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Newton's disputes with Hooke and Leibniz: Institutional, scientific and personal aspects.

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Abstract. This paper discusses the often fractious personal and academic relationships that Isaac Newton enjoyed with Robert Hooke and Gottfried Leibniz. It suggests that their disagreements operated at several levels: intellectual, methodological, institutional and personal. The disputes were related to a number of pre-existing rules of behaviour, notably those governing the correct ways to assign intellectual property and to manage disputes relating to it. Although these procedural codes concerned intellectual issues, they drew in part on etiquette in polite or genteel society more generally. The disputes were to some extent made possible by the appearance of new academies and societies, which provided new fora for disseminating results and for managing disagreements between scholars over extended distances. The presence of these intellectual institutions meant that there were novel aspects to the rules that governed these contests and indeed entirely new rules. Indeed, it was the way that the combatants attempted to get their preferred rules of engagement accepted more generally by others and the ways in which they manipulated them that conditioned the nature of their disagreements. More broadly, the capacity to engage in such contests was shaped by national pride, the ability to attract powerful support for respective causes and finally by the personalities of the individuals involved, which are perhaps best revealed in these situations.

1. Newton: the formation of a natural philosopher

Isaac Newton was born on the 25th of December 1642 in England, just a few months after the Civil War had begun in England.[1] His father had died a few months before he was born and his mother remarried when he was very young, producing three half-siblings. Information about what Newton did as a young man comes from three different sources: from surviving archival remains from his early years, from reminiscences by Newton himself towards the end of his life and from childhood acquaintances interviewed soon after he died (in March 1727). This evidence reveals that as a boy he was a bit of a loner who was happy when working alone, for example, wandering around local fields engaged in 'simpling' (looking for medicinal plants). Witnesses told the Lincolnshire antiquarian William Stukeley that as a boy Newton was interested in nature and astronomy, turning his rented accommodation into a giant sundial, but he was also fascinated by practical activities, building dolls houses, kites and clocks - 'playing philosophically', as Stukeley put it.

Many of these devices came from Newton's copy of John Bate, *Mysteries of Nature and Art* (figure 1), but he also got ideas from John Wilkins's *Mathematical Magick*. Newton himself later recalled that

[1] According to the Gregorian Calendar used from the late sixteenth century in Roman Catholic countries, Newton was born on 4 January 1643. He died on 20 March 1727 according to the older calendar used in England and on 31 March 1727 according to the Gregorian Calendar.

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although these pursuits distracted him from his scholarly pursuits at Grantham Free School, he always had the ability to catch up and outpace his colleagues.

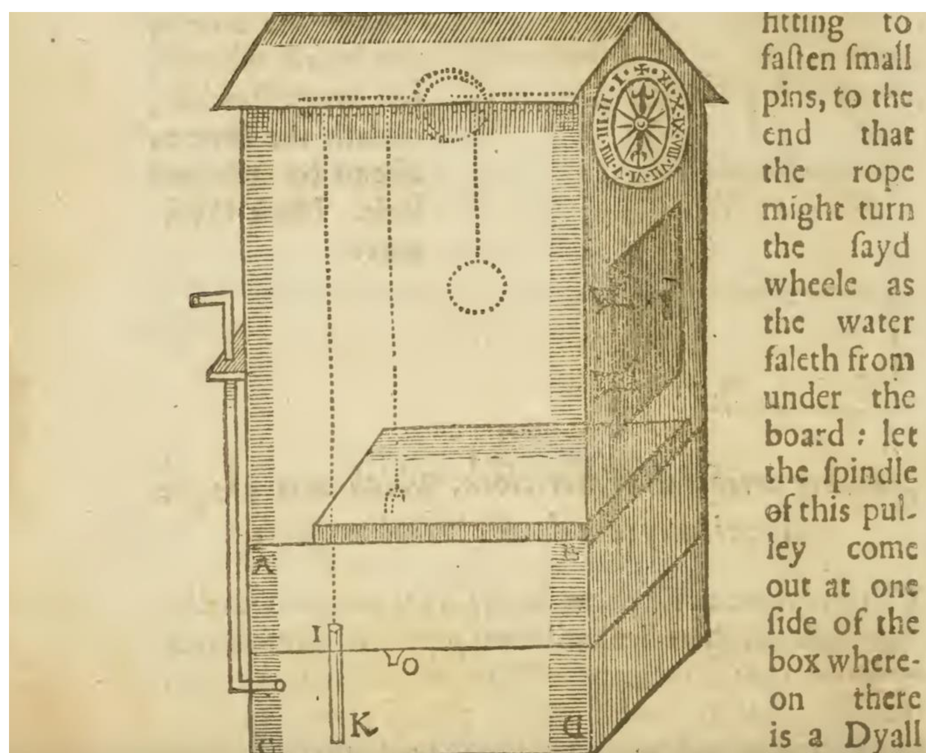


Figure 1. Clepsydra (water clock) from a book that Newton read as a schoolboy, *The Mysteries of Nature and Art* by John Bate (second edition, 1654).

Having stayed on for an extra term at Grantham to improve his Latin and Greek, Newton went to Trinity College at Cambridge (figure 3) in the summer of 1661. This was soon after the Restoration of Charles II and the College was returning from being what had been a strictly Puritan establishment to its pre-Commonwealth position as a pillar of the Church of England. Newton was a devout scholar but in the midst of this dramatic change in religious institutional context he became an innovative and radical student of divinity, a Christian who was beholden to no particular sect or denomination. In a relatively short space of time he grew dissatisfied with orthodox Christianity, believing that it had become deeply corrupt during its first three centuries of existence. By the mid-1670s he was a pronounced anti-trinitarian and – although outwardly a devout member of the Church of England – remained sceptical about many of its key tenets for the rest of his life.[2]

Newton studied the basic liberal arts curriculum at Cambridge until some point in 1664, when he decisively rejected standard Aristotelian doctrines and turned to the most authoritative modern authors. A great deal is known about his academic development because many of his notebooks survive at Trinity College and in Cambridge University Library. From early on he displayed great brilliance in mathematics, soon developing an excellent command of Euclid's *Elements*. Helped by his attendance at the lectures of Isaac Barrow, a Trinity scholar who was also the first Lucasian Professor of Mathematics, he started to devour the latest works in mathematics, particularly those composed by François Viète, René Descartes, Frans van Schooten, William Oughtred and John Wallis.

