

EXPERIMENTAL SPACES AND THE KNOWLEDGE ECONOMY

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In *The gifts of Athena* industrialization reveals the surge of a long trajectory, ever more present as the eighteenth century wore on. Here the first industrial revolution presses on inexorably, accelerating towards Birmingham — or Manchester, or Sheffield, or Derby, even to Lanarkshire or London. Mokyr, in a work of sweeping breadth, has elevated Industry to Enlightenment, transforming it from dusty manufacture to knowledge economy where knowing was as critical as doing. Eighteenth-century industry also created a powerful epistemology with profound consequences for the promotion of practical as well as philosophical knowledge. It is my proposition that one critical link between the menial and the scholarly in the eighteenth century lay in the creation of new experimental, as well as industrial, spaces. These sites were often one and the same.

The intent of this paper is to reflect upon this laboratory life, in a variety of spaces and practices, during the early-modern industrial economy. In my view, in such sites of inquiry apparent barriers between philosophic learning and social transformation were thus dissolved. The laboratory exemplifies a new version of Hume's vision of the uncanny advance of the West, where "The spirit of the age affects all the arts; and the minds of men, being roused from their lethargy, and put into a fermentation, turn themselves on all sides, and carry improvement into every art and science."¹

Probing early laboratories shatters precise distinctions across the philosophic spectrum — from theoretical elaboration by way of investigation at the bench, even to the establishment of experimental controls, to more straightforward exploratory adventures, even to crude trial and error, to hit and miss. The abstractions which have since attracted philosophers of science are really, as Ian Hacking argues, idealized kinds that may be construed variously as tests, adventures, diagnoses or dissections. In practice, all experimental kinds manufacture evidence that in some instances — such as in mere exploration or adventure — may prove to be ends in themselves, and not necessarily derive from or even lead to the elaborations which we conceive as theory.

It makes sense, to take but one example, that Humphry Davy, experimentalist, demonstrator, and lecturer of the Royal Institution, would contemplate the method which made his reputation. In his *Elements of chemical philosophy* in 1812, Davy described the

foundations of chemical philosophy [as] observation, experiment, and analogy. By observation, facts are distinctly and minutely impressed on the mind. By analogy, similar facts are connected. By experiment, new facts are discovered; and, in the

progression of knowledge, observation, guided by analogy, leads to experiment, and analogy confirmed by experiment, becomes scientific truth.²

Davy owed much to a generation of chemists and industrialists who were especially conscious of the particular and localized nature of their bench work. As David Gooding has pointed out, experimentation is often local and contingent where techniques and instruments first merge, and only later do the results seem exemplary and meaningful. It is the significance of the everyday, highly-peculiar circumstance, which I seek here to explore. The industrial world, of which Davy was indirectly heir, produced many an experimental space. And it was from such local spaces that the broad, interconnected and widely-debated knowledge economy described by Joel Mokyr would emerge.

Hume had thus begged the question as to how the industrial spirit of the age was constituted. Mokyr supplies one answer in the socio-economic proposition of accessibility. Mokyr has chosen to focus on the interconnections between industrialism and the wider process which came to be called ‘Enlightenment’, most notably as it sought to disseminate knowledge beyond the élite and into the deeper public culture.³ Before the Napoleonic period there was an array of scientific literature prefiguring what Mokyr describes as an explosion of technical literature after 1815.⁴ I wish, however, to draw attention to the vast growth of technical and natural philosophical discourse prior to 1815, of which surely the *Encyclopédie* is merely the best known example. But let me go further. One would find the notion of Industrial Enlightenment sustained even before the rising tide of technical publications became a torrent in the nineteenth century. Even in élite institutions like Britain’s two universities there was, perhaps surprisingly, a considerable interest amongst natural philosophers in industrial consequence.

INSTITUTIONAL SPACES

Method linked scholars to manufacture. John Hadley, the fourth Professor of Chemistry at Cambridge, from 1756, was one of the many who felt that there was enough in nature to inspire experimentalists — but without privileging theory. Hadley’s lectures were very much in the experimental and dramatic tradition of what he then described as “a very usefull as well as entertaining branch of Natural Philosophy”.⁵ In his manuscript *Introduction to chemistry*, Hadley defined his science, as indeed had others before him, as

the art of Separating Bodies into their simplest constituent parts, of uniting those parts again and reproducing the original Compound, and also by different mixtures and Various methods of Combining Bodies to produce new Substances which exist not in nature.⁶

It is not at all surprising that, like contemporaries in London and the provinces, scholars such as Hadley were interested in practical chemistry, as in the manufacture of alum, green vitriol, and of sulphuric acid.⁷ It is crucial to see Hadley not as

a solitary figure promoting experimental methods in industrial production. Rather he reflects attitudes widespread in natural philosophical and industrial communities throughout Britain. Upon Hadley's death in 1764, his position was filled by Richard Watson who, notoriously, and apparently cheerfully, claimed no knowledge of chemistry but promised to give it a try, "being tired of mathematics and natural philosophy".⁸ While promoting experimental demonstration at Cambridge, Watson developed a range of technical interests which were not, I believe, very unusual for philosophers. Watson's attitudes are not far off from the promotion of chemistry in medical practice and in industry by the likes of Joseph Black in Edinburgh. Thus, Watson, according to one account, "decided that the application of chemistry to the arts and manufactures was the most fitting theme at that time for a university course".⁹ Watson's chemical passions were essentially industrial.

Eighteenth-century natural philosophy was not a solitary occupation. Indeed, those like Hadley and Watson effectively legitimized the dissemination of knowledge. Here I would quarrel with the recent proposition that it was not until the next century that the constitution of "an unprecedentedly public form of knowledge, displayed in a rising tide" of books, lectures and exhibitions helped to make the industrial world accessible. It is my contention, following Watson, that such dissemination brought chemistry and industry face to face much earlier and in a wide variety of ways still little recognized.¹⁰ From the middle of the eighteenth century, as in the experimental experience of the engineer John Smeaton, F.R.S., so too in Watson's efforts at Cambridge, there was the same attempt to disperse natural knowledge in order to make some practical difference. This indeed was the view from the early nineteenth century. For example, Davy's lesser-known contemporary Samuel Parkes, then of the Haggerston Chemical Works in London, published five volumes of *Chemical essays* in 1815. Parkes proclaimed that the works of chemists like Scheele, Bergman and Watson had "contributed in no small degree to the information of the public mind, and to that growing taste for chemical pursuits which is one of the characteristics of the present age".¹¹ This is the difference, at least, that the promotion of chemical experiment had made by the beginning of the nineteenth century. Roused from their lethargy, it seems, Hume perhaps proved right about chemists at least.

