itself. He argued, moreover, that motion ought to be considered continuous in nature rather than the result of instantaneous impact because the former is more closely in line with the raw data received by our senses, which is the only authentic source of our knowledge of the phenomena. These arguments undermined the notion that God's activity could be taken to explain otherwise inexplicable natural phenomena. Kames' *Essays* attacked the central premise of mainstream natural theology by denying that knowledge of the natural world derived from philosophy also yielded knowledge of God.[25]

Kames believed that natural knowledge must strictly adhere to sensory experience and he rejected the 'whimsical doctrine' prevalent among natural philosophers that matter is essentially inert and motion carried out by the 'finger of God' according to natural laws. He characterised the contemporary natural philosopher as believing that 'when a stone falls, it is not the stone which acts, but the deity', and that 'it is the continual action of the deity which keeps the planets in elliptical orbits'.[26] In protest at this perspective, Kames drew attention to the self-motive power assumed of a moving person and declared that 'we cannot, *a priori*, conclude, that animate beings are endued with any sort of powers, more than inanimate', for 'experience here is our only guide'. This followed, for Kames, from the fact that powers are 'properties' or 'qualities', 'of which none of our external senses afford the perception', so that 'our want of perception of power, does not more conclude a negation of power to matter, than to spirit'.[27] That is, as we can only use sense experience to detect a power by way of its effects we can in no way determine the precise origin of

of Edinburgh, 1983), in which the debate is used to foreground the 'interiorisation' of Scottish 'scientific metaphysics' as part of a turn toward the science of the mind in the eighteenth century.

[24] See Chapter 3, 130–2.

[25] This argument is most clearly stated in the essay 'Of Our Knowledge of the Deity', but much of the material in the *Essays* supports it. For mainstream natural theology see Chapter 3.

[26] Henry Home, Lord Kames, 'Article I. Of the Laws of Motion', in *Essays and Observations, Physical and Literary*, vol. I (Edinburgh: 1754), 10.

[27] [Henry Home, Lord Kames], *Essays on the Principles of Morality and Natural Religion*, 1st ed. (Edinburgh: 1751), 13.

that power through those same effects. A stone or a planet, as far as our senses can tell, are just as apparently self-motive as the animate creation.

It was on this basis that Kames rejected the validity of mainstream natural theology and cast doubt on common notions of free will. Kames' *Essays* caused most controversy due to the latter. The essay 'Of Liberty and Necessity', in which he argued that experience does not in fact provide a secure basis for believing that we are any more free agents than are inanimate objects, seemed to some to deny the freedom of the will.[28] There were calls for Kames, who had a successful legal career – he took his title upon becoming a Lord Ordinary in the Court of Session in 1752 – to be excommunicated from the Church of Scotland. He subsequently attempted to clarify and defend his views in *Objections against the Essays on Morality and Religion Examined* (1756), and he received no official censure nor suffered any serious consequences for his alleged impiety.[29] Nonetheless, this episode demonstrates that his views encouraged contemporaries to question his motives and suspect that his brand of philosophy was designed to undermine faith.

Stewart treated Kames' and Hume's views on philosophy and religion as of a piece. Despite being moved to reply, he was dismissive of their intellectual heft. Stewart described Hume's 'very ingenious and profound system of the sceptical philosophy', with extended sarcasm, as founded upon 'sublime conceptions' which 'could not have entered into the head of the greatest physiologist on earth'.[30] Stewart had succeeded his father, Robert Stewart, the first occupant of Edinburgh natural philosophy chair in 1708 and founder of the Physiological Library of which Hume had been a member.[31] Little is known of Robert Stewart's teaching but, judging by John Stewart's description of Hume's philosophy, it is most likely that Hume departed considerably from the natural philosophy taught at Edinburgh. Hume would certainly have understood from the contents of the Physiological Library how far causation in physics was bound up with notions of divine agency. He

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[28] On Kames' views on this issue, which changed over time, and the wider context of this debate in Britain see James A. Harris, *Of Liberty and Necessity: The Free Will Debate in Eighteenth-century British Philosophy* (Oxford: Oxford University Press, 2005), esp. 88–107.

[29] For an account of Kames' life and this episode see Ross, *Lord Kames*, esp. 98–151.

[30] John Stewart, 'Article II. Some Remarks on the Laws of Motion, and the Inertia of Matter', *Essays and Observations*, 111–2. Hereafter, 'Some Remarks'.

[31] See Chapter 4, 175–6.

evidently judged at some point that these notions did not meet the required standard of empirical verification.[32]

In response to Hume's and Kames' scepticism, Stewart first argued that Kames' objections to the laws of motion hardly implied the apparent self-motive power of inanimate bodies nor the continuity of motion that he claimed it did. Rather, they merely supported Newton's conception of matter as essentially inactive. Stewart also rejected Kames' objection to the role of divine agency in physical explanation. He endorsed with some confidence the position of 'the most successful' philosophers, who have 'seen most reason to resolve all things finally, into an incorporeal, intelligent, and powerful first cause'.[33] Stewart conceded, however, that it 'is perhaps impossible for us to determine' the extent to which 'the concurrence of the Deity is necessary to the support of created beings in general'.[34] By admitting that 'we know nothing of the nature of motion or force, but by experience', he (perhaps unwittingly) acknowledged the premise of Kames' and Hume's argument.[35] This left Stewart facing the question they had set: how exactly do natural philosophers reason from observable effects to their apparent causes using the evidence of experience? From this followed an even thornier one: how exactly did the most 'successful' natural philosophers 'resolve all things' into a single, primary causal agent? Stewart had after all insisted, as was standard, that the investigation of cause and effect is the 'proper province of natural philosophy'.[36]

Stewart claimed that since there was no 'contradiction or absurdity' in the common notion of cause and effect, then there was no good reason to question the fact that motion is communicated as natural philosophers like Newton and himself took it to be.[37] The principle of inertia, he believed, was derived from sufficient instances of bodies either remaining at rest or in motion until they are either apparently caused to cease that motion

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[32] For Hume's views on religion and natural philosophy see David O'Connor, *Hume on Religion* (London: Routledge, 2001); Schliesser and Demeter, 'Hume's Newtonianism and anti-Newtonianism'; and Matias Slavov, *Hume's Natural Philosophy and Philosophy of Physical Science* (London: Bloomsbury, 2020). See also Chapter 3, 169–71 and Chapter 4, 207–8.

[33] 'Some Remarks', 128.

[34] 'Some Remarks', 108.

[35] 'Some Remarks', 80.

[36] 'Some Remarks', 127.

[37] 'Some Remarks', 105.

entirely or move by the agency of some other body or being. Accounting for such motion required no reference to the 'special concurrence' of the deity.[38] The many active powers Stewart thought were evident in nature – such as gravitation, electricity, and magnetism – were a quite different matter, however, because they could only be accounted for by an immaterial cause. He claimed that such powers give every appearance to us of having been effected by an 'intelligent active being', such that 'we see for certain, many motions begun by animated beings'. 'Why then', he wondered aloud, 'should it be accounted "whimsical" or unphilosophical to demand a cause for the attractive power of gravity?'.[39]

Stewart took it that, by experience, 'we are eye-witnesses of providence, but not of creation', but he didn't fully appreciate the force of Kames' and Hume's arguments against both clauses in this statement. They were questioning the very possibility that the mind could acquire knowledge of a single intelligent agent from the observation of natural phenomena alone, and rejected the conclusion that such observation makes anyone an 'eye-witness of providence'.[40] In hindsight, it seems like Stewart was too quick to dismiss his antagonists, whom he described as 'men who puzzle themselves with self-evident axioms, and stumble at the plainest demonstrations'.[41] He referred derisively to Hume's science of the mind as the discovery that he himself was 'nothing but a series of fleeting perceptions', but offered no specific defence against the claim that human perception cannot tell us whether any physical conjunction is brought about by divine agency, self-motive matter, or anything else.[42] Stewart was sure that the mind can 'for certain' perceive instances of an 'intelligent active being', but the only basis his account came close to offering for this certainty was by analogy with causal agency that we might more plausibly claim knowledge of by way of experience, such as human volition.

The delayed impact of Hume's and Kames' challenge is well illustrated by John Robison, a successor to Stewart in the natural philosophy chair. By the 1790s at the latest, Robison was teaching a 'system of mechanical philosophy' that rested its case for the validity of natural-philosophical explanation and the role of divine agency in nature on an

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[38] 'Some Remarks', 108.

[39] 'Some Remarks', 111–2.

[40] 'Some Remarks', 127.

[41] 'Some Remarks', 139.

