PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore *JS. 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.

glory and gravity

figure 24
Title-page of the first edition of the *Principia* (1687), from a copy that belonged to the Lancastrian astronomer and natural philosopher, Richard Towneley (1629–1707), University Library, Adams 5.68.3.

The publication of the *Principia* in 1687 secured Newton's intellectual reputation. It was the culmination of almost three years of frantic effort by Newton and by Edmond Halley, who saw the book through the press in London. Although many of the ideas in the *Principia* can be traced back as far as the 1660s, the form in which they were set out and the conclusions that were drawn from them were very much the product of the years 1684–7. In August 1684, Halley told Newton about a conversation that he had had at the Royal Society concerning planetary motion. Anxious that others might take the credit for discoveries that he felt were already his, Newton went to work to prove his theories of celestial dynamics. Drafts were composed and rushed to Halley in London to indicate Newton's priority. Copies of some of them were later deposited in the University Library as if they had been his Lucasian lectures. Yet, despite the haste, these manuscripts show that Newton had indeed now solved the principal problems of celestial mechanics. The final text of the *Principia* set out his mature thoughts about the operation (although not the cause) of gravity. Structured to follow the rules of scientific reasoning that Newton developed, the *Principia* nevertheless baffled many readers, who complained that not even its author could possibly understand it.

42 king's college, cambridge, keynes ms. 97, number 1
30.1 × 18.5

If, in midsummer 1684, Newton had any plans for the publication of a work of mathematics or natural philosophy, his attention was probably focussed on one of two possible subjects. The first of these was the treatment of the geometry of curved lines, on which he had recently been working; the second concerned his discoveries in the manipulation of infinite series and the invention of the calculus. Some of the ideas that

Newton long ago communicated to Collins had begun to surface in public. In particular, David Gregory, then a young professor of mathematics in Edinburgh, had recently published work that drew on knowledge of Newton's techniques. Gregory derived his information from his uncle, James, also a noted mathematician and natural philosopher. James Gregory, in turn, had been a consistent correspondent of Collins, who had first mentioned Newton to him in 1669.

By autumn 1684, however, Newton's attention was concentrated elsewhere, in an attempt to prove that the planets move in elliptical orbits as a result of the constant action of a force inversely proportional to the square of their distance from the sun. This sudden change of emphasis had been provoked by a visit from Edmond Halley (1656–1742), which probably took place in August. Halley may have met Newton in 1682, shortly after he returned to England from a journey through France and Italy. Halley's account of making the earliest evening observation of the comet of 1680 on the road to Paris certainly found its way into Newton's 'Waste Book' (see catalogue number 33) around this time. Halley had been elected to the Council of the Royal Society in 1683, and, when he called on Newton, he told him about a conversation that he had had with Robert Hooke and Sir Christopher Wren at a meeting of the Society on 14 January 1684. Hooke had claimed to be able to demonstrate that an inverse square law governed celestial mechanics. In response to this boast, Wren had set a challenge by offering a prize to the first of his companions who could prove the operation of this law.

Newton had been interested in the motion of heavenly bodies since the mid-1660s (see catalogue number 2). The idea of the inverse square law was in many ways a natural development of Johannes Kepler's laws of planetary motion, by then quite well known in England, in the light of Cartesian thinking about the force possessed by a body in motion. Descartes' influence was certainly apparent in the papers on motion that Newton composed in the late 1660s and early 1670s. In one of these, Newton had invoked Kepler's third law and extrapolated from it to an inverse square law applying to the 'endeavour [conatus] in the principal planets of receding from the sun'. He subsequently told both Halley and David Gregory that he had composed these words in 1673, before the publication of Christiaan Huygens' thoughts on the subject. Wren had discussed the possible operation of an inverse square law with Newton in 1677 and Hooke had touched on it in an exchange of letters with Newton between November 1679 and January 1680. Hooke had initiated this correspondence on becoming Secretary of the Royal Society, in an effort to tempt Newton out of the self-imposed silence into which he had retreated after 1676. Despite this, his delight in making mischief was so great, or his need for information so desperate, that he rushed to announce trials at the Royal Society of Newton's erroneous proposal that the path of a body falling towards the rotating earth might be a spiral. After nearly a year of total silence, Newton acknowledged Hooke's correction in the curtest possible manner. Nevertheless, it later appeared that Hooke's prompting played a significant role in encouraging Newton once more to think seriously about the behaviour of bodies moving under gravity.