One must raise a caveat to the proposal that one can reasonably describe "the history of the growth of useful knowledge [as] the history of an élite". It may seem, at first blush, that "the number of people who augmented the sets of propositional and prescriptive knowledge is small".¹² Even so, it may nevertheless be reasonable to acknowledge that there were numerous groups whose aim it was to meet, discuss, and even to propagate useful knowledge beyond social or intellectual élites. The Lunar Society of Birmingham may be the best-known coterie, but there were many such societies although not often populated by such luminaries as Watt or Priestley. Take, for example, the Spitalfields Mathematical Society which came into being in 1717. By the last quarter of the century, as Lunar influence waned, Spitalfields was a vibrant example of the growth of natural philosophy amongst artisans and the emergent industrial middle class — this time in the east end of London. Not only

did the Spitalfields Mathematical Society reflect a widespread and refined interest in natural philosophy, but its commitment to public education had crucial implications for the image of experimental philosophy by the end of the century.

Nor were the literate craftsmen of Spitalfields always excluded from the more ethereal realms of the Royal Society. The electrical experimentalist and schoolmaster, John Canton is a case in point. So too is John Dollond, familiar for his improvement of the achromatic lens. On the other hand, it is increasingly evident that the Spitalfields mathematicians formed a group singular in its social and economic diversity by the end of the eighteenth century. By then, the Spitalfields society contained an exceedingly broad range of occupations, including chemists, druggists, apothecaries and seedsmen, along with distillers, dyers, brewers, sugar refiners, weavers, iron mongers, mechanical inventors, optical and mathematical instrument makers, and later, actuaries, insurance men, brokers, and teachers.¹³

The notion of the expansion of propositional and prescriptive knowledge, the evasion and erosion of barriers that distinguish élites from artisans helps to refine our understanding of what Enlightenment came to mean. One thing, surely, it must have meant was some degree of self-awareness. Whether a concept of self as working class or as natural philosopher or as artisan had real meaning, it is abundantly clear that there were many in the late eighteenth century who did adopt a mission of public knowledge. It is for this reason that a society of Spitalfields mathematicians would promote an agenda including experiments, the dramatic use of apparatus for practical ends as much as entertainment and, especially, the means to reduce the cost of access so that lectures would ultimately be provided to audiences of hundreds of listeners at a time. In its published account of its repository of instruments, the Spitalfields society took great pains to point out that their lectures of 1798 were “on terms so easy, as to be within the reach of every individual, who has a taste to cultivate, or a curiosity to gratify”. Its objective by the early Napoleonic period was clearly to make experimental philosophy accessible to those otherwise excluded by price. The fee of 6 pence per lecture was significantly lower than most others had been since the early eighteenth century. Consequently, they were soon lecturing to five hundred people at meetings in Crispin Street.¹⁴ Given the times, the Society had no desire, however, to be smeared by a Jacobin brush. It was quick to assert that the Spitalfields mathematicians aimed “at real utility, but they aim at it in private, and are therefore too tranquil a nature to be blazoned in the annals of fame”.

A REVOLUTION AT HAND

We are, of course, aware that there were many like Joseph Priestley or James Watt, Jr, keen to adopt a democratic lexicon even as they promoted industry and experimental philosophy. In retrospect, it would appear that some had far more than a faint idea of the drastic changes surrounding them. One cannot quarrel entirely with Mokyr’s assertion that the “great economic minds of the age, from Adam Smith to David Ricardo, had only the faintest notion of the pending changes”.¹⁵ This may be true of contemporaries generally. However, I would like to challenge the version of the

industrial revolution that few then seemed to sense a “new economy” at work. I have described elsewhere a sense of profound transformation in the late eighteenth century. Take for example, the remarks made in 1766 by the industrialist Josiah Wedgwood who wrote to a friend about “the extensive capability of our manufacture for further improvement” and called its coming perfection “a revolution [that is] at hand”.¹⁶ It is precisely for this reason that the French state encouraged the recruitment, indeed the seduction, of skilled workmen and transport to France with their families and their skill. In 1784, James Watt complained to Josiah Wedgwood that responding to recruiting efforts required that it be

full of forcible arguments, of which I conceive the hints of the frog & snail diet, not the least powerful; nothing will make an englishman amends for the want of beef & pudding and if you had added something concerning being obliged to drink sour wine instead of honest ale it might have had its effect. It is highly proper that something of the like kind should be drawn up here as we have had at least as many visitors of that kind as the pottery.¹⁷

The fears of Watt and Wedgwood were magnified by a tide of foreign visitors. One French spy reported from England in 1794 that “I ... saw with dismay that a revolution in the mechanical arts, the real precursor, the true and principal cause of political revolutions was developing in a manner frightening to the whole of Europe, and particularly to France, which would receive the severest blow from it”.¹⁸ A *British* revolution shattered French dreams of Empire and security.

Such a sense of revolution surely was the consequence of the rapid expansion of propositional knowledge, propagated by new experimental research techniques and instruments, and by their increasing dissemination. But there is a question about what it was that was disseminated and the effects that might have been produced. Here I wish to raise the spectre of false knowledge, even notions of natural forces that could never have produced any prescriptive knowledge or useful result. As Mokyr points out of scientific revolutions, “What counts, above all, is what people *believe* to be true about the material world around them and how their actions and the way they run their lives affect their physical state”.¹⁹ It was in the new — and now often anonymous — experimental and industrial spaces, not alone in the theatres of public display, where these beliefs were constructed.

But what did eighteenth-century industrialists and experimentalists believe? How did they perceive their role as actors in the great epistemological revolution fashioned through instruments and at the bench by a myriad of disciples of a Galileo or a Newton? Eighteenth-century experimentalists were averse to readily accepting distinctions between experimental philosophy and technique. In the rapidly-expanding laboratory world of apparatus, it made no sense to separate instrumental innovation from the adventures of the bench or workshop. And we know that some, like the Newtonian Desaguliers, had fought strenuously against those who would elevate theory over practice. In the case of the engineer James Watt, like the potter Josiah Wedgwood or the physician Erasmus Darwin of the Lunar Society, there was no wish narrowly to confine interests to either manufacture, mechanics, or even medicine.

Our boundaries were not theirs; they may not even have understood them.²⁰ Many megabytes, for example, have been wasted on the effort to demonstrate that Watt knew nothing, or very little, of Joseph Black's theory of latent heat and the perennial pursuit of its influence on the innovation of the separate condenser. In my view, this is to miss the point. If latent heat interested Watt, it was largely because of its chemical rather than mechanical significance. While this might occasion some debate, my interest is rather in the degree to which Watt was intent on an experimental method. Certainly, by the 1790s when he was still seduced by pneumatic chemistry, Watt was prepared to state categorically that "Knowing the insufficiency of theory & the incompetence of the human mind to embrace every circumstance of a complicated subject of any kind, *I am a great friend to experiment*".²¹ If we are incompetent to know the natural world, then the *method* of experimental discovery necessarily took on much force.