[42] 'Some Remarks', 117.

alternative science of the mind to the one advanced by Hume.[43] For Robison, the mind was evidently so constituted as to acquire knowledge of physical causes from their effects *and* to perceive these causes as God's design. He put it to his students that establishing natural laws is in essence identifying appearances or events that appear to the mind to be connected. The 'Arrangement of these Appearances', he explained, 'forces us to consider the Universe as a *Work of Art*, and terminates in the Inferences of a *Supreme Mind – Natural Theology* – another notion of physical Laws'.[44]

Robison's position has been characterised as the successful integration of Thomas Reid's Common Sense philosophy into Scottish natural philosophy.[45] Another way to look at it is that Robison drew on the concept of Common Sense to pursue a similar strategy to figures like Reid in order to place his discipline on a firmer epistemological foundation in response to the same threat: sceptical empiricism. According to Robison, the business of mechanical philosophy was to inquire into the 'mechanical phenomena of the universe, in order to discover their causes, and by their means to explain subordinate phenomena'. The proper end of this enterprise was 'to improve arts [i.e. practical applications of natural knowledge], and thus increase man's power over nature'.[46] He adopted a definition of causation that attempted to close the gap between empirically verifiable phenomena and their apparent causes by declaring, at the very beginning of his lecture course, that 'every change in the state of things is considered as an EFFECT, indicating the agency, characterising the kind, and measuring the degree of its CAUSE'.[47]

Effects could be treated in this way because within this strategy Robison took it that 'man is induced by an instinctive principle, implanted in his mind by the Author of Nature to consider every change observed in the condition of things as an EFFECT', thereby fitting the human mind with the capacity to acquire knowledge of causal 'agency', 'kind', and

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[43] Robison's description of his lecture course was later made the title of a posthumous collection of his writings: John Robison, *A System of Mechanical Philosophy*, ed. David Brewster, vols I–IV (London: 1822).

[44] 'Introductions, c.1804', Lecture Notes of John Robison, Coll-204, University of Edinburgh Library Heritage Collections, 7.

[45] See Olson, *Scottish Philosophy*, 157–68; Smith, 'Emergence of Physics'; and Wilson, *Seeking Nature's Logic*, 201–307.

[46] John Robison, *Elements of Mechanical Philosophy: Being the Substance of a Course of Lectures on That Science* (Edinburgh: 1804), 16.

[47] John Robison, *Outline of a Course of Lectures on Mechanical Philosophy* (Edinburgh: 1784), 5.

'degree' from such material change. Our knowledge of causes is thus '*inferred* from the *observed* kind and degree of the change which we consider as its effect'.[48] In this way, Robison took the mind to be so constituted by its creator that knowledge of causes can be acquired directly from effects by nature, defining a cause as something found in the effect itself – a cause is change in observed effects rather than a separate entity of some kind that brings change about. This did not just apply to mechanical philosophy but to all natural philosophy and natural history, which share a basic definition. As he put it in the lecture theatre, 'the Employment of the Natural Philosopher and of the Natural Historian is the same, namely, Arrangement, and this constitutes the whole Science of both', for 'we observe connected appearances, but know nothing about Causes' beyond recognising effects as causal 'signs'.[49] In this respect, he followed Reid's view that determining the actual physical or efficient cause of natural laws – that is, inquiring into the agent responsible for them, God – is beyond the bounds of natural philosophy.[50]

Robison's appointment breathed new life into natural philosophy teaching at Edinburgh, yet his conception of physical inquiry was not breaking entirely new ground. Since John Stewart's death in 1759, the chair had been occupied by Adam Ferguson, whose serious intellectual concerns lay elsewhere, and James Russell, a surgeon by profession.[51] Robison's systematic mechanical philosophy teaching was quite new but he followed Russell in looking to the science of the mind in order to establish the means by which we can acquire knowledge of the physical world.[52] Russell's approach was also shared by James Gregory, who was appointed to a professorship in medicine with responsibility for the 'institutes', or theoretical side of the discipline, before moving to the chair of practical medicine in 1790, which was once held by his father, John Gregory (d. 1773).[53] Gregory seems to have fulfilled Robison's desire that natural-philosophical labour

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[48] Robison, *Elements*, 15.

[49] 'Introductions, c.1804', 4–5.

[50] See Chapter 4, 195–204.

[51] For Adam Ferguson's philosophical interests see Craig Smith, *Adam Ferguson and the Idea of Civil Society* (Edinburgh: Edinburgh University Press, 2018).

[52] For a brief overview of Russell's career at Edinburgh and his teaching priorities see Paul Wood, 'Russell, James (c. 1720–1773), Surgeon and Natural Philosopher', in *Oxford Dictionary of National Biography*, 2004, accessed 7th May. 2023: doi.org/10.1093/ref:odnb/65044.

[53] For an account of Gregory's treatment of causation and wider philosophy see Barfoot, 'James Gregory'.

be divided such that the teacher of mechanical philosophy could pass over the questions of how exactly the mind comes to know that it is created, and how it derives information about causal 'agency', 'kind', and 'degree' from the 'changes' observed in physical effects. For Robison, natural philosophy was tripartite: consisting of mechanics, physiology, and chemistry. According to his scheme, the study of how humans are constituted lay within physiology, i.e. theoretical medicine.

As professor of theoretical medicine, Gregory did indeed grapple with the empirical basis of cause and effect, and published his results in *Philosophical and Literary Essays* (1792). He was greatly preoccupied with mounting a defence against what he saw as Hume's case for determinism, on the basis that Hume's argument for causal nescience applied to both human volition and physical conjunction and denied human free will. To oppose these ideas, Gregory appealed to 'the evidence of language', claiming that patterns of ordinary speech reveal something of the natural patterns of thought. He was also concerned with 'mens [*sic*] direct attention to their own thoughts', by which he meant something like a conscious instinct. He argued that if Hume's determinism, or 'necessitarianism' did follow naturally from the constitution of the human mind, it would be 'universally admitted' by people rather than, as is the case, be 'very plainly' the 'general repugnance of men to admit'.[54] By these and other routes, such as by considering to what extent Newton's precise formulation of the laws of motion could apply to notions of the will, Gregory concluded his searching collection of essays by arguing that the relation between volition and action must be an 'occasional and separable conjunction', in contrast to cause and effect in physics, which he took to be the archetypal case of a 'constant conjunction'.[55]

Gregory was motivated by a desire to shore up Christian faith but he understood that Hume's argument was best met on its own terms. His empirical approach to the science of the mind included few references to God and Gregory was loathe to rest his contentions on anything but a strictly empirical basis. Kames himself had since mid-century come to agree with the likes of Gregory and Robison, and came to adopt a revised epistemology to support his views on ethics and natural theology. In the third edition of his *Essays* that appeared in 1779, 'corrected and improved', Kames included a new essay entitled 'Power, Cause and Effect' that criticised Hume's contention (formerly his own) that

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[54] James Gregory, *Philosophical and Literary Essays*, vol. II (Edinburgh: 1792), 47.

[55] Gregory, *Essays*, 458–9.

minds cannot tell the difference between volitions and physical conjunctions. He was still not willing to accept that it is possible to distinguish between cause and effect through the external senses, but by this time he believed it was nonetheless evident that, by nature, 'we have intuitive conviction, that every object which appears beautiful as adapted to an end or purpose, is the effect of a designing cause'. 'We are so constituted', he affirmed, 'that we cannot entertain a doubt of this, if we would', for 'as far as we gather from experience, we are not deceived'.[56]

Newtonian Metaphysics and the Rise of Materialist Atheism

Fears that sceptical empiricism and causal nescience might undermine Christian faith were exacerbated by anxiety about the growth of deism and materialist atheism. Following the onset of revolution in France in 1789, the apparent connection between the rise of irreligion and broad currents in contemporary politics stoked paranoia in several quarters. This both strengthened the case for a more strictly empirical conception of natural philosophy and encouraged its rejection. While some believed that physical inquiry rooted in an empirical science of the mind promised to provide true religion with a surer philosophical foundation, others believed it only emptied natural philosophy further of religious content, minimising if not altogether removing divine agency. Critics accused contemporary natural philosophers like John Leslie of giving succour to impiety and failing in their responsibility to support and defend the Christian religion.

The Leslie Affair was to some extent a clash between the two sides of a debate over this issue, yet respected academics were to be found only on one side. Both Leslie and the primary public defender of his appointment, Dugald Stewart, held similar views on causation to those of Robison and John Playfair. It was Playfair's appointment to Robison's chair at his death in 1805 that left open the professorship in mathematics Leslie so controversially took up. Playfair had been professor of mathematics since 1785, a role he took up upon the death of Matthew Stewart (b. *c*. 1717), the father of Dugald Stewart. Before taking up the moral philosophy chair in 1785, Dugald Stewart had taught

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[56] [Henry Home, Lord Kames], *Essays on the Principles of Morality and Natural Religion*, 3rd ed. (Edinburgh: 1779), 304.

mathematics on his aging father's behalf since 1775. Robison, Playfair, and Stewart had therefore dominated mathematics and natural philosophy at Edinburgh for decades, and they would not lightly accept assertions that the views they shared with Leslie concerning physical explanation undermined true religion and, by extension, public morals.

The case against the conception of physical inquiry they promoted was made on a considerable scale by Lord Monboddo in his six-volume *Antient Metaphysics*. Like Kames, Monboddo was a lawyer by profession, likewise taking his title when becoming a Lord Ordinary in 1767. He was an active member of Edinburgh's intellectual scene and became a founder member of the Select Society in 1754.[57] Quite unlike Kames, however, he argued that contemporary 'Newtonian' natural philosophy was excessively empirical, reducing the discipline to a materialist science, or at least something approximate to it, thereby underestimating the role of divine agency in nature and providing insufficient support for Christianity. Little appreciated in its own time, the central argument of *Antient Metaphysics* has also received less attention from modern scholars than other aspects of the text and Monboddo's other works, such as the *Origins and Progress of Language* (1773–92).[58] Modern scholarship has been most concerned with Monboddo's interest in the history of language and his designation of the orangutang as a kind of human, from which it has been argued that he was a proto-anthropologist and evolutionary theorist.[59] *Antient Metaphysics* does not seem to promise the modern reader much prefiguration of future developments in physics: Monboddo drew on ancient Greek philosophy in an attempt to revive and

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[57] He won the right to inherit to the Monboddo estate, and thus the title Lord Monboddo, only in 1782, as the property had been in legal limbo due to his father's involvement in the Jacobite rising of 1715. For an account of Monboddo's life see E. L. Cloyd, *James Burnett, Lord Monboddo* (Oxford: Clarendon, 1972).

