

## Conclusion

The preceding Chapters have shown that a considerable part of Hooke's scientific activities can be understood coherently if we regard him as an astronomer. His astronomical research was begun within a tradition instigated by Galileo's telescopic observations, which the author has named the Galilean Observational Paradigm. It was directed at the solar system, and its principal topics were the study of Saturn's ring, the surface features and satellites of the planets, selenography, and similar matters. Its main instrument was the 'long telescope'. The Paradigm was taken up by natural philosophers both in Continental Europe and also in England, where it was adopted during the Puritan Revolution and continued through the activity of the early Royal Society.

Hooke's research within the Paradigm was outstanding during the 1660s, especially in his contributions to *Philosophical Transactions*. The standard of his observation was comparable to that of Cassini. His astronomy even found its way into *Micrographia*, a part of which sparked a controversy with Auzout over the further development of long telescopes. Hooke worked with English optical instrument-makers to construct telescopes, and the talented astronomer Hevelius praised the telescope Hooke sent him. Hooke's illustration showing how to mount the telescope was also used in the frontispiece of Sprat's *History*.

Hooke played another important role in astronomy, mainly in the 1670s. He promoted the use of precision instruments for astronomical observations, such as telescopic sights and eyepiece micrometers. He battled with Hevelius over their necessity. Hooke himself used a telescopic sight and an eyepiece micrometer to detect the parallax of fixed stars. The instruments were to become essential tools for positional astronomy, and indispensable for the newly established observatories.

In the seventeenth century, humanity acquired three important vehicles by which to journey into unknown worlds: the telescope, the microscope, and the air pump. Hooke's commitment to the last two has been well known to historians of science. But now we should acknowledge that Hooke's name is closely linked to all three of them, and that he made many contributions to natural philosophy with these contrivances. This implies that Hooke occupied an important position in the history of experimental science using sophisticated scientific instruments.

However, it has been widely recognised that Hooke was an able experimental philosopher<sup>1</sup>, especially in the Baconian sense which differs sharply from the Cartesian

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<sup>1</sup> For example, see 'Abstract' of Pugliese; Inwood (2002), p. 15; Jardine (2003), p. 319.

in its approach to nature. Does the argument of the present paper, which sees Hooke as a leading astronomer in the mid-seventeenth century, extend our understanding of Hooke? To answer this point, it is necessary to consider more deeply the classification of science in the seventeenth century.

Thomas Kuhn constructed an intriguing analysis of experimental sciences in his well-known paper 'Mathematical versus Experimental Traditions in the Development of Physical Science'<sup>2</sup>. He drew a distinction between experiments for 'classical sciences' and those for 'Baconian sciences'.

Kuhn classified astronomy, harmonics, mathematics, optics, statics, and the theory of localised motion into the category of 'classical sciences'<sup>3</sup>, all of which have a history reaching back to ancient times. Although the classical sciences 'were empirical, the data their development required were of a sort which everyday observation, sometimes modestly refined and systematized, could provide'<sup>4</sup>. Thus 'experiments' for classical sciences could be either logical analysis or simple experiments to confirm a conclusion already known<sup>5</sup>.

Kuhn argued that a great change took place when Baconian sciences appeared in the seventeenth century. He contrasted their experimentation with that of classical sciences:

'When its practitioners, men like Gilbert, Boyle, and Hooke, performed experiments, they seldom aimed to demonstrate what was already known or to determine a detail required for the extension of existing theory. Rather they wished to see how nature would behave under previously unobserved, often previously nonexistent, circumstances'<sup>6</sup>.

Baconian sciences stress the importance of those experiments

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Cf. Steven Shapin, who argued that 'Hooke's contemporaries did not call him an experimental philosopher' (Shapin, 1989, p. 253). This was because Hooke's social position was not as high as Boyle, and because he collaborated extensively with craftsmen. But the author has a different interpretation. Hooke represented a new research trend with its own characteristics, and his contemporaries could not recognise the emergence of the new breed of experimental philosophers who later became dominant. They no longer needed high social position.