Thus, when Halley told him about Hooke's boasting in 1684, Newton was able to claim that he could now provide the necessary proof that an inverse square law governed the motion of the planets. Unfortunately, it turned out that he was unable to find where he had written this proof down. Nevertheless, by November, Newton had sent Halley a new tract, 'De motu', in which he had already extended his earlier thoughts. Newton realised that not just the planets but all heavenly bodies were governed by the same principles of force. Moreover, he had introduced for the first time an absolute notion of force, as distinct from the Cartesian notion that force might be relative to the body being moved. Despite the excitement that 'De motu' generated at the Royal Society, it was only a beginning. For the next year and a half, Newton worked furiously to clarify his definitions and to extend his calculations to heavenly bodies other than planets. Here, the observations of a comet that he had made in 1664 (see catalogue number 2) were put to work alongside the more detailed information that he had amassed about the comet of 1680 (see catalogue numbers 44 and 48). So intense was Newton's absorption in this new project (see catalogue numbers 7 and 16) that he seems to have abandoned his other activities entirely, breaking off the record of some chemical experiments in May 1684 and only picking it up again in April 1686 (see catalogue numbers 11 and 14).

On 28 April 1686, the Royal Society received the text of Book I of the *Principia*. Despite the prolonged absence of many members of its Council, the Society decided on 19 May that it should publish Newton's work. Halley, who was now the Society's Clerk, was 'intrusted to look after the printing it'. He immediately wrote to Newton on 22 May (letter on display) to consult him about publication and to warn him that Hooke had 'some pretension upon the invention of [the] rule of the decrease of Gravity, being reciprocally as the squares of the distances from the Center. He sais you had the notion from him, though he owns the Demonstration of the Curves generated thereby to be wholly your own…' Newton's reply dismissed Hooke's claims and he welcomed the first proofs that Halley sent him in June. But the prospect of bitter controversy made Newton anxious about some of what he had written. On 20 June he wrote to promise Halley the text of Book II of the *Principia*, which he had finished the previous summer, but warned 'I designed [the] whole to consist of three books… The third wants [the] Theory of Comets. In Autumn last I spent two months in calculations to no purpose for want of a good method, [which] made me afterwards return to [the] first Book & enlarge it [with] divers Propositions… The third I now designe to suppress.' He continued: 'Philosophy is such an impertinently litigious Lady that a man had as good be engaged in Law suits as have to with her. I found it so formerly & now I no sooner come near her again but she gives me warning.'

The final form of the *Principia* owed much to Halley's tact and patience. He encouraged Newton to persevere with Book III and waited quietly for its arrival. He supervised the printer and designed the woodcuts to illustrate the text. He tolerated Newton's further delays, agreeing to his desire that the completion of the book be postponed until at least late spring 1687. Above all, Halley accepted the costs of the publication of the book himself. The Royal Society was at the time as good as bankrupt, reduced to paying its officers, including Halley, in unsold copies of the lavish *History of Fishes* that it had published in 1686. Moreover, Halley's position had come under threat at the Society's elections, perhaps as a result of lobbying by Hooke.

I. Bernard Cohen, *Introduction to Newton's 'Principia'* (Cambridge, 1971), pp. 47–81; H. W. Turnbull, J.F. Scott, A.R. Hall and Laura Tilling (eds), *The Correspondence of Isaac Newton*, 7 vols (Cambridge, 1959–77), vol. 1, 297–303; vol. 2, 297–314, 400–402, 431–66 (part of which prints this letter); D.T. Whiteside (ed.), *The Mathematical Papers of Isaac Newton*, 8 vols (Cambridge, 1967–81), vol. 4, 409–653; Richard S. Westfall, *Never at Rest. A Biography of Isaac Newton* (Cambridge, 1980), pp. 378–90, 402–68; A. Rupert Hall and Marie Boas Hall (eds), *Unpublished Scientific Papers of Isaac Newton* (Cambridge, 1962), pp. 157–64, 231–301; John Herivel, *The Background to Newton's Principia* (Oxford, 1965); A. Rupert Hall, 'Newton on the Calculation of Central Forces', *Annals of Science*, 13 (1957), 62–71;