[2] The most authoritative biography of Newton as a natural philosopher remains R.S. Westfall, *Never at Rest: a Scientific Biography of Isaac Newton*, (Cambridge, 1980). For his religious views see R. Iliffe, *Priest of Nature: the Religious Worlds of Isaac Newton*, (Oxford, 2017).

Journal of Physics: Conference Series **2877** (2024) 012008 doi:10.1088/1742-6596/2877/1/012008

Figure 2. Woolsthorpe Manor, Newton's childhood home, in Woolsthorpe-by-Colsterworth, Lincolnshire, c. 1840.

Not only was Newton able to master the central methods and techniques in these works, but he developed and systematised them into coherent essays that would have stunned the mathematical world if they had been published. In 1665 to 1666, a period when he spent most of his time in Lincolnshire (figure 2) because of the continuing presence of plague at Cambridge, he discovered a way of expanding equations by infinite series (in modern terms, expressing a function approximately as a series of simple functions), found the Binomial Theorem and most significantly, devised what he called 'the fluxional method', his own version of the fundamental algorithms of differential and integral calculus.

Newton also read the latest publications in 'natural philosophy' (science) and was particularly taken with the philosophical system detailed by Descartes in his *Principia Philosophiae* (1644). Although he would later reject many of Descartes's central doctrines, notably the claim that terrestrial phenomena and the motions of planets were caused by fluids travelling in vortices, he was inspired by the ambitious intellectual programme that the Frenchman cultivated. Otherwise, he was drawn to the writings of major contributors to the newly founded Royal Society of London, the most significant of whom were Robert Boyle and Robert Hooke. Closer to home he learned important lessons about metaphysics, philosophy and natural theology from the works of the Cambridge Platonist, Henry More.[3]

In many cases Newton tried to reproduce the experiments and observations he found in these works, and occasionally he tested or extended them with innovative experiments. Alternatively he appealed to thought-experiments to test the plausibility of various claims, sometimes precociously rejecting some of the doctrines that modern authors were proposing. As in the case of mathematics, he was soon developing sophisticated theories of his own. During the 'marvellous year' of 1665-1666

[3] For Newton's mathematical development see N. Guicciardini, *Isaac Newton on Mathematical Certainty and Method*, (MIT, 2009).

Journal of Physics: Conference Series **2877** (2024) 012008 doi:10.1088/1742-6596/2877/1/012008

Newton discovered the heterogeneity of white light, the theory that sunlight or pure light is composed of the combination of more basic primary-coloured rays. That view overturned a theory that had been assumed to be obvious for two millennia, namely that colours were produced when white light was ‘modified’ in its passage through another medium.

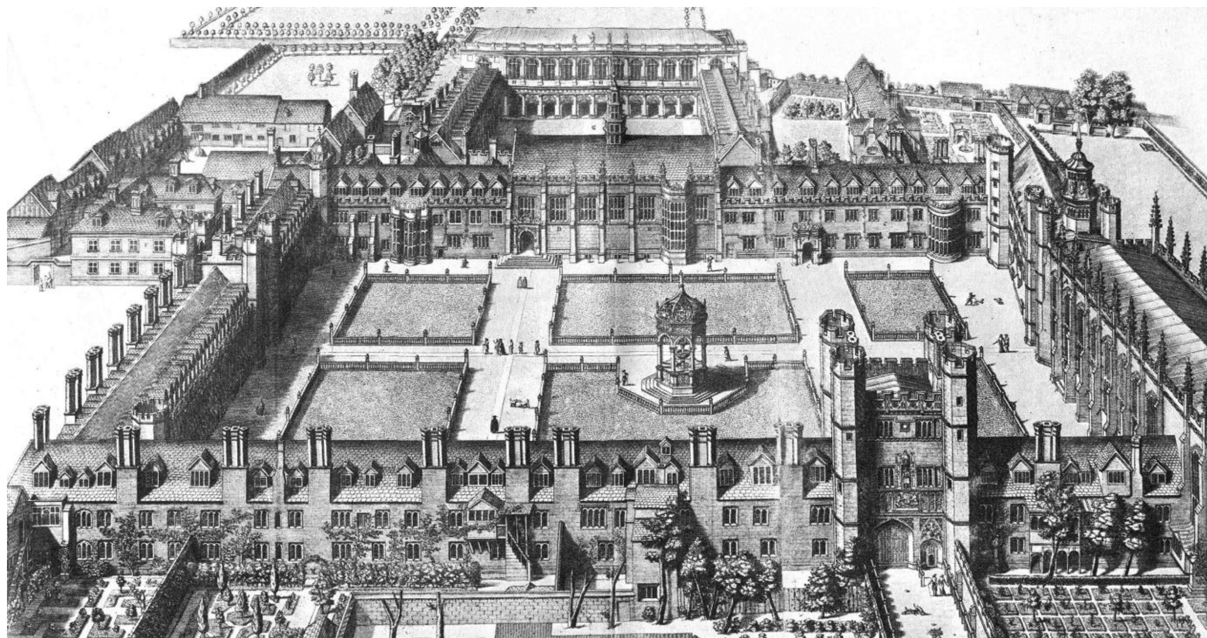


Figure 3. Trinity College, Cambridge, from David Loggan, *Cantabrigia Illustrata* (1690).

In a series of increasingly intricate experiments Newton demonstrated that when a carefully curated beam of sunlight hit a prism at a certain angle, the colours into which it was broken (refracted) having passed through the prism were already constitutive of the white light before it hit the prism. The prism did not modify the light but revealed its constituent components. Each primary-coloured ray had its own specific ‘degree of refrangibility’ (refractive index) that was unchangeable through successive refractions. Although Newton was well aware that the heterogeneity of light was an extraordinary discovery, he seemingly had no interest in publishing his findings.

Newton’s work on light and colour prompted him to think that because of chromatic aberration there were limits to the potential of refracting telescopes to produce clear and distinct images. Accordingly, in early 1668 he developed the first working reflecting telescope, which relied on one or more curved mirrors to produce an image. His invention brought him some measure of renown in Cambridge and within a few years brought him to the attention of the Royal Society. The search for a suitable alloy for the mirror may also have been the source of his interest in alchemy, which became another topic of interest in the late 1660s.

Either as an intellectual model or through personal contact, Isaac Barrow exercised substantial influence over the topics that Newton chose as his foci of study in the later 1660s. Barrow was particularly interested in geometrical optics and mathematics, and had developed techniques for solving problems that in an advanced form constituted the basis of the two main branches of calculus. Barrow was aware of Newton’s astonishing progress in some of these areas and when (in 1669) it was decided that he would become the Master of Trinity College, he did not have to look very far to find a suitable successor to recommend.