But what did James Watt actually mean by experiment? In the context of his research into the physiological effect of gases, Watt sought an efficient means to produce the same new airs upon which Joseph Priestley was then famously working. Watt attempted various trials of their effects, and designed a portable apparatus for breathing them. Even when, in 1786, Watt told Black that his "attention to philosophical subjects has much abated" and that he had given up on further experimentation, this was not to last long.²² In fact, he was then much agitated by experiments on the decomposition of water, for which discovery he later felt very much slighted. Watt's experimental practice reflected the experience of many other manufacturers, like the radical Thomas Cooper of Manchester at whose bench James Watt, Jr, would also conduct chemical investigations.²³ The laboratory life of the Watts was also very much that of Joseph Priestley, and of Josiah Wedgwood and his sons. James Watt's experiments were thus partly exploratory, partly an attempt to assess theoretical explanations for the hotly-contested phlogiston, and sometimes an effort to determine whether any practical benefits might be achieved, as in the assessment of the quality of airs for human life.²⁴ Of course, the production of new airs could prove unpleasant and even dangerous, as Watt discovered. At one point he was so nauseated that he swore never again to use any organic substance in an attempt at decomposition. This, of course, was more than occasionally the experience of those who made trials in pneumatic chemistry. Humphry Davy, amongst others, made himself quite ill by inhaling gases produced in the laboratory.²⁵

PRIVATE SPACES

The exploration of the eighteenth-century industrial economy is obscured by the anonymity of most private laboratory practice. It has, moreover, proved difficult to avoid the imposition of printed, and often much-polished, accounts by those who published their experience at the bench.²⁶ But there exist traces, in print, in manuscript, and in business records, of experimental practitioners who demonstrably traversed social and epistemological categories. Among the most revealing commentators on the eighteenth-century laboratory are those whose declared intent was to reach the

literate artisan and entrepreneur. For example Robert Dossie, the son of an apothecary, reflected in mid-century on the long-established connections between chemistry and pharmacy which existed not only in universities but in market towns as well. Dossie was apparently apprenticed to an apothecary and was exposed to chemistry and physics while attending one of the many courses of experiments with which the century abounds.²⁷ Similarly, his contemporary William Lewis was the son of a brewer in Richmond and a neighbour to the celebrated Stephen Hales. Lewis's father, also William, was sufficiently well off to send his son to Christ Church, Oxford, and by his late twenties the younger Lewis was already giving chemical lectures in his Laboratory in New Street, Fetter Lane, London, "with a View to the Improvement of Pharmacy, Trades, and the Art itself"²⁸

Such endeavours, of course, reflected the general trend toward public demonstrations which we find in the generation after Newton's death. Newton's disciples, such as J. T. Desaguliers, had included many dramatic mechanical contrivances in their lectures. But Lewis, at a time when public lectures were coming under attack, was intent that his efforts would reach beyond the most elaborate and often expensive shows of some experimental demonstrators. When, by 1748, he planned a *Commercium philosophico-technicum*, he attracted subscribers to a "foundation of philosophical and experimental history of arts". The aim was to expand laboratory examination of new materials by the use, most particularly, of "a small, commodious, and easily manageable apparatus, procurable at a moderate expense".²⁹ The spread of public lectures was reflected as well in a parallel expansion of private laboratories like that of George Fordyce, M.D., a pupil of Cullen in Edinburgh, who came to London in 1759 and started a course on materia medica. Fordyce established a laboratory in Theobald's Court off the Strand where Dossie probably undertook attempts to find a method of purifying otherwise putrefying whale and cod oil for use in trades. In their visits to tradesmen, both Dossie and Lewis received many an impetus for further experiments in the workshops and factories as well as in the private laboratories of London.³⁰

The apparent barriers between scholars and craftsmen, between philosophers and artisans, need to be considered carefully. Indeed, there were many in the eighteenth century who thought these distinctions not only undesirable but ultimately harmful to the philosophical enterprise. Evading such social or intellectual boundaries established critical foundations for the knowledge economy described by Mokyr. This is revealed in the intentions of experimentalists like Dossie and Lewis as well as illustrious industrialists such as Boulton, Watt, Wedgwood and their sons. In 1759 Dossie, in his *Elaboratory laid open*, began with a description of a large number of industrial practices, many of which had attracted patents, such as the manufacture of sulphuric acid at the Great Vitriol Works of Joshua Ward in Twickenham. By then Dossie had settled in Berwick Street, Soho, which was not only becoming fashionable but which was soon an area riddled with schools of natural and experimental philosophy.³¹ Dossie's works were much in demand. In 1759 he began his anonymous *Institutes of experimental chemistry* which followed his general plan of making

experimental philosophy a method useful in trades. Notably, Dossie then believed that this approach had been established by the French government, which had “diffused such a judgment and taste in design, among all classes of artisans, as render France ... the source of nearly all invention of fashions ...”. Dossie’s method attracted the attention of the *Critical review* which remarked:

In this age of dissipation and scribbling, it is with satisfaction we see the ingenious author of the *Elaboratory laid open*, resume the pen, in order to draw the attention of the public from the lighter amusements, now called learning, to the more severe and useful study of philosophy on the just principles of experiment.³²

Shortly thereafter, in 1760, Dossie became a member of the Royal Society of Arts where he would also have encountered William Lewis.³³ Both were regularly involved in the Society’s committees. Lewis, in the Committee on Chemistry, was especially active in the assessment of the utility of nitre and potash from various sources, including America.³⁴ A large part of the Society’s objective in these years was the attempt to seek materials and methods which could lead to the improvement of trades. This was the reason, for example, that in 1767 the Society offered a premium for the best production of china or porcelain made from British materials.³⁵ And from its formation in 1754, the Society clearly adopted chemical tests in the promotion of utility.

In many cases in the eighteenth century, epistemological differences inherent in education, training and technical expertise superficially distinguished experimental and natural philosophers from artisans and craftsmen. But this proves to be an easy historiographical contrivance, if not simply a difference reflecting class.³⁶ When Lewis published his *Philosophical commerce of arts* in 1763 he did so with the unequivocal intention of reaching skilled artisans, mechanics, instrument makers and entrepreneurs in an emerging industrial enlightenment.³⁷ For Lewis, much of the everyday life in the laboratory consisted of testing materials routinely employed in trades, such as much sought after preservatives for ships, inks, sealing-wax and endless other substances. It would be mistaken to see these as accounts simply of trials of materials. Lewis was equally concerned with theoretical developments in phlogiston theory, thus printing a translation in 1759, probably completed by his assistant Alexander Chisholm, of the works of Caspar Neumann. Even more significantly, Lewis was an adept experimentalist. He was called upon carefully to reproduce his own experiments on saltpetre, on behalf of the Society of Arts. At their instruction, Lewis tested Virginian saltpetre employing as a control substance the very finest nitre purchased in London shops. Notably, in light of the emergent power of computation in chemistry, he assessed the reactions by weight to determine the value of the residue after filtration with fixed vegetable alkaline. In this regard, Lewis was actually carrying on the work of Dossie but at a higher level of chemical sophistication. Both Dossie and Lewis were charged with the responsibility for examining the methods then employed in America in assaying potash. By 1767, the assessment of solutions and the results of filtration were replaced by the distinct measurement of the capacity to saturate acids in comparison to the purest alkali available. Two important means were

employed: first the measurement of the quantity of the acid not by vague volumetric measures like drops or teaspoons, “but by weight”. Moreover, Lewis assessed the saturation point by “the change of colour produced in certain vegetable juices, or on paper stained with them”.³⁸

