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The show that never ends: perpetual motion in the early eighteenth century

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> You will not be displeased to have a rather detailed account of a Machine about which opinions are so divided, and to which almost all the ablest Mathematicians are opposed. A very large number maintain the impossibility of Perpetual Motion [... but] I know very well, Sir, that it is only in England that the Sciences are sufficiently flourishing for the Author to gain from his Discovery a reward proportional to it.
>
> Willem 'sGravesande to Isaac Newton, August 1721

During high summer 1721, while rioters and bankrupts gathered outside Parliament, Robert Walpole's new ministry forced through a bill to clear up the wreckage left by the stock-market crash, the South Sea Bubble, and the visionary projects swept away when it burst. In early August the President of the Royal Society Isaac Newton, a major investor in South Sea stock, and the Society's curator John Desaguliers, doyen of the city's projectors, learned of a new commercial scheme promising apparently automatic profits, a project for a perpetual motion. Their informants were a young Viennese courtier Joseph Emmanuel Fischer von Erlach, a contact of Desaguliers recently engaged in industrial espionage in northern England, and the Leiden physics professor Willem 'sGravesande, who had visited London five years earlier. They reported that they had been summoned to a remarkable series of demonstrations in the castle of Weissenstein, the seat of the Landgrave of Hesse-Kassel. In a carefully guarded room of the castle there was set up a hollow wooden wheel covered in oilcloth, about 12 feet in diameter and 18 inches thick on an axle 6 feet in length. Its designer, a Saxon engineer and clockmaker Johann Bessler, who travelled Germany under the name Orffyreus, had been in Kassel for four years, published schemes for perpetual motion and been appointed commercial councillor. The Landgrave, well-known as a patron of advanced engineering schemes, commissioned him to build a new machine and put it on show before expert witnesses (Figure 1).[1]

Orffyreus' new wheel, they said, spun very fast though no external mover could be seen. Fischer got out his watch to time its spins – about twenty-six a minute. A cord wound round the axle was set to turn an Archimedean screw and the wheel's speed dropped to

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1 'sGravesande to Newton, 7 August 1721, in *Correspondence of Isaac Newton* (ed. H. W. Turnbull, J. F. Scott, A. R. Hall and Laura Tilling), 7 vols., Cambridge, 1959–77, vii, 143–6 and Fischer to Desaguliers, August 1721, in Henry Dircks, *Perpetuum mobile, or a History of the Search for Self-Motive Power*, second series, London, 1870, 110–12. See also R. T. Gould, 'Orffyreus' wheel', in *Oddities: A Book of Unexplained Facts*. London, 1928, 137–77 and C. A. Crommelin, 'La roue d'Orffyreus', *Janus* (1960), **48**, 47–52.

Figure 1. Orffyreus' perpetually moving wheel at Weissenstein Castle, showing the wheel's diameter and the suspended weight which it could lift. For the wheel's interior see Figure 4. From Orffyreus, *Triumphans perpetuum mobile Orffyreanum*, Kassel, 1719. Reproduced by permission of the Syndics of Cambridge University Library.

twenty cycles per minute. With enormous difficulty, the gentlemen tried to bring the wheel to a halt and were almost lifted off the ground in their efforts to do so, but at last it stopped. When they tried to restart it, to their astonishment the wheel swiftly accelerated until it regained its original speed and worked just as well when running backwards. It was not possible, regrettably, to inspect the inside of the wooden wheel though the witnesses could hear a number of weights gently falling when it turned. They ordered the axle to be uncovered and carefully examined the iron rods and the brass supports on which it rested but could see no connections leading outside the room. They courteously asked the Landgrave, who had seen under the wooden frame, whether there was a complex mechanism within. He reassured his guests that there was no deception involved, no hidden moving parts. He said the machine was so simple that a carpenter's boy could understand and make it once having looked inside.

Fischer and 'sGravesande immediately sent reports to Newton and Desaguliers. Other London instrument makers had already visited Kassel and been persuaded of the wheel's virtues. The visitors suggested that the Londoners start a joint stock company to exploit the machine's potential. £20,000 would buy the secret, to be returned to investors if the motion proved less than perpetual, and only in England, they reckoned, could such an invention receive its just reward. There was already news on the London market of a project for a perpetually moving wheel with an initial capital of £1,000,000. But the Kassel scheme soon foundered, for the day after its final show Orffyreus, furious with 'sGravesande's inquisitiveness, scrawled a protest on the wall of the room and then broke the wheel in pieces. Rumours spread that a female servant sworn to secrecy on pain of death had been seated in the next room working the machine. The castle room, and thus the machine's performance, were apparently insecure. Throughout the 1720s debates raged in the Republic of Letters about the show and the possibility of such perpetual motions.[2]

The project of perpetual motion is normally pushed back to the very edge of traditional history of science. It allegedly defines the bounds of human credulity and vain ambition and marks, with the Philosopher's Stone and stock-market Bubbles, the painful transition to rational understanding of the capacities of nature and art. It seems self-evident that neither nature nor technique can generate endless profit, so faith in perpetual motion is seen as a parable about the fallibilities of the human mind rather than about the capacities of technique. The enlightened held that such projects could only be corrected or directed by the command of abstract rational principles. In 1771, for example, a notorious London journalist William Kenrick cited the events as Kassel half-a-century earlier to stress that 'the mere exhibition of what is called a self-moving machine, without a display of its mechanism, or the principles on which its motion is begun and continued, could produce no conviction, would gratify no curiosity. The fate of Orffyreus and his machine is a proof

2 See note 1 and 'sGravesande to Crousaz, 1729, in Dircks, op. cit. (1), 113–14; Jean Allamand, 'Histoire de la vie et des ouvrages de Mr 'sGravesande', in Willem 'sGravesande, *Oeuvres philosophiques et mathématiques* (ed. Jean Allamand), 2 vols., Amsterdam, 1774, i, pp. xxiii–xxvii. The original version of this 'Histoire' is [Allamand], ''sGravesande', in Prosper Marchand's posthumous *Dictionnaire historique*, 2 vols., The Hague, 1758, ii, 214–41, on 223–6 (for the composition of this essay see Christiane Berkvens-Stevelinck, *Prosper Marchand*, Leiden, 1987, 70). For the London perpetual-motion project, see *Catalogue of Prints and Drawings in the British Museum: Political and Personal Satires,* London, 1873, ii, 443 (no. 1625, produced in 1720).

of this.' The very next year one of Kenrick's eminent targets, the Glasgow philosophy professor Thomas Reid, also recalled the early eighteenth century 'Phrenzy in the Nation about mechanical Projects. Many were ruined and many more were in danger of being drawn into Ruin by such Projectors. This Disease seems to have been cured in a great degree by shewing men clearly upon principles of Science the utmost Effects that the Mechanical Powers can produce', and according to Reid, significantly, it was Desaguliers who had first cured this madness. By 1775 , on the suggestion of the mathematician Jean d'Alembert, the Paris Academy of Sciences banned consideration of such schemes because 'the construction of a perpetual motion is absolutely impossible', and three years later the French historian of mathematics Jean Montucla ranked the Orffyreus episode amongst other absurd schemes for perpetual motion included in his new collection of *Mathematical Recreations*. These were moral arguments which connected the principles of rational mechanics with those of society. The Paris academicians declared that 'every opinionated attachment to a demonstrably false opinion, if it is joined to a perpetual preoccupation with the same object... is no doubt really folly, but is not seen as such if the opinion which produces this madness... does not trouble the social order'. Just as Reid was concerned about 'Visionary Schemes which would have produced ruin to many innocent families', so the French savants put domestic values above those of the projectors, whose 'belief that it is by a particular protection of Providence that they have found it out' produced 'popular opinions which have been fatal for many families'. For this enlightened historiography, the story of perpetual motion was a mere illustration of the inevitable and principled establishment of the equipoise of social prudence against popular delusion and baroque fantasy.[3]

But here I wish to put the career of Orffyreus' wheel nearer the centre of the natural philosophical enterprise, because it highlights the importance of rival ways of estimating value in early modern culture. Engines such as that shown at Weissenstein were to be used to drive fountains in the prince's parks, pump water from the state mines, model the ordered cosmos, save the cost of teams of labourers and raise funds from well-heeled financiers. These perpetually moving machines neatly connect several aspects of early eighteenth-century measurement which are currently drawing a great deal of attention from historians.

First, baroque savants disputed the best way of evaluating the net effects of mechanical motion. Some of the most important episodes in these *vis viva* disputes were in fact immediate and specific responses to Orffyreus' promise of perpetual motion in the early 1720s, and were connected with ways of representing the moral and the natural order.

3 William Kenrick, *An Account of the Automaton Constructed by Orffyreus*, London, 1770 and *A Lecture on the Perpetual Motion*, London, 1771 (an attack on Reid: citation from this text, 1); Thomas Reid to Richard Price, 1772, in *Correspondence of Richard Price* (ed. W. Bernard Peach and D. O. Thomas), 2 vols., Durham, 1983, i, 153–4. The Académie's ban is in *Histoire de l'Académie Royale des Sciences* (1775), Paris, 1778, 61–6, discussed in Roger Hahn, *The Anatomy of a Scientific Institution: The Paris Academy of Sciences 1666–1803*, Berkeley and Los Angeles, 1971, 145. For Montucla's view in 1778 see Jacques Ozanam, *Recreations in Mathematics and Natural Philosophy* (ed. Jean Montucla), 1st English edition (tr. Charles Hutton), 4 vols., London, 1803, ii, 105–6. For cautionary surveys see Hermann von Helmholtz, 'On the interaction of natural forces' (1854), in *Popular Scientific Lectures* (ed. Morris Kline), New York, 1962, 59–62 and Arthur Ord-Hume, *Perpetual Motion: The History of an Obsession*, London, 1977.

Perpetual-motion machines were apt occupants of the courtly and academic world of baroque absolutism and were easily understood as emblems of the permanent workings of the divinely ordered world-machine and thus the rationally managed state. It was expected that their performances, political and theatrical, would involve dramas accessible to a courteous audience while their inmost principles remained privy to the calculations of the eminent and the skilful.[4]

Secondly, engineers promoted devices such as water-wheels and steam-engines to drive pumps and other systems. They were often closely connected with perpetual-motion projects, as in the engineering schemes managed by the Marquis of Worcester, his colleagues and his successors, around the publicly funded Ordnance Works at Vauxhall from the 1630s in various forms until the 1690s. Similarly, in 1721 Orffyreus' wheel was evaluated in direct comparison with contemporary Newcomen engines on trial at Kassel. These engineers claimed they had ways of measuring the return on such machines to estimate the relative efficiency of overshot and undershot water-wheels or the comparative costs of horsepower and engines worked by fire. There was much dispute about the validity of inferences from results obtained in the philosopher's study or the lecture-room to the workings of the mine or the mill.[5]

Finally, such machines were also touted as viable commercial investments. The value of Orffyreus' wheel was ultimately assessed in the highly unstable world of metropolitan finance. The traumas of new monetary systems and credit mechanisms, very intense during the collapses of the exchanges of Paris and London in the early 1720s, only dramatized the puzzle of fixing secure values in market society. In this period, terms such as 'credit', 'calculation' and 'speculation' shifted their senses rapidly between problems of knowledge and of finance. At the Mint and on the Exchange, Newton and his allies were closely involved with both the recoinage of the 1690s and the stock-market crises of the 1720s, events decisive in the appearance of a powerful and calculating fiscal-military state. They tried the values of gold and silver coin, hunted forgers to the death, and tried to manage market behaviour. If 'corrected by good orders & laws well executed', Newton told the government in 1700, 'then credit becomes a very safe and soveraign remedy'.[6]

4 Otto Mayr, *Authority, Liberty and Automatic Machinery in Early Modern Europe*, Baltimore, 1986, 67–81, 107–14; Jean-Pierre Séris, *Machine et communication: Du théâtre des machines à la mécanique industrielle*, Paris, 1987, 11–34; Hélène Vérin, *La Gloire des ingénieurs: L'intelligence technique du XVIe au XVIIIe siècle*, Paris, 1993, 102–11, 181–7.

5 See Anthony Wallace, *The Social Context of Innovation*, Princeton, 1982, 40–52 for Vauxhall, steam-engines and perpetual motion. See also, for comparison, Frances Willmoth, 'Mathematical sciences and military technology: the Ordnance Office in the reign of Charles II', in *Renaissance and Revolution* (ed. J. V. Field and F. A. J. L. James), Cambridge, 1993, 117–32, on 122. For eighteenth-century measures of machines' efficiency see Terry S. Reynolds, *Stronger than a Hundred Men: A History of the Vertical Water Wheel*, Baltimore, 1983, 204–33; Svante Lindqvist, *Technology on Trial: The Introduction of Steam Power into Sweden 1715–1736*, Stockholm, 1984, 67–77; and Alan Morton, 'Concepts of power: natural philosophy and the uses of machines in mid-eighteenth-century London', *BJHS* (1995), **28**, 63–78.

6 For British finance and the fiscal-military state see P. G. Dickson, *The Financial Revolution in England: A Study of the Development of Public Credit 1688–1756*, London, 1967, 41; J. G. A. Pocock, *The Machiavellian Moment*, Princeton, 1975, 425–7, 460–1; John Brewer, *The Sinews of Power: War, Money and the English State 1688–1783*, London, 1989, 137–61. For Newton's role see R. S. Westfall, *Never at Rest: A Biography of Isaac Newton*, Cambridge, 1980, 551–79, 604–23 (citation from 619) and Larry Stewart, *The Rise of Public Science: Rhetoric, Technology and Natural Philosophy in Newtonian Britain, 1660–1750*, Cambridge, 1992, 160–9.