Newton had recently composed a tract entitled *‘De analysi per aequationes numero terminorum infinitas’* (‘On the analysis of equations by an infinite number of terms’) and with Barrow’s help it was communicated to a handful of mathematicians in London. Having displayed such outstanding

ability in optics and mathematics, Newton was duly appointed as the second Lucasian Professor of Mathematics in September 1669. In honour of Barrow, he chose optics as his first subject of the lectures he delivered as professor.

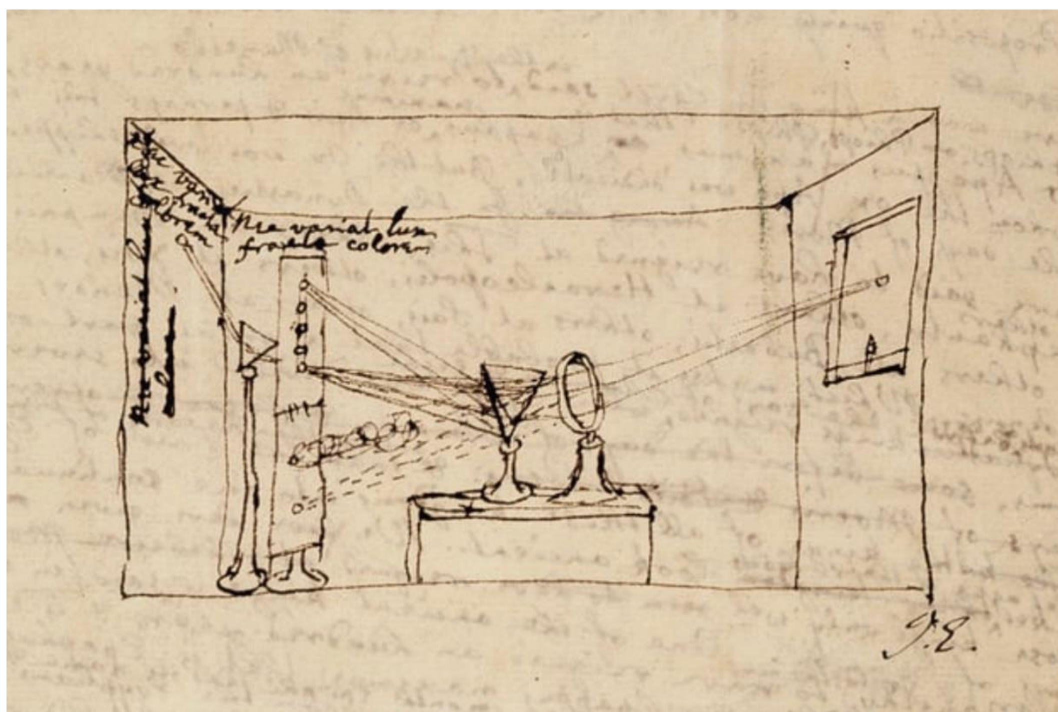


Figure 4. The only surviving image drawn by Newton himself of the 'crucial experiment' demonstrating the heterogeneity of white light with light coming in from a hole in a window board at the right, passing first through a lens and next through a prism, after which an oblong-shaped figure composed of overlapping coloured circles appears on a board on the left. An individual primary ray (in this case red) is separated and passes through a hole in the board and is refracted through a prism on the other side of the board. Newton said that the defining characteristic of the 'primary' ray of light was not so much its colour as its index of refraction or what he called its 'degree of refrangibility'. Provided that the angle of entry into successive prisms remained the same and the prisms were set at the same orientation, its index of refraction would (he claimed) remain the same through successive refractions. © The Master and Fellows of New College Oxford.

2. The trouble with Hooke

Prompted by Barrow and by the Secretary of the Royal Society, Henry Oldenburg, the first scientific paper that Newton published was on the heterogeneity of white light. In this paper, which appeared in the February 1672 issue of the *Philosophical Transactions*, he claimed that he had been surprised when he noticed that a beam of sunlight being refracted by a prism had projected an 'oblong' shape on a wall behind it (see figure 4). This had led him to perform a 'crucial experiment', which had ruled out any other explanation for the appearance of the image on the wall other than the intrinsic differential refrangibility of primary light rays.

In the essay Newton enthusiastically put forward a 'mathematicist' view of what a ray of light is, that is, he set out to offer an 'abstract' account of a ray of light that represented it in terms of its measurable features. Such an approach was supposed to avoid any commitment to any 'physical' theory of light, that is, Newton was not supposed to commit himself to a position on whether light was made of waves, particles or anything else. Although in a throwaway remark he did reveal his belief in a particle theory of light, he would claim for the rest of his career that this abstract approach, which

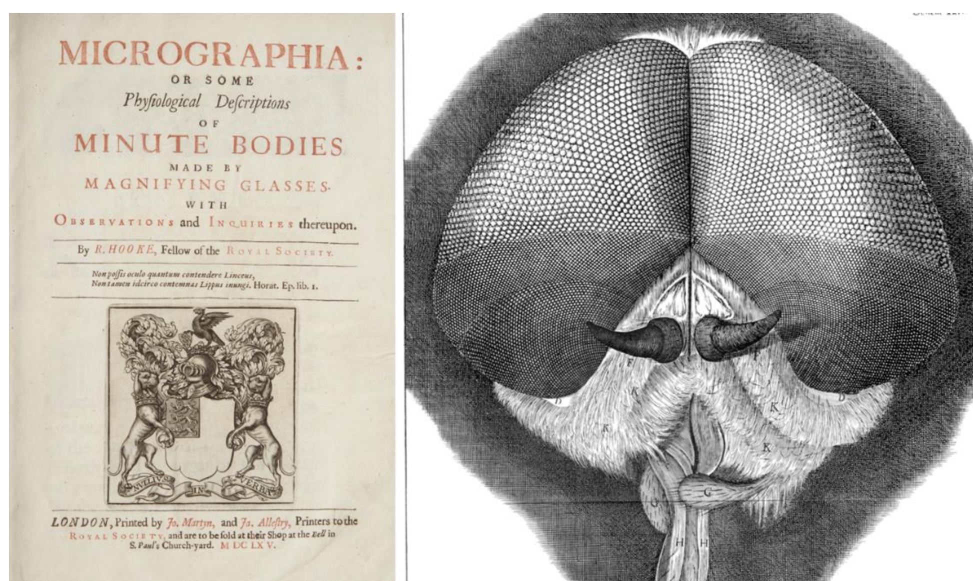
Journal of Physics: Conference Series **2877** (2024) 012008 doi:10.1088/1742-6596/2877/1/012008

could achieve a very high level of certainty, was the only way to avoid barren disputes in natural philosophy. In his Lucasian lectures he had already contrasted the certainty achievable through introducing mathematical techniques into natural philosophy with the more conjectural or hypothetical status of merely 'probable' claims.