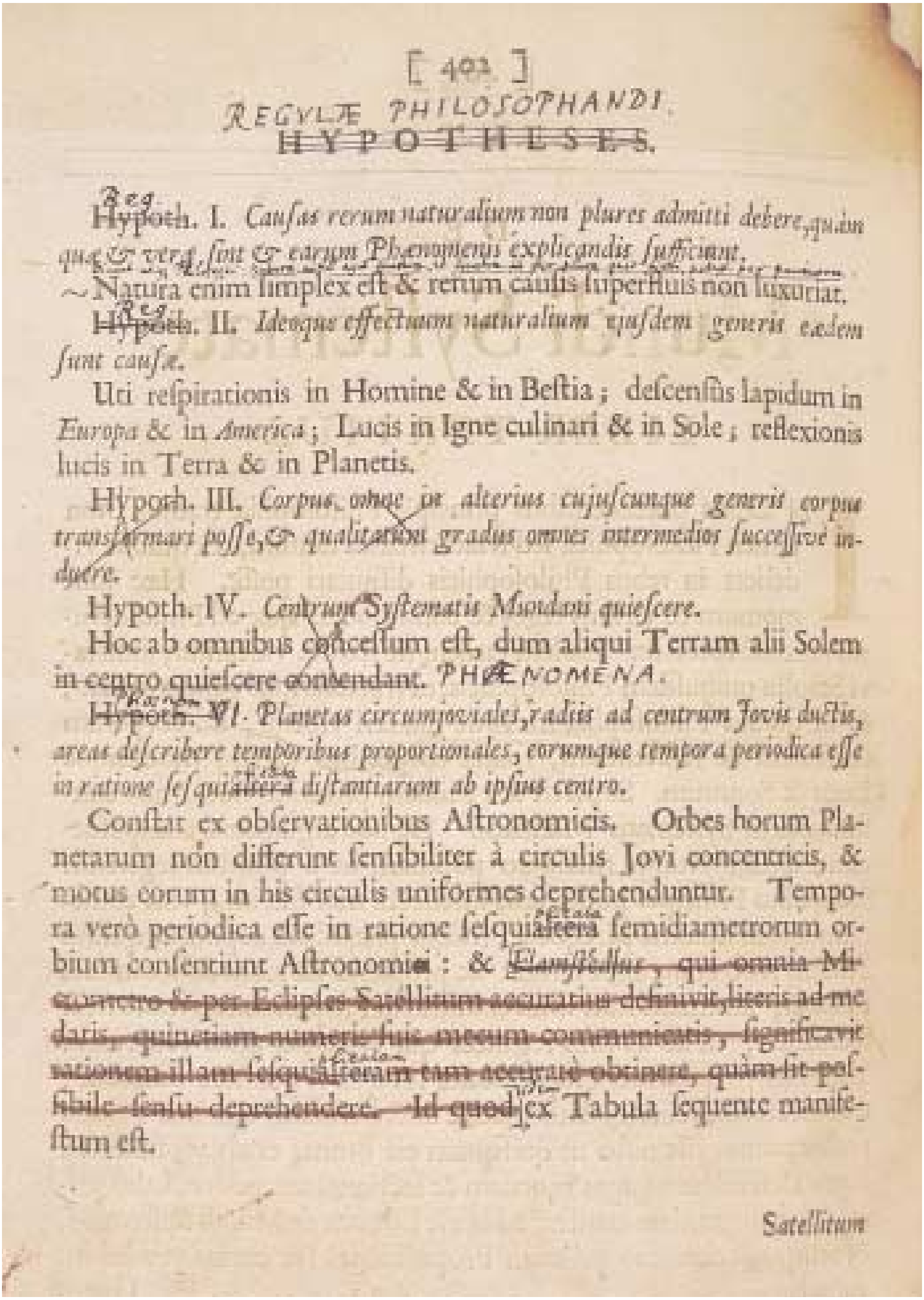
Thomas Birch (ed.), *The History of the Royal Society of London*, 4 vols (London, 1756–7), vol. 3, p. 519; vol. 4, 347, 370, 479–80, 486, 491, 527, 545; Alan Cook, *Edmond Halley* (Oxford, 1998), pp. 147–78.

Sotheby sale, 13 July 1936, lot 137; purchased by Gabriel Wells for £310 and subsequently sold to J.M. Keynes. Exhibited 5 July–29 August 1983, Fitzwilliam Museum, Cambridge: David Scrase and Peter Croft, *Maynard Keynes. Collector of Pictures, Books and Manuscripts* (Cambridge, 1983), pp. 83–4.