In philosophical debates about living force, engineers' disputes about rival machines, and commercial fights about money and the market, it was politically vital to establish and enforce agreed standards of value. Solutions to this problem of evaluation were also solutions to the problem of social order. New standards of measurement often challenged customary practices in artisan culture and rested on the power of the state to enforce them. The political order used these standards to reinforce systems of credit, to be understood both in terms of financial status and of plausible belief. The credit vested in field trials, demonstration devices and standard measures all relied on practitioners exercising very tight control over the places where devices were put to the test. The organization, enclosure and discipline of these spaces were key features of the new systems of production and exchange in the eighteenth century. Without such control, secure values simply could not be obtained and the devices would never become viable commodities.[7]

Orffyreus' machine was initially patronized by an enlightened prince within the milieu of court society, scrutinized by foreign experts in engineering and natural philosophy, touted as an investment opportunity and then undermined by the processes of gossip, publicity and histrionics. One way of interpreting this career is to consider the relative control which different practitioners exercised over these varying spaces. A room in Weissenstein, dominated by rather well-understood conventions of court society, was different from the coffee houses, lecture rooms and print shops of Leipzig, Amsterdam and London. When the Royal Society's curator set out to discredit the worth of Orffyreus' machine, he might command the spaces of demonstration at the Society's house at Crane Court, but always found it harder to manage public opinion on the Exchange. So the exploration of these mechanisms retraces the pathways of Orffyreus' wheel and its display. The story begins in early eighteenth-century Saxony, where Orffyreus established his reputation. At Kassel, his orchestrated shows depended on the technological and political settings in which these shows were interpreted. In 'sGravesande's university at Leiden, intriguing natural philosophical and ethical strategies were used to make sense of such profitable displays. Finally, in London, the estimates of perpetual-motion schemes are placed in the context of credit crises and the troubles of public audiences and new expertise.

PERPETUAL MOTION AND ABSOLUTIST MECHANICS

Early modern schemes for perpetual motion often had a rather specific location in the lands dominated by the Habsburgs, the Empire and northern Italy. Printed descriptions appeared in the ornate works of the princes' Jesuit advisers and in the publicity of ambitious artisans,

7 For the politics of measurement see Witold Kula, *Measures and Men*, Princeton, 1986, 167–84 (for France) and Peter Linebaugh, *The London Hanged: Crime and Civil Society in the Eighteenth Century*, Harmondsworth, 1991, 55–8, 162–3 (for Britain). For credit mechanisms see Simon Schaffer, 'A social history of plausibility', in *Rethinking Social History* (ed. Adrian Wilson), Manchester, 1993, 128–57, on 137–41; Pamela Smith, *The Business of Alchemy: Science and Culture in the Holy Roman Empire*, Princeton, 1994, 131–40; Steven Shapin, *A Social History of Truth*, Chicago, 1994, 194–202. For the discipline and enclosure of places, see Michel Foucault, *Discipline and Punish: The Birth of the Prison*, Harmondsworth, 1979, 141–9.

especially clockmakers. Managers expert in hydraulics and mining, competing courts and the extended communities of clockmakers and artisans promoted concerns with wondrous machines, automata capable of the dramatic performance of excessive or apparently endless work. The mechanical automata which stocked each *Wunderkammer* and displayed the regular order of the heavens were pervasive images of absolutist power. These metaphors were put to a range of political uses. In an essay on 'the political body of Europe' in 1736 the young Frederick the Great, 'the meticulous king of small machines', made the metaphor into a common lesson about prediction and permanence: 'as an able mechanic is not satisfied with looking at the outside of a watch, but opens it, and examines its springs and wheels, so an able politician exerts himself to understand the permanent principles of courts, the engines of the politics of each prince, and the sources of future events. He leaves nothing to chance; his transcendent mind forsees the future and from the chain of causes penetrates even the most distant ages'. Especially important here was the connection between privy access to the interior of machines of state and machines of commerce, and command of their publicly effective powers.[8]

Those charged with managing the state found legitimacy in such enterprises and often attributed technical triumphs directly to the princes who sponsored them. Thus in Hanover in 1678 Leibniz proposed erecting a vast obelisk carrying a perpetually moving clock of his own design as a monument to his ducal master's power. In 1695 he was told by the Hesse-Kassel cabinet secretary that because of the Landgrave's support for, and personal mastery of, the mechanical arts, 'one cannot wish enough life and prosperity to such a prince, because these will not only produce the same for his people, but yet extend their glorious effect well beyond, so that the whole human race may profit from discoveries made under his protection'. The eminence of such courts, which depended on the traditional order of fixed property and continual warfare, needed other sources of support to sustain it. The crises following the catastrophes of the Thirty Years' War demanded ways of mediating between the worlds of court, academy and market. Wondrous and ingenious models of the world-machine to be distributed through polite culture became increasingly valued. Self-moving machines, like alchemical transmutations, could well show how to understand and manage endless commercial gain and stable social order.[9]

The texts in which these schemes appeared were paper theatres for wealthy readers. They included Jesuit works such as Caspar Schott's *Technica curiosa*, printed at Nuremburg in 1664, where ball-driven clocks and belts were described, and Francesco

8 Frederick II, *Considérations sur l'état présent du corps politique de l'Europe* (1736), cited in Mayr, op. cit. (4), 108. Compare with Foucault, op. cit. (7), 136, on 'the meticulous king of small machines' Frederick the Great for whom 'the celebrated automata were not only a way of illustrating an organism, they were also political puppets, small-scale models of power'; and Jean-Marie Apostolides, *Le Roi-machine*, Paris, 1981, 130–1 on absolutism as the emergence of 'a king-machine whose sole body is confounded with the machine of State'.

9 Leibniz to Duke Johann Friedrich, autumn 1678, in Leibniz, *Sämtliche Schriften und Briefen, Erste Reihe: Allgemeine Politischer und Historischer Briefwechsel*, 14 vols., Darmstadt and Berlin, 1923–, ii, 89–90 and Haas to Leibniz, 1695, cited in Hans Philippi, *Landgraf Karl von Hessen-Kassel: ein deutscher Fürst der Barockzeit*, Marburg, 1976, 613. For baroque commerce and court society see William Clark, 'The scientific revolution in the German nations', in *The Scientific Revolution in National Context* (ed. Roy Porter and Mikuláš Teich), Cambridge, 1992, 90–114, on 97–8, 104–5; Bruce Moran, *The Alchemical World of the German Court*, Stuttgart, 1991, 171; and especially Smith, op. cit. (7), 126–31, 209–17.

Lana-Terzi's *Magisterium naturae et artis* (printed in Brescia, 1684–92), a work dedicated to the Emperor and stocked with a detailed classification of the various forms of perpetual-motion machines. The Emperor also consulted the engineer Georg Böckler's *Theatrum machinarum novum* (1686, reissued at Nuremburg in 1703), which pictured a dramatic series of self-moving wheels driven by overbalancing weights or water-flow. Even more important was the Saxon instrument maker Jakob Leupold's *Theatrum machinarum generale*, issued at Leipzig in 1724, an expansion of Böckler's text. Leupold's demonstrations of the effects of the extra moment of sliding weights within a hollow wheel belong to precisely the same context as, and were printed immediately after, those of Orffyreus. These works inhabited the world of politics, theatre and hydraulics. This is just the world described in Pamela Smith's remarkable study of the career of Johann Becher, the alchemist, engineer and economic reformer whose career, she shows, involved many transfers between artisanal technique and courtly statecraft. In the 1650s Becher first came to the notice of such connoisseurs of ingenious novelties as Henry Oldenburg and Samuel Hartlib because he 'hath found, he saith, the perpetual motion, the possibility whereof hath been hitherto so much disputed by Philosophers'. After he tried similar projects at Mainz and Vienna, Becher published his disputed scheme for a perpetually moving clock in London. When Becher visited him to discuss the project, Christian Huygens, for one, did not think the scheme 'absolutely impossible'. During the 1670s, a very similar project for a perpetual 'Archimedes Machine' was presented to the Paris Academy of Sciences by the Huguenot engineer Bernard de la Coste. When the academicians rebuffed him, he successfully appealed to the court of Brandenburg for endorsement and satirized those 'sovereign Arbiters of the Sciences' who had failed to recognize the 'grace of God' which had inspired his valuable devices.[10]

Such disputes fuelled the politics of the Republic of Letters, involving savants such as Leibniz at Hanover, Denis Papin at Marburg and Johann Bernoulli at Basel. Journals such as the Leipzig *Acta eruditorum* and the London *Philosophical Transactions* carried plentiful reports of projects. Careful distinctions were made between machines which might move forever and machines which might do useful work without an external source of motion, between public effects and secret designs. For example, when designing new engines for the state mines in the Harz mountains, Leibniz argued that manpower should only be used for skilled tasks, horsepower could not be indefinitely increased, but that the rational ordering of natural powers could secure practically endless advantage through 'an invention, which, so to speak, makes my capital'. This device would 'have the effect and advantage of a perpetual motion, though it is no such thing: for this perpetual motion, such as is sought, is impossible'. What was impossible, he reckoned, was a completely self-powered device. But he also emphasized, characteristically, that such machines would depend on 'a very simple little piece which is hidden, and it is in this that the secret consists. Those who see it working and don't know about the hidden bit will scarcely understand

10 For the court settings of perpetual-motion schemes see R. J. W. Evans, *The Making of the Habsburg Monarchy 1550–1700*, Oxford, 1979, 338–9 and Smith, op. cit. (7), 190–1; for Leupold see Lothar Hiersmann, *Jacob Leupold*, Leipzig, 1982, 24ff.; for Becher, Oldenburg and the Royal Society see Smith, ibid., 59–60, 259 n44; for Becher and Huygens see Huygens to Carcavy, 26 February 1660, in Christiaan Huygens, *Oeuvres complètes*, 22 vols., The Hague, 1888–1950, iii, 28. For Bertrand de la Coste see Hahn, op. cit. (3), 142.

how it's all done.' Alan Gabbey has demonstrated in his indispensable taxonomy of the various forms of perpetual motion in baroque rational mechanics that contrasts depending on whether machines could do work, whether they could move forever and whether they relied on an external source of motion, were highly significant for the cosmologies which such philosophers were expected to produce at court. And as Jean-Pierre Séris points out in his study of frictionless machines, the relation between theoretical and practical mechanics worked out in the theatres of machines at this conjuncture often touched on the most fundamental problems of natural philosophy.[11]

Few, if any, of these natural philosophers denied the possibility of a perpetually moving system powered by some external natural agency. In 1690 Johann Bernoulli argued that since nature was a perpetually moving machine it should be possible for mechanics to design a perpetually moving device. Leibniz, who had seen the automata and clocks on show at the *Wunderkammer* in Kassel, responded that this was to confound natural and artificial things and eventually judged, in 1714, that there must be a profound distinction between the works of God and those of engineers because 'the machines of nature... are still machines in their smallest parts, into infinity'. It was the political charge of this theme which helped drive the notorious debate between the rival court philosophies of Leibniz and Newton. In 1715 Leibniz alleged that according to his London enemies 'God had not sufficient foresight to make a perpetual motion.' Samuel Clarke, the court chaplain, riposted that while 'among men, an artificer is justly esteemed so much the more skilful, as the machine of his composing will continue longer to move regularly without any further interposition of the workman... with regard to God, the case is quite different because he not only composes or puts things together but is himself the author and continual preserver of their original forces or moving powers'. Clarke immediately connected this point with his attack on 'those men who pretend that in an earthly government things may go on perfectly well without the king himself ordering... anything'. So tests of such machines were also tests of the right way of understanding the mechanisms of absolutist rule.[12]

Orffyreus' career involved a series of these public tests, in German courts, Dutch journals and on the London market (Figure 2). He was born in Zittau in 1680, to become a student of theology and medicine, the beneficiary of a wealthy marriage. He took up clock-making as an apprentice to the expert Saxon horologist Jakob Mahn. Between 1712 and 1715 he put three successive wheels on show in western Saxony. A brilliant showman and bold polemicist, Orffyreus soon established a pattern for these displays, aping the ciphers and sealed containers of earlier mathematicians and mechanicians. Small model wheels were proffered as promises of future return. At Gera and elsewhere he invited courtiers and

11 Leibniz to Duke Johann Friedrich, autumn 1678 and August 1679, in Leibniz, op. cit. (9), ii, 89–90 and 189, discussed in Jon Elster, *Leibniz et la formation de l'esprit capitaliste*, Paris, 1975, 89; Alan Gabbey, 'The mechanical philosophy and its problems', in *Change and Progress in Modern Science* (ed. Joseph Pitt), Dordrecht, 1985, 9–84, on 42–44, 75; and Séris, op. cit. (4), 159–210.

12 Leibniz, 'The monadology' (1714); Leibniz to Caroline, November 1715; Clarke to Caroline, November 1715; all cited in *Leibniz's Philosophical Papers and Letters* (ed. Leroy E. Loemker), Chicago, 1956, 1055, 1096 and 1098–9 and discussed in Gabbey, op. cit. (11), 63–6. For the politics of these rival models of power and artifice see R. W. Meyer, *Leibniz and the Seventeenth Century Revolution*, Cambridge, 1952, 142ff.; Elster, op. cit. (11), 172–7; Steven Shapin, 'Of gods and kings', *Isis* (1981), **72**, 187–215. For Leibniz at Kassel see Bruce Moran, 'Science at the Court of Hesse-Kassel', Ph.D. thesis, UCLA, Los Angeles, 1978, 176.