Although Oldenburg told Newton that the paper had been received with applause from the Fellows of the Royal Society, it was criticised by Christiaan Huygens and Robert Hooke. Hooke, the chief experimentalist in the Royal Society and an accomplished practitioner of scientific optics, was upset by Newton's brief defence of a particle theory of light and claimed that both the particle model and the theory of the heterogeneity of light were ungrounded 'hypotheses'. The latter, he said, was an ingenious conjecture but no more plausible than many other theories that could account for the basic phenomena Newton had mentioned. Hooke confirmed that the latter did occur as Newton had described them, but added – to Newton's irritation – that he had known about them for some time. He added that his own wave theory of light accounted for the phenomena much better than did Newton's theory of the heterogeneity of light.[4]

Newton, who many years earlier had derived both inspiration and information from his reading of Hooke's *Micrographia* (figure 5), took serious umbrage at Hooke's remarks. In a number of letters that he wrote in the months following the publication of his 1672 paper, he insisted that the heterogeneity of white light was an undeniable matter of fact and that he had proved this by means of the 'crucial experiment' – to such an extent that it had a 'mathematical' level of certainty. While his own theory was much more than a 'hypothesis', Hooke's wave theory *was* a mere hypothesis, unsupported by the sort of robust evidence and watertight arguments that Newton had provided.

This exchange with Hooke marked the onset of Newton's antipathy to Hooke's ideas and his distrust of Hooke's academic conduct, and more generally it confirmed Newton's contempt for the public sphere. After this, Newton would always prefer to disseminate his work – if it was to be published at all – to a group of like-minded, clever people who agreed with most if not everything he said. Conversely, he argued that the public sphere was a place where an uninitiated audience was always liable to misunderstand difficult ideas that went against their prejudiced opinions.


MICROGRAPHIA:
OR SOME
Physiological Descriptions
OF
MINUTE BODIES
MADE BY
MAGNIFYING GLASSES.
WITH
OBSERVATIONS and INQUIRIES thereupon.

By R. HOOKE, Fellow of the ROYAL SOCIETY.

Non possis oculo quantum contendere Linceus,
Non tamen idcirco contemnas Lippus inungi. Horat. Ep. lib. 1.

NVLLIVS IN VERBA

LONDON, Printed by Jo. Martyn, and Ja. Allestry, Printers to the ROYAL SOCIETY, and are to be sold at their Shop at the Bell in S. Paul's Church-yard. M DC LX V.

Figure 5. Frontispiece of Hooke's *Micrographia* with image of the eyes of a housefly seen through a microscope.

[4] The letters described in this essay are printed in H.W. Turnbull et al. eds, *The Correspondence of Isaac Newton*, 7 vols (Cambridge, 1959-77).

Journal of Physics: Conference Series **2877** (2024) 012008 doi:10.1088/1742-6596/2877/1/012008

By the mid-1670s Newton had withdrawn from the scientific Republic of Letters, upset both by the way he had been dragged into disputes and by the way he felt that Oldenburg, the editor of the *Philosophical Transactions*, had abused his good will in order to fill up copy with debates about his theory (a sentiment provoked in part by Hooke himself). Newton stayed put in Trinity College, physically and mentally, and devoted himself to alchemy and theology.

Nevertheless, in late 1675 he was tempted into revealing his thoughts on the physical basis of natural phenomena. He sent a long essay to the Royal Society, which he called the '*Hypothesis of Light and Colours*', to be delivered at its meetings in the first few weeks of December. The paper provided an extraordinarily rich insight into Newton's personal beliefs about natural philosophy, which until this point he had refused to make public. Along with light and colour, the essay covered topics such as music, the nature of electricity and magnetism, and even the mind-body relationship.

Hooke was present when the paper was read out and he immediately accused Newton of plagiarising various ideas from *Micrographia*. With his friend Christopher Wren and others, he started a new rival scientific 'club' before the month was out, mounting a deliberate attempt to degrade the standing of the Royal Society. The club devoted its inaugural meeting to Hooke's accusation that Newton had stolen his central notions from *Micrographia*.

When Newton got to hear about the affairs of Hooke's new society, he was understandably livid. He drafted a series of replies to Hooke's allegations and in what would become a characteristic rhetorical *modus operandi*, he argued that Hooke himself was an arch-plagiarist, having stolen all his best lines from Descartes's *Principia Philosophiae*. As the affair threatened to spin out of control, Newton was temporarily convinced by several people, including Hooke, that the latter's views had been misrepresented to him (they had not). As a result, he wrote the famous letter to Hooke (in early February 1676) in which he said that if he had seen further than others, it was because he was standing on the shoulders of giants.

As with their earlier contretemps, Newton never forgot how Hooke had behaved towards him, and it clearly influenced his own conduct in the third and greatest contest between them. This concerned the allocation of credit for key doctrines of the *Principia Mathematica* (figure 6), which was published in the summer of 1687. This fracas began with the exchange of a series of letters in 1679-1680. Hooke, who was now Secretary of the Royal Society, had tried to drag Newton back into discussions about natural philosophy, notably on the topic of orbital dynamics. Specifically, he asked Newton how an elliptical planetary orbit could be analysed in terms of its inertial motion coupled with centrally attracting forces (i.e. emanating from the Sun) that operated according to an inverse-square law.

Newton responded somewhat unwillingly to Hooke's letters but soon returned to alchemy and theology. In the summer of 1684, he was forced to engage with the topic once more as a result of a visit to Cambridge by the astronomer Edmond Halley. In a now famous meeting, Halley asked Newton what was essentially Hooke's question, i.e. whether he could show that an elliptical planetary orbit was the result of an inverse-square force law. Having worked on the subject for the best part of two years, in the summer of 1686 Newton sent Halley (effectively the editor of the work) the first two of the three 'books' that would compose the published *Principia*. Among many other intellectual jewels, Newton's text described the three laws of motion and the notion of 'attraction' – a more abstract mathematical representation of universal gravitation – operating according to an inverse-square law.