<sup>2</sup> Kuhn (1977), pp. 31-65.

<sup>3</sup> *Ibid.*, pp 37 & 39.

<sup>4</sup> *Ibid.*, p. 38.

<sup>5</sup> *Ibid.*, pp. 42-43.

<sup>6</sup> *Ibid.*, p. 43.

‘which Bacon himself described as “twisting the lion’s tail”. These were the experiments that constrained nature, exhibiting it under conditions it could never have attained without the forceful intervention of man’<sup>7</sup>.

To perform such experiments,

‘The next hundred years witnessed the rapid introduction and exploitation of telescopes, microscopes, thermometers, barometers, air pumps, electric charge detectors, and numerous other new experimental devices’<sup>8</sup>.

However, Kuhn believed that ‘To the conceptual transformations of the classical sciences, the contributions of Baconianism were very small’<sup>9</sup>, and that the importance of Baconian sciences, which were based on the new type of experiments, was established during the eighteenth century in the fields of chemistry, magnetism, electricity, theory of heat, and so on<sup>10</sup>.

As Bennett wrote, Kuhn’s distinction of two traditions has ‘no historical grounds’<sup>11</sup> at least for the seventeenth century. Experiments carried out in the spirit of Baconian science raised substantial change even in the classical sciences, as the case of Galileo’s telescopic observations clearly shows. Hooke himself applied the telescope to extend the human senses in order to see hitherto unknown phenomena<sup>12</sup>.

But although Kuhn’s distinction does not hold, it does lead us to mark out a group of experiments in the seventeenth century which were made to observe phenomena not normally apparent to human beings. Those experiments involved the use of sophisticated scientific instruments, constructed by mathematical practitioners or specialised instrument-makers. Their collaboration became essential, and natural philosophers had to establish face-to-face relationships with them.

To differentiate such experimental practice, which started in the seventeenth century, from Kuhn’s misleading definition of Baconian science, which supposedly was begun in the eighteenth century, the author would like to introduce the new term ‘experimental natural philosophy’. Hooke clearly belonged to this tradition, and his experiments may be categorised with those for experimental natural philosophy.

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<sup>7</sup> *Ibid.*, p. 44.

<sup>8</sup> *Ibid.*

<sup>9</sup> *Ibid.*, p. 45.

<sup>10</sup> *Ibid.*, p. 47.

<sup>11</sup> Bennett (1986), p. 6.

<sup>12</sup> Bennett (2003), p. 65. As Hunter wrote, ‘Hooke went far beyond Bacon’ (Hunter, 2003, p. 120).

Bennett produced an informative analysis in the 1980s to illuminate the origin of experimental natural philosophy. When Margaret 'Espinasse mentioned Hooke's instruments in *Robert Hooke* (1956), she wrote that 'these must be regarded as by-products of a constant preoccupation with the basic general problems of science'<sup>13</sup>. Criticising her view, Bennett wrote that:

'He [Hooke] can best be seen as drawing on a long established tradition of instrumentation in the study and practice of the *mathematical sciences* in England, that goes back to [Robert] Recorde and [Thomas] Digges' (author's italics)<sup>14</sup>.

Bennett sought to avoid the traditional dichotomy 'between the scholar and the craftsman' by introducing an intermediate domain of 'mathematical sciences' for mathematical practitioners<sup>15</sup>. He showed that applied mathematics, such as surveying, navigation and astronomy, was called 'mathematical sciences' in England from the mid-sixteenth century. The character of the mathematical sciences was set by Robert Recorde (1510-1558), John Dee (1527-1608), Thomas Digges (1546-1595) and others in the sixteenth century<sup>16</sup>. Changing political and economic conditions demanded the technical improvement of navigation, fortification, surveying and cartography.