Eighteenth-century industry manufactured laboratory spaces. The public world of early-modern science and of its experimental practitioners, in the Society of Arts for example, broadened (and perhaps deepened) the appeal of experimental philosophy along with its array of instruments. But the factory floor especially pressed experimentalists beyond mere trials into efforts to determine the basic chemistry and physics of manufacturing processes. This implied, as in the cases of Dossie, Fordyce and Lewis, a less anecdotal and progressively more analytical and inductive approach to the gathering of facts from manufactories. It is increasingly clear that those versed in matters experimental might well have considered practice at the bench or on the shop floor quite as fundamental as disputes over theory. Inductivism of this sort made particular facts alongside generalizations in chemical philosophy.

This was the case, as we will see, within the pottery enterprises of Josiah Wedgwood. Wedgwood was immensely well read, and very much up to date regarding the latest chemical disputes and speculations emanating from the Continent. Continental challenges to phlogiston were of concern to his friends like Joseph Priestley and James Watt, among others. But the extant record demonstrates that, from hints in the same chemical literature, Wedgwood’s manufactory consistently tried to find better ways of creating and firing earths and glazes. The depth of his knowledge and the range of these trials and experiments may seem surprising if we persist in thinking of early-modern industry purely as a matter of mechanics and skill.

THE MANUFACTURER’S INHERITANCE

Many examples might be found of those adept at experiment seeking employment in early industrial concerns. Alexander Chisholm is of particular interest in so far as he bridged the world of the experimental demonstrator and the industrial chemist. At mid-century, Chisholm had come out of Marischal College, Aberdeen to become an assistant to Lewis in London chemical lectures. Upon Lewis’s death in 1781, Chisholm was immediately employed by Josiah Wedgwood and recorded thousands of experiments and trials that built upon his work with Lewis.³⁹ Not only was Chisholm engaged in the production of Wedgwood’s pottery, he exchanged a broad international correspondence on issues then at the centre of the chemical revolution. It is especially revealing that Chisholm and Lewis, both the products of a university education, made a specific effort (as would Richard Watson) to engage the manufactory as well. In the surviving records of Lewis’s and Chisholm’s early work, many of which ultimately fell into the hands of Josiah Wedgwood, there were numerous reports of first-hand journeys to manufacturing sites along with many extracts of published chemical works, especially from the Continent.⁴⁰ There is a clear continuity between the efforts of Lewis, Chisholm and later of Wedgwood and his sons. This is true both of the nature of the topics they explored and of an evolving ideology which asserted

the necessity of the dispersal of craft and experimental knowledge. In one notebook clearly attributable to Chisholm, for example, there are translated extracts from Johann Jacob Reinhard's *Vermischte Schriften* (1760–69) where the German declared that he had “followed the practice of the English, who make known by the press such of their projects as they think may be of publick utility.... By this means *the general good must be promoted ...*”.⁴¹ In such a circumstance it is hardly surprising that workshop practice should have been a source of much chemical knowledge and ultimately the beneficiary of the experimental work already performed by Lewis and Chisholm. It once proved difficult to trace many of the more than two hundred volumes of research, notes, and results sold on Lewis's death in 1781. However, it is now clear that many of these are extant both in the Wedgwood archive and in the British Library. Thus, excerpts from Venel's articles in Diderot's *Encyclopédie*, found in the Wedgwood MSS in the British Library, are almost certainly those translated by Chisholm. Commenting upon published works, our experimentalists would clearly have been sympathetic to a passage from Venel which appeared in these bound notebooks:

'Tis principally on account of the mediocrity of these little tracts (among other false aspects) that the chemists are looked upon as simple workmen, or at most as workmen of experiments; and that men do not even suspect that there exists or can exist a truly philosophic, rational, transcendental chemistry, or chemists who venture to extend their views beyond objects merely sensible, and who without exceeding the limits of their art, see the path of grand physicks traced out within its circumference.⁴²

Chisholm was at the chemist's cutting edge. It is apparent from one identifiable commonplace book that he was examining issues related to the properties of airs appearing in various reports before 1770. This was especially the case, not surprisingly, concerning fixed and inflammable air, topics then of much interest especially among chemists associated with Priestley and Wedgwood.⁴³ In the 1780s, Chisholm also entered with Wedgwood upon experiments on “wolfrom or tungsten” in the laboratory at Etruria in the Midlands. Chisholm nonetheless suggested that he might have to seek the advice of the chemist Richard Kirwan of the Chapter Coffee House Society in London shortly before Kirwan decamped to Ireland. The range of Chisholm's experiments was immense, with particular concern to the shrinkage of clays, the chemical composition of earths, the colours produced by minerals, the production of acids and, of course, the mystery of phlogiston. It must surely be the case that Chisholm's expertise, developed in his years with Lewis, had recommended him to Wedgwood.⁴⁴ Even Chisholm's “London experiment book” begun a decade earlier, in 1772–73, with experiments on colours in glazes, contains many later additions on enamels and some on prismatic colours from the work of Wedgwood's partner, Thomas Bentley of Liverpool.⁴⁵

Wedgwood's partnership with Bentley from 1769 is often regarded as the foundation of Wedgwood's fortunes. Bentley's research on colours seems to have coincided nicely with the experimental approach Wedgwood was then adopting. Wedgwood was fascinated, for example, by what he had learned of a method of gilding by

electricity which he heard that Joseph Priestley had tried with copper, presumably after building a battery of sufficient charge.⁴⁶ Wedgwood was constantly on the search for new knowledge. When he had missed the lectures of James Ferguson on mechanics at Newcastle (presumably near Stoke), he traded Ferguson some lessons on pottery-making in return for Ferguson's providing philosophical information over dinner. Likewise, in 1771, he was able to secure James Keir's translation of Maquer's *Chemical dictionary* which he described as a virtual "Chemical Library".⁴⁷ Keir was one more link in these experimental networks.

Bentley moved from Liverpool to London in 1769 to manage the Wedgwood showrooms, close by those of Matthew Boulton. The ensuing correspondence between London and the manufactory at Etruria notably reveals Wedgwood's constant search for new methods and new materials. Desire for British production of white porcelain, as the Society of Arts's premium already proposed, was sufficient to attract a large number of interlopers who might compete with the Staffordshire pottery. Bentley was approached in 1775 by a Matthew Horne of Lambeth with a "Scheme for an Experimental Work". This was intended virtually as a joint-stock or society "for the purpose of trying the materials lately brought from Cornwall" to which Horne claimed to have access.⁴⁸ Indeed, as Chisholm and Wedgwood would find in the laboratory, clays were highly variable as even the same sites might produce clays heterogeneous in their chemical composition, and hence in their reactions in the kiln. As they discovered, no effort to restore original reactions could be certain of working.⁴⁹ This would be important even if it were just an inducement to further experiment or unstructured random trials. But the search for crucial chemical knowledge was essential to the image Chisholm, Wedgwood, and his sons projected from the laboratory. It is particularly remarkable that the workshop, and the laboratory *in* the factory, bore much resemblance to the gentleman's bench.