On receiving Newton's writings an evidently apprehensive Halley told him that Hooke expected some credit for the prompts on orbital dynamics he had allegedly given Newton in their earlier correspondence. Now that it was an argument about the allocation of intellectual property, Newton was in his element and he vented his spleen on paper. He told Halley that Hooke had no rights at all in the matter and that where he (Newton) had given demonstrations, Hooke had merely made a series of inspired 'guesses' in relation to the issue. Newton attempted unconvincingly to show that he himself had dropped hints about his knowledge of the relationship between the inverse-square law and universal gravitation in texts written during the 1670s, some of which Hooke might have seen. He

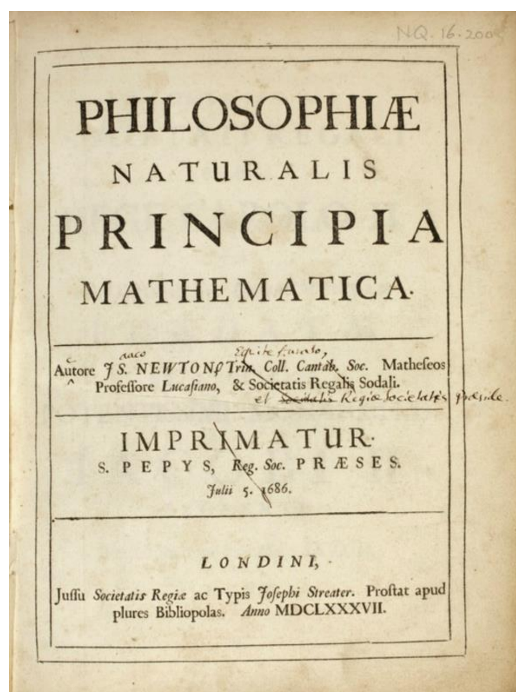
would have been on safer ground arguing that no-one (including himself) had imagined that such a force existed before his own recent work.

Halley also told Newton that some heated discussions had taken place in a coffee house where Hooke had told those present that for some time he had been in possession of the proof that planetary orbits arose from an inverse-square law. He had apparently added that he had kept it to himself so that others, trying and failing to provide such a demonstration, would know how important the discovery was. Halley reassured Newton that Hooke's friends were deeply sceptical about this claim, saying that if it had been that important to him, he should have published it. As will be seen, such an accusation might well have been levelled against Newton two decades later.

In a postscript to his letter to Halley, Newton portrayed Hooke's conduct as 'very strange'; he had finished no intellectual projects of any note but stirred up disputes in natural philosophy by claiming other people's work for himself. As Hooke had done before, Newton continued, he was turning philosophy into a 'litigious lady'. Hooke's behaviour confirmed to him that legal arguments were corrosive of science and had no place in it. What one put forward as a natural philosopher could only be supported by rational argument and by accurate and precise observational or experimental evidence. If scientific claims were backed by such evidence and had a profound mathematical basis – as with the law of universal gravitation – then neither plausible hypotheses nor any number of people arrayed against it were sufficient to overturn it.

Newton briefly threatened to withdraw the third book but thanks in part to Halley's great diplomatic skills, he completed the final book and despatched it to London early the following year. This text, which Newton termed '*The System of the World*', explained the paths of comets, the motions of the tides, the precession of the equinoxes and the shape of the Earth according to universal gravitation. Later, he boasted that he had made the last book more technically forbidding to thwart the pretensions of 'smatterers in mathematics'.

Newton became internationally famous within months of the publication of the *Principia*. In many ways he was the first scientific celebrity and people came from Italy, France, the Netherlands and many other places to see him. He was elected as one of the two MPs for the University of Cambridge (figure 7) following the Glorious Revolution of 1688-1689 and in the middle of the following decade he became a government official. He was Warden of the Royal Mint from 1696, overseeing what became known as the Great Recoinage, and was appointed Master of the Mint at the end of 1699.



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore J S. NEWTON, *Trin. Coll. Cantab. Soc.* Matheseos Professore *Lucasiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,
Jussu *Societatis Regiæ* ac Typis *Josephi Streater*. Prostat apud plures Bibliopolas. *Anno* MDCLXXXVII.

Figure 6. Corrected frontispiece to Newton's copy of 1687 *Principia* indicating his knighthood and Presidency of the Royal Society – notes for printer of 1713 second edition (© Master and Fellows Trinity College).

Journal of Physics: Conference Series **2877** (2024) 012008 doi:10.1088/1742-6596/2877/1/012008

Newton continued his spectacular rise to prominence in the following century, becoming President of the Royal Society in 1703 and publishing his great book *Opticks* in the following year. He was knighted for his services to the state in 1705, when Queen Anne took a break from horse-racing at Newmarket to come down and tap him on the shoulder, and a Latin translation of *Opticks* was published as *Optice* in 1706, bringing his optical doctrines and general scientific approach to a wide European readership.

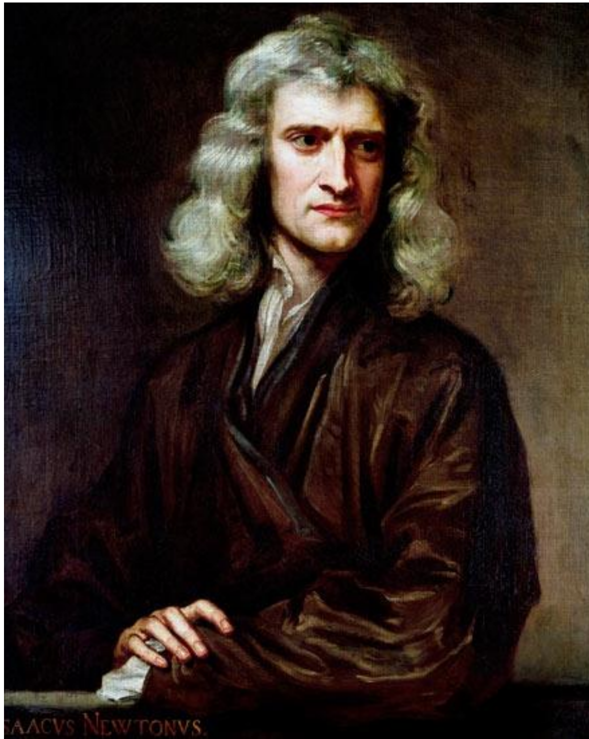


Figure 7. The new MP for the University of Cambridge: portrait of Newton in 1689 by Godfrey Kneller.