Figure 2. Johann Bessler, called Orffyreus (1680–1745). From R. T. Gould, *Oddities*, London, 1928, 136, plate 3. Reproduced by permission of the Syndics of Cambridge University Library.

journalists to witness the lifting of large weights from the axle of a swiftly turning wheel (Figure 3). Rumours from Vienna in 1713 that the Emperor had promised a huge reward to his court engineer to build a perpetual-motion machine prompted Orffyreus to make similar demands. His work was reported in the *Acta eruditorum*, edited by the eminent Leibnizian Christian Wolff. The journal took an indulgent view and noted Orffyreus' standing as an expert in medicine, chemistry and mechanics. Though Wolff doubted that the wheel was a purely mechanical device, or that it could be used to drive mills, he did suggest that such perpetual machines could well be powered by some form of atmospheric subtle fluid. Orffyreus' stage routine was now fixed. In autumn 1715 he staged a public trial at Merseburg of a wheel 6 feet in diameter which could raise as much as 70 pounds

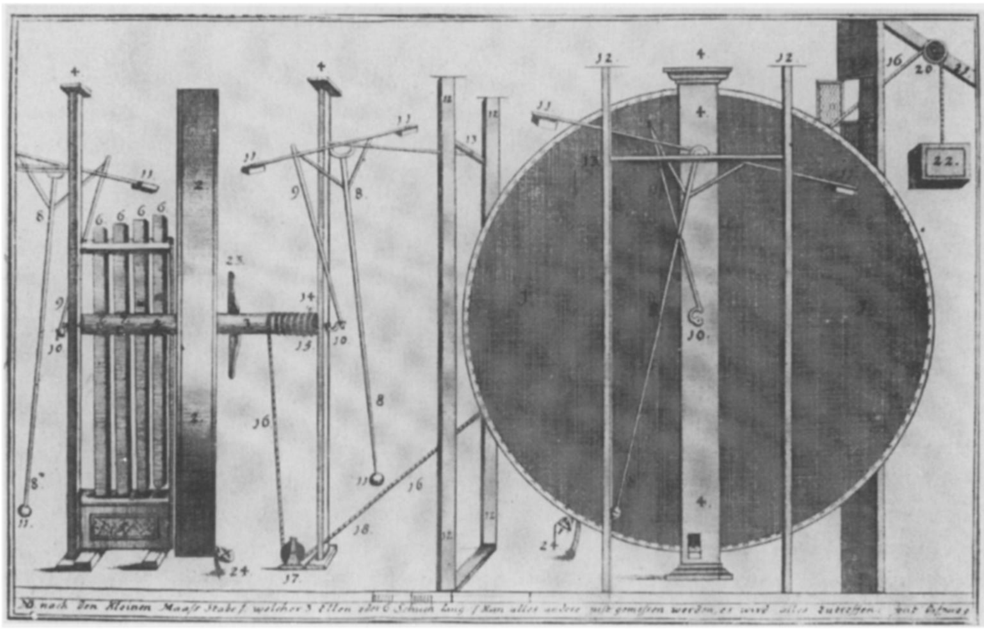


Figure 3. The interior of Orffyreus' first perpetually moving wheel as built in Saxony: edge-view at left, side-view at right. From Orffyreus, *Grundlicher Bericht von dem Perpetua ac per se Mobili*, Leipzig, 1715. Reproduced by permission of the Syndics of Cambridge University Library.

suspended through a high window. He won an influential audience, including Wolff and his Halle colleague the eminent physician Friedrich Hoffmann, and the Duke and his court. By December 1715, both the Duke and Wolff were prompted to produce written and sealed testimonials of what they had seen and its success.[13]

Orffyreus then issued a pamphlet from Leipzig describing his wheel and enrolling more powerful backers. These resources could not prevent, and helped incite competitors and critics, most of them exploiting the techniques of the prize system and of well-understood artificial trickery. Jakob Mahn, Orffyreus' former master, claimed priority in the invention, frustrated, so he stated, solely by lack of funds. The mechanic Johann Borlach announced the following year, 1716, that perpetual motion was impossible and that Orffyreus' wheel must be moved by a servant hidden in the adjoining room, the first appearance of this rumour of concealment. Borlach printed a diagram of the mechanism this hidden assistant must use. Steinbrück, a local pamphleteer, attempted to call Orffyreus' bluff with a huge wager, while the mathematician Christian Wagner and the model maker Andreas Gärtner both claimed they could replicate the wheel simply with trick mechanisms concealed within. Gärtner used these challenges to further his own career. After beating off wagers

13 'Nova literaria mathematica de perpetuo mobili...', *Acta eruditorum* (January 1715), 46–7; review of Wolff, *Mathematisches Lexikon*, in *Acta eruditorum* (February 1717), 92; and 'Relatio de perpetuo mobilii Joh. Ernesti Eliae Orfyrei', *Acta eruditorum* (November 1718), 497–9. Compare with Henry Dircks, *Perpetuum mobile*, first series, London, 1861, 206–8, and second series, op. cit. (1), 95–8.

in Dresden, he was hired as model-master at the Polish court and got backing for three successive devices using a system of spiral tracks carrying a series of metal balls. Gärtner's strategy was to ape Orffyreus' routines, including the celebrated locked room, but to draw attention away from the promise of surplus work towards his own virtuosity. Thus he insisted that these were not truly perpetual devices and could never be enlarged to do useful work, but simply amusements testifying to his own skill as an artist. Gärtner's elegant devices were touted as courtly tricks which taught much about his art and nothing about nature's powers or economic reform. In 1719 he returned to Dresden to challenge Orffyreus in a new pamphlet war, alleging the base, literally discourteous, enterprise of the Saxon wheelmaker. At issue were subtly different models of audience, skill and of mechanics.[14]

THE MACHINATIONS OF THE LANDGRAVE'S ENGINEERS

By the end of 1716 Orffyreus had abandoned the storms of Saxon polemic for Kassel, 130 miles to the west, the *Residenzstadt* of the Landgrave Karl. For five years the wheels and their maker enjoyed the court's patronage and protection. The enclosure of Orffyreus' wheel within Weissenstein Castle secured his own place as court engineer and councillor and removed him temporarily from the vivid world of Leipzig journalism. Now he could manage his audiences carefully. Kassel was the nexus of a long tradition of courtly mechanics and noble learning, a city Pierre Ramus had once judged the Alexandria of Germany because of its princely patronage of elegant and accurate instruments. The Landgrave's Renaissance predecessors had cultivated eminent clockmakers and artisans such as Jost Bürgi and Eberhart Baldewein, maker of the celebrated astronomical automaton the *Wilhelmsuhr*.[15] In the 1690s, on tour in Italy, Karl himself commissioned fine telescopes and microscopes for his cabinet and recruited Italian workmen to start craft studios in his capital. The Leiden maker Jan van Musschenbroek had supplied an array of air-pumps, mechanical apparatus, optical and medical equipment for the state university at Marburg and for the court. Kassel attracted Huguenot refugees and Karl ordered the construction of a new upper town to house them. Hydraulic works were developed in the court gardens, palaces and the city. Moreover, Karl helped fund over half his government's budget with subsidy deals in exchange for Hessian mercenaries supplied to the major Protestant powers, notably Sweden, Britain and the Netherlands. Part of the profits went towards engineering and industrial investment. German clockmakers were encouraged to work in the capital, older automata and models were restored for display in the cabinet and court ceremonials instituted to honour the regime with spectacular works of mechanical display. Foreign philosophers such as Nicolas Hartsoeker and Christian Wolff, expelled from his chair at Halle by the Brandenburg regime, were attracted there. So were a range of masters in the working of gems, ivory and amber. In 1709 the Landgrave inaugurated a huge *Kunsthaus*, with rooms for arts and natural wonders, for his clocks, optical and mathematical rooms, an observatory and an associated *Modellhaus* for replicas of

14 Dircks, op. cit. (13), 208–9 and Dircks, op. cit. (1), 98–101; Gould; op. cit. (1), 144–5. These episodes should be compared with the strategies of revelation and concealment of Leibniz, Huygens and Hooke; see Rob Iliffe, 'In the warehouse: privacy, property and priority in the early Royal Society', *History of Science* (1992), **30**, 29–68.

15 Moran, op. cit. (12), 144–77.

engineering schemes. These displays became the centre of an extended network of visits and curious interest.[16]

Closely involved in these developments was the Huguenot Denis Papin, who in the 1670s had worked for Huygens in Paris and Boyle in London, went to Marburg as mathematics professor in 1688, and became court engineer at Kassel in 1695. Papin's experiences in Hesse were in many ways a precedent and a caution for that of Orffyreus. Papin was a veteran hydraulic engineer, a fierce critic of perpetual-motion schemes, and an expert in making devices like air-pumps into marketable commodities. His inaugural lecture at Marburg had lauded the power of mathematics in the development of engines and was soon followed by debates with Johann Bernoulli, Leibniz and Huygens on the possibility of useful work being derived from perpetual machines. At stake, too, was the role of the philosopher as counsellor on the plausible success of rival engines, whether in the mines or at court. In 1689 Papin used the *Acta eruditorum* to publish a scheme for a steam-pump in which a vacuum was to be formed by the rapid condensation of steam in a closed cylinder. He intended that this Hessian pump should win him backing from the economic interests at court. After years of lobbying the Landgrave eventually hired him at Kassel. Leibniz commented that 'Mr Papin will do well to stay there near a great prince who knows and likes the matters in which he excels.'[17]

But matters did not run so smoothly. Despite his energetic publication and construction of a series of steam-pumps, and despite his attempts to interest Leibniz's employer the Elector of Hanover in schemes for pumps in the Harz or hydraulic engines at his court at Herrenhausen, Papin never received what he judged sufficient finance or status. His failures were all the more galling because of the contemporary development of steam-engines in Britain. In 1698 Thomas Savery was granted a patent in London for the development of a steam-pump for draining water from the mines. It was demonstrated at the Royal Society the following year and news of the scheme soon reached Kassel. The Landgrave endorsed Papin's proposal to stage comparisons with the Savery scheme and demonstrate the financial prospects of his own scheme. 'I had the honour to show the English scheme to my lord', Papin told Leibniz in early 1705, 'which put my own invention back into his head and made him revive the desire to advance this business'.[18] In 1707 Papin arranged the publication of his most ambitious pump scheme, the *Ars nova*, but without success. He set out to stage public demonstrations of his pumps, which involved turning a water-wheel by

16 Hugo Brunner, *Geschichte der Residenzstadt Cassel* (1913), Frankfurt-on-Main, 1978, 199–250; Philippi, op. cit. (9), 609–15; Franz Adrian Dreier, 'The *Kunstkammer* of the Hessian Landgraves in Kassel', in *The Origins of Museums* (ed. O. Impey and A. MacGregor), Oxford, 1985, 102–9; Ludolf von Mackensen, *Die naturwissenschaftlisch-technische Sammlung in Kassel*, Kassel, 1991, 26–8; Maurice Daumas, *Scientific Instruments of the 17th and 18th Centuries and their Makers*, London, 1972, 143; Peter de Clercq, 'Exporting scientific instruments around 1700', *Tractrix* (1991), **3**, 79–120.

17 Leibniz to Haas, 10 August 1696, in Ernst Gerland, *Leibnizens und Huygens Briefwechsel mit Papin*, Berlin, 1881, 209. For Papin and Leibniz in the early 1690s see Séris, op. cit. (4), 250–8 and Elster, op. cit. (11), 79–88. For the steam-engines at Kassel see E. Wintzer, *Denis Papins Erlebnisse in Marburg*, Marburg, 1898, 19–23; J. Payen, 'Huygens et Papin', in *Huygens et la France* (ed. René Taton), Paris, 1982, 197–208, on 202–5; Wallace, op. cit. (5), 55–8.

18 Papin to Leibniz, 15 January 1705, in Gerland, op. cit. (17), 339–40. For Savery see L. T. C. Rolt and J. S. Allen, *The Steam Engine of Thomas Newcomen*, New York, 1977, 24; R. L. Hills, 'Review of the history of the Savery engine', *Transactions of the Newcomen Society* (1987), **58**, 27–44, on 31.

pressurized jets, and a steamboat he had designed was launched on the river Fulda with a view to sailing it downriver to Bremen. Court attention began to wander towards the more attractive proposals coming from the English engineers, and Papin's reputation was not helped when one of his engines blew up, wounding the Landgrave himself. After complaining of the presence of 'many over-powerful enemies', Papin packed his bags and returned to London.[19]

In England Papin sought, equally unsuccessfully, to persuade the Royal Society to stage comparison trials between his pumps and those of Savery, while Newton advised on the best means to estimate the force of the engine by firing shot across a known distance. Eventually Papin tried to get the Society to set up a joint-stock company to exploit his own work and to distinguish it from 'those chymerical projects which are but too frequent', but this proposal, too, proved abortive.[20] Papin's failures at Kassel and London were ample testimony to the difficulties, even in such apparently favourable milieux, in mobilizing effective long-term support for court-sponsored engineering. The key problem was the promise of public performance. In his attacks on perpetual-motion schemes promoted in the 1680s, Papin had always claimed that 'without losing any labour and charges in trying, people may be sure that the thing can never do'. But for his own steam-pumps, the need for public trial was urgent. Debating whether there should be public comparisons of steam-pumps in the Harz with men or with horses. Leibniz drew on his rich experience to advise Papin on the theatre of machines necessary to impress his master:

> To speak about a design to a prince in order to make him a proposition, it is necessary to have a little more information, particularly on the effect and the expense required to obtain this effect. For doubtless this will be the first thing which my lord the Elector will ask me. For example, given a particular water jet, it would be necessary to be able to judge approximately how much it would cost to keep it going during a certain time... but the men who are employed in this kind of operation are scarcely biddable when one wants them to depart from their daily routine. And it is necessary that the utility of the thing, and their own profit, be very visible to get them to accept any novelty.