Bennett wrote that 'In the first half of the seventeenth century, Gresham College, its professors and its lectures, provided a focal point for the mathematical sciences'<sup>17</sup>. Briggs established the tradition of mathematical sciences at Gresham College<sup>18</sup>, which flourished until the death of Gellibrand in 1636<sup>19</sup>.

The inaugural speech of Christopher Wren as Gresham Professor of Astronomy in 1657 confirms the role of the College in the mathematical sciences:

'Founder *Gresham* hath adorn'd this opulent City, with the Profession of the Sciences, in his own House, by a rare Example, leaving the *Muses* to be *here* his Heirs and Successors for ever; who seem to be affected with the Place, having preserv'd it in Esteem, by furnishing it hitherto with Men of most eminent Abilities, especially in mathematical Sciences; among whom the Names of *Gunter*,

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<sup>13</sup> 'Espinasse (1956), p. 74.

<sup>14</sup> Bennett (1980), pp. 41 & 44.

<sup>15</sup> Bennett (1986), p. 1.

<sup>16</sup> *Ibid.*, pp. 6-7. See also Bennett (1986).

<sup>17</sup> Bennett (1982), p. 9.

<sup>18</sup> *Ibid.*, p. 10.

<sup>19</sup> Adamson (1980), p. 20.

*Brerewood, Gillibrand [sic], Foster*, are fresh in the Mouths of all Mathematicians'<sup>20</sup>.

The College's tradition of mathematical sciences induced changes in university education. In 1619, about two decades after the establishment of the College, Henry Savile (1549-1622), Warden of Merton College, founded two science chairs at Oxford for 'scientiae mathematicae', *i.e.* geometry and astronomy<sup>21</sup>.

Hooke engaged in the tradition of mathematical sciences as Gresham Professor of Geometry. But Bennett did not overlook another aspect of Hooke's research. In the sixteenth and seventeenth century, a distinction was made between 'natural philosophy', which was concerned with the causal and theoretical understanding of the natural world, and 'mathematical sciences', which engaged in the development of mathematical techniques to useful ends<sup>22</sup>. Hooke not only subscribed to the tradition of mathematical sciences, but:

'he, more than anyone else, also applied it to the new investigative attitude to nature that in England derived from William Gilbert and Francis Bacon, and had developed into the natural philosophy characteristic of the early Royal Society'<sup>23</sup>.

So Hooke bridged the divide between mathematical sciences and natural philosophy. He did this through his use of scientific instruments for experiments, for as Bennett showed Hooke's important contribution to mathematical sciences was in instrumentation.

In fact, Hooke's activities were of wider scope. Table 6 has been compiled by the author from the index to 'The Work of Dr. Robert Hooke', published in the sixth and seventh volumes of *Early Science in Oxford* (1930). These volumes include many documentary extracts from Hooke's research. The table categorises the scientific and technological items from the index under three headings. In principle, items which appear in multiple extracts are listed in the table<sup>24</sup>.

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<sup>20</sup> Wren (1750), pp. 205-206.

<sup>21</sup> Strickland Gibson (ed.), *Statvta antiqva vniversitatis Oxoniensis* (Oxford, 1931), p. 528.

<sup>22</sup> Bennett (1986), p. 2.

<sup>23</sup> Bennett (1980), p. 44.

<sup>24</sup> The categorisation is for heuristic purposes, and is not free from arbitrariness.