[58] Contemporary readers tended to be negative and incredulous. The success of his central enterprise was summarised as 'a laborious attempt to revive the errors in the ancient philosophy, but so enveloped in the old metaphysical jargon as to render it a labour not worth the pains to detect the design' in '*Antient Metaphysics*', *The Westminster Magazine* 7 (1779), 543. For Monboddo's engagement with the history of philosophy and civilisation, of which later volumes of *Antient Metaphysics* are mostly concerned, see R. J. W. Mills, 'Egyptomania and Religion in James Burnett, Lord Monboddo's "History of Man"', *History of European Ideas* 47, 1 (2021): 119–39.

[59] See Oscar Sherwin, 'A Man with a Tail — Lord Monboddo', *Journal of the History of Medicine and Allied Sciences* 13, 4 (1958): 435–68; and Arthur O. Lovejoy, 'Monboddo and Rousseau', *Modern Philology* 30, 3 (1933): 275–96.

reinject its metaphysics back into contemporary natural philosophy, particularly by way of a synthesis of the ideas of Plato and Aristotle.[60]

Monboddo hoped, as he put it, to 'revive antient Theism' in order to correct the insufficient role played by spirit, or 'mind', in modern physics. He was motivated to develop such a Neoplatonic natural philosophy in order to better defend against Hume's sceptical empiricism and the materialist atheism that his scepticism encouraged.[61] Monboddo believed that natural philosophy so reformed by way of ancient theism could 'establish, not only the great truths of natural religion, but some of the fundamental doctrines of Christianity'.[62] While he opposed the 'atheistical' scepticism of Hume he based some of his arguments on the same premises as Hume did before drawing the opposite conclusion. He argued that the limits of the human mind and sensory experience are evidence of God's necessary and unceasing activity in maintaining the motion observed of animate and inanimate bodies.[63]

Monboddo praised the Cambridge Platonist Ralph Cudworth as a rare modern whose metaphysics he admired, but Monboddo held a far more critical view of Newton than did George Cheyne, who like Monboddo hailed from the north-east and was influenced by Neoplatonism. Monboddo's position was in fact closer to the views expressed by Andrew Michael Ramsay.[64] Like Ramsay, Monboddo was concerned with the absence of theism in modern philosophy, but, writing thirty years later, he was faced with new threats. Monboddo was most preoccupied with the influence of contemporary authors like Pierre Henri Thiry, Baron d'Holbach, author of *La Système de la Nature* (1770) and

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[60] The place of *Antient Metaphysics* in modern historical scholarship is given tribute in Yenter, 'Metaphysical Implications', with the text discussed in a brief final section written not by Yenter but Aaron Garrett, an editor of the volume in which the chapter appears. In this section, Yenter/Garrett did not connect Monboddo's case to genuine religious concerns or debates. For the extent to which Monboddo was more generally working in an empiricist tradition see Silvia Sebastiani, 'Monboddo's "Ugly Tail": The Question of Evidence in Enlightenment Sciences of Man', *History of European Ideas* 48, 1 (2022): 45–65.

[61] [James Burnett, Lord Monboddo], *Antient Metaphysics: Or, the Science of Universals*, vol. I (Edinburgh: 1779), i. Hereafter, *Antient Metaphysics*.

[62] *Antient Metaphysics*, viii (Introduction).

[63] *Antient Metaphysics*, vi (Introduction).

[64] *Antient Metaphysics*, iii (Preface).

Hume, whose *Dialogues concerning Natural Religion* appeared posthumously in 1779 but was apparently in circulation in manuscript form prior to that.[65]

Monboddo was quite sure their influence stemmed from deficiencies in contemporary natural philosophy. He claimed that the 'farthest remove' contemporary philosophers go 'from matter is to Mathematics'. Such limited ambition led them to believe that this shallow level of abstraction comprised the 'whole of philosophy', convincing some that 'nothing exists except body, and its attributes'.[66] In his view, the moderns had all too often supposed an incorporeal power to account for the creation of the universe but not its maintenance. Descartes' 'theology' was sound but his 'physiology' was 'absolute materialism', having derived 'every thing from Matter once set in motion by the Deity'. Though the scope of Newton's philosophy was narrower, he also went only so far as to admit that the stars were formed 'by Almighty Power and Wisdom' before claiming that, once created, 'they go on of themselves by the power of matter and mechanism merely, without the agency of Mind'. This was in contrast to ancients like Plato and Aristotle, who took it that 'Mind is author of all the motion in the universe'. As such, Monboddo believed ancient philosophy to be more 'universal' than the Newtonian philosophy of the present and better 'entitled to the name of *philosophy*, and the *first philosophy*, as it explains the principle of all motion, and all production in the heavens and in the earth'.[67] Only by giving a proper account of how incorporeal power animated the material realm, Monboddo thought, could contemporary natural philosophers clearly account for the complete world picture and God's relationship to nature.

Monboddo's case against Newtonian philosophy was rooted in the causal agnosticism Newton most clearly displayed in his treatment of gravitation in the *Principia*. By electing not to determine the origin of gravitation, Newton was more of a 'scientifical mechanic' than a philosopher, because 'nothing deserves the name of philosophy except what explains the causes and principles of things'.[68] It was essential, Monboddo believed, not to confuse mathematical demonstration with physical explanation, for the former is simply not elaborated at a high enough level of abstraction to provide true insight into

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[65] *Antient Metaphysics*, iv–v (Preface). Monboddo claimed to have seen 'two specimens of his [i.e. Hume's] posthumous impiety': one 'a treatise upon Suicide', the other a 'Discourse on the mortality of the Soul' (v).

[66] *Antient Metaphysics*, i (Preface).

[67] *Antient Metaphysics,* i–iii (Introduction).

[68] *Antient Metaphysics*, iv (Introduction) and 544.

physical reality. The mathematical treatment of observational data did not grasp the physical processes it purported to explain, merely offering a kind of description of them. In his view, Newton's argument for gravitation amounted to a 'hypothesis' rather than an explanation due its lack of metaphysical content. He was pleased to report that the Newtonians had since improved on Newton's treatment by identifying gravity's true cause, 'the constant agency of mind'. Monboddo singled out Andrew Baxter for praise on this score for having attempted to draw up a 'system of pure Theism'.[69]

He thought problems remained, however, regarding the laws of motion and concept of inertia. Monboddo suggested that they should be rejected in favour of the view that all bodily motion is 'immediately produced by Mind'.[70] In support of this argument he drew attention to the limits of empirical science and supposed that – following Kames' earlier arguments – as experience alone leads us, on balance, to the conclusion that matter in motion is self-motive, 'mind' must be held entirely responsible for that motion. It followed for Monboddo that inertia is invalid and that it cannot be axiomatic, as in Newton's first law of motion, that 'every 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'.[71] Monboddo also questioned the notion of circular motion as a product of multiple forces acting simultaneously toward different directions, such as in planetary orbits. He claimed that this compound conception of force was entirely without foundation and such motion better conceived as the result of 'one Simple Power'.[72]

Antient Metaphysics is prolix and epic in scale. Across its six volumes the author's focus shifted from philosophy to history before the final volume delivered an account of Monboddo's own Neoplatonic theological views. The service Monboddo attempted to render to true religion, especially in the earlier volumes of the work, boils down to his opposition to the excessively mechanical and empirical bent of modern physics. In its causal agnosticism, having established the 'Gravitation of the Celestial Bodies a *Fact* not a *Cause*', Newton's natural philosophy 'favours' materialism and 'gives too great an Advantage to Atheism'.[73] Monboddo thought modern empiricism had led to the corruption

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[69] *Antient Metaphysics*, iv. For Baxter see Chapter 3, 153–60.

[70] *Antient Metaphysics*, xix and 509–18.

[71] *Principia*, 62.

[72] *Antient Metaphysics*, 519–27.

[73] *Antient Metaphysics*, 251.

of philosophy through the gradual abandonment of theism and, thus, the loss of any metaphysics worthy of the name. The decline of metaphysics could be arrested and philosophy revived, in his view, by drawing on the works of ancient philosophers who, despite having been pagans, held a more worthy conception of physics than most modern Christian philosophers.

The solution to the rise of irreligion offered in *Antient Metaphysics* was idiosyncratic and, particularly in recommending Aristotle's treatment of motion, ran counter to most people's idea of the direction modern philosophy ought to be heading. Nevertheless, Monboddo's concern about the excessive empiricism of Newtonian natural philosophy reflected the central philosophical issues at play in the opposition to Leslie's appointment. Much of the debate provoked by the affair following Dugald Stewart's *Short Statement of Some Important Facts Relative to the Election of Professor Leslie* (1805), which defended Leslie's appointment, revolved around church involvement in university business and the occupation of chairs by clergymen, but Stewart had been clear that Leslie's opponents rested much of their case against him on his remarks about causation. He reported their charge to be that '"he denies such a necessary connexion between cause and effect as implies an operating principle in the cause"', and it is clear enough that they believed Humean causal nescience to be effectively a denial of our capacity to acquire knowledge of God by way of natural philosophy. Stewart protested that Leslie was only considering 'physical' causes and hit back that no 'necessary' connection could indeed be supposed between the 'supreme Being', whose power and will are anyway unconstrained by necessity, and natural phenomena.[74] Stewart pointed out that sharing Hume's premises did not entail arriving at the same conclusions, and many no doubt concurred.