43 isaac newton, *Philosophiae naturalis principia mathematica*
(London, 1687)
(figures 24 & 25)
4^{o}: a-3o^{4}
19.7 × 13.4 cm
Cambridge University Library, shelfmark Adv. b. 39.1

On 5 July 1687, Halley wrote to Newton: 'I have at length brought your Book to an end, and hope it will please you. the last errata came just in time to be inserted.' Despite the acclaim that greeted his achievements, however, Newton still felt that there was more to be done. A particular problem remained the explanation of universal gravitation. Newton's treatment of gravity had been one of the revolutionary aspects of his work. By showing that its effects could account in detail for the movements of the heavens, Newton had been able to give universal force to the laws of motion that he propounded. Yet, in the eyes of many of his most distinguished contemporaries, his achievement was qualified by the failure to provide a properly philosophical account of gravity. Newton could describe the effects of gravitation but he could not explain them adequately. Newton's friend, Nicolas Fatio de Duillier, felt that he had the answer and, for a time in the early 1690s, it seemed possible that he might produce a new edition of the *Principia*. Others of Newton's growing band of young disciples, particularly David Gregory, also discussed his plans to augment the work.

Newton himself returned to his chemical experiments (see catalogue number 14) and to the optical papers of the mid-1670s (see catalogue numbers 26 and 28). With Fatio's prompting, he reconsidered the possibility that some sort of subtle matter or aether might be responsible for the effects of gravity. Newton's historical and theological reading encouraged him to search for more wide-ranging philosophical explanations. He confided many of these to Gregory, in particular ideas that the divine will itself might animate the actions of gravity. Newton was by



[402]

REGULÆ PHILOSOPHANDI.

~~HYPOTHESES.~~

~~Hypoth.~~ Reg. I. *Causas rerum naturalium non plures admitti debere, quàm quæ & veræ sint & earum Phænomenis explicandis sufficiant.*

Natura enim simplex est & rerum causis superfluis non luxuriat.

~~Hypoth.~~ Reg. II. *Ideoque effectuum naturalium ejusdem generis eædem sunt causæ.*

Uti respirationis in Homine & in Bestia; descensûs lapidum in *Europa* & in *America*; Lucis in Igne culinari & in Sole; reflexionis lucis in Terra & in Planetis.

Hypoth. III. *Corpus omne in alterius cujuscunque generis corpus transformari posse, & qualitatum gradus omnes intermedios successivè induere.*

Hypoth. IV. *Centrum Systematis Mundani quiescere.*

Hoc ab omnibus concessum est, dum aliqui Terram alii Solem ~~in centro quiescere contendant.~~ PHÆNOMENA.

~~Hypoth. VI.~~ Phænom. I. *Planetas circumjoviales, radiis ad centrum Jovis ductis, areas describere temporibus proportionales, eorumque tempora periodica esse in ratione sesquialtera distantiarum ab ipsius centro.*

Constat ex observationibus Astronomicis. Orbes horum Planetarum non differunt sensibiliter à circulis Jovi concentricis, & motus eorum in his circulis uniformes deprehenduntur. Tempora verò periodica esse in ratione sesquialtera semidiametrorum orbium consentiunt Astronomi: & ~~Flamstedius, qui omnia Micrometro & per Eclipses Satellitum accuratius definivit, literis ad me datis, quinetiam numeris suis mecum communicatis, significavit rationem illam sesquialteram tam accuratè obtinere, quàm sit possibile sensu deprehendere. Id quod~~ ex Tabula sequente manifestum est.

Satellitum

figure 25
Newton's own copy of the *Principia*, marked with revisions for the second edition, University Library, shelfmark Adv. b. 39.1, p. 402.

now familiar with a wide range of classical and patristic sources, with the ideas of Philo of Alexandria, and with the syncretising interpretations that had been placed on them by early modern authors, including the Cambridge Platonists and, perhaps, Justus Lipsius. He came to believe that these sources provided evidence to support his interpretation of gravity. They allowed him to construct a history of religion in which his own metaphysical speculations became identical with the true doctrinal foundations of pristine belief.