### Table 6 Categorisation of Hooke's Research

(a) Purely technological

alloy, balance (spring, wheel with spring), burning glass, brick, carriage and chariot, cider [squeezing] engine, diving, clock escapement, flight and flying, glass making, gunpowder, lamp, leather, level, powder engine, saddle on spring, salt making, signalling, spectacles, surveying, tanning, whale shooting, wind-mill

(b) Between technology and natural philosophy

air-gun, barometer (marine, wheel &c), dividing engine, elasticity, hygroscope, magnet (dipping, loadstone, variation &c), measurement of the earth, quadrant, sounding, lens grinding, pendulum (circular, clock &c), sea-bucket, specific gravity, tides, strength of wood, velocity in water, velocity of bullet, watch, water-poise, weather-clock, weather-glass

(c) Natural philosophical

air (pressure, density, rarefaction, weight &c), air-pump, algebra, arithmetical machines, ammonites, atmosphere, attraction, capillary attraction, circle squaring, circulation of blood, comet, combustion, density, earthquake, experiments with fish, experiments with glass, experiments with ice, falling bodies, fossils, freezing, fresh water from salt, gravity, helioscopes, hydrostatics, incubator, lens (objective, aspheric &c), light (reflection, refraction &c), method of experiments, mineral, micrometer, microscope, microscopy, motion, motion of the earth and the planets, muscle, observation of planets and their satellites (eclipse, occultation, details &c), parallax, petrification, pores in wood, prism, respiration, reflecting mirror, sap in trees, skin grafting, spark, transfusion of blood, tobacco-oil, telescope, telescopic sight, thermometer, vacuum, vibration

Hooke clearly contributed to the development of 'pure' technology as (a) shows. The items under (b) could be related to mathematical sciences, because they have much to do with, for example, navigation. But the items under (c) were those on natural philosophy and instruments for scientific experiments. These indicate Hooke's commitment to experimental natural philosophy.

Numerically Hooke's activities under (b) and (c) predominated over those under (a). So we may conclude that Hooke's activity was not purely technological, but extended into natural philosophy and especially into the gap which then existed between them. Hooke developed the tradition of experimental natural philosophy on the basis of mathematical sciences in the latter half of the seventeenth century.

Was the practice carried seamlessly into the eighteenth century? The author believes that the tradition encountered serious difficulty under the dominance of Newton, at least in the realm of astronomy. This arose from the difference in attitude to experimental instruments between Hooke and Newton, or rather between the early Royal Society and the institution as it had become at the turn of the century.

The difference is exemplified in the contrasting assessments of Hooke and Newton of the brand-new Newtonian reflector. Hooke was critical of it, because he found technical difficulties in scaling it up for practical use. Newton wrote proudly that he saw 'with it Jupiter distinctly round and his Satellites, and Venus horned'<sup>25</sup>. But Galileo had already observed them nearly half a century before, and astronomers in the second stage of the Galilean Observational Paradigm were endeavouring to perform far more advanced astronomical observations. The Newtonian reflector was far from practical for them, and Hooke and Huygens shared the same poor opinion of it. The reality was that they *did* have advanced long telescopes, with which they *had already achieved* significant discoveries. However Newton saw only the future possibilities of the reflector, because *in theory* the instrument had to be superior to the refractor.

So while Hooke's attitude was experimental, Newton's was theoretical. Newton did make experiments with colours, but prisms and lenses, the tools he used, were not at all new or sophisticated. If we apply Kuhn's arguments, Newton's experimental instruments were those for 'older forms of experiment', which 'simply expand[ed] and elaborate[d] the empirical elements'<sup>26</sup>. Moreover, 'The prism Newton purchased to examine "the celebrated phenomena of colors" descends from medieval experiments with water-filled globes'<sup>27</sup>.

Certainly Newton constructed reflectors himself, but it was possible for him to make them alone. He did not need intense collaboration with optical instrument-makers. By contrast, it was not possible for Hooke to make long telescopes without the collaboration of optical instrument-makers such as Reeve and Cock. His telescopes were typical tools for experimental natural philosophers, who sought to

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<sup>25</sup> *Newton Corresp.*, 1, p. 3.

<sup>26</sup> Kuhn (1977), p. 69.

<sup>27</sup> *Ibid.*, p. 45.

discover and explore unknown mysteries of nature with sophisticated instruments.