Orffyreus, who reached Kassel just a decade later, attempted to solve this problem through his own careful histrionics.[21]

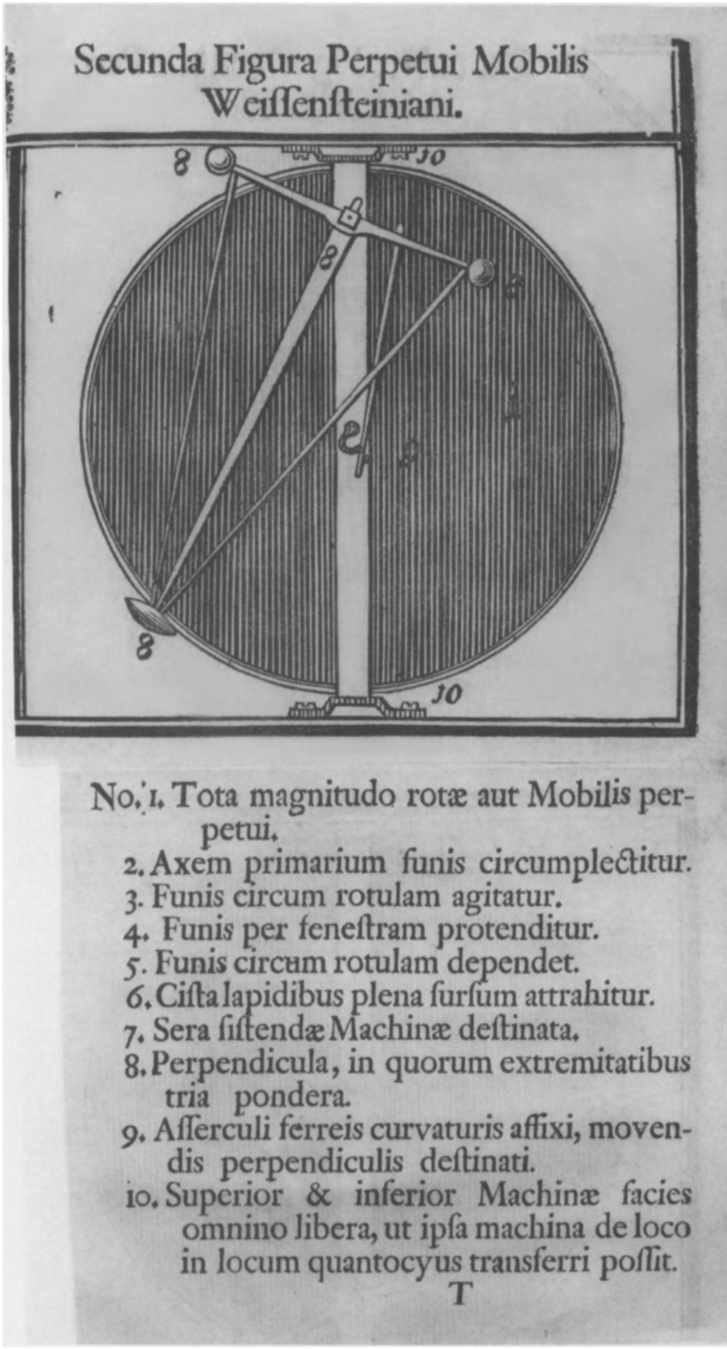
FIELD TRIALS AT KASSEL

At Weissenstein, Orffyreus initially tried to restage the more successful routines he had adopted in Merseburg. Having secured from Karl the status of *Kommerzialrat* he rebuilt a wheel of unprecedented size and in late October 1717 he moved it to a room where it

19 Papin to Leibniz, 7 July 1707, in Gerland, op. cit. (17), 378. For Papin's departure from Kassel see Philippi, op. cit. (9), 611–12.

20 Papin, 'Proposition concerning a new invented boat', 11 February 1708 and Papin to Sloane, 31 December 1711, in Gerland, op. cit. (17), 386–7, 394–7. For Papin in London see J. L. Heilbron, *Physics at the Royal Society during Newton's Presidency*, Los Angeles, 1983, 31; and Stewart, op. cit. (6), 24–6, 175–6.

21 Denis Papin, 'Observations on a French paper concerning a perpetual motion', *Philosophical Transactions* (1685), **15**, 1240–1; Leibniz to Papin, 25 October 1705, in Gerland, op. cit. (17), 356–7. For Leibniz's earlier experiences with Becher and princely patrons, see Smith, op. cit. (7), 255–8; Elster, op. cit. (11), 83–4; and compare with Leibniz to von dem Bussche, 5 January 1684, in Leibniz, op. cit. (9), iv, 12–14, 'it is almost impossible to complete something difficult under these circumstances and with these obstacles when one is not oneself a workman and cannot be continually present on site'.



No. 1. Tota magnitudo rotæ aut Mobilis perpetui.
2. Axem primarium funis circumplectitur.
3. Funis circum rotulam agitatur.
4. Funis per feneſtram protenditur.
5. Funis circum rotulam dependet.
6. Ciſta lapidibus plena ſurſum attrahitur.
7. Sera ſiſtendæ Machinæ deſtinata.
8. Perpendicula, in quorum extremitatibus tria pondera.
9. Aſſerculi ferreis curvaturis affixi, movendis perpendiculis deſtinati.
10. Superior & inferior Machinæ facies omnino libera, ut ipſa machina de loco in locum quantocyus transferri poſſit.

T

Figure 4. The interior of Orffyreus' perpetually moving wheel at Weissenstein Castle, showing the pendulum mechanism. For the wheel's exterior see Figure 1. From Orffyreus, *Triumphans perpetuum mobile Orffyreanum*, Kassel, 1719. Reproduced by permission of the Syndics of Cambridge University Library.

could stand freely. 'It has not only pleased this mighty Prince to protect me against my numerous enemies, but also to give me a home in his princely Castle of Weissenstein... to name me one of his most honoured servants and restore to me some of the honour and income that I lost in my native country, wishing, no doubt, to give to Kassel the honour which by right belonged to Saxony.' During November he arranged the drama of the wheel within a locked room, opened and resealed after two weeks and then sealed until January 1718. The wheel stayed in motion throughout the show. The Landgrave, like his ducal colleague in Saxony, was then persuaded to produce an official certificate of these results, a testimonial which Orffyreus published in his most ambitious work, the *Triumphant Orffyrean Perpetual Motion*, issued in October 1719 both in Latin and in German. The text contained a series of dedications to the Landgrave, to the public and to God, diagrams of the wheel's interior, and a brief description of the two pendulums and the falling weights which drove it (Figure 4). The *Acta eruditorum* reported in some detail that, through his Weissenstein performance, Orffyreus had successfully answered suspicions that some kind of clockwork was concealed inside the wheel. News of the wheel and the pamphlet spread via Leipzig and the Netherlands to Britain.[22] One important visitor to Kassel was the London instrument maker John Rowley, master of mechanics to the new monarch, the Hanoverian George I, and designer of newfangled orreries for English clients and for the Habsburg commander Eugene of Savoy. An avid designer of automatic wheelwork, Rowley spread news of the wheel back in London. Desaguliers reckoned that Rowley's report carried so much conviction that 'besides the common herd of Perpetual Motion men, which every age affords, some very ingenious men made an attempt that way, and were countenanc'd in it by some great mathematicians, who, when the scheme was laid before them, declar'd they knew no reason why it should not do'.[23]

Interest from the ingenious, the great and the financially astute brought Orffyreus his next and best chance to establish his wheel's repute. Fischer's and 'sGravesande's arrival in Kassel in 1721 was the culmination of a set of closely linked technical, political and commercial interests in the installation of newfangled steam-engines which were rather rapidly developed in Britain and whose performance drew the attention of several European states (Figure 5). Savery had died in 1715, and a new joint stock company was soon formed to take over his patents and license the development of Savery and Newcomen steam-engines. By the time of Rowley's Kassel visit, two dozen of the Newcomen engines had already been set up in British mines. Demonstration models of these machines were sometimes shown by Desaguliers in London to his guests, including both 'sGravesande and Fischer.[24] The well-connected Fischer, godson of the Imperial court chancellor and heir to the principal Viennese court architect, was touring western Europe on Leibniz's recommendation to collect coins and medals for the Imperial cabinet. In July 1718, he received instructions from Vienna to begin discreet inquiries into the new steam-engines in

22 Orffyreus, *Triumphans perpetuum mobile Orffyreanum*, Kassel, 1719, 10–12 and 'Relatio de perpetuo mobili Joh. Ernesti Orffyrei', *Acta eruditorum* (November 1718), 497–9 on 498. This passage from the *Acta* is silently omitted in Dircks, op. cit. (1), 96.

23 J. T. Desaguliers, *Course of Experimental Philosophy*, 2 vols., London, 1734–44, i, 175–8. For Rowley see Henry C. King and John R. Millburn, *Geared to the Stars*, Bristol, 1978, 154–6.

24 Rolt and Allen, op. cit. (18), 58–74; Lindqvist, op. cit. (5), 112–14; Stewart, op. cit. (6), 236.

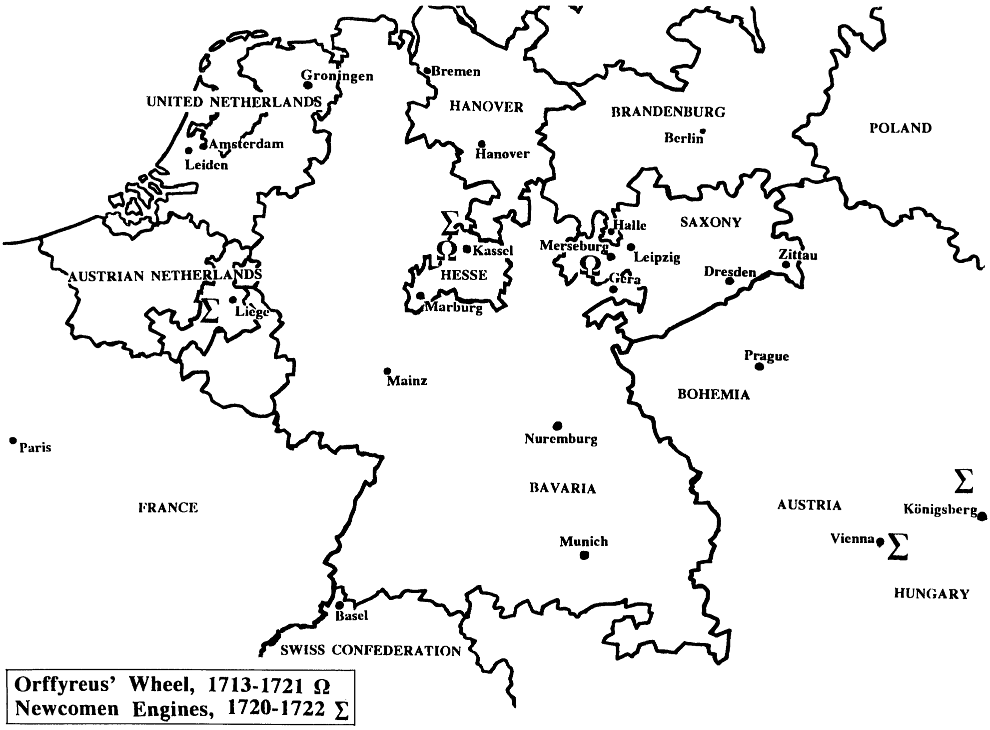


Figure 5. Distribution of Newcomen engines and of Orffyreus' wheels in the Empire, 1713–22.

Britain. At first he disguised himself in artisan's clothes to work as a labourer during his industrial espionage there. Then, after contacting Desaguliers and attending a demonstration of a model at the Royal Society in January 1719, he soon began representing himself to the Imperial *Hofkammer* as an expert in steam engineering (Figure 6). By summer 1720 a Durham engineer supported by Fischer, Isaac Potter, had reached Vienna to plan the installation of steam-pumps at the state mines in Königsberg on the Hungarian border, and during spring 1721 a similar device was set up by one of Desaguliers' contacts in the Austrian Netherlands.[25]

The field trials of these engines, rarely successful but often dramatic, were widely publicized through the extensive correspondence network of the Imperial mining

25 For the architectural context of Fischer von Erlach and his father Johann see T. Zacharias, *Joseph Emmanuel Fischer von Erlach*, Vienna, 1960, 15–24, and Joseph Rykwert, *The First Moderns: The Architects of the Eighteenth Century*, Cambridge, MA, 1980, 67–75. For the engines see G. J. Hollister-Short, 'The introduction of the Newcomen engine into Europe', *Transactions of the Newcomen Society* (1977), **48**, 11–24 and 'A new technology and its diffusion: steam engine construction in Europe 1720–1780', *Industrial Archaeology* (1978), **13**, 9–41 and 103–28; and Mikuláš Teich, 'The early history of the Newcomen engine at Nova Bana (Königsberg)', *East Central Europe* (1982), **9**, 24–38. Desaguliers' demonstration is recorded in Royal Society of London Journal Book (22 January 1719), **11**, 282.