In Leslie's defence, Stewart cited Robison's *Proofs of a Conspiracy*, which had addressed what they both saw as the real threat to contemporary natural philosophy: the perversion of modern physics in support of scepticism regarding the truth of revelation and the existence of God. This was especially concerning because some of the leading lights of European science, such as the French philosopher and mathematician Pierre-Simon Laplace (d. 1827), were understood to have erred in exactly this way. Robison praised Laplace as 'one of the most brilliant ornaments of the French academy of sciences' and, in light of his *Exposition du Système du Monde* (1796), an 'excellent observer of Nature, the

[74] Stewart, *Short Statement*, 87.

admirer of Newton, and the person who has put the finishing stroke to the Newtonian philosophy'.[75] Yet what Robison saw as the widespread rejection of revelation in Revolutionary France – having been judged 'incompatible with their Rights of Man' – has worked to 'warp' the judgement of men like Laplace, leading them to suppose that astronomy proves the Earth to be no more significant to its creator than a 'pepper-corn'. Meanwhile Robison saw others, such as the French astronomer, mathematician and politician Jean Sylvain Bailly (d. 1793), abandoning the teachings of scripture by eliding God with his attributes as defined by the operations of nature alone.[76]

Deists were one thing and materialist atheists another, even more concerning, spectre. Robison affirmed that

> every man who has been a *successful* student of Nature, and who will rest his conclusions on the same maxims of probable reasoning that have procured him success in his past researches, will consider it as next to certain there is another state of existence for rational man.[77]

However, successful students of nature like Laplace evidently did not conclude much more than that. In the case of deists like Laplace and Bailly, Robison put the problem down to a lack of 'patience' which he connected to a vain overestimation of the power of human reason. This was for him in stark contrast to Bacon, Locke and Newton, whose caution and modesty made them exemplars of the proper approach to physical inquiry. Atheism, for Robison, results from an even greater degree of immodesty, considerably less philosophical success, and a good deal of false reasoning. Robison and Stewart were in agreement that contemporary atheists were misled by bad science and, in particular, a misunderstanding of Newton's achievements.

They believed that atheists had utilised Newton's remarks about a material ether by simply taking his conjectures in the queries to the *Opticks* as proofs. These figures assumed

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[75] John Robison, *Proofs of a Conspiracy against All the Religions and Governments of Europe* (London: 1797), 231. Hereafter, *Proofs*. For an account of the influence of the French Revolution on Robison and Playfair see J. B. Morrell, 'Professors Robison and Playfair, and the Theophobia Gallica: Natural Philosophy, Religion and Politics in Edinburgh, 1789-1815', *Notes and Records of the Royal Society of London* 26, 1 (1971): 43–63.

[76] *Proofs*, 229–33. For Laplace's natural philosophy see Roger Hahn, 'A Scientist Responds to his Skeptical Crisis: Laplace's Philosophy of Science', *The Skeptical Tradition around 1800*, eds Johan Zande and Richard H. Popkin (Dordrecht: Springer, 1998), 187–201.

[77] *Proofs*, 238.

an invisible material ether to be ‘a *fac totum*’ in order to develop materialist theories of ‘muscular motion, animal sensation, and even of intelligence and volition’. This was despite such theories contradicting ‘all the principles of mechanics’ and Newton’s investigation into the possibility of an ether having proved ‘inconclusive’.[78] While materialists were not all equally dangerous, Robison pointed out that the materialism of a compatriot like Joseph Priestley is ‘but a step to the Atheism of [the philosopher and controversialist Denis] Diderot [d. 1784] and [philosopher, mathematician and revolutionary politician Nicolas de] Condorcet [d. 1794]’.[79] Robison clearly feared the prospect of radicalism and materialist atheism radiating out from the new French republic and influencing philosophers in Britain and elsewhere. Nonetheless, Robison was evidently confident that his conception of physical inquiry would put the discipline on a firm foundation in the face of attacks on true religion. For both Robison and Stewart, it was precisely by defending the proper limits of the discipline that natural philosophers might both continue to advance science and counter the rise of philosophical impiety.

Newton in Context: Facts, Philosophy, and History

While Robison and Stewart presented a broadly united front on what constituted proper physical inquiry, they held different positions both on technical matters regarding causation and on Newton’s own philosophical practice. Their views were shaped by their understanding of the history of philosophy and Newton’s place in it. Newton’s Scottish readers had always considered his discoveries and approach to philosophy as historically significant and placed them within the broader sweep of philosophical history, but by the late eighteenth century figures like Stewart, Robison, and Playfair began to pay greater attention to historical context. They produced biographies of leading Scottish philosophers

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[78] *Proofs*, 484.

[79] *Proofs*, 486. For Priestley’s materialism see James Dybikowski, ‘Joseph Priestley, Metaphysician and Philosopher of Religion’, in *Joseph Priestley, Scientist, Philosopher, and Theologian*, eds Isobel Rivers and David L. Wykes (Oxford: Oxford University Press, 2008), 80–112. For a brief account of atheism and deism in eighteenth-century France see Caroline Warman, ‘Philosophy and Religion: Deism, Materialism, Atheism’, in *The Cambridge History of French Thought*, eds Michael Moriarty and Jeremy Jennings (Cambridge: Cambridge University Press, 2019), 234–40.

and mathematicians of the past generation and carried over a sensitivity to more precise details of a thinker's life and individual practice to their treatment of Newton.[80] They broadly agreed that Newton had practiced a particularly empirical natural philosophy, his caution and modesty preventing him from drawing firm conclusions on 'metaphysical' or even certain 'physical' questions. They saw his causal agnosticism as representative of a strict adherence to the appearances of nature, wherein he eschewed explanation *of* those appearances, advancing no firm views regarding what gave rise to them.

For Robison and Playfair, this tendency was only to be applauded and admired, but for Stewart it was a defect.[81] Stewart was in no doubt about the importance of Newton's legacy in general terms, deeming gravitation to be 'the most astonishing and sublime discovery which occurs in the history of science'.[82] Despite being 'an original and inventive genius... led by the light of Bacon's philosophy', Newton did not practice what Stewart understood as proper natural philosophy.[83] He was critical of Newton for confusing philosophical and mathematical analysis, such as in the case of the laws of motion, which in the *Principia* he styled 'axioms' as well as 'laws'. For Stewart, Newton's laws of motion were properly 'principles' established by the kind of inductive reasoning that Bacon had pioneered. He also criticised certain of Newton's readers, such as Thomas Reid, for not

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[80] For Dugald Stewart's biographical interests as the first historiography of the Scottish Enlightenment see Paul Wood, 'Introduction', *Essays in Reinterpretation*, Wood, 1–35. Playfair wrote biographies of Robison, Matthew Stewart, and the natural philosopher James Hutton (1726–97): see John Playfair, *The Works of John Playfair*, ed. James G. Playfair, vol. IV (Edinburgh: 1822), 1–178.

[81] Stewart's views on Newton and natural philosophy have not received adequate scholarly attention. He is viewed as a Common Sense philosopher through whom natural philosophers received Common Sense ideas in Olson, *Scottish Philosophy*. He is also referenced in Ducheyne, *"Main Business of Natural Philosophy"*, as having put his 'finger on an important asymmetry between mathematical versus natural-philosophical analysis and synthesis' (3), but Stewart's views themselves are not explored. His engagement with natural-philosophical methods is typically connected to his ethics and philosophy of mind, as in Charles Bradford Bow, 'Molyneaux's Problem in the Scottish Enlightenment', *Historical Reflections* 45, 3 (2019): 22–41; and Sofia Calvente, '"The Father of the Experimental Philosophy of the Human Mind": Descartes and the Scottish Enlightenment's Moral Philosophers', *Journal of Scottish Philosophy* 20, 3 (2022): 217–35.

[82] Dugald Stewart, *Elements of the Philosophy of the Human Mind*, vol. II (Edinburgh: 1814), 322. Hereafter *Elements*.

[83] Stewart, *Short Statement*, 52–4.

recognising this confusion and treating physical 'principles' and mathematical 'axioms' as equivalent.[84]

A principle, properly speaking, was for Stewart an 'assumption (whether resting on fact or on hypothesis), upon which, as a *datum*, a train of reasoning proceeds'. In Euclidean geometry, 'definitions' are in essence such principles, while in natural philosophy they may be the 'general experimental truths which form the ground-work of our general reasonings'.[85] Axioms, on the other hand, are '*elemental* truths' or '*elements of reasoning*', as they were for Euclid, which in physics include 'a belief in *the continuance of the Laws of Nature*', 'a belief in *our own identity*', and in the '*evidence of memory*'.[86] This kind of confusion was important because it was indicative of the limits of Newton's philosophical practice. For all the technical excellence of Newton's treatment of gravitation, Stewart believed it was not the 'discovery of an efficient cause, but only the generalization of a fact'. Newton established physical principles but did not reason from them, by way of axioms, to arrive at full explanation.[87] His mathematical argument for gravitation merely amounted to the establishment of 'a general fact', i.e. the inverse-square law by which 'bodies tend to approach each other'.[88] This fact could, like a law of motion, serve as a principle upon which reasoning may proceed, but it must not be confused with the terminus of this reasoning: explanation.