The growth of laboratory practice in the late eighteenth century spanned the apparent gulf from manufactory to drawing room, from workshop to lecture hall. The trade in instruments provides the traces of experimental enthusiasm. But the variability of apparatus and materials plagued experimentalists and, consequently, even the expanding market for chemical devices which Wedgwood was soon supplying. This is especially evident in the 1780s, by which time Wedgwood had become a generally reliable source for chemical apparatus. For example, in 1784 when Priestley was "in the midst of an interesting course of experiments" very likely associated with the composition of water, he wrote to Wedgwood's manager William Cox to obtain small glazed retorts.⁵⁰ Such manufacturing connections would clearly serve mutual commercial as well as philosophical interests. But the appeal of experiment was a much wider affair. Alexander Chisholm, acting on Wedgwood's behalf, wrote to the evangelical Anglican, Thomas Gisborne, that they had limited stock of the retorts, mortars, and evaporating pans Gisborne required for his own experiments. Chisholm advised that Wedgwood could manufacture a supply of the desired dimensions as he "has great pleasure in accommodating gentlemen in these respects, & in contributing his mite to facilitate chemical inquiries ...".⁵¹ Similar kinds of requests were made of his nephew and employee Thomas Byerley by the instrument dealer

and probable Portuguese spy, Jean-Hyacinthe de Magellan, to supply thermometers and pyrometers most likely for Magellan's extensive export trade.⁵² Of course, as a dedicated experimentalist, Wedgwood was a purchaser as well. Just when Watt and Priestley were fully engaged in chemistry, Wedgwood bought a patented Electrical Machine from Nairne & Blunt in London.⁵³

The Wedgwoods' interest in experiments was part of the long tradition of practical chemists — in which we can include the likes of Priestley, James Watt, Matthew Boulton, or James Keir. Only a few weeks before Priestley's request of Wedgwood in 1784, James Watt, whose concerns had turned to chemistry, attempted to construct pipes for Wedgwood which were to be of a particular thickness, probably to be used in the production of airs.⁵⁴ But within two years, Watt would also tell Joseph Black that his attention to "philosophical subjects" had "much abated" and that he tried no new experiments.⁵⁵ Experimental philosophy, however, had been a passion. Indeed, in 1783 he had told his long time friend, Dr James Lind, that "The ardour of youth, and the pleasure of experimenting have been obliged to give way to the necessity of attending to business ...". But not sufficiently, it would seem, to have avoided some role in Matthew Boulton's 1784 attempt to determine the nature of thunder by using an explosive balloon — the explosion of which, unfortunately, was overwhelmed by the shouts of the "considerable number of people assembled to see the experiment".⁵⁶

Watt's lament about business actually disguised his fascination with the composition of airs and the identification of gases. At least since the 1770s, Watt had been aware of Priestley's examinations of airs, especially as Priestley had sought samples from Boulton of those "breathed by the different manufacturers in this kingdom [and] ... in those places where you expect the air to be the worst, on account of bad fumes or a number of people working together &c, and not at your place in the country, but in the middle of the town".⁵⁷ By 1782, Watt reflected on his research into latent heat, which he owed in large part to Black, and on the superheating of water which he thought could immediately transform it into air rather than steam. Watt believed that this was "confirmed by an experiment which Dr Priestley made the other day *in his usual way of Groping about ...*".⁵⁸ Watt's experiments on airs were not readily revealed, he reported to Black, as he had "little ambition or desire to publish any of the few experiments I have made". He told Black that he found himself "so sett upon by many of my friends to do it that I cannot any longer resist their importunities".⁵⁹

The rage for trials of airs was such that his laboratory work was in danger of collapsing, not from the weight of trade — but, of going unnoticed. Watt was not only aware of the latest debates between British and French chemists. He reported that the "whole world is full of those flying balls at present" and that Mongolfier's experiments on inflammable air had gone so far that the French Academy was to raise a balloon 70 feet high with "4 or 5 criminals tyed to it".⁶⁰ Watt's efforts were not nearly so dramatic. He quietly revealed his reflections on air in a letter to Jean-André De Luc, the Swiss chemist and geologist and friend of Priestley, which was published in the *Philosophical transactions* in 1784.⁶¹ As David Miller has recently argued, even though Cavendish received most of the credit for the discovery of the decomposition

of water *into its constituent parts*, he was not really seeking it as a combination any more than was Watt. Indeed, the oblique recognition of Watt's contribution to chemistry followed in some measure from work on acids and the decomposition of water.⁶² But Watt felt slighted, especially as Lavoisier and Cavendish took the glory for the chemical analysis of water. Watt complained that "The one is a French financier; and the other a member of the illustrious house of Cavendish, worth above £100,000, and does not spend £1000 a year. Rich men may do mean actions".⁶³

PHILOSOPHIC PARTNERS

The range of Watt's adventures in the laboratory suggests the breadth of a knowledge economy. From the 1760s he had speculated on the manufacture of alkalis, following the lead of Black and pursuing a trail of experiments until he "brought it to a probability of succeeding". This led him to consider entering into a partnership with James Keir but, typical of Watt, he was hesitant. In 1769, he lamented the spectre of "a great deal of Experiment still before us a certain expense & loss of time to be Incurred", especially as he was "tired of projects & of being a burden to My friends". He thought Keir might be an agreeable partner; yet "as he speaks so little I cannot think I know him so well as I should do ...".⁶⁴ The silent Keir, however, was an exceedingly learned chemist and manufacturer who had practical experience in the laboratory as well as the factory. A lifetime of know-how would teach him that the difficulties chemists encountered were complex ones that had as much to do with the differences in the apparatus as from the variable qualities of bodies, whether mechanical or chemical. A chemical nomenclature was one thing, but the composition of crucibles yet another. Even within the factory, the laboratory and the workshop proved virtually inseparable.