Newton's inclination to theory was seen also in his mechanics. Newtonian mechanics derived from synthesising the preceding theories of Copernicus, Kepler, Galileo and others, rather than from new observations and experiments by Newton. Newton certainly relied on astronomical data, but he obtained it from able observers such as Flamsteed<sup>28</sup>. Newton's attitude was exactly of the kind Kuhn ascribed to classical sciences. Henceforth the author refers to it as 'theoretical natural philosophy'.

We saw in Chapter 5 that Gresham College, which supported mathematical sciences, fell into crisis in the latter half of the seventeenth century<sup>29</sup>. Analysis of the numerical data taken by R.K. Merton for his famous work of 1938 shows a relevant trend appearing at the Royal Society. He classified articles from the Society's journal, *Philosophical Transactions*, from 1665 to 1702, and counted the number of papers in each category<sup>30</sup>.

Fig 7-1 is a graph drawn by the author from the data. From the total number of papers in *Philosophical Transactions*, it plots the percentage of articles on physical sciences, and also the percentages of papers on its sub-categories of astronomy and technology. The graph shows that all three percentages decreased during the last fifteen years of the seventeenth century, though those of astronomy and technology papers fluctuated before then. If we remember that astronomy was closely coupled with navigation in that period, the decline of both astronomy and technology seems to imply that the Royal Society was losing its interest in the practical application of science, or mathematical sciences, towards the end of the century.

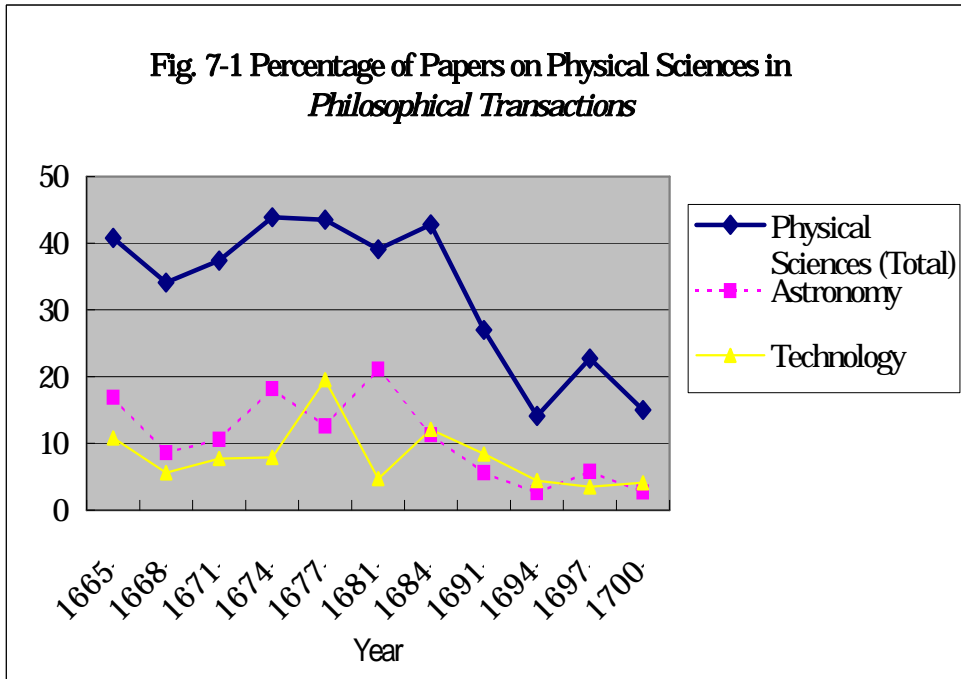
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<sup>28</sup> Newton's belief in the superiority of theory over observation is seen in his letter of 16 February 1665, when he sought observational data of the moon from Flamsteed. He wrote 'if you [Flamsteed] publish them without such a Theory to recommend them, they will only be thrown into ye heap of ye Observations of former Astronomers' (*Newton Corresp.*, 4, p. 87).

<sup>29</sup> See the section on 'The Establishment of Greenwich Observatory'.