The 'unknown physical or metaphysical cause' of gravitation remained so because Newton did not identify its origin.[89] Though Newton did perceive the 'inimitable unity and harmony of design' evident everywhere through 'the operations of Divine Wisdom', he only made good on that perception in his speculative queries, this being their 'chief value' for the philosopher.[90] It is easier to understand Stewart's defence of Leslie's causal nescience when it is understood that he considered Newton's historic discovery and technically proficient treatment of gravitation to have been the identification of what Stewart preferred to call a 'physical' rather than an 'efficient' cause. A physical cause is merely the

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[84] *Elements*, 42 and 316.

[85] *Elements*, 42

[86] *Elements*, 46–7.

[87] *Elements*, 322.

[88] Dugald Stewart, *Philosophical Essays* (Edinburgh: 1810), ix–x.

[89] Stewart, *Philosophical Essays*, x.

[90] Stewart, *Elements*, 395.

establishment of a general fact; an efficient cause is the identification of an agent. Identifying physical causes, as Newton did, can certainly be of profound significance. His causal agnosticism regarding efficient causes is therefore philosophically permissible and hardly impious, but it does not represent the full potential and proper end of the discipline. Stewart criticised Newton for overlooking the importance of the distinction between these two kinds of causes.[91] Stewart shared with others, like Thomas Reid, the view that the advent of Baconian inductivism was a pivotal moment in modern natural philosophy (if not philosophy more generally). However, whereas Reid thought Newton had taken natural-philosophical explanation as far is it might go, Stewart deemed Newton to have been, in effect, too cautious.

Stewart therefore departed from the view typically held by Newton's readers, that a law of nature was in itself explanatory and implied divine agency. He was nonetheless sanguine about the capacity of philosophy to support true religion through the identification of his efficient causes, thus delivering a greater depth of explanation than that offered by way of the establishment of natural laws, i.e. general facts, by way of his physical causes. Philosophers could establish efficient causes, in which God is taken to be the agent, by way of inductive reasoning from the empirical facts of nature – from principles by way of axioms – which for Stewart represented the highest standard of philosophising. He identified the 'Newtonian school' as representative of this standard, but believed that the successes of this school owed more to the methodological influence of Bacon than to Newton's confusion of principles and axioms and preference for physical over efficient causes. Stewart did believe *a priori* arguments for the existence and attributes of God could be successful, singling out for praise those of Samuel Clarke, but he considered *a posteriori* arguments – i.e. those made from his notion of experimental truth – to be far stronger.[92]

Robison followed Stewart in presenting Newton's discovery of gravitation as the discovery of a 'general phenomenon', but apparently had fewer qualms about the limited nature of his philosophical practice. Newton claimed to know 'no explanation but the mere

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[91] Noting Reid's and others' inability to see this point, Stewart declared that 'I have no scruple to say, that Newton has been guilty of indefinite and ambiguous expression' in Dugald Stewart, *Philosophy of Active and Moral Powers of Man* (Edinburgh: 1828), 263.

[92] For Stewart's assessment of Clarke's *a priori* arguments see Dugald Stewart, *Outlines of Moral Philosophy* (Edinburgh: 1793), 156–7.

description' and he discussed the 'modesty of his procedure' in entirely positive terms.[93] His most sustained engagement with Newton's philosophy and legacy was in an essay on the history of astronomy, which he framed as the story of how the 'art' of astronomy came to be in 'beneficial alliance' with 'philosophy'. From this alliance, 'society' has derived unprecedented benefits in modern times, chiefly from the products of Newton's 'exalted genius', which came to 'speculate' on the forces responsible for planetary motion and deliver 'exquisite knowledge of the mere phenomena that is absolutely necessary for some of the most important applications of them to the arts'.[94] Newton's philosophy was presented as an ideal combination of inductive and deductive reasoning. He identified the law of gravitation through inductive reasoning and subsequently applied mathematics to produce, by way deductive reasoning, the 'exquisite knowledge of the mere phenomena' that Robison thought had transformed modern life.

Newton's reluctance to identify the origin of gravitation was the chief virtue of his philosophy, and certainly not a defect. Robison defended Newton against what he took to be the most dangerous accusation against him: that he believed bodies to be really physically attracted toward each other. Rather, Newton established the 'matter of fact' that bodies *appear* to attract. *Contra* Stewart, Robison believed 'every attempt to explain an ultimate law of nature, by assigning its cause, is absurd in itself, against the acknowledged laws of judgment, and will most certainly lead to error'. He claimed Newton was of the same opinion, having 'modest and proper diffidence in his own understanding' not to fall into such errors.[95] Nevertheless, Robison thought Newton had been proven wrong when he supposed, in a speculative mood, 'that, in the course of ages, things would go into disorder,

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[93] John Robison, *A System of Mechanical Philosophy*, Brewster, vol. III (London: 1822), 135 and 385. Hereafter, 'Astronomy'.

[94] 'Astronomy', 1–2. For the origins of the essay see David Brewster, 'Preface of the Editor', *A System of Mechanical Philosophy*, John Robison, vol. I (London: 1822), vii. Rather than consider Robison's engagement with Newton's *philosophy*, scholars have tended to view Robison as an adherent of Common Sense philosophy and, essentially, a certain kind of Newtonian *scientist* – e.g. Olson, *Scottish Philosophy*, 157–168 and Smith, 'Emergence of Physics'. According to David B. Wilson, Robison was not only a Common Sense natural philosopher but a practitioner of 'Phlogiston physics', by which Wilson meant a physics characterised by an almost reckless 'craving for knowledge' (234), and as a 'Boscovichian' Newtonian, due to Robison's admiration for the natural philosopher and Jesuit Roger Boscovich's matter theory: Wilson, *Seeking Nature's Logic*, 201–71.

[95] 'Astronomy', 92 and 385.

and need the restoring hand of God'. Robison believed that the Italian-born mathematician Joseph-Louis Lagrange (d. 1813) had recently 'demonstrated that no such disorder will happen'.[96]

Robison's history of astronomy placed Newton's achievements in the context of the contributions of familiar names, such as Copernicus, Tycho, Kepler, and Descartes, but he also made space for what he saw as the pioneering work of Robert Hooke, 'one of the most ardent and ingenious students of nature in this busy period'.[97] Hooke's inclusion in Newton's intellectual context was uncommon among Scottish authors and is representative of a more nuanced interpretation of Newton's historical context. Hooke's experiments with pendulums at the Royal Society led, for Robison, to a theory of the 'change of motion' that, though it did not explain planetary motion accurately, exhibited 'strict reasoning, from good principles'. In this way, Hooke anticipated both Newton's theory of gravitation and Antoine Lavoisier's chemical theories, the latter being 'a philosopher inferior perhaps only to Newton'.[98] However, the most pronounced shift in Robison's treatment of Newton's discoveries with respect to previous Scottish accounts of this history was the detailed biographical context he outlined. This context was designed to exhibit what circumstances Newton's 'talents and disposition' were brought to bear on the 'arduous tasks' by which he revolutionised the science of the heavens.[99]

Robison also drew uncommon attention to Newton's biography in order to better illustrate points about his character and philosophical practice. These digressions, like those in Playfair's 'General View of the Progress of Mathematical and Physical Science since the Revival of Letters in Europe' (1816–9), reflect a greater sensitivity to how Newton's work was conditioned by its intellectual context and the practical circumstances he found himself in. Robison's account drew on Newton's correspondence with Hooke and Richard Bentley, and Playfair drew attention to what would later be known as Newton's *annus mirabilis* of 1666, when he made precocious advances in mathematics and optics. This focus encouraged a more nuanced view of Newton's relative significance, but the extent and detail of Robison's and Playfair's biographical engagement with Newton also had the effect of drawing far greater attention to his discoveries than those of anyone else

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[96] 'Astronomy', 389.

[97] 'Astronomy', 90.

[98] 'Astronomy', 91–2.

[99] 'Astronomy', 92.

mentioned in their accounts, reinforcing the pivotal nature of his contribution to the history of learning.[100] Combined with the laudatory remarks that had been issued virtually as standard by Newton's admirers since the appearance of the *Principia*, this new biographical emphasis underlined the exemplary and revolutionary character of Newton's natural philosophy.

The wider remit of Playfair's overall subject matter, natural philosophy, offered him greater scope than Robison for considering the influence of Newton's impact on the physical sciences.[101] In general terms, he upheld the basic conception of proper physical inquiry promoted by Robison and Stewart. However, by giving a glowing assessment of the restrained philosophical practice through which Newton's contributions to knowledge were made, he sided with Robison over the more critical Stewart. The physics of the *Principia*, which, 'had the merit of effecting an almost entire revolution in mechanics', was for Playfair just one of Newton's ground-breaking innovations. Newton's precocious work in mathematics and optics revealed how, even in his youth, Newton was 'the most patient, faithful, and sagacious interpreter of nature' and 'the most profound and inventive of geometers', a combination 'hitherto without example'.[102] Playfair emphasised the value of his conjectural queries and presented Newton's achievements as something of an extension of Bacon's methodological ingenuity, judging that it was 'only for such men as Bacon or Newton to soar beyond the region of poetical fiction, still keeping sight of probability, and alighting again safe on the *terra firma* of philosophic truth'.[103]

Newton's legacy was not entirely positive, however, for despite the fact that the geometrical calculus he developed in his youth was 'the instrument which was to conduct

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[100] Playfair's 'Dissertation Second: Exhibiting a General View of the Progress of Mathematical and Physical Science since the Revival of Letters in Europe' was published in two parts: Part I in the second and Part II in the fourth volumes of *Supplement to the Fourth, Fifth and Sixth Editions of the* Encyclopaedia Britannica, vols II & IV (Edinburgh: 1824). Hereafter the first part is 'General View (I)' and the second 'General View (II)'.