Hooke's star fell as Newton's rose. In the 1690s he continued to make important contributions to meetings at the Royal Society and made brilliant observations on the age of the Earth and the possibility of evolution. Nevertheless, his reputation was already overshadowed by that of his nemesis and in part thanks to Newton it would continue to suffer in the following centuries. He died in 1703, not long before Newton became President of the Royal Society and the publication of *Opticks* effectively overshadowed many of the major contributions that Hooke had made to optics.

It was Hooke's misfortune to experience the peak of his career at the same time as Newton came to prominence. In the early decades of the Royal Society he had been a scientific dynamo, able to make original contributions in a wide range of practical and theoretical scientific fields. In some ways this breadth was a burden to him and he was charged by many – including Newton – with being unable to properly finish any of the projects he started. Although in many ways this was unfair, Hooke could never match Newton's unrivalled expertise in the fields of mathematics and mathematical physics. It was also no small advantage to Newton that he outlived his foe for over two decades.

3. Leibniz and his disciples

As Newton rose to become a totemic scientific figure and a major state administrator, he was forced to confront a full-scale attack on his intellectual system mounted by the German diplomat, philosopher and mathematician Gottfried Leibniz (1646-1716) (figure 8). By the 1690s, Leibniz's main job was as a librarian and historian to the House of Brunswick, where he was also a Privy Counsellor of Justice. Although his major role was to compose a history of the House of Brunswick, he had developed a reputation as an outstandingly brilliant mathematician as a result of working with Christiaan Huygens

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in Paris in the mid-1670s. Here he created what is now taken to be the modern algorithms and notation of differential and integral calculus in 1675-1676, and the results of his path-breaking researches were published in the *Acta Eruditorum* in 1684 and 1686.[5]

Contact between Newton and Leibniz was sporadic in the late seventeenth century, but in 1676 Newton did send Leibniz two major accounts of large parts of his own mathematical development. These letters did not contain any explicit reference to the calculus and although Leibniz did briefly see Newton's '*De analysi*' in a short trip to England in October 1676, he was only concerned to mine it for its infinite series. Although Newton had included radically innovative expositions of series expansions within the letters, Leibniz did not learn anything concerning the calculus either from them or from his visit.

Despite the fact that the *Principia* gave Leibniz and his followers scant evidence of Newton's knowledge of the calculus, mathematicians such as David Gregory and Fatio de Duillier were aware of the great advances he had made in private. Indeed, once the *Principia* appeared, his supporters made progressively bold claims about his rights as the first inventor of the calculus. Through the 1690s they moved from the position that Newton was an independent inventor of calculus, to alleging that Leibniz's calculus was inferior and then finally to the accusation that Leibniz was a cunning plagiarist. Newton was of course entirely responsible for not releasing his early pioneering mathematical work to a wider audience, but goaded on by such arguments, in 1704 he released a bravura tract on calculus ('*De Quadratura Curvarum*', appended to his *Opticks*) that he had drafted over a decade earlier.

In turn, Leibniz and his supporters, notably the great Swiss mathematician Johann Bernoulli, believed that Newton was reverse engineering the rudiments of the calculus from Leibniz's published works. Following an anonymous pro-Leibnizian review of '*De Quadratura Curvarum*', in 1710 the Oxford Newtonian John Keill launched a savage attack on Leibniz's probity and mathematical ability. As a Fellow of the Royal Society Leibniz demanded that the Society condemn the behaviour of Keill, a fellow member, but under Newton's leadership, the Society refused to do anything of the sort. Indeed, Newton actively supported Keill behind the scenes.

Leibniz now looked more closely at the metaphysical and theological foundations of Newton's system and came to see that they were underpinned by beliefs that he took to be infantile, unphilosophical and unChristian. He reserved particular scorn for Newton's claim that space was the divine 'sensorium', a notion he had briefly outlined in a series of statements added to the 1706 *Optice*, was both a depraved form of metaphysics and on the face of it, a heretical statement that space was God's body. In due course Newton would claim that he had only stated that space was *analogous to* God's sensory organ, but Leibniz's own copy of the tome (along with a number of other examples) explicitly equated the two.

At this point Leibniz exerted significant influence over European mathematics and natural philosophy, and his criticisms carried weight with many. Like almost all of his contemporaries he admired the mathematical accomplishments of the *Principia*, but he found its core doctrines to be obnoxious. To begin with, the notion of an infinitely large 'absolute' space, a uniquely privileged frame of reference or container for all of God's created universe, was self-evidently absurd. Such a concept spoke to the limits on understanding exerted by the force of the imagination, which concocted entities where none existed.

While Leibniz had long attacked the notions of atoms and the void as jejune, he reserved particular disgust for the doctrine of attraction or universal gravitation. As he saw it, the claim that all bodies naturally attracted all other bodies with no intervening medium was an absurd and even dangerous fiction that took natural philosophy back to the Dark Ages. No-one, not even the medievals with their notions of 'sympathy' and 'antipathy', had envisaged something so conceptually pernicious. While Newton made a virtue out of refusing to say what the physical basis of universal gravitation was,

[5] For accounts of the priority dispute see A.R. Hall, *Philosophers at War: The Quarrel between Newton and Leibniz* (Cambridge, 1980) and D.B. Meli, *Equivalence and Priority: Newton versus Leibniz* (Oxford, 1993).

Journal of Physics: Conference Series **2877** (2024) 012008 doi:10.1088/1742-6596/2877/1/012008

Leibniz condemned it as a philosophically barren ‘occult quality’. It had no basis in material reality and thus could not be invoked as the cause of any natural phenomenon.

In response to such criticisms, Newton produced three ‘rules’ of philosophising in the second edition of *Principia* in 1713. The third rule justified the methodological procedure of induction, outlining the conditions under which it was legitimate to derive inferences about general principles or laws from a limited number of cases. Clearly directed against Leibniz and his philosophy, Newton added: ‘*We are certainly not to relinquish the evidence of experiments for the sake of dreams and vain fictions of our own devising*.’ His conviction that the Leibnizian philosophy was a self-indulgent and perverse whimsy was echoed in the Preface to the *Principia* composed by the Plumian Professor of Astronomy, Roger Cotes. Cotes noted that Cartesian or Leibnizian-style accounts of invisible vortices that moved planets around a central body had no basis in reality and enjoyed the status only of an ingenious novel.