<sup>30</sup> Merton (1970), pp. 46-47. The author used a reprint of Merton's paper.





The argument is supported by the paper by Margaret Deacon on the history of marine science at the Royal Society. Marine science was pursued for the development of navigation, and it included the study of seawater, tides, soundings, &c. Though the science was an important field for the early Royal Society, it began to decline toward the end of the seventeenth century. Deacon summarises:

‘Most branches of [marine] science seem to have suffered around the turn of the century from the changing mood of society reflected in the scientists’ attitude to their work...They lost the incentive of the Baconian vision of the unity of basic research and its useful application’<sup>31</sup>.

The decline of mathematical sciences is an interesting topic, and much more study is needed into its cause. But we may safely conclude now that in the seventeenth century there were at least four important areas relating science and technology: arts and crafts (purely technological) for artisans and craftsmen; mathematical sciences for mathematical practitioners; experimental natural

<sup>31</sup> Deacon (1965), p. 46.

philosophy; and theoretical natural philosophy (Table 7).

**Table 7 Science and Technology in the Seventeenth Century**

(Technology)	Arts and Crafts	
	Mathematical Sciences	
	Experimental Natural Philosophy	} Natural Philosophy
	Theoretical Natural Philosophy	
(Science)		

The point of the classification lies in the differentiation of the two elements of natural philosophy, the experimental and the theoretical. The basic idea came from Kuhn's distinction between classical and Baconian sciences, but there are several differences. First, the area of mathematical science is now established following Bennett's argument, and experimental natural philosophy is articulated from it. Second, experimental and theoretical natural philosophies no longer correspond to specific scientific disciplines (fields), contrary to Kuhn's categorisation of astronomy to classical sciences and chemistry to Baconian. In the author's classification, the same discipline could be either experimental or theoretical. Thus the Newtonian approach to telescopes was characterised as theoretical, while Hooke's was experimental. Indeed astronomy, a typical classical science, could be experimental as Hooke's astronomical research exemplifies.

The author has stressed the fact that Hooke is associated with three leading instruments: the telescope, the microscope and the air pump. They extended the human senses, and made access possible to unknown worlds. If we were to accept Kuhn's classification, it would follow that Hooke opened up new fields for Baconian sciences with these instruments: astronomical observations, microscopy, and the study of air. He should have been a hero of the Baconian sciences.

But there is a problem: is astronomy Baconian? The telescope had a subtle but important difference from other two instruments. While the microscope and the air pump opened up completely unknown worlds, human beings since ancient times had known something about celestial bodies, the objects of telescopic observations.

Taking the author's categorisation the problem disappears, and a new

perspective is obtained. We can argue that, in the seventeenth century, experimental aspects were 'generated' in astronomy by Hooke and others through the use of sophisticated long telescopes. That is, the long telescope separated astronomy into the theoretical and experimental realms, or, in other words, into mechanical explanations of the cosmos and astronomical observation<sup>32</sup>.

From this perspective, it is clear that preceding historiographies of astronomy have concentrated on the theoretical side. For example, it is common to describe the astronomical revolution, a major field of the Scientific Revolution, as a progression from Copernicus, through Tycho, Kepler, and Galileo to Newton<sup>33</sup>. The astronomical revolution was completed when mechanics, *i.e.* its theoretical base, was perfected. The importance of Newton is in his achievement in mechanics. With Newton, the mathematical view of science began to dominate, and experimental scientists were destined to decline<sup>34</sup>. In this historiography there is no room to discuss astronomical discoveries such as Saturn's ring.

From the experimental side, however, a quite different view appears. Now astronomical observations are at the centre of the historiography, and its luminaries must have excelled within the contemporary trend of observations, that is, the Galilean Observation Paradigm. They were not Kepler or Newton, but Riccioli, Hevelius, Huygens, Cassini, Wren and Hooke. The names of Flamsteed, Halley, Bradley and Herschel must also be added. We must also pay heed to the institutionalisation of national observatories. It is rare to see historiography along these lines<sup>35</sup>.