[101] The literature on Playfair's engagement with Newton and his views on natural philosophy have cast him as a Common Sense natural philosopher, as in Olson, *Scottish Philosophy*, 157–168, and a 'Leibnizian' Newtonian, as in Wilson, *Seeking Nature's Logic*, 276–86. Wilson's case rests on his view of Playfair's natural philosophy as 'nondogmatic... Newtonian realism' crucially 'influenced' by a 'constricted version of the philosophy of Leibniz', which Wilson connects to Playfair's opinion that Leibniz invented calculus independently.

[102] 'General View (II)', 68.

[103] 'General View (II)', 89.

him safely through all the intricacies of his future investigations', its subsequent influence in Britain led to the decline of mathematics relative to continental Europe. Following the priority dispute between Newton and Leibniz over the invention of calculus, developments in algebraic calculus in the rest of Europe had facilitated an advancement of mathematical physics that put British achievements in that period to shame.[104] Playfair became a prominent critic of the preference for geometry apparently typical of British Newtonians, and lamented both that Newton, 'influenced by the prejudices of the times', took against algebraic calculus and the fact that his system had to be completed by a foreigner, Laplace, by building on the recent work of a host of other continental European mathematicians and philosophers.[105]

Nevertheless, for Playfair these 'successors' have, 'after near a century of the most ingenious and elaborate investigation', merely been 'extending the philosophy of Newton to its utmost limits' and have thereby confirmed the treatment of gravitation in the *Principia* as his most lasting and foremost achievement.[106] 'In ascertaining the existence, and in tracing the effects, of the principle of gravitation', Playfair believed Newton had completed the 'most difficult research that had yet been undertaken' with such success 'of which there had been no [such] instance in the history of human knowledge'.[107] While he believed there may be found Newton's equal in mathematics, 'no one... will come forward as his rival... in the philosophy of nature'.[108] By 'philosophy of nature', Playfair meant 'experimental and inductive investigation', and his verdict on Newton's overall superiority is best understood in comparison with Bacon. Whereas Reid, Stewart, and others had implied Bacon to be at least the equal of Newton in historical significance, Playfair was sceptical about what posterity might think of Bacon's contribution to philosophy and was eager to point out some of the limitations of Bacon's methodology. He believed Bacon did not appreciate the importance of 'accurate measures of physical quantities' nor how 'in many cases, the result

[104] 'General View (II)', 28–9. See Amy Ackerberg-Hastings, 'John Playfair on British Decline in Mathematics', *Bulletin (British Society for the History of Mathematics)* 23, 2 (2008): 81–95.

[105] John Playfair, 'Art. I. *Traité de Méchanique Céleste*. Par P. S. La Place, Membre de l'Institut National de France, et du Bureau de Longitude. Paris. Vol. 1. An 7. Vol. 3. & 4. 1805', *The Edinburgh Review* 22, 11 (1808), 282.

[106] Playfair, '*Traité*', 249–50.

[107] 'General View (II)', 115.

[108] 'General View (II)', 131.

of a number of particular facts, or the collective instance arising from them, can only be found out by geometry'. In these cases, mathematics proves to be a 'necessary instrument in completing the work of induction'.[109]

Newton's discovery of gravitation appears to fit the Baconian inductive model, being 'only necessary where the thing to be explained is new, and where we have no knowledge, or next to none, of the powers employed'. However, what has been understood from its *effects* seems to go beyond what Bacon himself envisioned for physical inquiry.[110] Bacon's contribution also appears out of step with the state of contemporary natural philosophy in that he seems to have 'placed the ultimate object of philosophy too high, and too much out of the reach of man' in supposing that the philosopher could 'arrive at the knowledge of the essences of the powers and qualities residing in bodies', such as the essence of heat or of colour.[111] As it now appears, 'the highest point which our science is destined to reach' seems rather to be in the identification of 'laws of action', reducing the phenomena to 'a few general facts', or 'in some cases, as is that of gravity, to one only'.[112]

Following Stewart and Robison, in Playfair's telling Newton was a careful and rigorous student of nature whose example illustrates the triumph of physical inquiry as an enterprise rooted in the establishment of facts and the tracing of effects from those facts. This is notwithstanding the utility and validity of his conjectures and the penetrating 'genius' by which he saw so deeply into nature as to make the most extraordinary and, as yet, fundamental discovery of all: the 'principle' of gravitation. Playfair does say that 'the sagacity of Newton, like the *Genius* of Socrates, seemed sometimes to inspire him with wisdom from an invisible source', but explains that

> by a profound study of nature, her laws, her analogies, and her resources, he seems to have acquired the same sort of *tact* or *feeling* in matters of science, that experienced engineers and other artists sometimes acquire in matters of practice, by which they are often directed right, when they can scarcely describe in words the principle on which they proceed.[113]

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[109] 'General View (II)', 93–4.

[110] 'General View (II)', 93.

[111] 'General View (II)', 98.

[112] 'General View (II)', 99.

[113] 'General View (I)', 107.

Newton's genius was for Playfair really a kind of instinct derived from his extensive study of nature and therefore something more cultivated and artificial than the concept of genius as a natural mental capacity possessed in extraordinary degree, as William Duff and Alexander Gerard had conceived of it.[114] For Playfair, as for Robison and Stewart, Newton's diligent commitment to science was above all restrained and modest in its ambition, and he gave little sense of what Newton either thought about divine agency or contributed to natural theology. Like Robison, his predecessor in the natural philosophy chair at Edinburgh, Newton's legacy was bound up with the practical consequences of his discoveries and their influence on modern society.

Nevertheless, in a review of Laplace's *Traité de Mécanique Céleste* (1798–1825), Playfair claimed the one 'blemish' of the work was its lack of consideration for 'final causes' and the full philosophical implications of the Newtonian system. While Playfair observed that Laplace had rendered such issues strictly inessential to natural philosophy, it was for Playfair quite right to infer from Newtonian cosmology 'Wise Design and Intelligence', as 'no one will be so absurd as to argue, that it is the work of chance'.[115] Yet this criticism obscured the extent to which the treatment of divine agency in natural philosophy had changed over the course of the previous century, since Newton's own time. Playfair and many of his contemporaries, such as Robison, gave far less attention to God's role in nature in their physical inquiries than had been standard in the mid-eighteenth century and before. Notwithstanding Dugald Stewart's view of proper natural-philosophical explanation, they worked with a much stricter conception of what that inquiry could reveal about the 'Wide Design and Intelligence' apparently so evident. Men like Robison and Playfair saw natural philosophy as a primarily practical enterprise, not one devoted to establishing metaphysical truth or uncovering the mysteries that lie beyond the facts of nature.

Conclusion: A Man of Science

Following the death of Leslie, Playfair's successor as professor of natural philosophy at Edinburgh, the chair was taken up in 1832 by the natural philosopher/physicist James

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[114] See Chapter 4, 205–12.

[115] Playfair, '*Traité*', 279.

David Forbes (d. 1868).[116] He had been born in 1809, four years into Playfair's tenure. By the 1830s, the redefinition of natural philosophy at Edinburgh was complete. Since the 1750s, the discipline had been reconceptualised and the notion of physical inquiry at its core had entered mainstream scientific discourse in Britain. By no accident, Newton's reputation had during this time modified so that he remained one its most pioneers. He continued to be cast as an exemplary practitioner of the physical sciences. His shifting reputation prevented his philosophy from appearing fundamentally antiquated or outmoded and he was understood in terms that allowed his philosophy to be portrayed by yet another generation as a prefiguration of the modern. By the 1830s, this saw him become something of a proto-scientist, an icon and personification of physical inquiry for practitioners of the natural sciences who believed themselves to be living at the dawn of a modern age.

Newton continued to be renowned for the discovery of gravitation, an act which had always captured what Newtonian philosophy was all about. By the late eighteenth century, this meant the identification of the fundamental facts or laws of nature through inductive inference, and the subsequent careful tracing of the effects arising from them using deductive logic and mathematics. Newton's natural genius was thought to have been directed by his virtues and personal characteristics, restraining his ambitions. His impressive conclusions were viewed as the result of hard, patient labour through the application of advanced mathematical techniques that he himself had developed for the very task. For all that Newton was supposedly deified in the eighteenth century, the view that emerged in Scotland and became generalised in the 1830s was of a thoroughly mortal yet nonetheless extraordinary philosopher and mathematician.

Newton's reputation had changed alongside natural philosophy itself. Between the early eighteenth century and the early nineteenth century, philosophers developed a more strictly empirical conception of their discipline. Physical inquiry was more explicitly distinguished and consciously pulled apart than ever before from metaphysical inquiry through responses to the sceptical empiricism of David Hume and Lord Kames, and the deism and atheism to which it had been connected. Newton accordingly became an exemplar of a particularly empirical natural science. There was no doubt for most that

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[116] There is scant literature on Forbes: see John Campbell Shairp, et al., *Life and Letters of James David Forbes* (London: 1873).

Newtonian natural philosophy revealed God's hand in nature, but the human mind was deemed by many incapable of fathoming any more than that fact. Natural phenomena were mere facts and appearances that gave limited insight, if any, into the immaterial agent who had brought the phenomena about.