The marriage of theology, ancient history, and philosophy that Newton attempted to broker in the 1690s (see catalogue number 56) in fact looked back to work that he had suppressed in the mid-1680s. This included the drafts that he had initially composed for what became Books II and III of the *Principia*, as well as the related 'Theologiae gentilis origines philosophicae' (see catalogue number 15). In the manuscript of 'De motu corporum liber secundus' (see catalogue number 7), Newton gave an account of the fluid heavens through which both planets and comets were propelled by a force that obeyed the inverse square law. This began with a discussion of the philosophy of the ancient atomists, the religion of Numa Pompilius, and the astronomy of the Egyptians and Babylonians. These were Newton's predecessors in the restoration of the true understanding of nature, who had had privileged access to the teachings of a pristine religion before its corruption by vain men. Increasingly, the writings of Newton and his closest disciples would focus on the restoration of religion that had to follow the rediscovery of ancient philosophy. At the same time, Newton began to collect further evidence that ancient understandings of gravity and of celestial motion were similar to his.

Most of Newton's difficulties continued to relate to the final parts of Book II and to Book III of the *Principia*. At the start of Book III, he had defined a number of hypotheses that would govern his approach to natural phenomena. He began to modify these in the early 1690s, gradually developing them into a set of rules for the practice of natural philosophy. These rules were supposed to underpin the interpretation of a group of phenomena that Newton again introduced in changes that he made to the text of the first edition. Newton entered these corrections onto p. 402 of an interleaved copy of the *Principia* (see figure 25) and onto the blank leaf facing that page. On 21 July 1706, David Gregory wrote: 'Sir Isaac Newton shewed me a copy of his Princ. Math. Phil. Nat.

interleaved, and corrected for the Press. It is intirely finished as farr as Sect. vii. Lib. II. pag. 317. He takes this same Sect. vii. to be the hardest part of the book… In the beginning of Lib. III. he leaves out Hyp. iii, and puts another in its place… These three he now calls *Regulae Philosophandi*. Hyp. v. &c he calls by the title of *Phaenomena*. Hyp. iv is the only one that he leaves that name to; & it comes after the *Phaenomena*.'

Preparations for the printing of a second edition of the *Principia* began in 1708. The changes that Gregory had described were eventually incorporated in that edition. A few of Newton's more adventurous ideas of the 1690s also persisted in the form of a new 'General Scholium' at the end of Book III (see catalogue number 62). A fourth 'Regula Philosophandi' was added to the third edition of the *Principia* in 1726. Taken together, such alterations helped to establish the myth of Newton as a philosopher who did not 'feign hypotheses'. Yet, paradoxically, that was exactly how he had originally started to explain the system of the world.

H. W. Turnbull, J.F. Scott, A.R. Hall and Laura Tilling (eds), *The Correspondence of Isaac Newton*, 7 vols (Cambridge, 1959–77), vol. 2, 481–2; Betty Jo Teeter Dobbs, *The Janus Faces of Genius* (Cambridge, 1991), pp. 169–212; Rudolf de Smet and Karin Verelst, 'Newton's Scholium Generale: The Platonic and Stoic Legacy – Philo, Justus Lipsius and the Cambridge Platonists', *History of Science*, 39 (2001), 1–30; Robert Iliffe, '"Is he like other men?" The Meaning of the *Principia Mathematica* and the Author as Idol', in Gerald MacLean (ed.), *Culture and Society in the Stuart Restoration* (Cambridge, 1995), 159–76; I. Bernard Cohen, *Introduction to Newton's 'Principia'* (Cambridge, 1971), pp. 23–6 and plates 2–3; Alexandre Koyré and I. Bernard Cohen (eds), *Isaac Newton's Philosophiae Naturalis Principia Mathematica*, 2 vols (Cambridge, 1972), vol. 2, 550–5; W.G. Hiscock (ed.), *David Gregory, Isaac Newton and their Circle* (Oxford, 1937), pp. 36–7; John Harrison, *The Library of Isaac Newton* (Cambridge, 1978), pp. 22, 202.

Listed as imperfect by the booksellers who appraised Newton's library for his executors [at some point this book was badly damaged by fire and water]; presented to Cambridge University Library by the fifth Earl of Portsmouth. See *A Catalogue of the Portsmouth Collection of Books and Papers written by or belonging to Sir Isaac Newton* (Cambridge, 1888), p. 47.