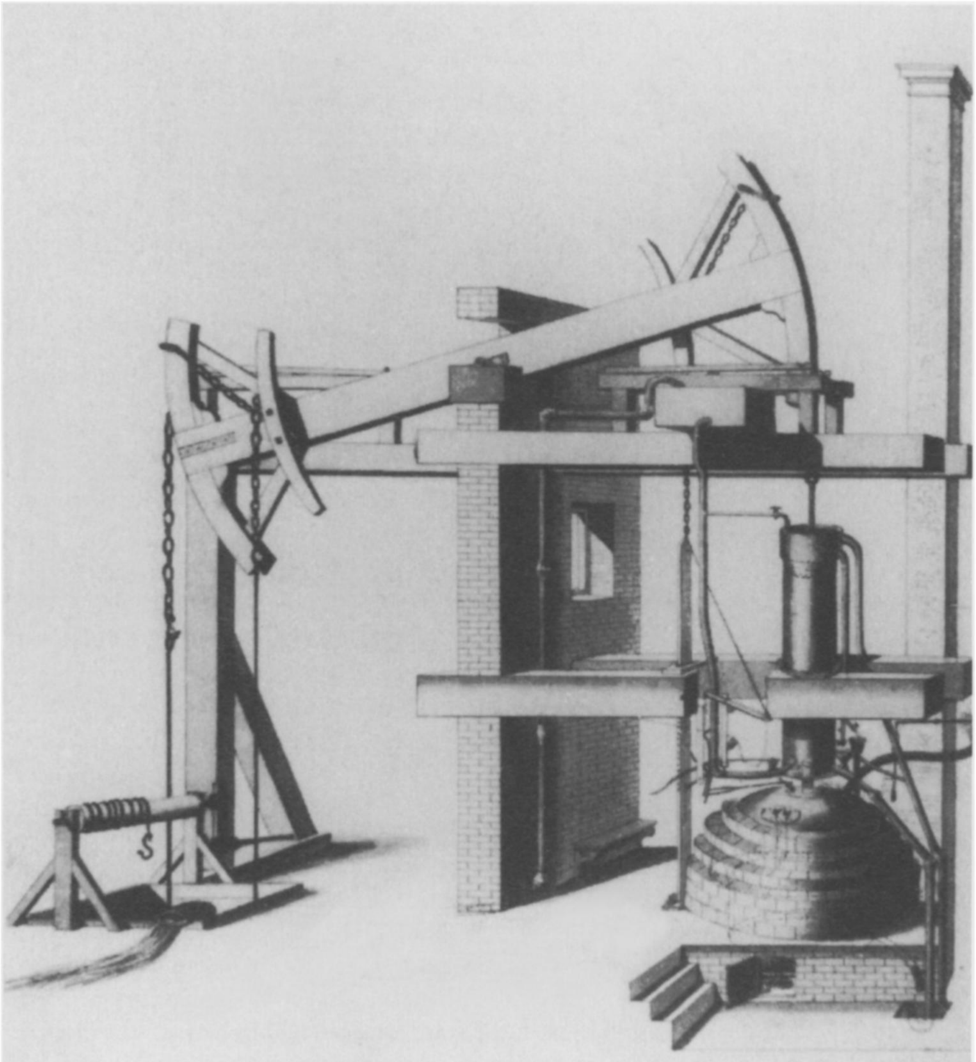


Figure 6. Fischer von Erlach's picture of a Newcomen engine, probably based on an English original, *c* 1721–22. From L. T. C. Rolt and J. S. Allen, *The Steam Engine of Thomas Newcomen*, Hartington and New York, 1977, 74, fig. 32. Reproduced by permission of the Syndics of Cambridge University Library and Moorland Publishing Co. Ltd.

administration. In spring 1721 the Hessian government decided to commission a similar engine for its own works. On Desaguliers' recommendation, Fischer was summoned to Kassel to aid with the construction and 'sGravesande, already known as an expert on the principles of machine design, joined him there in the summer to act as consultant. On 3 August the two men signed a contract with the Landgrave's building superintendent Roman de Badeveld to improve steam-engine design and establish exclusive rights over all new steam-engines in Germany. Fischer and 'sGravesande spent the summer at Kassel constructing a demonstration device of a Newcomen engine to show the court and justify their privilege. Within ten months Fischer was back in Vienna, actively engaged in the design of a large steam-pump for the gardens of Prince Schwarzenberg. Eventually Fischer would become the chief architect of the Viennese court. It was these foreign experts who provided Orffyreus with his new audience for the dramatic shows of his rival source of power in the summer of 1721.[26]

Technology transfer requires the movement of skills and personnel, not easily transmitted by formal recipes and printed schemes. This was a familiar truth in early eighteenth-century Europe. Workers such as Isaac Potter at Königsberg, John O'Kelly at Liège, or the Swedish entrepreneur Marten Triewald, another colleague of Desaguliers who set up steam-engines in Newcastle from 1718 and in Sweden from 1727, were held to possess special skills which were hard to communicate save by face-to-face instruction. Field trials showed how troublesome this transmission really was. The Kassel model engine, for example, was never developed. Just as Leibniz had warned Papin about the resistance of mine administrators to the introduction of new techniques, so Potter told the pre-eminent *philosophe* Montesquieu, who visited him on site in Königsberg in 1728, that 'the great difficulties which are found in new establishments come from the local inhabitants. Those who rent horses for the mines or sell provisions are so many people who have their own interests to defend.' As Svante Lindqvist has explained, the Newcomen engines seemed to place very few new demands on available techniques. They relied on a boiler designed like a brewer's copper, a cylinder comparable with those cast in brass in gun foundries and a regulator which relied on the same principles as contemporary clockwork. But Potter, for example, found it almost impossible to recruit brass-founders and clockmakers of sufficient skill at Königsberg, while in Liège Kelly's engines were only rarely in commission. Such machines were fragile devices which required much expertise on-site and acknowledged craftsmen to run them reliably.[27] So to demonstrate the orderly performance of these machines it was necessary to build up their plausibility in advance. This was why the new systems of financial intelligence and reportage, and the older systems of court patronage, played a decisive role in the estimation of the workings of these engines.

Orffyreus' performances of summer 1721 were staged in direct comparison with those of the model engines touted by Fischer and his colleagues. Newcomen engines had to run continuously to be effective in pumping. They displaced widely distributed pump systems with a single dramatically centralized prime mover. To establish the worth of this range of devices the milieux of field trials and of joint stock investments had to be reconciled with the more mannered shows of court society and the eager stories of the journalists.

26 Allamand, op. cit. (2), p. xxiii; Hollister-Short, 'Introduction', op. cit. (25), 21–2 and 'A new technology', op. cit. (25), 27–8; Teich, op. cit. (25), 26–7. For Fischer in Vienna, see Zacharias, op. cit. (25) 19–21; Erich Kurzel-Runtscheiner, 'Die Fischer von Erlachschen Feuermaschinen', *Beiträge zur Geschichte der Technik und Industrie* (1929), **19**, 71–91; and Daniel von Guldenberg to Heinrich von dem Bussche, 1725, in D. Hoffmann, 'Die frühesten Berichte über die erste Dampfmaschine auf dem europäische Kontinent', *Technikgeschichte* (1974), **41**, 118–31, on 128.

27 Lindqvist, op. cit. (5), 112–13. Hollister-Short cites Montesquieu in 'A new technology', op. cit. (25), 20. For Leibniz on workers' resistance, see Elster, op. cit. (11), 97–102.

Attention was to be directed away from the performances of the machines themselves and towards the heterogeneous publics of European philosophy and commerce. The Leipzig instrument maker Leupold filled his *Theatrum machinarum* with many descriptions of types of steam-engine, alongside equally graphic perpetual-motion schemes. Carefully managed models and impressive diagrams displaced actual encounters with the unreliable engines. In late summer 1721, news of the dramatic trials in the rooms at Weissenstein, together with copies of 'sGravesande's letter to Newton, were published in Dutch, French and English gazettes. As Desaguliers observed, the judgement of 'great mathematicians' added to the credibility of the wheel's performance. Outstanding among these was 'sGravesande, whose judgement of Orffyreus' performance was an important source of the wheel's authority.[28]

THE WHEEL IN THE REPUBLIC OF LETTERS

'sGravesande commanded considerable resources for the establishment of his own authority in mechanics and experimental philosophy. As a young lawyer in 1713 he had already helped found the widely read *Journal littéraire*, a free-thinking Hague periodical he frequently used to enter public debate on moral and natural philosophy. He acquired the nickname Ixixius, because of his taste for algebra, and his mathematical skill drew the attention of Newton and his cronies when in London as part of the Dutch embassy in 1715–16. The following year, with backing from Newton, he was made mathematics professor at Leiden.[29] He explained to Newton that he planned a new teaching strategy, relying to an unprecedented extent on the kinds of demonstration device whose use he discussed with Desaguliers in London: 'I flatter myself that I have had some success in giving a taste of your philosophy in this University; as I talk to people who have made very little progress in mathematics I have been obliged to have several machines constructed to convey the force of propositions whose demonstrations they had not understood.'[30]

'sGravesande worked with the Leiden instrument maker Jan van Musschenbroek to design a remarkable (and expensive) cabinet of such demonstration devices, and his immensely successful two-volume *Physices elementa mathematica*, issued in 1720, was profusely illustrated with these machines.[31] This Leiden scheme was widely imitated and helped reinforce the link between new philosophies and the show of ingenious mechanisms. In early 1720 Desaguliers repeated 'sGravesande's demonstrations of central force before the Royal Society with an apparatus he had copied from the Dutch textbook. In 1724, when

28 News of the wheel is in *Mercure historique et politique* (September 1721), 363 and *Present State of Europe* (August 1721), **32**, 306–8. For drawings of Potter's engines by Leupold and by Fischer see Rolt and Allen, op. cit. (18), 70, 74.

29 Allamand, op. cit. (2), pp. ix–xii; Anne C. van Helden, 'Theory and practice in air pump construction: the cooperation between Willem Jacob 'sGravesande and Jan van Musschenbroek', *Annals of Science* (1994), **51**, 477–95, on 481–2. See also M. C. Jacob, *The Radical Enlightenment: Pantheists, Freemasons and Republicans*, London, 1981, 185–7, 245, and Berkvens-Stevelinck, op. cit. (2), 111 for the *Journal littéraire*.

30 'sGravesande to Newton, 13/24 June 1718, in A. R. Hall, 'Further Newton correspondence', *Notes and Records of the Royal Society* (1982), **37**, 7–34, on 26.

31 For the Leiden cabinet, see C. A. Crommelin, *Descriptive Catalogue of the Physical Instruments of the 18th Century*, Leiden, 1951, 24–41; Peter de Clercq, *The Leiden Cabinet of Physics*, Leiden, 1989, 6–9; van Helden, op. cit. (29), 485–6.

Marten Triewald began a lecture course in Edinburgh, he was delighted to find there 'one or two listeners who had been to 'sGravesande's lectures in Leiden'. Philosophical principles were supposed to link up with commercial ones. The Musschenbroek workshop, which supplied Marburg with air-pumps and microscopes, was also commissioned to produce devices for the court cabinet at Kassel, and 'sGravesande may well have taken a personal role in marketing the Leiden machines there. His university's cabinet eventually included steam-engine models adapted from the British fire machines. As late as 1761 at the British court, King George III was supplied by his instrument maker George Adams with equipment and documents directly based on 'sGravesande's work.[32]

The aim of 'sGravesande's new pedagogy was to link two different senses of demonstration. The status of geometrical proof, hitherto limited to mathematics, was now to be attributed to the practical theatre of instrumental performance. Experimental demonstration allowed a bridge to be constructed between the courtly academy and schemes of the coffee-house. Included in the Leiden cabinet was a series of elegant mechanical models, not merely the five classical machines, but also models to demonstrate properties of the cycloid, of centrifugal forces and to compare the forces of moving bodies in collision, arrayed on a so-called 'philosophical table'. Equipped with his university chair, which now included experimental physics, command of the presses, from whence he issued his major textbook, an equally popular handbook for students, and a series of important critical essays, and the support of one of Europe's greatest instrument makers, the Leiden natural philosopher was excellently placed to act as judge and publicist of the events at Kassel.[33]

When 'sGravesande reported to Newton from Kassel in August 1721 he observed that most mathematicians ruled out the possibility of a perpetually moving machine which could do useful work. However, 'I have the honour to tell you that about seven years ago I believed I had discovered the error of these demonstrations because they cannot be applied to all possible machines.' Leibniz, for one, was allegedly wrong to base his whole philosophy of motion on the premise of the impossibility of mechanically produced perpetual motion. When he returned to Leiden, 'sGravesande set to work to revise his youthful argument so as to construct a demonstration which would back up the plausibility of Orffyreus' scheme. No such wheel could run by clockwork alone, because of the effects of wear and tear on its springs. Instead, he directed his analysis to the laws of collision. This was his critical point: contemporary philosophical understanding of mechanical impact was much less secure than Orffyreus' room in Weissenstein Castle. So in autumn 1721 he commissioned from Musschenbroek an apparatus to estimate the mechanical effect of falling bodies based on a set-up Leibniz had described thirty-five years earlier (Figure

32 For Desaguliers' demonstration see Royal Society of London Journal Book (28 January 1720) **11**, 437; for Triewald see Lindqvist, op. cit. (5), 210; for Kassel see de Clercq, op. cit. (16), 83 and van Helden, op. cit. (29), 488; for Leiden steam-engine models see de Clercq, op. cit. (31), 50–3; for Adams see A. Q. Morton and Jane Wess, *Public and Private Science: The King George III Collection*, London, 1993, 245.

33 Edward G. Ruestow, *Physics at Seventeenth and Eighteenth-century Leiden*, The Hague, 1973, 116–19; van Helden, op. cit. (29), 488; Daumas, op. cit. (16), 137–9, 143. For 'demonstration' see Simon Schaffer, 'Machine philosophy: demonstration devices in Georgian mechanics', *Osiris* (1994), **9**, 157–82, on 157–9.