This was the vision of Newton that David Brewster would have become familiar with as a student at Edinburgh in the 1790s. The influential portrait later drawn by him in influential biographies of Newton bears a remarkable resemblance to it and indicates that Newton's reception in the later Scottish Enlightenment did much to shape Newton's legacy in the English-speaking world until, at least, the second half of the twentieth century.[117] The role played by Scottish natural philosophy in shaping his work has been partly obscured by the sense that Brewster was operating in a scientific rather than a natural-philosophical context.[118] The emergence of the independent disciplines of physics, chemistry, and biology in the early nineteenth century is often taken to mark the start of the modern history of science.[119] For many, this development reflects a breakdown of the discipline of natural philosophy which suggests, along with other developments associated with the birth of modern science, that a major shift occurred in the conception of natural inquiry at this time. Some contemporaries certainly suggested as much, but their fears over the increasing fragmentation of natural knowledge do not necessarily reveal that a singular notion of natural inquiry was either in the process of being lost or undergoing fundamental change. This chapter has argued that a reconceptualisation of physical inquiry occurred over time and began many decades prior to the 1830s. This ought to be seen not as the replacement of natural philosophy with (modern) science, but as a redefinition of the discipline of natural

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[117] Brewster's *Memoirs* was identified as the hitherto standard account in Richard S. Westfall, *Never at Rest: A Biography of Isaac Newton* (Cambridge: Cambridge University Press, 1981). For Newton's modern reception see Introduction, 14–33. For an account of Brewster's ideas about scientific discovery and debt to the Scottish Enlightenment see Bill Jenkins, 'The Mind's Magic Lantern: David Brewster and the Scientific Imagination', *History of European ideas* 47, 7 (2021): 1094–1108. For Brewster's activities in Scotland in the early nineteenth century see Bill Jenkins, 'David Brewster at the Royal Society of Edinburgh: Science, Politics and Patronage in Scotland, 1808–37', *Scottish Historical Review* 101, 1 (2022): 20–45.

[118] See, for instance, Higgitt, *Recreating Newton*.

[119] This view is well expressed in the structure of Nye (ed.), *Cambridge History of Science*; and Peter J. Bowler and John V. Pickstone (eds), *The Cambridge History of Science. Volume 6: The Modern Biological and Earth Sciences* (Cambridge: Cambridge University Press, 2009), which take their points of departure from the emergence of these disciplines in the early nineteenth century.

philosophy prior to the more literal redefinition of the word 'science' which, eventually, rendered the term 'natural philosophy' obsolete.

Concern over the splintering of natural knowledge not only encouraged the use of new terminology but prompted some contemporaries to emphasise the underlying unity of all physical inquiry. This was the goal of Mary Somerville's *Connexion of the Physical Sciences* (1834), and it was in a review of Somerville's book that William Whewell made first mention of the term scientist. He noted, however, that its adoption had met with plenty of disapproval from 'gentlemen' of the British Association at their summer meetings since its foundation in 1831.[120] Whewell praised Somerville's ambition, execution, and her general standing within the field. He also lamented the 'disintegration' of science, comparing the breakdown of what had once been a single systematic body of knowledge to a 'great empire falling to pieces'. Even 'physical science', itself just one piece of a formerly unitary conception of science, was being 'endlessly subdivided, and the subdivisions insulated'. Somerville's attempt to tease out the fundamental essence of physical inquiry was for Whewell one way to 'remove the evil' of this unfortunate 'division of the soil'.[121]

Somerville, who as a woman was prevented from both accessing much formal education and from playing more than a limited part in institutions like the British Association, mostly educated herself.[122] Later she established contact with prominent Edinburgh intellectuals, like Playfair, who initiated a correspondence between Somerville and William Wallace, Leslie's successor as professor of mathematics at Edinburgh. Her conception of physical science was one with which those who did study at Edinburgh at the turn of the nineteenth century would have been quite familiar. She began the *Connexion of the Physical Sciences* by observing that

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[120] Whewell indicates this was a discussion among gentlemen, though women were in fact present at meetings from the first one held in York in 1831: see Rebekah Higgitt and Charles W. J. Withers, 'Science and Sociability: Women as Audience at the British Association for the Advancement of Science, 1831–1901', *Isis* 99, 1 (2008): 1–27.

[121] [Whewell], 'Art. III', 60.

[122] For an account of Somerville's life and conception of natural philosophy/science see James Secord, 'Mary Somervilles' Vision of Science', *Physics Today* 71, 1 (2018): 46–52; Secord, *Visions of Science*, 107–37; and Robyn Arianrhod, *Seduced by Logic : Émilie du Châtelet, Mary Somerville and the Newtonian Revolution* (Oxford: Oxford University Press, 2012), 161–257.

> all the knowledge we possess of external objects is founded upon experience, which furnishes facts; and the comparison of these facts establishes relations, from which induction, the intuitive belief that like causes will produce like effects, leads to general laws.

Immediately following this passage, she referenced the case of gravity and the example of Newton, who 'was led to the discovery of one of those powers with which the Creator has ordained that matter should reciprocally act upon matter'.[123] Staying with the heavens, 'which affords the most sublime object of study', she completed the picture by affirming that physical astronomy identifies and compares the operation of laws in the terrestrial and heavenly realms before it 'traces, by an uninterrupted chain of deduction from the great principle that governs the universe, the revolutions and rotations of the planets, and the oscillations of the fluids at their surfaces'.[124]

The *Connexion of the Physical Sciences* was written to provide the specialist and lay reader with a general account of the modern state of natural science (though it happily employed the term 'natural philosophy') and in the main offered an overview of the most important theories and discoveries across its many disciplinary and sub-disciplinary branches. Newton's prominence in the very definition of physical science with which Somerville opened her account reflects the continued influence of his example in this period. Just a few years before the *Connexion of the Physical Sciences* appeared, David Brewster published *The Life of Sir Isaac Newton* (1831), the first book-length biography of Newton to appear anywhere. In the preface, Brewster scolded Newton's 'disciples' for leaving the life of their 'master' so poorly accounted for relative to some of Newton's 'illustrious predecessors', and he promised the reader a correction. Brewster claimed that his work, the only biography 'on any considerable scale that has yet appeared', was based on a wealth of primary source material, unlike the 'extremely scanty' ones hitherto used by Newton's biographers.[125] While Brewster's biography was on an unprecedented scale and drew on plenty of source material, he did not challenge or redraw the basic outline of the reputation Newton had acquired in Scotland by the late eighteenth century.

The *Life* and its expanded sequel, the *Memoirs*, paid greatest attention to what would become the major themes in Newton's modern reception: his precocity,

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123 Mary Somerville, *On the Connexion of the Physical Sciences* (London: 1834), 1.

124 Somerville, *Connexion of the Physical Sciences*, 2.

125 David Brewster, *The Life of Sir Isaac Newton* (London: 1831), 9. Hereafter *Life*.

mathematical innovations, ground-breaking optical work, discovery of universal gravitation, and rivalry with Leibniz. Newton's alchemical research was addressed with mild confusion and incredulity, but Brewster made some sense of this work by associating Newton's alchemy with the queries to the *Opticks*. His interests in theology and chronology were presented as evidence of the 'analogy' Newton drew between the 'book of nature' and revelation. Brewster described Newton's piety as 'one of the proudest triumphs of the Christian faith', wherein 'he dissolved the league which genius had formed with skepticism'.[126] The account of Newton's religious views was intended as a rebuttal to claims made by the French natural philosopher/scientist Jean-Baptiste Biot (d. 1862) and others that Newton's piety was a symptom of the mental breakdown he supposedly experienced in 1693, and this was noted by Brewster in the preface as a major historiographical contribution that he intended his biography to make.[127] Brewster argued that Newton's engagement with theology predated any 'temporary indisposition' or 'supposed insanity', and he rejected the claim made by Newton's impious continental European readers, such as Laplace, that only 'anxiety' led Newton to take religion seriously toward the end of his life.[128]

Brewster seems to have departed from the received view of Newton's philosophy only in his treatment of the influence of Bacon. Brewster repeated the typical description of Newton's character and philosophical approach as modest and patient, describing his discoveries as 'the fruit of persevering and unbroken study'. For Brewster, these discoveries were less the result of 'extraordinary sagacity' than 'industry and patient thought'. Yet that was not meant to deny that Newton was an 'inspired genius' who had carried out 'the profoundest speculations'.[129] Brewster, however, entirely objected to the notion – common among 'modern writers' – that Newton owed a debt to Bacon's methodological influence. He insisted that Newton made no mention of Bacon's writings and that many, such as the Italian polymath Leonardo da Vinci (d. 1519), Copernicus, and Galileo, 'had described in the clearest manner the proper method of philosophical investigation' before Bacon had. This opinion significantly developed the more critical

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[126] *Life*, 264.

[127] For Biot's biography of Newton, originally an article published in *Biographie Universelle* (1822), see Higgitt, *Recreating Newton*, 19–42.

[128] *Life*, 10 and 243.