If the general anti-fictivist tenor of the Newtonian response to Leibniz were not already clear, Newton himself summarised it in the ‘General Scholium’ that appeared at the end of the new edition. The existence of universal gravitation, he thundered, had been demonstrated through the analysis of countless phenomena, but as yet he had not determined its physical cause. Ungrounded hypotheses about such a cause had no place in experimental philosophy and he would not *feign* anything of the sort. His famous phrase ‘*Hypotheses non Fingo*’ would become a central credo of the Enlightenment.

At the start of 1713, following months of diligent historical research, Newton distributed what he called the *Commercium Epistolicum*, a textually-dense collection of letters and papers that effectively demonstrated that he had developed the fundamentals of calculus almost half a century earlier. This very substantial text did not convince Leibniz's followers, who increasingly objected both to Newton's documentary approach and to his cultivation of acolytes. Indeed, in a fascinating mirroring of Newton’s complaint about Hooke, Johann Bernoulli was dismayed by the way Newton had turned the whole process into a courtroom dispute.

Leibniz in particular objected both to the aggressive behaviour of Keill and also to Newton’s evident refusal to rein him in. Early on in the dispute Leibniz and Bernoulli were inclined to believe that Newton’s followers had acted without his permission and at least publicly they refused to attribute any spite or malevolence to him. Belatedly, and only in the last few months of his life (he died in November 1716), Leibniz came to see that Newton had always been manipulating his powerful contacts and altering his surroundings to his own advantage. Although he could only guess at the full extent of Newton’s active complicity in the attacks that were mounted against him, Leibniz recognised Newton as a devious puppet master who incited his toadies to act in his defence and connived in their actions, while all the time wearing a mask of disinterested objectivity.

In turn, and seemingly oblivious to his own cultivation of acolytes, Newton claimed that Leibniz had created an ‘army of disciples’ who were trying to dominate the Republic of Letters and populate it with his conceptual excrescences. Worse still, Leibniz had transformed the Republic Letters in his own image, creating journals such as the *Acta Eruditorum*, which functioned as indoctrination conduits for his own followers to spread his diseased ideas. As for his own documentarism, this had been forced on him by the propensity of the Continental European mathematicians to issue competitions to solve mathematical problems. Better a courtroom to solve these issues than turning it into a game.

4. The Hanoverian solution

While the dispute between Leibniz, Newton and their respective acolytes was pursued over a number of different academic theatres, major political shifts now exercised an unexpected impact on its outcome. Queen Anne died on 1 August 1714 and following the legislation laid down in the 1701 Act of Settlement to protect the Protestant succession, Leibniz's own patron Georg Ludwig became George I of England. Georg came over to England soon after he was made King, bringing with him his niece Princess Caroline, married to his son (also Georg) who would become George II in 1727. Caroline was a tutee of Leibniz; in various letters exchanged between them he told her that she was his favourite student and that he was relying on her to take true philosophy into the heart of the British state.

Journal of Physics: Conference Series **2877** (2024) 012008 doi:10.1088/1742-6596/2877/1/012008

Within days of her arrival in England, Newton and his key confidant Samuel Clarke went round to Caroline's residence at Kensington Palace. They showed her a number of spectacular and surprising experiments that corroborated key Newtonian doctrines and countered Caroline's Leibnizian arguments with accounts of why the Newtonian system was reasonable and theologically-acceptable. While Newton and Clarke cultivated Caroline with increasing success, she continued to meet various anti-Newtonians including the Astronomer Royal, John Flamsteed. However, Newton had exceptional access to political and intellectual power, and his allies had direct access to the ears of the Hanoverian court. In the meantime the King and senior ministers advised Leibniz to stay in Hanover and to get on with his job of writing the history of the House of Brunswick.

It was with Caroline's support that in 1715 Leibniz began a philosophical correspondence with Clarke that was to become the most famous intellectual exchange of the eighteenth century. In the fourth letter sent in the spring of 1716, increasingly agitated at Caroline's ongoing and evident defection to the enemy, brilliantly identified and dismantled the core elements of the Newtonian philosophy, charging that Newtonianism was a dangerous bundle of 'fictions' and 'chimeras'.

In a codicil to the letter, which was addressed to Caroline, Leibniz told her that when he was a youth and philosophically immature, he believed in the void – it was a 'pleasing imagination', he went on, but the product of juvenile ignorance. Men imagined nature was as finite as their own mind but wrongly – for example, atomists believed that nature was finite because they themselves were finite creatures while '*The least corpuscle is actually subdivided in infinitum and contains a world of other creatures, which would be lacking ... if that corpuscle was an atom.*' To assert that the subdivision of nature stopped at the size of an atom was an arbitrary fiction – the result of limited humans conceiving the world in their own image.

Figure 8. Leibniz, by Christoph Bernard Francke, c. 1695 (Herzog Anton Ulrich Museum).

As Leibniz suspected, Caroline was no longer proselytising on his behalf. She received Leibniz's critique of the void on 7 May 1716 and passed it on to Newton the very next day, as the latter's acknowledgement on the document attests. In the final letter that Leibniz wrote, he ranged widely over the bundle of nonsensical doctrines that, he argued, lay at the heart of the Newtonian philosophy.

Journal of Physics: Conference Series **2877** (2024) 012008 doi:10.1088/1742-6596/2877/1/012008

Newton's acolytes might peddle a superficial philosophy that allowed fictitious entities such as vacuous spaces and atoms but the 'superior reasons' of metaphysics did not allow them.

According to Leibniz, the collective Newtonian mind lacked the sort of discipline that metaphysics provided. It was a 'strange imagination' that made all matter gravitate to every other piece of matter, and Clarke and other Newtonians had nothing cogent to say about the substance that composed ostensibly empty Newtonian space. Was it full of nebulous 'spirits' like the sort of 'odd imaginations' of Henry More and the credulous medievals?

Once, in an Age of Reason, philosophical progress had been achieved with the works of mechanical philosophers like Descartes and his followers. Now, Leibniz continued, amidst the Newtonian hysteria, people were again returning to the 'spectres of the imagination'. At best this was a pagan belief-system whose core doctrine of universal gravitation was a dangerous chimera, a perpetual miracle or occult quality. At worst such doctrines were leading the unwary to the 'kingdom of darkness' – the realm of the Devil.

There was of course a complex nationalistic tenor to the whole dispute. Even if George I would find it difficult to pass himself off as a Briton, it was a historical irony of immense proportions that Leibniz's great patron had become monarch in the land of the English. Newton always took some convincing that certain types of foreigner were not hostile to him or his country, and there was something decidedly un-English about Leibniz and his philosophy. Yet he knew that the triumph of his own philosophy would not happen simply by assuming that its truth would win out by itself. While Newton and Clarke worked on Germans at the court of the new King, following the end of the War of the Spanish Succession (in 1713) Newton's followers did what they could at home and abroad to acquire Dutch and French allies.