Experimental enthusiasm was widespread amongst manufacturers. Thus James Keir sought out the views of the Wedgwood factory on samples of white lead he had sent to Etruria, all the while speculating on its potential in manufacturing. Once again, the problem was in the variability of the samples. Keir repeated Tom Wedgwood's experiments made "in [his] joint capacity as chemist & potter" and concluded that it was hardly likely that a new method of making it should improve the manufacturing prospects. Keir's report on samples is of particular note because he was responding also to having been sent a paper by Tom Wedgwood on heat, one of the essential problems that confounded the phlogiston dispute. In Keir's view, to contemplate such important and, then pressing, difficulties was proof that Tom Wedgwood as well as the entrepreneurial Josiah "may be considered truly deserving the name which the old chemists took to themselves, of *Philosophers by Fire*".⁶⁵ This was not mere flattery. Keir's interest in using white lead in glazing had obviously piqued the interest of Wedgwood's pottery as much as elevating Keir's own prospects. It made sense to turn to the Wedgwoods for reasonable advice, if only because it was Josiah Wedgwood who was supplying Keir with the very tubes and retorts he was using in his own Tipton laboratory near Birmingham. Keir reported, in the 1780s, that many potters had been trying the lead as a glaze, sometimes in conjunction with other

substances such as salt, but the results were found wanting.⁶⁶ Initially, the issue was whether some experiments might be undertaken to improve the possibilities in the pottery. Four years later, Keir was still looking.

It was in this context that Keir and Tom Wedgwood exchanged views on how best to proceed in laboratory practice. Keir told Tom Wedgwood, in the autumn of 1791, that he was delighted “to find there is any one in this Country who has courage & ability to attempt such delicate & difficult experiments as those you intend”. They were looking for what Keir called the “foundation of reasoning on chemical combinations”. Keir was anxious to recommend that the investigation of physical properties include the refractive powers of liquids and mixtures, pointing out that “It was by observing the great refractive powers of the diamond that Newton conjectured its affinity to inflammable bodies long before any experiments had given that idea”. Keir compared this to his recent work on nitrous acid in “its phlogisticated & dephlogisticated states, & their consequent comparison ...”. From experiments on metallic solutions by acids he concluded that Tom Wedgwood “may render your plan of experiments more extensive & interesting by not confining them to liquids, but also to comprehend such solids as can be dissolved in any of your liquids, as metals, salts, &c”.⁶⁷ Such collaborations between industrial chemists were extensive. Above all, perhaps, they reveal a profound knowledge of theoretical debates in chemistry in which they too sought a role.

Chemistry was a good foundation for young men who might find themselves in trade in the new industrial towns. For example, James Watt’s nephew Robert Harrison, apprentice to an earthenware manufacturer in Fenton, left a commonplace book which detailed his visits to industrial sites, along with recipes for the production of porcelain and colours for painting on pottery. Harrison included an account of the trials of Samuel Galton in the production of prismatic colours used in glazes and enamels from which Harrison derived notions regarding the chemical composition of different types of glass.⁶⁸ Such issues induced much curiosity about chemical reactions, and notably of laboratory technique, from gentlemen and from men of trades. Indeed, it was widely recognized that a chemical education could be especially desirable. Matthew Boulton saw such practical education as a necessity. As he told his son,

A man will never make a good Chymist unless he acquires dexterity, & neatness in making expts, even down to the pulverising in a Mortar, or blowing the Bellows, distinctness, order, regularity, neatness, & Cleanliness are necessary in the Laboratory, Manufactory, & the Counting house.⁶⁹

Both landed and industrial families had responsibilities to sons and estates. Coke of Brookhill Hall, Nottinghamshire wrote to Watt asking his advice regarding the education of his own son, whom he intended possibly for the “Iron or Cotton Branches”. Coke thought it possible to send him to Glasgow “where he might attend the chemistry, natural philosophy, & mathematical Professors, but a situation where he would see more of the practical Branches of these Things in Germany or Saxony perhaps would be more proper”.⁷⁰ Watt may well have answered that access to a laboratory would

be a more useful education. Like Matthew Boulton, Watt was also determined that his sons be educated in practical knowledge. This was part of the reason that James Watt, Jr, established a friendship with Thomas Cooper, the Manchester manufacturer and Jacobin into whose library and laboratory he gained access. But it was not only sons who received such an education. James Keir, democrat and chemist, was concerned that his daughter not be reduced to playing music on his assumption that “girls who were good players were good for nothing else”. His only child Amelia was encouraged to take an interest in botany and became, according to Dr Thomas Beddoes, “somewhat of a chemist”. Keir completed in 1801, but never published, his “Dialogues on chemistry between a father and a daughter”.⁷¹

Education and enterprise were pillars essential to the foundation of experimental practice and instrumentation in the late eighteenth century. Josiah Wedgwood’s interest in manufacturing chemistry thus went far beyond glazes, the design of furnaces, or a clay thermometer much sought after. Wedgwood was a manufacturer of large amounts of chemical apparatus as well, producing retorts, pipes and crucibles for the experimenter — in other words, the very devices for which he himself had use. Thus, for example, in the 1780s Joseph Priestley sought Wedgwood retorts in various sizes for a set of experiments “in which they are absolutely necessary”. Likewise, James Watt in his chemical laboratory required of Wedgwood clay pipes thick enough not to break but such as to allow heat to penetrate quickly.⁷² Significantly, it was not merely Wedgwood’s expertise as a potter that recommended him to his chemical friends. It was the fact that he was himself familiar with the various clays and glazes able to withstand the trials of the chemist’s bench and furnace. This occasioned a correspondence with Lavoisier on English clays useful for crucibles and pipes “to stand the incomparably more intense heats which modern discoveries have produced”. Wedgwood sent to Paris specimens of clay so that Lavoisier “could make your own experiments & determine such proportions of them as may in every respect correspond with your immediate views”. It was Wedgwood’s hope to assist “in the least degree those luminous exertions to which science & the arts are so greatly indebted ... in the prospect of your revolution having the happy issue it so highly deserves”.⁷³ Or so he claimed, despite his immediate friends of phlogiston like Watt and Priestley.

ERROR AND ENLIGHTENMENT

No doubt beliefs about the composition and structure of the material world could affect philosophic allegiance and economic choice. But what if these beliefs were wrong? The consequences of such beliefs were, and might often be, counterintuitive. It is not at all necessary that the knowledge of the natural world be true or even accurate for there to be a useful result. Take, for example, the feeling of Wedgwood, and even more controversially of James Watt, that their chemical experiments sustained the phlogiston theories of Joseph Priestley in his increasingly bitter exchange with Lavoisier and his French legions. Certainly, Wedgwood and Watt, and many of the leading British experimentalists, notably those of London’s Chapter Coffee House

Society in the 1780s, were increasingly adept in chemistry and its utility.⁷⁴ But this is not to suggest that ideas of nature are purely a matter of circumstance or social construction.⁷⁵ I wish to propose the rather more dramatic version of knowledge, and its techniques, as formative and fruitful simply by way of expanding the public arena for research. In this case, natural knowledge, right or wrong, has a utility particularly in a process of dissemination of technique and experimentalism so essential to the late eighteenth century.