The author does not claim that historiography centred on experimental natural philosophy is superior to that centred on theoretical natural philosophy. He merely points out that we could delineate the history of experimental natural philosophy independently from that of theoretical natural philosophy. Each has its own historical roles, and should be valued equally.

However, the history of experimental science is not so developed as the history of theoretical science. This may be because the importance of the tradition of experimental natural science is not recognised as that of the tradition of theoretical natural science. Even in the modern world experimental science, which is supported by technicians and craftsmanship in dirty laboratories, co-exists with theoretical science, which is monopolised by prestigious scientists in their neat offices.

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<sup>32</sup> This argument differs from the 'Baconisation' of astronomy, which implies that the classical science of astronomy was transformed into experimental activities.

<sup>33</sup> For example, Kuhn (1957), Chap 6ff.

<sup>34</sup> Jardine (2003), p. 319.

<sup>35</sup> A rare exception is Helden (1985).

Nevertheless, the history of experimental science tends to be a side story to the history of theoretical sciences. The author suggests that Hooke's historical significance becomes clearer when we describe the history of experimental science as an independent tradition *per se*: Hooke is then among the founding fathers of the tradition of experimental natural philosophy in its strict sense.

Hooke died on 3 March 1703, at the age of sixty-seven. 'About *July* 1697, he began to complain of the swelling and soreness of his Legs, and was much over-run with the Scurvy, and about the same time being taken with a giddiness he fell down Stairs'<sup>36</sup>. Eventually he lost his sight, and became bedridden until his death<sup>37</sup>.

As Inwood found out recently from Captain Knox's diary, at the last moment at midnight on 2 March 1703 Hooke sent his maidservant to Knox, the close friend of his later life<sup>38</sup>. But Knox arrived too late. He laid out Hooke's body with Harry Hunt, Hooke's able assistant, and sealed up Hooke's room following the custom of those days.

The Royal Society announced Hooke's death at the meeting on 3 March. Three days after he died, Hooke's body 'was decently and handsomely interr'd in the Church of St. *Hellen* in *London*, all the Members of the ROYAL SOCIETY then in Town attending his Body to the Grave, paying the Respect due to his extraordinary Merit'<sup>39</sup>.

Three centuries have passed since then. Following the collapse of the Cold War, the social milieu around science has changed dramatically. The glory of pure science, represented by physics, is now sometimes tainted by the odium of 'Cold War Science'. It is often said that traditional science is acquiring more and more the characteristics of 'technoscience', or that science is changing from 'Mode 1' to 'Mode 2'<sup>40</sup>. In this changing and confusing climate, we are obliged again to ask ourselves the age-old but basic question: 'What is science?'

The author believes that it is worthwhile to revisit Hooke now. He inhabited a time when science and technology were not yet conjoined but each was expanding into new areas, or they were conjoined in an alternative way.

In 1892, almost two centuries after his death, Hooke's mortal remains along

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<sup>36</sup> *Posthumous*, xxvi.

<sup>37</sup> The symptoms suggest that Hooke may have suffered from diabetes. See Kassler & Oldroyd (1983), p. 590.

<sup>38</sup> Inwood (2002), p. 438.

<sup>39</sup> *Ibid; Posthumous*, xxvi.

<sup>40</sup> The terms 'Mode 1' and 'Mode 2', now fashionable in science policy, were coined by *The New Production of Knowledge*, Michael Gibbons *et al.* (eds.), (London, Sage, 1994).

with those of 700-1000 others were removed from St. Helen's. They were re-buried together in a site at the City of London Cemetery at Wanstead<sup>41</sup>. Is not it the time for us to re-structure science and technology, and 're-embed' them into the new societal structure of the twenty-first century?

(The end of the paper)

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<sup>41</sup> Cooper (2003), p. 71.