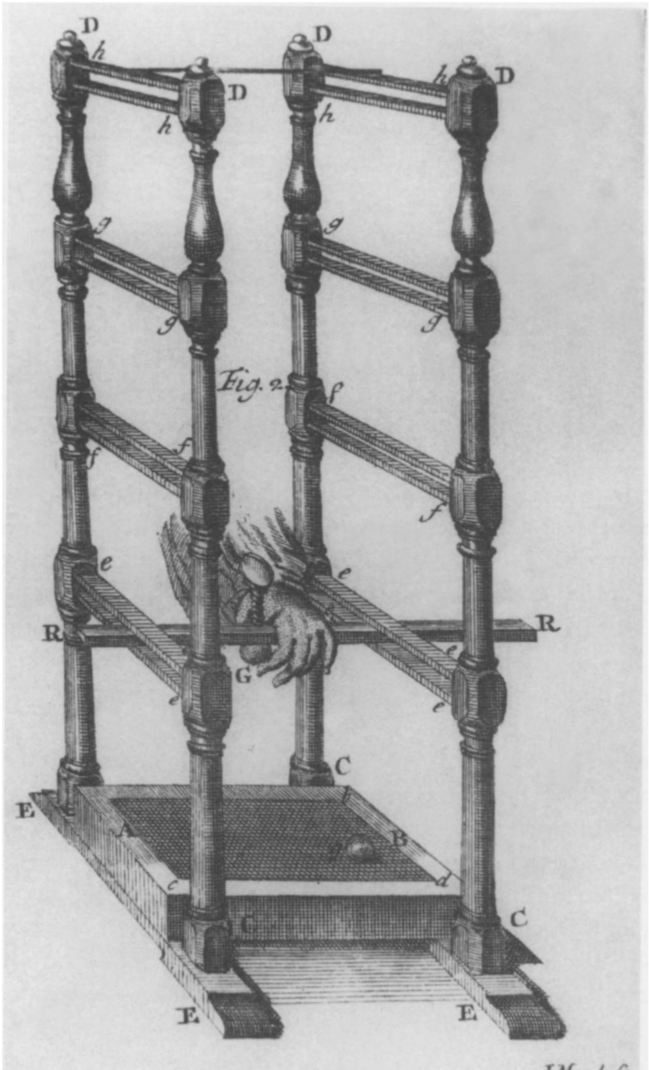


Figure 7. 'sGravesande's apparatus for estimating motion of falling bodies, built by Jan van Musschenbroek in autumn 1721. From Willem 'sGravesande, *Physices elementa mathematica experimentis confirmata*, Leiden, 1742, vol. 1, plate 32, fig. 2. Reproduced by permission of the Syndics of Cambridge University Library.

7).[34] Musschenbroek provided him with a series of balls of different size, just like those the professor imagined worked within the wheel. Then he dropped these balls into yielding wax. 'sGravesande found that for a given ball the size of indentations was proportional to

34 'sGravesande to Newton, 7 August 1721, in Newton, op. cit. (1), vii, 144; Allamand, op. cit. (2), p. xv; 'sGravesande, 'Remarques touchant le mouvement perpetuel', in *Oeuvres*, op. cit. (2), i, 305–12. Here 'sGravesande mentions that he had performed these trials, and so changed his view on the law of force, between sending the letter to Newton in August 1721 and his composition of this paper eight months later.

the height of the drop. He assumed that such indentations would be proportional to the force acquired in falling, a premise established in his book of 1720. He concluded that forces, which he now identified with quantities of motion, must vary as the squares of bodies' speeds, not the speeds alone, a view directly contrary to that he had learnt in London and printed in his textbook. When his brother-in-law stumbled on 'sGravesande in the midst of these trials, the professor 'repeated the experiment before him with the same satisfaction which he would have had if he had confirmed the view which he had defended up till then'.[35]

On the basis of these experiments, 'sGravesande swiftly composed two related essays. One, on the collision of bodies, was printed in the *Journal littéraire* in April 1722. Here he announced the results of his trials with falling weights and claimed they supported the estimation of motions by the square of bodies' speeds. The authority of mathematical demonstration should be granted to experimental performances. The other essay on perpetual motion, finished at the same time, argued that even under the theory where force was proportional to speed, it might well be possible for a body to rise quicker than it descended and so perpetual motion would be plausible, while under the new and correct account, where quantities of motion were measured by the square of speeds, 'I cannot persuade myself that it is contradictory to construct a machine which would have within it a principle of the increase of force because of the laws of nature... what we know of these laws must make us envisage as very possible a Machine such as that which we would need to gain force to counterbalance that lost by friction.'[36]

'sGravesande reckoned that small impulses might sometimes be recouped indefinitely. The case of automata was relevant here. Many Dutch Cartesians reckoned that an automaton shaped like a human being might be indistinguishable from the real person, while Leibniz had once told 'sGravesande's Leiden predecessor, Burchard de Volder, that 'there is no doubt whatever that a man could make a machine capable of walking about for some time through a city and of turning exactly at the corners of certain streets'. 'sGravesande reversed these metaphors, claiming that phenomena such as the circulation of the blood showed that machines could well run forever with active principles working as a salutary means of recruiting lost work. Appealing to Newton's own views, published in 1706 in the *Optice*, he wrote that 'there are in nature active principles to re-establish the motion which is lost in such encounters... would there not be some boldness in being so sure that it is contradictory to profit from these principles?' The Newtonian doctrine of active principles provided the principal English warrant for the public demonstration of experiments. Such lectures became the equivalent of religious theatre, involving the display of excessive and admirable powers put into matter at the creation by God. These powers could then become valuable commodities. 'sGravesande explained that if Orffyreus' wheel

35 The apparatus is in Leiden: see Crommelin, op. cit. (31), 29 and de Clercq, op. cit. (31), 28–9. See also Pierre Costabel, ''sGravesande et les forces vives', in *Mélanges Alexandre Koyré* (ed. I. Bernard Cohen and René Taton), 2 vols., Paris, 1964, i, 117–34 on 124–8; T. L. Hankins, 'Eighteenth-century attempts to resolve the vis-viva controversy', *Isis* (1965), **56**, 281–97, on 287; Carolyn Iltis, 'The Leibnizian–Newtonian debates', *BJHS* (1973), **6**, 343–77, on 358–61.

36 'sGravesande, 'Essai d'une nouvelle théorie de choc', in *Oeuvres*, op. cit. (2), i, 217–51 (originally published in *Journal littéraire* (1722), **12**, 1–54 and 190–7) and 'Remarques touchant le mouvement perpetuel', ibid., i, 305–12.

'is perpetual motion, the author well merits the recompense he asks; if it is not, the public can discover a beautiful invention without those who have promised the reward being committed to anything'.[37]

These arguments, soon to flower into a series of *vis viva* disputes, were originally firmly wedded to the Dutchman's estimate of a reasonable financial return on Orffyreus' investment. In October 1722 Johann Bernoulli, then embroiled in the calculus fight with the Newtonians, sent to Leiden a long paper on the estimation of living force and the virtues of Orffyreus' wheel. Bernoulli condemned the adulation of Newton, sarcastically wondered what 'sGravesande's erstwhile English friends would make of his sudden 'fall into one of the heresies of Mr Leibniz', then insisted on the possibility of 'a mixed perpetual motion, that is, one where art and nature combine to perpetuate the motion'. Bernoulli reckoned that 'sGravesande's 'active principles' must involve this combination and guessed that Orffyreus' wheel was just such a device, perhaps using magnets or springs. He even claimed that he himself had also designed such a machine, and was only waiting for 'some skilled workman to execute my project', though Bernoulli would be satisfied with less cash than Orffyreus was demanding. As Bernoulli quickly predicted, 'sGravesande's arguments famously failed to quell criticism. In fierce debates with philosophers throughout the Republic of Letters which continued into the 1730s, 'sGravesande had progressively to clarify the recipes for his experiments on falling bodies and explain the metaphysical meaning he attributed to them. He printed tables allowing his readers to estimate the volume of an indentation from its horizontal diameter, though larger balls would make shallower impressions. He gave careful instructions on the kind of clay or wax which must be used, preferably dense, uniform and soft, and the oil with which the balls must be coated lest they stick on impact. He got Musschenbroek to design a robust machine to control the way in which the balls were dropped and the height from which they fell, then used the *Journal littéraire* to revise and clarify these new performances.[38]

The most ferocious response to his papers came from London, where Newton's lieutenants, such as Samuel Clarke, published angry attacks on his experimental skill and his repute. Clarke saw a sinister connection between these new Dutch experiments, the old errors of Leibniz, and the recent mistakes of a Paduan mathematician, Giovanni Poleni, whose 1718 text on hydraulics also endorsed the measure of force as the square of bodies' speed. In 1722 the London physician Henry Pemberton claimed that Poleni's impact trials neglected the resistance of different substances to bodies moving through them, and so

37 Leibniz, 'Reply to the thoughts on the system of pre-established harmony' (1702), in Leibniz, op. cit. (12), 935; 'sGravesande, 'Remarques touchant le mouvement perpetuel', in *Oeuvres*, op. cit. (2), i, 311–12. The source is Isaac Newton, *Opticks* (1730), New York, 1952, 399: 'seeing therefore the variety of motion which we find in the world is always decreasing, there is a necessity of conserving and recruiting it by active principles, such as are...the case of fermentation, by which the heart and blood of animals are kept in perpetual motion and heat' (1706 version). For the display of active principles in lectures see Simon Schaffer, 'Natural philosophy and public spectacle', *History of Science* (1983), **21**, 1–43. Thanks to Joe Gross for help with these arguments.

38 Bernoulli to 'sGravesande, 31 October 1722, in Allamand, op. cit. (2), pp. xxxvi–xlv. For 'sGravesande's recipes see Costabel, op. cit. (35), 131–3. For Bernoulli's earlier notions of 'mixed perpetual motion' see Gabbey, op. cit. (11), 58–9 and compare with P. M. Heimann, 'Geometry and nature: Leibniz and Johann Bernoulli's theory of motion', *Centaurus* (1977), **21**, 1–26. For his relations with Newton see A. R. Hall, *Philosophers at War*, Cambridge, 1980, 199, 240–1.

could not be used to decide on the proper measure of force. Clarke drew a portentous conclusion about the moral order of mixed mathematics: 'That in Mathematicks themselves, which are a real Science, and founded in the necessary Nature of things, men of very great abilities in abstract computations, when they come to apply those computations to the Nature of Things, should persist in maintaining the most palpable absurdities, and in refusing to see some of the most evident and obvious truths, is very strange.'[39]

Desaguliers tried to preserve the peace of the Republic of Letters. 'sGravesande and his colleagues 'are too curious in making and too faithful in relating their Experiments, not to have us credit the Facts'. Still, he conceded the engineering uses of trials on impact which 'give us a Principle to direct the Practice of some mechanical operations which was not very well known before'. In 1733 he went to Leiden, taking with him apparatus designed by the London maker George Graham, to show that force varied as the speed. 'sGravesande immediately designed a counter-demonstration, duly repeated in London. There Desaguliers used arguments taken from Pemberton's essay and from its anonymous postscript by Newton to argue that forces must be estimated by their time of action, that larger impressions took longer to make, and so that the size of an impression did not measure a body's action.[40]

'sGravesande's experiments were certainly vulnerable to criticism. The Londoners reckoned that measuring the size of an indentation, and choosing the substance to be impacted, were both nice matters. Disputants could always locate some tacit assumption upon which such an experiment depended, and then expose this assumption to criticism. Critics claimed that he made illegitimate assumptions about the cohesion of substances such as clay. In order to make indentations' size proportional to bodies' action, he assumed that resistance in soft bodies must be proportional to the number and displacements of particles moved. This made indentation look like continuous rather than sudden action. Desaguliers complained that since rigid bodies instantaneously changed motion and so could not conserve their living force, his enemies banned all talk of them: 'it would be as unfair to debar us of that privilege, as to say that the Science of Mathematicks cannot be true, or must not be applied to Physicks; because Mathematicians reason about ... such penetrable Solids as do not exist in Nature'.[41] The characteristic troubles of replication and of the negotiable meaning of a decisive experiment became obvious and urgent. It was from the English capital, after all, that 'sGravesande and Fischer had expected the most significant financial and philosophical support for Orffyreus' wheel.

39 For the answer to Poleni see Henry Pemberton, 'A letter ... concerning an experiment, whereby it has been attempted to shew the falsity of the common opinion in relation to the force of bodies in motion', *Philosophical Transactions* (1722), **32**, 57–66, on 58. Clarke's remarks are in 'A letter occasioned by the present controversy among mathematicians', *Philosophical Transactions* (1728), **35**, 381–9, on 382.

40 J. T. Desaguliers, 'An account of an experiment contrived by G. J. 'sGravesande relating to the force of moving bodies', *Philosophical Transactions* (1733), **38**, 143–4 and op. cit. (23), i, 398–400. See also op. cit. (23), ii, 63: 'I am now convinc'd that all the Phaenomena of the Congress of Bodies may be equally solv'd according to the Principles of the Defenders of the new, as well as those of the old Opinion'. Newton was the 'excellent and learned friend' who prepared Pemberton's postscript to his 'Letter' (ibid., 67–8), see Iltis, op. cit. (35), 363.

41 For the English response see Iltis, op. cit. (35), 362–76. Compare Desaguliers, op. cit. (23), ii, 54–5 against 'sGravesande's argument that momentum is lost when bodies fall into soft obstacles.

THE WHEELS OF COMMERCE

Debates about the estimation of living forces were immediately linked with the problem of assessing the value of a machine's worth. In his discussion of eighteenth-century attempts to give reliable numerical estimates for technical projects, Svante Lindqvist reminds us of the importance of control: 'one must be able to control the necessary physical and social realm in terms of time and space'. The London of Walpole and Desaguliers was not a realm of easy physical and social stability, but was, instead, home to the extremes of shifting credibility and credulity. One cunning London printer had even made £2000 in one day by gulling investors in 'a Company for carrying on an undertaking of Great Advantage but no one to know what it is'.[42] Though Orffyreus' scheme had been endorsed by two German courts, by professors from Halle, Basel and Leiden, and by engineers and philosophers well known to the Royal Society, it had to compete with others of equal plausibility in a world dominated by rival criteria of value.