44 cambridge university library, ms. add. 3965, f. 355r

29.8 × 18.7 cm

The appearance of a comet in November 1680 (see catalogue number 48) had entranced astronomers across Europe, Newton included. The comet blazed particularly brightly in the morning sky towards the end of the month, before appearing to fall into the sun. Shortly after the end of the first week of December, observers noticed a second, spectacular comet in the evening sky, moving away from the sun. Newton tracked the movements of the new comet, eventually using a seven-foot refracting telescope with micrometer for this purpose. He was able to record its position into early March, later than anyone else. At first, Newton, like almost every other astronomer, believed he had seen two different comets during the winter of 1680–1. The Astronomer Royal, John Flamsteed, who had observed the comet from Greenwich was however sceptical about this. In correspondence with Newton, he suggested that there might only ever have been a single comet. Newton was at first intrigued by Flamsteed's theory that comets reversed their direction near the sun, but he was not convinced. Nevertheless, he continued to collect information about the comet from a variety of acquaintances and to try to tabulate their findings. He observed the comet of 1682 (see catalogue number 47) with interest.

Newton's work in the early years of the 1680s began to convince him that the paths of comets might be conic sections, rather than straight lines. Eventually, in proposition xli of Book III of the *Principia*, he plotted a parabolic orbit for the comet of 1680–1. In the process, he modified his criticism of Flamsteed. By autumn 1685, he accepted that there had only been one comet in 1680–1. He also adopted a version of Flamsteed's suggestion that some form of magnetism attracted and repelled comets from the sun. Newton, however, did not ascribe the motion of comets to a magnetic force. He argued instead that it was a product of universal gravitation.

Much of Newton's continued work on Book III of the *Principia* was designed to support these claims. This became particularly important for him since he gradually assigned a larger and larger role to comets in his cosmology. The paths of comets undermined Cartesian explanations of celestial mechanics and established the power of Newton's concept of universal gravitation. Ideas about comets also supported the theories about ancient wisdom and philosophy that Newton developed from the mid-1680s. As the second edition of the *Principia* advanced, he came to believe that comets played an essential role in the circulation of active principles that promoted change and motion around the universe. He indicated to his disciples that comets were the means by which God managed his creation, suggesting that they were intimately involved in the key events of human history. Stars and planets themselves might once have been comets, and the collision of a comet with the earth might bring about the final conflagration of the world that Christians expected at the end of days. The techniques that Halley developed to calculate the period of return of comets and hence to plot some of their orbits as ellipses were deployed to support these arguments (see catalogue number 49). Thus by 1714, Newton's successor as Lucasian Professor, William Whiston, had calculated that the passage of the comet of 1680–1 had once been responsible for causing Noah's Flood.

Newton communicated the calculations on display to Roger Cotes in October 1712, as he completed the revisions to Book III for the second edition of the *Principia*. Based on Flamsteed's records (see catalogue number 18) and refined by Halley's techniques, they set out a method for correcting observations of the apparent position of comets when seen from the earth. This procedure allowed Newton to determine accurately the paths of comets through the heavens and provided the information to support his calculation of their parabolic or elliptical orbits. Newton later added calculations for the comet of 1723 to these tables of the comets of 1683 and 1682 in the third edition of the *Principia* (1726).

J.A. Ruffner, 'Newton's Propositions on Comets: Steps in Transition, 1681–84', *Archive for History of Exact Sciences*, 54 (2000), 259–77; Sara Schechner Genuth, *Comets, Popular Culture, and the Birth of Modern Cosmology* (Princeton, 1977), pp. 133–215, 270–306; Simon Schaffer, 'Comets & Idols: Newton's Cosmology and Political Theology', in Paul Theerman and Adele F. Seeff, *Action and Reaction* (Newark, 1993), pp. 206–31; David C. Kubrin, 'Newton and the Cyclical Cosmos: Providence and the Mechanical Philosophy', *Journal of the History of Ideas*, 28 (1967), 325–46; Gary W. Kronk, *Cometography*, vol. 1 (Cambridge, 1999), pp. 369–78; H. W. Turnbull, J.F. Scott, A.R. Hall and Laura Tilling (eds), *The Correspondence of Isaac Newton*, 7 vols (Cambridge, 1959–77), vol. 2, 315–430; vol. 5, 347–8; Betty Jo Teeter Dobbs, *The Janus Faces of Genius* (Cambridge, 1991), pp. 169–212; I. Bernard Cohen, *Introduction to Newton's 'Principia'* (Cambridge, 1971), pp. 235–6; Alexandre Koyré and I. Bernard Cohen (eds), *Isaac Newton's Philosophiae Naturalis Principia Mathematica*, 2 vols (Cambridge, 1972), vol. 2, 748–58.

Presented to Cambridge University Library by the fifth Earl of Portsmouth. See *A Catalogue of the Portsmouth Collection of Books and Papers written by or belonging to Sir Isaac Newton* (Cambridge, 1888), pp. 4–5.