Even in the instance of metrology and standardization, the fundamental philosophical decisions might appear to be uncertain, without any clear experimental foundation, and nonetheless stick. Take, for example, the assertion by James Watt of the unit of horsepower. I have written elsewhere that this was to some degree a marketing device, to distinguish the capacities of his engines from those already operating in British mines.⁷⁶ Enlightenment and experiment did not always exclude traditional or common understanding. It is significant that, in his own account of the derivation of the standard, James Watt acknowledged a certain amount of fudging and a tradition derived from pre-existing mechanical practice:

[Boulton and Watt] ... felt the necessity of adopting some mode of describing the power, which should be easily understood by the persons who were likely to use them. Horses being the power then generally employed to move the machinery in the great breweries and distilleries of the metropolis, where these engines first came into demand, the power of a mill-horse was considered by them to afford an obvious and concise standard of comparison, and one sufficiently definite for the purpose in view. A horse going at the rate of 2½ miles an hour raises a weight of 150 lbs. by a rope passing over a pulley, which is equal to the raising 33,000 pounds one foot high in a minute. This was considered the horse's power; but in calculating the size of the engines, it was judged advisable to make a very ample allowance for the probable case of their not being kept in the best order....⁷⁷

The notion of horse power, whatever its real meaning, followed a custom of a lengthy lineage and out of the common experience of mechanics in mills and mines.

It may appear that Watt's successful measure was to some extent arbitrary. Nonetheless, it did provide the requisite basis for a comparative computation between rival engines of diverse designs. Whether Watt's computation was a matter of convenience "to facilitate office work" as was once suggested, or a means of "facilitating and regularizing his own work", it was a brilliant attempt at standardizing the measure of, and the difference between, engines of various types.⁷⁸ In standardization, as instrument-makers likewise discovered, commercial possibilities abounded. Horsepower hence became, in one sense, a marketing device. This is readily apparent when the concept took hold in the 1790s. Thus, while James Watt, Jr, in his discussions with his father, could describe engines in terms of the diameter of the cylinder, length of stroke of the piston, load, consumption of coals per day, even the cost of coals per ton, ultimately orders for their engines were to be placed in terms of horsepower.⁷⁹ The concept became a kind of shorthand or proxy measure by which to describe, but

not to evade or disguise, the technical considerations involved.

Indeed, the heterogeneous circumstances for which engines were intended obviously might alter the consumption of energy in a range of mechanical ways. The Soho firm, for example, reminded the proprietors of a grain mill in Essex that a small engine of 4 Horse would not meet their needs efficiently as “the taxes upon a 4 Horse Engine (such as Friction, loss of Heat & Steam, Friction of ye Mill work) are so great in proportion to the power that we are persuaded that such very small Engines will not answer” and that it would actually be more profitable for them to erect an engine of twice the horsepower.⁸⁰ Writing from Clifton, near Bristol, James Watt, Jr, suggested in 1797 that “the increasing want of power in most of the Mines” represented an opportunity which those who had attempted to evade the Watt patent could not possibly meet. The year earlier, from Newcastle, he had reported on trials of a winding engine for a colliery at Benwell. Rainy weather had interfered with the pit gear but “The Engine however acted its part perfectly and gave great satisfaction to a large Company who attended with great patience”, immediately resulting in six orders for twenty-horsepower engines.⁸¹ The horsepower standard furthermore made it possible to determine the value of an engine for the purpose of a premium to be paid to Boulton and Watt so long as their patent remained in force. Various means had been made to establish a yard-stick of the translation of energy into power, such as savings of coal, the size of the cylinder, the stroke of the cylinder, or even the depth of water to be drawn. This had made discussions with proprietors a potentially complex matter as in the Boroughs Water Works in Southwark, where the engine premium followed the size and stroke of *both* the engine cylinder and that of the pump. Ultimately, however, a fixed rate per horsepower was established for all new engines and this greatly simplified the negotiations.⁸² Measure moved natural philosophy into the marketplace.

SITES OF EXPERIMENTAL KNOWLEDGE

The spread of experimental enthusiasm ranged from James Keir’s drawing room to his factory, from the Wedgwoods’ various laboratories to James Watt’s workshop, to innumerable country homes and societies of manufacturers throughout Britain. The demonstrations that lecturers provided had been tested on many occasions, sometimes in the hundreds of trials, before friends in small societies and libraries. These occasioned the production of innumerable pieces of apparatus from the likes of Watt, Wedgwood and countless others. Thus Thomas Henry of Manchester, physician, manufacturer and lecturer, who was a force in the Manchester Literary and Philosophical Society, was constantly promoting lectures. Thomas lost his laboratory temporarily in 1795 following a move but experimental interests continued as did lectures. Even his son Thomas Henry, Jr, appears to have considered delivering lectures on chemistry in America to which Priestley and Cooper had also fled.⁸³ Likewise, William Henry, who would establish his reputation as a chemist and manufacturer of magnesia, in 1798 requested from Watt furnaces for the pneumatic apparatus “which will be necessary in a Course of Chemical Lectures which I am about to deliver at the

solicitations of several gentlemen".⁸⁴ William Henry likewise ordered apparatus from Wedgwood apparently both for the production of aerated waters and for experimental purposes, even for a course of lectures that he had entered into in 1806.⁸⁵

The emergence of pneumatic chemistry and medicine had provided new markets for laboratory devices far beyond the trials of Priestley or Lavoisier. William Henry published accounts in the *Manchester Chronicle* on the effects of bad air in sick wards, and notably of the tests on the lack of oxygen conducted by Lavoisier in the General Hospital in Paris.⁸⁶ It was this concern, as much as anything, which led to the spread of interest in the experiments of Watt and Thomas Beddoes on oxygen and nitrous oxide in the treatment of consumptive patients. At Beddoes's urging, Watt manufactured a breathing apparatus which soon attracted the attention of many practitioners willing to give it a try.⁸⁷ Erasmus Darwin concluded that the apparatus was swiftly adopted in several infirmaries such as those at Nottingham and Shrewsbury.⁸⁸ The result was not only the Pneumatic Institution in Bristol promoted by Beddoes, but Beddoes was also soon at work establishing a chemical theatre and providing chemical lectures of his own.

Experimental and industrial interests converged in the eighteenth century. But, for reasons which would require a more extensive exploration, the profound philosophical comprehension of many industrialists, even of artisans and craftsmen, has been carefully divorced in the historiography from the contemplations of the early-modern scholar and philosopher.⁸⁹ Of course, it might well be objected that, given the Wedgwoods' special interests in clays and glazes, their chemical concerns were unique. But this profoundly misrepresents the epistemology of Enlightenment. Many manufacturers whose modern reputation rests on industrial innovation had a broad range of philosophical and experimental passions. As Watt had stressed to Thomas Percival in Manchester in 1794, "Even in the simple science of mechanics, I cannot trust to theory, much less in the obscure paths of physiology; let us therefore try our theories by experiment, when one thing does not do, let us try another, until we are come to the most apposite, & let the doses & manner of exhibition be varied as much as they permit".⁹⁰ The issue here is not whether our manufacturers subsequently made, or even contributed, much of a theoretical nature. It is, rather, whether there were real or effective boundaries which either prohibited or discouraged their interests in the philosophical or experimental debate. If such barriers ever did exist, many chose to ignore them in a widening knowledge economy. In the interest of accuracy, we should also do so.