[129] *Life*, 293.

attitude toward Bacon's example shown by Playfair, but in general terms ran counter to a long-established mainstream view, shared by Somerville, that held Bacon to have been, as she put it, the 'restorer of true philosophy'.[130] Brewster took Galileo to be a much better precursor to Newton, for Galileo's 'whole scientific career... was one continued example of the most sagacious application of observation and experiment to the discovery of general laws'.[131]

Brewster's Newton was a philosopher dedicated to discovering natural laws and facts before diligently tracing the physical effects of these discoveries. In this way, Brewster had sketched out the template of a modern practitioner of empirical natural science and affirmed that, while further discoveries have and will continue to be made, 'the achievements of genius, like the source from which they spring, are indestructible'.[132] Newton was immortalised by Brewster as a 'great mind' for all mankind, but his ideas were presented more like those of Brewster and his contemporaries than those of Newton himself and the natural philosophers of his own age. Newtonian philosophy was, in Brewster's reckoning, delivered entire by Newton and left for his disciples to establish as the new orthodoxy. For this orthodoxy to rise, the rival philosophies of Descartes and Leibniz had to fall. Once this had happened, the discipline was set to continue advancing long into the future. What Brewster missed in his concluding remarks was the century and a half of constant transformation in natural philosophy that Newton's readers and admirers had brought about through a rich and complex set of debates over his legacy. For all that he was admired, his readers could never agree entirely about exactly *what* he had discovered and *how* he had managed to do so.

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[130] Somerville, *Connexion of the Physical Sciences*, 33.

[131] *Life*, 295–6.

[132] *Life*, 292.

CONCLUSION

This dissertation has argued that Newton's philosophy was held up in Scotland as an ideal example of physical inquiry at different times by different people who saw different things in it. This did not happen due to any amendment or clarification on Newton's part, and it was not the result of the publication or discovery of new aspects of Newton's thought. Nor was it the result of greater competence on the part of Newton's readers to understand his ideas. His philosophy invited reinterpretation and was met with a variety of responses over time due primarily to the issues inherent in it which, in new contexts and as his readers' priorities shifted, provoked the development of important new ideas. Engagement with Newton's treatment of gravitation best illustrates this process and was the most powerful aspect of his catalytic influence on the Scottish Enlightenment. This is because gravitation served as a philosophical problematic that Newton's readers continuously sought to solve across the period. The discovery and proof of a universal immaterial attractive force somehow operating through and between (apparently) physically unconnected bodies posed particularly fruitful and challenging questions about the nature of matter, divine agency, and the ideal approach to physical inquiry. These issues struck at the very core of what natural philosophy was understood to be, and therefore raised important questions about philosophy more generally.

Newton's causal agnosticism was of great importance to his earliest Scottish readers for whom we have detailed evidence of their reading, Archibald Pitcairne and David Gregory. They believed that Newton's pursuit of final causes by way of empirically verifiable forces in nature was a move of historic significance that promised to reform the discipline of natural philosophy. Though Gregory and Pitcairne praised Newton's refusal to identify the origin of gravitation, natural powers such as gravitation were typically understood in their day as somehow effected by God, the author of nature. For this reason, authors such as George Cheyne and John Keill soon went beyond Pitcairne and Gregory by explicitly identifying the law of gravitation as divine legislation (a notion supported by Newton's remarks in the 'Scholium Generale'). This view took Newton's discovery of gravitation to be the most profound insight into nature yet achieved and the identification of a genuine physical cause.

Though Pitcairne and Gregory probably read the *Principia* while housemates in Edinburgh in the late 1680s, these opinions were articulated contemporaneously in quite different settings, both inside and outside Scotland, in the following decades. However, much remained unresolved about the true nature and origin of gravitation by the mid-eighteenth century. Newton's Scottish readers, motivated to a considerable extent by the potential for natural theology to provide a defence against atheism and deism, were not content to remain agnostic on these questions. Cheyne, Andrew Baxter, and Colin Maclaurin participated in debates over divine agency and the role of reason in religion that presented competing notions of gravitation which went significantly beyond what Newton himself had said regarding the question of what gravitational force actually *is*. They shared a general voluntaristic conception of divine agency, and the debates over gravitation they contributed to reveal how important technical theological issues were for natural philosophers in this period, despite how little Newton had written on the matter.

Newton's readers also significantly expanded upon the fairly scant explicit remarks he made about his own methodology. Maclaurin and Thomas Reid outlined competing conceptions of his method of discovery, the latter departing from Maclaurin and other earlier readers by arguing that inductive inference alone – Reid's 'principle of common sense' – was capable of establishing the existence of a universal gravitational force in nature. Reid's view, articulated most clearly in an unpublished paper given to the Glasgow Literary Society, reflected broad and important developments in the Science of Man and was part of a refashioning of Newton's reputation in the second half of the eighteenth century. At this time, the use of inductive inference was given relatively greater weight than the application of deductive reasoning and mathematics in accounting for Newton's logic of discovery. This refashioning supported new ideas about philosophical discovery that emphasised the power of imagination, evidenced in Adam Smith's essay on the history of astronomy written while at Glasgow, and new theories of genius developed by William Duff and Alexander Gerard in Aberdeen.

The origin of gravitation began to be treated in a new light in response to sceptical-empiricist causal nescience, such as that of Henry Home, Lord Kames and David Hume. Reid spoke of gravitation as a natural law effected by God but also emphasised the essential inscrutability of its origin, a formulation that would be shared by many in the second half of the eighteenth century. The confidence with which Newton's readers hitherto identified gravitation as evidence of God's hand in nature was replaced by the acknowledgement that the capacity for humans to acquire knowledge of physical causes from their effects could itself only be determined by an empirical science of the mind. As a result, this argument could be outsourced to physiology, the science of the human body, and divine agency began to play a less prominent role in physics. The acquisition of knowledge of God through natural inquiry was reduced for most to a commonplace assumption and preliminary formality, especially in an educational context, making natural philosophy seem like a quintessentially practical endeavour and no longer the so-called handmaiden to theology. The natural laws or principles which natural philosophers took as the desiderata of their enterprise were increasingly conceived as physical causes that give rise to observable effects with the caveat that they *served* as causes but need not be taken to describe actual physical processes. Gravitation was judged to be the appearance of attraction, but not necessarily a real physical attractive force in nature.

For some, like John Robison and John Playfair, this was proper natural philosophy and was as far as the human mind was fitted by its creator to go in ascertaining causation from natural phenomena. For others, like James Burnett, Lord Monboddo and Dugald Stewart, Newton had not established physical explanation *per se* – though natural philosophy could and did do better. Monboddo's and Stewart's visions of proper natural philosophy were completely different, however. Stewart agreed with his fellow Edinburgh professors Robison and Playfair on what modern physical enquiry entailed, but not on Newton's practice. Monboddo believed that Newtonian natural philosophy had lost proper metaphysical content, impiously downgrading the place of theism in physics. By this time, however, Monboddo's views were dismissed along with his preference for the natural philosophy of the ancients. The ideal of natural philosophy David Brewster would have been introduced to at Edinburgh in the 1790s, which had been thoroughly transformed in roughly a century since David Gregory had taught John Keill there, fed in to nineteenth-century notions of the natural sciences and shaped Brewster's influential biographies of Newton published in 1831 and 1855.

There was, however, ultimately no universal consensus reached nor definitive resolution found to what Newtonian philosophy is or should be, let alone what Newton himself actually meant. This dissertation concludes that no single Scottish Newtonianism can be said to have emerged in this period. Nor, however, were there splintered, rival interpretations of Newton's philosophy that may be usefully catalogued as distinct Newtonianisms. What the different responses to Newton's philosophy examined here show is that neither his reception nor natural philosophy more generally were conceptually static during the Scottish Enlightenment, as they are often treated in the secondary literature. This has implications for the historiographical categories of Scientific Revolution and Enlightenment, for it is widely believed that the former established a conceptual foundation for natural philosophy by 1700 which subsequently served as an inspiration and model for the latter. Newton's reception in Scotland suggests that this view underappreciates both the extent of conceptual innovation in natural philosophy that occurred in the eighteenth century and the centrality and importance of natural inquiry to Enlightenment concerns. The 'philosophy' of the Enlightenment did not just draw on contemporary 'science'. Natural inquiry was integral to some of the most important debates of the eighteenth century. Through Newton's reception, this dissertation has shown how natural philosophers and natural philosophy were vital to the Scottish Enlightenment.

The account of Newton's reception offered here is intended as an alternative to those that tell of the triumph of Newtonian science in Scotland by 1700. These accounts often take Newtonianism to be an oppositional ideology best understood in contrast to Cartesianism, Leibnizianism, and other rival philosophies. On this view, contemporary debates are treated as pitting the Newtonians against their enemies, groups formed not only along intellectual lines but determined by broader social forces. Newton's natural philosophy has, in such accounts, been treated as a capsule of scientific modernity and the Newtonians those responsible for opening it and successfully conveying its contents into the intellectual mainstream. However, this scholarship has, this dissertation argues, not paid enough attention to how Newton's ideas were actually understood nor the motivations behind the writings of the so-called Newtonians.

This study has attempted to draw greater attention to Newton's Scottish readers' own ideas through their explicit engagement with his example and the many ways in which Newton's ideas were understood and used in the Scottish Enlightenment. This account of Newton's reception emphasises complexity and debate and situates his readers in intellectual contexts that best reflect shifting conceptions of natural knowledge and wider contemporary concerns. If this dissertation has achieved its purpose, it has shown how conceptual innovation within eighteenth-century Scottish natural philosophy transformed central aspects of the so-called new science of the seventeenth century, leaving a quite different discipline in the hands of nineteenth-century natural scientists. In this way, this study has outlined the process by which Newton's ideas can really be said to have given shape to the modern world.

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