In the London stock market in 1720, pamphleteers satirically asked what 'charm' would 'effectually gain the consent of the subscribers', and answered that fictional (and real) projectors offered 'only that of extraordinary gain – a plausible scheme for procuring them cent. per cent. is a snare they have no power to avoid'. A mechanism which offered the promise of extraordinary gain from an allegedly ingenious principle to which none were allowed access was a remarkably accurate picture of contemporary metropolitan reality. Judging the value of clockwork machines, especially those on show at court, was very difficult. This was the point of some of Swift's jokes in *Gulliver's Travels*, composed in the early 1720s, in which the Imperial courtiers of Lilliput took Gulliver's clock to be his living god, while the mathematically trained King of Brobdingnag took Gulliver himself to be 'a piece of Clockwork (which is in that country arrived to a very great perfection)'. Furthermore, artisans and financiers both justified their machinations by appealing to occult principles, while fashionable physicians explained the maladies of market society with the same esoteric forces with which the natural philosophers explained the working of the cosmos. Swift acutely placed perpetual motions amongst these schemes being marketed by projectors, both financial and philosophical.[43] He asked 'wise philosophers' to explain 'what magic makes our money rise when dropt into the Southern main', while

42 Svante Lindqvist, 'Labs in the woods: the quantification of technology during the late Enlightenment', in *The Quantifying Spirit in the Eighteenth Century* (ed. Tore Frängsmyr, J. L. Heilbron and Robin Rider), Berkeley and Los Angeles, 1990, 291–314, on 311. For the London political context see E. P. Thompson, *Whigs and Hunters*, Harmondsworth, 1977, 197–218; J. P. Kenyon, *Revolution Principles*, Cambridge, 1977, 198–9; and David Dabydeen, *Hogarth, Walpole and Commercial Britain*, London, 1987, 15–40. For the printer's scheme see Virginia Cowles, *The Great Swindle*, London, 1960, 126. For the ubiquity of credit, see Peter Earle, *The Making of the English Middle Class*, London, 1989, 115–23.

43 William Chetwood, *The Stock Jobber*, London, 1720, cited in Lewis Melville, *The South Sea Bubble*, London, 1921, 80–1. For nervous maladies and Newtonian active principles, see Roy Porter, 'The rage of party: a glorious revolution in English psychiatry?', *Medical History* (1983), **29**, 35–50 and Anita Guerrini, 'Ether madness: Newtonianism, religion and insanity in eighteenth-century England', in *Action and Reaction* (ed. Paul Theerman and Adele F. Seeff), Newark, 1993, 232–54. For Swift on perpetual motion in 1712 see Stewart, op. cit. (6), 209, and for clockwork see 'Travels into several remote nations of the world by Lemuel Gulliver' (1721–26), in Swift, *Selected Writings* (ed. John Hayward), London, 1968, 30, 99.

Daniel Defoe wrote that 'some give Men no Rest till they are in their Debt, and then give them no Rest till they are out again; some will credit no body, and some again are for crediting every body'. All this was nothing but an 'artificial trick and cheat'. Images of inexhaustible, invisible and imaginary gain, the devices of perpetual motion, abounded in contemporary ballads: 'Our cunning South Sea, like a god/turns nothing into all things.'[44] Contemporaries on both sides of the Channel explicitly connected the behaviour of public credit with endless motion and with the artifice of gain and loss, whether in *Gulliver's Travels* or in Montesquieu's equally biting attack on the French credit crisis in his *Persian Letters* (1721).[45]

Natural philosophers were often protagonists of these debates, and in the midst of the credit crises 'sGravesande himself penned an essay setting out the Bubble's dubious basis. When the British government passed an act against rival projects in June 1720, the Dutch brokers, in particular, exploited their invulnerability to such legislation and interest in new bubbles boomed. It was feared that 'it is in the power of Holland to draw away every shilling in England'. Representatives from several German states, including Hesse-Kassel, bought South Sea stocks in wild speculation on the Amsterdam exchange.[46] In the same months, 'sGravesande showed his Dutch readers how schemes for perpetual reward should be viewed. He distinguished between the intrinsic, or real, value of stocks and their current value, which depended on the market's credulity. In a fixed-sum game, like the South Sea scheme, the more stocks sold the greater the real loss sustained by new subscribers and the profit retained by the Company's owners. In the person of a rational philosopher, for whom morality and religion involved merely 'a perpetual attention to find occasions on which to be useful', the Dutch professor posed the moral question of the status of expertise and the ethics of investment. He explained the influence of interest on mathematicians:

> They scarcely ever mistake in what concerns their science...the principal reason is that in their science it is in no way a question of matters where the passions have much influence. But get a mathematician to reason on things where the passions are concerned, and there he is as human as anyone else. Ask him how much three and two make, and he will answer five; there it is a matter of abstract ideas and he does not mistake. But ask him how much three écus and two écus make, and I would not want to swear that he would always tell you five. There is a difference between coolly calculating to discover what one has been asked to seek; and making a calculation when a Company, which deals in millions of pounds sterling, employs you to find out what something is.

There was a direct connection between these reflections on the Bubble and those on perpetual motion. In both projects, 'sGravesande reckoned that the existence of an intrinsic

44 Swift, 'The South Sea Project', cited in Melville, op. cit. (43), 150; Defoe, *A Review* (1706), **22**, 502–3 and *Considerations on the Present State of Great Britain*, London, 1717, 146, cited in Simon Schaffer, 'Defoe's natural philosophy and the worlds of credit', in *Nature Transfigured* (ed. John Christie and Sally Shuttleworth), Manchester, 1989, 13–44, on 30; 'A South Sea Ballad, to a new tune, called the Philosopher's Stone', cited in Melville, op. cit. (43), 147.

45 For Montesquieu on the credit crisis, see Letter 142 in C. J. Betts (ed.), *Persian Letters* (1721), Harmondsworth, 1973, 256–8 and Pocock, op. cit. (6), 468. For Swift see Pat Rogers, 'Gulliver and the engineers', in *Eighteenth Century Encounters*, Brighton, 1985, 11–25 and Stewart, op. cit. (6), 332–3.

46 For the 1720 credit boom in Amsterdam and the link with Hesse-Kassel see John Carswell, *The South Sea Bubble*, London, 1961, 165 and Melville, op. cit. (43), 65.

active principle which could truly restore the system's working must be the sole criterion of moral and commercial value.

> Whence come the riches with which so many people are now laden? Has some treasure been found? Has some mine been discovered? Has the earth suddenly become more fertile? Has commerce grown? Or indeed has some miracle taken place? Has a rain of gold fallen? If nothing of this kind has happened, if real goods have not been increased, what you have won another has lost or must necessarily lose.[47]

Defoe had once asked in rather similar terms how 'Adventures lose their Vein of Oar in the Mine and yet find it in the Shares?... if any Man requires an Answer to such things as these, they may find it in this Ejaculation – Great is the power of Imagination!' The Dutch professor now had a sterner answer – only material realities could warrant genuine gain. Twelve months later, in summer 1721, 'sGravesande reckoned that just such a source of fresh work had been found, as he energetically helped promote Orffyreus' scheme on the London market.[48]

There were many such schemes for perpetual motion on offer. In 1724 Johann Hatzfeld, a German natural philosopher, printed a tract announcing a perpetual-motion machine, submitted it to the Royal Society and was summarily turned away from Newton's door. Hatzfeld complained to Newton that the Landgrave of Hesse-Kassel was 'laughed at as well as I am for pretending to confirm his assertion by an ocular demonstration'. Hatzfeld, later provided 'sGravesande's successor at Leiden, Jean Allamand, with details of the Orffyreus wheel to include in a detailed account of the events at Kassel, and by 1726 was wrapped up in London engineering scandals which also embroiled Desaguliers himself. At the end of that year the London papers reported that in Berne 'an illiterate man, who, tho' a pretty good mechanick, does not understand one syllable of the mathematicks, is said to have found out the perpetual Motion. The Machine is inclosed in a Box and works continually by one Wheel which is affixed to the side of it.' Similar projects were offered to the Royal Society by a Mansfield surgeon in 1727 and by an Irish gentleman in summer 1729.[49] At the end of the 1720s 'sGravesande engaged in further debates with the court tutor at Kassel, the Swiss mathematician Jean-Pierre de Crousaz, who had held the important mathematics chair at Groningen and had won a prize at the Paris Academy for his defence of God's action in preserving force in the world as a function of bodies' speed. Unlike 'sGravesande, the staunchly Cartesian Crousaz was sure Orffyreus' whole scheme was fraudulent.[50]

Desaguliers acted as the Royal Society's adjudicator over all these European projects. He was an acknowledged expert in exposing the deceit involved in foreign claims to extraordinary work, whether those of Leibnizian academicians or more catchpenny

47 'sGravesande, 'Dissertation morale sur le commerce des actions de la compagnie du sud', in *Oeuvres*, op. cit. (2), ii, 272–93, first quoted on 289 and second on 278, both of which can be dated to July 1720. Allamand describes the origin of this text in Marchand, op. cit. (2), ii, 239.

48 Defoe, *A Review*, op. cit. (44).

49 Hatzfeld to Newton, 1724, in Newton, op. cit. (1), vii, 253–4; *London Journal* (10 December 1726); Stewart, op. cit. (6), 241, 349. For Hatzfeld's link with Orffyreus and 'sGravesande see Marchand, op. cit. (2), ii, 223.

50 Jacqueline de la Harpe, *Jean-Pierre de Crousaz*, Geneva, 1955, 166; for Crousaz and the 1720 prize see Carolyn Iltis, 'The decline of Cartesianism in mechanics', *Isis* (1973), **64**, 356–73, on 359–60; for Crousaz and Kassel see Charles Ingrao, *The Hessian Mercenary State*, Cambridge, 1987, 13.

showmen. From 1719 he showed in his lectures how the muscular feats of a German 'Samson' performing at the Haymarket could be reproduced by anyone who knew the principles of mechanics. Rational philosophy could reproduce, and thus discredit, the extraordinary feats of mere labourers. An Italian engineer present at the Society in autumn 1721 praised Desaguliers fulsomely, 'as skilled in physics as in mechanical experiments'. The visitor noted the careful staging of the Society's demonstrations. Desaguliers would supply the fellows with instruments to try at home and no devices were kept permanently in the demonstration room, which was used only to show trials in public after careful rehearsal elsewhere. As he explained rather bitterly to Newton, the Society's gentlemen seemed to wish 'Models of new and useful Engines' every week. The privileged sites of such controlled performances were not the public theatres and fairgrounds, but the Royal Society's weekly meetings and lectures in Westminster.[51]

This was precisely where men such as Desaguliers sought to win control so that authoritative estimates of real value could be produced and the failings of rival projectors represented. Just before the Italian's visit, in November 1721, Desaguliers set out a long demonstration at Crane Court designed to show the falsehood of the Kassel wheel's principle. He reckoned that all such machines depended on the claim that a group of weights near the edge of one side of the wheel would always preponderate over another group of weights nearer the centre on the other side of its axle. He designed a demonstration device to show his fellows that 'the force is due to the quantity of the motion, and the quantity of the most depends upon the height it fell from in gaining it, whether it fell in a straight line or a curve'. This device involved a simple wheel of the same size as that of Orffyreus, but with its inner lever easily and significantly visible. In the relatively secure space of the demonstration room the curator of experiments showed his fellows how different weights hung at the opposite ends of a lever within the wheel would overbalance and how their effects would be limited. 'In a Machine of this kind, the Weights will indeed move... if the Wheel be turn'd round, but will never be the Cause of the Wheels going round'. Desaguliers used this performance to insist that deluded projectors were simply confusing a theorem about momenta with a corollary about distances from a lever's fulcrum. Calculation could control speculation, because bad logic bred bad projects.[52]

He reiterated these demonstrations as a proposal for the Copley Lecture of late 1729, when he attacked the claims of the French academician Claude Perrault, whose edition of Vitruvius, graced with descriptions of the great works of the French state, was the most influential architectural work amongst the courtly texts of baroque aesthetics. It was cited

51 British Library MSS ADD 4433, fols. 321–64 and Desaguliers, op. cit. (23), i, 255; Stewart, op. cit. (6), 125–7; Carlo Poni, 'The craftsman and the good engineer: technical practice and theoretical mechanics in Desaguliers', *History and Technology* (1993), **10**, 215–32, on 224–5. For the visit to the Society in autumn 1721 see Anita McConnell, 'L. F. Marsigli's visit to London in 1721', *Notes and Records of the Royal Society* (1993), **47**, 179–204, on 191–2. Desaguliers complains to Newton, 29 April 1725, in Newton, op. cit. (1), 315. For an interesting text on the evaluation of inventions translated by Desaguliers see Archibald Pitcairne, 'A solution of the problem concerning inventors' (1688), in *The Works of Dr Archibald Pitcairne* (ed. J. T. Desaguliers and G. Sewell), London, 1715, 135–63.

52 Desaguliers, 'Remarks on some attempts made towards a perpetual motion', *Philosophical Transactions* (1721), **31**, 237, and Royal Society of London Journal Book (2 November 1721), **12**, 158 and (9 November 1721), **12**, 161–2.