In one of his final warnings to Caroline and to the new Hanoverian regime, Leibniz charged that England was now the land of irrational chimeras. No-one would have published this *dreck* in the early years of Charles II but the vanguard of good English science (with the exception of Christopher Wren) had long since died. Newton's doctrines lay at the heart of a diabolical national cult with Newton as its head. Newtonianism, he insinuated, was a false religion that was acquiring illegitimate power through its proximity to the new sovereign. However, he was keenly aware that he could do little to influence Caroline, far as he was from London and from other centres of European intellectual authority.

5. The source of disputes

How does one explain how and why such disputes arose between Newton, Hooke and Leibniz? Partly they can be attributed to social roles and personal mental attitudes, and partly to intellectual and political institutional structures. In short Newton inherited rules and regulations about how to publish and conduct debates in natural philosophy and mathematics, and in time he shaped them to suit his own purposes. He did not always emerge victorious from his encounters with his antagonists and indeed he was successful only when he acquired requisite social and political power and later,when he enjoyed substantial authority as head of major intellectual and government institutions.

Newton's disagreements with Hooke and Leibniz can of course be understood at a conceptual level. Hooke was the outstanding optical theorist and practitioner at the Royal Society before Newton's arrival on the scene, and in his *Micrographia* he described extraordinary phenomena that resulted from superbly-designed experiments, explaining them in terms of his wave-theory of light. Newton knew the doctrines of *Micrographia* in detail and he learned a great deal about how natural philosophy and how to perform experiments from reading it. Nevertheless, although his private views were close to Hooke's in many respects, notably concerning the existence of one or more aethers, he was deeply uncomfortable with Hooke's appeal to wave theories to explain the phenomena of light and colour.

Newton never confronted Leibniz's own metaphysical system in the way that Leibniz did his own. Even without access to the metaphysical and theological writings that Newton composed behind the scenes, Leibniz could see enough of Newton's beliefs in his published writings to know that he was committing a series of philosophical *faux pas*. Newton could and did turn to his friend Samuel Clarke

Journal of Physics: Conference Series **2877** (2024) 012008 doi:10.1088/1742-6596/2877/1/012008

to attack the detailed fabric of Leibniz's system but he himself had little appetite to engage charitably with Leibniz's key ideas. To Newton Leibniz was an obvious academic type and was knowable without the need for the hard graft to master his doctrines. He was a peddler of obscure and false doctrines, an old-fashioned scholastic philosopher who relied on the precarious fabrications of metaphysics rather than the safe method and robust facts of his own true natural philosophy.

A central element in the dispute between Newton and Leibniz was over the fictional status of their respective theories. Here there were significant similarities underpinning their very substantial differences. Newton's antihypotheticalism, which underpinned his critiques of the philosophies of both Hooke and Leibniz, was closely related to his private religious concerns regarding the power of the imagination. This personal attitude showed itself in a broader cultural form in his attacks on the hypotheses of his enemies and by the intensity with which he declared that he did not feign hypotheses.

In turn, Leibniz clearly saw that Newtonianism had a social structure. Headed by an intellectual despot, it was a deviant institution that deployed subtle techniques to persuade unwary disciples to believe in its absurd inanities. As such it was no more than an idolatrous sect whose leader denied that it was a cult or that it had disciples. In turn, Newton saw Leibniz as someone whose central mission was to cultivate disciples and to create the social and material conditions that would best allow his ideas to flourish.

Newton was correct that the nature of his disputes was affected by the new intellectual landscape in which it took place. In a world where new scientific journals were proliferating and flourishing, both Bernoulli and Leibniz insisted that academic spoils went to those who had first published the algorithms of the calculus and thereby made them available to the Republic of Letters to be put to good use. Naturally, this also served as a mark of intellectual priority. It was incomprehensible that Newton had not published this most valuable of discoveries when he had had the chance, and if he had known of these techniques he would surely have given evidence of his mastery of them in his 1676 correspondence with Leibniz.

As a counter to what he took to be the unfair control they exerted over polite conversation, Newton countenanced new editions, popularisations and public demonstrations of his doctrines. More prosaically, he marshalled individuals such as his friends Edmond Halley and Samuel Clarke, Charles Montague (the Earl of Halifax and Chancellor of the Exchequer when Newton became Warden of the Mint), major luminaries in the Church of England and ultimately, Princess Caroline. Of course, he benefitted from his own standing as a grandee of British institutions and of European science.

Although Newton's psychic substructure is evidently displayed in these disagreements, any remarks about his psyche, to be Newtonian about the matter, must remain conjectural and hypothetical. At the level of the banal, it is uncontroversial that he was immensely sensitive to perceived slights on his ability and integrity, and to these he responded vigorously and sometimes brutally. Whatever childhood, genetic or other causes are invoked to explain his dealings with Hooke, Leibniz and others often says more about the analyst and their times than it does about Newton himself.[6]

Newton's professed dislike of what he called 'contests' should be taken with some grains of salt, for even if he was concerned that science might descend into petty squabbling he engaged in disputes with great relish once they started. As noted earlier, his harsh condemnation of Hooke's alleged propensity for litigiousness contrasted with his own very quick recourse to the same in his mathematical priority contest with Leibniz. It may be that unlike in natural philosophy, he found litigation acceptable and even necessary in mathematics, in which case the publication of the *Commercium Epistolicum* was a normal part of mathematical communication. Outside his devotees, few others thought that digging up and publishing old manuscripts was relevant to the issue.

[6] On the subject of Newton's personality, Frank Manuel's *A Portrait of Isaac Newton* (Cambridge, 1968) remains insightful.

In any case, the intellectual property disputes that arose in natural philosophy and mathematics were inevitable consequences of his own publication practices and strategies. Whenever proof was required of his own precedence in any area he showed himself to be a brilliant documentarian, but also a conspiracy theorist of an extraordinary ability. With the power and authority to underpin his native talent, he was a formidable opponent. Earlier in Newton's career, when there was no hope of ending the contentions in which he found himself, his solution to these bruising encounters was to retreat to the safety of his College. Later, when he had the support of senior politicians and influential courtiers, the thin-skinned and conspiratorial Knight of the Realm made sure that the business of disputing ended in his favour.