In the age of enlightenment and industry, laboratory and taxonomy were equally powerful tools of dissemination. It is significant, in an age of experimentation, that standardization imposed a language which could be widely understood. This was just as true in the case of Linnaeus and Lavoisier as it was with Watt. Standardization was fundamental to the process of specification which came to underpin a reformed system of patents. This is crucial because patents, notably when specifications had to be provided, became a system of diffusion as well.⁹¹ But one should not assume that demands for specifications would only have an impact when they were accurate

or even very nearly true. I believe this is especially important. Mokyr refers to the 1806 Report to Parliament on the woollen industry which intended to make clear the necessity for men of considerable capital “to try the experiments which are requisite, and incur the risks and even losses, which always occur, inventing and perfecting new articles of manufacture ...”.⁹² Leaving aside the implications for the organization of manufacturing, one essential issue must surely be the linking of experiment and risk. Here I think I might part company with Mokyr to a small degree. The key may not lie strictly in propositional knowledge as such, but rather in the limits of understanding which raised the need for further experiments and thus the expansion, elucidation and dissemination of technique. If this is the case, the real utility of a knowledge economy was the broadening of the social base of experimental activity. Mokyr is surely right that much was owed to the scientific aura promoted by experimentalists.⁹³ This was a matter which applied as much to the promotion (by Watt or Wedgwood, for example) of industrial production as to fears (by Percival or Beddoes) of the disease and germs that infected the growing manufactories and industrial cities.

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61. James Watt, "Thoughts on the constituent parts of water and of dephlogisticated air; with an account of some experiments on that subject. In a letter from Mr. James Watt, Engineer, to Mr. De Luc, F.R.S.", *Philosophical transactions*, lxxiv (1784), 329–53. Cf. Miller, *Discovering water* (ref. 58), 52–53.

62. Miller, *Discovering water* (ref. 58), 62–63.
63. James Watt to Joseph Fry, 15 May 1784. Quoted in Jenny Uglow, *The Lunar men: Five friends whose curiosity changed the world* (New York, 2002), 360.
64. BCL, JWP 4/59/7. Watt to William Small?, 20 October 1769. On Keir see J. L. Moilliet and Barbara M. D. Smith, *A mighty chemist: James Keir of the Lunar Society* (privately printed, 1962).
65. Keele University, Wedgwood MSS. E1–697, James Keir to Thomas Wedgwood, 19 April 1792.
66. Keele University, Wedgwood MSS. E1–698, James Keir to Thomas Wedgwood, 26 December 1787.
67. Keele University, Wedgwood MSS. E1–692, James Keir to Thomas Wedgwood, 27 October 1791.
68. Imperial College & Science Museum Library, London. Recipe book of Robert Harrison, MS. 449, vol. ii, esp. pp. 75ff. On Galton see Uglow, *The Lunar men* (ref. 63), 352.
69. Quoted in Miller, *Discovering water* (ref. 58), 91.
70. BCL, JWP, 4/13/23. Possibly Daniel Parker? Coke to Watt, 25 March 1792.
71. Cornwall Record Office, Davies Gilbert correspondence. DG41/48/2. Thomas Beddoes to Davies Gilbert (Giddy), 21 November? 1791; J. L. Moilliet, “Keir’s ‘Dialogues on chemistry’ — an unpublished masterpiece”, *Chemistry and industry*, 19 December 1964, 2081–3.
72. Keele University, WM 1506. Priestley to Mr. Cox at Josiah Wedgwood’s, 2 June 1784; WM 1507, James Watt to Wedgwood, 6 April 1784.
73. Keele University, WM 1111. Wedgwood to Lavoisier, 19 August and 7 August 1791 (copies).
74. Cf. Levere and Turner, *Discussing chemistry and steam* (ref. 31), *passim*.
75. Mokyr, *The gifts of Athena* (ref. 3), 24.
76. L. Stewart, “The boast of Matthew Boulton: Energy, innovation and projectors in the Industrial Revolution”, in *Economia e energia Secc. XIII–XVIII*. Instituto Internazionale di Storia Economica ‘F. Datini’ (Prato, 2003), 993–1010.
77. Quoted in H. W. Dickinson and R. Jenkins, *James Watt and the steam engine* (1927; repr. London, 1989), 355–6.
78. Cf. Dickinson and Jenkins, *James Watt* (ref. 76), 5, 354.
79. BCL, JWP, Parcel E. James Watt, Jr, to his father, 24 September 1795.
80. BCL, Matthew Boulton Papers, 254. Boulton–Watt to James Cooper, 23 November 1792.
81. BCL, JWP, Box 38/3. James Watt, Jr, to Matthew Robinson Boulton, 11 February 1796.
82. *Ibid.*
83. BCL, JWP 4/65/13. Thomas Henry to Watt, 6 December 1794; 4/65/14. Henry to Watt, 16 April 1795. See also W. V. Farrar, Kathleen R. Farrar, and E. L. Scott, “Thomas Henry (1734–1816)”, and W. V. Farrar, Kathleen R. Farrar, and E. L. Scott, “Thomas Henry’s sons: Thomas, Peter and William”, in William Vernon Farrar, *Chemistry and the chemical industry in the 19th century: The Henrys of Manchester and other studies*, ed. by Richard L. Hills and W. H. Brock (Aldershot and Brookfield, 1997), chaps. 1 and 2.
84. BCL, JWP 6/35/39. Jn. Bouby to Watt, 7 December 1797; JWP 6/35/32. William Henry to Watt, 15 December 1798. On William see esp. W. V. Farrar, K. R. Farrar, and Scott, “Thomas Henry’s sons”, *op. cit.* (ref. 83), and *idem*, “William Henry and John Dalton”, *ibid.*, chap. 3.
85. See Keele University, Wedgwood MSS. L26–4440, Thos and Wm. Henry to Wedgwood and Byerley, 20 December, 1800; *idem*, L26–4441, 2 February 1801; L26–4442, William Henry to Thos. Byerley, 26 September 1801; L26–4444, William Henry to Wedgwood and Byerley, 9 December 1802.
86. BCL, JWP, C1/16. Thomas Henry to Watt, 28 December 1794.
87. Keele University, WM 35. Beddoes to Thomas Wedgwood, 22 February 1795? Cf. Trevor H. Levere, “Dr. Thomas Beddoes: The interaction of pneumatic and preventive medicine with chemistry”, [*Interdisciplinary science reviews*, vii \(1982\), 137–47.](#)

88. BCL, JWP, 4/65/6. Erasmus Darwin to Watt, 29 April 1795.
89. See here the foreword by Margaret Jacob to the reprint of Musson and Robinson, *Science and technology in the industrial revolution* (London, 1989).
90. BCL, JWP 4/65/19. Watt to Thomas Percival, 22 November 1794.
91. Mokyr, *The gifts of Athena* (ref. 3), 286.
92. Mokyr, *The gifts of Athena* (ref. 3), 139.
93. Mokyr, *The gifts of Athena* (ref. 3), 194.