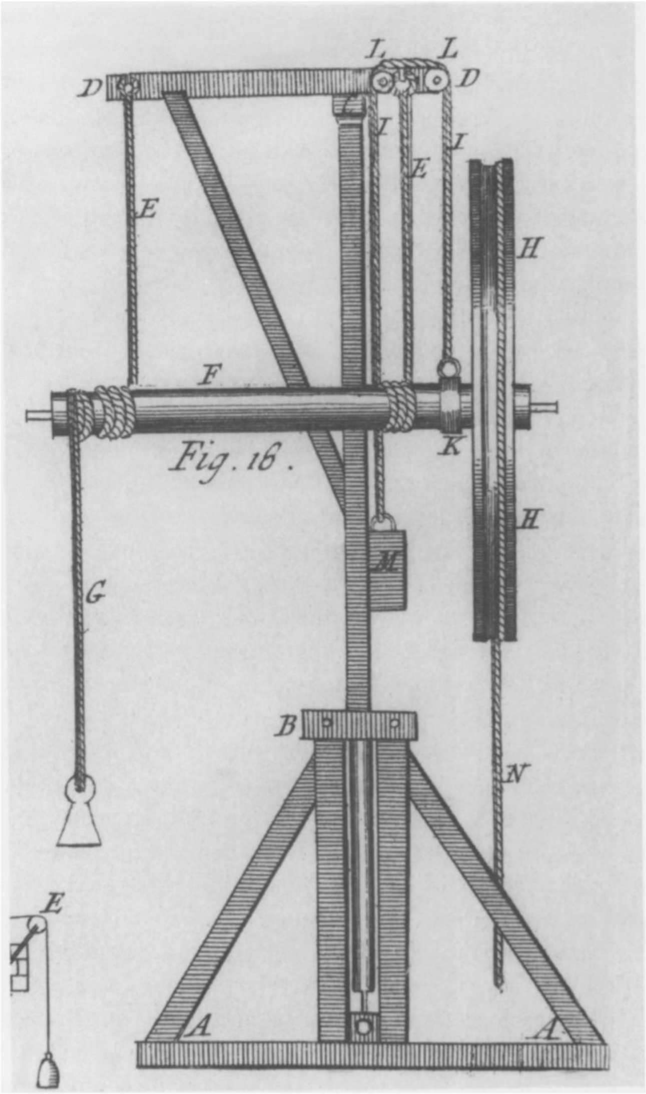


Figure 8. Desaguliers' apparatus designed to refute Perrault's scheme for a frictionless machine, built winter 1729–30. From John Desaguliers, *Course of Experimental Philosophy*, London, 1734, vol. 1, plate 17, fig. 18. Reproduced by permission of the Syndics of Cambridge University Library.

with enthusiasm by Poleni, who had drawn such harsh criticism from Clarke and Pemberton in the early 1720s for his Leibnizian estimates of force. Perrault's recent and posthumous *Receuil de plusieurs machines de nouvelle invention* (1700) promoted a design for a frictionless machine. 'This, were it true, wou'd be a great Improvement and of vast service in Mechanical works', Desaguliers told Sloane. 'I don't doubt but upon the Authority of so great a Man some People have been and several may be induc'd to be at the Expence of such a Machine' (Figure 8). Desaguliers reckoned that by drawing attention to the errors of such an authority as Perrault he could 'demonstrate Mathematically and experimentally by Models wherein he is deceiv'd'. In his lecture against Perrault, a 'person who is considerable in mechanical performances', he demonstrated that if 'an Engineer should alter the Manner of Working... in Mons. Perrault's Way, instead of gaining an Advantage, he must call in three more Men to perform the Work'. Such contrivances simply did not yield a profitable return.[53]

These cautionary models themselves eventually became the profitable stock-in-trade of a number of public lecturers. In the mid-1740s Benjamin Martin, who had taken Desaguliers' place as the leading lecturer in experimental philosophy, freely adapted these attacks on Perrault and on Orffyreus for his own courses since 'the nature of this proposition [was] not understood by smatterers in mechanics'. Amongst these lecturers, attacks on the mistakes of engineers employed by Europe's greatest courts were transmuted into condemnations of the ignorant vulgar vainly dreaming of endless advantage. Though Orffyreus died in 1745, his career became an enlightening parable with many uses, by no means all hostile. During the 1760s his deeds were used by 'sGravesande's biographer and academic successor Allamand to teach that madness and genius were closely allied, so that it was scarcely surprising that men like Orffyreus 'could make discoveries which had escaped the sagacity of the most able people'. Writers such as Montucla might riposte, using Desaguliers' estimates of the maximum effort which any worker could produce to demolish the possibility of infinitely profitable machines. But while Paris academicians urged that deluded inventors wrongly thought themselves inspired just because orthodoxy was against them, Allamand reckoned that established academic prejudice too often cowed proponents of perpetual motion into silence: 'I doubt that up till now anyone has proved the impossibility of perpetual motion.' Allamand's remarks were soon taken up in London's Grub Street in the early 1770s by Kenrick, who had his own scheme to propose and the cause of materialism to defend against priestcraft. He enthusiastically agreed that though 'it is generally supposed that the mathematicians have published demonstrations of the impossibility of a perpetual motion', he could 'safely take upon me to affirm that no such demonstration was ever published by any... They have not done it. The could not do it.' This dissident tone became increasingly characteristic of the anti-academic polemics of the later eighteenth century. Thus the episode at Weissenstein ended up amidst the low life of the high Enlightenment.[54]

53 Desaguliers to Sloane, 12 December 1729, British Library MSS Sloane 4050, fol. 244. See also Desaguliers, 'An examination of M. Perault's new invented Axis in Peritrochio said to be entirely void of friction', *Philosophical Transactions* (1730), **36**, 22–30, on 227, and Stewart, op. cit. (6), 128, 241. For Perrault and Poleni, see Rykwert, op. cit. (25), 23–4, 48 n2. For Perrault on the 'advantage' of frictionless machines see Séris, op. cit. (4), 171–2 and Antoine Picon, *Claude Perrault 1613–1688*, Paris, 1988, 96–7.

54 For Martin on 'smatterers' see *Philosophia Britannica*, 2 vols., Reading, 1747, i, 106–8; a comparable remark is in Henri Pitot, 'Règles pour connoistre l'effet qu'on doit espérer d'une machine', *Mémoires de l'Académie Royale des Sciences*, 1737, 269–72. For Montucla on Desaguliers see Ozanam, op. cit. (3), ii, 100. For Orffyreus' reputation see Allamand, op. cit. (2), p. xxvi and Kenrick, *Account*, op. cit. (3). Kenrick denies any argument against perpetual motion in his *Lecture*, op. cit. (3), 3. For Kenrick's *London Review* defence of philosophical materialism in summer 1775 see John Yolton, *Thinking Matter*, Oxford, 1984, 117. For the milieux of such writers see Jacob, op. cit. (29), 200–1; Robert Darnton, *Mesmerism and the End of the Enlightenment in France*, Cambridge, MA, 1968, 26–33; and Hahn, op. cit. (3), 140–58.

CONCLUSION

The story of Orffyreus' wheel has required a tour of the places of its performance. We have discovered the heterogeneity of the various audiences for this machine and the complexity of the processes through which its capacities were assessed. Performance is as much a promise of success as a display of power, requiring the establishment of new systems of credit and authority, and control over specific places where value can be assessed. This is why the history of perpetual-motion machines is crucial for the history of natural philosophy's culture. In establishing the means through which devices could be judged plausible or visionary, early modern culture established the conventions through which, and the sites where, confidence could be secured and valued. This history is indeed a history of mentalities, just as the Enlightenment supposed, but it is also a social history of the process through which the apparently self-evident grounds of belief were set up. In market societies self-evidence was the result of exclusion. Most folk could not be trusted, especially those who worked for hire or were suspected of weaker reason. While Desaguliers might win royal patronage, others saw him as a 'Gimcrack Wizard' and he always struggled to get the officers of the Royal Society to treat him as something other than their servant. In the debates about perpetual motion, wizardry and superstition were never very distant. When 'sGravesande was confronted with the possibility that at Weissenstein a serving woman had been the source of the wheel's motion, he answered that 'I pay little attention to what a servant can say about machines: perhaps in turning her master's roast-jack she thought she saw a perpetual motion.'[55]

The genteel tones of bourgeois conversation relied on the burgeoning market for philosophical wares and the crazy tempests of public opinion. The career of other world-machines, such as the orrery, exemplifies this point. In 1713 Richard Steele described Rowley's orrery in these terms: 'A Lady would easily conceive what are the uses of Sun and Stars, and be better pleased in being compared to them for the future ... this one engine would open a new Scene to their Imaginations, and a whole Train of useful Inferences concerning the Weather and the Seasons, which are now from Stupidity the Subjects of Discourse, would raise a pleasing, an obvious, an useful, and an elegant Conversation.'[56] While perpetually moving wheels were symbols of divine wisdom, state power and commercial folly, orreries and philosophical tables were designed to provide the Georgians with topics for civil conversation about nature's capacities.

This set of performances has often been seen as part of the formation of the balanced world of civil society, but it was at least as significantly an aggressive, if fragile, attempt to monopolize authority over nature and art. Many social groups had reasons to resist, notably the artisans whose skill was to be discredited, exploited, patronized and obscured in public demonstrations. As Peter Linebaugh has pointed out, imposition of standard measures was often directed against customary workers and other 'little inconsiderable persons'. Elsewhere in the old regime, attempts to create new rationalities of measurement

55 'sGravesande to Crousaz, 1729, in Dircks, op. cit. (1), 113–14. For Desaguliers as wizard see British Library MSS ADD 38175, fol. 215; for his troubles as servant see Desaguliers to Mortimer, MSS ADD 4435, fol. 108. For the heterogeneous audiences of eighteenth-century natural philosophy, see Svante Lindqvist, 'The spectacle of science', *Configurations* (1992), **1**, 57–94, on 88–90. For the distribution of trust see Shapin, op. cit. (7), 86–95.

56 Richard Steele, *The Englishman* (29 October 1713), in King and Millburn, op. cit. (23), 154.

were contested by traditional clerical guardians of the faith, against whom some of the *philosophes* so strenously argued. Indeed, during the eighteenth century many savants sought to associate the ignorance of the clergy with that of their plebeian flock.[57] 'sGravesande, for example, never convinced all his audience of the virtues of his shows and values. During 1721, while he was in Kassel, his whole programme was severely attacked in a leading French journal by the Jesuit Louis-Bertrand Castel, an authority on colour theory soon to pen an equally pugnacious critique of Newton's *Opticks*. Castel wrote that 'sGravesande 'seems to want to reduce men to the possession of nothing save their eyes' by banning all reliance on customary opinion and insisting upon the value of carefully staged trials:

> Why this crowd of experiments, of tedious researches, where, under the pretext that Nature wishes us to grasp her secrets, she is ceaselessly put to the torture, disguising her to know her better? It is good to perform experiments, but when I see entire books of physics like this one full of these rare, curious and (if you like) ingenious experiments, which one is told art has furnished to the English, with scarcely any of those simple, artless and easy experiences which Nature abundantly furnishes to all countries, to all minds, I recall that art alters everything.'[58]

The significance of this tortuous artfulness and these suspect variations in cultural geography has provided the focus of this essay. Orffyreus' wheel was inaugurated amongst the *Kunstkammern* of court society. This is an origin of the public museum: an institution where the state put art works on show to bolster its authority, where the wonders were tended by officers of the palace and where those present as witnesses were treated as polite guests. These displays were an integral aspect of the technology of power in absolutist Europe. Visits to such wonders were designed to reinforce the power of the princely master of such excessive performance.[59] In that society, it has been argued, balance was precarious and status rose and fell like the weights on Fortune's wheel. Assessments of value changed in a manner which resembled the habits of finance capital. But these habits were never easily reconciled. In the early eighteenth century the lecture-demonstration and the display of experimental machines helped mediate the relation between the court and the exchange. In Kassel in 1721 the visits, and the conversations and commentaries which surrounded them, were associated with the evaluation of a commodity promising infinite reward. Calculations of the worth of such a scheme are unusually lucid emblems of the critical relationship between the values of the state and the market.[60]

57 Richard Sennett, *The Fall of Public Man*, London, 1986, 56–63; Reinhart Koselleck, *Critique and Crisis*, Oxford, 1988, 62–9; Jürgen Habermas, *The Structural Transformation of the Public Sphere*, Cambridge, 1992, 31–7, 57–61. For artisan resistance to metrology, see Linebaugh, op. cit. (7), 162–3; for clericalism and superstition see Jacques Revel, 'Forms of expertise: intellectuals and popular culture in France, 1650–1800', in *Understanding Popular Culture* (ed. Steven Kaplan), Paris and New York, 1984, 255–73, on 262.

58 [Louise-Bertrand Castel], *Mémoires de Trévoux* (May–October 1721), 1761, cited in Allamand, op. cit. (2), p. xxxv. For Castel against Newton see D. S. Schier, *Louis-Bertrand Castel: Anti-Newtonian Scientist*, Cedar Rapids, 1941, and for his attack on 'sGravesande see Loup Verlet, *La Malle de Newton*, Paris, 1993 158–60.

59 For the princely show as a technology of power see Apostolides, op. cit. (8), 148–59; Mario Biagioli, *Galileo Courtier*, Chicago, 1993, 120–33; William Eamon, *Science and the Secrets of Nature*, Princeton, 1994, 223–4; Krzysztof Pomian, *Collectors and Curiosities*, Cambridge, 1990, 261–7; Eilean Hooper-Greenhill, *Museums and the Shaping of Knowledge*, London, 1992, 103; Smith, op. cit. (7), 103–4. For modern science museums see Stella Butler, *Science and Technology Museums*, Leicester, 1992, 35–7.

60 For civil society and the exchange, see Sennett, op. cit. (57), 80–7; Norbert Elias, *The Court Society*, Oxford, 1983, 91; Jean-Christophe Agnew, *Worlds Apart: The Market and the Theater in Anglo-American Thought 1550–1750*, Cambridge, 1986, 157.